IEA HPT Annex 52 - Long-term performance monitoring of GSHP systems for commercial, institutional and multi-family buildings

Case Study Summary Report

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Preface

This report is part of the work within IEA HPT Annex 52 - *IEA HPT Annex 52 - Long-term performance monitoring of GSHP systems for commercial, institutional and multi-family buildings*, with project period January 1st, 2018, to December 31, 2021. The Annex 52 Operating Agent is Sweden.

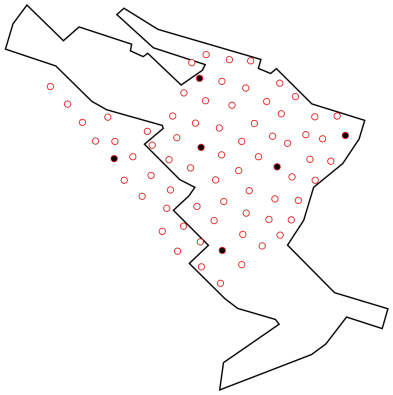
Annex 52 created a library of quality long-term measurements of GSHP system performance for commercial, institutional and multi-family buildings. While previous work was surveyed, the emphasis of the annex was on recent and current measurements. The annex also refined and extended current methodology to better characterize GSHP system performance serving commercial, institutional and multi-family buildings with the full range of features shown on the market, and to provide a set of benchmarks for comparisons of such GSHP systems around the world.

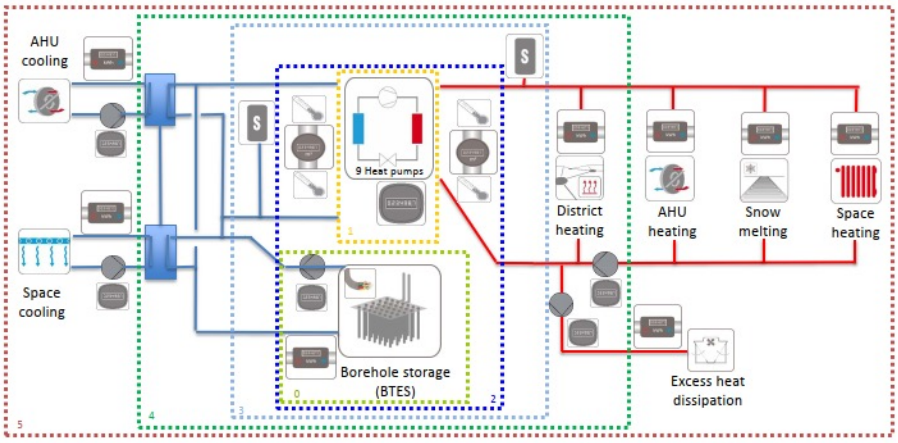
The results from the annex aid building owners, designers and technicians in evaluation, comparison and optimization of GSHP systems. It also provides useful guidance to manufacturers of instrumentation and GSHP system components, and developers of tools for monitoring, controlling and fault detection/ diagnosis. This will lead to energy and cost savings.

This document provides 2-page summaries of the completed monitoring projects within Annex 52, organized by country. Reference to the full case study report with more details is given for each monitoring project. Additional publications related to the monitoring projects are also listed.

List of case studies:

#	Country	Building name	Location	Building type	Ground source
1	FINLAND	Aalto University	Espoo	University	Boreholes
2	GERMANY	AOV	Vechta	Office	Boreholes
3	GERMANY	GEW	Gelsenkirchen	Office	Boreholes
4	GERMANY	KON	Konstanz	Residential	Boreholes
5	GERMANY	EFB	Berlin	Office	Energy piles
6	GERMANY	VGH	Lüneburg	Office	Energy piles
7	GERMANY	WGG	Neumarkt	School	Energy piles
8	NORWAY	Scandic Flesland	Bergen	Conference hotel	Boreholes
9	NORWAY	Kalnes energy central	Sarpsborg	Hospital campus	Boreholes
10	NORWAY	KIWI Dalgård	Trondheim	Supermarket	Boreholes
11	NORWAY	Moholt 50/50	Trondheim	Residential/Office	Boreholes
12	NORWAY	Sweco office building	Bergen	Office	Boreholes
13	SWEDEN	Studenthuset	Stockholm	Office	Boreholes
14	SWEDEN	Xylem	Emmaboda	Industry	Boreholes
15	SWEDEN	Traktorn	Lund	Residential	Boreholes
16	SWEDEN	Briljanten	Lund	Residential	Boreholes
17	SWEDEN	Domstolen	Jönköping	Office	Aquifer
18	SWEDEN	IKEA	Uppsala	Warehouse	Boreholes
19	SWEDEN	Backadalen	Gothenburg	Residential	Boreholes
20	SWEDEN	NUS	Umeå	Hospital	Boreholes
21	SWEDEN	Forskningen	Stockholm	Residential	Boreholes
22	SWEDEN	Frescati NPQ	Stockholm	University campus	Boreholes
23	SWEDEN	Rosenborg	Stockholm	Office	Aquifer
24	SWEDEN	Frölunda Club house	Gothenburg	Club house	Boreholes
25	SWEDEN	Lindhagen	Stockholm	Office	Boreholes
26	UK	Hugh Aston Building	Leicester	University	Boreholes
27	UK	The Crystal	London	Office	Boreholes/Energy piles
28	USA	ASHRAE HQ	Atlanta	Office	Boreholes





Building information	
Building name	Aalto University building
Location	Espoo, Finland
Year of building construction	2018
Ground source system operation start date	2018
Building Type	University, shopping center, metro station
Building floor area	40120 m² net
Analysed monitoring period	2019-10-01 to 2020-09 30
Unique features of the system	Simultaneous heating and cooling all year

Heat pump information	
Heat pump	9 brine-to-water HP
Heat pump system type	Centralized HP
Nominal total heat pump heating capacity	790 kW_{th} , no DHW heating
Nominal total heat pump cooling capacity [kW_{th}]	790 kW_{th}
Refrigerant	R410A

Ground source information	
Ground source	74 groundwater-filled vertical boreholes, 310 m
Undisturbed ground temperature	8.6°C
Borehole heat exchanger type	Single U-tube
Source side brine type	Water-Ethanol 28%

Evaluation period	Oct 1 2019 – Sept 30 2020
Building space heating load met by system [MWh_{th}]	3242
Building cooling load met by system [MWh_{th}]	642
DHW load met by system [MWh_{th}]	0
Thermal energy extracted from the ground [MWh_{th}]	1993
Thermal energy injected to the ground [MWh_{th}]	267
Thermal balance ratio (extracted/rejected)	7.5
Heating load (incl. DHW) met by ground source (%)	95%
Cooling load met by ground source (%)	67%
COP	3.7±0.4
SPFH2	3.5 ±0.4
SPFC2	9.3 ±0.9
SPFHC2	3.9 ±0.4

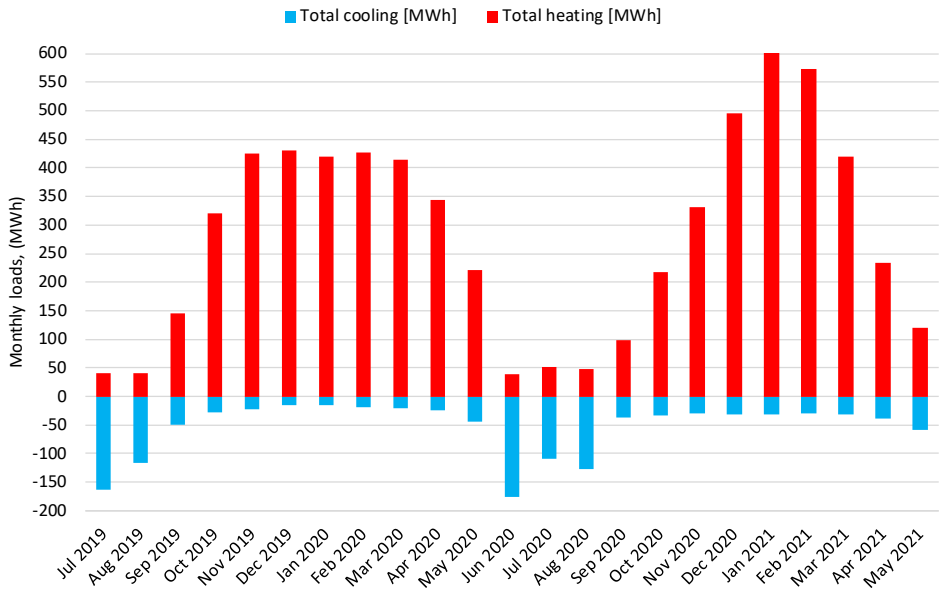


Figure 1. Monthly heating and cooling loads over the monitoring period

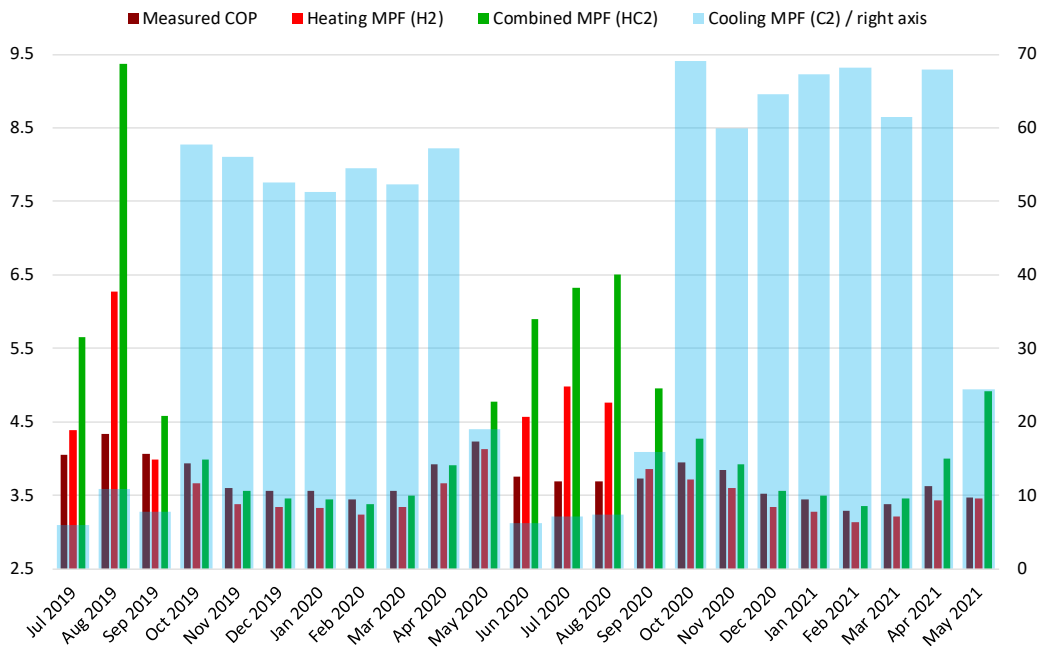
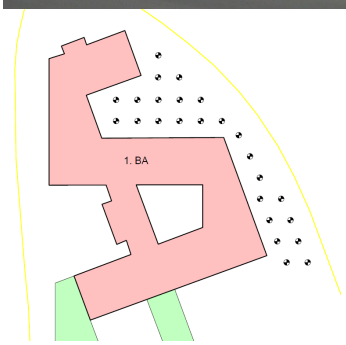


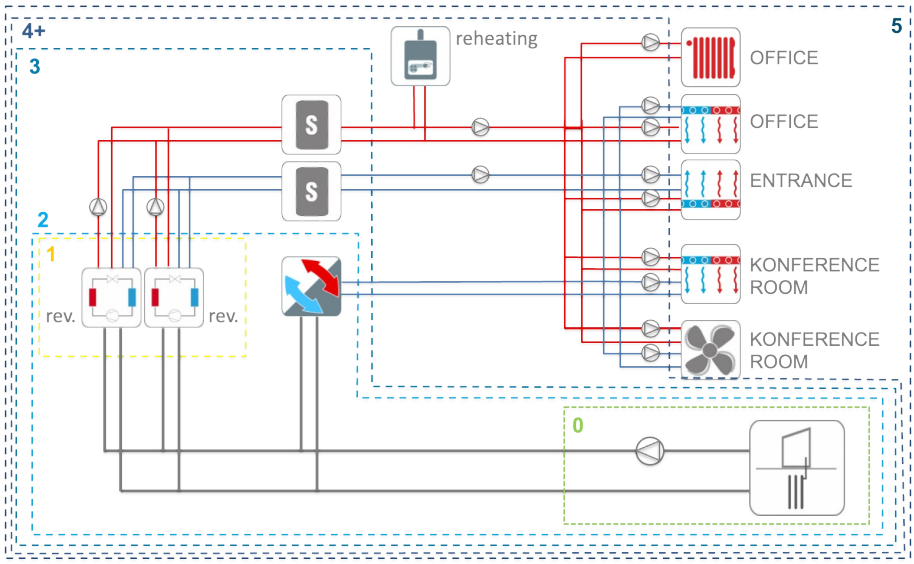
Figure 2. Monthly performance factors for system boundary H2/C2/HC2, over the whole monitoring period. Heat pump measured COP is included as reference

PUBLICATIONS

Todorov, O., Vallin, S., Virtanen, M., Leppäharju, N. (2021). Case study report for monitoring project – Aalto University New Campus Complex, Otaniemi (Espoo). Finland. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/cm70-g204

Todorov, O., Alanne, K., Virtanen, M., & Kosonen, R. (2021). A Novel Data Management Methodology and Case Study for Monitoring and Performance Analysis of Large-Scale Ground Source Heat Pump (GSHP) and Borehole Thermal Energy Storage (BTES) System. Energies (Basel), 14(6), 1523–. https://doi.org/10.3390/en14061523





Building information	
Building name	AOV
Location	Vechta, Germany
Year of building construction	2010
Ground source system operation start date	2010
Building Type	Office building
Building floor area	6750 m² net
Analysed monitoring period	2011 to 2019

Heat pump information	
Heat pump	2 reversible brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	75 kW_{th} , no DHW heating
Nominal total heat pump cooling capacity [kW_{th}]	113 kW_{th}
Refrigerant	R407c

Ground source information	
Ground source	25 grouted vertical boreholes, 100 m
Undisturbed ground temperature	11.3°C
Borehole heat exchanger type	Double U-tube
Source side brine type	Ethylen-Glycol 30

Period (Jan - Dec)	2011	2012	2013	2014	2015	2016	2017	2018	2019
Building space heating load met by system [MWh_{th}]	190.2	188.3	287.6	245.4	257.0	284.9	265.8	284.7	281.1
Building cooling load met by system [MWh_{th}]	103.3	81.8	59.8	74.6	57.6	72.9	59.5	91.3	53.0
DHW load met by system [MWh_{th}]									
Thermal energy extracted from the ground [MWh_{th}]	24.5	42.8	85.6	72.8	60.1	78.4	104.9	156.9	165.0
Thermal energy injected to the ground [MWh_{th}]	302.7	278.6	219.1	263.0	227.1	241.1	139.2	167.7	120.6
Thermal balance ratio (extracted/rejected)	0.08	0.15	0.39	0.28	0.26	0.33	0.75	0.94	1.37
Heating load (incl. DHW) met by ground source (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Cooling load met by ground source (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

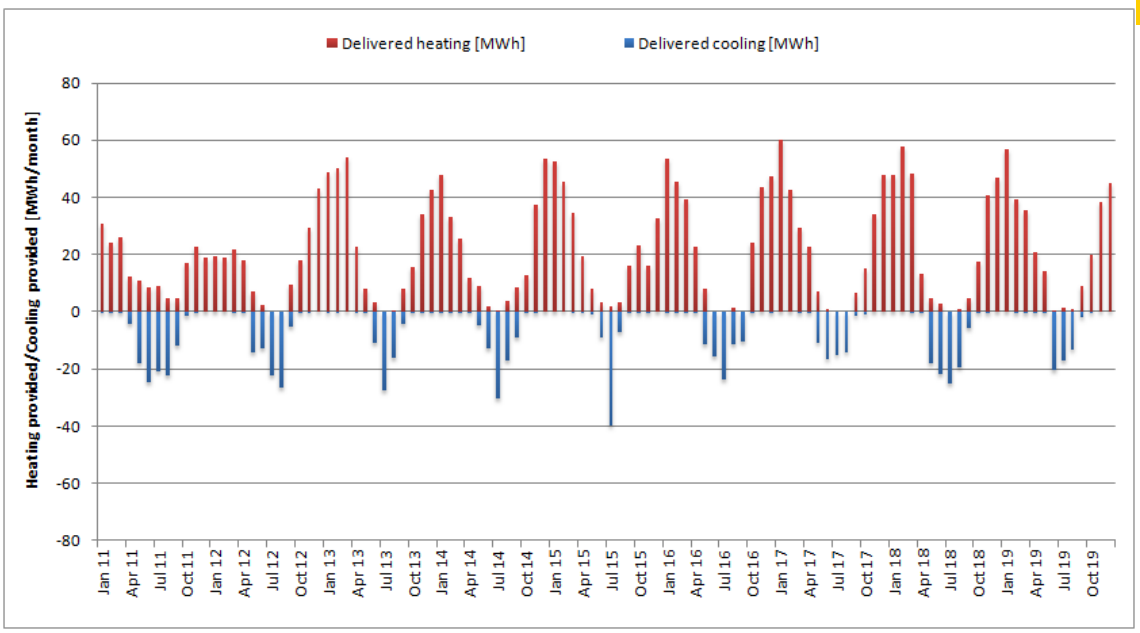


Figure 1. Monthly heating and cooling loads over the monitoring period

Period (Jan - Dec)	2011	2012	2013	2014	2015	2016	2017	2018	2019
SPFH0	4.3	6.1	12.0	10.7	11.3	14.5	18.8	29.8	35.6
SPFH1*	4.5	3.7	3.3	3.3	4.0	2.9	3.0	2.9	3.2
SPFH2	4.0	3.3	3.1	3.0	3.7	2.8	2.8	2.8	3.0
SPFH3	1.4	1.6	1.1	1.3	1.4	1.1	0.4	0.7	1.0
SPFH4	2.7	2.5	1.1	1.1	1.2	1.1	1.0	1.1	1.4
SPFH5	2.6	2.4	1.1	1.1	1.1	1.1	1.0	1.1	1.3
SPFC0	44.1	72.9	81.3	71.5	50.1	69.6	47.7	51.3	51.1
SPFC1	7.6	8.8	24.8	16.4	8.5	16.0	14.7	14.4	28.5
SPFC2	3.2	3.2	4.2	4.0	1.7	3.4	2.8	4.0	4.3
SPFC3	0.6	2.7	3.4	3.1	1.4	2.8	2.4	3.2	3.1
SPFC4	0.5	2.5	2.9	2.7	1.3	2.4	2.1	2.7	2.4
SPFC5	0.5	2.3	2.7	2.5	1.2	2.3	2.0	2.6	2.3
SPFHC0	26.0	29.6	31.0	32.0	29.1	36.0	28.7	38.0	40.8
SPFH1C*	4.3	3.7	3.5	3.5	3.3	3.1	3.0	3.2	3.4
SPFHC2	3.7	3.2	3.2	3.2	3.0	2.9	2.8	3.0	3.2
SPFHC3	1.1	1.9	1.4	1.6	1.4	1.4	0.8	1.2	1.3
SPFHC4	1.9	2.5	1.4	1.4	1.2	1.3	1.2	1.4	1.5
SPFHC5	1.8	2.4	1.3	1.4	1.2	1.3	1.1	1.4	1.5

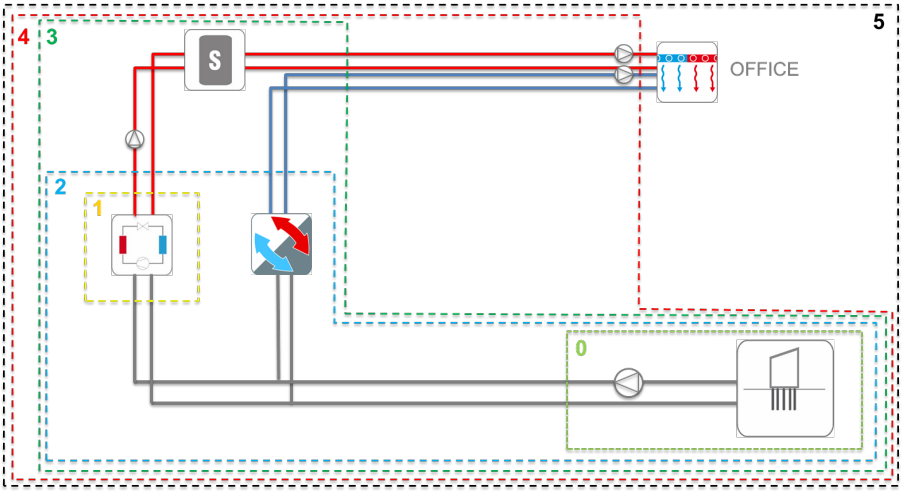
Figure 2. Performance factors over the monitoring period

PUBLICATIONS

Bockelmann, F. (2021). Case study report for AOV, Germany. Office building with borehole heat exchanger. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/s338-wf13

Bockelmann, F. and Kley, Ch. 2021. It works - long-term performance measurement of ground source heat pump systems. 13th IEA Heat Pump Conference. Jeju, Korea. April 26-29.

Bockelmann, F. and M. N. Fisch. 2020. It works – Long-term performance measurement and optimization of six ground source heat pump systems in Germany. Energies 2019, 12 (24), 4691. 2019.; https://doi.org/10.3390/en12244691



Building information

Building name	EFB
Location	Berlin, Germany
Year of building construction	2003
Ground source system operation start date	2003
Building Type	Office building
Building floor area	20 700 m² net
Analysed monitoring period	2006-2019

Heat pump information

Heat pump	1 brine-to-water HP
Heat pump system type	Centralized HP
Nominal total heat pump heating capacity	107 kW_{th} , no DHW heating
Nominal total heat pump cooling capacity [kW_{th}]	150 kW_{th}
Refrigerant	R407c

Ground source information

Ground source	196 energy piles, 8.5 m
Undisturbed ground temperature	10.6°C
Source side brine type	Water

Period (Jan - Dec)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Building space heating load met by system [MWh_{th}]	966.6	970.1	971.3	986.3	1197.1	908.6	1035.3	1102.5	922.1	875.4	1041.0	1034.2	995.8	897.8
Building cooling load met by system [MWh_{th}]	50.1	57.3	55.5	49.8	48.0	42.6	42.2	26.6	35.0	36.1	31.0	18.3	70.0	60.7
DHW load met by system [MWh_{th}]														
Thermal energy extracted from the ground [MWh_{th}]	95.4	109.3	122.2	142.4	139.5	96.9	84.8	33.3	10.3	31.2	24.1	33.0	33.5	23.8
Thermal energy injected to the ground [MWh_{th}]	63.7	71.5	63.4	53.2	50.7	45.3	45.1	28.0	36.4	36.4	37.8	34.8	55.2	29.7
Thermal balance ratio (extracted/rejected)	1.50	1.53	1.93	2.68	2.75	2.14	1.88	1.19	0.28	0.86	0.64	0.95	0.61	0.80
Heating load (incl. DHW) met by ground source (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Cooling load met by ground source (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

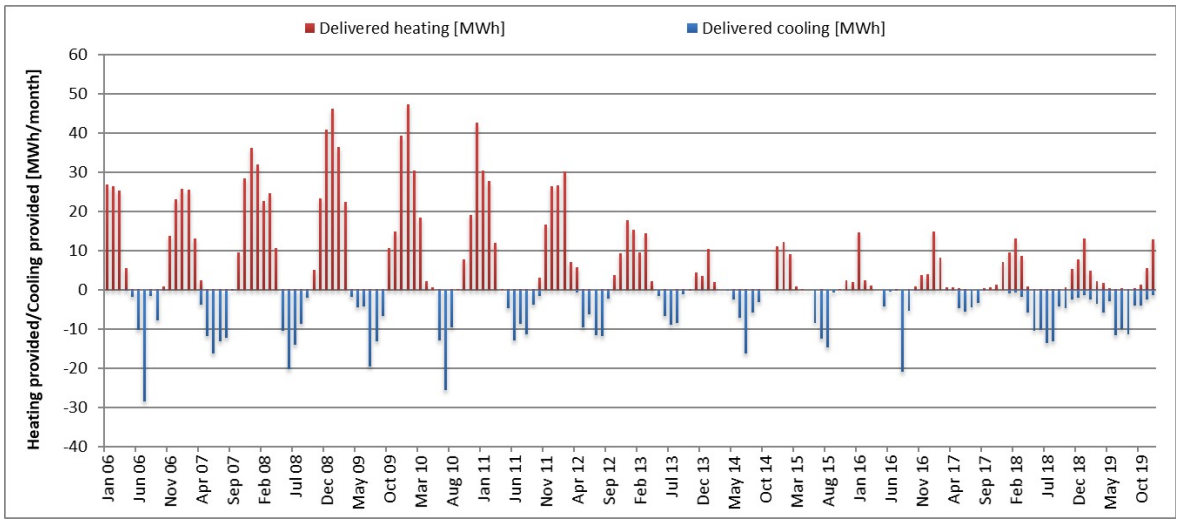


Figure 1. Monthly heating and cooling loads over the monitoring period

Period (Jan - Dec)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
SPFH0	38.2	42.2	40.9	44.3	43.9	40.1	42.5	30.0	20.6	62.4	34.4	36.7	33.5	15.8
SPFH1*	5.6	5.7	5.4	5.1	5.1	5.2	5.5	5.5	5.5	5.4	5.7	7.2	6.5	6.9
SPFH2	5.1	5.1	4.9	4.6	4.6	4.7	5.0	4.9	4.9	4.9	4.9	6.0	5.7	5.6
SPFH3	4.7	4.8	4.7	4.4	4.4	4.4	4.6	4.5	4.5	4.4	4.5	5.5	5.2	5.1
SPFH4	4.4	4.4	4.3	4.1	4.0	3.9	4.1	3.6	3.1	2.9	2.8	3.5	4.1	4.0
SPFC0	50.7	38.7	41.4	52.1	53.6	42.9	47.3	40.1	40.3	36.9	47.0	231.2	62.0	62.6
SPFC2	39.8	31.0	36.2	48.8	50.7	40.4	44.3	38.0	38.7	36.6	38.5	121.7	78.6	128.1
SPFC3	39.8	31.0	36.2	48.8	50.7	40.4	44.3	38.0	38.7	36.6	38.5	121.7	78.6	128.1
SPFC4	24.3	20.2	25.1	30.5	35.1	31.7	32.4	15.9	22.1	21.4	26.4	23.5	35.7	27.0
SPFHC0	42.4	40.7	41.1	46.2	46.1	41.0	44.0	33.9	33.3	45.5	41.2	64.5	46.9	27.1
SPFH1C*	5.6	5.7	5.4	5.1	5.1	5.2	5.5	5.5	5.5	5.4	5.7	7.2	6.5	6.9
SPFHC2	6.8	6.8	6.4	5.8	5.8	6.1	6.7	7.0	10.3	9.7	9.2	9.0	13.0	12.6
SPFHC3	6.4	6.4	6.0	5.5	5.5	5.8	6.3	6.5	9.5	8.9	8.5	8.2	12.0	11.6
SPFHC4	5.8	5.7	5.5	5.1	4.9	5.1	5.5	4.9	6.4	5.8	5.4	5.0	8.8	7.9

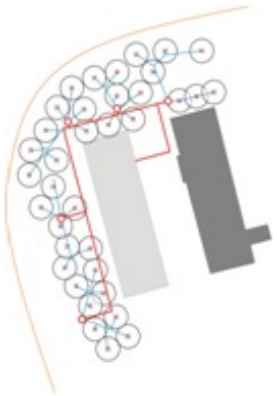
Figure 2. Annual performance factors over the monitoring period

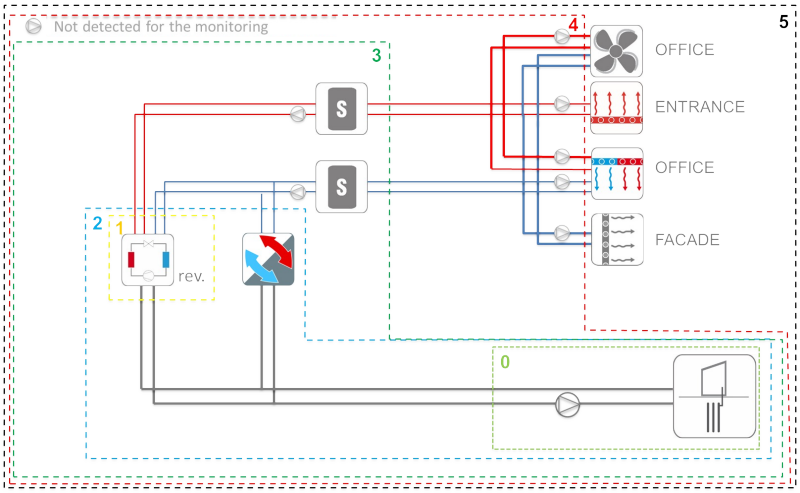
PUBLICATIONS

Bockelmann, F. (2021). Case study report for EFB, Germany. Office building with energy piles. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/2hb1-h641

Bockelmann, F. and Kley, Ch. 2021. It works - long-term performance measurement of ground source heat pump systems. 13th IEA Heat Pump Conference. Jeju, Korea. April 26-29.

Bockelmann, F. and M. N. Fisch. 2020. It works – Long-term performance measurement and optimization of six ground source heat pump systems in Germany. Energies 2019, 12 (24), 4691. 2019.; https://doi.org/10.3390/en12244691





Building information

Building name	GEW
Location	Gelsenkirchen, Germany
Year of building construction	2004
Ground source system operation start date	2004
Building Type	Office building
Building floor area	6 200 m² net
Analysed monitoring period	206-Sep 2019

Heat pump information

Heat pump	1 reversible brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	326 kW_{th} , no DHW heating
Nominal total heat pump cooling capacity [kW_{th}]	320 kW_{th}
Refrigerant	R134a

Ground source information

Ground source	36 grouted vertical boreholes, 150 m
Undisturbed ground temperature	12°C
Borehole heat exchanger type	Double U-tube
Source side brine type	Water-Monoethylene Glycol 25%

Period (Jan - Dec)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Building space heating load met by system [MWh_{th}]	584.0	588.8	614.8	680.2	68.9	0.0	0.0	462.9	600.1	582.7	791.7	498.6	711.4	439.8
Building cooling load met by system [MWh_{th}]	277.2	451.8	164.7	472.8	485.1	393.1	414.5	330.5	393.0	352.5	440.7	454.2	709.5	558.0
DHW load met by system [MWh_{th}]														
Thermal energy extracted from the ground [MWh_{th}]	114.0	67.0	121.0	339.0	346.0	352.0	233.0	343.0	276.0	267.0	269.0	284.0	320.0	171.3
Thermal energy injected to the ground [MWh_{th}]	517.0	235.0	156.0	374.0	324.0	220.0	271.0	200.0	271.0	225.0	274.0	267.0	405.0	349.5
Thermal balance ratio (extracted/rejected)	0.22	0.29	0.78	0.91	1.07	1.60	0.86	1.72	1.02	1.19	0.98	1.06	0.79	0.49
Heating load (incl. DHW) met by ground source (%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Cooling load met by ground source (%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100

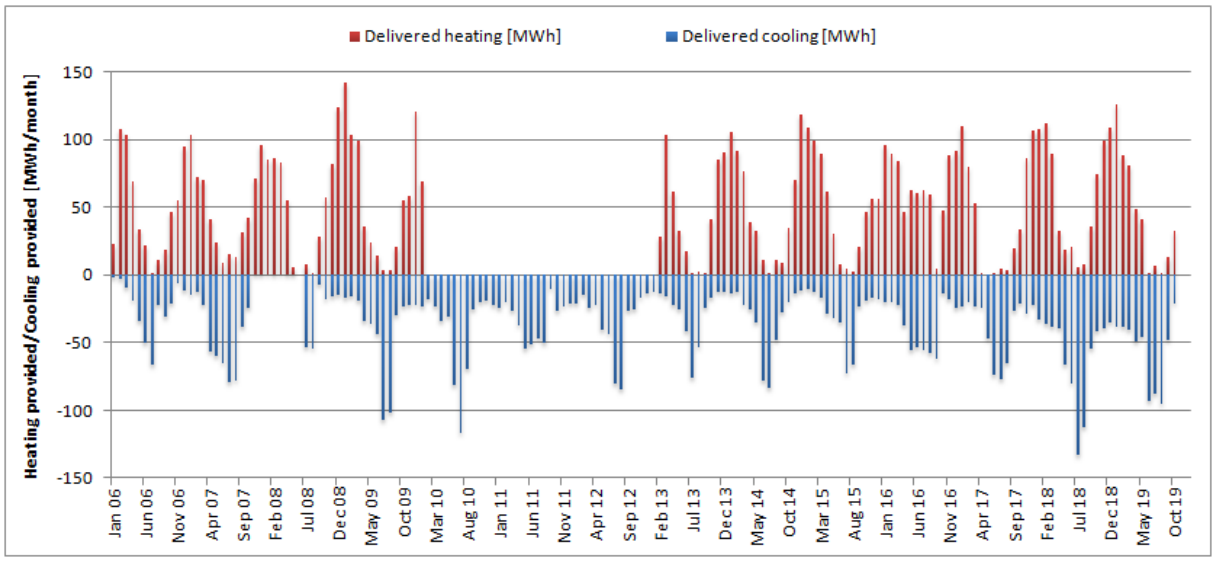


Figure 1. Monthly heating and cooling loads over the monitoring period

Period (Jan - Dec)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
SPFH0				11.0				9.4	8.0	9.4	6.6	10.6	10.5	8.1
SPFH1*	2.4	2.3	2.6	2.7				1.7	2.4	2.8	2.7	2.3	2.7	2.4
SPFH2	2.4	2.3	2.6	2.4				1.5	2.1	2.4	2.4	2.0	2.4	2.2
SPFC0				21.1				15.8	21.3	13.5	59.5	17.0	27.5	24.8
SPFC1	2.3	6.8	1.6	4.3				4.8	5.1	4.0	12.1	3.8	4.8	4.4
SPFC2	2.3	6.8	1.6	3.7				4.1	4.4	3.4	10.8	3.4	4.4	3.9
SPFHC0	0.0	0.0	0.0	14.7				11.1	11.6	10.9	11.9	13.0	16.0	14.8
SPFH1C*	3.4	3.8	2.0	3.8				2.8	3.6	3.7	4.0	3.6	4.6	3.8
SPFHC2	3.4	3.8	2.0	3.3				2.5	3.2	3.3	3.5	3.2	4.1	3.4

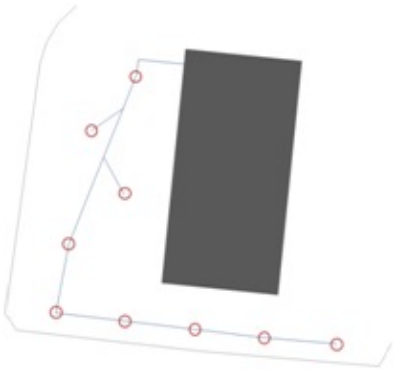
Figure 2. Performance factors over the monitoring period.

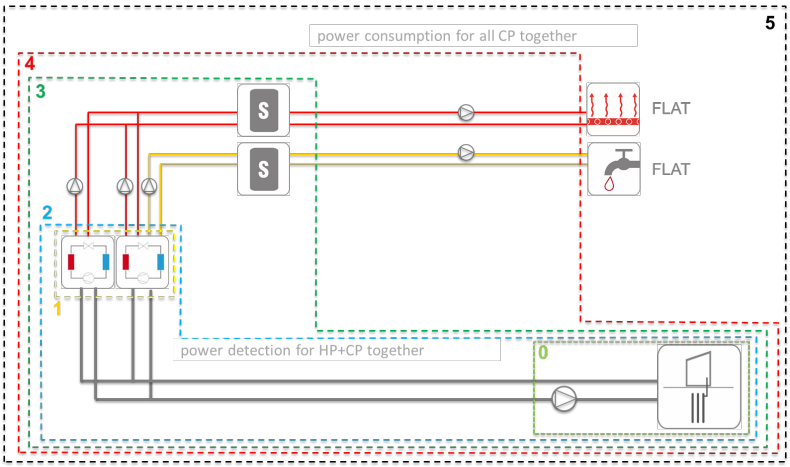
PUBLICATIONS

Bockelmann, F. (2021). Case study report for GEW, Germany. Office building with borehole heat exchanger. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/0cfw-xw78

Bockelmann, F. and Kley, Ch. 2021. It works - long-term performance measurement of ground source heat pump systems. 13th IEA Heat Pump Conference. Jeju, Korea. April 26-29.

Bockelmann, F. and M. N. Fisch. 2020. It works – Long-term performance measurement and optimization of six ground source heat pump systems in Germany. Energies 2019, 12 (24), 4691. 2019.; https://doi.org/10.3390/en12244691





Building information	
Building name	KON
Location	Konstanz, Germany
Year of building construction	2016
Ground source system operation start date	2016
Building Type	Multi-family building
Building floor area	1 100 m² net
Analysed monitoring period	2017-2019

Heat pump information	
Heat pump	2 brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity [kW_{th}]	30 kW_{th}
Nominal total heat pump DHW capacity [kW_{th}]	27 kW_{th}
Refrigerant	R410A and R134A

Ground source information	
Ground source	9 grouted vertical boreholes, 100 m
Undisturbed ground temperature	12.4°C
Borehole heat exchanger type	Double U-tube
Source side brine type	Water-brine 25%

Evaluation period	2017	2018	2019
Building space heating load met by system [MWh_{th}]	76.8	69.7	68.1
DHW load met by system [MWh_{th}]	34.3	32.4	38.2
Thermal energy extracted from the ground [MWh_{th}]	143.7	155.1	149.1
Heating load (incl. DHW) met by ground source (%)	100%	100%	100%
SPFH2	3.8	3.8	4.1
SPFH4	3.0	3.0	3.1

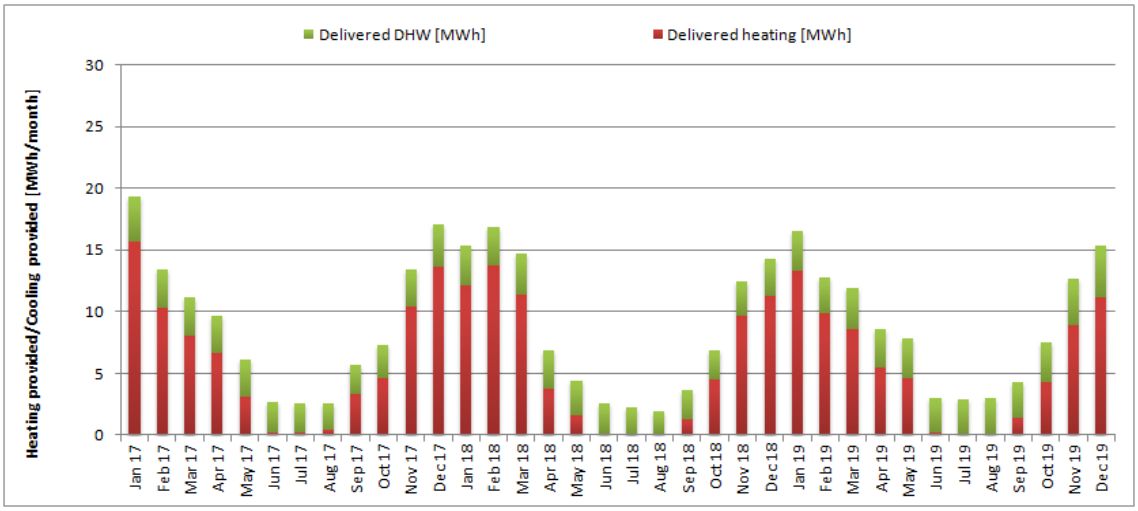


Figure 1. Monthly heating and DHW loads over the monitoring period

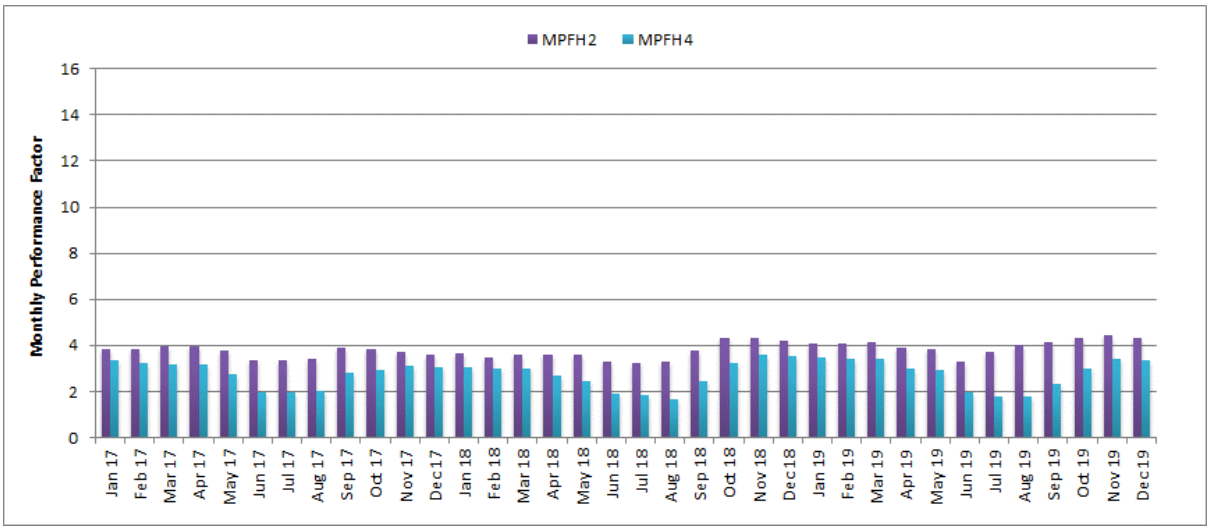


Figure 2. Monthly heating Performance Factors for different system boundaries over the monitoring period

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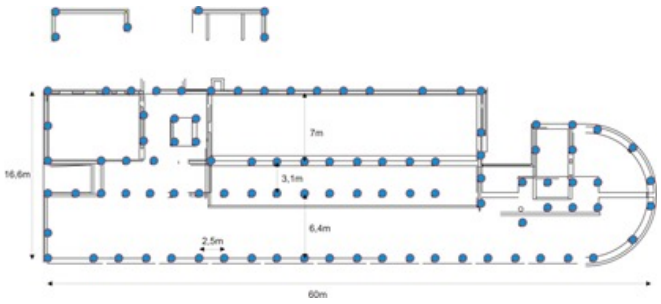

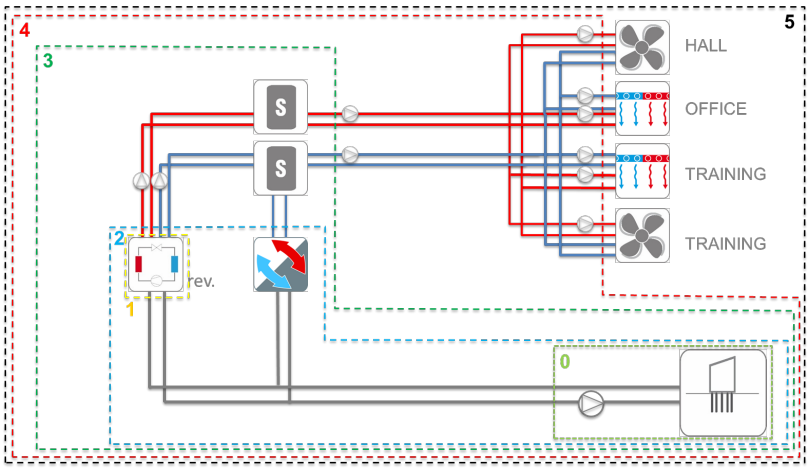

Building information

Building name	VGH
Location	Lüneburg, Germany
Year of building construction	2002
Ground source system operation start date	2002
Building Type	Office building
Building floor area	4000 m² net
Analysed monitoring period	2006-2017

Heat pump information

Heat pump	1 reversible brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity [kW_{th}]	82 kW_{th} , no DHW heating
Nominal total heat pump cooling capacity [kW_{th}]	89 kW_{th}
Refrigerant	R407c

Ground source information

Ground source	101 energy piles, 17.5-21.5 m, total length 1926 m
Undisturbed ground temperature	13°C
Pile material	Reinforced concrete
Source side brine type	Water-Glycol 20

Period (Jan - Dec)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Building space heating load met by system [MWh_{th}]	25.9	43.1	97.4	90.5	60.1	76.8	99.1	88.2	54.2	25.0	16.7	53.5
Building cooling load met by system [MWh_{th}]	16.3	2.7	6.8	19.7	16.9	13.6	23.8	27.0	24.0	10.3	14.4	15.3
DHW load met by system [MWh_{th}]												
Thermal energy extracted from the ground [MWh_{th}]	9.5	25.4	77.5	76.6	50.5	68.0	75.5	72.1	37.6	10.6	5.9	43.2
Thermal energy injected to the ground [MWh_{th}]	24.5	5.2	12.2	23.6	26.9	31.0	40.9	46.4	39.4	26.5	26.1	24.0
Thermal balance ratio (extracted/rejected)	0.39	4.87	6.37	3.24	1.88	2.19	1.85	1.55	0.95	0.40	0.23	1.80
Heating load (incl. DHW) met by ground source (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Cooling load met by ground source (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

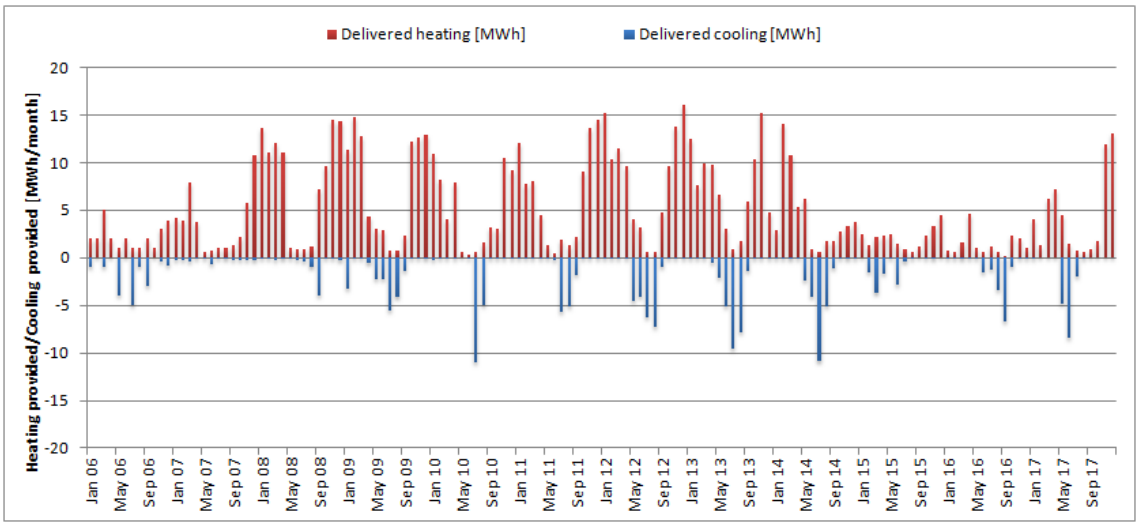

Figure 1. Monthly heating and cooling loads over the monitoring period

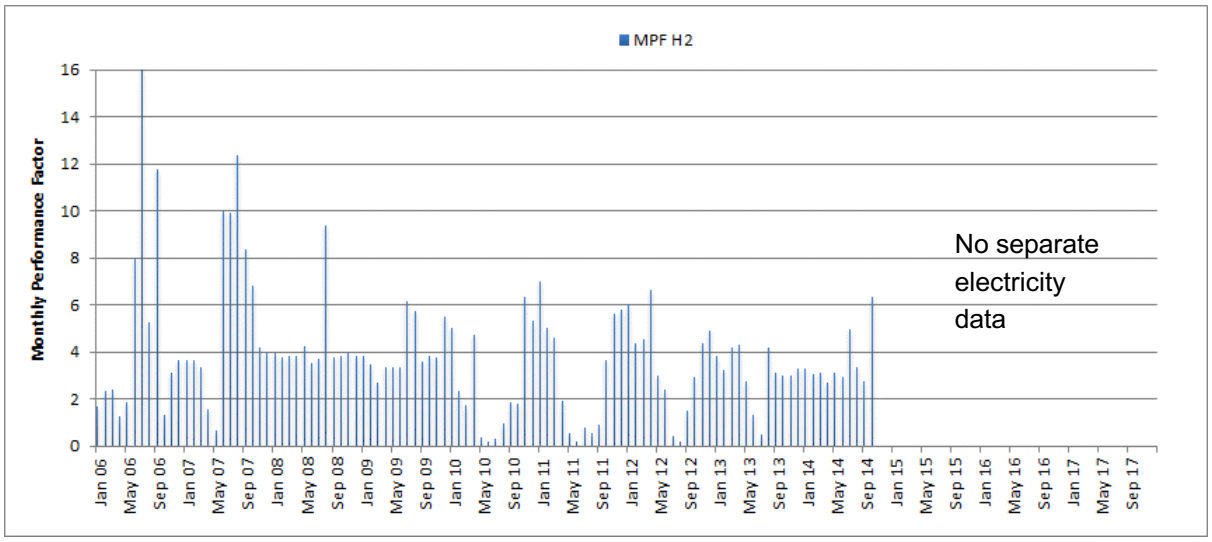

Figure 2. Monthly heating performance factors over the monitored period

Period (Jan - Dec)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
SPFH2	2.7	3.4	3.9	3.7	2.6	2.8	3.5	3.1	3.7			
SPFC2	2.4	8.4	2.6	10.9	6.0	3.1	3.5	3.6	2.0			
SPFHC2	2.6	3.5	3.8	4.2	3.0	2.9	3.5	3.2	2.9	1.4	1.5	2.8

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Bockelmann, F. (2021). Case study report for VGH, Germany. Office building with energy piles. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/5e1b-ad59

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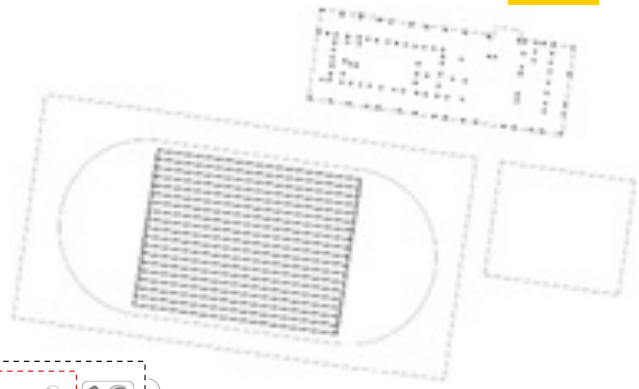

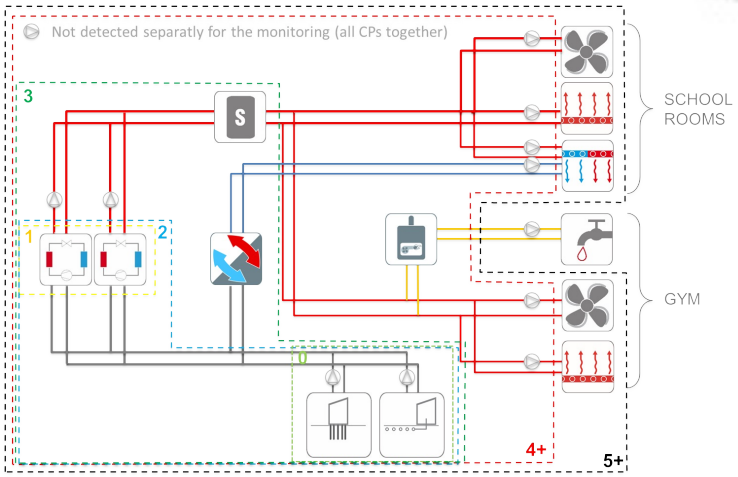

Building information

Building name	WGG
Location	Neumarkt i.d. Opf, Germany
Year of building construction	2015
Ground source system operation start date	2015
Building Type	School with gym
Building floor area	2 900 m² net
Analysed monitoring period	2017-2019

Heat pump information

Heat pump	2 brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	42.8 kW_{th} , no DHW heating
Refrigerant	R410A

Ground source information

Ground source	96 energy piles, 8-12 m. Total length 1004 m + Agrothermal field of 4400 m²
Undisturbed ground temperature	11.7°C
Pile material	Reinforced concrete
Source side brine type	Propylene glycol

Evaluation period	2017	2018	2019
Building space heating load met by system [MWh_{th}]	296.4	258	246.5
Building cooling load met by system [MWh_{th}]	93.3	115	92.5
Thermal energy extracted from the ground [MWh_{th}]	164.6	184.2	182.5
Thermal energy injected to the ground [MWh_{th}]	94.9	125.8	86.7
Thermal balance ratio (extracted/rejected)	1.73	1.46	2.11
Cooling load met by ground source (%)	100%	100%	100%

Period (Jan - Dec)	2017	2018	2019
SPFH0	31.8	44.8	
SPFH1*	5.3	4.8	
SPFH2	4.7	4.4	
SPFH4	4.4	3.3	
SPFH5	2.4	1.8	
SPFC0	157.7	136.7	
SPFC2	122.6	109.9	
SPFHC0	45.0	61.6	
SPFH1C*	5.3	4.8	
SPFHC2	6.2	6.3	
SPFHC4	5.2	4.4	
SPFHC5	2.9	2.3	

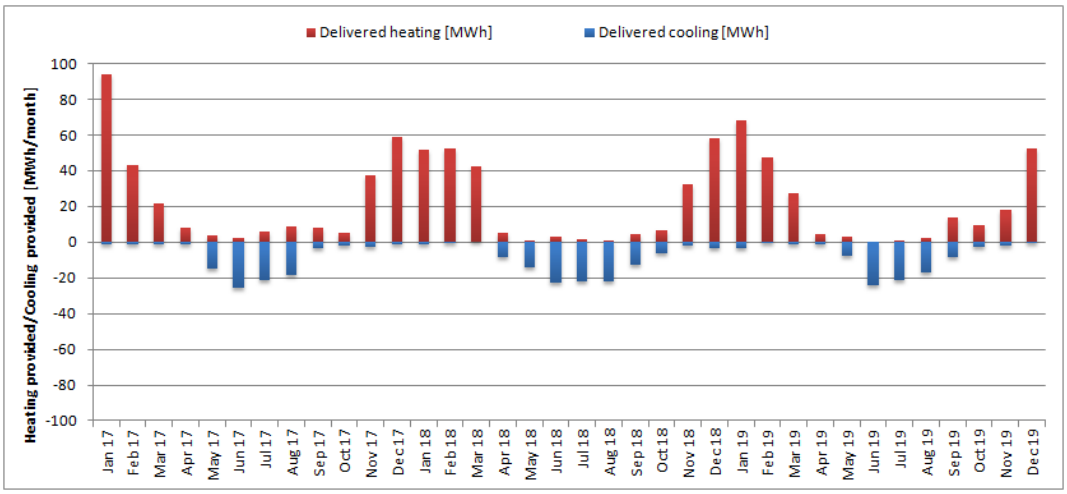

Figure 1. Monthly heating and cooling loads over the monitoring period

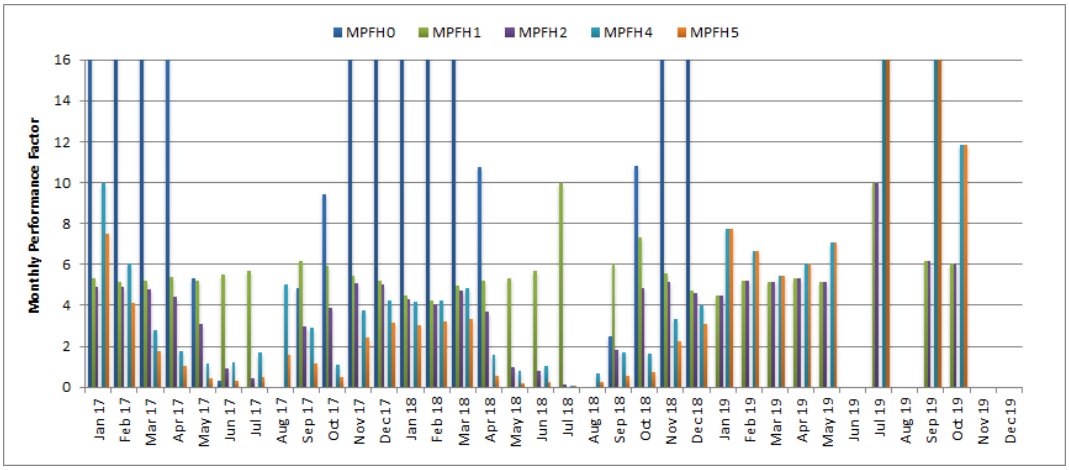

Figure 2. Monthly heating performance factors over the monitoring period

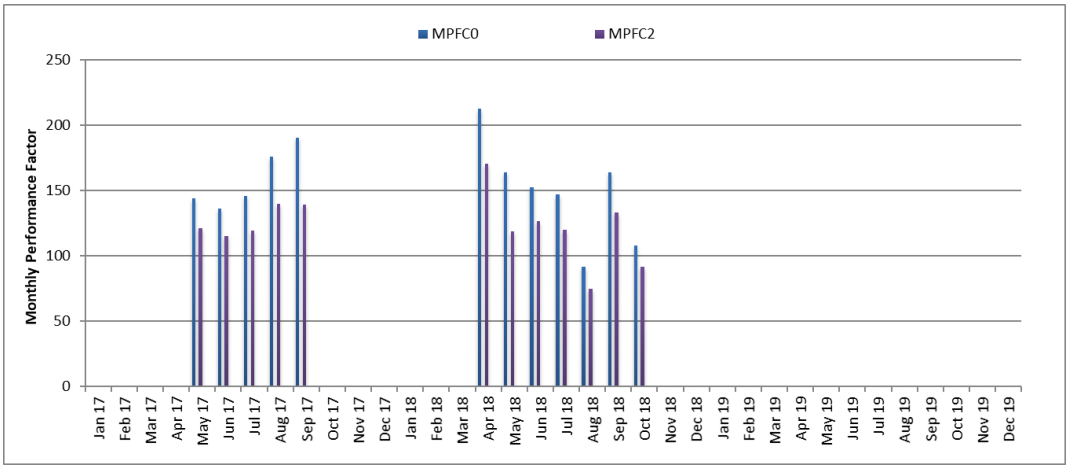

Figure 2. Monthly cooling performance factors over the monitoring period

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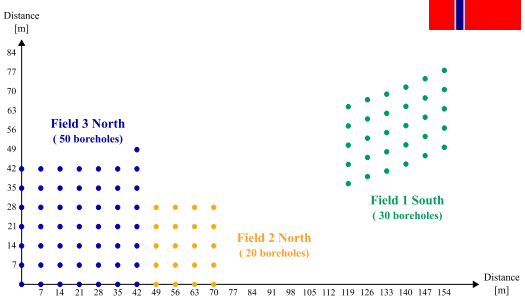

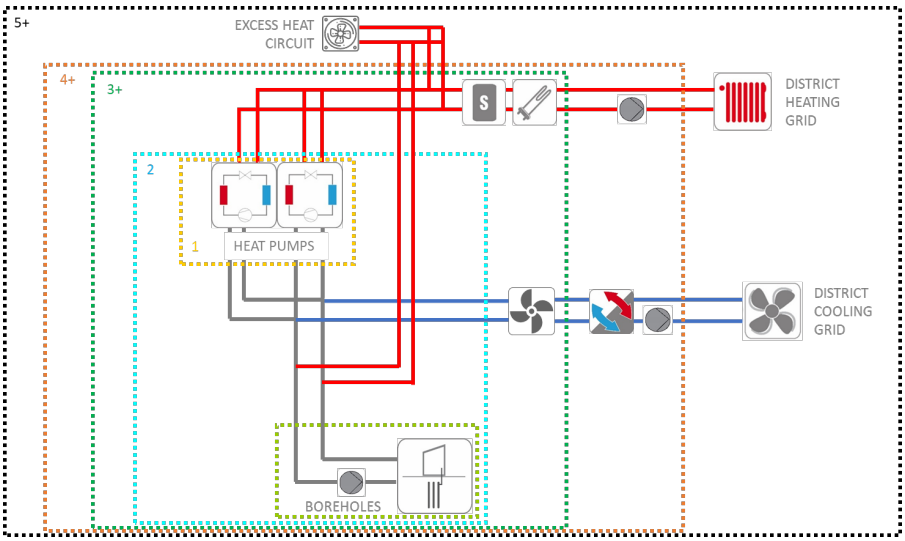

Building information	
Building name	Kalnes energy central, Østfold hospital
Location	Sarpsborg, Norway
Year of building construction	2015
Ground source system operation start date	2015
Building Type	Hospital
Building floor area	80 000 m² gross
Analysed monitoring period	2016-2019

Heat pump information	
Heat pump	2 reversible brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	2.7 MW_{th} , no DHW heating
Nominal total heat pump cooling capacity	2.6 MWth
Refrigerant	Ammonia, R134a

Ground source information	
Ground source	100 grouted vertical boreholes, 250 m
Undisturbed ground temperature	8.1°C
Borehole heat exchanger type	Single U-tube
Source side brine type	Water-Ethanol 35%

Evaluation period	2016	2017	2018	2019	2020
Total heating load met by system [MWh_{th}]	9682	9349	8897	8174	7287
Total cooling load met by system [MWh_{th}]	5299	4909	5772	4552	4785
Thermal energy extracted from the ground [MWh_{th}]	81.7	819.8	1814.2	1780.9	1361.4
Thermal energy injected to the ground [MWh_{th}]	143.6	545	754.4	618.7	1595.6
Thermal balance ratio (extracted/rejected)	0.57	1.5	2.4	2.88	0.85
SPFH2	4.3	4.7	4.4	4.7	4.8
SPFH4	3.4	3.5	3.0	3.7	3.9

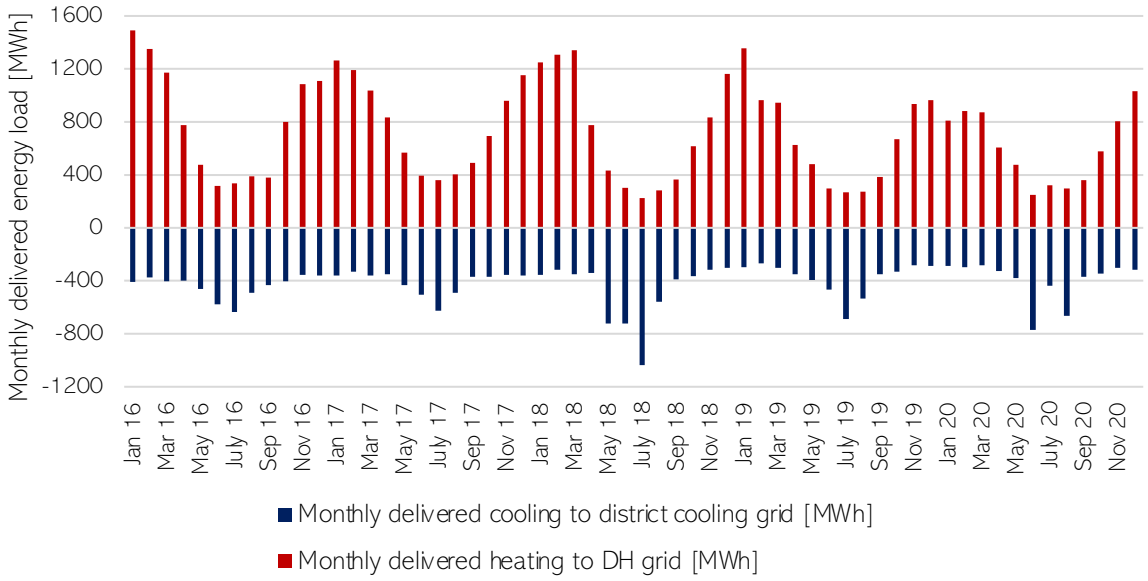

Figure 1. Monthly heating and cooling loads over the monitoring period

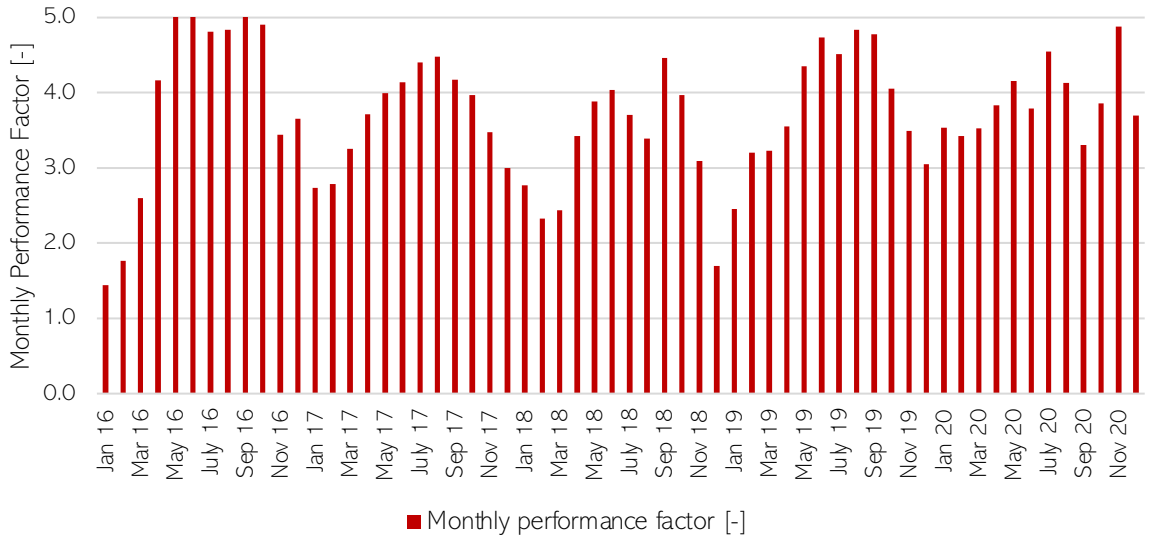

Figure 2. Monthly performance factor PFHC4 over the monitoring period

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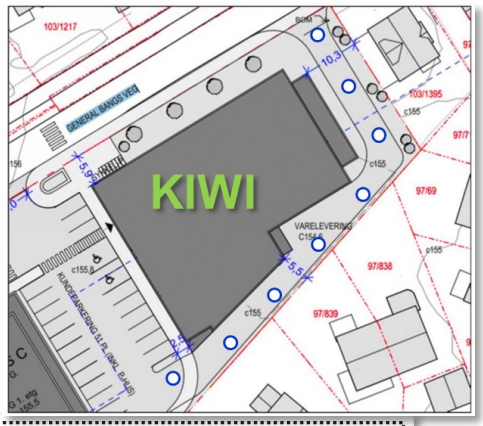
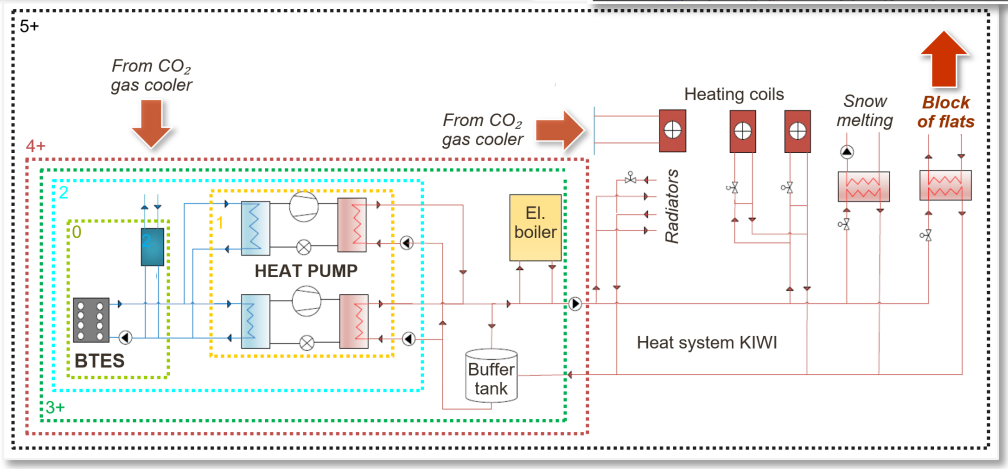
Ebnes and E. Hagen, "Driftsvurdering av Kalnes energisentral - Operational assessment of Kalnes energisentral," NMBU, 2017.





Building information	
Building name	KIWI Dalgård
Location	Trondheim, Norway
Year of building construction	2017
Ground source system operation start date	2017
Building Type	Supermarket + apartments
Building floor area	1250 m² gross for supermarket. No data for apartments.
Analysed monitoring period	January-December 2018

Heat pump information	
Heat pump	2 brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	76 kW_{th}
Refrigerant	R410A

Ground source information	
Ground source	8 groundwater-filled vertical boreholes, 264 m
Undisturbed ground temperature	~5°C (based on mean air temp, not measured)
Borehole heat exchanger type	Single U-tube
Source side brine type	Water-Ethanol 35%

Evaluation period	2018
SPFH1	2.9

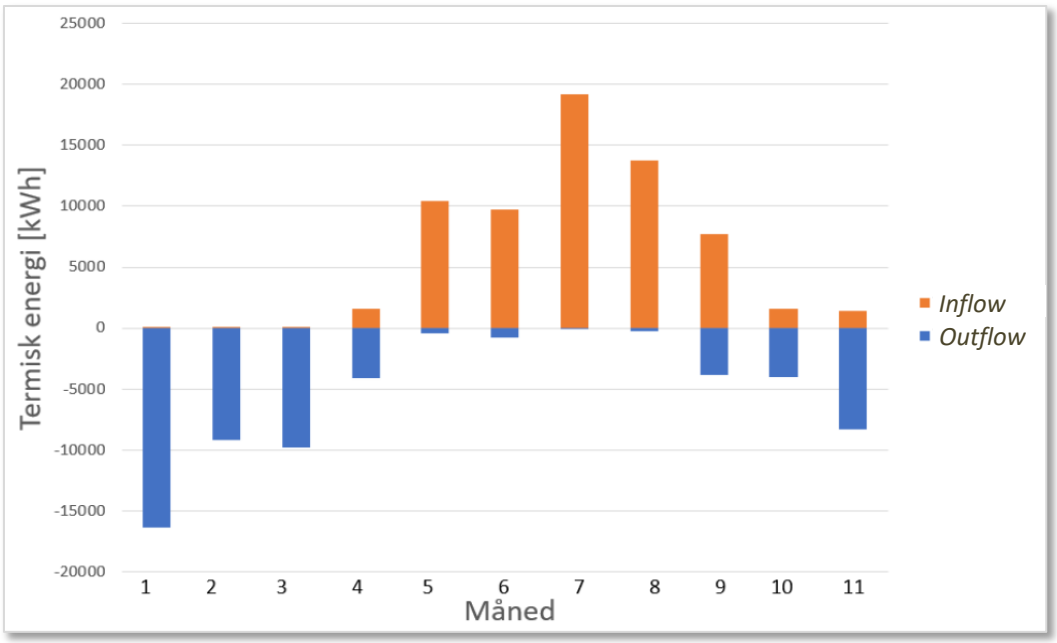


Figure 1. Monthly heating and cooling loads over the monitoring period

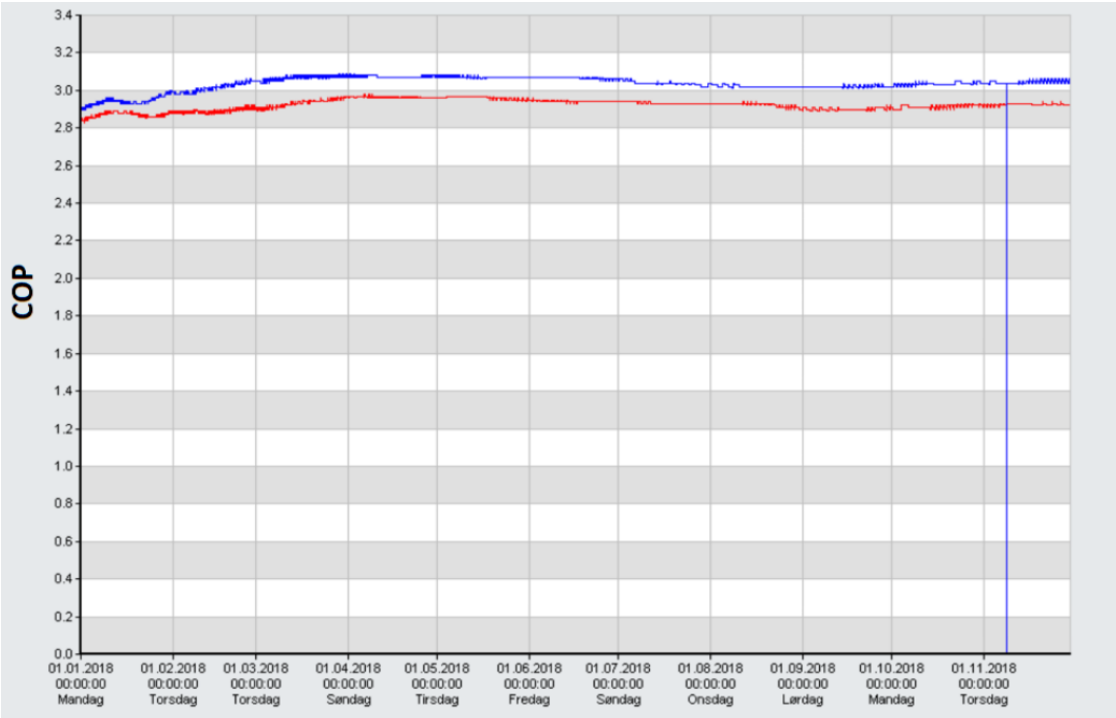
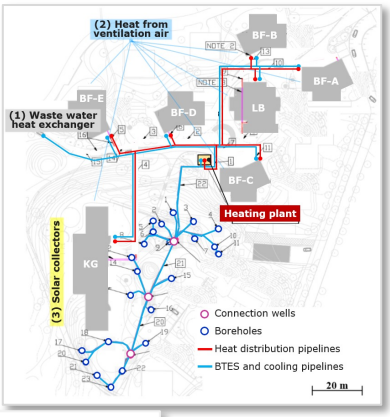
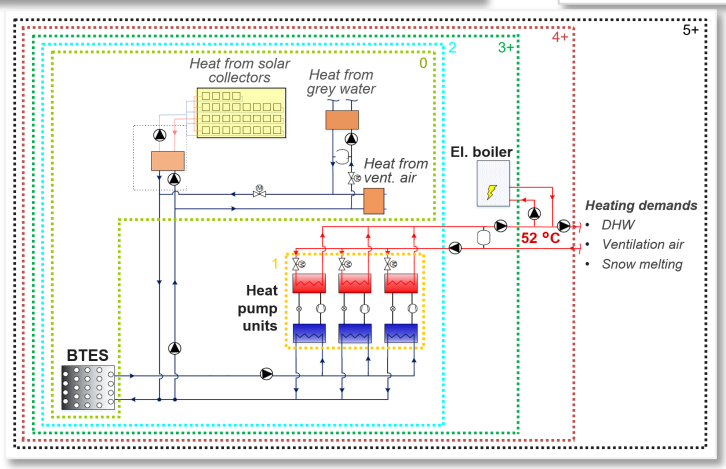


Figure 2. Measured daily performance factor for the two R410A heat pump units, January to November 2018, DPFH1

PUBLICATIONS

Stene, J. (2021). Case Study report for 1) KIWI Dalgård, 2) The SWECO Building and 3) Moholt 50|50 – Norway. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/wa60-2121





Building information	
Building name	Moholt 50/50
Location	Trondheim, Norway
Year of building construction	2016/17
Ground source system operation start date	2016 October
Building Type	Multi-family building + supermarket, library and kindergarden
Building floor area	25 000 m²
Analysed monitoring period	October 2016 to February 2020

Heat pump information	
Heat pump	3 brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	252 kW_{th}
Nominal total heat pump cooling capacity	unknown
Refrigerant	R410A

Ground source information	
Ground source	23 groundwater-filled vertical boreholes,250m
Undisturbed ground temperature	~5°C (based on mean air temperature, not measured)
Borehole heat exchanger type	Single U-tube
Source side brine type	Water-Ethanol 24%

Evaluation period	Sept 2018 – Oct 2019
SPFH1	3.2
SPFH1+	2.8
SPFHC1	3.8
SPFHC1+	3.4

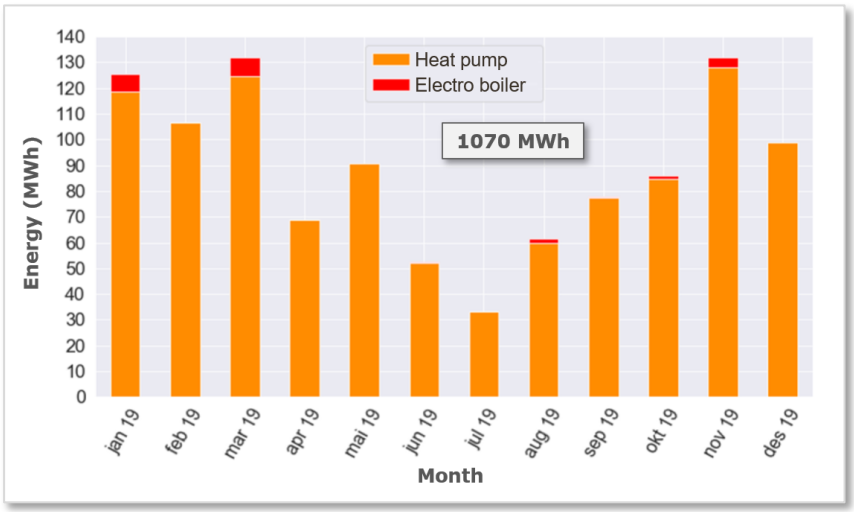


Figure 1. Measured monthly heat supply from the heat pump and electric boiler

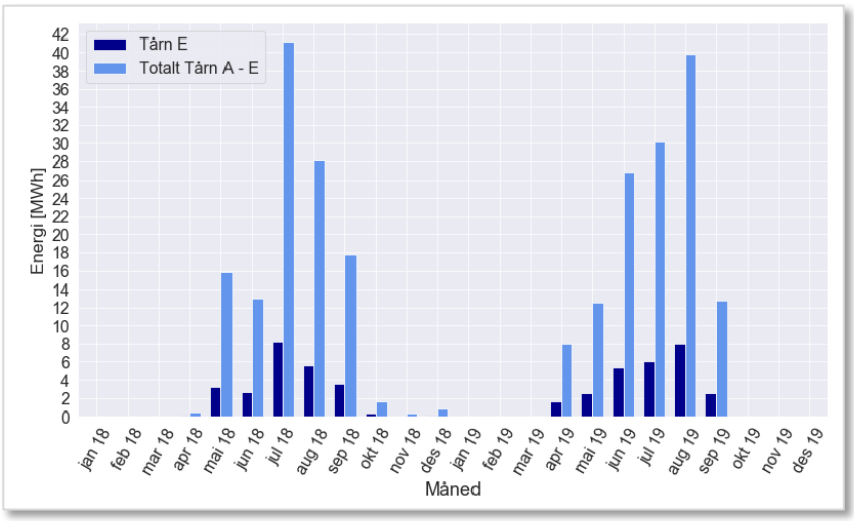


Figure 2. Measured monthly cooling demands for blocks of flats

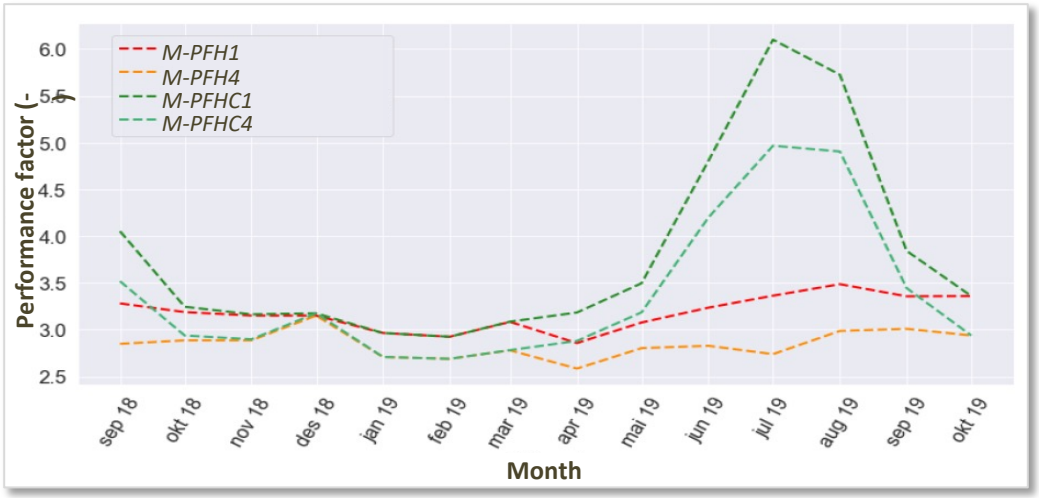
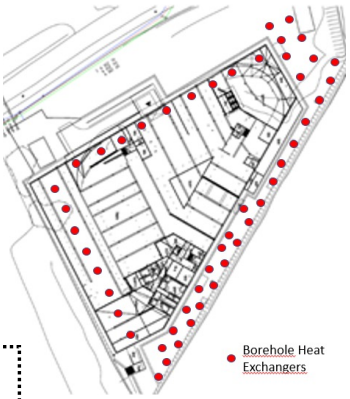
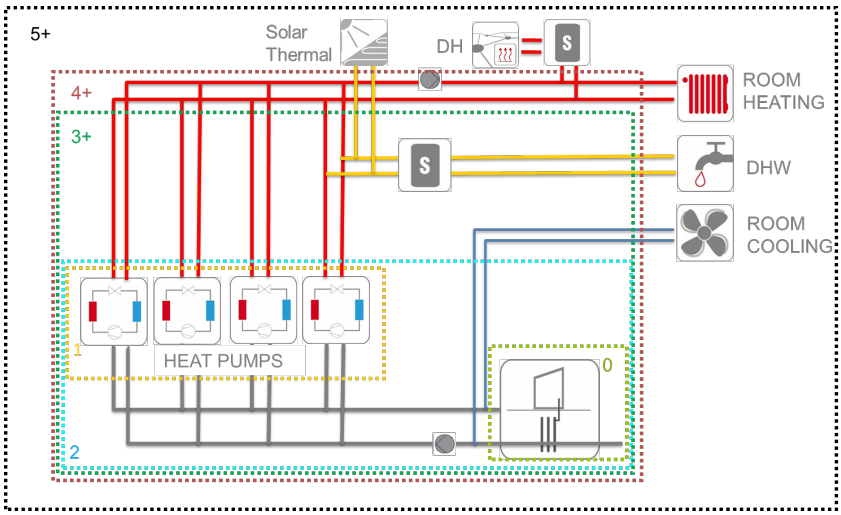


Figure 3. Monthly performance factors over the monitored period

PUBLICATIONS

Stene, J. (2021). Case Study report for 1) KIWI Dalgård, 2) The SWECO Building and 3) Moholt 50|50 – Norway. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/wa60-2121





Building information	
Building name	Scandic Flesland
Location	Bergen, Norway
Year of building construction	2016-17
Ground source system operation start date	2016-17
Building Type	Hotel
Building floor area	18 000 m² net
Analysed monitoring period	2018 – October 2020

Heat pump information	
Heat pump	4 brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	320 kW_{th}
Nominal total heat pump DHW capacity	160 kW_{th}
Refrigerant	R410A

Ground source information	
Ground source	50 groundwater-filled vertical boreholes, 200 m
Undisturbed ground temperature	8.8°C
Borehole heat exchanger type	Double U-tube
Source side brine type	Monopropylene glycol

Evaluation period	2018	2019
Building space heating load met by system [MWh_{th}]	1228	1665
Building cooling load met by system [MWh_{th}]	131.8	107
DHW load met by system [MWh_{th}]	158	151
Thermal energy extracted from the ground [MWh_{th}]	276	259
Thermal energy injected to the ground [MWh_{th}]	132	107
Thermal balance ratio (extracted/rejected)	2.1	2.4
SPFH4	4	-
SPFHC4	4.4	-

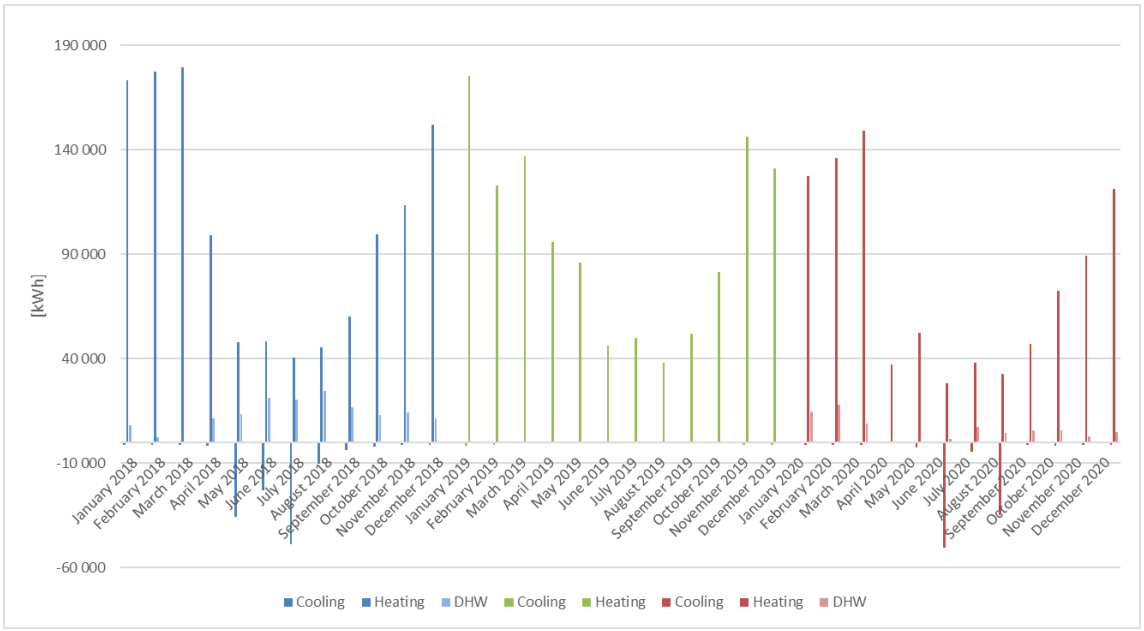


Figure 1. Monthly heating and cooling loads over the monitoring period

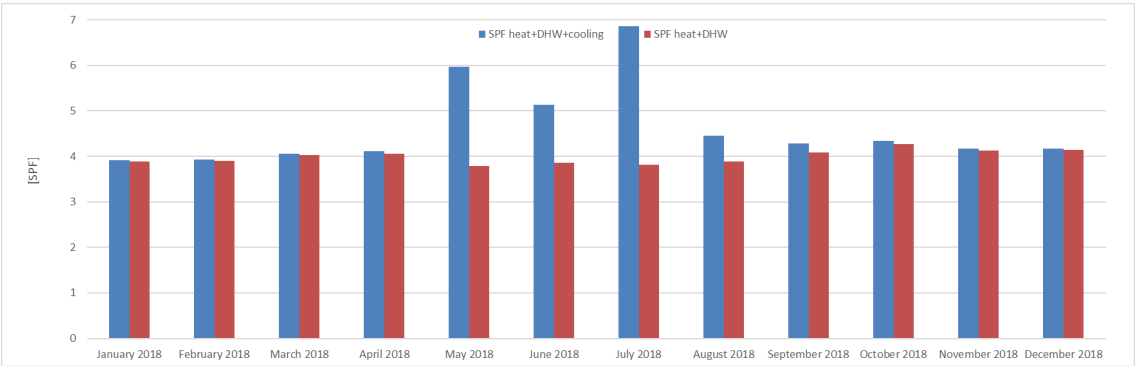


Figure 2. Monthly performance factors over the monitoring period

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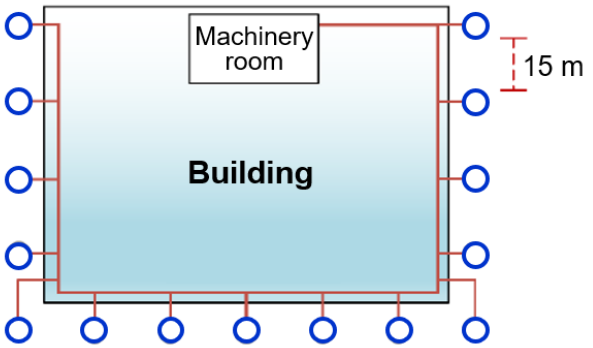
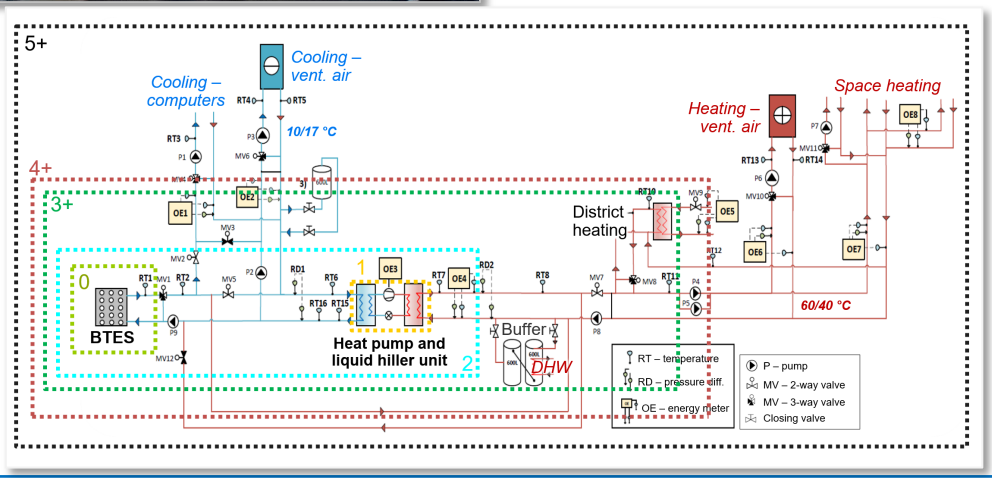
Midttømme, K., Risinggård, V.K., Hetland, S., Clauß, J., Sivertsen, O. (2021). Case study report for Scandic Flesland Airport, Norway. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/03xm-xy55

Ramstad, R.K., B. Fondnes Rørleggerfirma AS. Scandic Hotell Flesland – dimensjonering av grunnvarme Utgave 1 09.06.2015, technical report Asplan Viak AS.

Midttømme, K., Ramstad, R.K, Sivertsen, O, 2017 Norwegian Case Study. Hotel Scandic Flesland Airport, Technical NOTE EEA Project Geothermal 4Pl CMR -17 F311701 TN2





Building information	
Building name	SWECO Building
Location	Bergen Norway
Year of building construction	2016
Ground source system operation start date	2016
Building Type	Grocery store + offices
Building floor area	18 000 m²
Analysed monitoring period	January – December 2018

Heat pump information	
Heat pump	1 brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	190 kW_{th} , no DHW heating
Nominal total heat pump cooling capacity [kW_{th}]	195 kW_{th}
Refrigerant	Ammonia R717

Ground source information	
Ground source	15 groundwater-filled vertical boreholes, 220 m
Undisturbed ground temperature	~8°C (based on mean air temperature, not measured)
Borehole heat exchanger type	Single U-tube
Source side brine type	Water

Evaluation period	2018
SPFH1	3.4
SPFH2	2.5
SPFHC1	3.6
SPFHC2	2.7

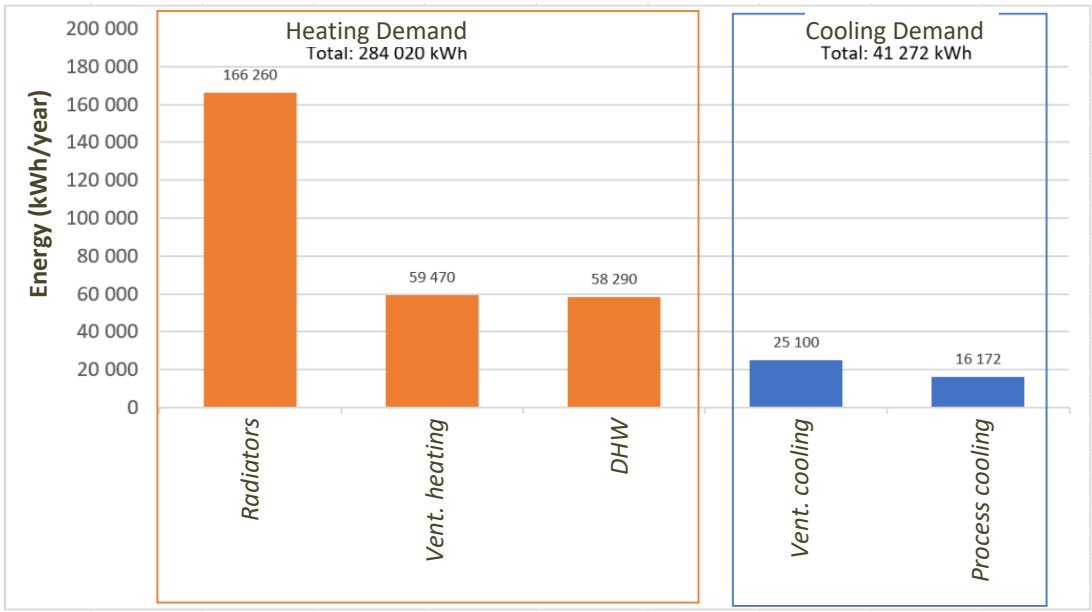


Figure 1. Annual heating and cooling loads over the monitoring period

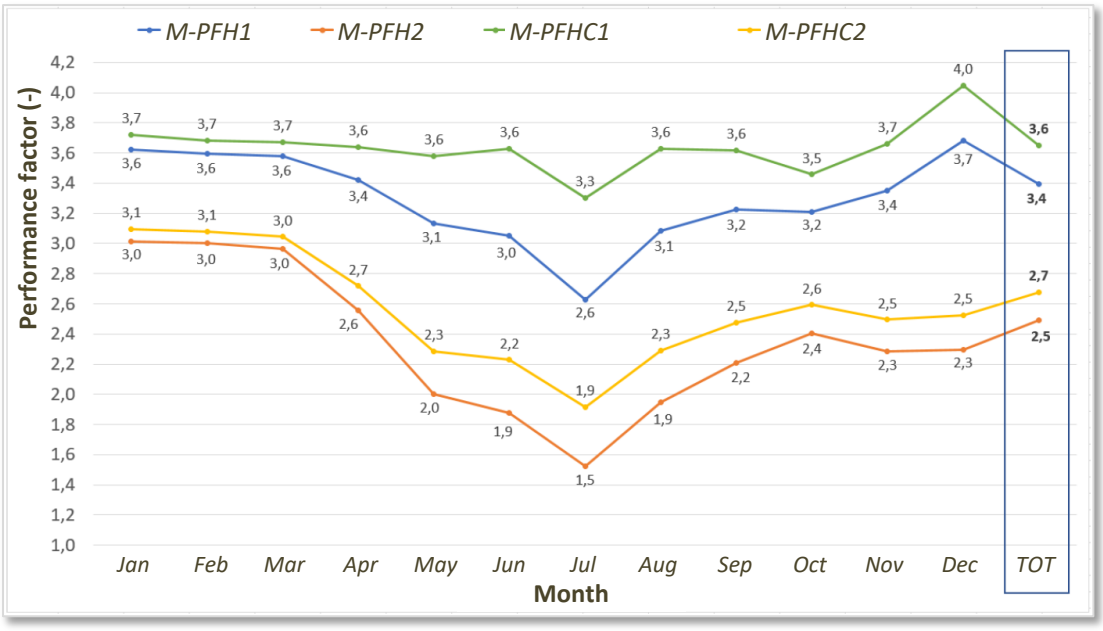
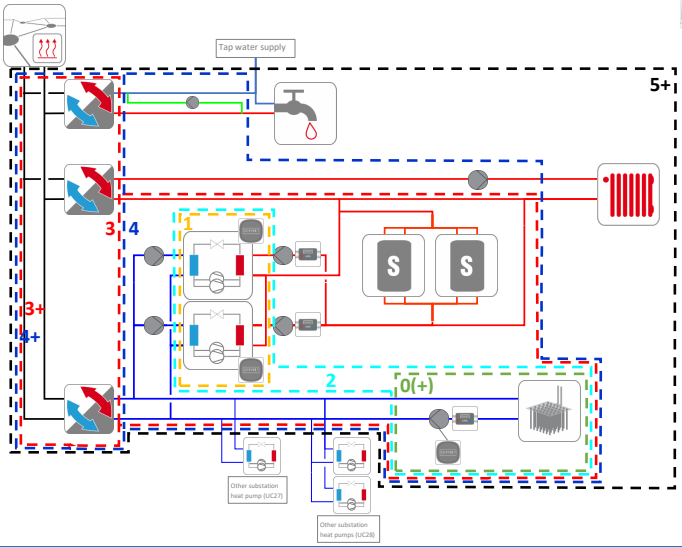


Figure 2. Monthly performance factors over the monitoring period.

PUBLICATIONS

Stene, J. (2021). Case Study report for 1) KIWI Dalgård, 2) The SWECO Building and 3) Moholt 50|50 – Norway. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/wa60-2121



Building information	
Building name	Backadalen
Location	Backadalen, Göteborg, Sweden
Year of building construction	1969-71
Ground source system operation start date	2015-2016 the two first substations, 2017-2019 the entire area
Building Type	Residential buildings
Building floor area	86 650 m²
Analysed monitoring period	2020-07-01 to 2021-06-30

Heat pump information	
Heat pump	31 brine-to-water HPs
Heat Pump system type	Centralized HPs in 14 substations
Nominal total heat pump heating capacity	1900 kW_{th}
Refrigerant	R407c + R410a

Ground source information	
Ground source	146 groundwater-filled vertical boreholes, 270-300 m
Undisturbed ground temperature	7.8°C
Borehole heat exchanger type	Single U-tube, turbo collector
Source side brine type	Water-Ethanol 28%

Evaluation period	2020-07-01 to 2021-06-30
Building space heating load met by system [MWh_{th}]	5400 (estimated)
Building cooling load met by system [MWh_{th}]	none
DHW load met by system [MWh_{th}]	none
Thermal energy extracted from the ground [MWh_{th}]	3700 (estimated)
Thermal energy injected to the ground [MWh_{th}]	5800 (estimated)
Thermal balance ratio (extracted/rejected)	0.56
Heating load (incl. DHW) met by ground source (%)	60-70% (estimated)
Cooling load met by ground source (%)	none
SPFH1’	3.9
SPFH3’	3.7

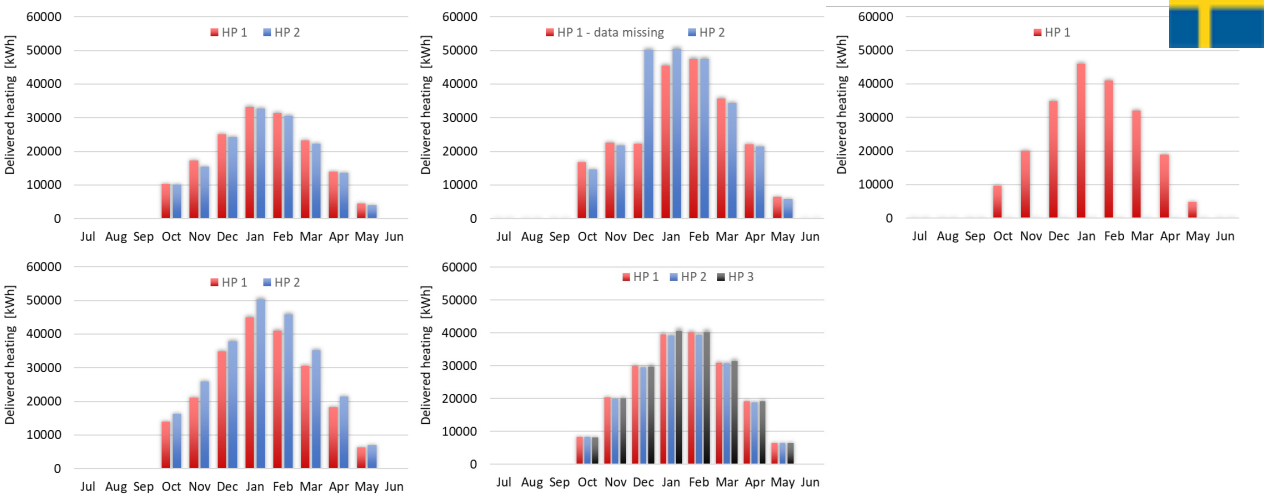


Figure 1. Monthly heating load for substations UC03, UC21, UC27, UC35 and UC38 over the monitoring period

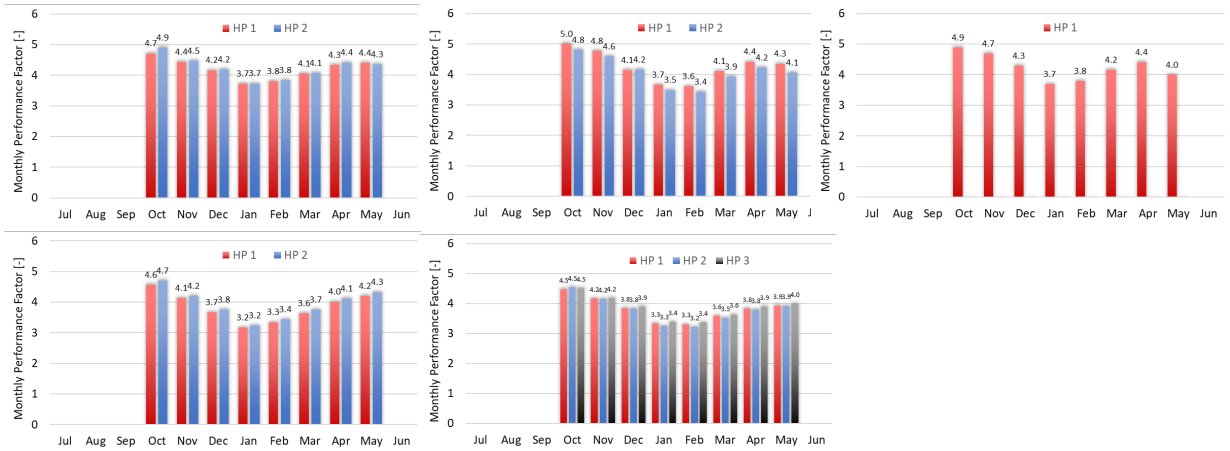


Figure 2. Monthly performance factor (MPFH3') for substations UC03, UC21, UC27, UC35 and UC38 over the monitoring period.

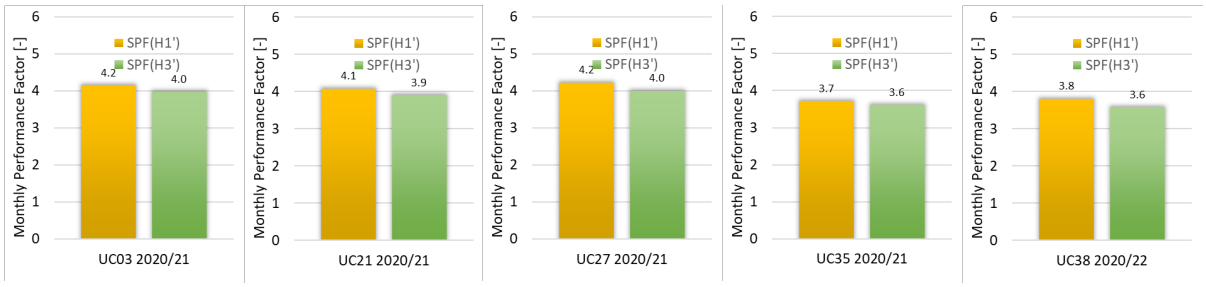
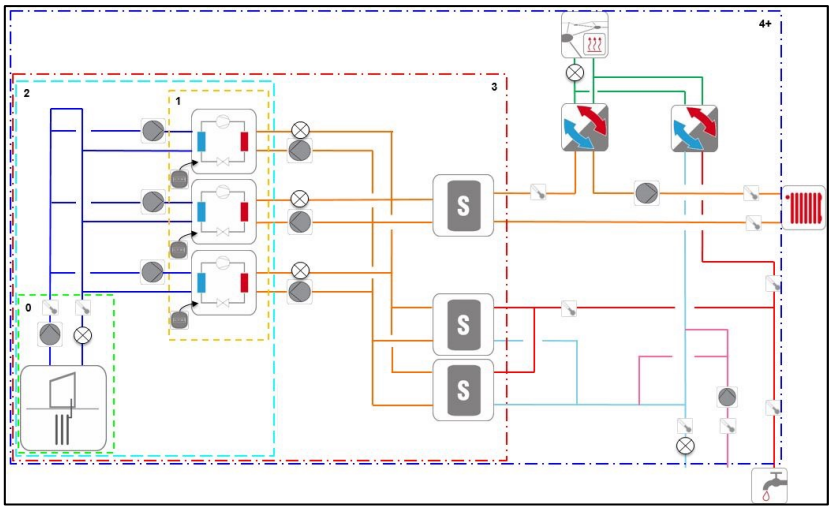


Figure 2. Seasonal performance factor (SPFH3') for substations UC03, UC21, UC27, UC35 and UC38 over the monitoring period.

PUBLICATIONS

Walfridson, T. (2021). Case study report for Backadalen, Sweden. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/r7zd-s388



Building information	
Building name	Kv Briljanten
Location	Lund , Sweden
Year of building construction	1964 and 1991
Ground source system operation start date	2018
Building Type	Multi-family building
Building floor area	12 000 m²
Analysed monitoring period	Feb 2018 to Dec 2021

Heat pump information	
Heat pump	3 water-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	80 kW_{th}
Nominal total heat pump DHW capacity	160 kW_{th}
Refrigerant	R410A

Ground source information	
Ground source	19 groundwater-filled vertical boreholes, 350 m
Undisturbed ground temperature	11.1°C
Borehole heat exchanger type	Single U-tube
Source side brine type	Water-Ethanol 25%

Evaluation period	2nd Feb 2018 - 1st Feb 2019	2nd Feb 2019 - 1st Feb 2020	2nd Feb 2020 - 1st Feb 2021
Building space heating load met by system [MWh_{th}]	1281	1718.5	1681.2
DHW load met by system [MWh_{th}]	244.2	303.2	321.5
Thermal energy extracted from the ground [MWh_{th}]	820.6	1018.5	827.5
SPFH1	3.4	3.2	3.2
SPFH4+	2.7	2.8	2.9

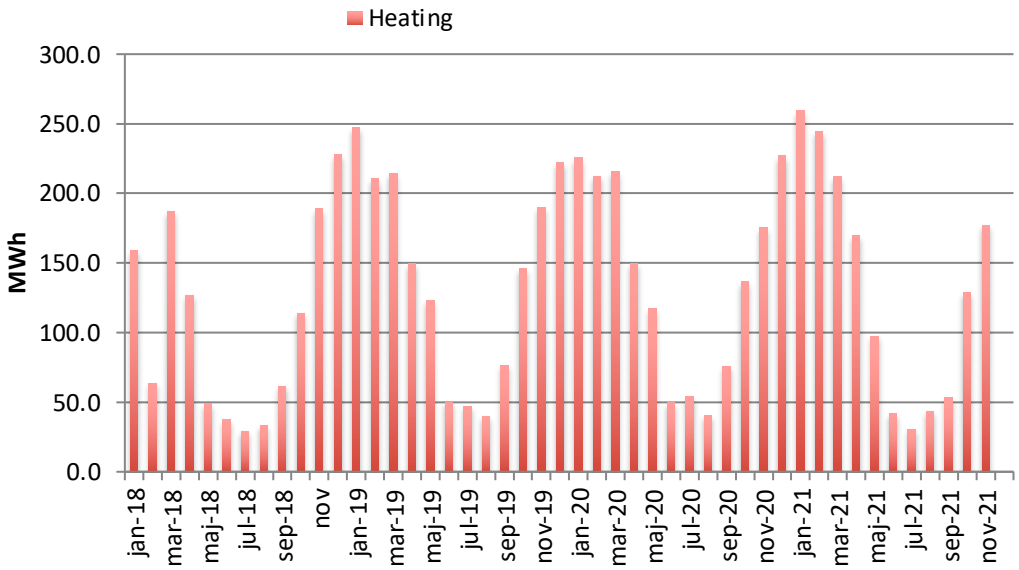


Figure 1. Monthly heating loads over the monitoring period

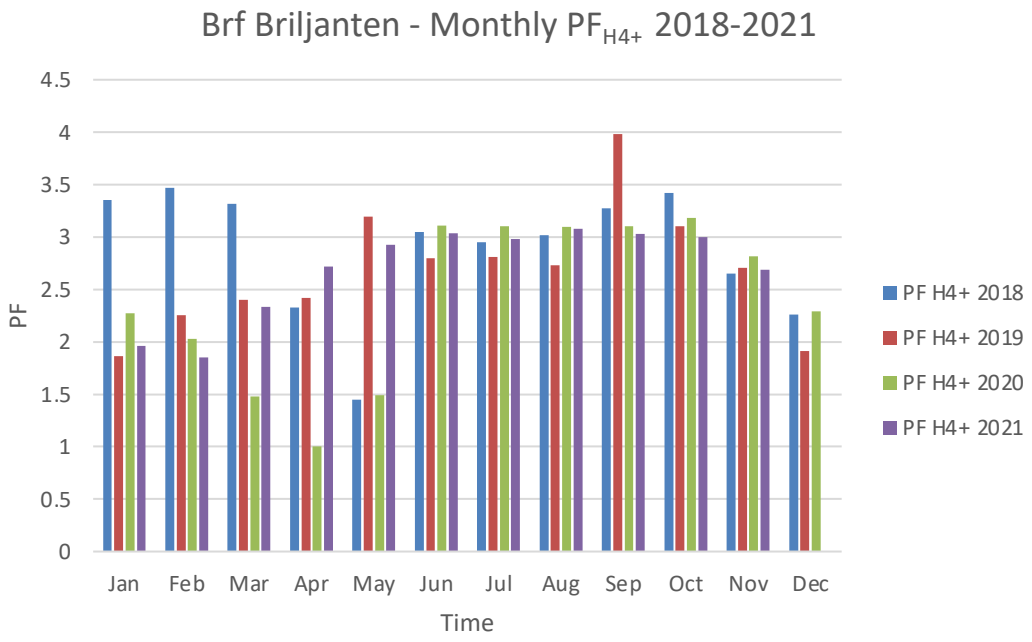


Figure 2. Overall monthly performance factors MPFH4+ over the monitoring period.

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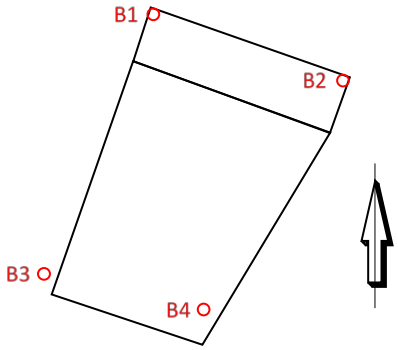
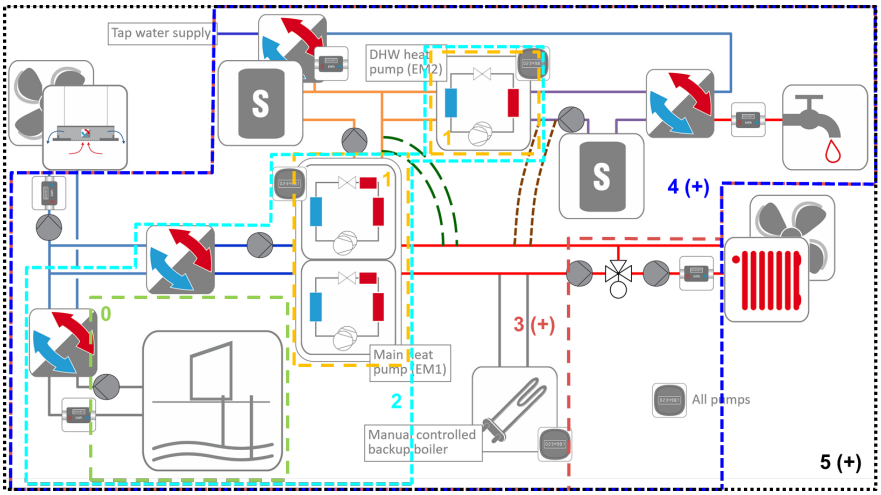
Ekestubbe, J. (2021). Case study report for Brf Briljanten, Lund, Sweden. Long-term performance analysis of the GSHP system for a multi-family building. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/te3s-cb70





Building information	
Building name	Domstolen
Location	Jönköping, Sweden
Year of building construction	2011
Ground source system operation start date	2011
Building Type	Office (court building)
Building floor area	7600 m² net
Analysed monitoring period	Sept 2012 to Aug 2014

Heat pump information	
Heat pump	2 brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	300 kW_{th}
Nominal total heat pump DHW capacity	60 kW_{th}
Refrigerant	R410A

Ground source information	
Ground source	2+2 groundwater wells, x135-160 m
Undisturbed ground temperature	10°C
Flow capacity	10 l/s

Evaluation period	Sep 2012 – Aug 2013	Sep 2013 – Aug 2014
Building space heating load met by system [MWh_{th}]	287	210
Building cooling load met by system [MWh_{th}]	116	135
DHW load met by system [MWh_{th}]	15	15
Thermal energy extracted from the ground [MWh_{th}]	144	115
Thermal energy injected to the ground [MWh_{th}]	94	115
Thermal balance ratio (extracted/rejected)	1.5	1
Heating load (incl. DHW) met by ground source (%)	100%	100%
Cooling load met by ground source (%)	100%	100%
SPFH4	2.5	2.7
SPFH4⁺	2.5	2.7
SPFC4	5.7	5.8
SPFHC4	3	3.4
SPFHC4⁺	2.9	3.4

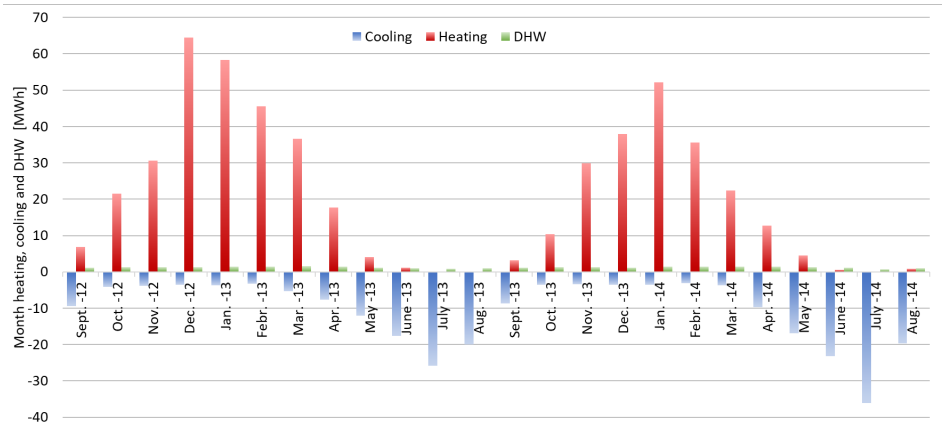


Figure 1. Monthly heating and cooling loads over the monitoring period

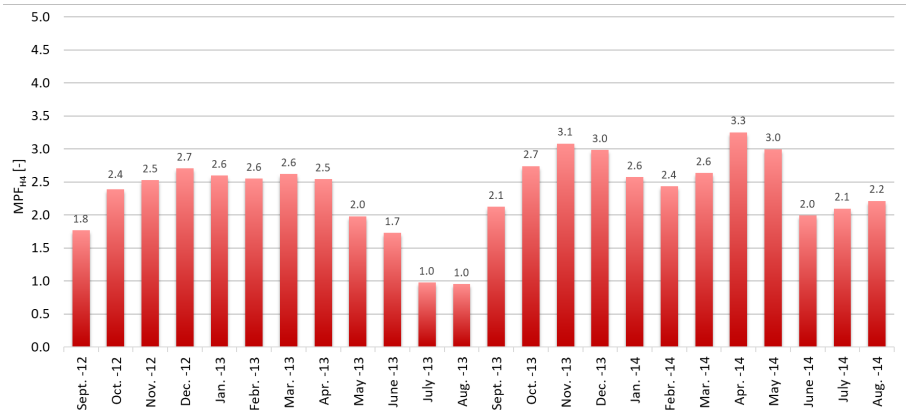


Figure 2. Monthly performance factors (MPFH4) over the monitoring period.

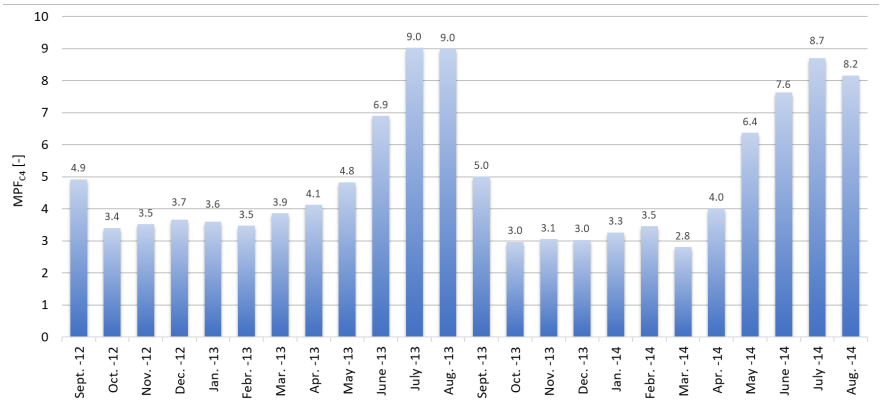
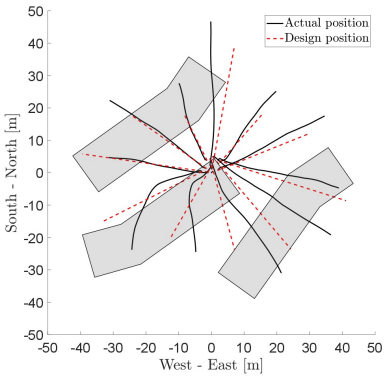


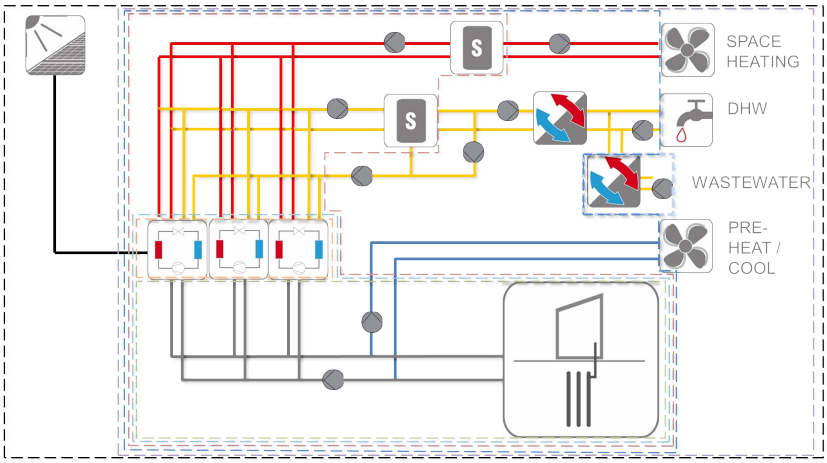
Figure 2. Monthly performance factors (MPFC4) over the monitoring period.

PUBLICATIONS

Walfridson, T. (2021). Case study report for Domstolen, Sweden. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/znp0-a619

Walfridsson, T., Larsson, M, Benson, J., Räftegård, O., Gustafsson, O., Haglund-Stignor, C., Axelsson, L. and Tiljander, P. (2021). Long-term evaluation of an office building with large-scale heat pump and aquifer system in southern Sweden. Proceedings of the 13th IEA Heat Pump Conference. April 26-29, 2021 Jeju, Korea.





0 1 2 3 4 4+ 5 5+

Building information

Building name	Forskningen
Location	Stockholm, Sweden
Year of building construction	2017
Ground source system operation start date	2017
Building Type	Student apartments
Building floor area	10 590 m²
Analysed monitoring period	May 2019 to Feb 2020

Heat pump information

Heat pump	3 water-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	180 kW_{th}
Nominal total heat pump DHW capacity	180 kW_{th}
Nominal total heat pump cooling capacity	120 kW_{th}
Refrigerant	R410A

Ground source information

Ground source	11+1 groundwater and grout-filled inclined boreholes, 100-350 m. Total borehole length 3085m + 100 m
Undisturbed ground temperature	9.8°C
Borehole heat exchanger type	Single U-tube + coaxial
Source side brine type	Water-Ethanol 28%

Evaluation period	2019-05-28 to 202-02-03
Building space heating load met by system [MWh_{th}]	177.8
DHW load met by system [MWh_{th}]	305.7
Thermal energy extracted from the ground [MWh_{th}]	247.4
Thermal energy injected to the ground [MWh_{th}]	74.2
Thermal balance ratio (extracted/rejected)	3.3
Heating load (incl. DHW) met by ground source (%)	100%
Cooling load met by ground source (%)	100%

Start of evaluation period	2019-05-26
End of evaluation period	2020-02-03
PFH1[1]	3.56 ±0.09
PFH4	2.95 ±0.28
PFH4+	2.97 ±0.28
PFH5	2.52 ±0.24
PFH5+	14.97 ±1.92
PFH5*	2.29 ±0.22
PFH5*'	4.14

[1]*heat pump internal electricity use is included.*

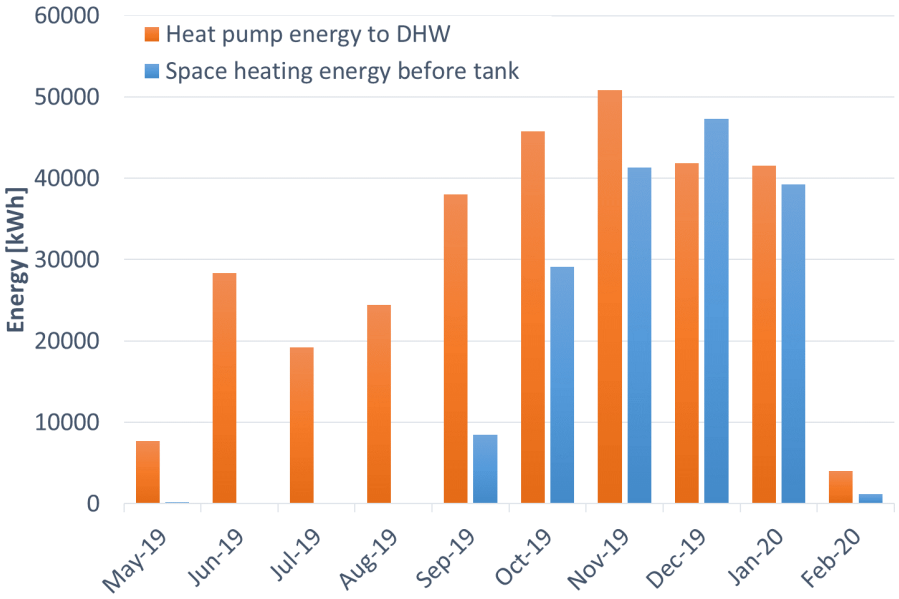


Figure 1. Monthly heating and DHW loads over the monitoring period

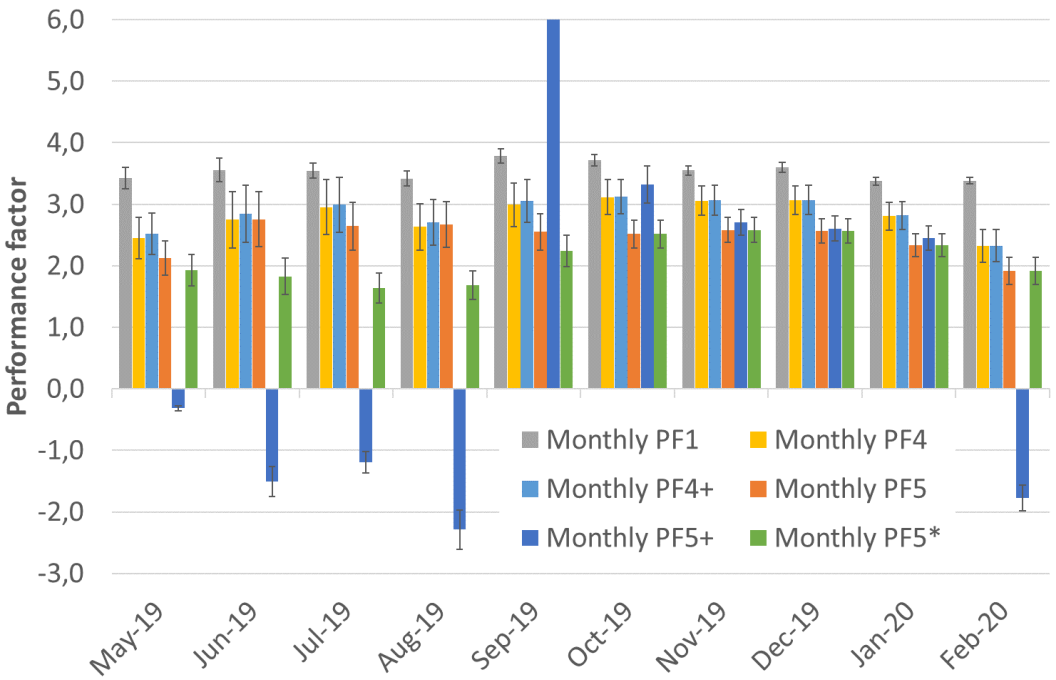
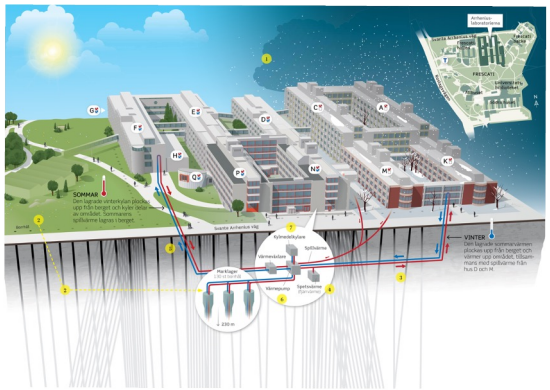
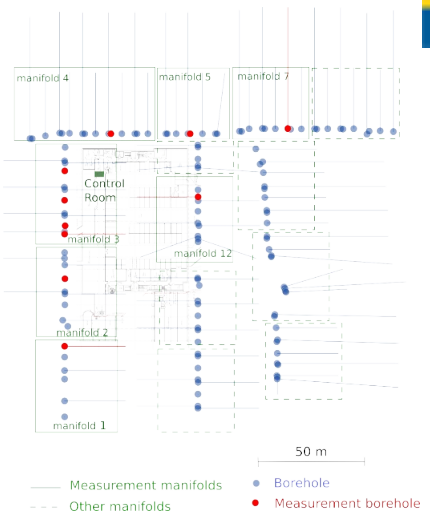


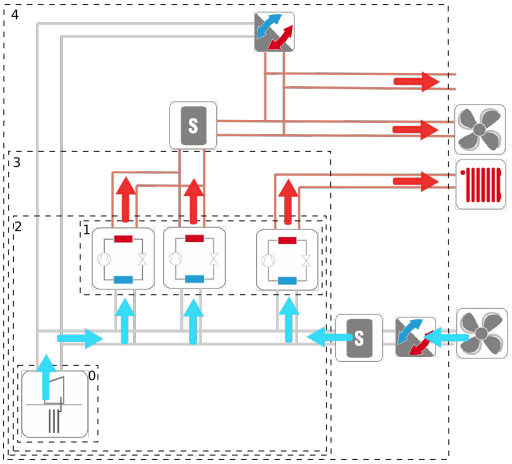
Figure 2. Monthly performance factors over the monitoring period.

PUBLICATIONS

Mazzotti-Pallard, W. (2021). Case study report for Forskningen, Stockholm, Sweden. Three plus energy buildings (by design) with GSHPs, variable-length boreholes, ventilation recovery and pre-heating, wastewater recovery & PV panels. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/dfs2-v474







Building information

Building name	Frescati NPQ
Location	Stockholm, Sweden
Year of building construction	2013-2015
Ground source system operation start date	2016
Building Type	Office/university building
Building floor area	16 500 m² net
Analysed monitoring period	2017 to 2019

Heat pump information

Heat pump	3 water-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	1750 kW_{th}
Refrigerant	Ammonia

Ground source information

Ground source	130 groundwater-filled vertical boreholes, 230 m
Undisturbed ground temperature	9°C
Borehole heat exchanger type	Single U-tube
Source side brine type	Water-Ethanol 28%

Evaluation period	2017	2018	2019
Building space heating load met by system [MWh_{th}]	731	650	598
Building cooling load met by system [MWh_{th}]	415	658	552
Thermal energy extracted from the ground [MWh_{th}]	1001	1650	1233
Thermal energy injected to the ground [MWh_{th}]	2606	3471	2855
Thermal balance ratio (extracted/rejected)	0.38	0.47	0.43
SPFH1	x±0.x	x±0.x	x±0.x
SPFH2	x ±0.x	x ±0.x	x ±0.x
SPFC2	x ±0.x	x ±0.x	x ±0.x
SPFHC2	x ±0.x	x ±0.x	x ±0.x

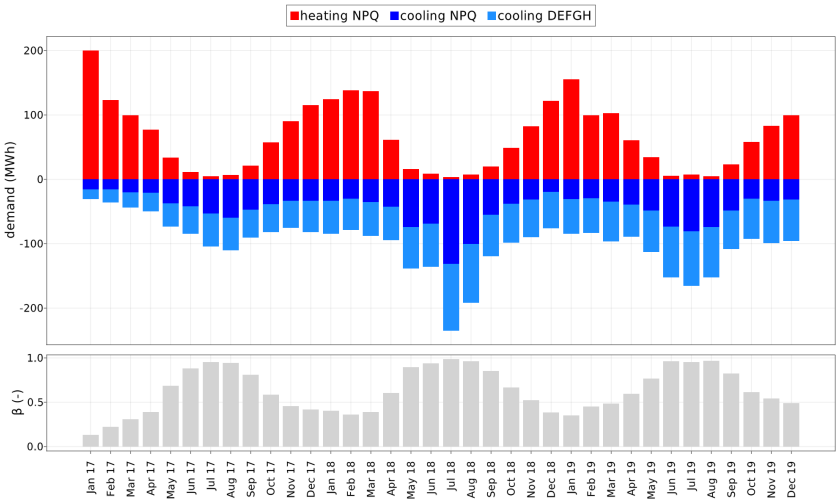


Figure 1. Monthly heating and cooling loads over the monitoring period

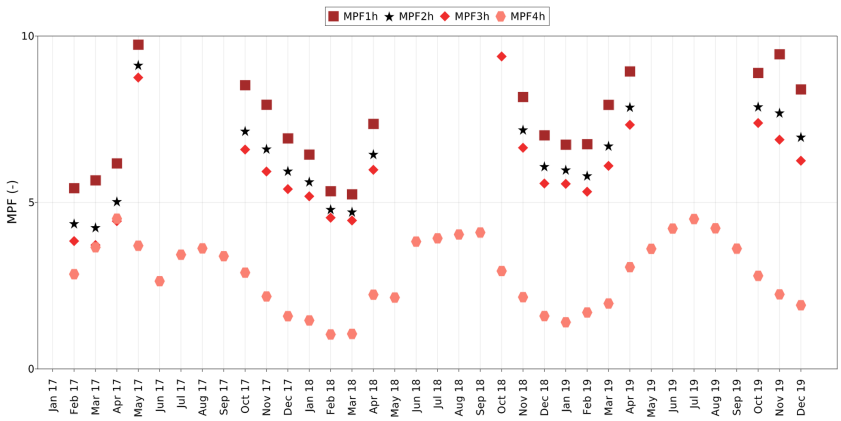


Figure 2. MP1h, MPF2h, MPF3h and MPF4h during the monitoring period.

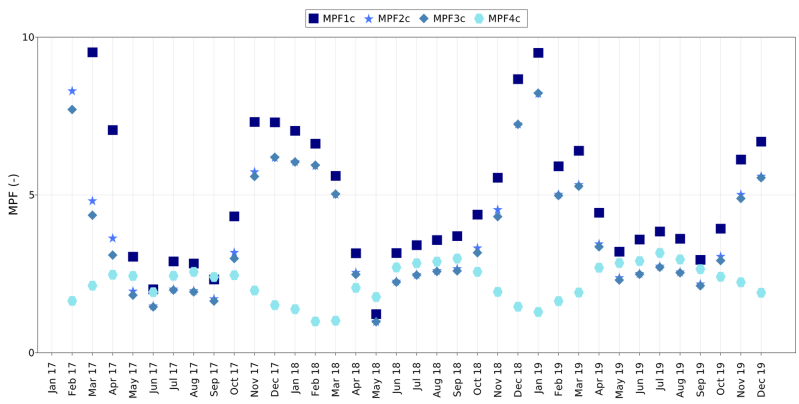


Figure 3. MPF1c, MP2c, MPF3C and MPF4c during the monitoring period.

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Lazzarotto, A. (2021). Case study report for Frescati NPQ, Sweden. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/emqr-m785

Lazzarotto, A., Acuña, J., Monzó, P., 2016. Analysis and modeling of a large borehole system in Sweden. European Geothermal Congress 2016, Strasbourg, France, 19-24 Sept 2016

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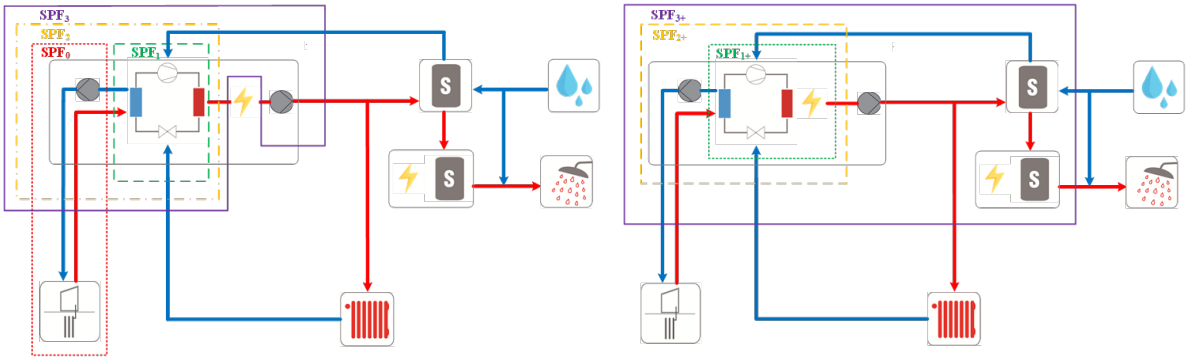
Monzó, P., Lazzarotto, A., Acuña, J., Tjernström, J., Nygren, M., 2016. Monitoring of a borehole thermal energy storage in Sweden, in: CLIMA 2016-Proceedings of the 12th REHVA World



Building information	
Building name	Frölunda Clubhouse
Location	Gothenburg, Sweden
Year of building construction	2004
Ground source system operation start date	2009
Building Type	Clubhouse
Building floor area	240 m²
Analysed monitoring period	2014 to 2016

Heat pump information	
Heat pump	1 water-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	5 kW_{th}
Nominal total heat pump DHW capacity	11 kW_{th}
Refrigerant	R407C

Ground source information	
Ground source	1 groundwater-filled vertical borehole, 230 m
Undisturbed ground temperature	~8°C (not measured, based on mean air temperature)
Borehole heat exchanger type	Single U-tube
Source side brine type	Water-Ethanol

Evaluation period	2014	2015	2016
Building space heating load met by system [MWh_{th}]	15.3	15.1	16.3
DHW load met by system [MWh_{th}]	8	8	8.3
Thermal energy extracted from the ground [MWh_{th}]	13.6	15.5	17.1
SPFH1	3.9 ± 0.2	3.8 ± 0.2	3.6 ± 0.2
SPFH2	3.6 ± 0.2	3.5 ± 0.2	3.3 ± 0.2
SPFH3	3.0 ± 0.2	2.9 ± 0.2	2.8 ± 0.2
SPFH1+	3.4 ± 0.2	3.4 ± 0.2	3.2 ± 0.2
SPFH2+	3.2 ± 0.2	3.2 ± 0.2	2.9 ± 0.2
SPFH3+	2.3 ± 0.2	2.3 ± 0.2	2.2 ± 0.2

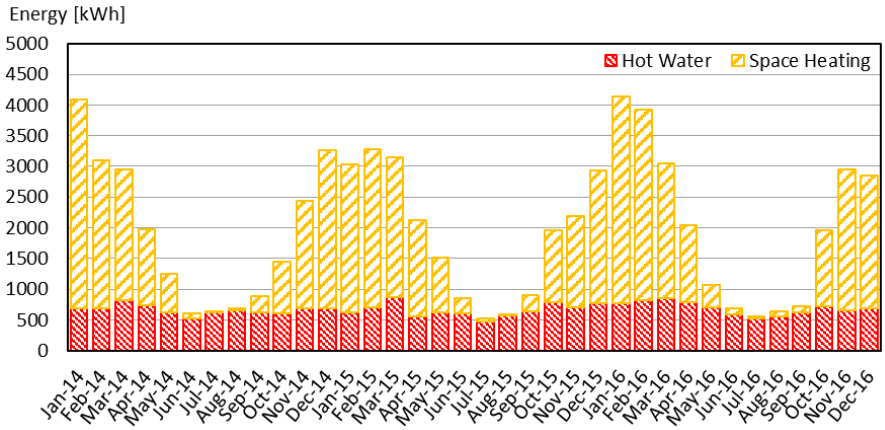


Figure 1. Monthly heating and DHW loads over the monitoring period

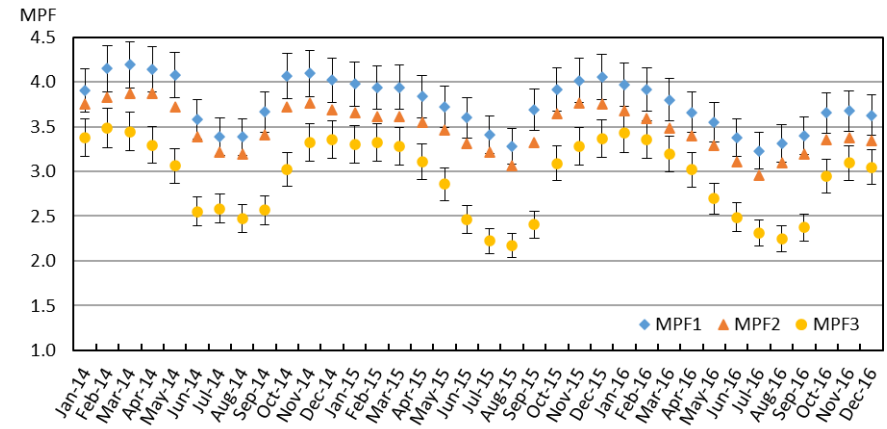


Figure 2. Monthly performance factors over the monitoring period.

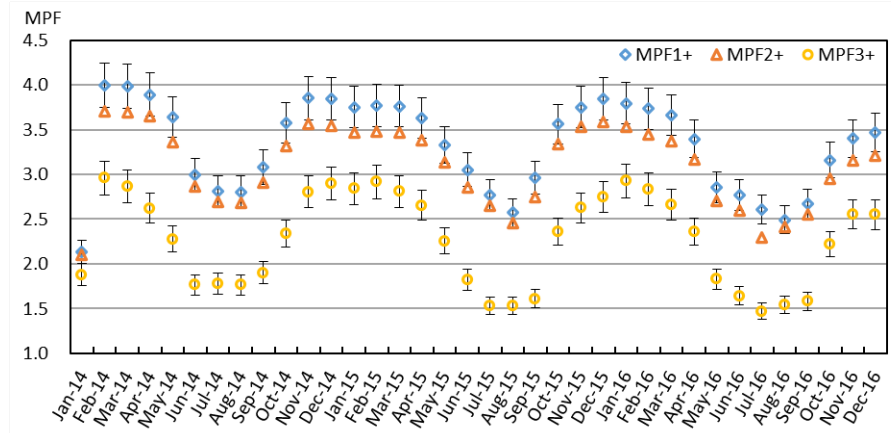


Figure 3. Monthly performance factors over the monitoring period.

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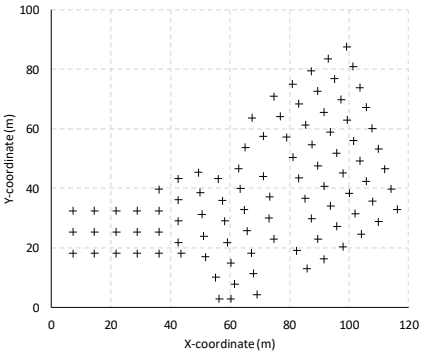
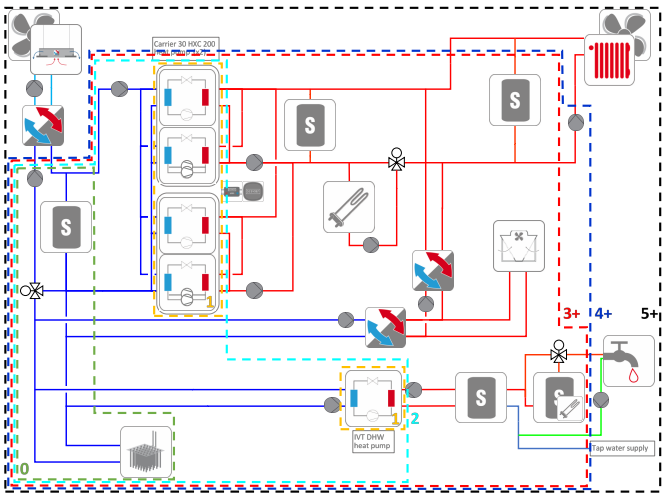
Liu, H., Zhang, H. and Javed, S., 2020. Long-term performance measurement and analysis of a small-scale ground source heat pump system. Energies, 13(17), p.4527.

Liu, H. and Zhang, H. Performance Evaluation of Ground Heating and Cooling Systems – Long-term performance measurements of two case buildings. MSc Thesis, University of Lund, Lund, Sweden, 2020.





Building information	
Building name	IKEA Uppsala
Location	Uppsala, Sweden
Year of building construction	2009
Ground source system operation start date	2009
Building Type	Furniture warehouse
Building floor area	36 000 m²
Analysed monitoring period	Dec 2016 to Apr 2020

Heat pump information	
Heat pump	3 brine-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	1700 kW_{th}
Nominal total heat pump cooling capacity	1400 kW_{th}
Refrigerant	R134A + R407C

Ground source information	
Ground source	99 groundwater-filled vertical boreholes, 168 m
Undisturbed ground temperature	6.8°C
Borehole heat exchanger type	Double U-tube
Source side brine type	Water-Ethanol 15%

Evaluation period	2017	2018	2019
Building space heating load met by system [MWh_{th}]	587 (missing data)	1280	1240
Building cooling load met by system [MWh_{th}]	73 (missing data)	469	167
Thermal energy extracted from the ground [MWh_{th}]	477 (missing data)	959	918
SPFH1	3.95±0.18	3.76±0.17	3.63±0.16
SPFC1	3.92 ±0.18	3.63 ±0.16	3.58 ±0.16
SPFHC1	3.94 ±0.18	3.72 ±0.17	3.63±0.16

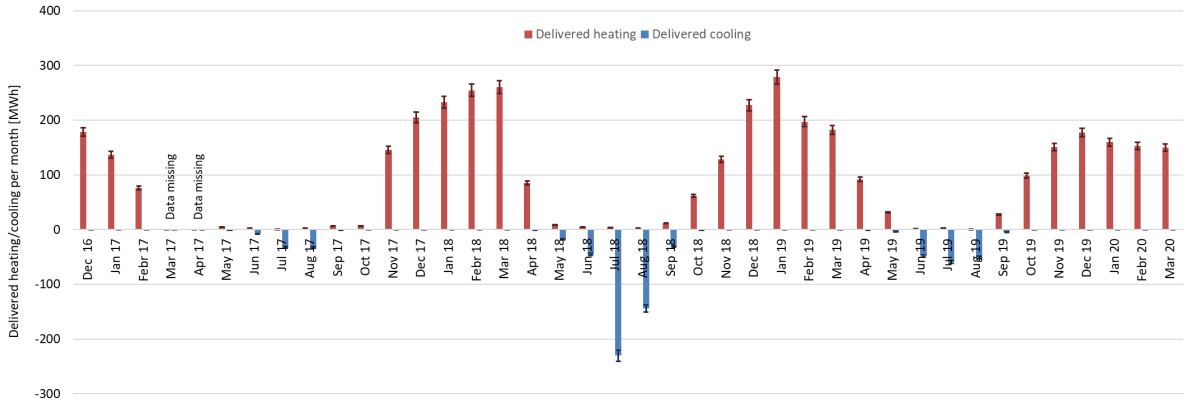


Figure 1. Monthly heating and cooling loads over the monitoring period

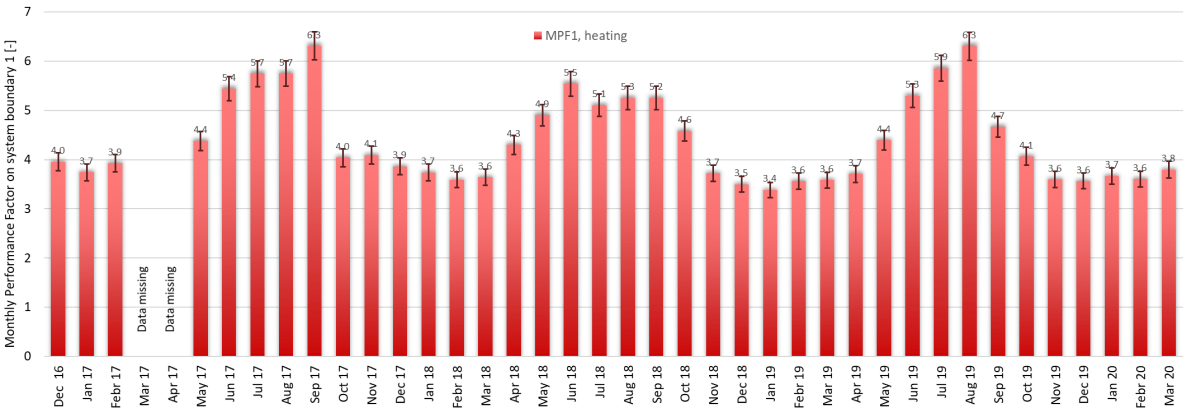


Figure 2. Monthly performance factors (MPFH1) over the monitoring period.

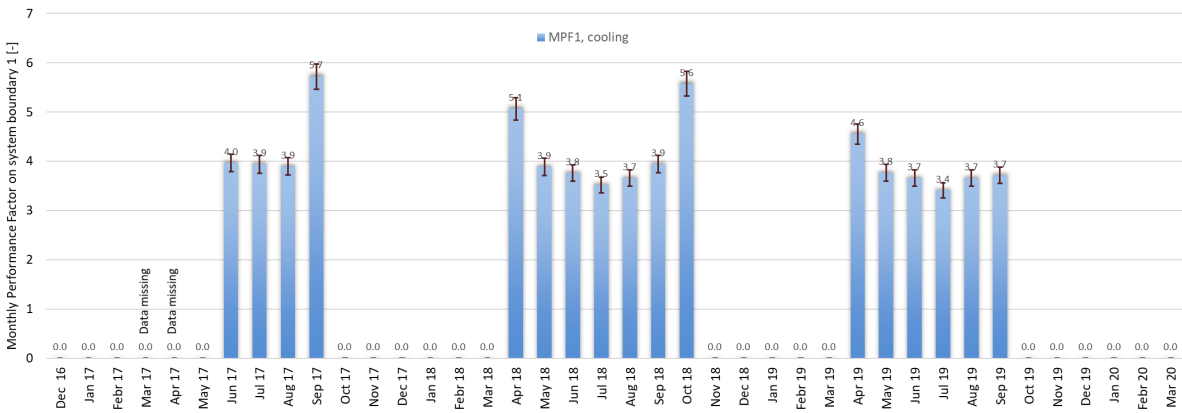


Figure 3. Monthly performance factors (MPFC1) over the monitoring period.

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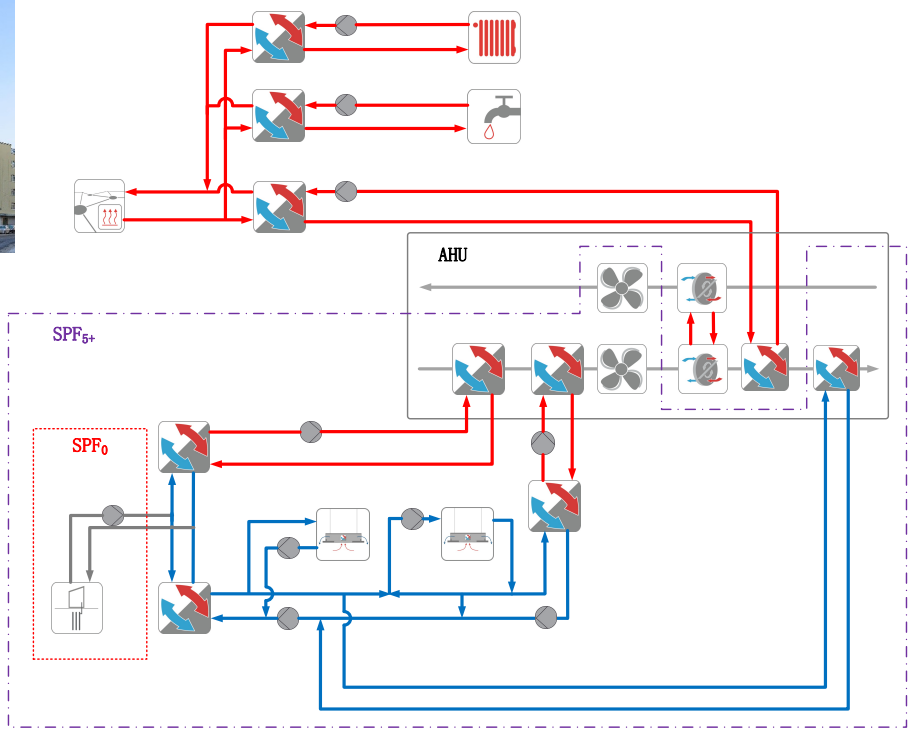
Walfridson, T. (2021). Case study report for IKEA Uppsala, Sweden. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/vda5-8s77



Building information	
Building name	Entré Lindhagen
Location	Stockholm, Sweden
Year of building construction	2014
Ground source system operation start date	2014
Building Type	Office/commercial
Building floor area	65 265 m²
Analysed monitoring period	2014 to Aug 2018

System configuration information	
Heat distribution	Radiators supplied by district heating
Cooling distribution	Active chilled beams
DHW production	District heating
Supplementary cooling	Ambient-air cooling

Ground source information	
Ground source	144 groundwater-filled vertical boreholes, 220 m
Undisturbed ground temperature	10.5°C
Borehole heat exchanger type	Double U-tube
Source side brine type	Water

Evaluation period	2014	2015	2016	2017
Building space heating load met by system [MWh_{th}]	1230	1435	1520	1590
Building cooling load met by system [MWh_{th}]	1305	1345	1510	1260
Thermal energy extracted from the ground [MWh_{th}]	640	680	810	890
Thermal energy injected to the ground [MWh_{th}]	715	590	800	560
Thermal balance ratio (extracted/rejected)	0.9	1.2	1.0	1.6
Heating load (incl. DHW) met by ground source (%)	9%	13%	13%	13%
Cooling load met by ground source (%)	55%	44%	53%	45%
SPFH5+ (pre-heating)	136 ± 2	102 ± 2	136 ± 2	123 ± 2
SPFC5+	145 ± 2	145 ± 2	119 ± 2	125 ± 2

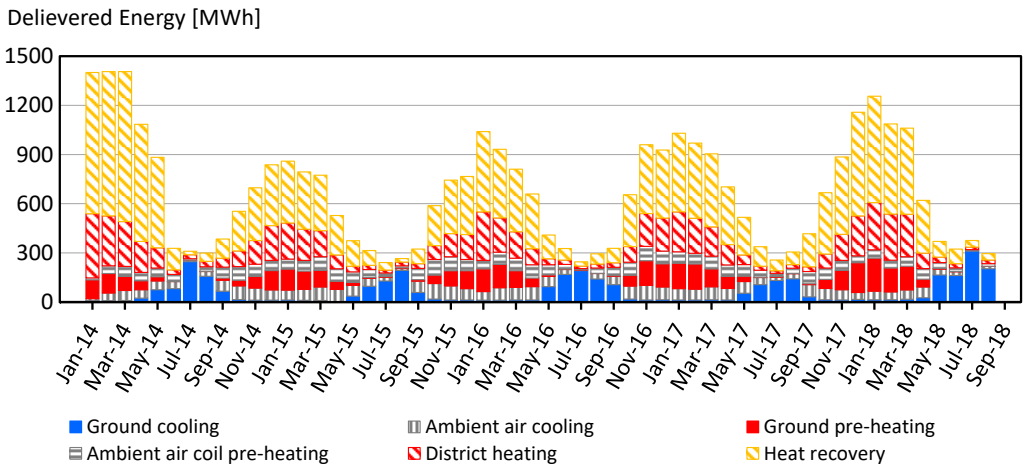


Figure 1. Monthly heating and cooling loads over the monitoring period

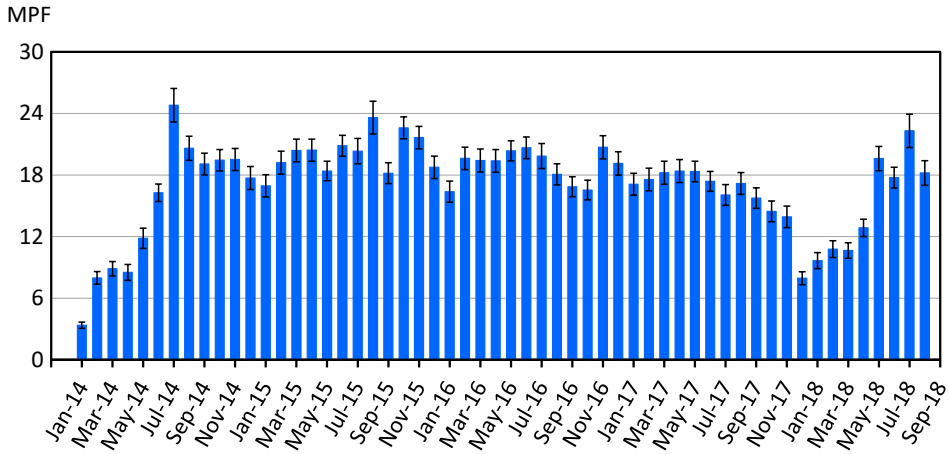


Figure 2. Monthly performance factors (MPFC5+) for cooling over the monitoring period.

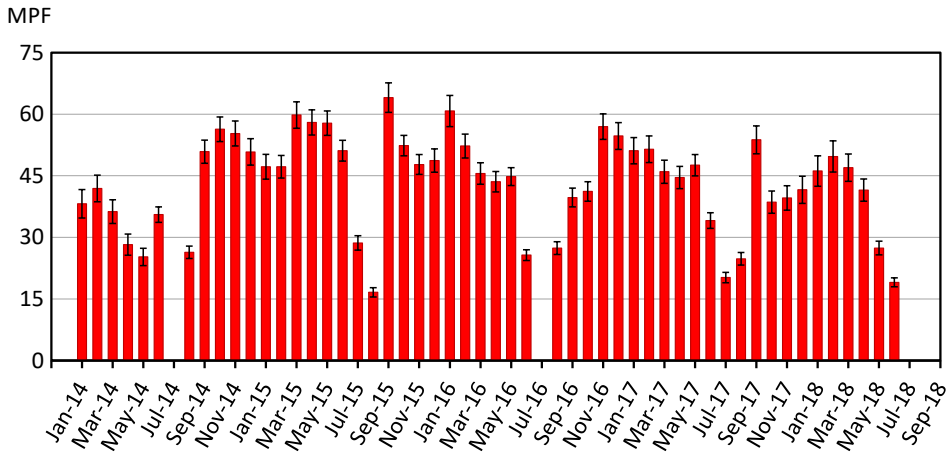


Figure 3. Monthly performance factors (MPFH5+) for pre-heating over the monitoring period.

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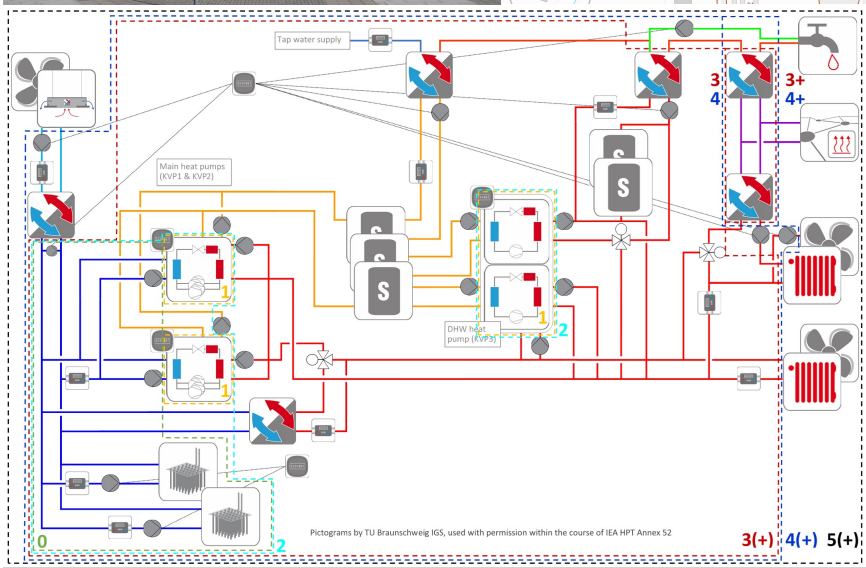
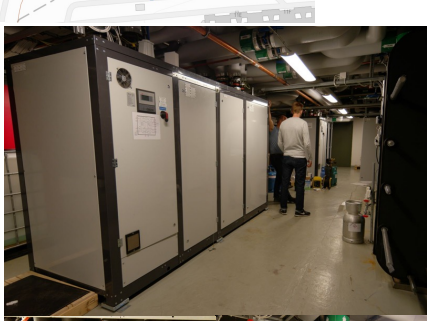
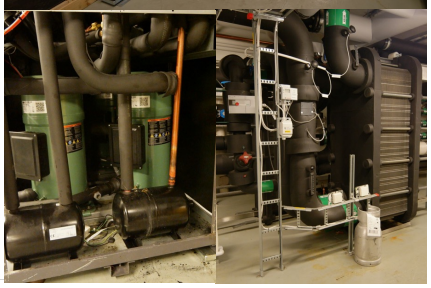
2-PAGE CASE STUDY SUMMARY NUS SWEDEN







Building information

Building name	Norrlands Universitetssjukhus (NUS)
Location	Umeå, Sweden
Year of building construction	1907 - present
Ground source system operation start date	2016
Building Type	Hospital
Building floor area	530.000 m²
Analysed monitoring period	2017-01-01 to 2021-12-31

Heat pump information

Heat pump	3 brine-to-water HPs
Heat Pump system type	Centralized HPs
Nominal total heat pump heating capacity	1400 kW_{th}
Refrigerant	R134a + R410a

Ground source information

Ground source	125 groundwater-filled vertical boreholes, 200-250 m
Undisturbed ground temperature	4.0°C
Borehole heat exchanger type	Single U-tube
Source side brine type	Water-Ethanol 28%

Evaluation period	2017	2018	2019	2020	2021
Building space heating load met by system [MWh_{th}]	5700	4700	4900	5200	4400
Building cooling load met by system [MWh_{th}]	4200	5100	4300	3800	3700
DHW load met by system [MWh_{th}]	490	310	320	630	650
Thermal energy extracted from the ground [MWh_{th}]	690	860	1300	2000	1500
Thermal energy injected to the ground [MWh_{th}]	1400	2100	1600	1300	710
Thermal balance ratio (extracted/rejected)	0.50	0.40	0.78	1.6	2.1
SPFH4	5.0	5.3	5.1	4.4	4.7
SPFC4	5.7	6.0	5.5	5.0	5.2
SPFHC4	5.1	5.7	5.3	4.6	4.9

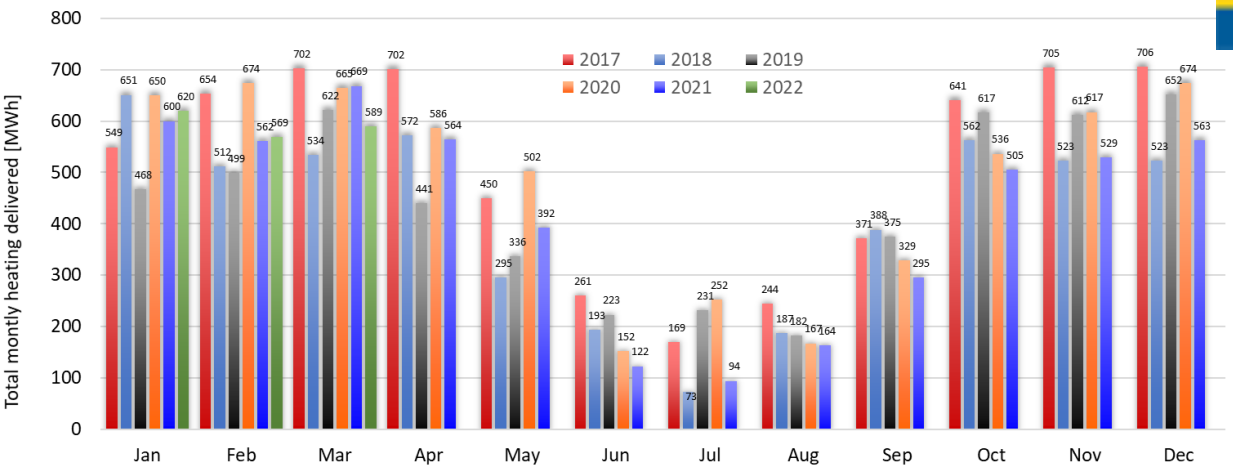


Figure 1. Total monthly heating delivered from the GSHP system including preheating of DHW.

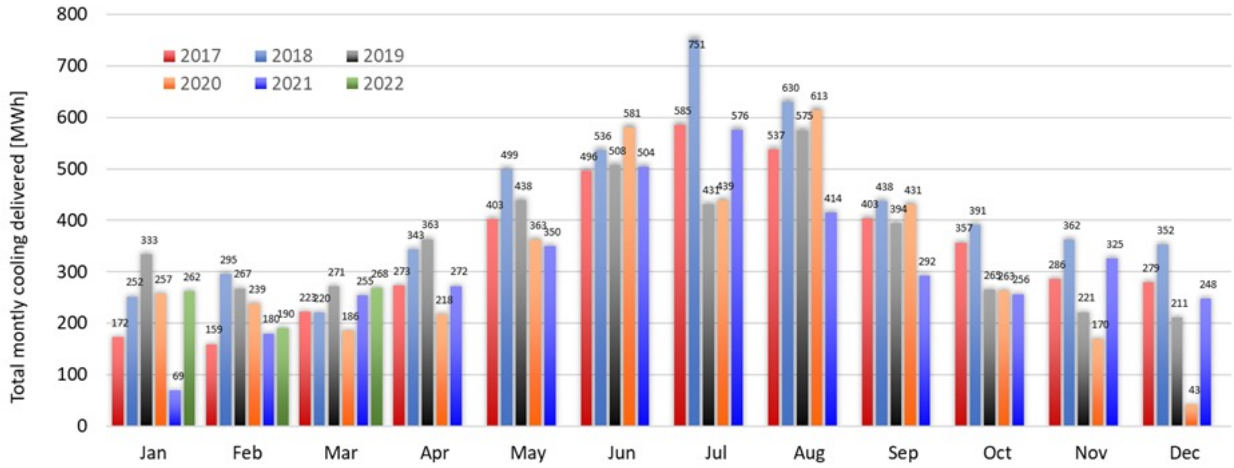


Figure 2. Total monthly cooling delivered from the GSHP system..

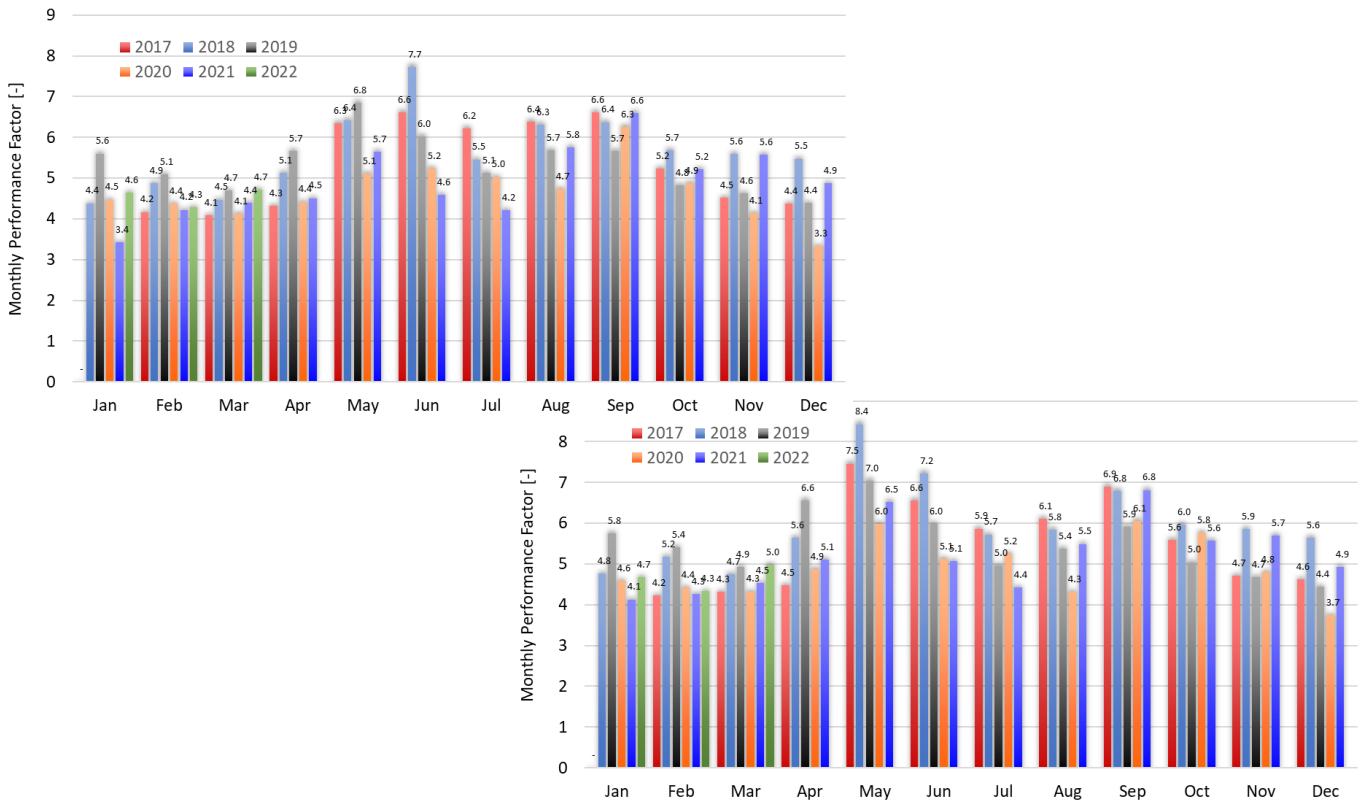
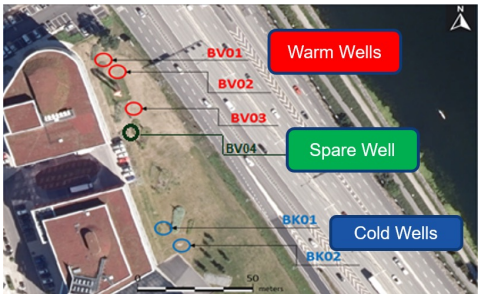
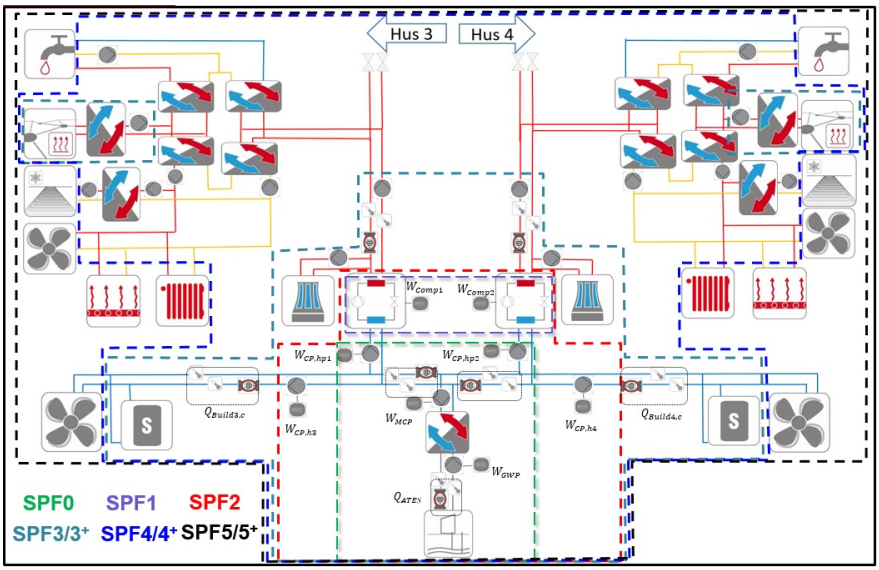


Figure 2. Monthly heating performance factors MPFH4 top left and cooling MPFC4 bottom right, over the monitoring period.

PUBLICATIONS

Walfridson, T. (2021). Case study report for Norrlands Universitetssjukhus, Umeå, Sweden. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/6wbj-pf98





Building information	
Building name	Rosenborg
Location	Stockholm, Sweden
Year of building construction	2015
Ground source system operation start date	2016
Building Type	Office building
Building floor area	18 000 m² net
Analysed monitoring period	March 2019 to April 2020

Heat pump information	
Heat pump	2 water-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	849+986 kW_{th}
Nominal total heat pump cooling capacity	701+814 kW_{th}
Refrigerant	R134A

Ground source information	
Ground source	5+5 groundwater wells, 13 m (warm) and 20 m (cold)
Undisturbed ground temperature	10°C
Groundwater pumping rate	50 l/s

Evaluation period	Apr 2016 -Mar 2017	Apr 2017 -Mar 2018	Apr 2018 -Mar 2019	Apr 2019 -Mar 2020
Building space heating load met by system [MWh_{th}]				456
Building cooling load met by system [MWh_{th}]				381
Thermal energy extracted from the ground [MWh_{th}]	182	168	122	85
Thermal energy injected to the ground [MWh_{th}]	9	239	275	236
Thermal balance ratio (extracted/rejected)	21	0.71	0.45	0.36

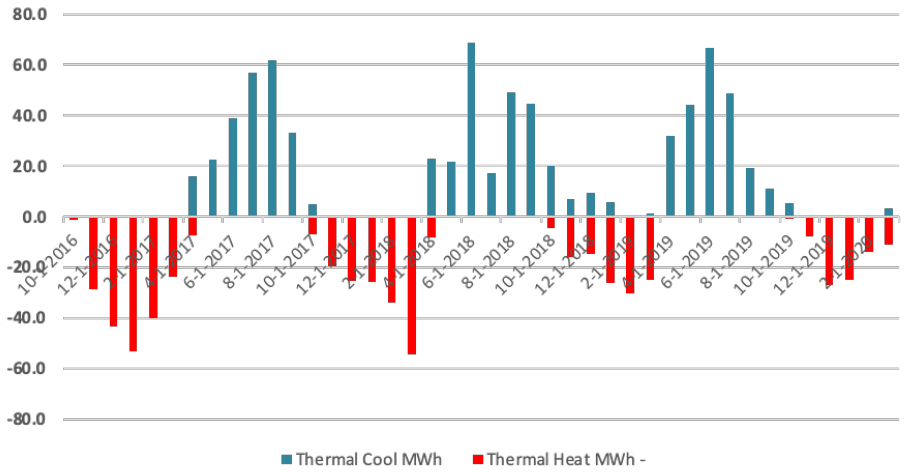


Figure 1. Monthly heating and cooling loads over the monitoring period

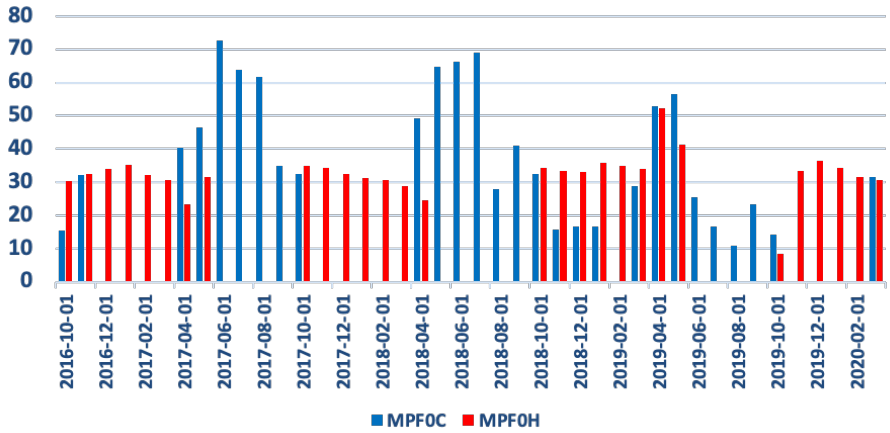


Figure 2. Monthly performance factors over the monitoring period.

Start of evaluation period *End of evaluation period*	*October 1st 2016* *March 31st 2017*	*April 1st 2017* *March 31st 2018*	*April 1st 2018* *March 31st 2019*	*April 1st 2019* *March 31st 2020*
SPFH0	33.2	30.6	33.6	32.9
SPFH1*	-	-	-	5.0
SPFH2*	-	-	-	4.6
SPFC0	22.1	53.1	38.5	23.9
SPFC1	-	-	-	4.4
SPFC2	-	-	-	6.4
SPFHC0	33.1	40.4	36.8	25.8
SPFHC1	-	-	-	4.9
SPFHC2	-	-	-	5.5

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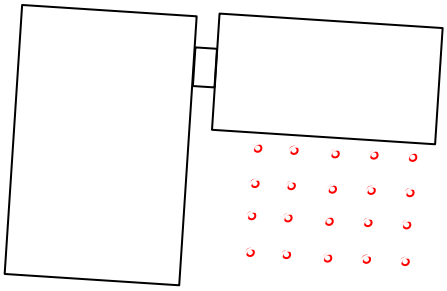
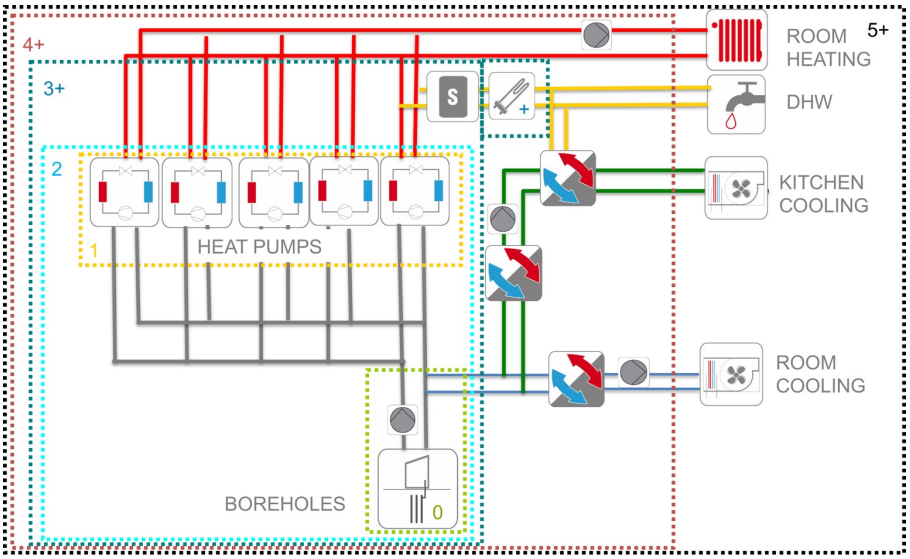
Abuasbeh, M. (2021). Case study report for Rosenborg, Sweden. GSHP installation coupled with aquifer thermal energy storage ATES suppling heating and cooling for two commercial buildings. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/6h7v-bt33

Abuasbeh, M., & Acuna, J. (2018). Ates system monitoring project, first measurement and performance evaluation: Case study in Sweden. Research Conference Proceedings. International Ground Source Heat Pump Association Research Conference, Stockholm, Sweden. https://doi.org/10.22488/okstate.18.000002

Abuasbeh, M., Acuña, J., Lazzarotto, A., & Palm, B. (2021). Long term performance monitoring and KPIs' evaluation of Aquifer Thermal Energy Storage system in Esker formation: Case study in Stockholm. Geothermics, 96, 102166. https://doi.org/10.1016/j.geothermics.2021.10216



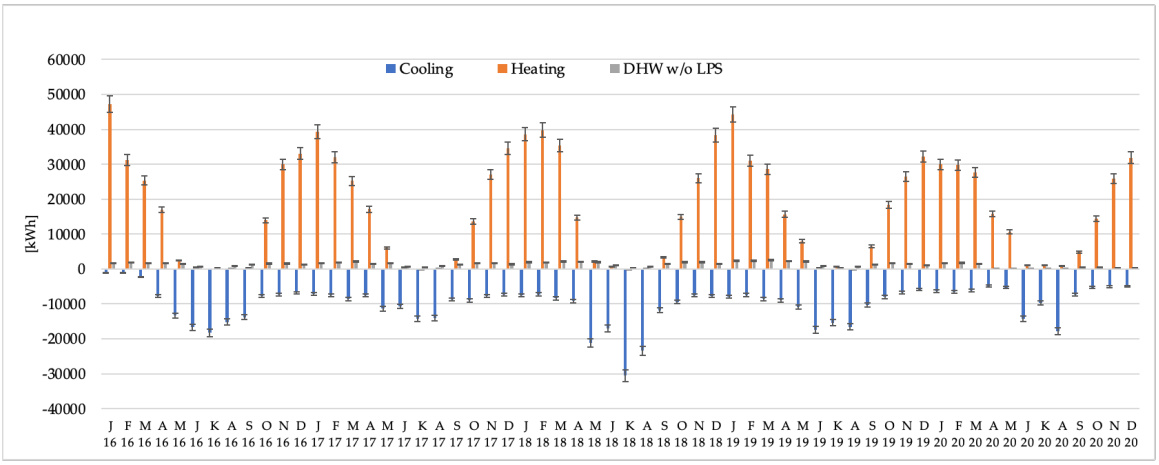


Building information	
Building name	Studenthuset
Location	Stockholm, Sweden
Year of building construction	2013
Ground source system operation start date	2013
Building Type	Mixed-use university building
Building floor area	6035 m² net
Analysed monitoring period	January 2016 to December 2020

Heat pump information	
Heat pump	5 water-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	200 kW_{th}
Nominal total heat pump DHW capacity	40 kW_{th}
Refrigerant	R407C

Ground source information	
Ground source	20 groundwater-filled vertical boreholes, 200 m
Undisturbed ground temperature	9.2°C
Borehole heat exchanger type	Single U-tube
Source side brine type	Water-Ethanol 28%

Evaluation period	2016	2017	2018	2019	2020
Building space heating load met by system [MWh_{th}]	201	198	214	212	194
Building cooling load met by system [MWh_{th}]	111	114	161	124	94
DHW load met by system [MWh_{th}]	16	17	19	19	7
SPFH1*	3.8±0.23	3.84±0.23	3.79±0.23	3.88±0.23	4.06±0.26
SPFH2	3.44 ±0.20	3.48 ±0.21	3.50 ±0.20	3.54 ±0.21	3.63 ±0.22
SPFH3+	2.62 ±0.13	2.65 ±0.13	2.70 ±0.13	2.74 ±0.13	2.71 ±0.13
SPFH4+	1.47 ±0.07	1.47 ±0.07	1.58 ±0.07	1.54 ±0.07	1.55 ±0.07
SPFC2 = SPFC3	36.88 ±7.20	37.02 ±7.22	45.69 ±9.16	39.91 ±7.78	33.72 ±6.70
SPFC4	2.89 ±0.16	2.81 ±0.16	3.27 ±0.19	3.02 ±0.17	3.01 ±0.17
SPFHC2	4.98 ±0.19	5.07 ±0.19	5.61 ±0.21	5.19 ±0.20	5.06 ±0.20
SPFHC4+	1.8 ±0.28	1.7 ±0.30	2.0 ±0.29	1.8 ±0.29	1.8±0.35



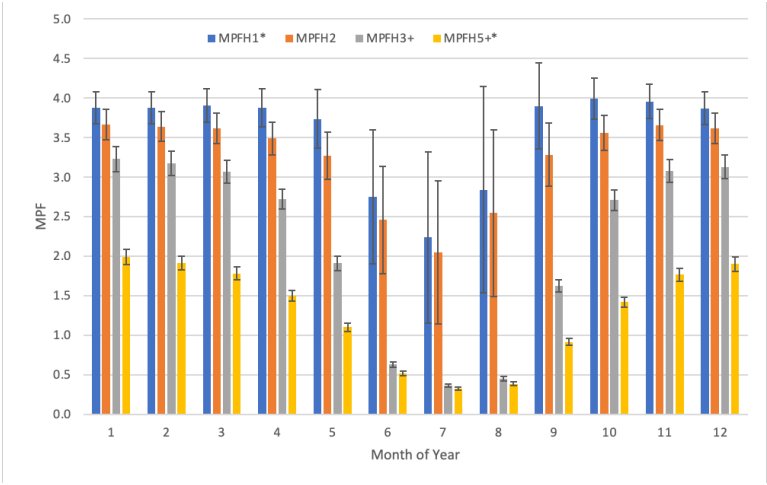


Figure 2. Binned monthly performance factors with uncertainty for heating over the five years monitoring period.

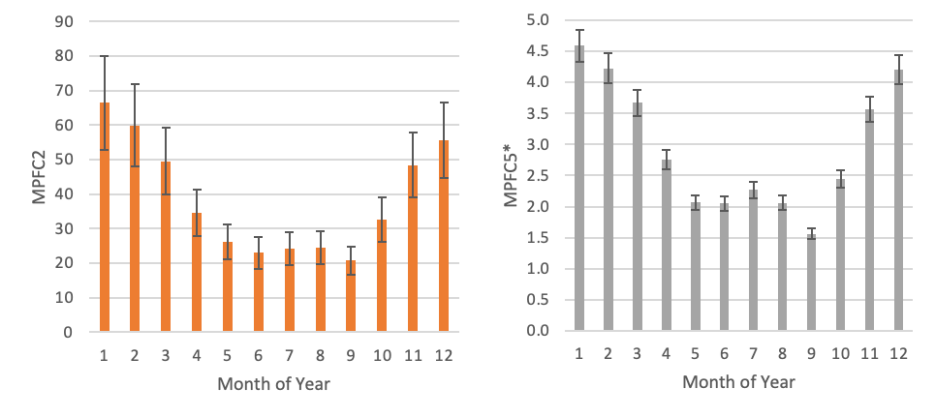


Figure 3. Binned monthly performance factors with uncertainty for cooling over the five years monitoring period.

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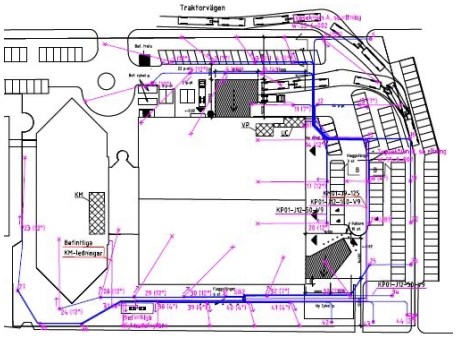
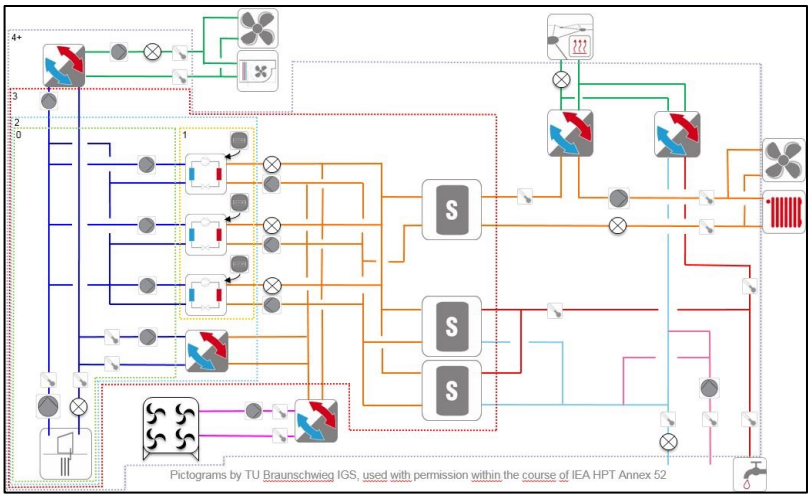
Gehlin, S., Spitler, J.D., Larsson, A. & Annsberg, Å. (2018). Measured performance of the University of Stockholm Studenthuset ground source heat pump system. 14th International Conference on Energy Storage-EnerSTOCK2018, Adana, Turkey.





Building information	
Building name	Kv Traktorn
Location	Lund, Sweden
Year of building construction	1960s and 1980s
Ground source system operation start date	2017
Building Type	Office building
Building floor area	12 000 m²
Analysed monitoring period	Sep 2017 to Dec 2021

Heat pump information	
Heat pump	3 reversible water-to-water HP
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	80 kW_{th}
Nominal total heat pump DHW capacity	80 kW_{th}
Nominal total heat pump cooling capacity	287 kW_{th}
Refrigerant	R410A

Ground source information	
Ground source	44 groundwater-filled vertical boreholes, 120 m
Undisturbed ground temperature	11.1°C
Borehole heat exchanger type	Single U-tube
Source side brine type	Water-Ethanol 25%

Evaluation period	Sep 2017 – Aug 2018	Sep 2018- Aug 2019
Building space heating load met by system [MWh_{th}]	680.3	694.8
DHW load met by system [MWh_{th}]	61	68
Thermal energy extracted from the ground [MWh_{th}]	465.7	412.9
Thermal energy injected to the ground [MWh_{th}]	244.9	191.3
SPFH1	3.9	3.6
SPFH4+	4.0	3.8

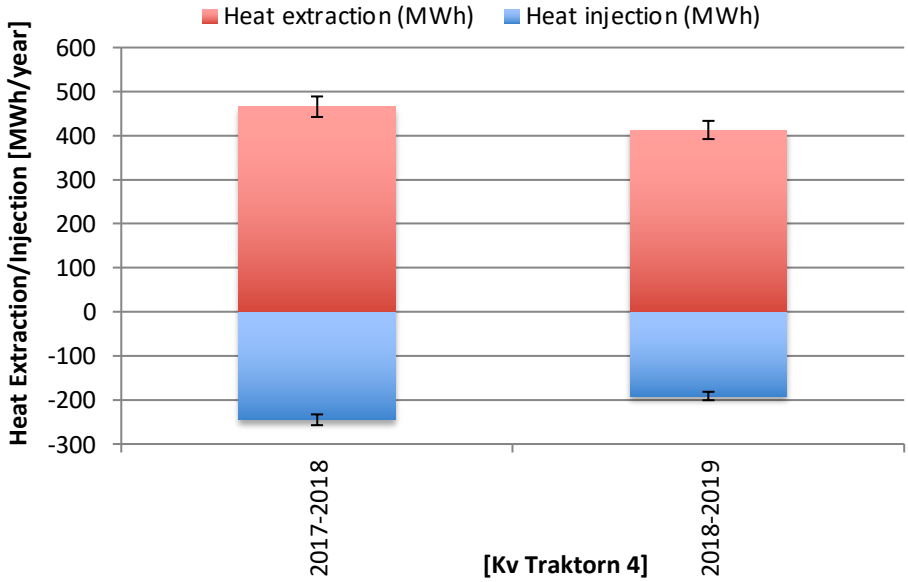


Figure 1. Annual heating and cooling loads over the monitoring period

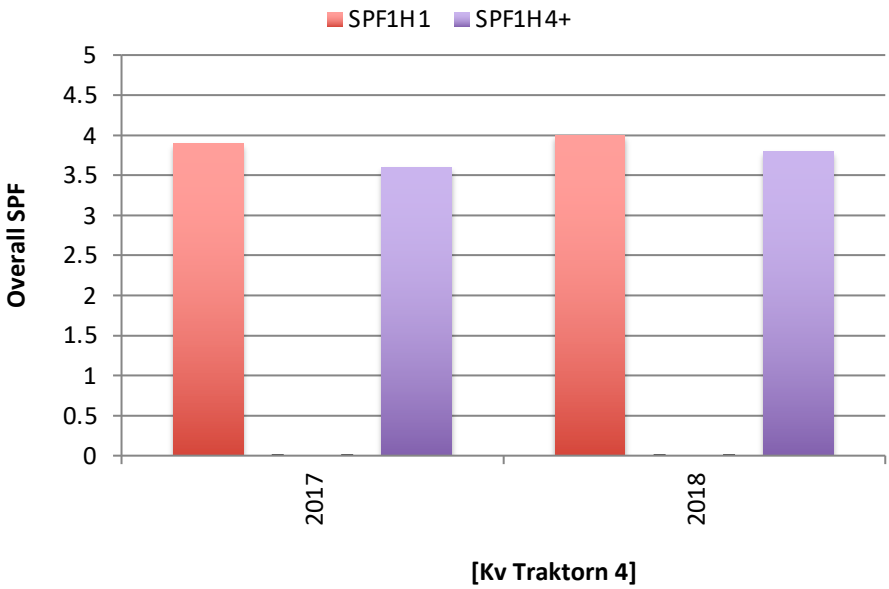


Figure 2.Seasonal performance factors SPFH1 and SPF H4+ over the monitoring period.

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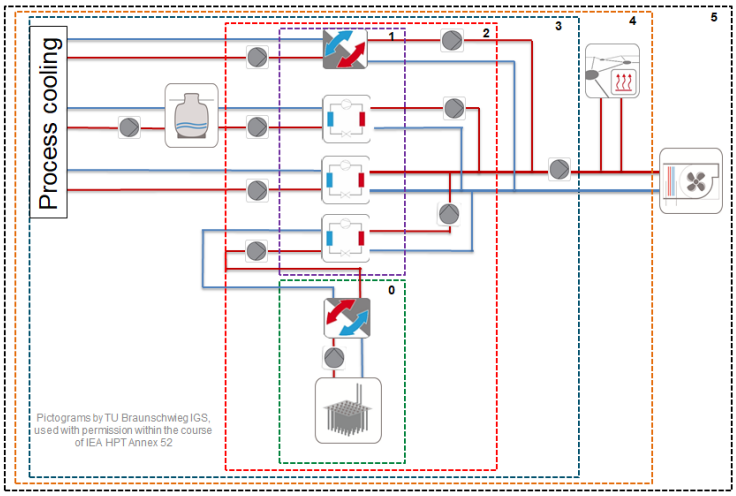

Building information

Building name	Xylem foundry
Location	Emmaboda, Sweden
Year of building construction	~1990
Ground source system operation start date	2010
Building Type	Industrial workshops
Building floor area	110 000 m²
Analysed monitoring period	Sept 2016 to Aug 2021

Heat pump information

Heat pump	11 water-to-water HP
Heat Pump system type	Mostly centralized HP
Nominal total heat pump heating capacity	480 kW_{th} BTES + 1525 kW_{th} waste heat capture
Nominal total heat pump cooling capacity	1149 kW_{th}
Nominal cooling capacity BTES system (at delta T 10°C)	800 kW_{th}
Refrigerant	R410A (BTES HPs), R134a (waste heat capture HPs)

Ground source information

Ground source	140 groundwater-filled vertical boreholes, 150 m
Undisturbed ground temperature	8.5°C
Borehole heat exchanger type	Open coaxial
Source side brine type	Water

Evaluation period	Sep 2016 -Aug 2017	Sep 2017 -Aug 2018	Sep 2018 -Aug 2019	Sep 2019 -Aug 2020	Sep 2020 -Aug 2021
Building space heating load met by system [MWh_{th}]	310	239	2902	2198	2242
Building cooling load met by system [MWh_{th}]	2153	1667	1606	2164	3349
Thermal energy extracted from the ground [MWh_{th}]	310	239	2300	1832	1785
Thermal energy injected to the ground [MWh_{th}]	2153	1667	1818	2550	3556
Thermal balance ratio (extracted/rejected)	0.14	0.14	1.22	0.72	0.50
Heating load met by ground source (%)	2-3%	2-3%	24.5%	20.8%	22.6%
SPFH1			4.29	4.43	4.24
SPFH2			3.63	4.04	3.68
SPFC1			13.2	13	13.2
SPFC2			11.9	13.2	11.9

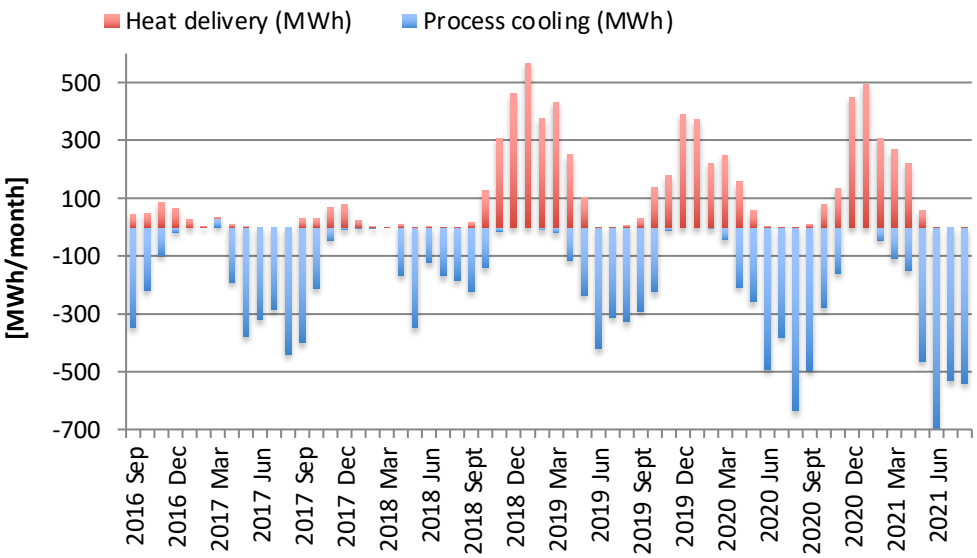

Figure 1. Monthly heating and cooling loads over the monitoring period

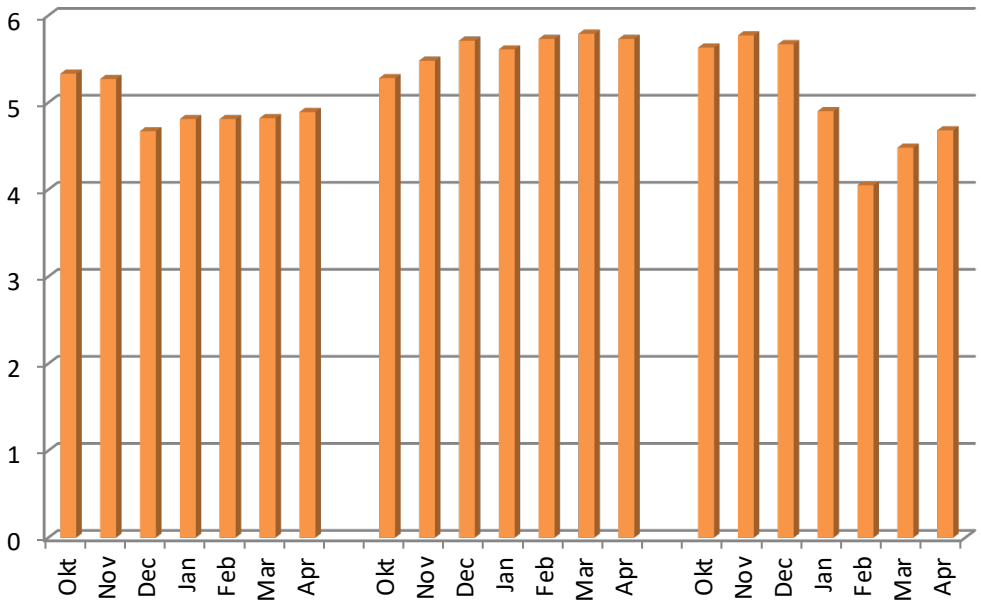

Figure 2. Monthly performance factors MPFH1 over the monitoring period.

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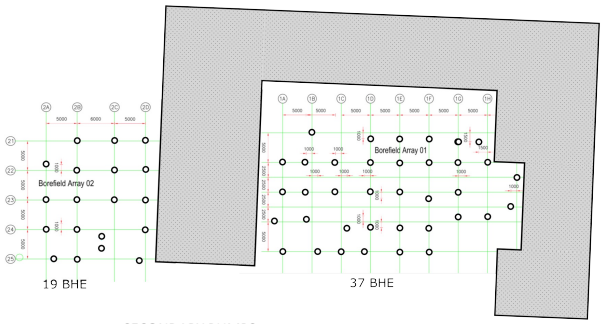

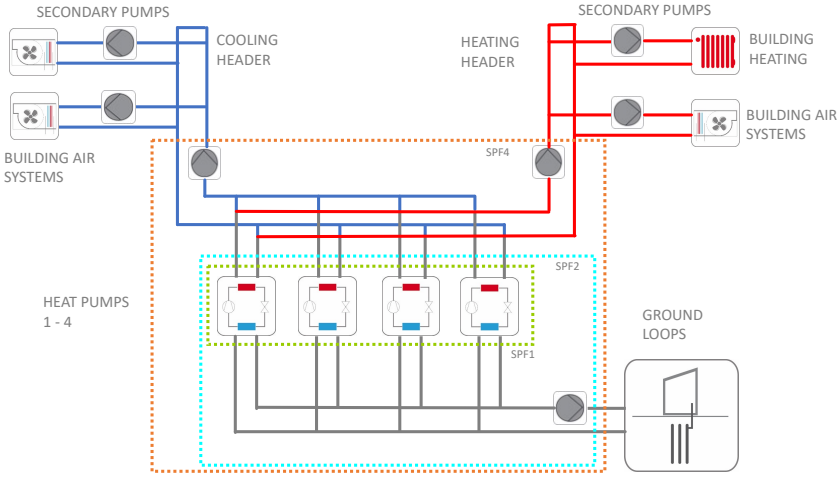

Building information	
Building name	Hugh Aston Building
Location	Leicester, UK
Year of building construction	2010
Ground source system operation start date	2010
Building Type	University building
Building floor area	16 467 m² net
Analysed monitoring period	May 2010 to April 2012
Unique features of the system	5 floors, all cooling by GSHP, partial heating along with gas

Heat pump information	
Heat pump	4 two-stage reversible water-to-water heat pumps
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	110 kW_{th}
Nominal total heat pump cooling capacity [kW_{th}]	120 kW_{th}
Refrigerant	R410A

Ground source information	
Ground source	56 grouted vertical boreholes, 100 m
Undisturbed ground temperature	12.3°C
Borehole heat exchanger type	Single U-tube
Source side brine type	Water

Evaluation period	May 2010 – April 2011	May 2011 – April 2012
SPFH1	2.89	3.55
SPFC1	3.99	3.87
SPFHC1	3.31	3.67
SPFHC2	2.69	3.16
SPFHC4	2.22	2.61

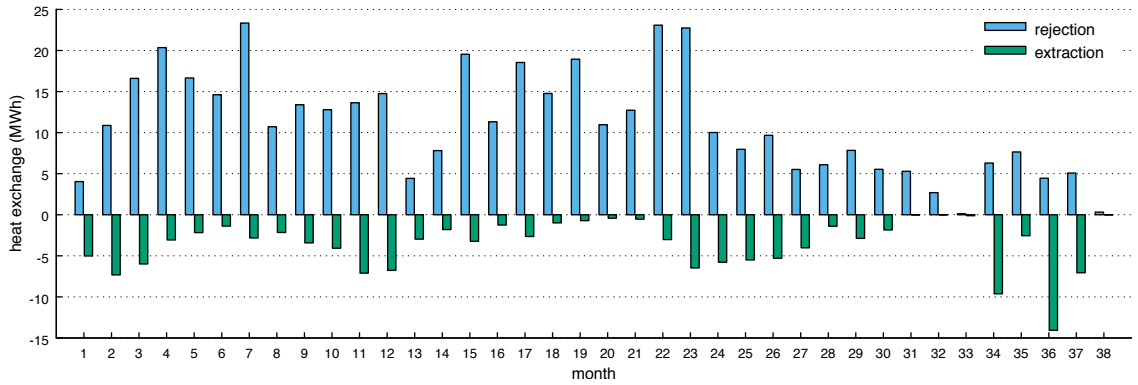

Figure 1. Monthly heating and cooling loads over the monitoring period

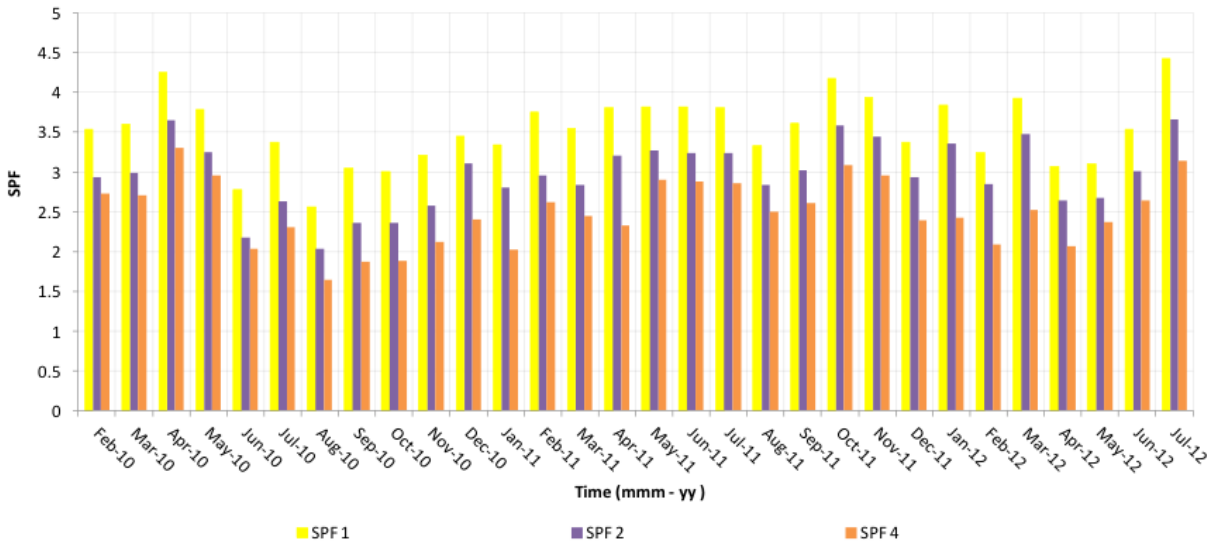

Figure 2. Monthly variations in Performance Factor over the monitoring period

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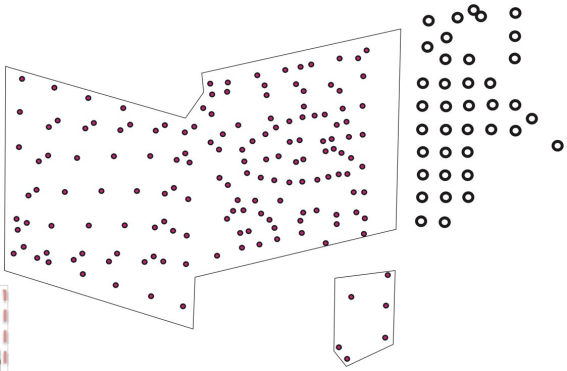

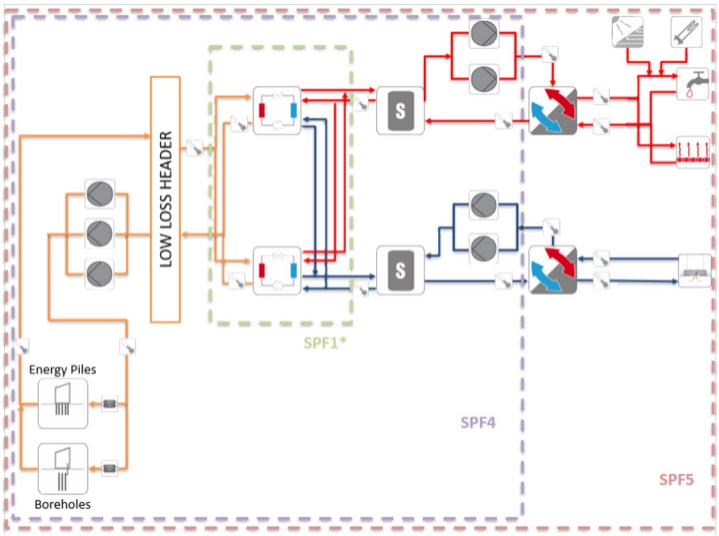

Building information

Building name	The Crystal
Location	London, UK
Year of building construction	2012
Ground source system operation start date	2012
Building Type	Office and Exhibition building
Building floor area	6 920 m² net
Analysed monitoring period	March 24 2013 to March 23 2021

Heat pump information

Heat pump	2 two-stage reversible water-to-water heat pumps
Heat Pump system type	Centralized HP
Nominal total heat pump heating capacity	814 kW_{th}
Nominal total heat pump cooling capacity [kW_{th}]	780 kW_{th}
Refrigerant	R410A

Ground source information

Ground source	160 energy piles, 21 m + 36 grouted vertical boreholes, 150 m
Undisturbed ground temperature	12.8°C (piles), 13.4°C (boreholes)
Borehole heat exchanger type	2U-tube in energy piles, single U-tube in boreholes

Start of evaluation period End of evaluation period	March 25th 2013 March 25th 2014	March 25th 2014 March 25th 2015	March 25th 2015 March 25th 2016	March 25th 2016 March 25th 2017	March 25th 2017 March 25th 2018	March 25th 2018 March 25th 2019	March 25th 2019 March 25th 2020	March 25th 2020 March 25th 2021	March 25th 2013 March 25th 2021
SPFH1*	2.61	2.91	3.23	3.70	3.53	3.02	2.55	2.31	3.04
SPFH1+*	2.61	2.85	3.13	3.56	3.44	2.95	2.51	2.25	2.97
SPFC1*	2.47	2.43	2.65	2.93	2.69	2.05	1.55	1.12	2.15
SPFC1+*	2.47	2.35	2.54	2.80	2.60	2.02	1.54	1.10	2.09
SPFHC1*	2.53	2.57	2.82	3.27	3.10	2.41	1.69	1.54	2.45
SPFHC1+*	2.53	2.49	2.71	3.13	3.00	2.34	1.68	1.49	2.39
SPFH4	2.25	2.59	2.84	3.24	3.21	2.71	2.36	2.19	2.72
SPFH4+	2.25	2.55	2.77	3.14	3.13	2.66	2.33	2.13	2.67
SPFC4	1.76	1.76	2.15	2.36	2.30	1.78	1.45	0.95	1.78
SPFC4+	1.76	1.73	2.08	2.29	2.23	1.76	1.44	0.95	1.75
SPFHC4	1.95	1.97	2.34	2.73	2.72	2.12	1.58	1.36	2.08
SPFHC4+	1.95	1.93	2.27	2.64	2.65	2.09	1.57	1.32	2.04
SPFH5	2.00	2.35	2.47	2.70	2.78	2.40	2.14	1.96	2.39
SPFH5+	2.00	2.31	2.42	2.64	2.73	2.36	2.12	1.92	2.35
SPFC5	1.39	1.55	1.83	1.92	1.91	1.56	1.34	0.76	1.53
SPFC5+	1.39	1.53	1.79	1.88	1.87	1.55	1.34	0.78	1.51
SPFHC5	1.61	1.75	2.00	2.24	2.31	1.87	1.46	1.13	1.80
SPFHC5+	1.61	1.72	1.96	2.19	2.26	1.85	1.46	1.12	1.77

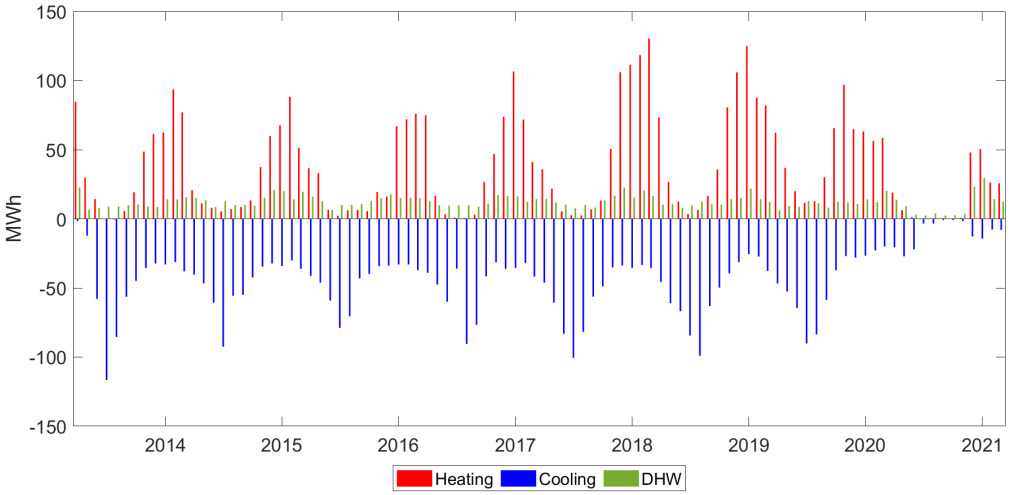

Figure 1. Monthly heating and cooling loads over the monitoring period

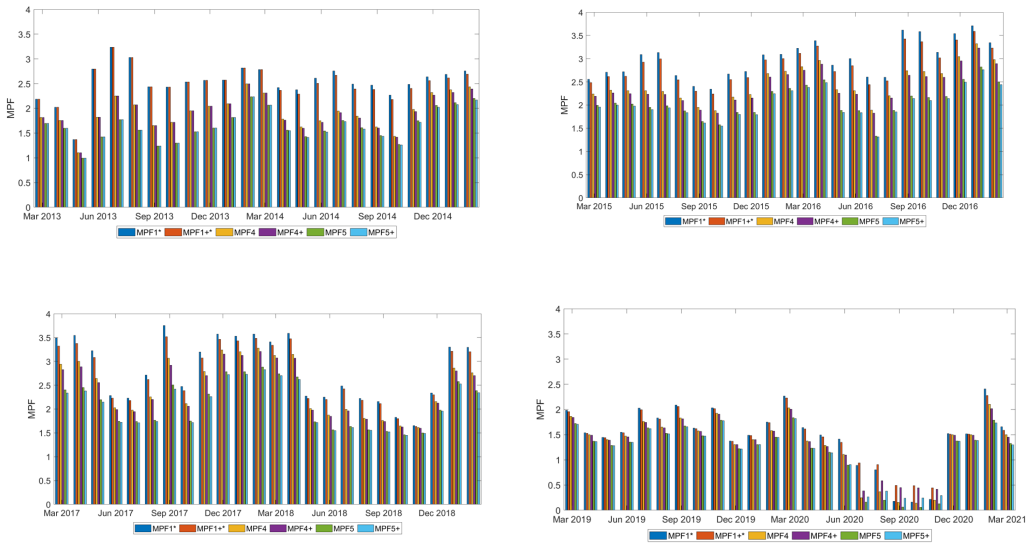

Figure 2. Monthly overall (H+C) performance factors for different system boundaries

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Turner, J., Loveridge, F. Rees, S.J. (2021). Case study report for the Crystal Building, United Kingdom. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. https://doi.org/10.23697/kmxr-hw82

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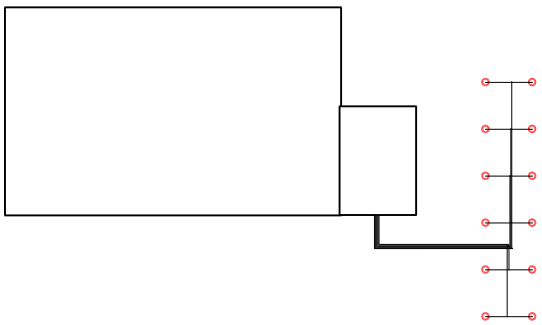

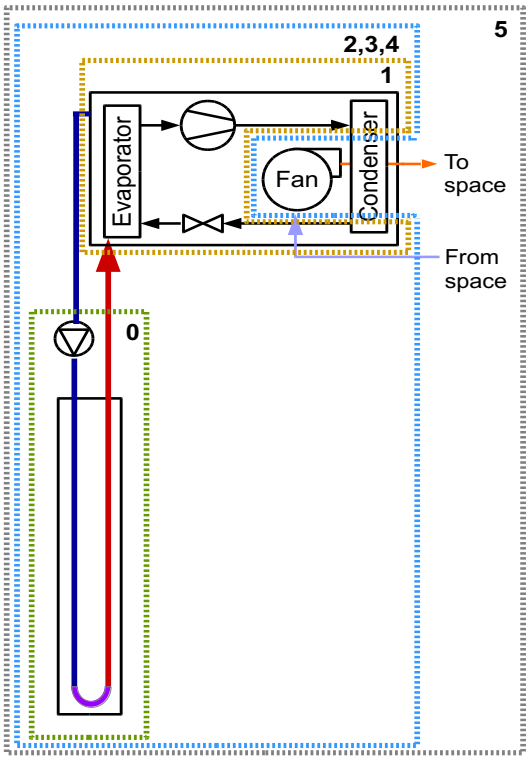

Building information	
Building name	ASHRAE Headquartes building
Location	Atlanta, Georgia, USA
Year of building construction	1965
Ground source system operation start date	2008
Building Type	Office
Building floor area	1445 m² gross
Analysed monitoring period	2011-July-1 to 2013-June 30
Unique features of the system	Part of a living lab. Only 2nd floor is served by GSHP system

Heat pump information	
Heat pump	14 reversible Water-to-air HP
Heat Pump system type	Distributed HP
Nominal total heat pump heating capacity	90 kW_{th} , no DHW heating
Nominal total heat pump cooling capacity [kW_{th}]	119 kW_{th}
Refrigerant	HFC-410A

Ground source information	
Ground source	12 grouted vertical boreholes, 122 m
Undisturbed ground temperature	19.4°C
Borehole heat exchanger type	Single U-tube
Source side brine type	Water

Evaluation period	July 1 2011 – June 30 2012	July 1 2012 – June 30 2013
Building space heating load met by system [MWh_{th}]	11.1±0.8	17.3±1.2
Building cooling load met by system [MWh_{th}]	81.0±11	66.3±9
DHW load met by system [MWh_{th}]	0	0
Thermal energy extracted from the ground [MWh_{th}]	6.9±0.7	10±0.8
Thermal energy injected to the ground [MWh_{th}]	72.5±5.3	58.4±3.8
Thermal balance ratio (extracted/rejected)	0.095±0.02	0.17±0.03
Heating load (incl. DHW) met by ground source (%)	100%	100%
Cooling load met by ground source (%)	100%	100%
SPFHC0	20±5	39±10
SPFH5	2.7 ±0.2	3.8 ±0.2
SPFC5	3.8 ±0.5	3.9 ±0.6
SPFHC5	3.7 ±0.5	3.7 ±0.4

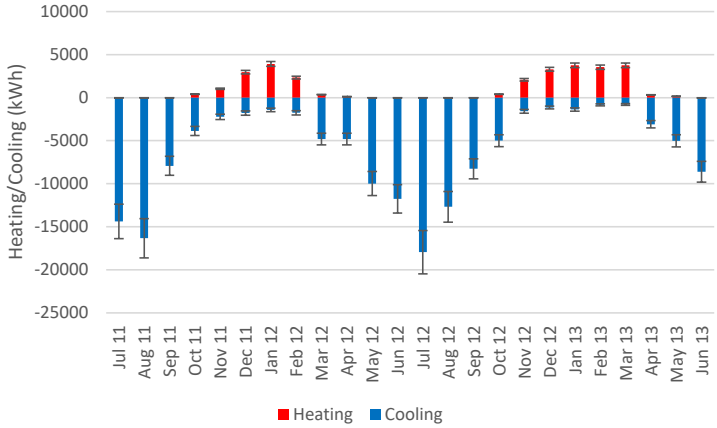

Figure 1. Monthly heating and cooling loads over the monitoring period

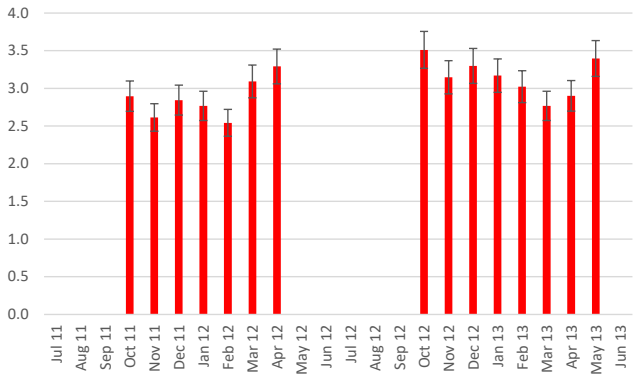

Figure 2. Monthly heating performance factors for boundary 5, over the monitoring period

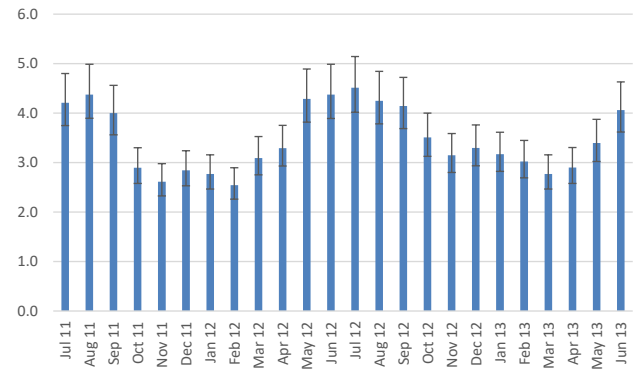

Figure 3. Monthly cooling performance factors for boundary 5, over the monitoring period

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