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Towards Decarbonized Heating and Cooling!

Borehole Thermal Energy Storage (BTES) Applications in Scandinavian Countries

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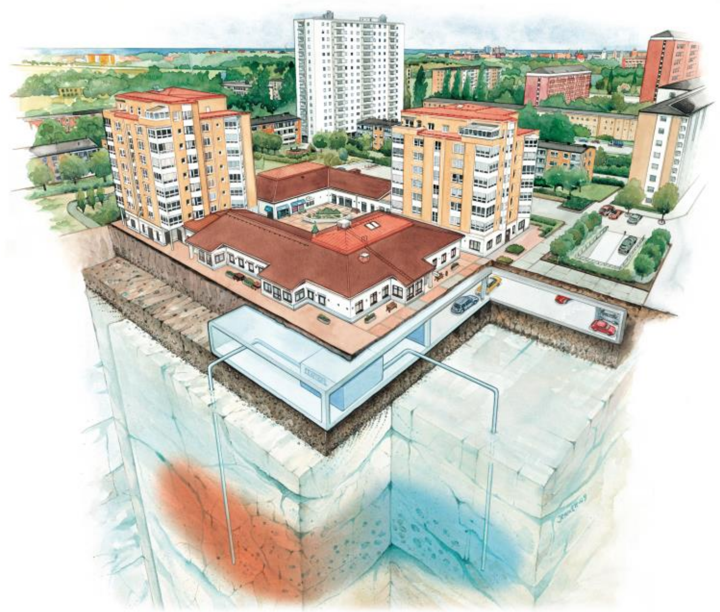
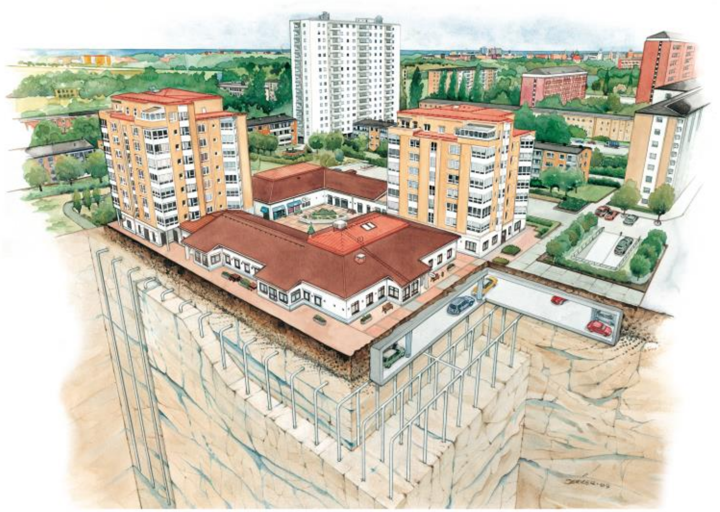
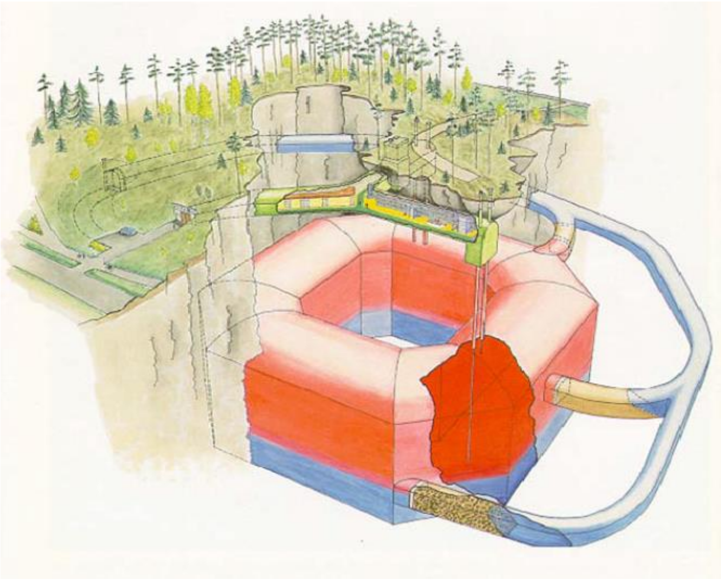
Underground Thermal Energy Storage (UTES)





Figures: *Swedish Geoenergy centrum; Hellström (2022)*



Aquifer TES

- Geologically dependent
- Easily applicable
- Environmental concerns
- Moderate no of installations

Borehole TES

- Possible in any Geology
- Practical and Modular
- Low storage efficiency
- Large no of installations

Cavern TES

- Geologically dependent
- High capital costs
- Large-scale applications
- Few installations

UTES in Sweden

- ATES: Less than 100 systems of more than 100 kW capacity
- BTES: A few thousand systems of larger than 2500 m total depth
- CTES: Only four systems

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100,000-m BTES Club

- Daxing Airport, China
- Epic Systems Wisconsin, USA
- Tijanjin Cultural Center, China
- Ball State University Campus, USA
- Seoul Lotte Tower, S Korea
- ELI-NP Marugele, Romania
- Zhungguancon International Center, China

Figure: *Gehlin (2023)*

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10,000-m BTES Club

- Sweden: 50+
- Norway: 20+
- Finland: 20+
- Germany: 10+
- Switzerland: 10+

Figure: *Gehlin (2023)*

Largest BTES in Nordics

Figure: *Gehlin (2023)*

Applications of BTES

- Monovalent Systems
- Bivalent Systems
- High-Temperature Storage
- Low-Temperature Storage
- Low-Exergy Systems
- Microgrids

→

Case 1 – Bivalent Application

Case 2 – HT Application

Case 3 – DGC

Case 4 – LowEx

Application – Bivalent Systems

- Designed for 50-60 % of the power required at design conditions
- Cover about 85-90 % of the annual energy demands
- Remaining 10-15 % energy load covered by an auxiliary source like DH or EH

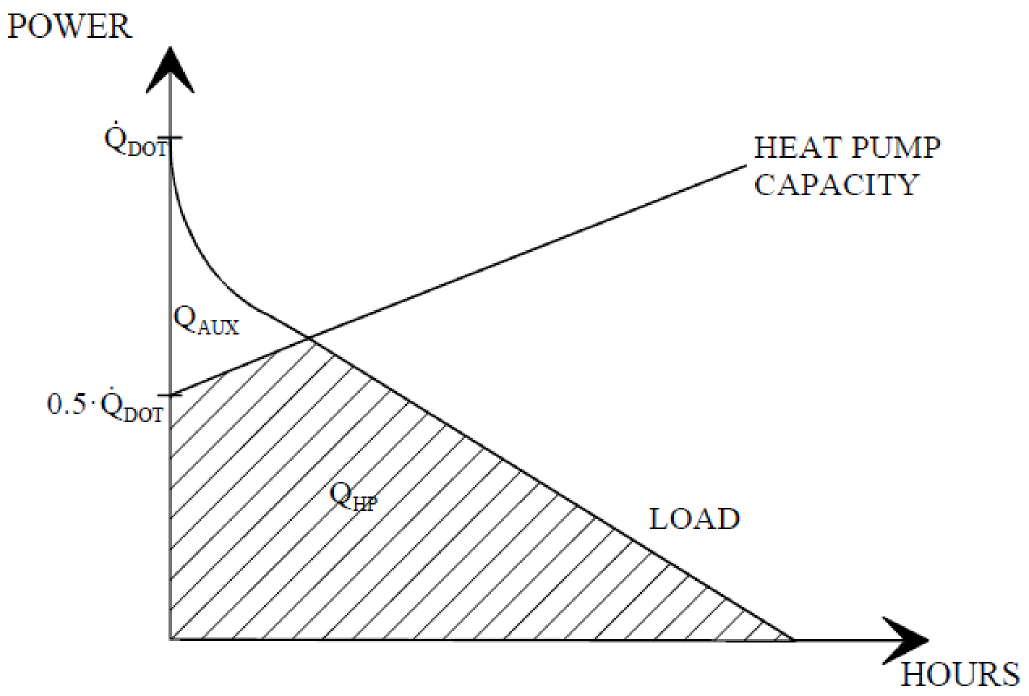

Figure: *Karlsson et al. (2003)*

Case 1 – Astronomy House

- Lund University
- Installed in 2021
- Floor area: 5300 m^2
- 20 boreholes
- Rectangular configuration
- Each 200 m deep

Case 1 – Astronomy House

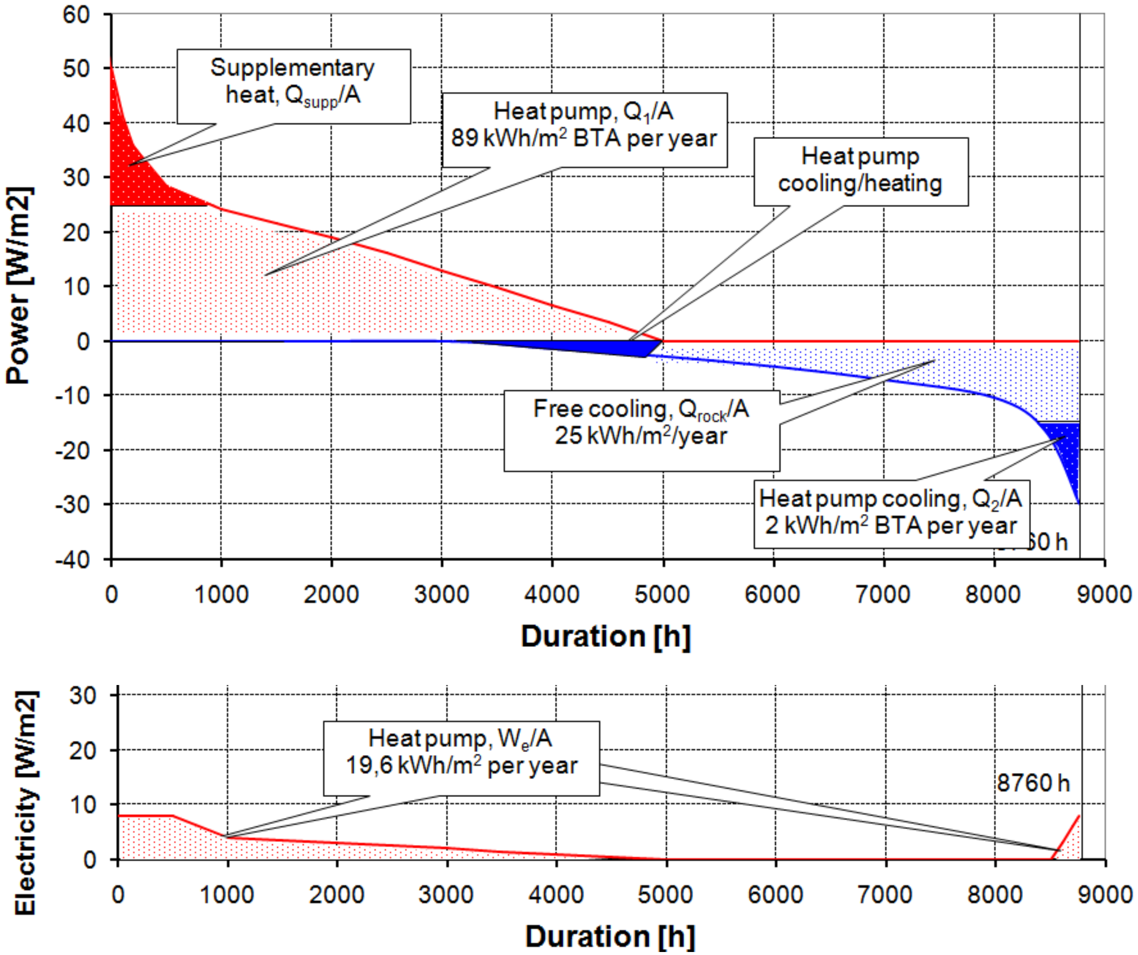

Figure: *Fahlén (2016)*

Case 1 – Astronomy House

Energy Balance	MWh/year	kWh/m²/year
Heating Demand	515	97
Cooling Demand	155	29
Heating form Heat Pump	475	89
Supplementry Heating (District Heating)	40	8
Free Ground Cooling	130	25
Heat Pump, simultaneous heating and cooling	15	3
Heat Pump, cooling only	10	2
Electricity for Heat Pump	104	20
Electricity for Circulation Pumps	7	1

Case 1 – Astronomy House

Performance Evaluation	Value
Seasonal Performance Factor – Heat Pump (including circulation)	4.5
Seasonal Performance Factor – Free Cooling	47
Seasonal Performance Factor – Ground Source (HP + Free Cooling)	5.7
Seasonal Performance Factor – Total (Ground Source + DH)	4.4

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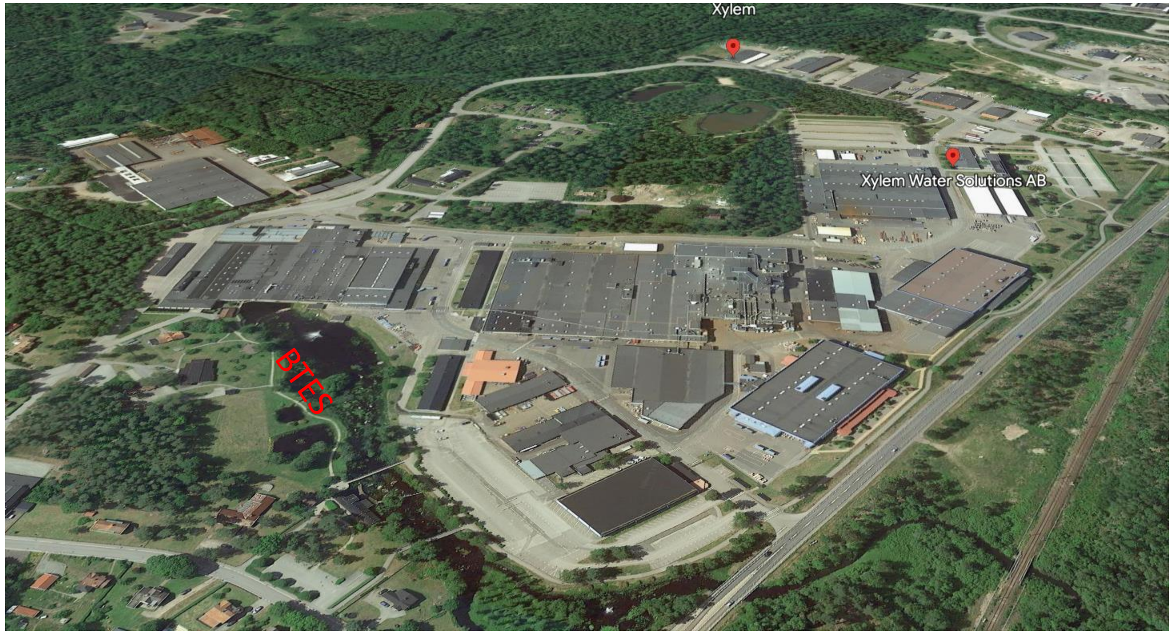
Application – HT BTES

- Luleå (1983-1989)
  - ✓ 120 BHE, 65 m
  - ✓ DH (Seasonal)
  - ✓ Heat from steel plant
- Emmaboda (2010)
  - ✓ 144 BHE, 150 m
  - ✓ Heat from foundry
  - ✓ Changed to discharge with HP
- Kolbotn (2022)
  - ✓ 60 BHE, 100 m
  - ✓ Soccer field heating
  - ✓ Solar and PV-driven ASHP (Seasonal)
- Anneberg (2001)
  - ✓ 99 BHE, 65 m
  - ✓ Solar (Seasonal)
- Drammen (2020)
  - ✓ 100 BHE, 50 m
  - ✓ Solar & ASHP (Seasonal)

Case 2 – Xylem Emmaboda

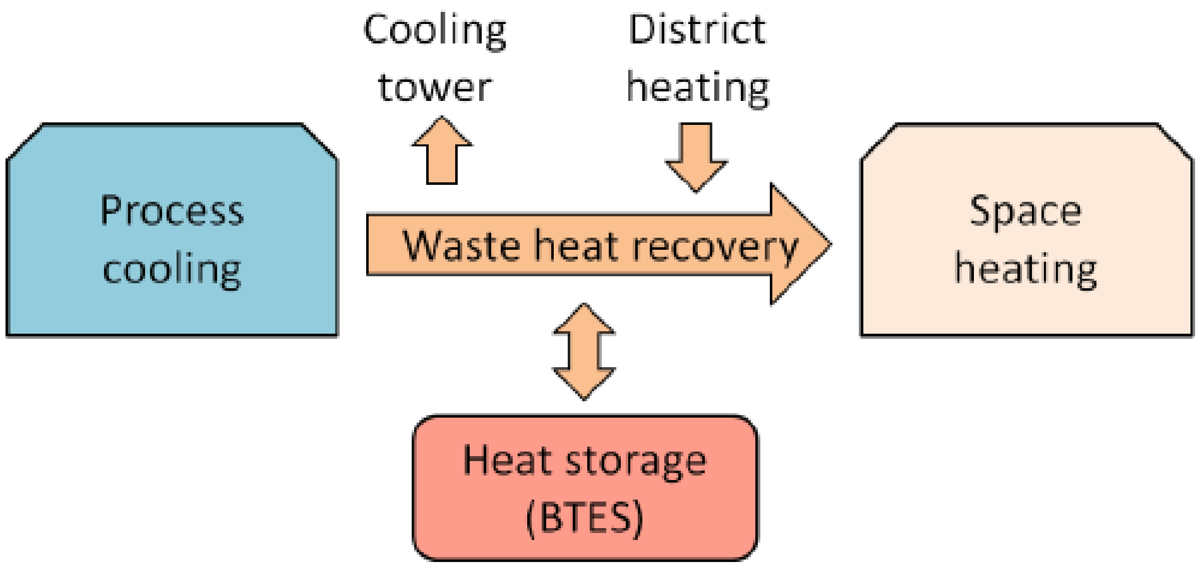
- Floor area: 110,000 m^2
- HT BTES installed in 2010
- 140 boreholes
- Rectangular configuration
- Each 150 m deep
- Coaxial (open to bedrock)

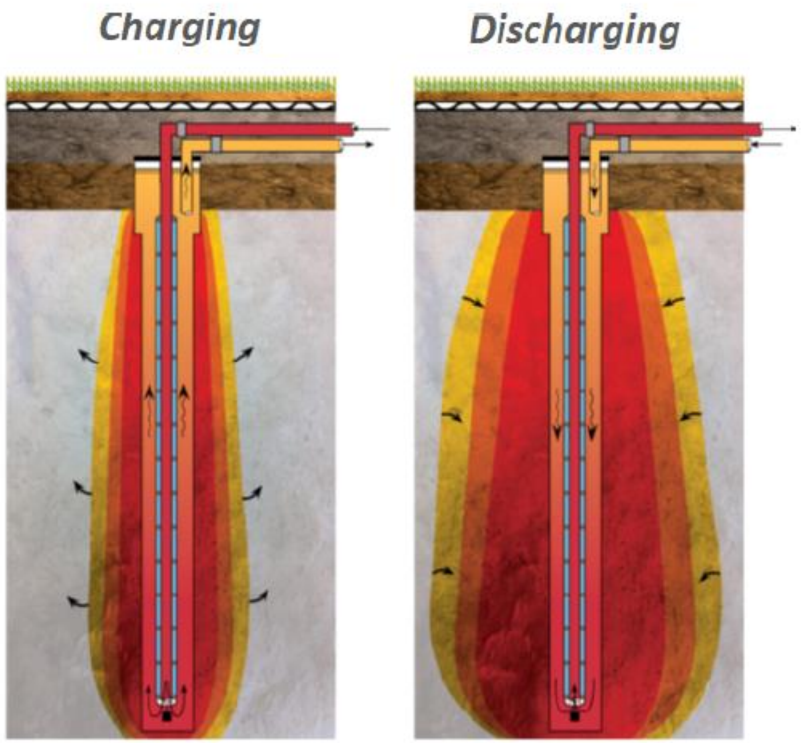


Case 2 – Emmaboda

- Original Design
  - ✓ 11,000 MWh heating demand, 5.5 MW peak load
  - ✓ 9,000 MWh cooling demand, 1.6 MW peak load
  - ✓ District heating capacity: 5 MW
  - ✓ Cooling tower capacity: 1.5 MW
  - ✓ 11 Heat pumps
  - ✓ 3600 MWh storage at a maximum supply temperature of 70 °C
  - ✓ Charging temperature of 60 °C at the end of summer
  - ✓ Discharging temperature of 40 °C at the end of winter

Case 2 – Emmaboda





Figures*: Andersson et al (2023)*

Case 2 – Emmaboda

- Problems
  - ✓ Storage temperature reached only 45 °C after charging
  - ✓ Heat recovery substantially lower than designed
  - ✓ Hydraulic contact with the bedrock
  - ✓ Heat carrier pressure controlled by groundwater level
  - ✓ Circulation under vacuum pressure (at around -35 kPa)
  - ✓ Technical problems with gas and cavitation
  - ✓ Larger heat losses than expected

Case 2 – Emmaboda

- Modified design
  - ✓ 8 new heat pumps on discharging side (800 kW)
  - ✓ Heat distribution temperature: 40 – 60 °C
  - ✓ Cooling distribution temperature: 20 – 45 °C
  - ✓ 7000 MWh injection (3 years total)
  - ✓ 6000 MWh extraction (3 years total)

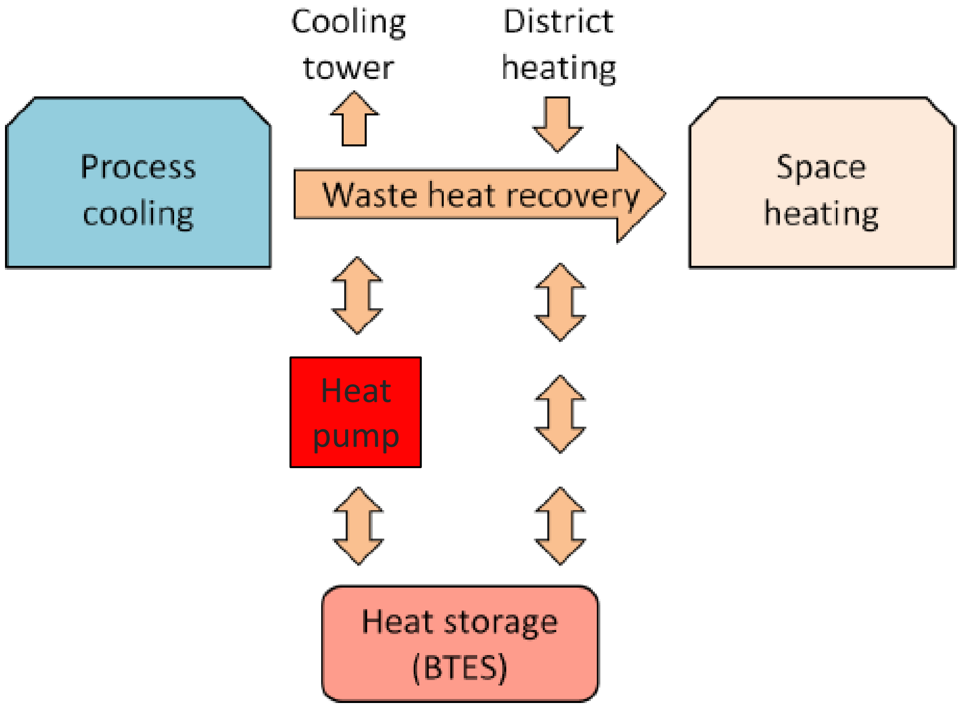
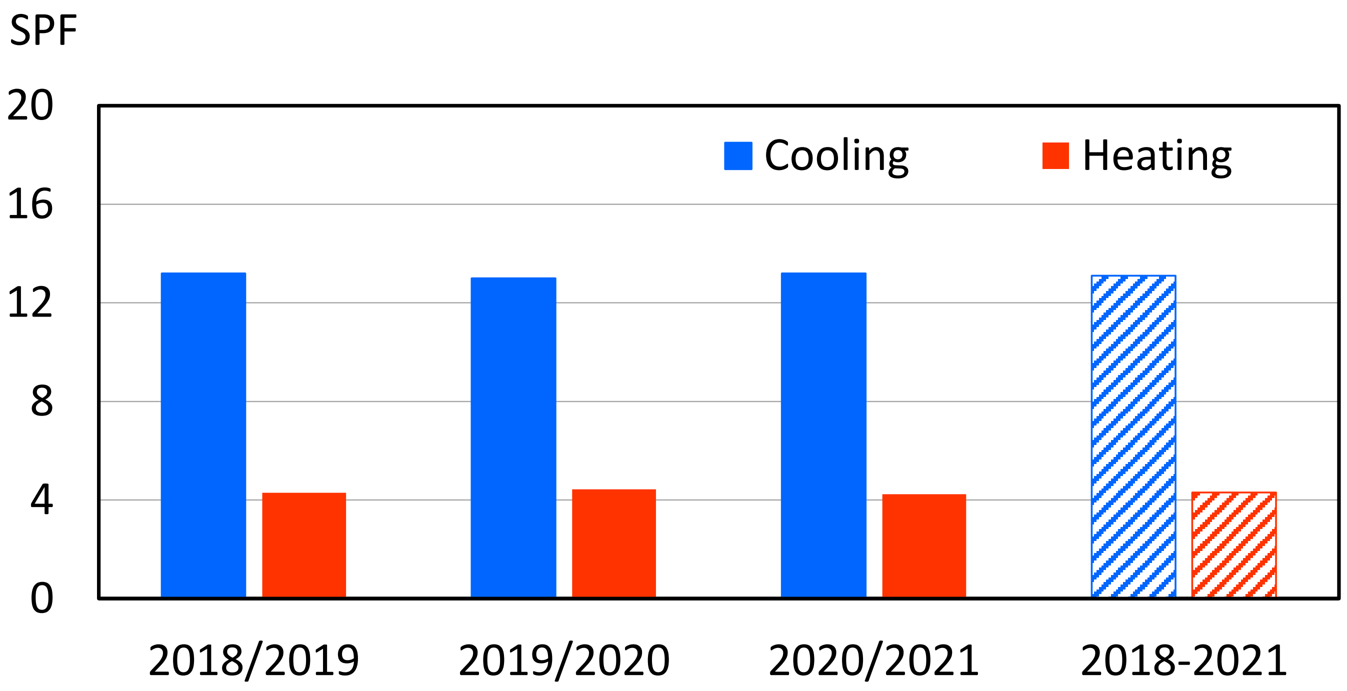


Figure: *Modified from Andersson et al (2023)*

Case 2 – Emmaboda



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Application – LT BTES

- Designed for passive cooling
- Passive heating for balancing/charging the BTES
- Integration with other renewable energy sources
- Natural ground temperature levels

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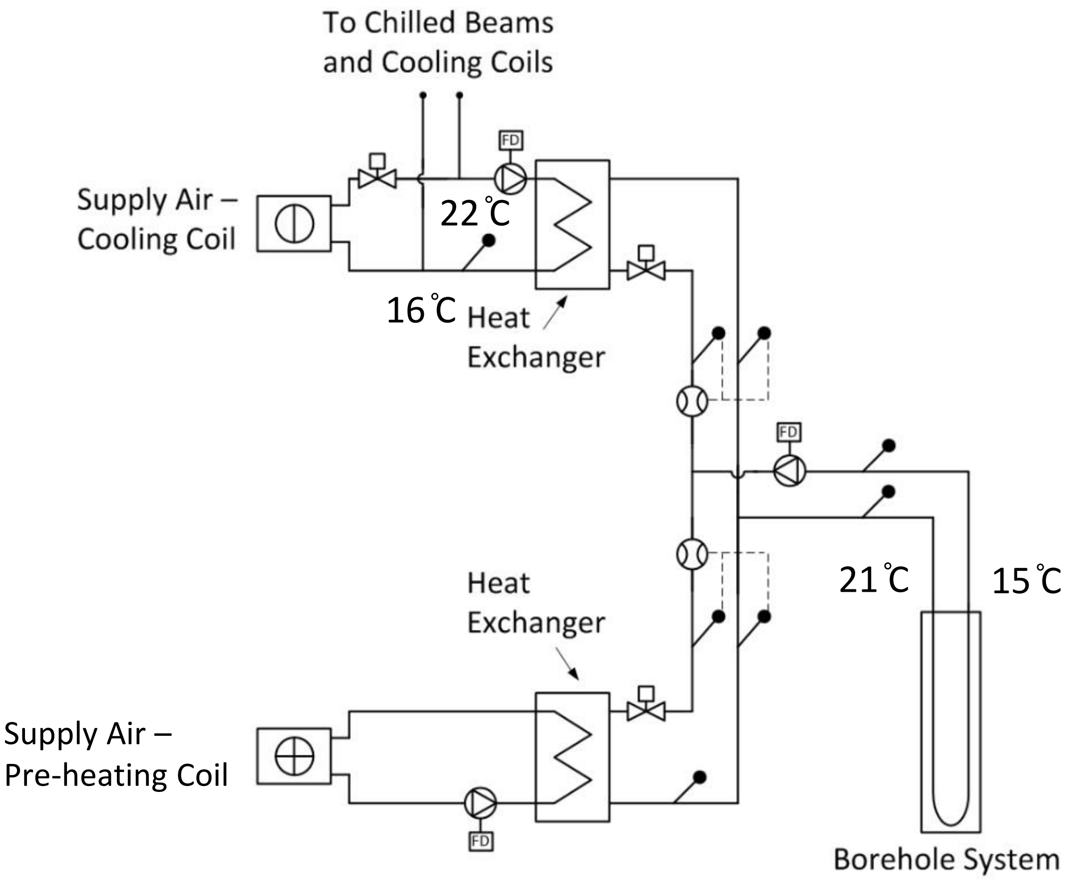
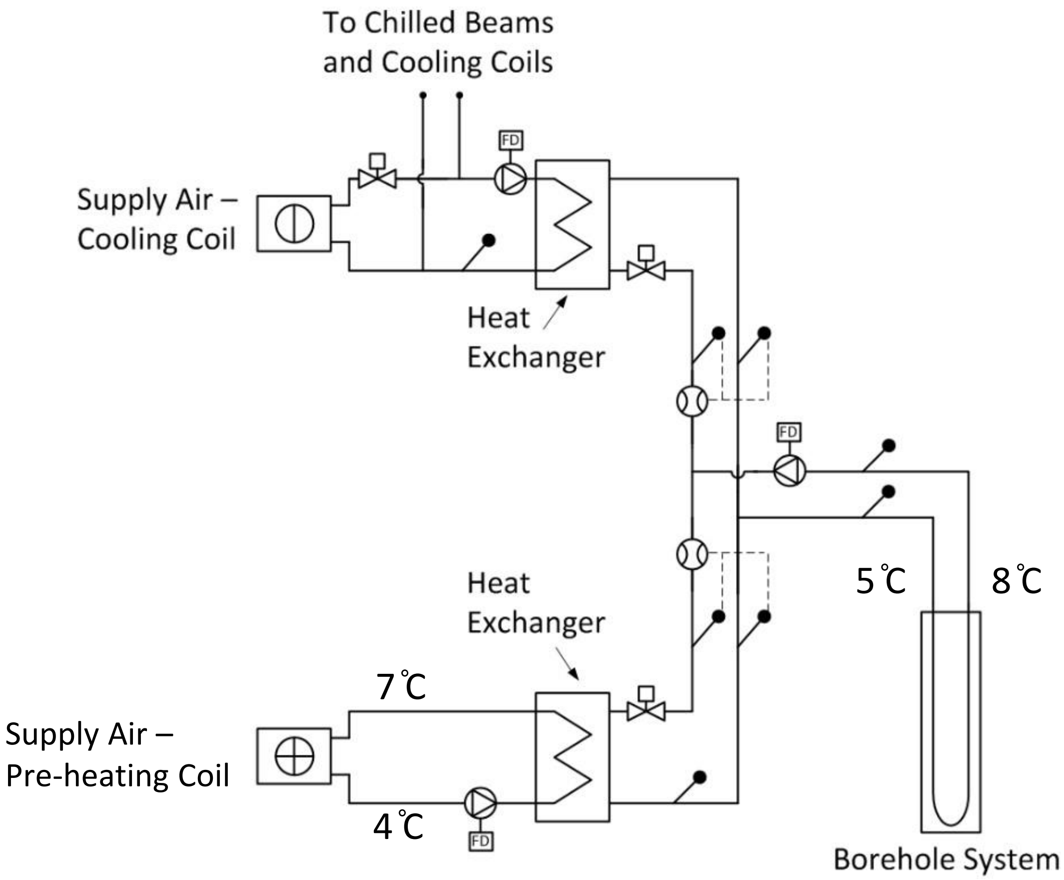
Application – LT BTES





Application – LT BTES

- Several Pilot Buildings

Entré Lindhagen, Stockholm (2013)
144 boreholes, 230-m deep each

Polishuset, Malmö (2012)
12 boreholes, 200-m deep each

Klipporna, Malmö (2014)
70 boreholes, 220-m deep each

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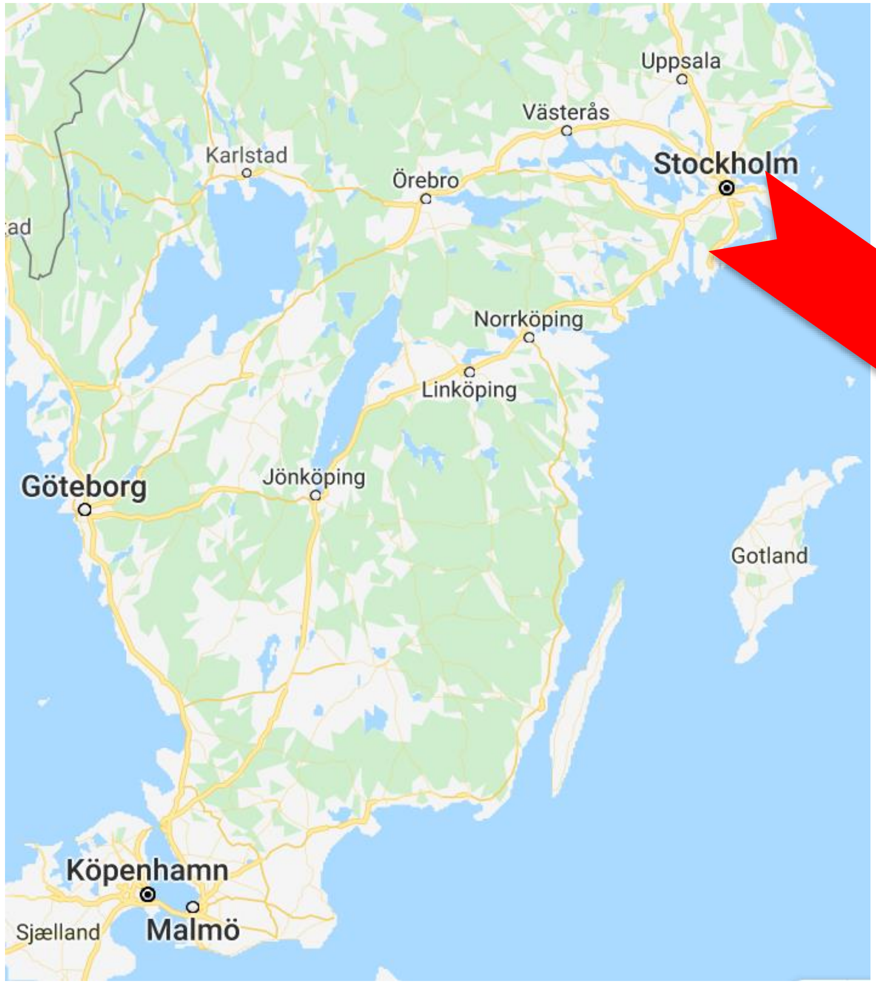
Case 3 – Entré Lindhagen



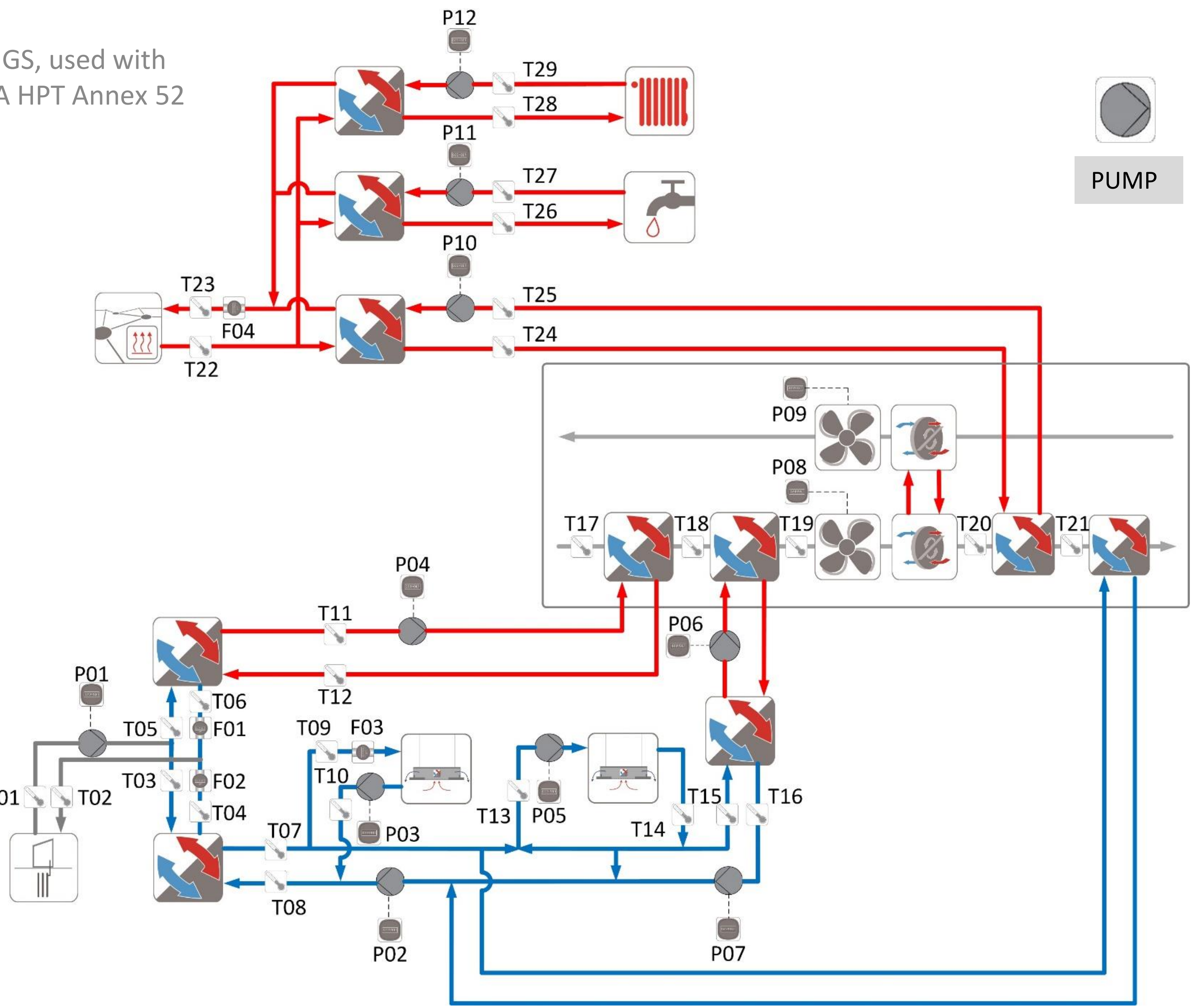
Entré Lindhagen, Kungsholmen,
Central Stockholm, Sweden
(LAT 59.337, LON 18.012)

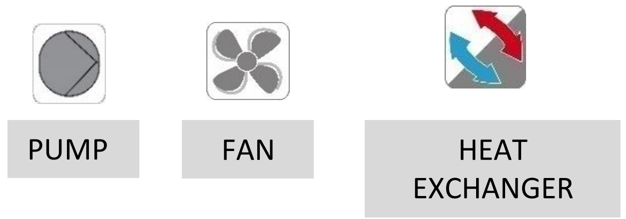
Case 3 – Entré Lindhagen

	[Entré Lindhagen, Stockholm]
Year (building)	[2014]
Net floor area	65,265 m²
System type	BTES / DGC (Deep Green Cooling, Skanska)
Boreholes	144 x 220 m (2U)
Monitoring period	5 years

Case 3 – Entré Lindhagen

Pictograms by TU Braunschweig IGS, used with permission within the course of IEA HPT Annex 52





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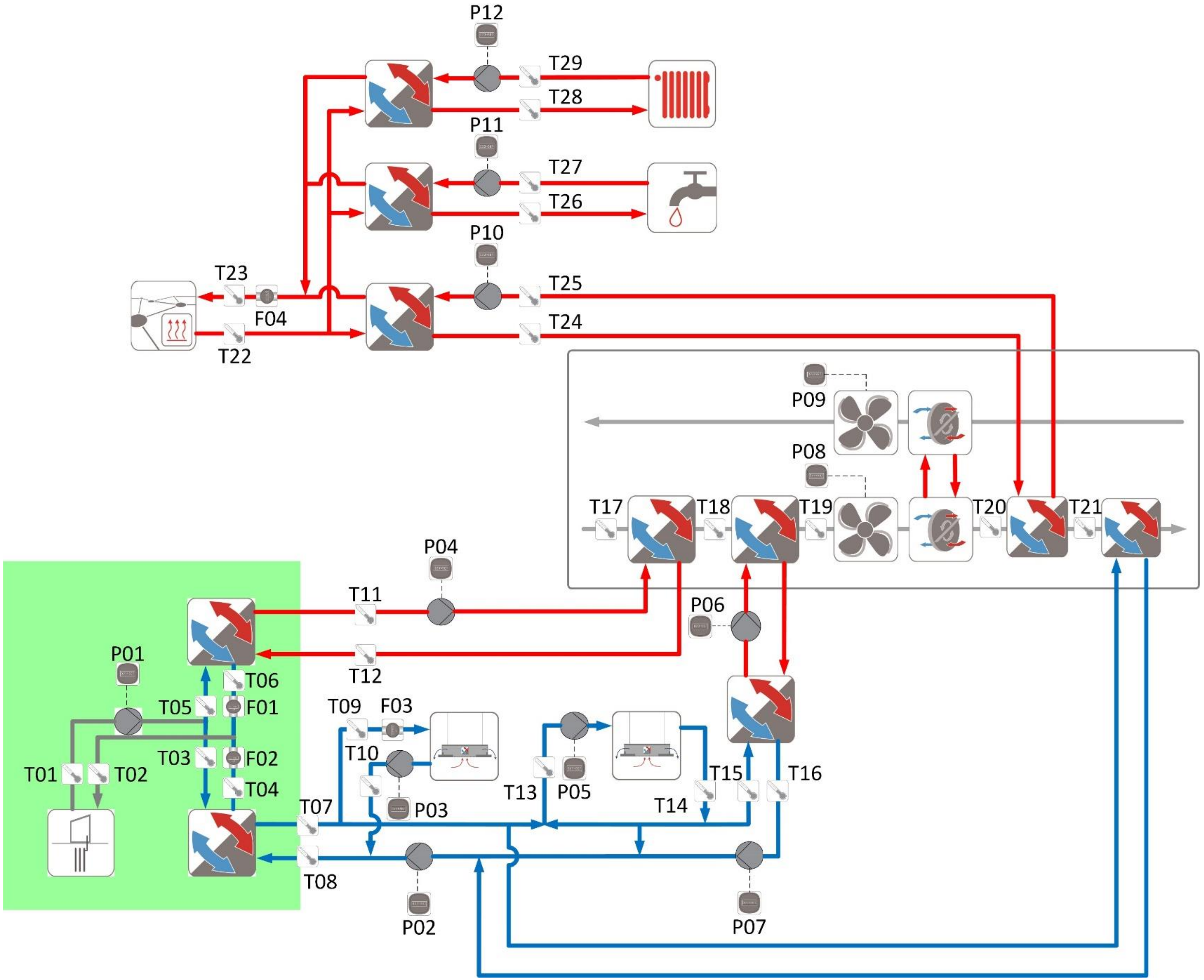

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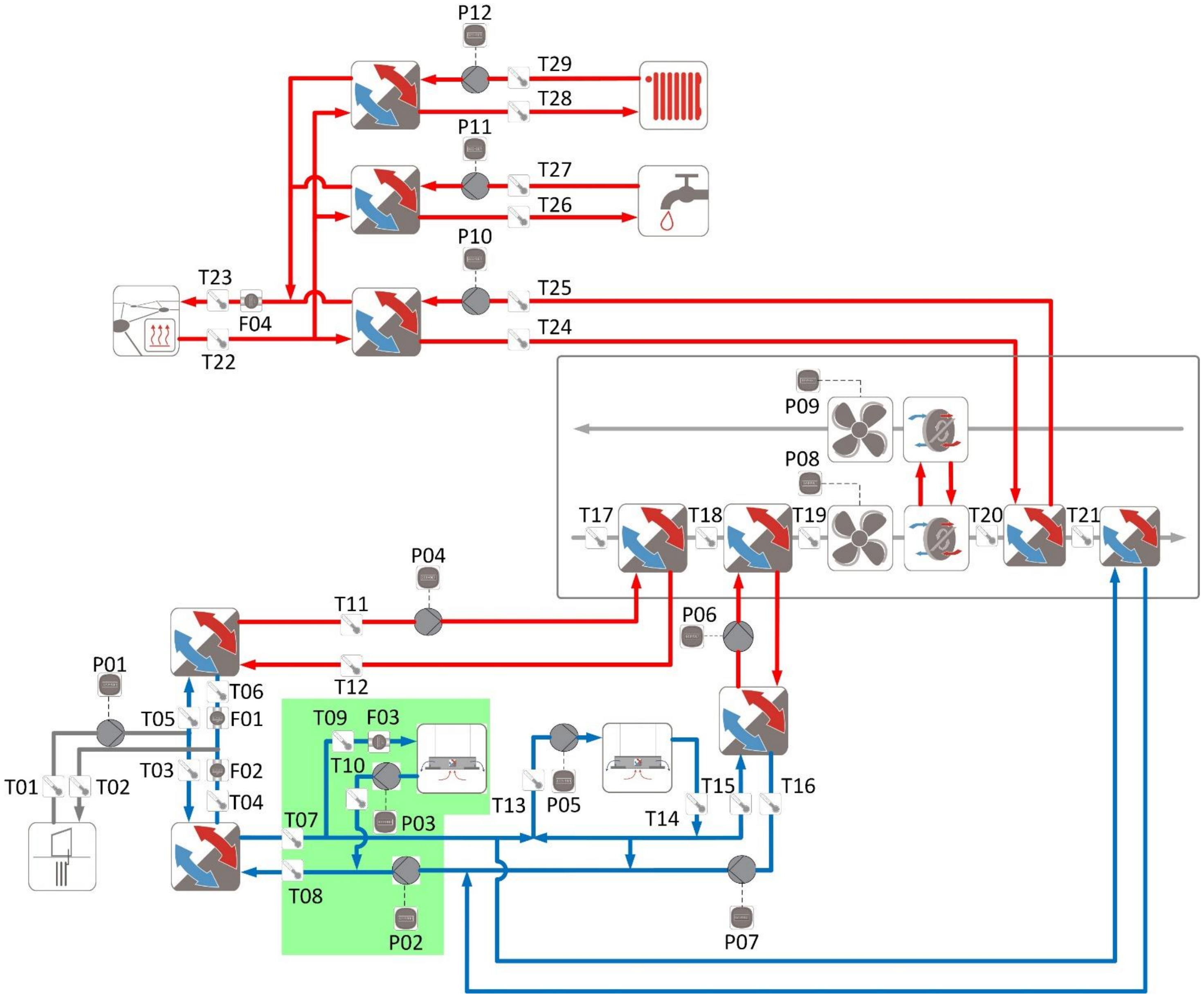

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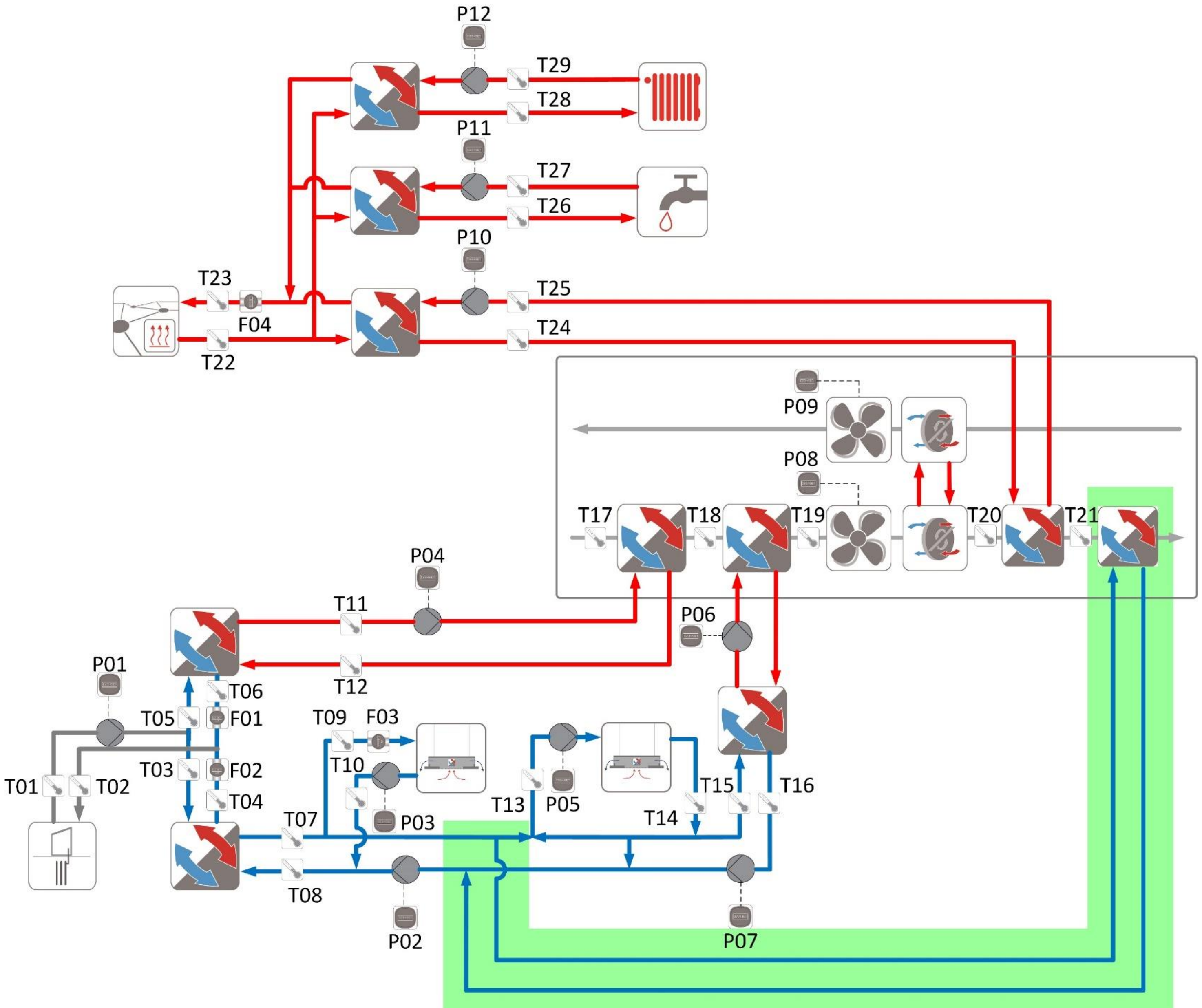

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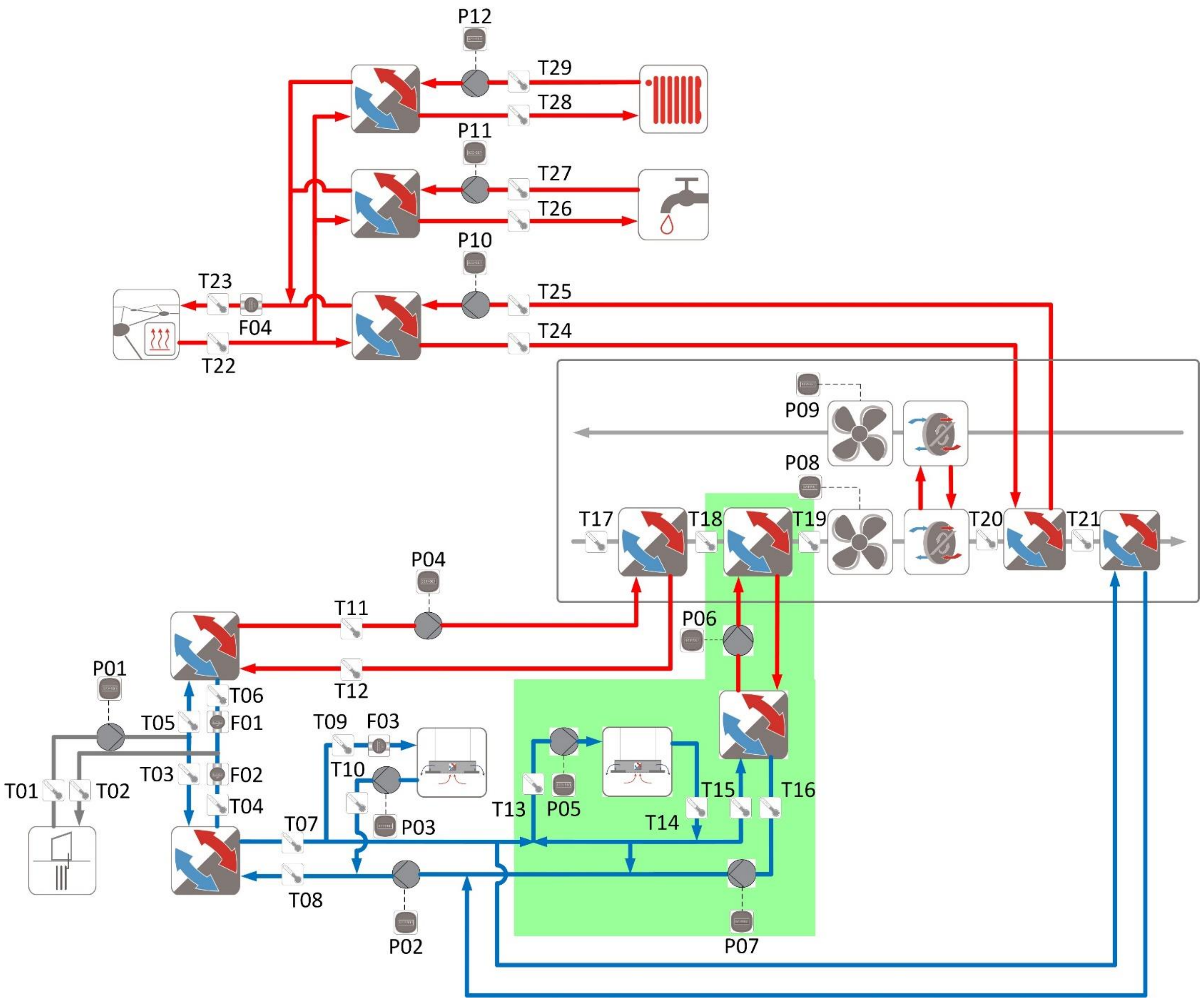

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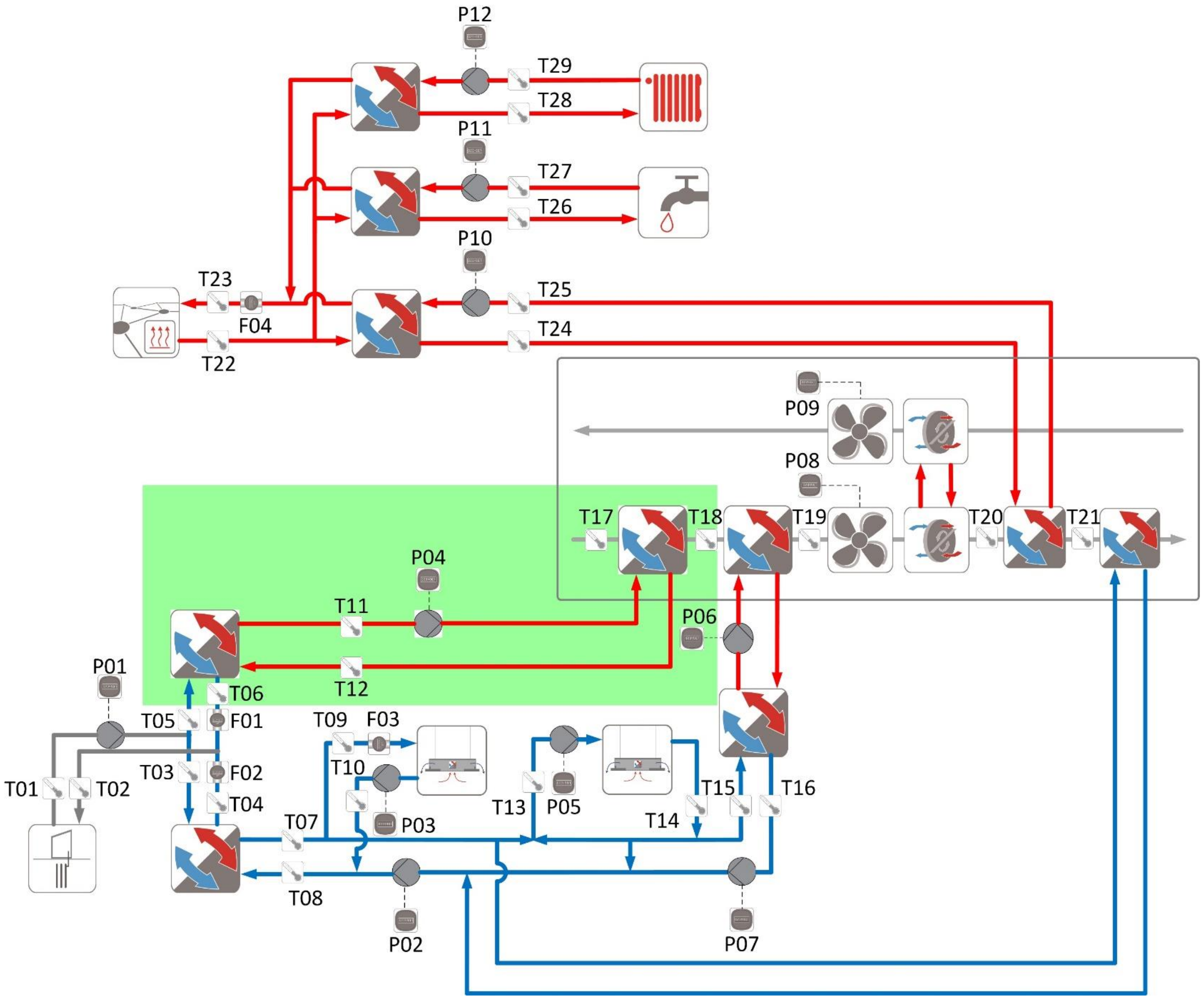

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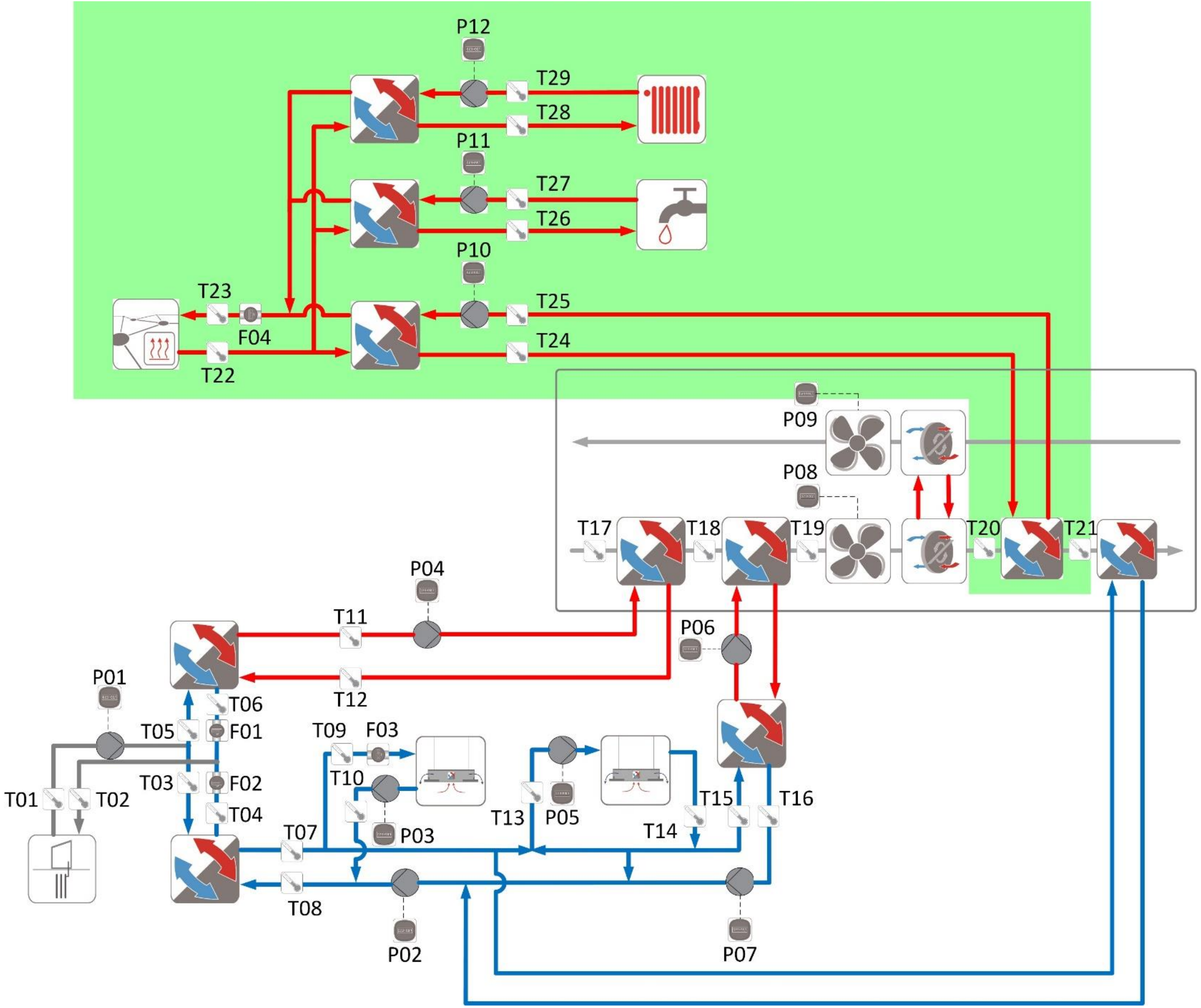

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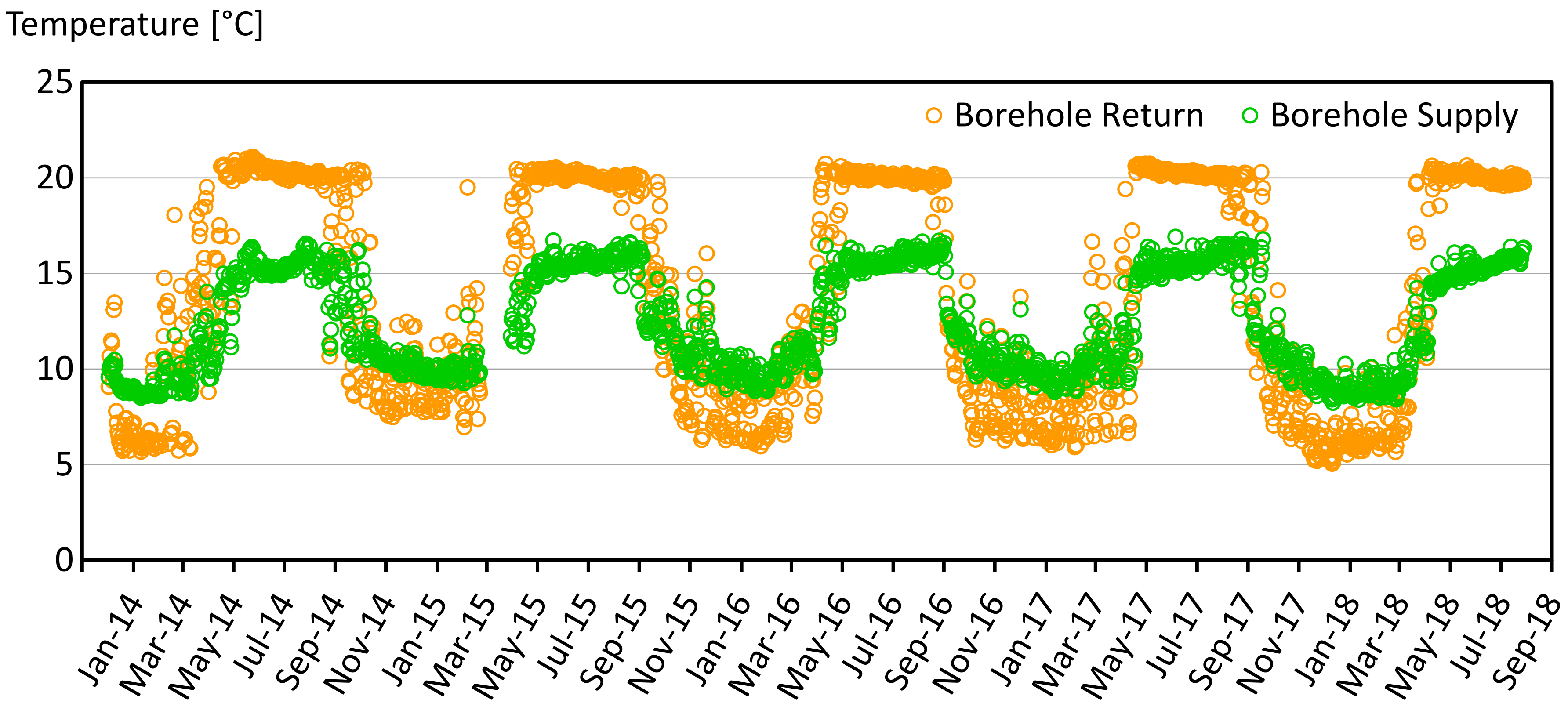

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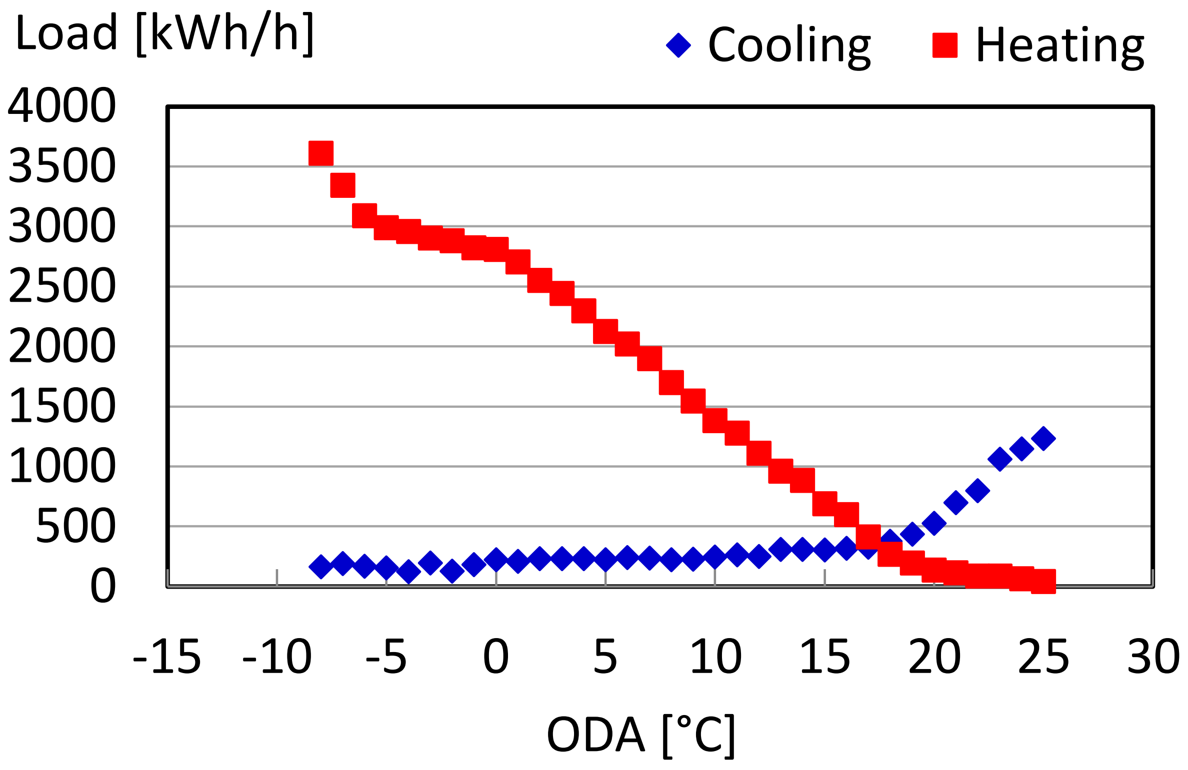

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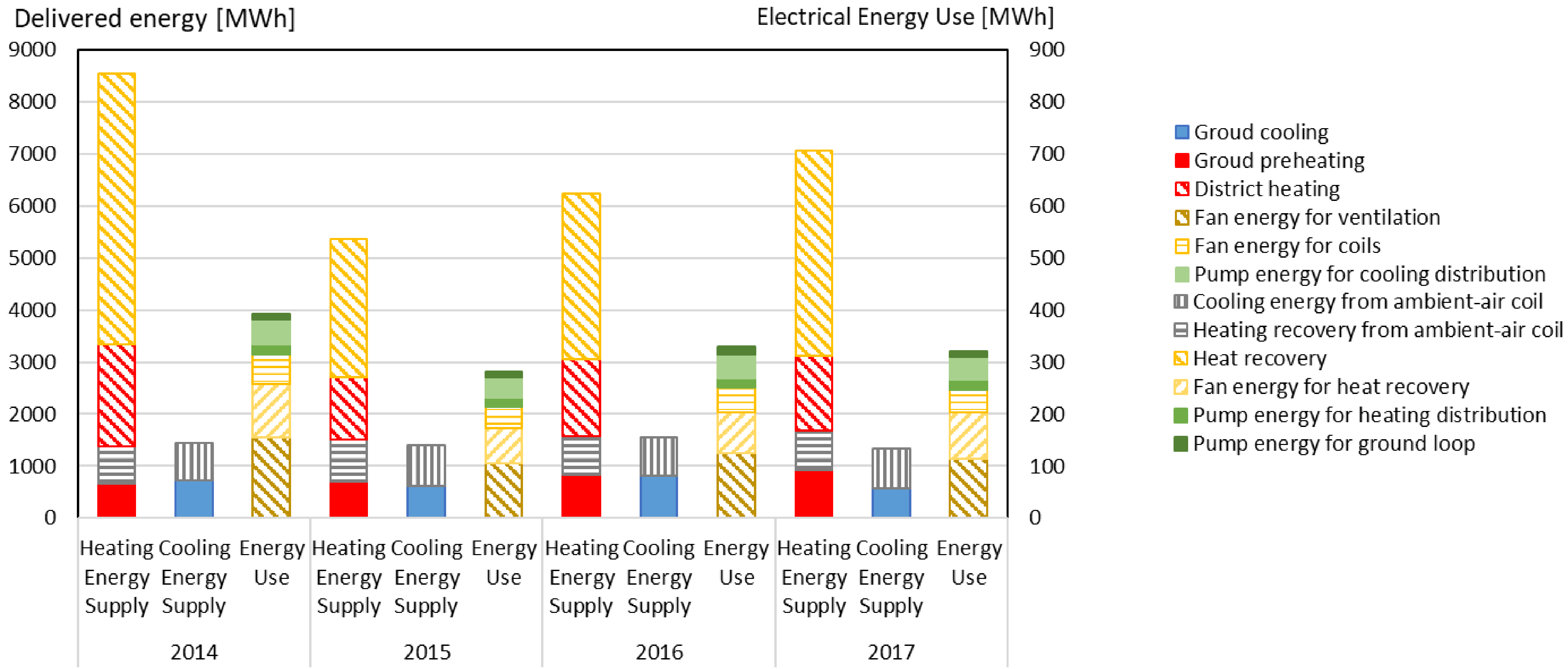

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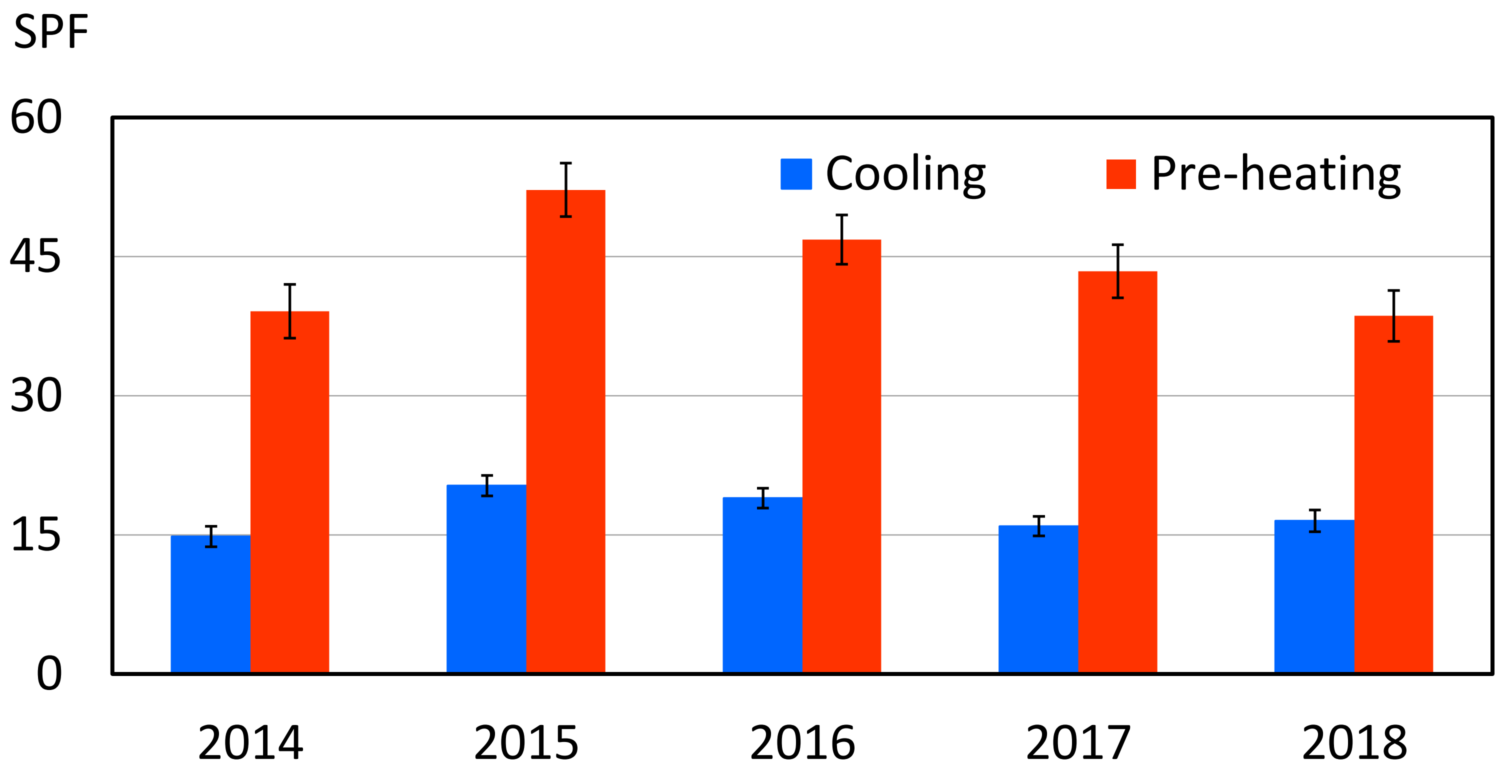

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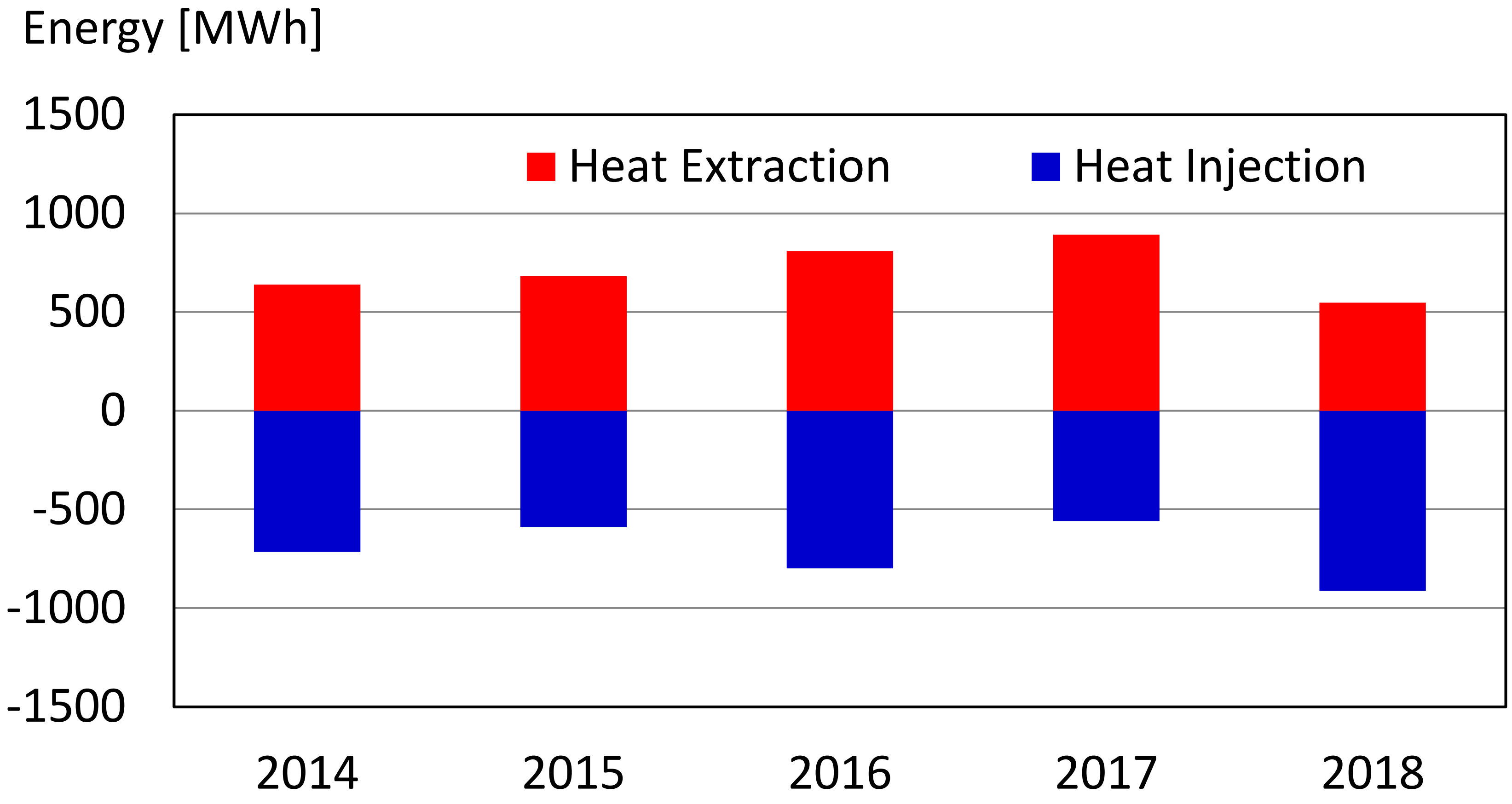

Application – LowEx Systems

- A new application type for thermal energy supply in zero-energy-buildings and plus-houses
- Two- to three-fold better performance factors than state-of-the-art today
- Low-cost solution

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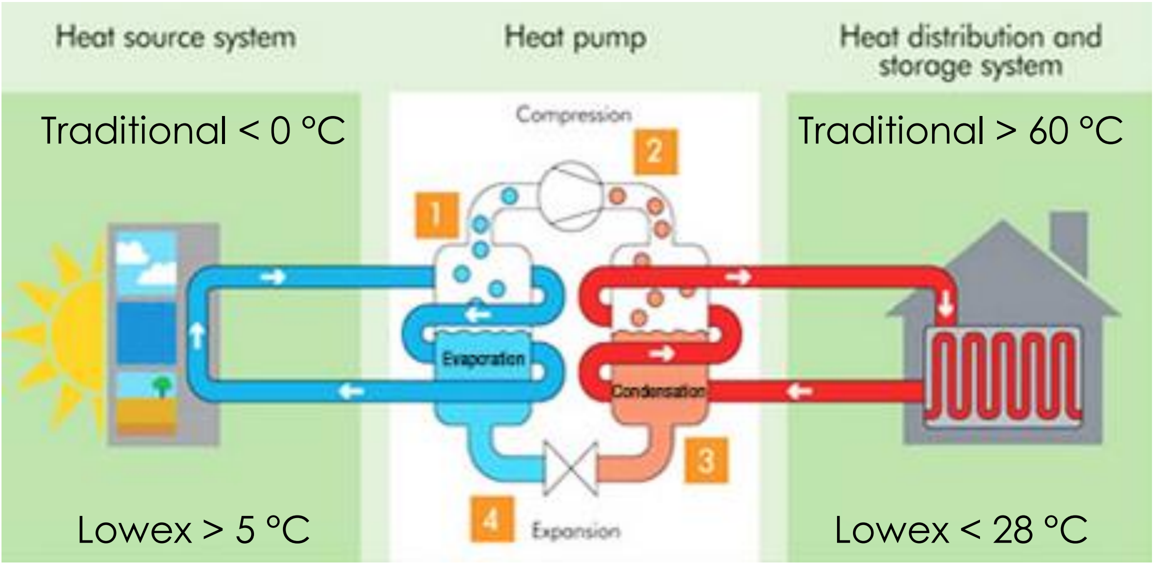
Application – LowEx Systems

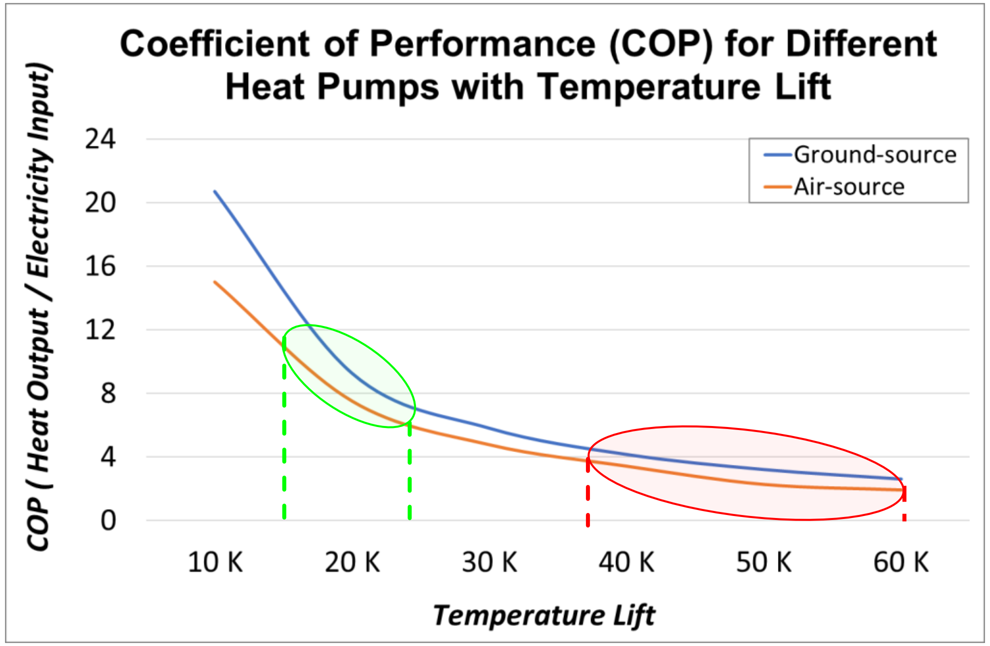
- Low-temperature heating; Small ΔT over the heat pump
  - ✓ Mean borehole exit fluid temperature of over 5 ℃ for heating
  - ✓ Maximum supply temperature of 28 ℃ to the building

- High-temperature direct ground cooling; Without compressors
  - ✓ Maximum borehole exit fluid temperature of 15 ℃ for cooling

Application – LowEx Systems

- Novel heat pumps
- Low-temperature lift between source and supply temperature
- Performance improvements





Application – LowEx Systems

Lia Kindergarten, Oslo

Lindeberg Sykehjem, Oslo

Gullhaug Torg, Oslo

Powerhouse Telemark, Porsgrunn

House Zero, Cambridge

Case 4 – Gullhaug Torg

- Built in Nydalen, Oslo
- Mixed used with shops, offices, apartments
- Floor area: 11,200 m^2 (18 floors)
- 25 boreholes
- Irregular configuration, min 5 m spacing
- Each 300 m deep

Picture: *Skanska (2021)*

Case 4 – Gullhaug Torg

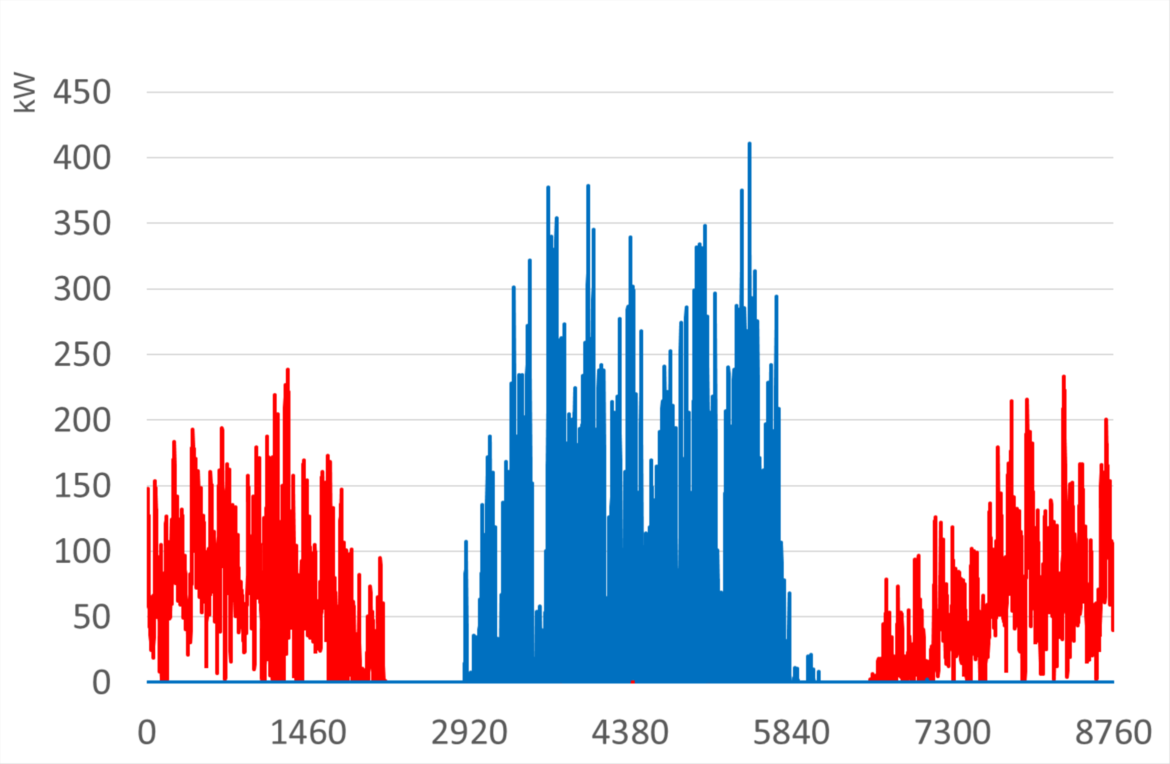
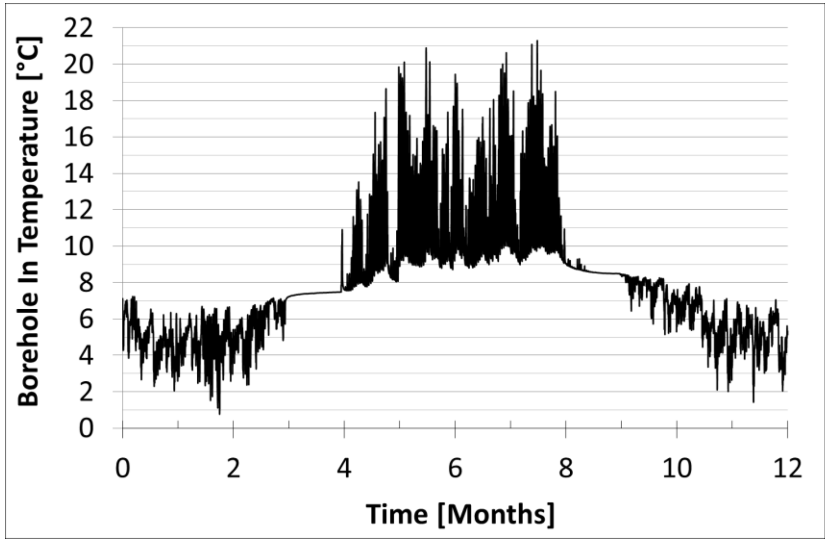
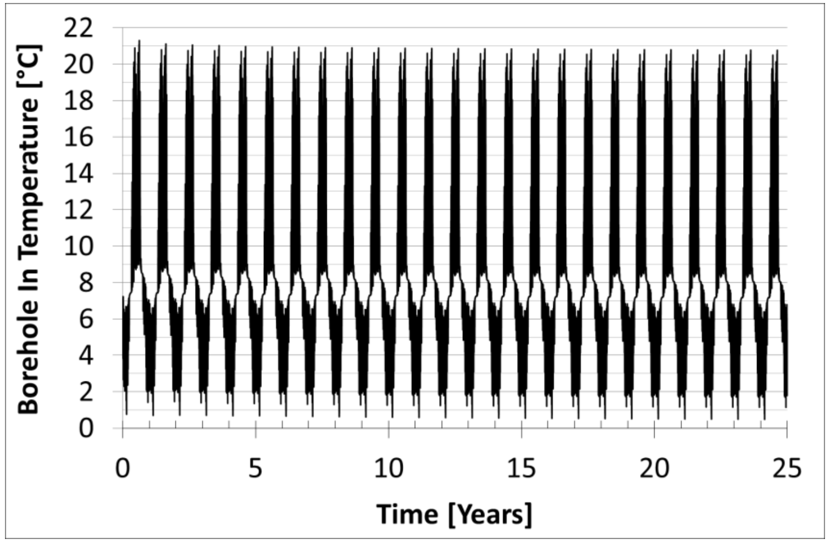
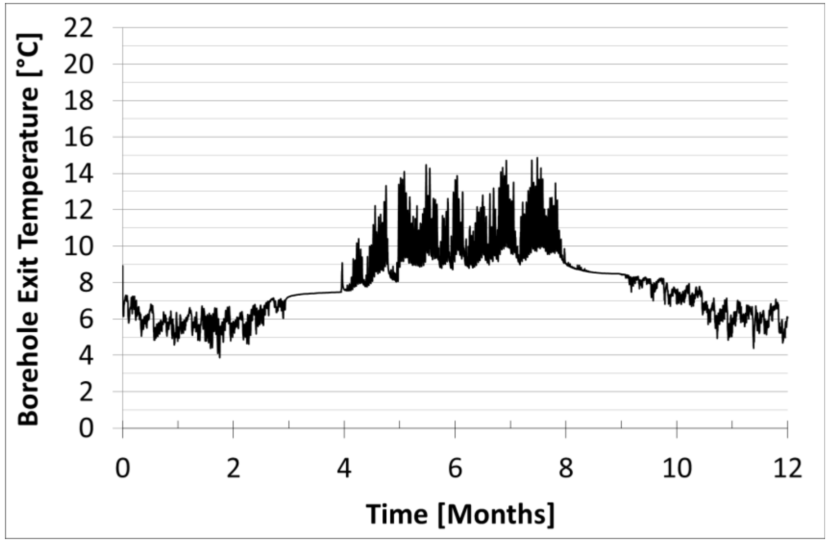


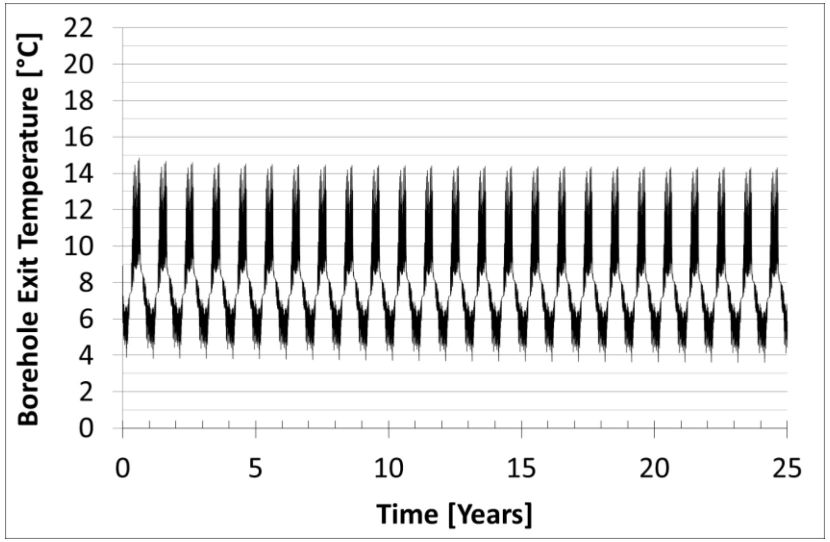
Table: Summary of building heating and cooling demands				
Power / Energy	Offices	Residential	Restaurant	Peak / Total
Heating Power (kW)	160	143	25	238
Cooling Power (kW)	171	127	120	411
Heating Energy (MWh)	115	144	16	275
Cooling Energy (MWh)	87	72	37	195

Case 4 – Gullhaug Torg









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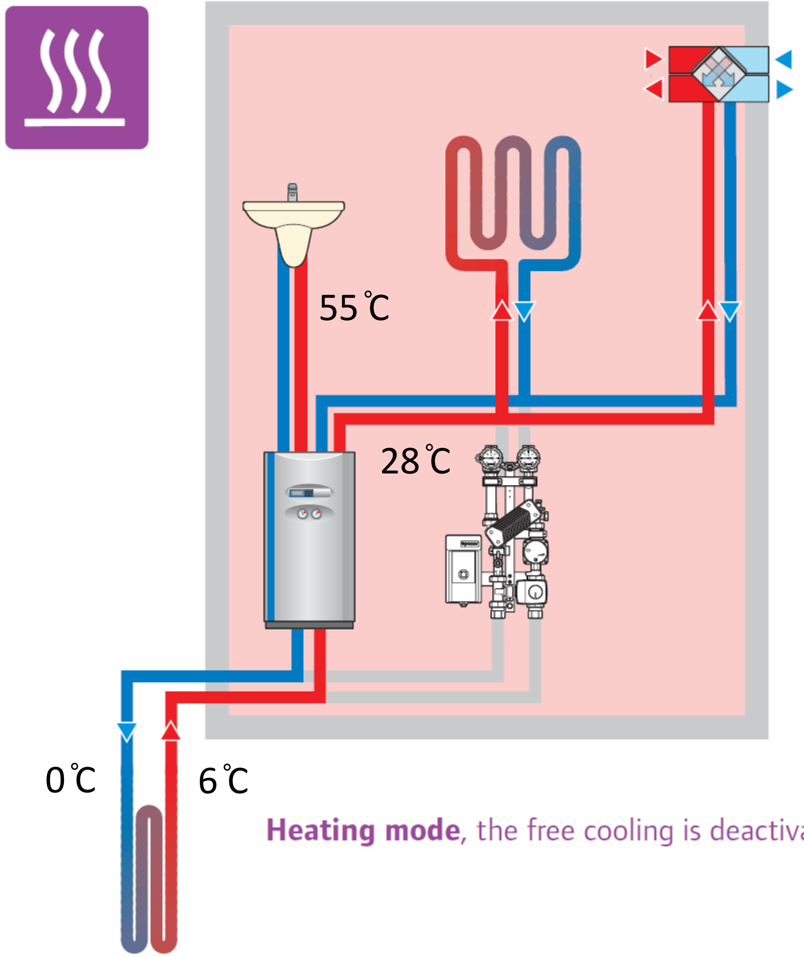
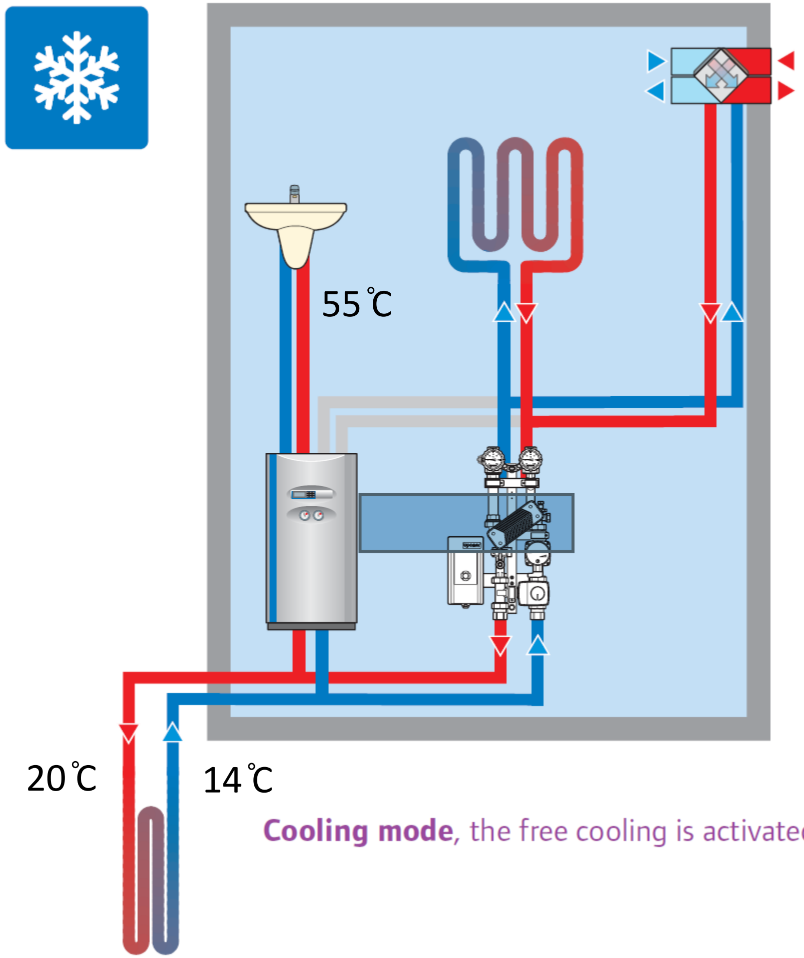


Heating mode, the free cooling is deactivated



Cooling mode, the free cooling is activated

Fig: www.uponor.se

Case 4 – Gullhaug Torg

Performance Evaluation	Value
Seasonal Performance Factor – Heat Pump (including circulation)	8
Seasonal Performance Factor – Free Cooling	60

Summary

- Positive experience of BTES in bivalent systems
- Unflattering experiences with HT BTES applications
- Good examples of BTES in LT applications
- BTES in LowEx applications under development

End of Presentation