

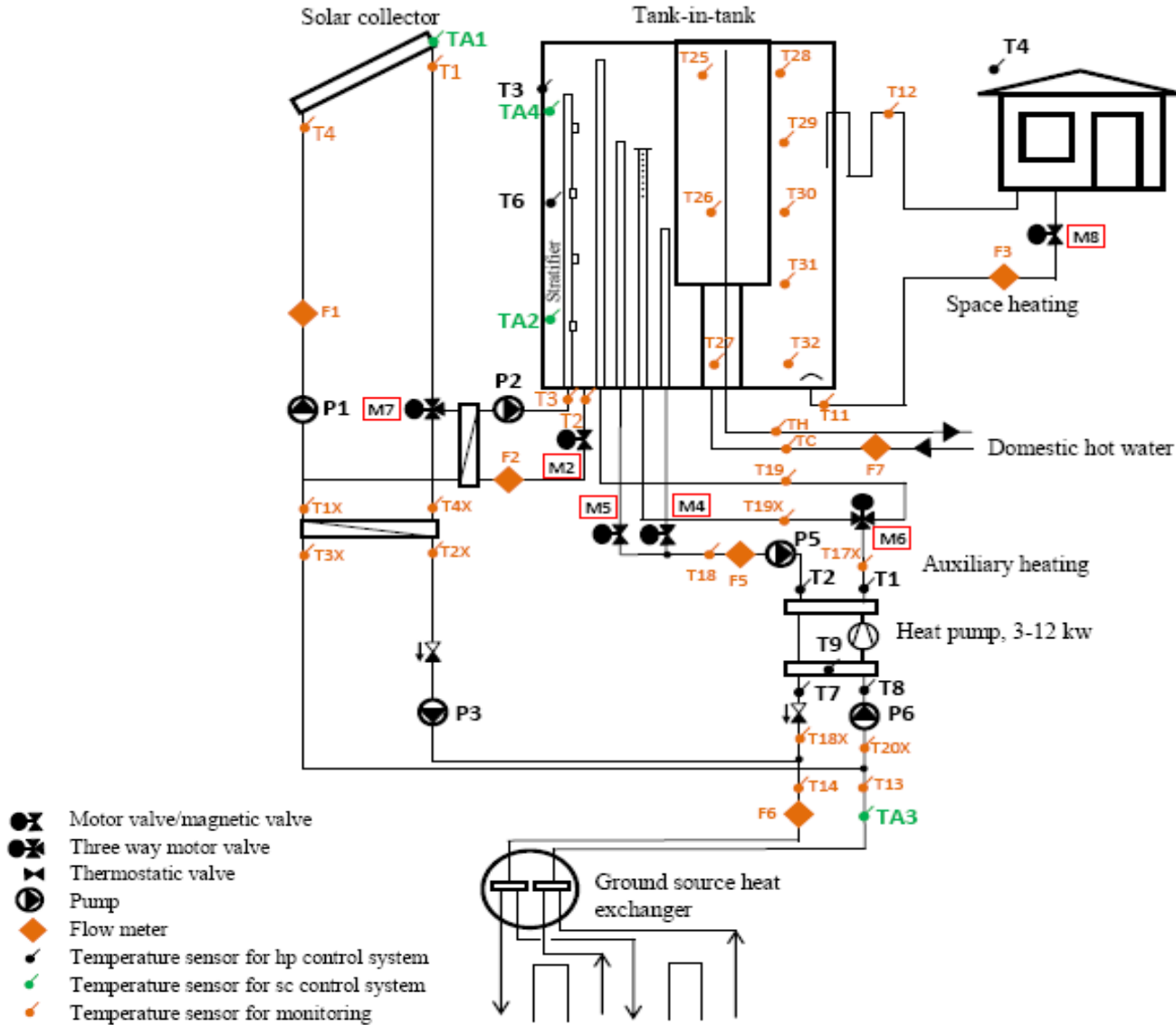
Experimental investigations on a solar-assisted ground source heat pump system with horizontally buried tubes

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The system layout



Component	Description
Solar collector	9.6 m ² , Evacuated tubular collectors, type Thermomax HP 450, Kingspan
The combi-storage (Tank-in-tank)	Total volume 0.725 m ³ , inner domestic water tank 0.175 m ³ , 5 ports
Plate heat exchangers	Heat transfer area 0.5 m ² , 9 kW capacity
Heat pump	HGX 12P/110-4s, heating capacity 3-12 kW, R134a
Circulation pump	P1: NMT PLUS 25/80-180, IMPPUMPS
	P2: UPS 25-40-180, Grundfos
	P3: UPS 25-60-180, Grundfos
	P5: Alfa 125-60-180, Grundfos
	P6: Magna 25-60-180, Grundfos
Horizontal ground heat exchanger	Total length 240 m; Cover area 8.5 m x 30 m; HDPE pipe outside diameter/wall thickness 40 mm/2.5 mm
Controller	LMC 320 for the auxiliary loop; UVR63 for the solar collector loop

The solar collectors, hot water tank and heat pump

Solar collectors

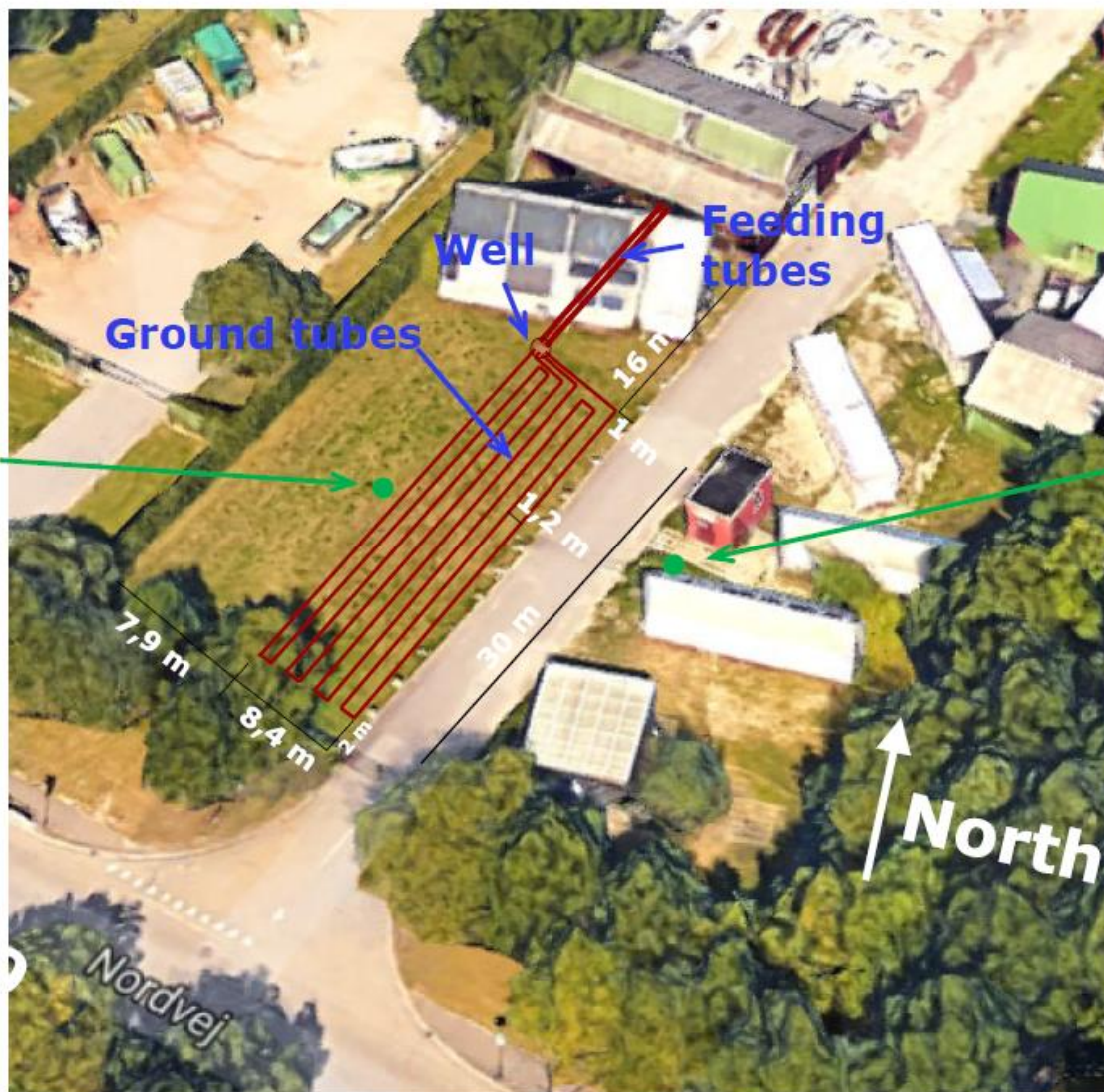


Hot water tank



Heat pump

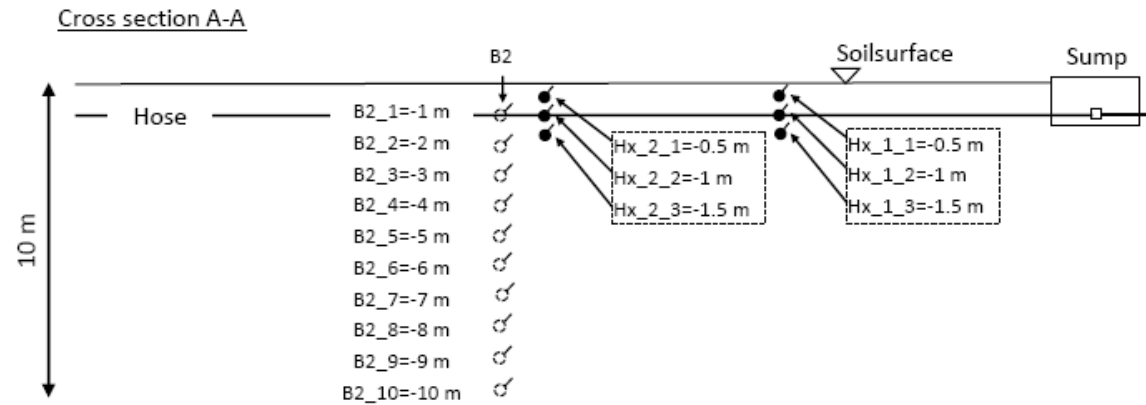
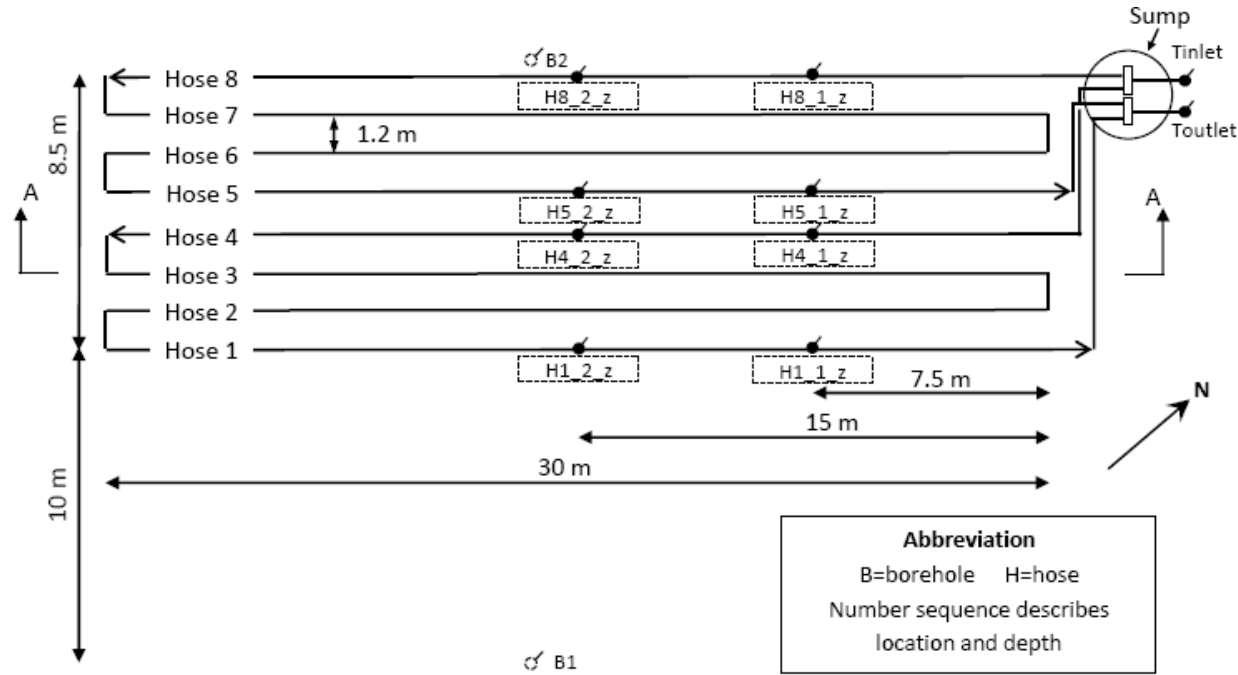
The horizontal ground tubes



B2 : 10 m borehole with temperature sensors every meter

B1 : 10 m borehole with temperature sensors every meter

Placement of the horizontal ground tubes

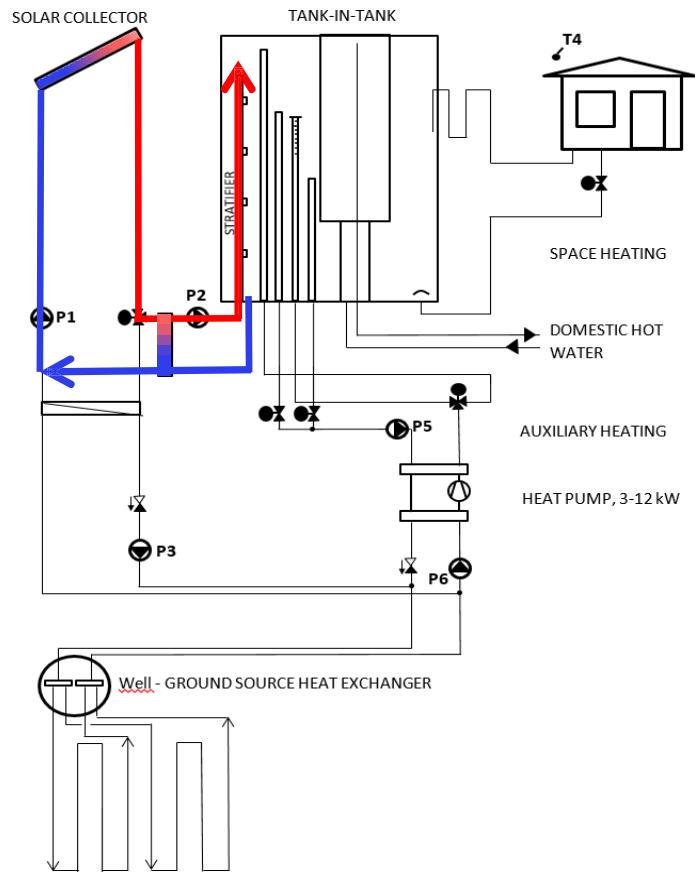


Construction of the ground source heat storage using horizontal tubes

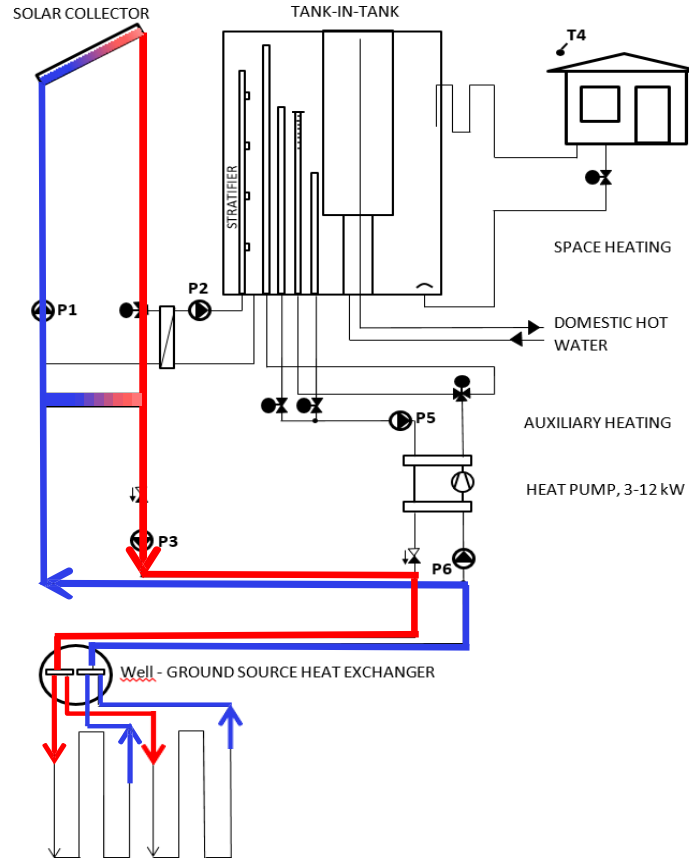


Operation modes - charge

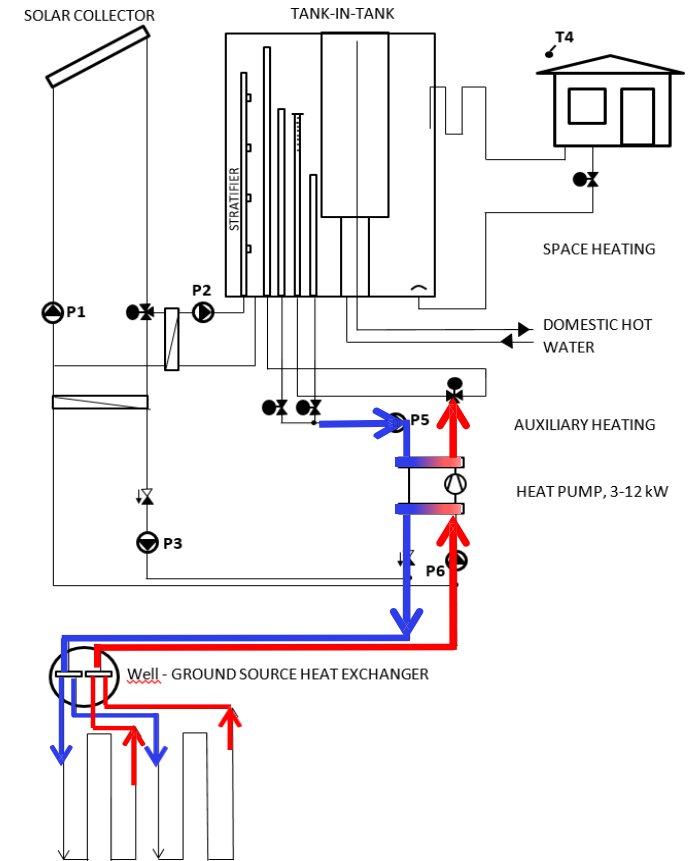
Solar to tank



Solar to ground

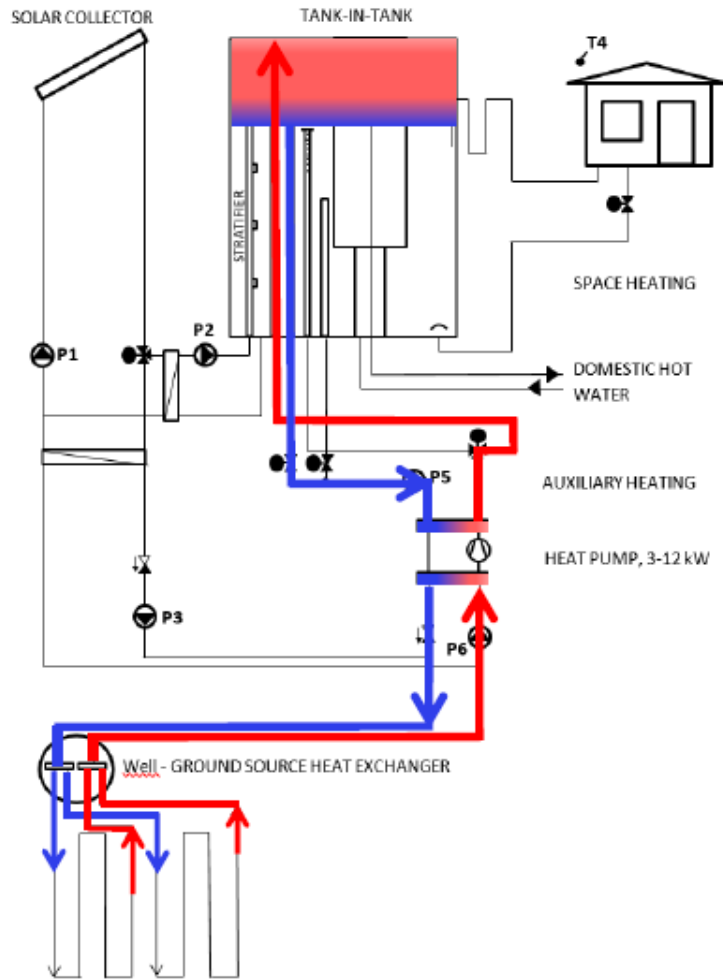


Heat pump to tank

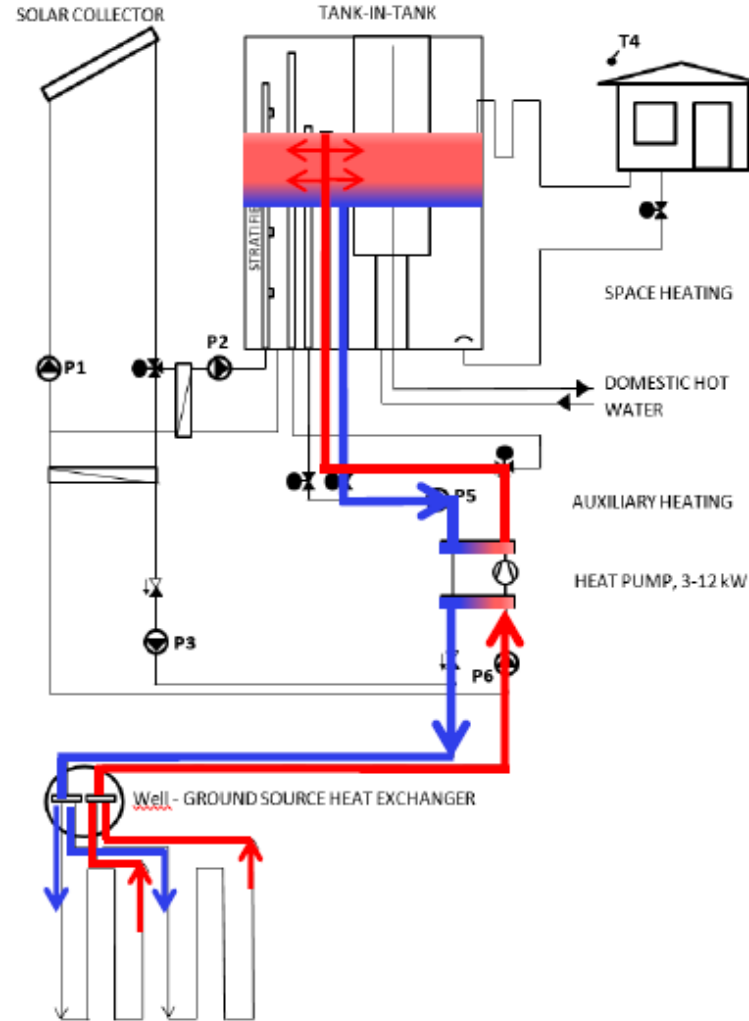


Operation modes - charge

Heat pump to domestic hot water (DHW)

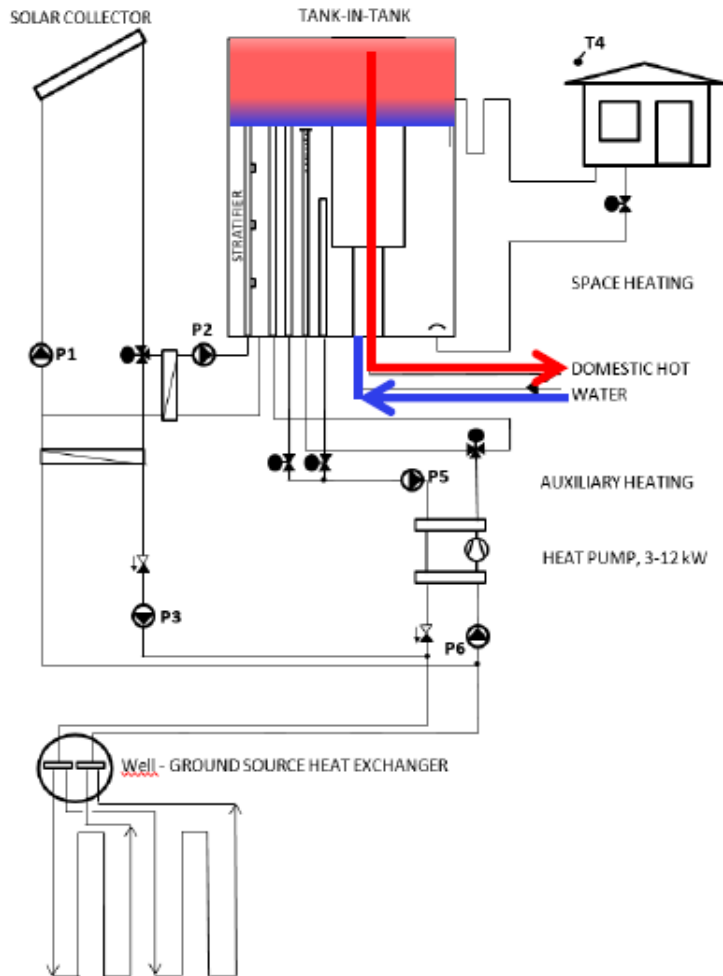


Heat pump to space heating (SH)

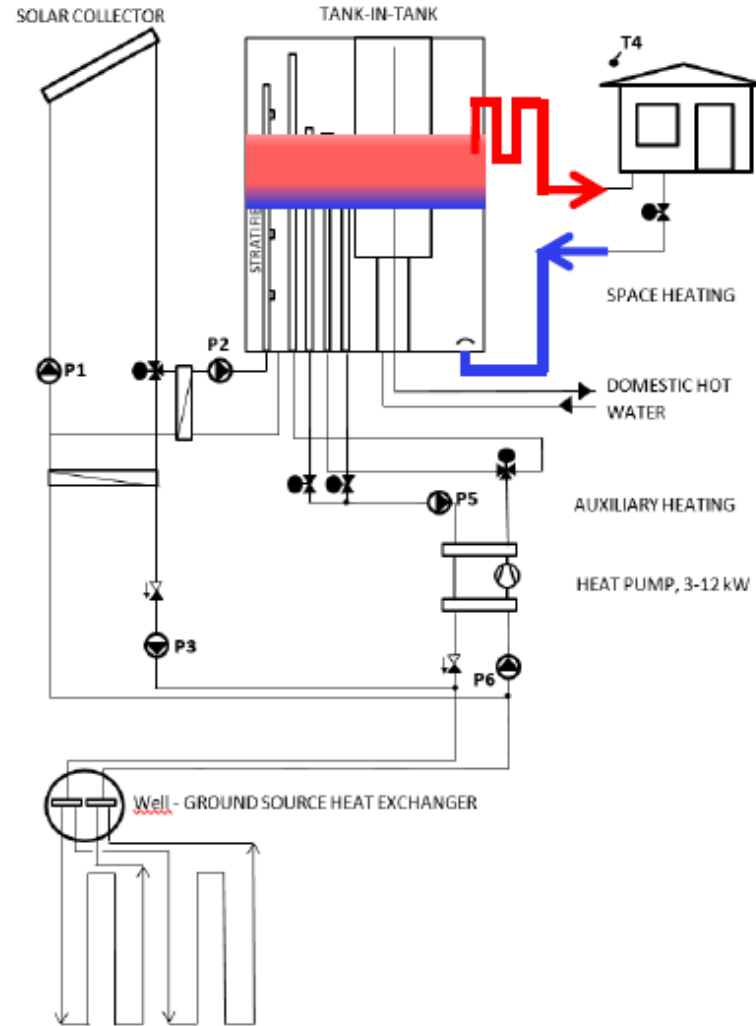


Operation modes - discharge

Domestic hot water draw off



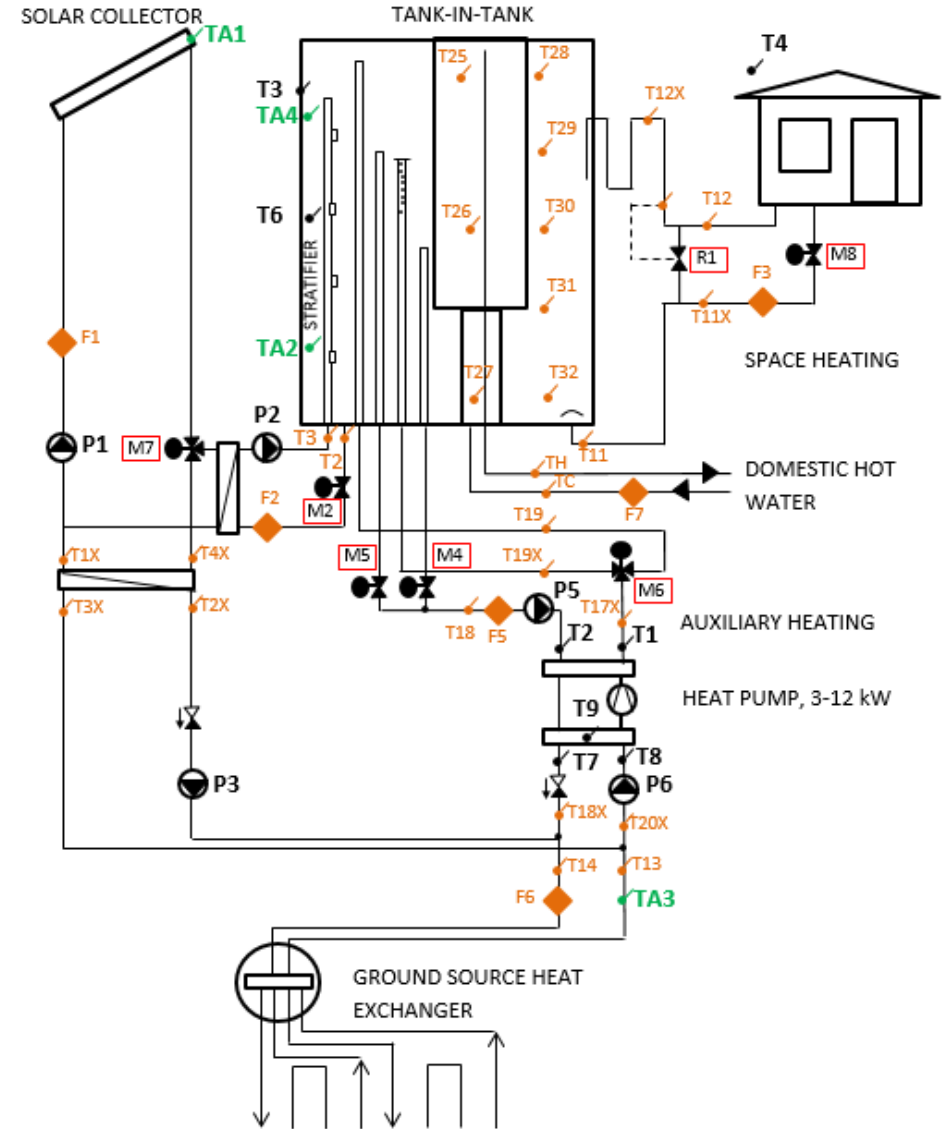
Spac heating draw off



Control strategy – solar collector loop

Control system from Technische Alternative, UVR 63

- Solar to tank (1. priority)
- Flow in collector loops: 3 l/min (0.28 l/min per m² solar collector area)
- Start: $TA1 > TA2 + 8 \text{ K}$ and $TA1 > 20 \text{ °C}$ and $TA2 < 70 \text{ °C}$
- Stop: $TA1 < TA2 + 2 \text{ K}$
- Stop if:
 - $TA2 > 75 \text{ °C}$, restart prohibited until $TA2 < 70 \text{ °C}$
 - $TA1 > 130 \text{ °C}$, restart prohibited until $TA1 < 110 \text{ °C}$
- Solar to ground (2. priority)
- Flow in collector loops: 3 l/min (0.28 l/min per m² solar collector area)
- Flow in ground loop: 20 l/min
- Start: $TA1 > TA3 + 8 \text{ K}$ and $TA1 > 20 \text{ °C}$ and $TA3 < 30 \text{ °C}$
- Stop: $TA1 < TA3 + 4 \text{ K}$
- Stop if:
 - $TA1 > 130 \text{ °C}$, restart prohibited until $TA1 < 110 \text{ °C}$
- Operation time: 20 min
- Stop time: 5 min



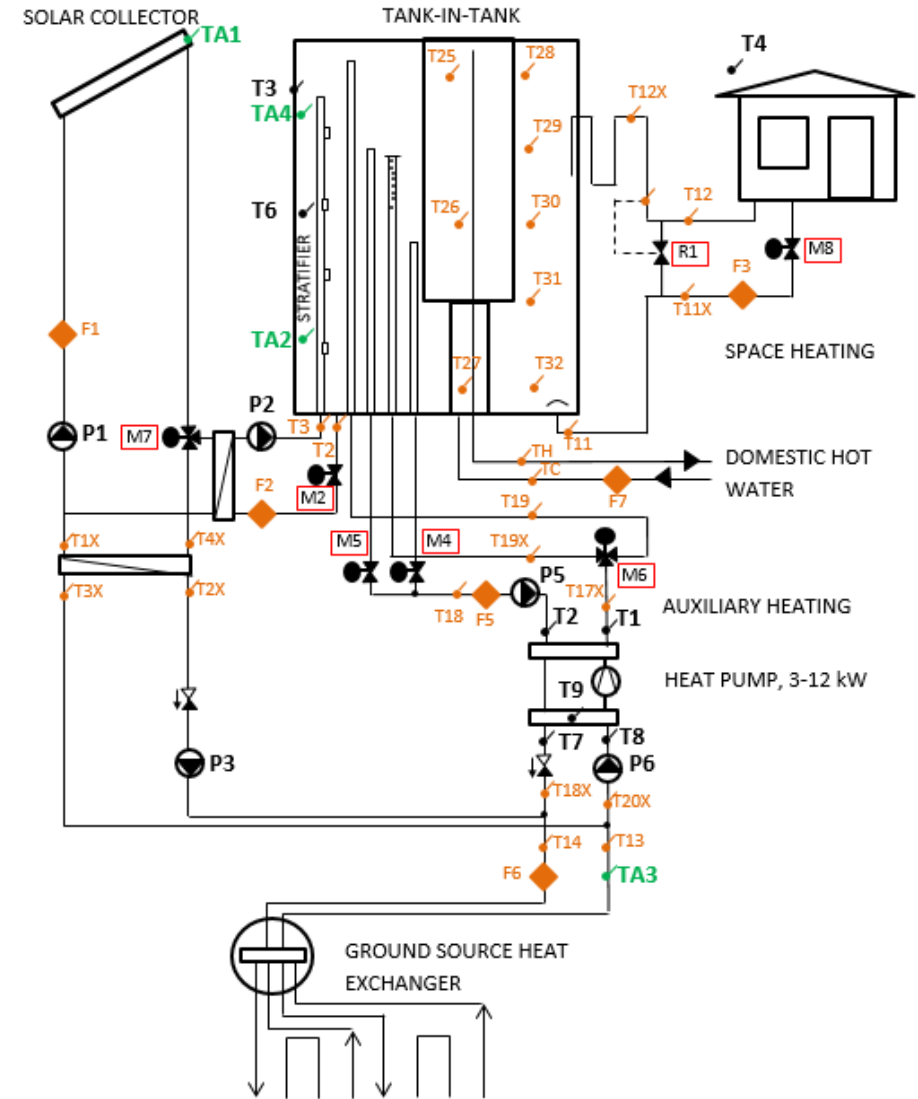
Control strategy – heat pump loop

Control system from Lodam, LMC 320

- Heat pump to domestic hot water (1. priority)
- Flow in HP-tank loop: 15 l/min
- Flow in HP-ground loop: 20 l/min
- Start: $T3 < 52\text{ °C} - 4\text{ K}$
- Stop: $T3 > 52\text{ °C}$

- Heat pump to space heating (2. priority)
- Flow in HP-tank loop: 15 l/min
- Flow in HP-ground loop: 20 l/min
- Start: $T6 < 28.5\text{ °C} - 4\text{ K}$
- Stop: $T6 > 28.5\text{ °C}$

**Heat pump is controlled by frequency inverter (30-70 Hz).
Power is regulated based on tank temperature**

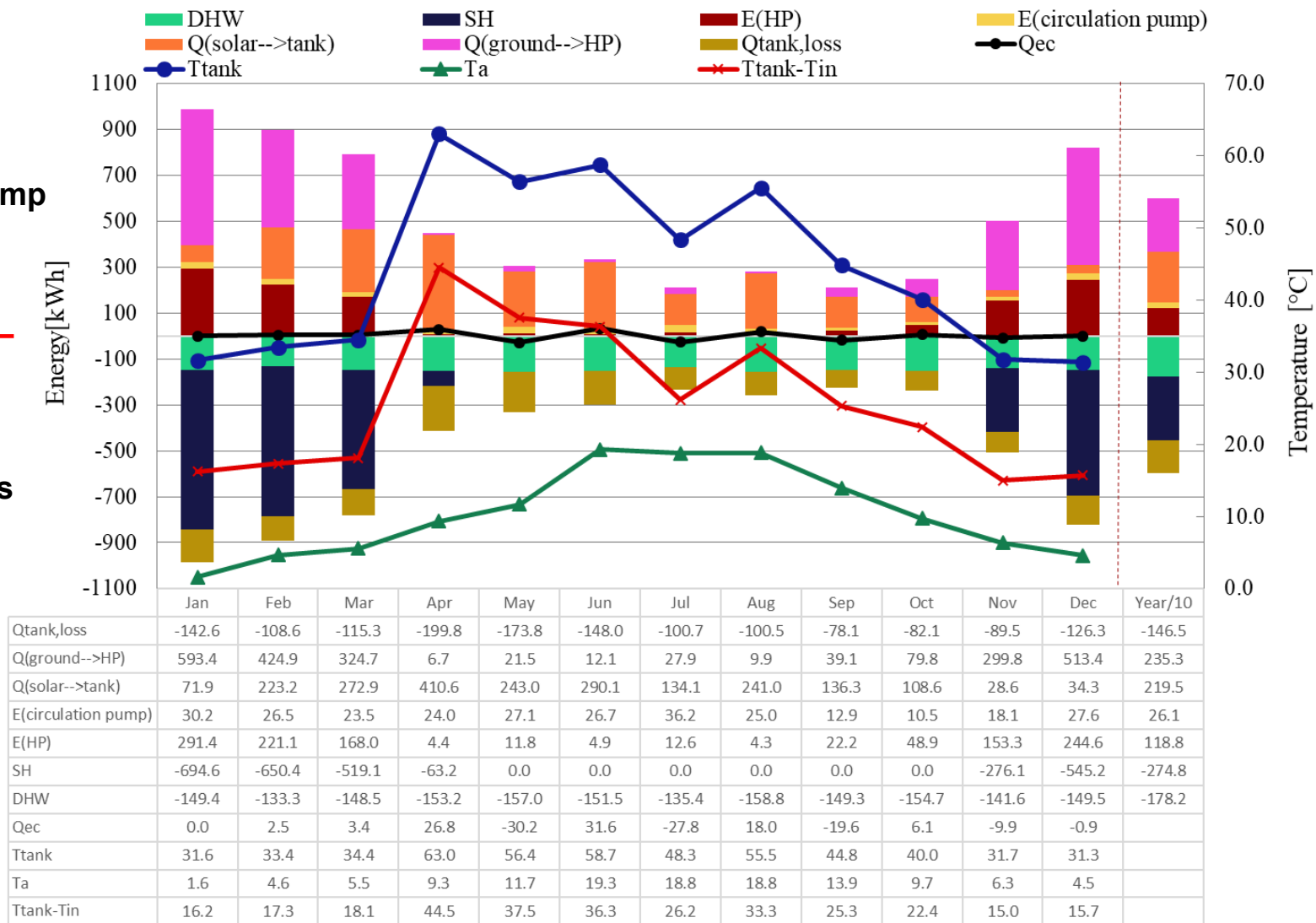


Monthly heat demand and energy balance in 2019

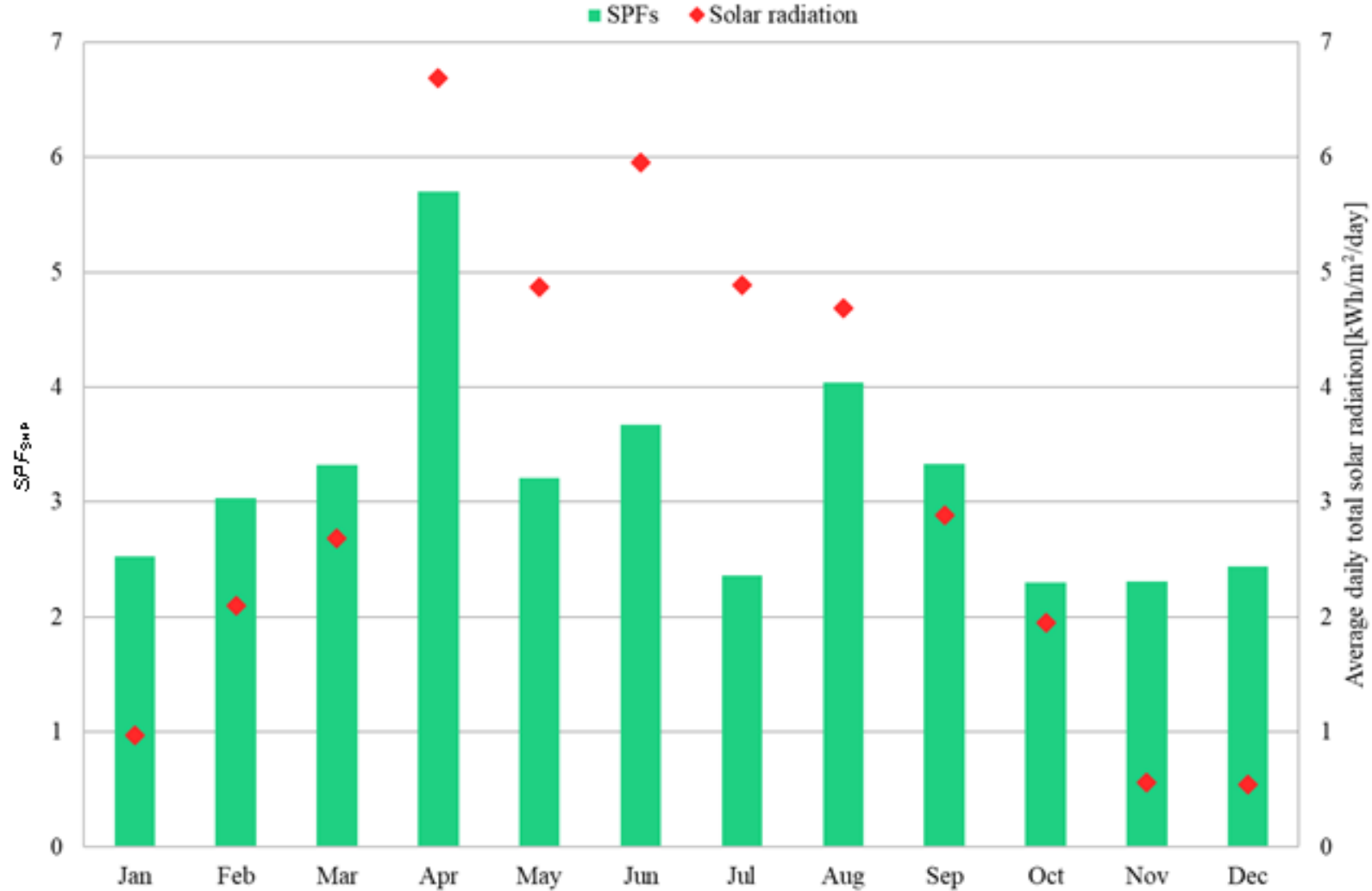
Production:
Solar/ground/Eheat pump



Consumption:
DHW/SH/tank heat loss



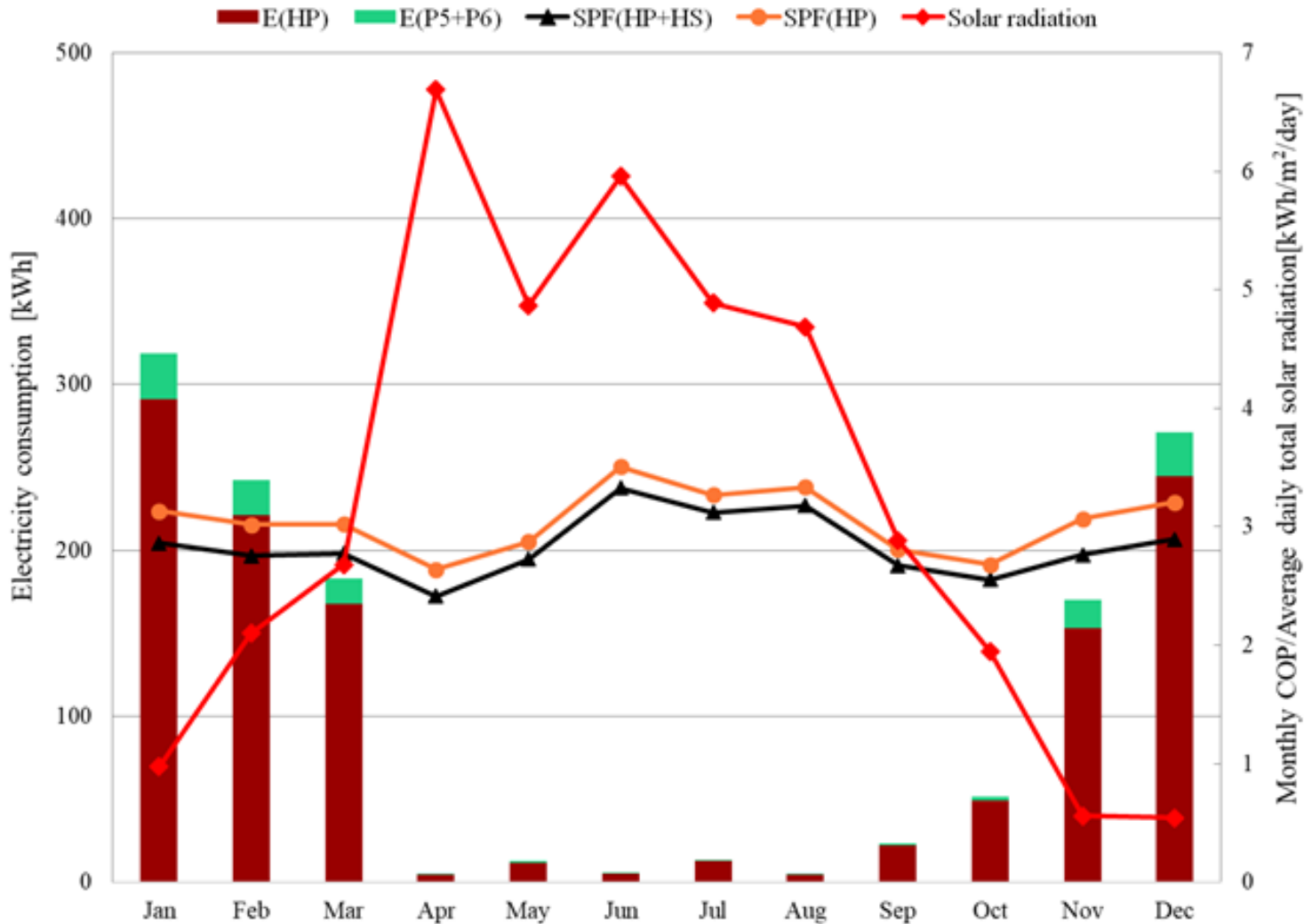
System performance factor and the solar radiation



System performance factor

$$SPF_{SHP} = \frac{\int (\dot{Q}_{SH} + \dot{Q}_{DHW}) dt}{\int (\sum \dot{E}) dt}$$

El. consumption & monthly performance of the heat pump



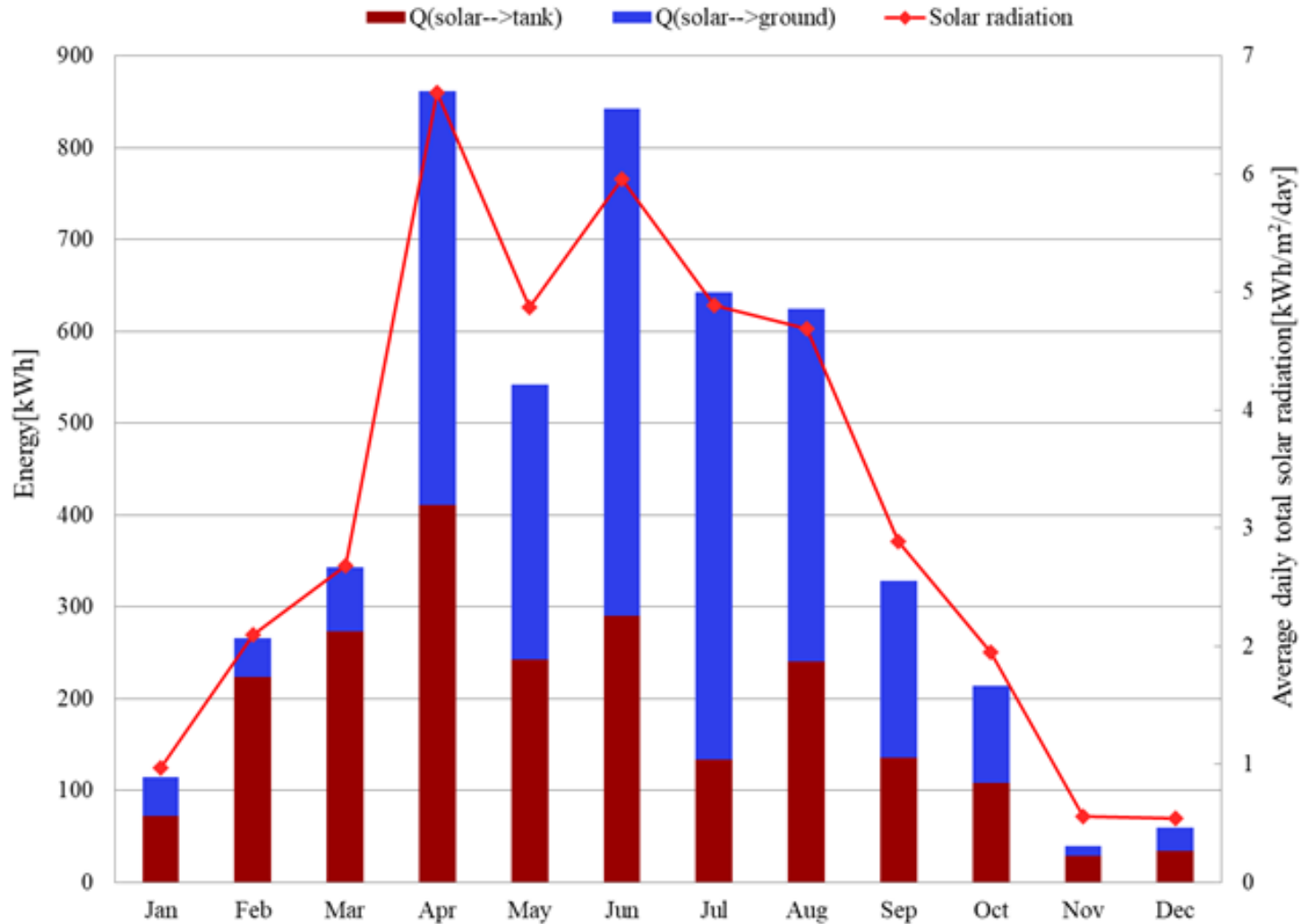
performance of the heat pump system

$$SPF_{HP+HS} = \frac{\int (\dot{Q}_{HP}) dt}{\int (\dot{E}_{HP} + \dot{E}_{P5} + \dot{E}_{P6}) dt}$$

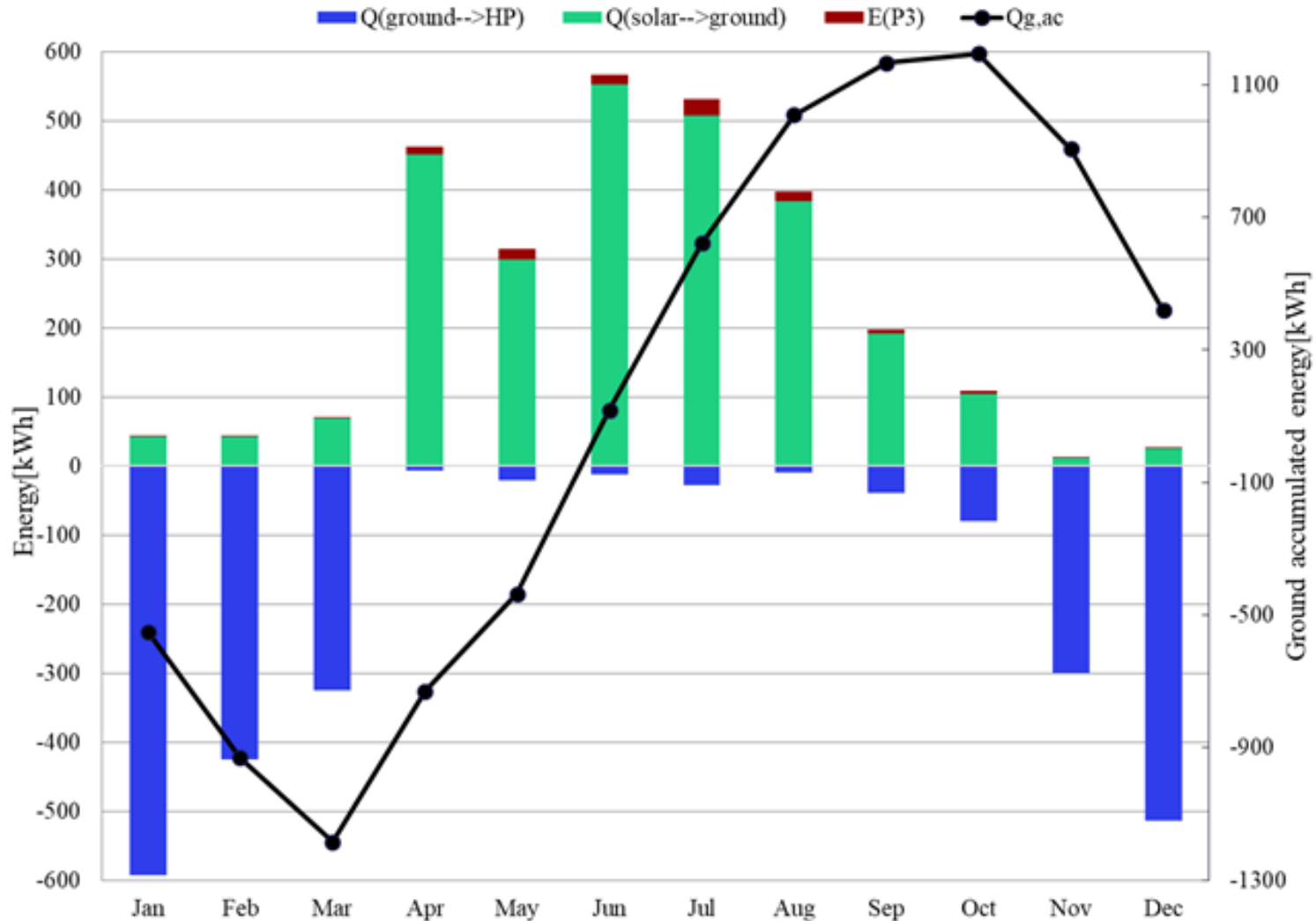
performance of the heat pump

$$SPF_{HP} = \frac{\int (\dot{Q}_{HP}) dt}{\int (\dot{E}_{HP}) dt}$$

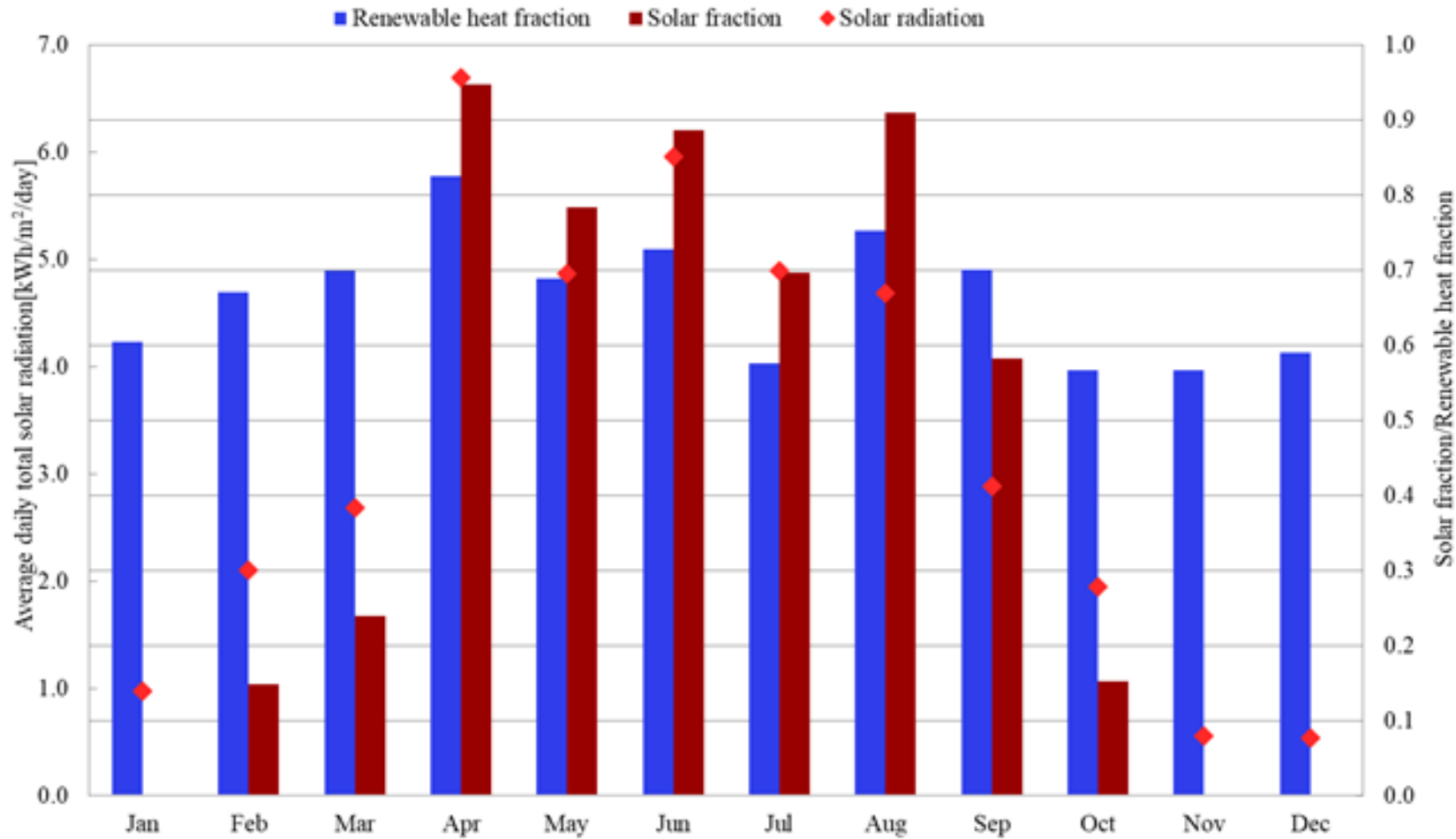
Solar radiation and monthly solar heat in 2019



The monthly energy flow of ground (charging/discharging)



System performance factor and the solar radiation



The solar fraction

$$f_{\text{sol}} = 1 - \frac{\int (\dot{Q}_{\text{HP}}) dt}{\int (\dot{Q}_{\text{DHW}} + \dot{Q}_{\text{SH}}) dt}$$

the renewable heat fraction

$$f_{\text{re}} = 1 - \frac{\int (\sum \dot{E}) dt}{\int (\dot{Q}_{\text{SH}} + \dot{Q}_{\text{DHW}}) dt} = 1 - \frac{1}{SPF_{\text{SHP}}}$$

Conclusions

- Annual system performance factor: 2.8; peak 5.7 in April.
- Solar covered 37% of storage heat; heat pump used 84% of electricity.
- More solar heat went into ground charging than direct use.
- Ground storage stabilized performance and boosted winter efficiency.
- Renewable heat fraction stayed stable, averaging 65%.

References:

Zhang, C., Nielsen, E., Fan, J., Furbo, S., & Li, Q. (2021). Experimental investigation on a combined solar and ground source heat pump system for a single-family house: Energy flow analysis and performance assessment. *Energy and Buildings*, 241, Article 110958.

<https://doi.org/10.1016/j.enbuild.2021.110958>

Zhang, C., Nielsen, E., Fan, J., & Furbo, S. (2022). Thermal behavior of a combi-storage in a solar-ground source heat pump system for a single-family house. *Energy and Buildings*, 259, Article 111902.

<https://doi.org/10.1016/j.enbuild.2022.111902>



Thank you

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