Experimental testing of solar photovoltaic/thermal collector as a heat pump source under outdoor laboratory conditions

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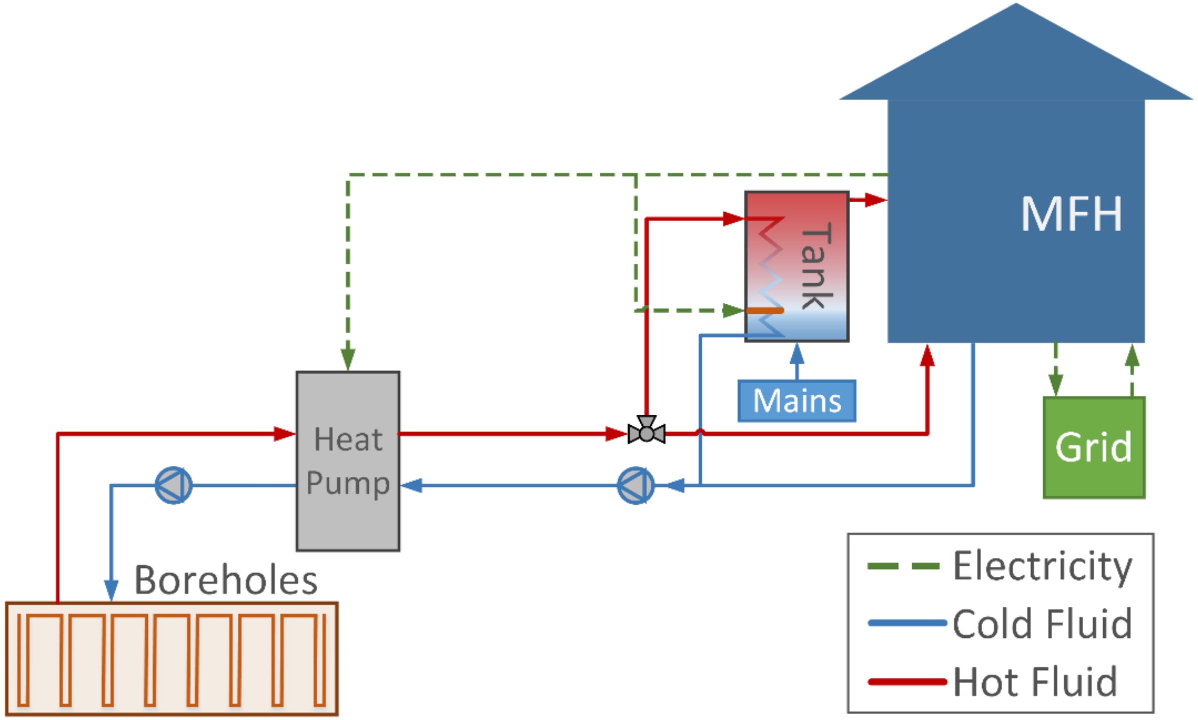
17th May 2023, Chicago, Illinois

Barriers to heat pump adoption

Heat pumps of all types have drawbacks for large property owners

- GSHP: lack of land and higher investment costs
- ASHP: noisy heat exchangers
- EAHP: lack of ventilation



Barriers to heat pump adoption

Heat pumps of all types have drawbacks for large property owners

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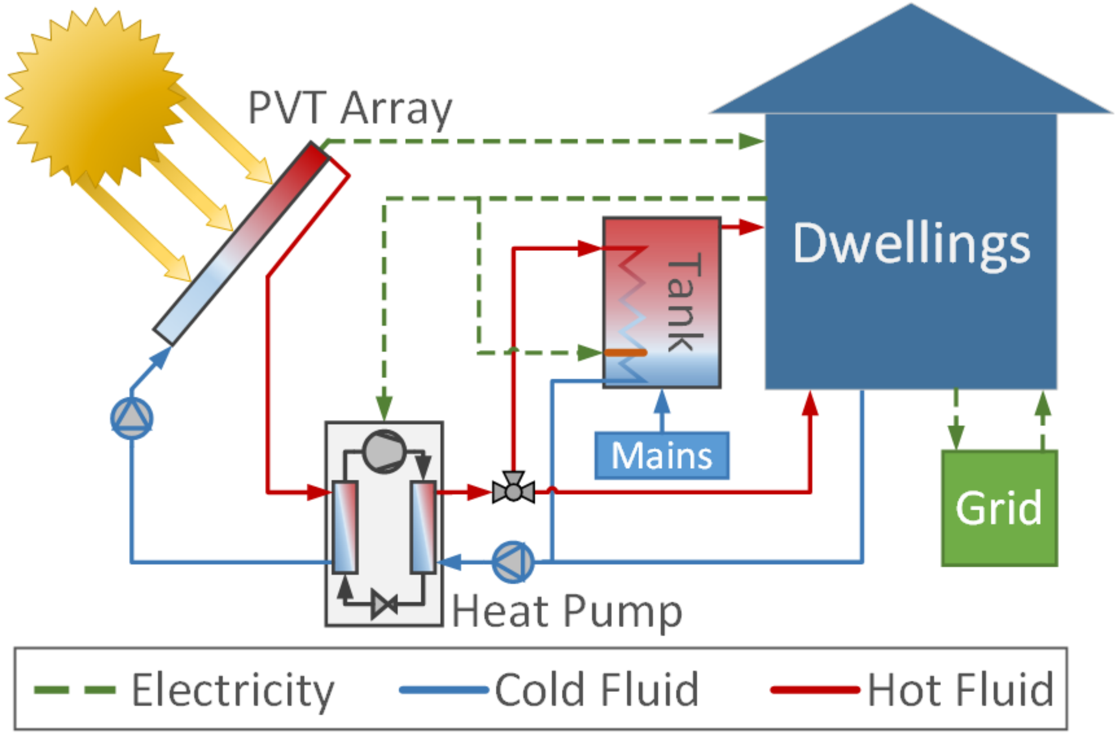
- ASHP: noisy heat exchangers
- EAHP: lack of ventilation

Combine it with solar PVT to reduce borehole length, spacing and drilling costs, improve SPF or replace HEX



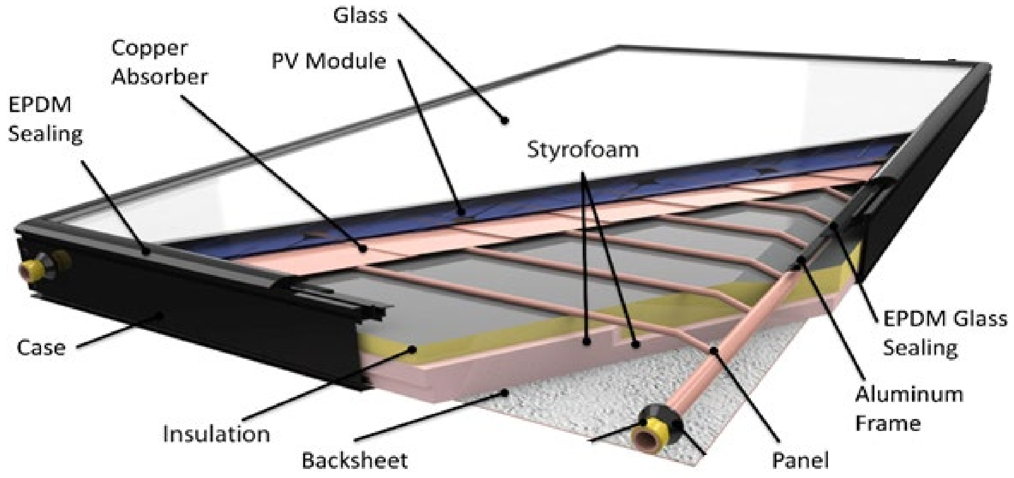
Source: *Sommerfeldt, N., Beltran, F., Madani, H., 2020. Solar PVT for heat pumps: Collector development, systems integration, and market potential, in: BuildSim-Nordic 2020 Conference Proceedings.*

What is PV/thermal?

- Hybrid panels capable of producing ***electricity and heat simultaneously*** from the same collector

➢ Fluid

- Water
- Air
- Refrigerant



Source: *https://www.solarchoice.net.au/blog/solimpeks-hybrid-pv-thermal-solar-panels-in-australia/*

➢ Glass cover

- Glazed → When maximizing ***thermal*** output
- Unglazed → When maximizing ***electrical*** output

➢ Insulation

- Insulated → **Higher operating temperatures** – avoid heat losses to ambient
- Uninsulated → **Lower operating temperatures** – enhance heat capture from air

Why PV/thermal (PVT) hybrid?

- Rapid growth and cost decline in PV
- PVT looks like PV, but with 3x or 4x energy production
- Cooled PV produces more electricity and increases life
- Potential cost reductions with HP applications

Objective

- Empirically characterize the performance of an unglazed and uninsulated PVT collector designed specifically for HP integration

- Find a range of U-values of the collector for different operating conditions that can be used for dynamic system simulations

- Calculate the required PVT array area needed to act as the sole source of a HP for a villa in Sweden

Methodology

- Tests performed at outdoor testing facility at KTH Royal Institute of Technology in Stockholm, between 4th and 20th of October 2022
- Simultaneous heat and electricity production
- Varying inlet temperatures, flow rates and weather conditions
  - Flow rates: 30 to 35, 40 to 45 and 50 to 55 $l/h.m^2$
  - Inlet temperatures: -10°C to 10°C
- Results used to determine thermal performance curves and U-value

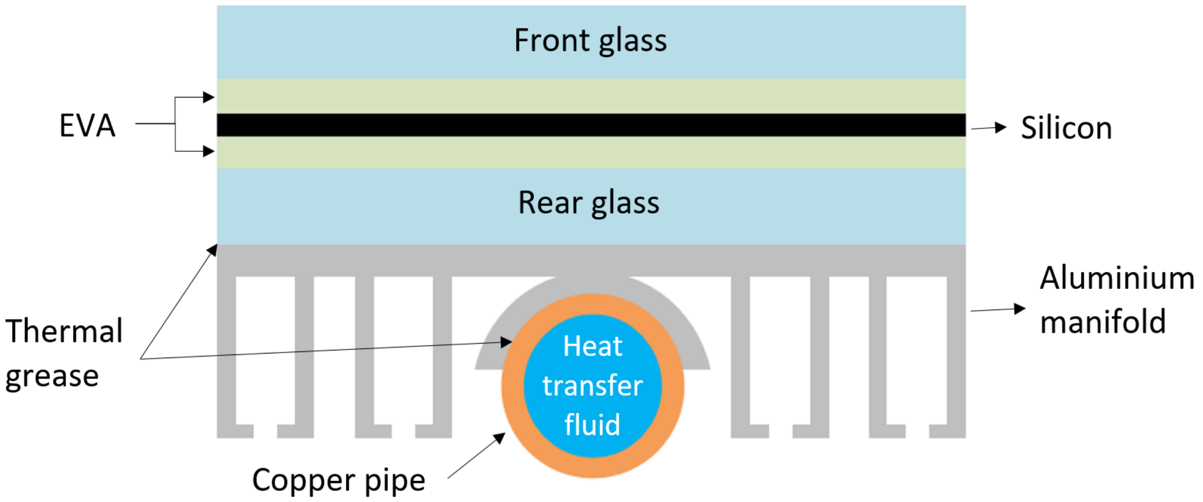
Testing facility

20 m² PVT collector array

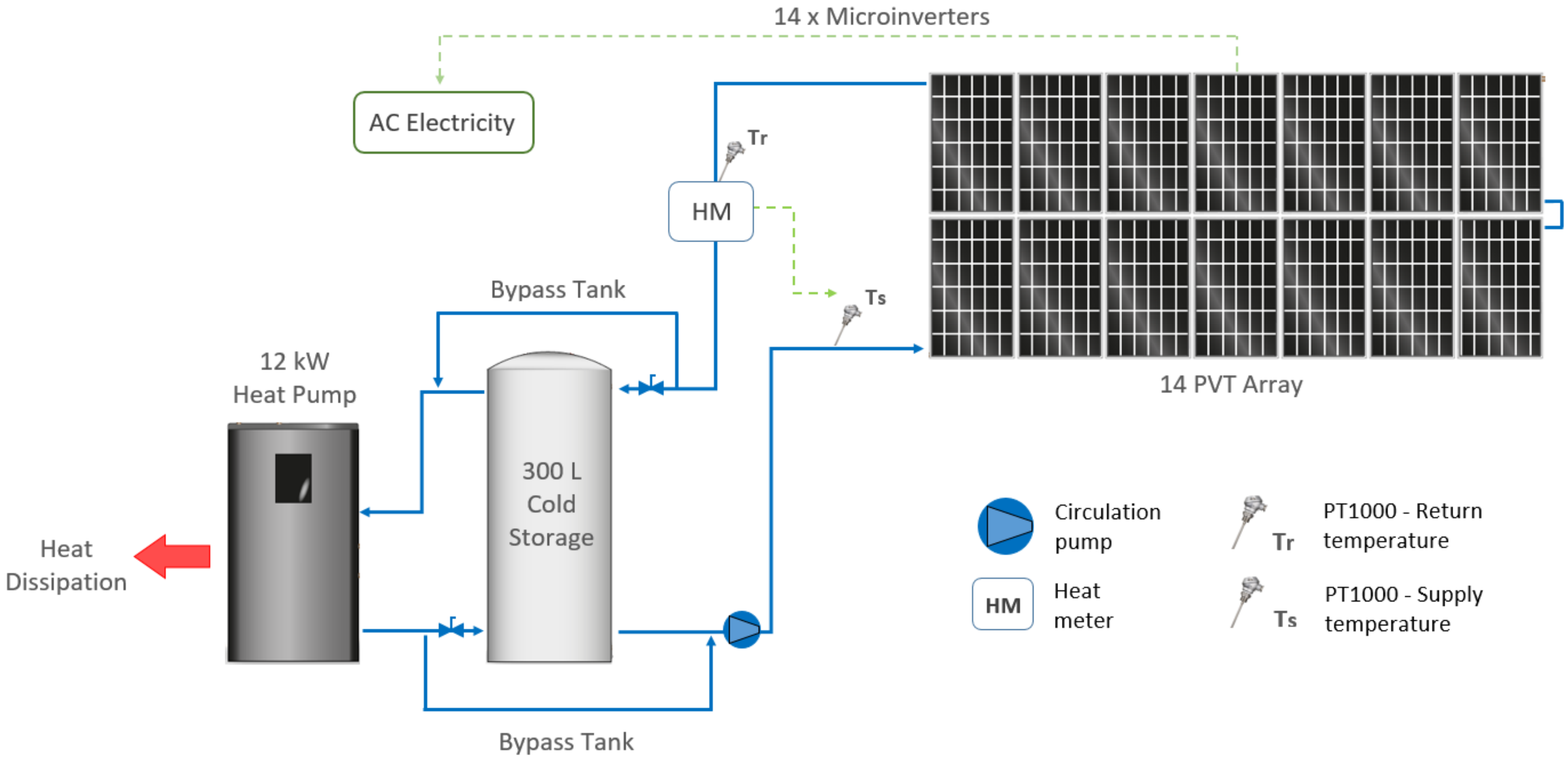
3-12 kW HP + 300 l cold tank

PVT collector

- Glass – glass 285W PV module
- 6 x (aluminum manifold + 12 mm copper pipe) in harp configuration
- Unglazed and uninsulated



Monitoring system

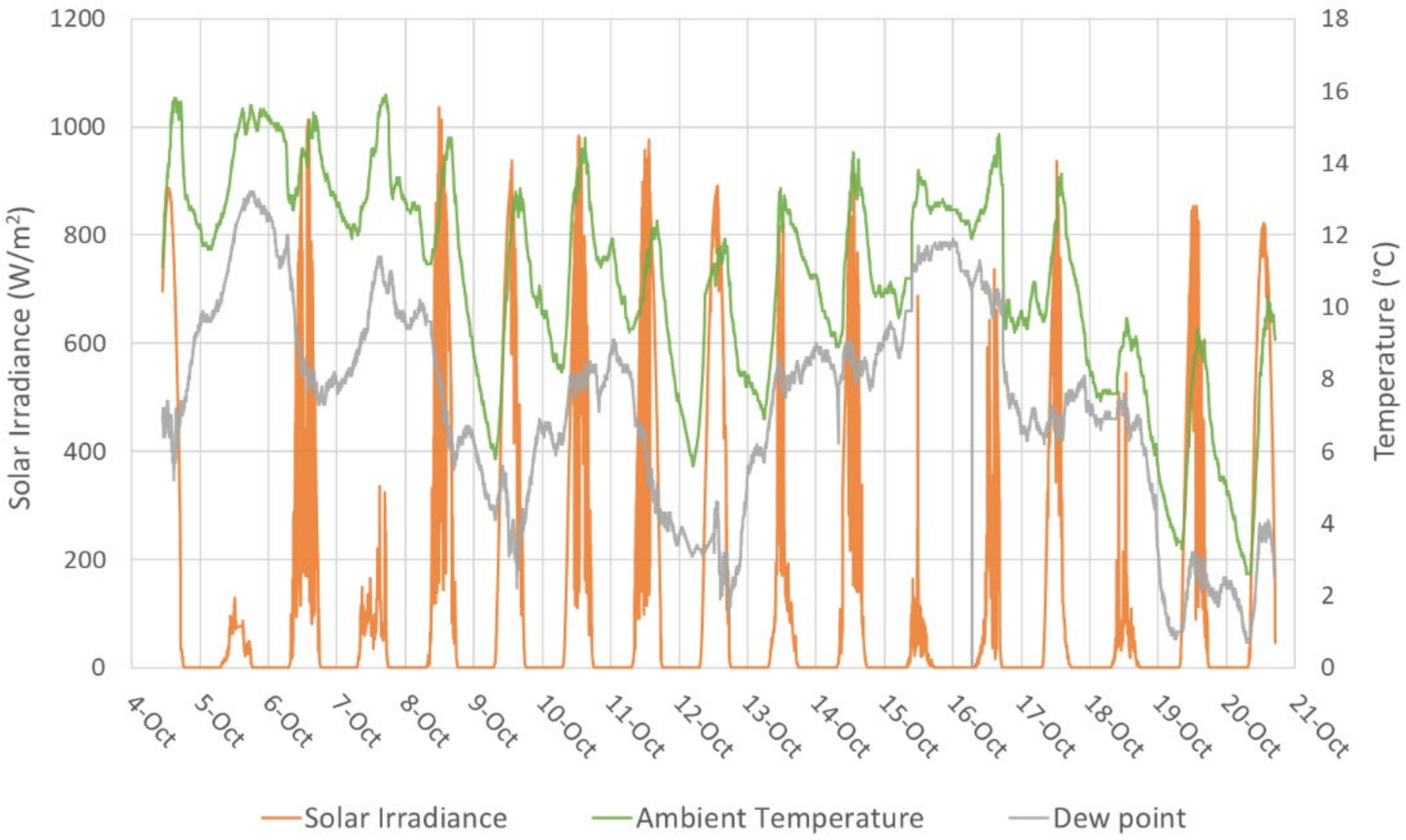


Results – Weather data

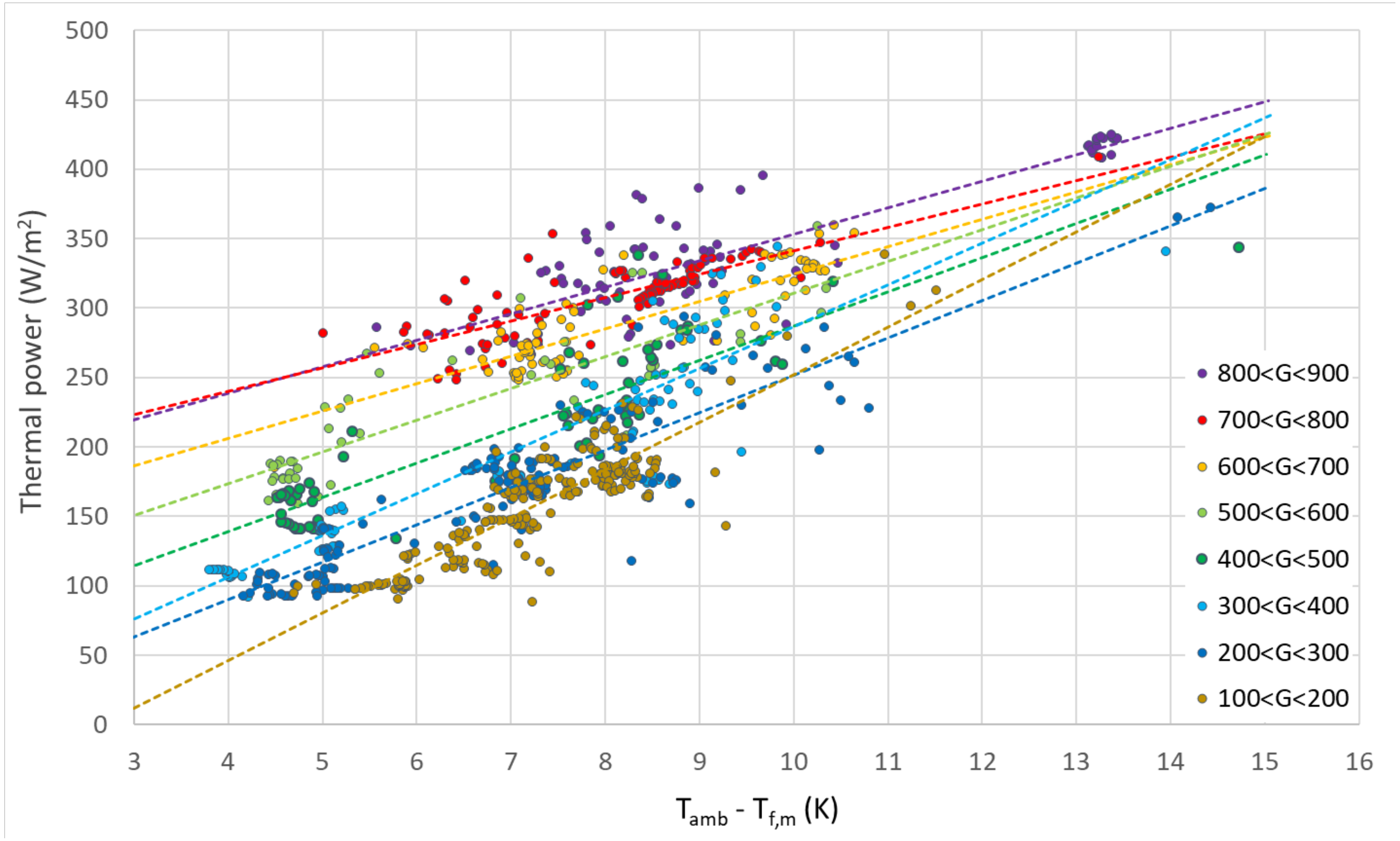
- Ambient temperature:
  2 to 16°C

- Dew point:
  0 to 13°C

- Solar irradiation:
  0 to 1000 W/m²
  0.4 to 5.1 kWh/m².day

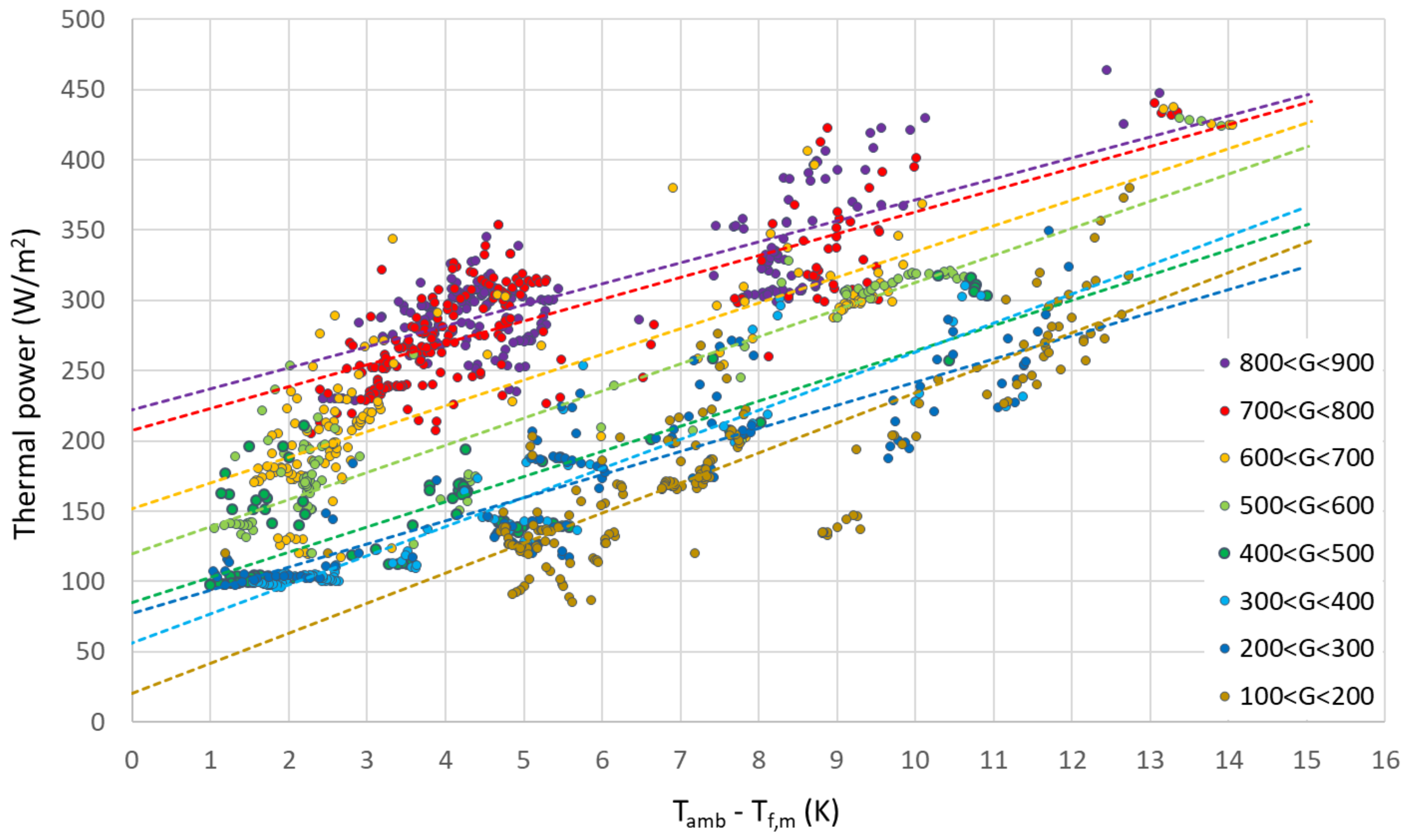


Results – Flow rate 30 to 35 l/h.m^2



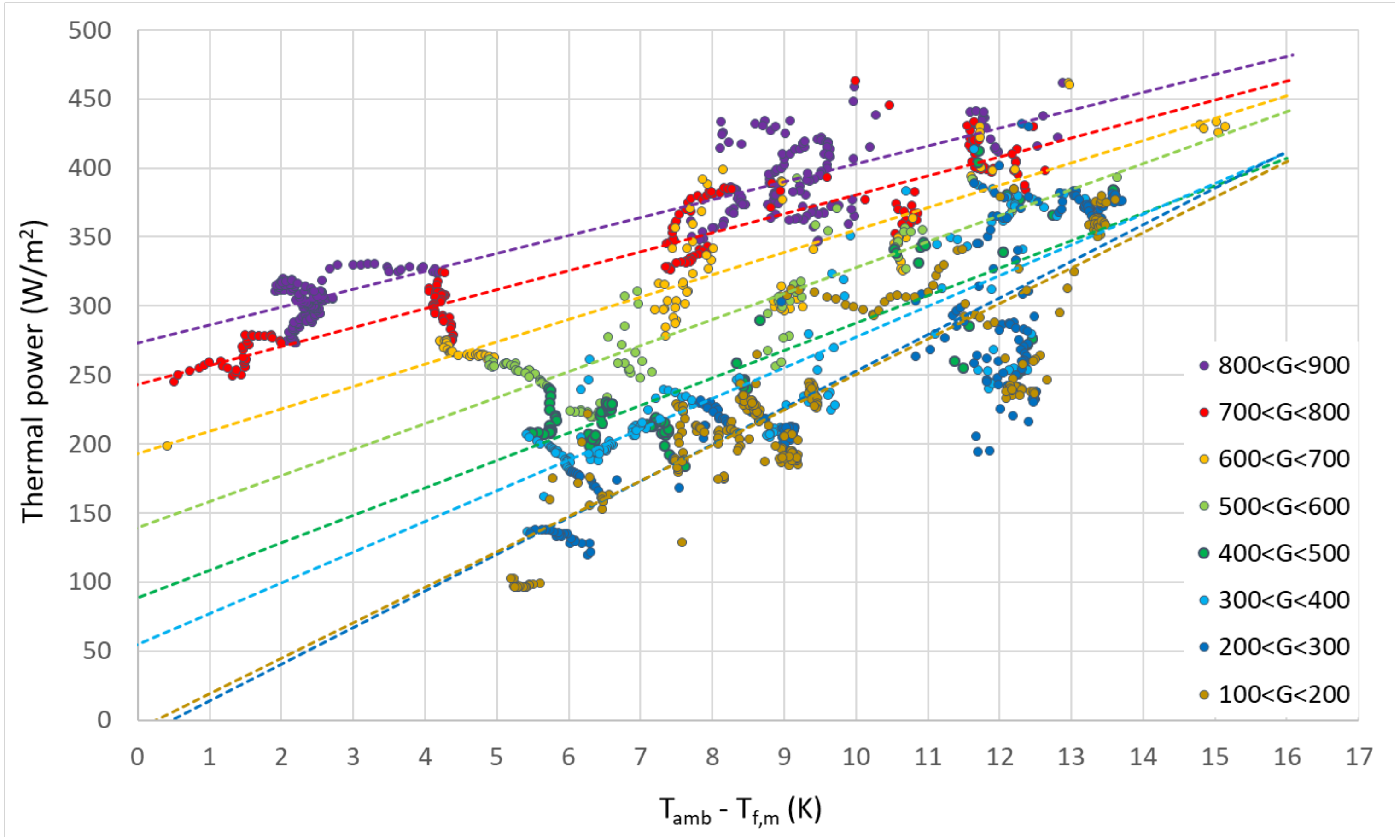
Solar Irradiance W/m^2	HEX U-value $Wm^{-2}K^{-1}$	Y-intercept Wm^{-2}@$\Delta T=0$	R^2
100<G<200	34.3	-90.9	0.78
200<G<300	26.9	-17.8	0.82
300<G<400	30.1	-14.3	0.84
400<G<500	24.6	40.8	0.75
500<G<600	22.8	82.6	0.73
600<G<700	19.7	127.3	0.71
700<G<800	16.9	172.8	0.65
800<G<900	19.1	162.6	0.73

Results – Flow rate 40 to 45 l/h.m^2



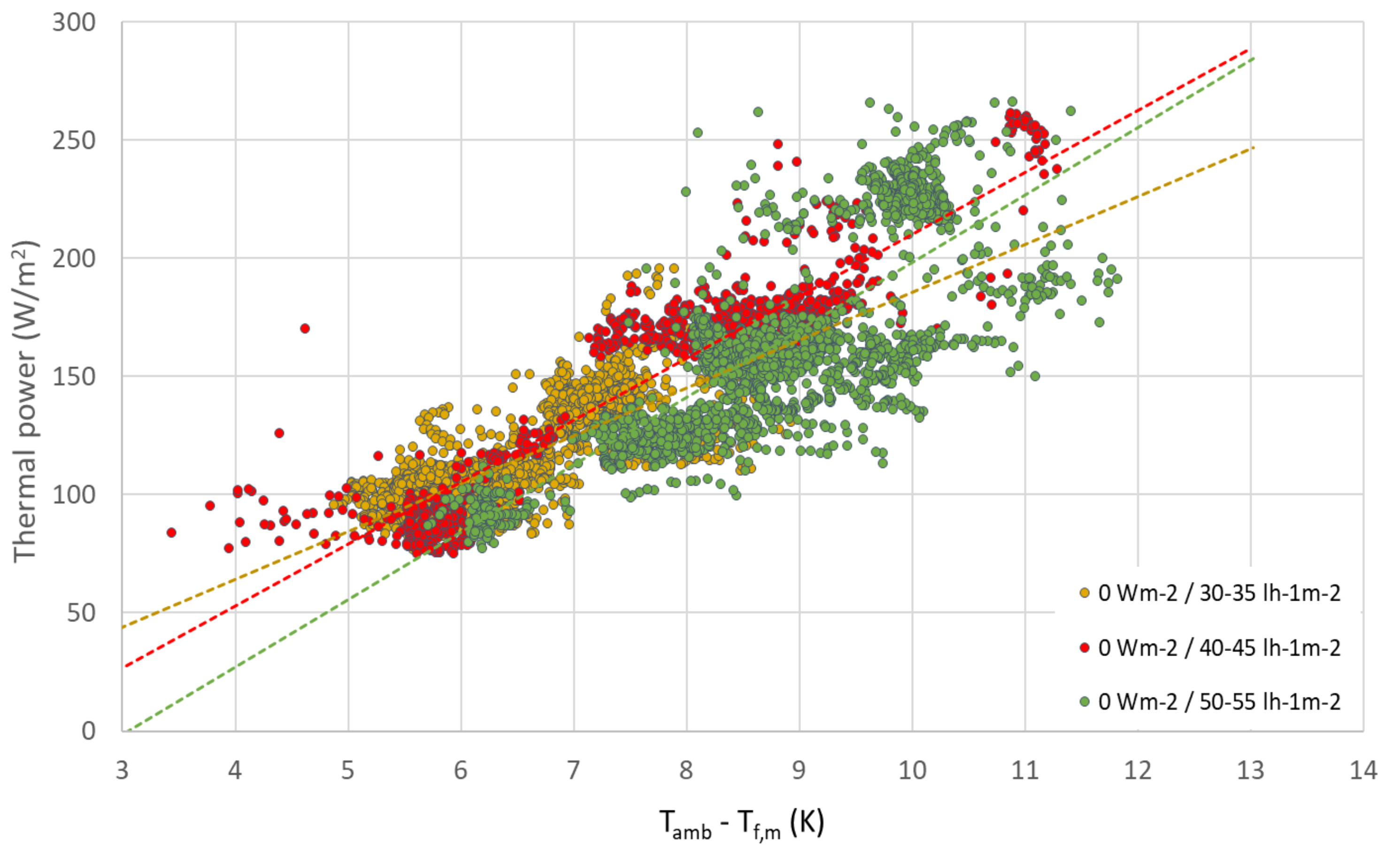
Solar Irradiance W/m^2	HEX U-value Wm^{-2}K^{-1}	Y-intercept Wm^{-2}@ΔT=0	R^2
100<G<200	21.4	20.3	0.73
200<G<300	16.5	77.1	0.74
300<G<400	20.7	56.4	0.85
400<G<500	17.9	85.4	0.71
500<G<600	19.3	119.9	0.83
600<G<700	18.3	151.8	0.74
700<G<800	15.6	207.4	0.62
800<G<900	14.9	222.5	0.61

Results – Flow rate 50 to 55 l/h.m^2



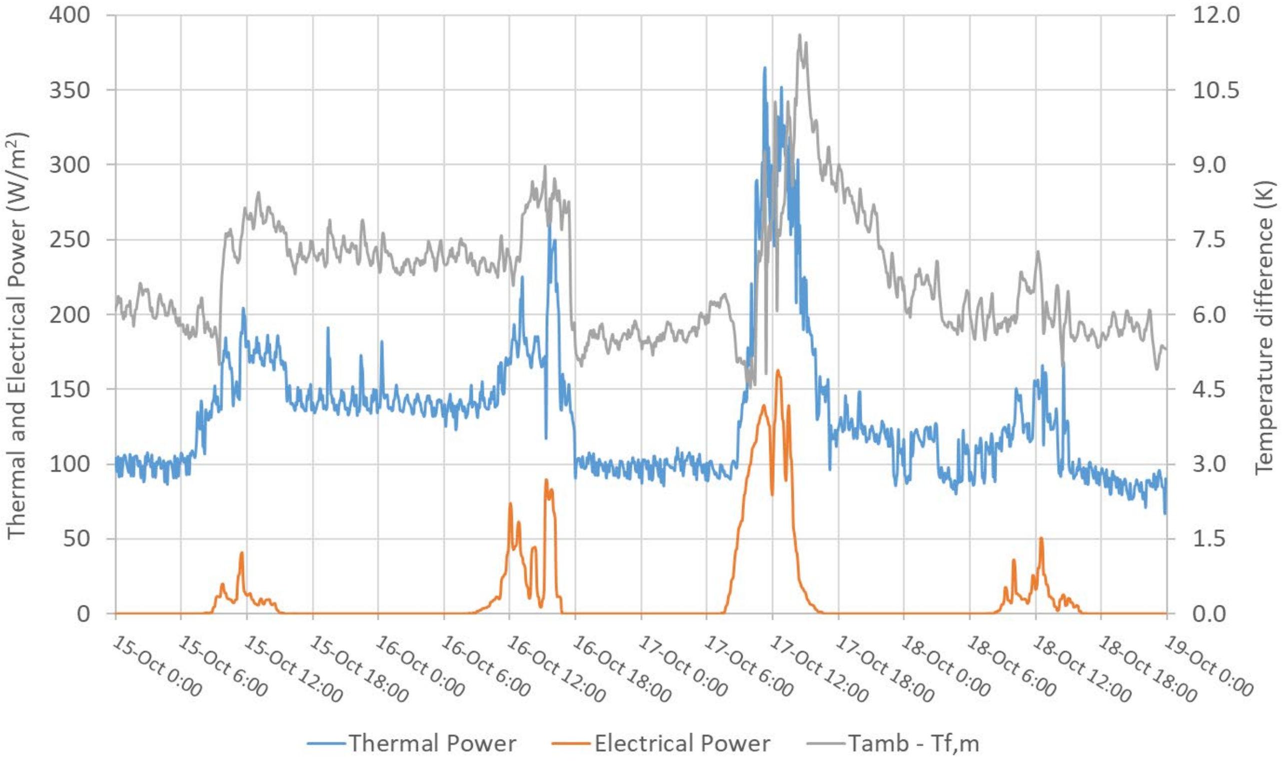
Solar Irradiance W/m^2	HEX U-value $Wm^{-2}K^{-1}$	Y-intercept Wm^{-2}@$\Delta T=0$	R^2
100<G<200	25.7	-6.8	0.75
200<G<300	26.5	-12.5	0.73
300<G<400	22.3	55.0	0.72
400<G<500	19.9	89.0	0.72
500<G<600	18.8	139.4	0.75
600<G<700	16.1	193.5	0.77
700<G<800	13.7	243.5	0.89
800<G<900	13.0	273.1	0.87

Results – No solar irradiation



Flow rate l/h.m²	No solar irradiance		
	W/m²K	W/m²@ΔT=0	R^2
30 to 35	26.5	-12.5	0.73
40 to 45	22.3	55.0	0.72
50 to 55	19.9	89.0	0.72

Results – Time series performance



Day	Heat kWh/m²-day	Electricity kWh/m²-day	Solar irradiation W/m²	Average $T_{amb} - T_{f,m}$ K
15th October	3.25	0.07	0.46	8.88
16th October	3.37	0.23	1.30	8.98
17th October	3.58	0.64	3.31	9.36
18th October	2.51	0.10	0.62	7.29

Discussion – U-values

- U-values in the range of 13 to 19 W/m^2K for high solar irradiation levels and 20 to 35 W/m^2K for low solar irradiation levels

- Upper range of typical unglazed and uninsulated collector but 40 to 60% lower than PVTs designed for heat pump integration

Discussion – PVT sourced heat pump

- Most residential heat pumps in villas in Sweden have 10-15 kW of thermal capacity

- Likely to have a COP of 2 when operating at peak capacity

- PVT should be able to supply between 5 and 7.5 kW at the evaporator, meaning a minimum of 250 W/m^2 with 20 m^2 array

- Possible during cold sunny days, but at least double the size when operating during cloudy days or nighttime

Discussion – Other studies

- Previous research showed an SPF of 1.6 could be achieved in Stockholm with a PVT area of 4.5 m^2 per kWh_{th} of heat pump nominal power
- If PVT design could be improved to enhance heat capture from air – SPF of 2.6 could be achieved making it competitive with ASHP
- Studies carried out in Germany SPF of 3.3 and 3.6 were achieved with areas of 2.5 and 3 m^2/kWh_{th} with an improved collector design.

Conclusions

- Specific thermal output of 100 to 250 W/m^2 when there is no solar irradiance
- 20 m^2 PVT array capable of providing 9 kW peak on a sunny day, and 5 kW peak during nighttime
- Room for improvement in PVT collector design for heat pump integration
- 75% of the energy captured by the PVT collector for a day in October comes from ambient air

Where do we go from here?

- Currently testing 4 commercially available PVT collectors with different absorber designs
- Deriving thermal performance coefficients for use in dynamic system simulations of PVT – HP and PVT – GSHP in Trnsys
- Identifying best design strategies for PVTs specifically designed for heat pump integration

THANK YOU!

Questions?