Experimental Results: Gas-fired Membrane-based Semi-open Sorption Water Heater

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Session 4A: Dev. in gas HPWHs

Acknowledgments

- Department of Energy (Contract DE-EE0006718.00)
- DOE Building Technology Office
  - Antonio Bouza
  - Jim Payne
  - Michael Geocaris

Outline

- Motivation
- What is a sorption heat pump
- What is a *semi-open* sorption heat pump
- Experimental results from prototype semi-open system

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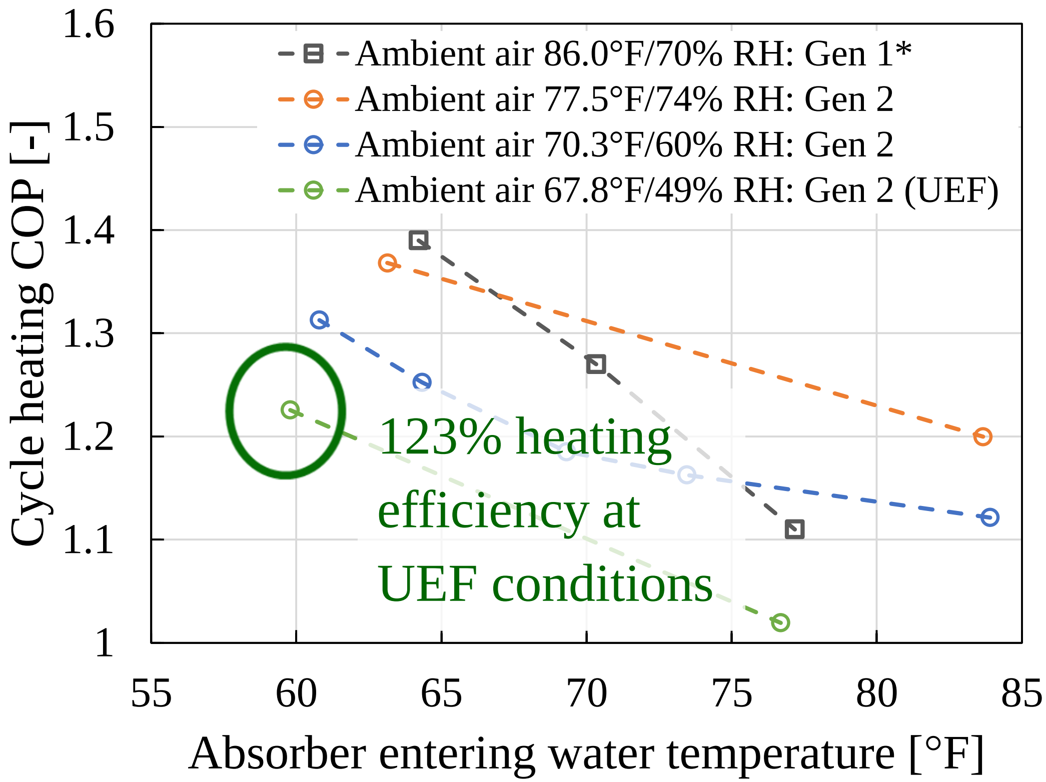
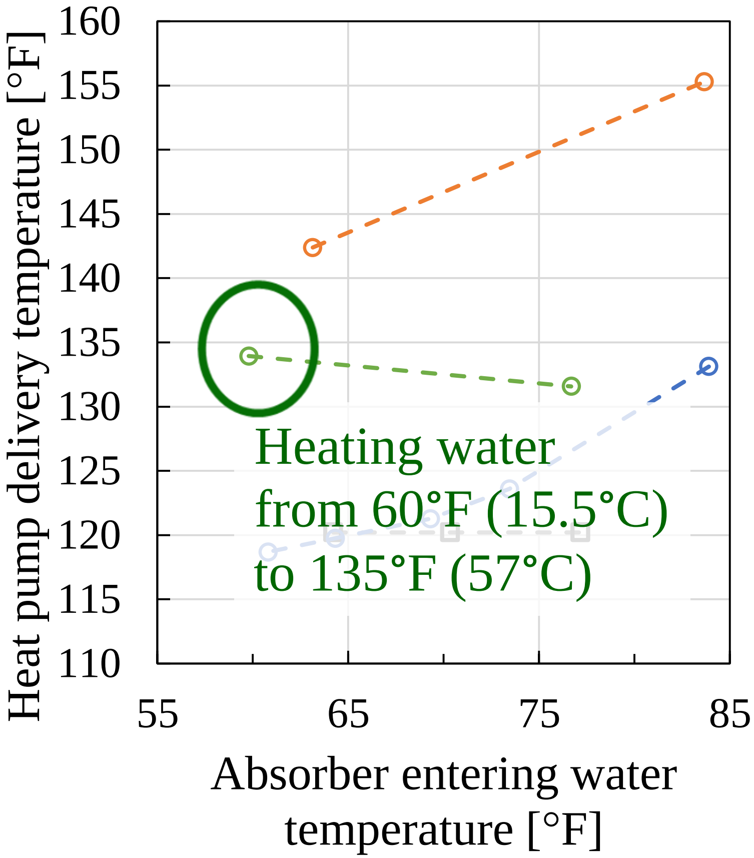
Experimental Results





- Heating capacity: 700 – 1400 W
- Typical uncertainties: 6-8% of COP; 3% of capacity

*Gen 1: Chugh, Devesh; Kyle R. Gluesenkamp, Omar A. Abdelaziz, Saeed Moghaddam (2017). "Ionic liquid-based hybrid absorption cycle for water heating, dehumidification, and cooling", *Applied Energy*, 202, 746-754.

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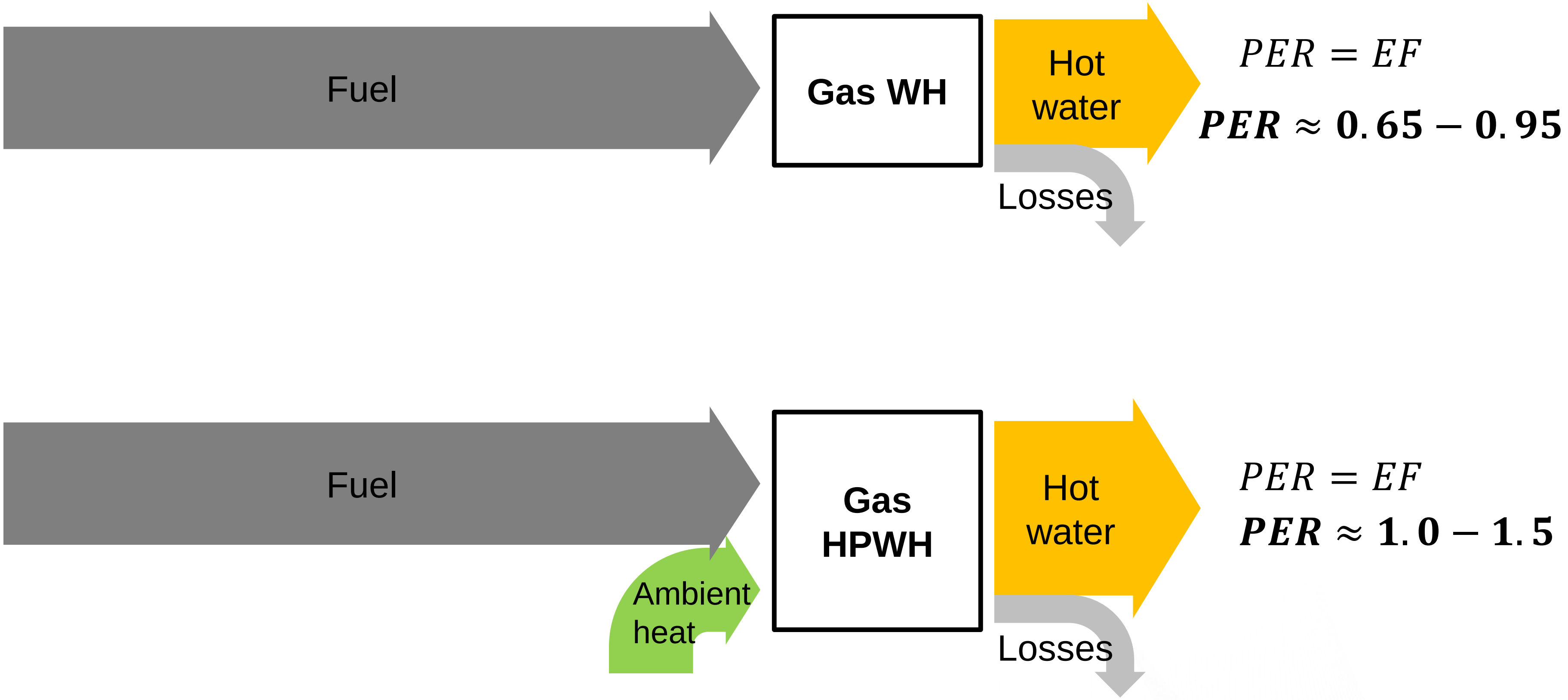
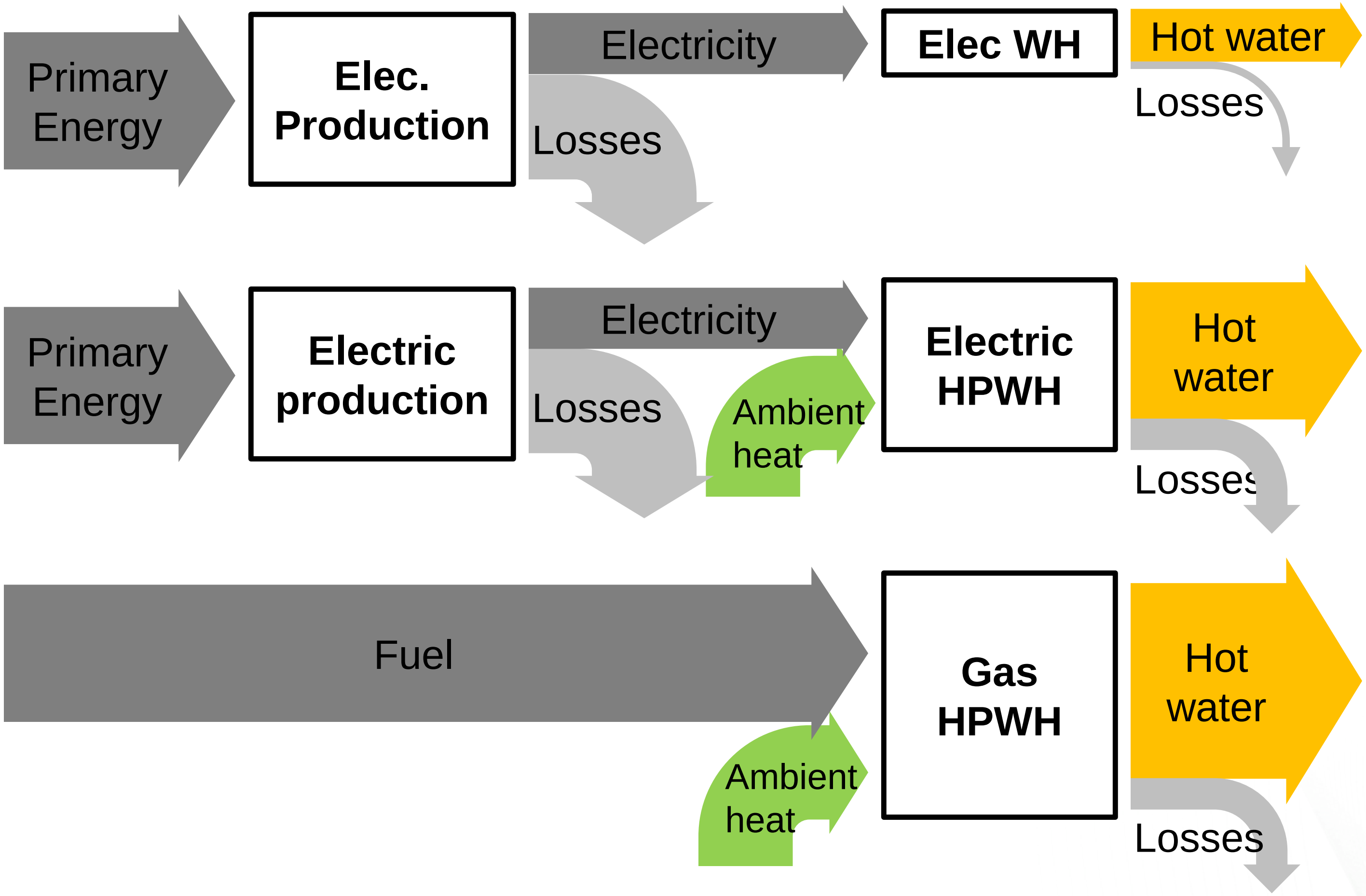
Gas HPWH Motivation: Primary Energy



- Gas HPWHs: highest primary efficiency vs. other gas tech.
- Cost and novelty are current barriers – R&D needed

Gas HPWH Motivation: Primary Energy



$PER = \eta_{grid} EF$

$PER \approx 0.33 * 0.9$

$\boldsymbol{PER \approx 0.30}$

$PER = \eta_{grid} EF$

$PER \approx 0.33 * 3$

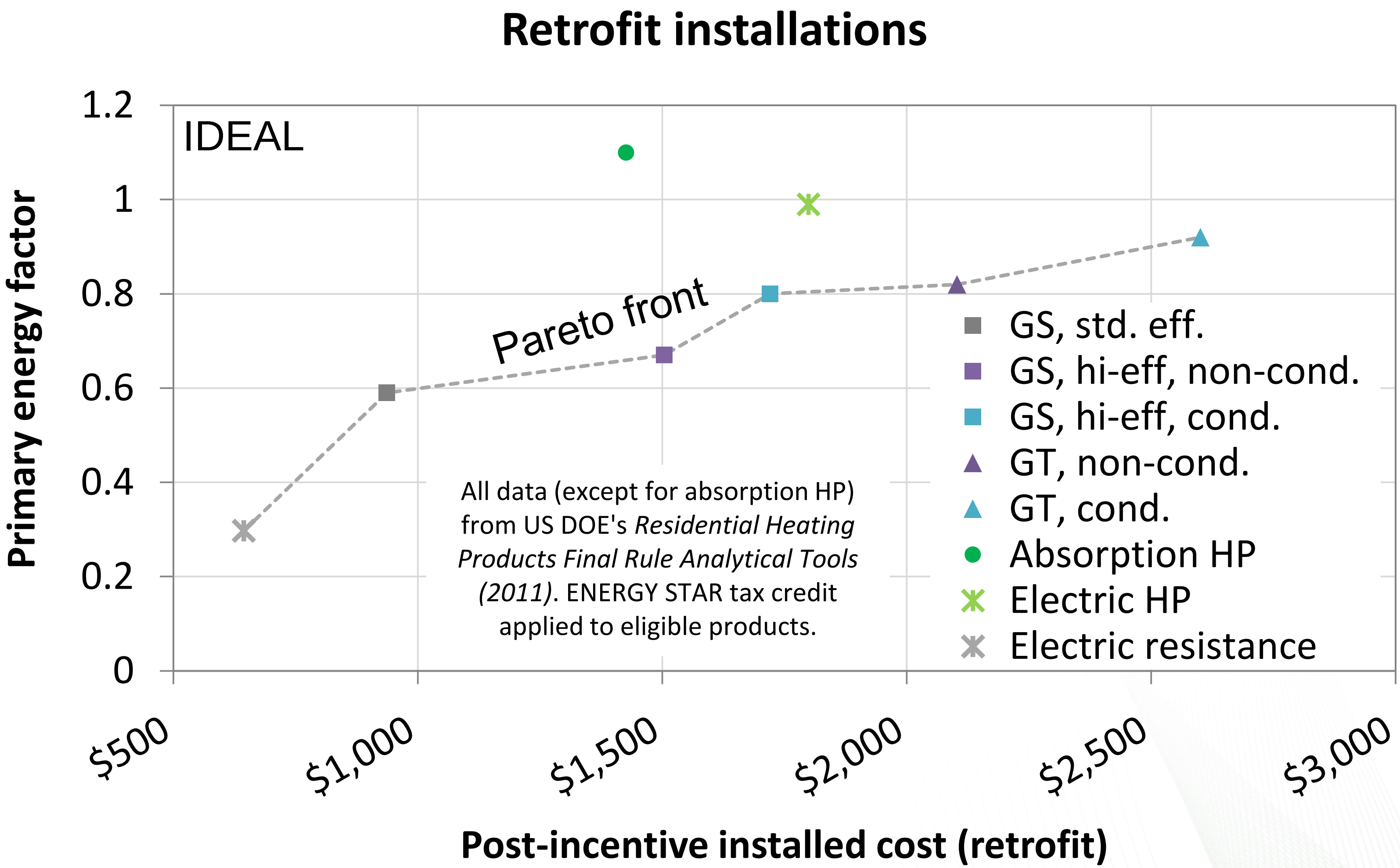
$\boldsymbol{PER \approx 1.0}$

$PER = EF$

$\boldsymbol{PER \approx 1 - 1.5}$

- Gas HPWHs: highest primary efficiency vs. electric tech.
- Cost and novelty are current barriers – R&D needed

Vision: New Cost Effective Gas Option



GS: gas storage
GT: gas tankless
HP: heat pump

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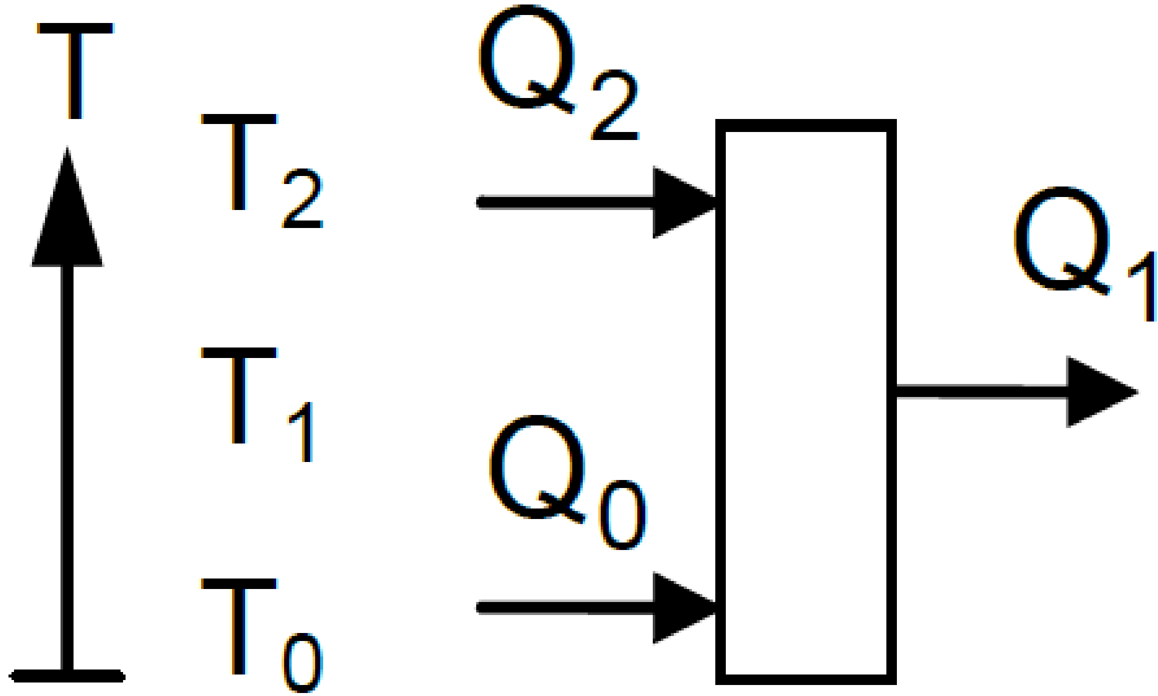
What is a Thermally Driven Heat Pump?

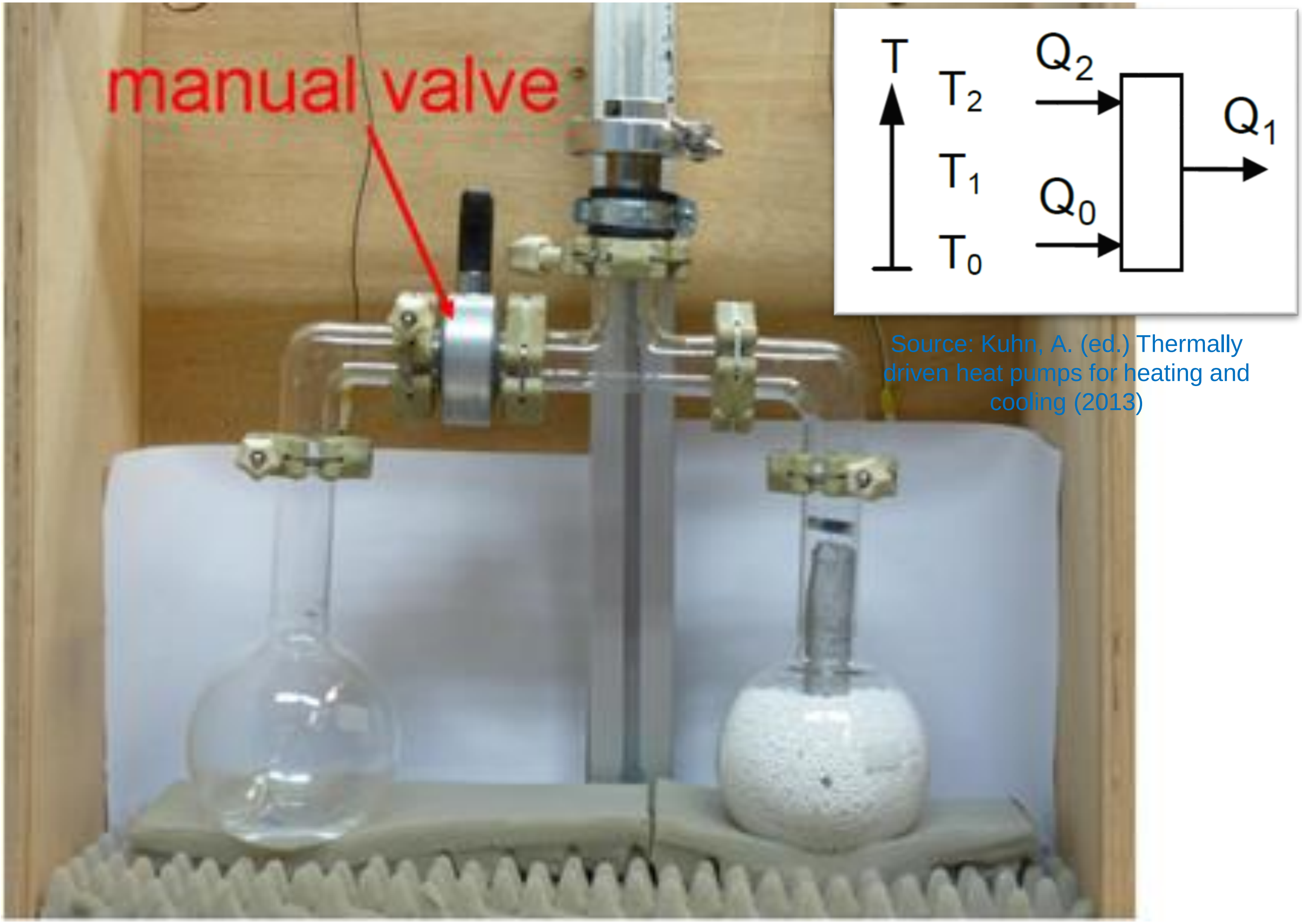
T: temperature

Q: heat flow



Source: Kuhn, A. (ed.) Thermally driven heat pumps for heating and cooling (2013)

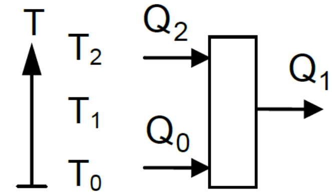
What is a Sorption Heat Pump?

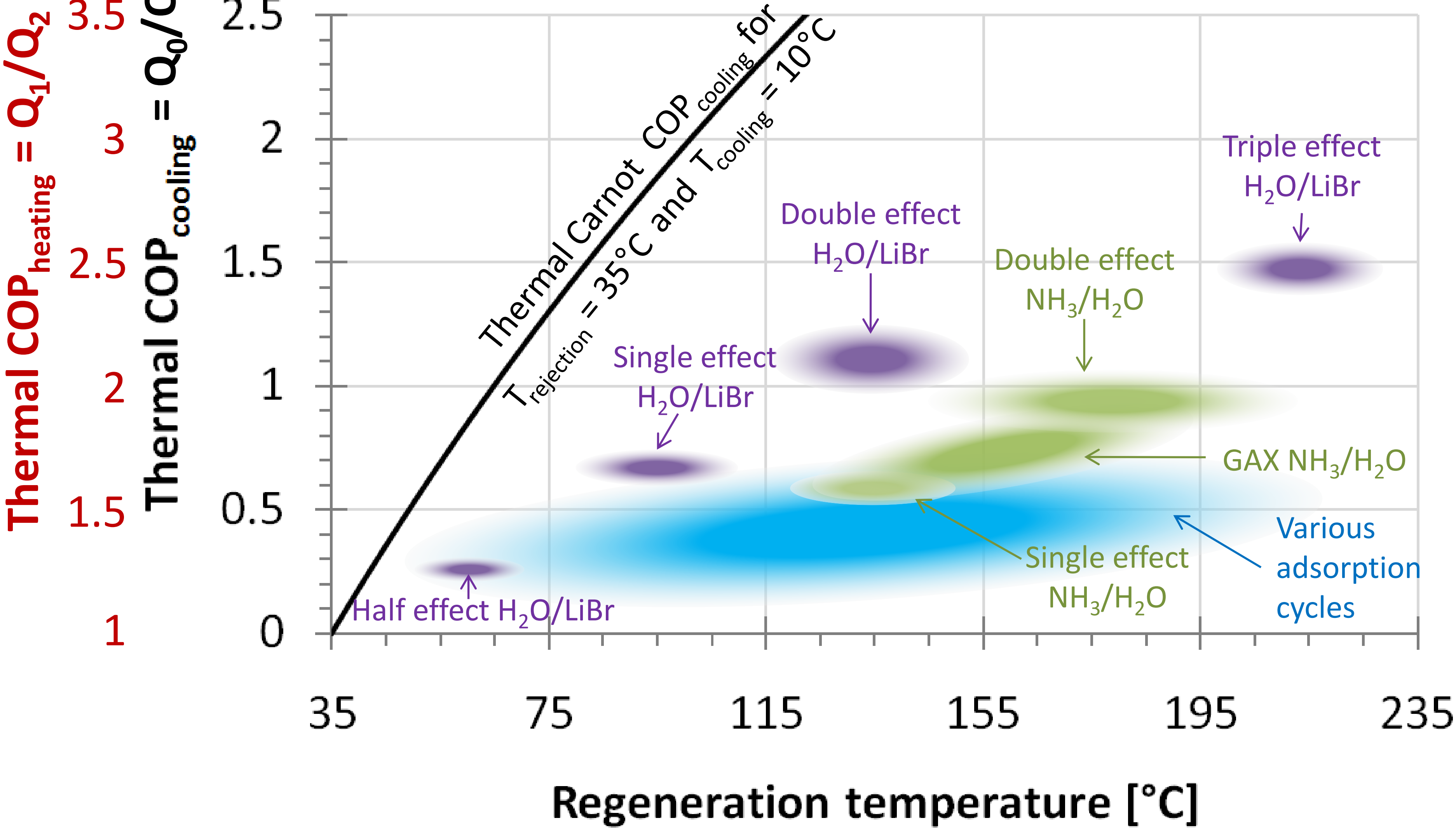


Source: Kuhn, A. (ed.) Thermally driven heat pumps for heating and cooling (2013)

Source: http://www.annex34.org/the-magic-of-thermal-cooling

Sorption Technologies

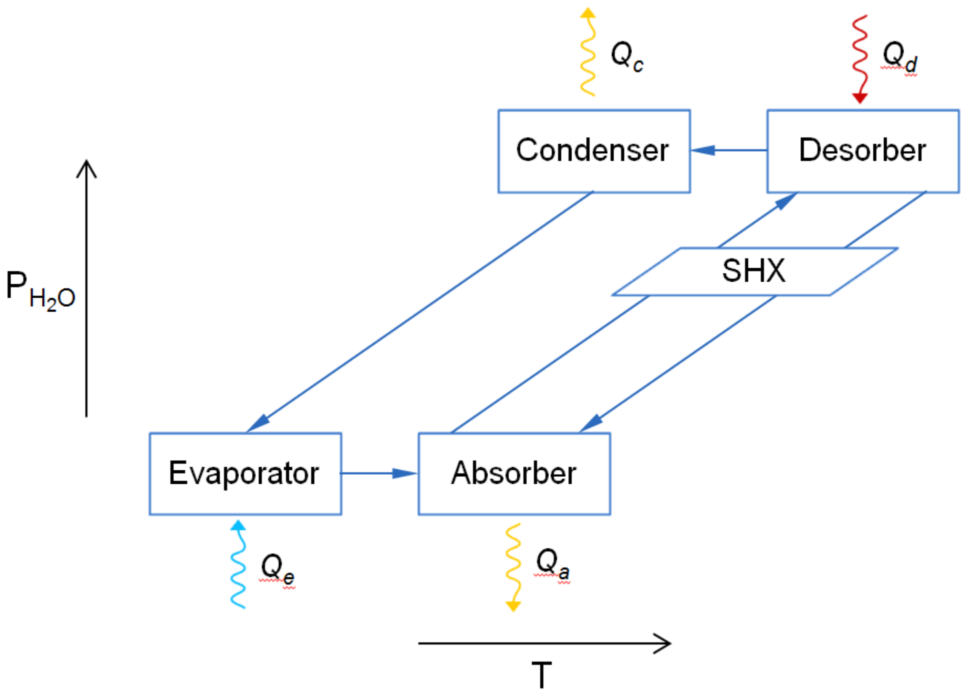




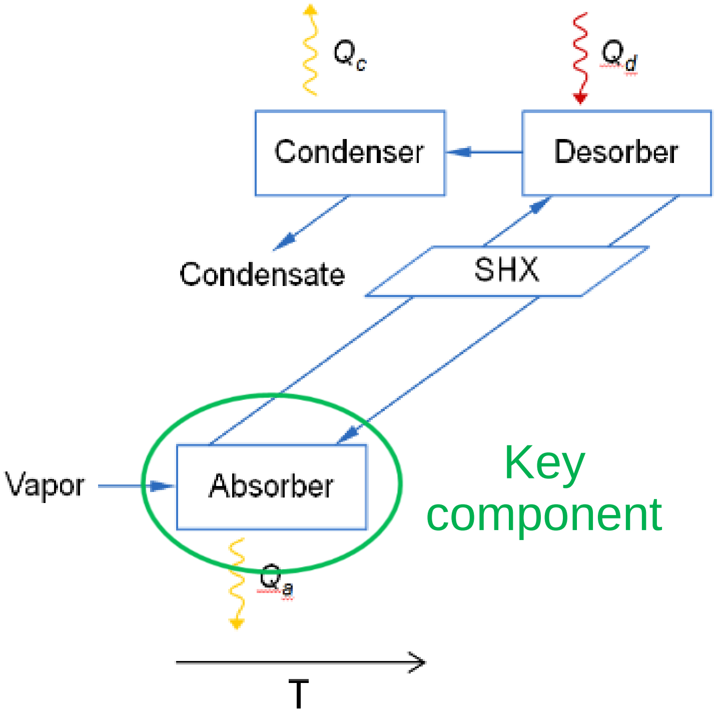
Adapted from: K. Gluesenkamp and R. Radermacher, "Heat Activated Cooling Technologies for Small and Micro CHP Applications," in *Small and Micro CHP Systems*, R. Beith, Ed., ed Cambridge, UK: Woodhead Publishing Ltd., 2013.

Semi-open Sorption Architecture

Traditional closed



Semi-open



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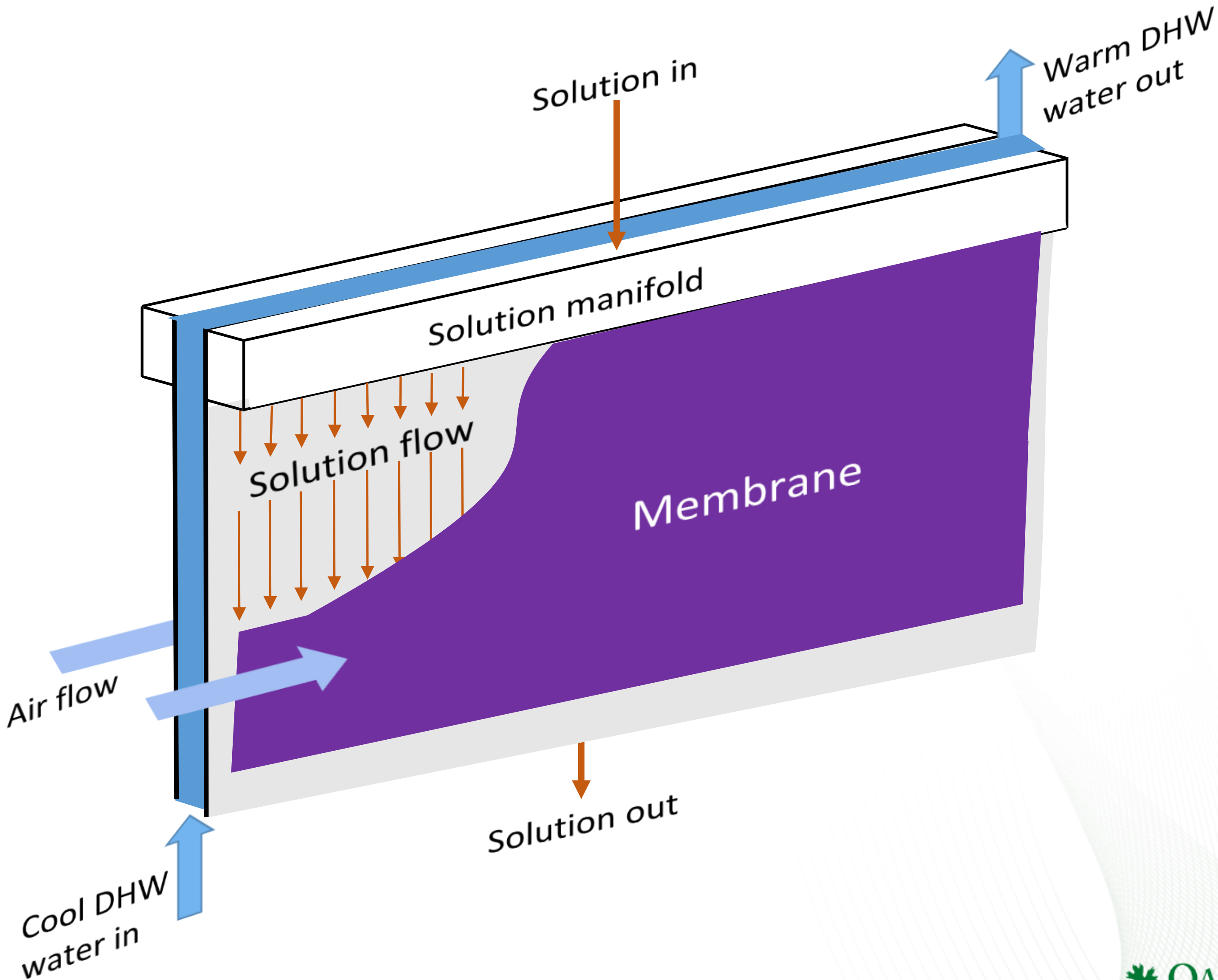
Key Component: Semi-open Absorber



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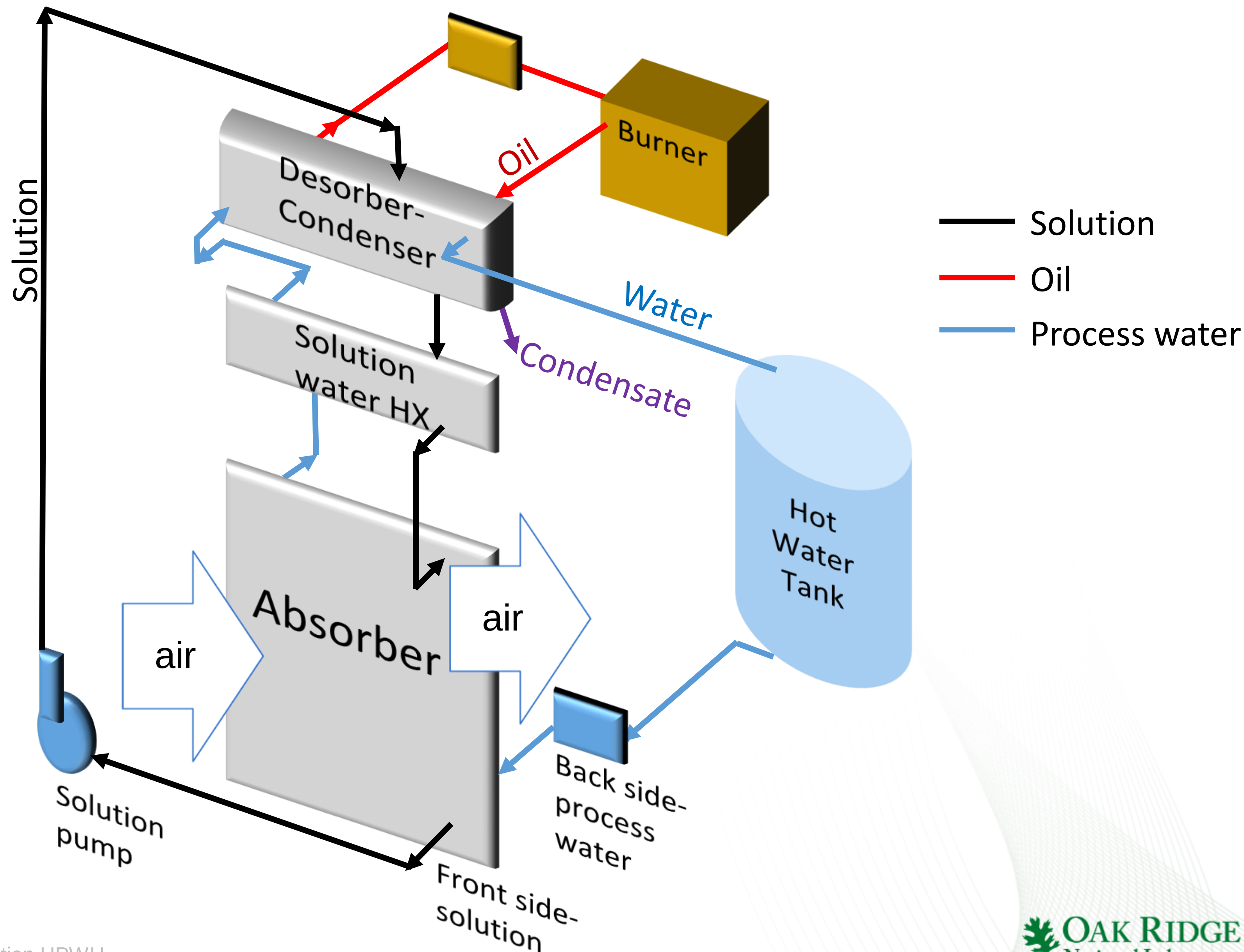
Open Absorption Water Heater



Main Benefit

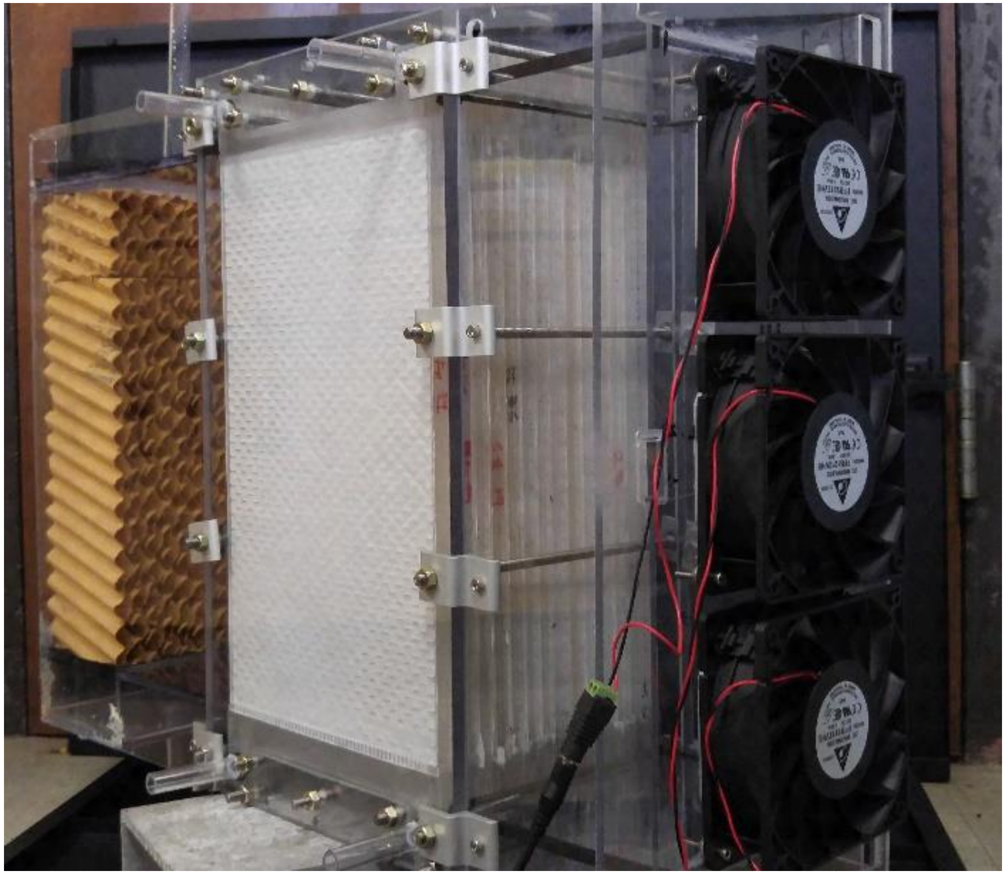
Significant cost reduction compared with traditional sorption

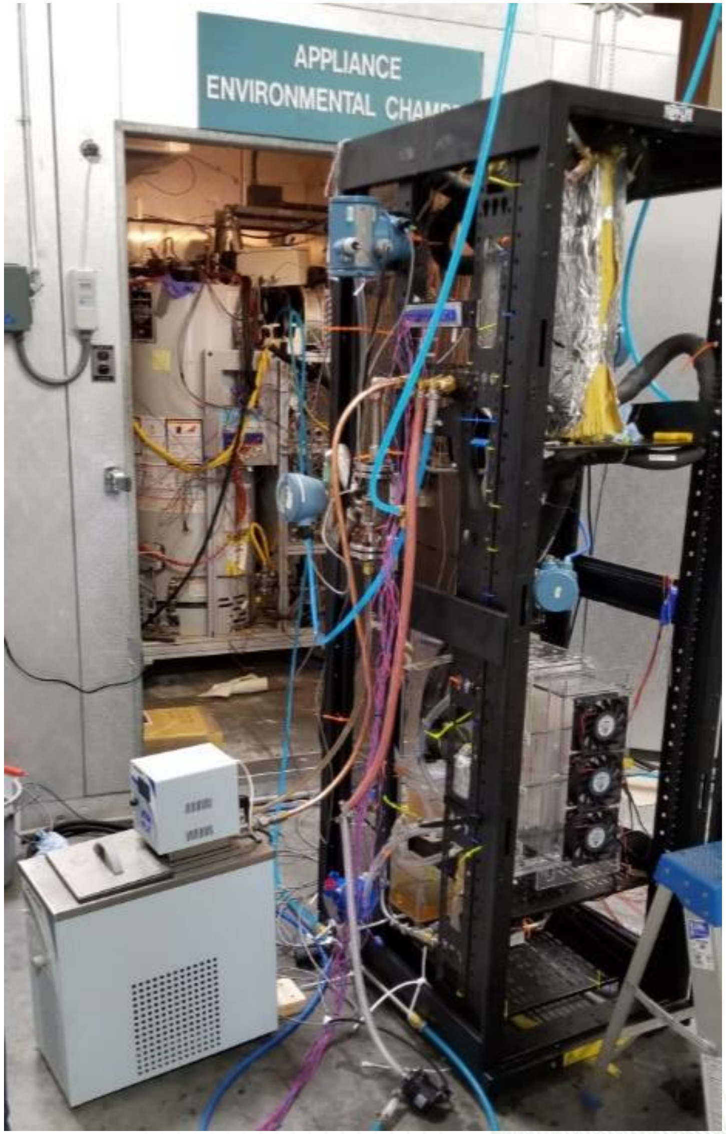
Component	Traditional closed sorption	Semi-open sorption
Vessel materials	Carbon steel	Polymer
Solution pump	Hermetic, with hydrostatic plus 1–15 kPa variable head	Nonhermetic with constant hydrostatic head
Vacuum requirements	Periodic vacuum pumping	None
Vessel pressure rating	Must withstand full vacuum (34 ft)	Only hydrostatic pressure differentials (~2 ft)
Evaporator	Required	Not required

K. Gluesenkamp, D. Chugh, O. Abdelaziz, and S. Moghaddam, "Efficiency Analysis of Semi-Open Sorption Heat Pump Systems," Renewable Energy, 2016.

Prototype Evaluation at ORNL

Absorber assembly





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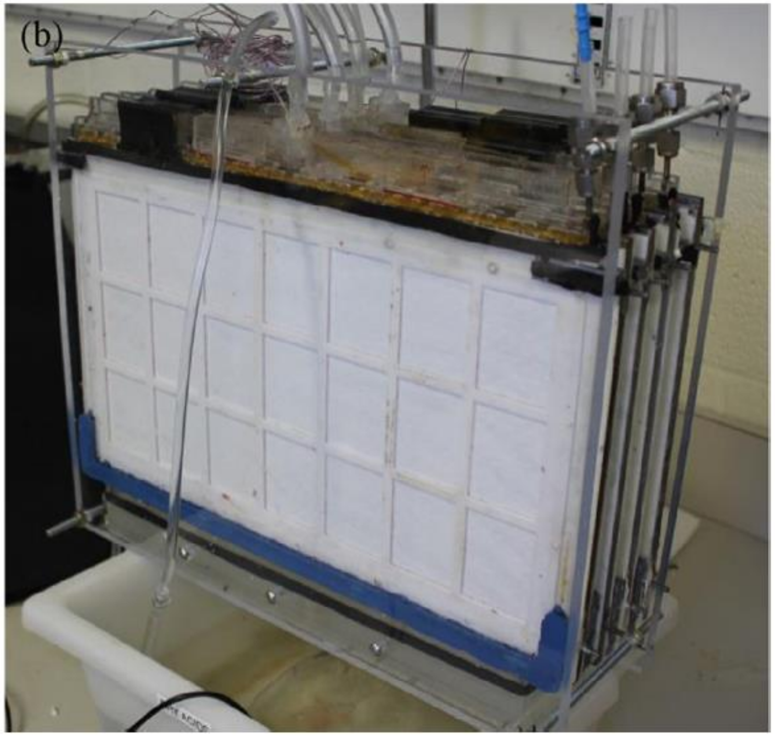
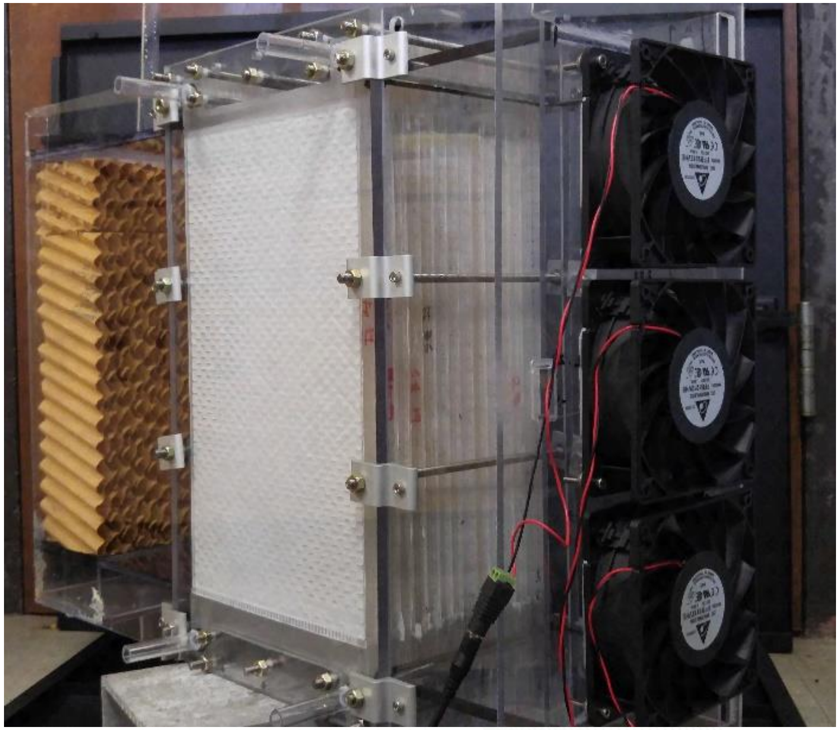
Prototype Generations

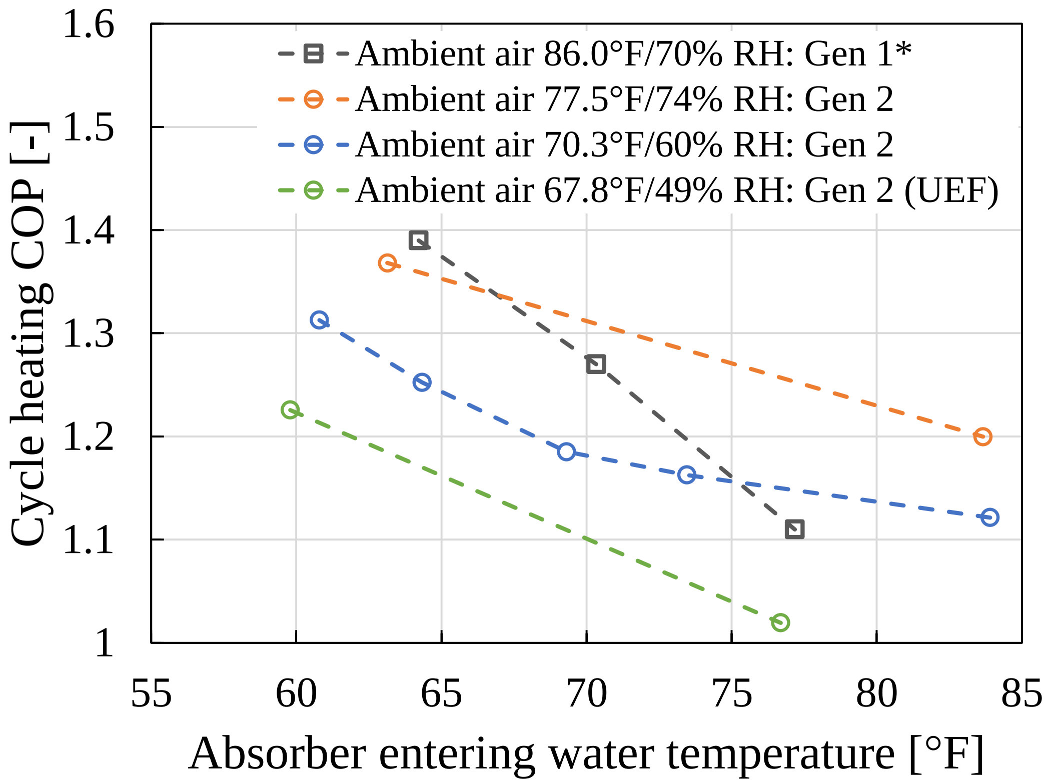
Generation 1:

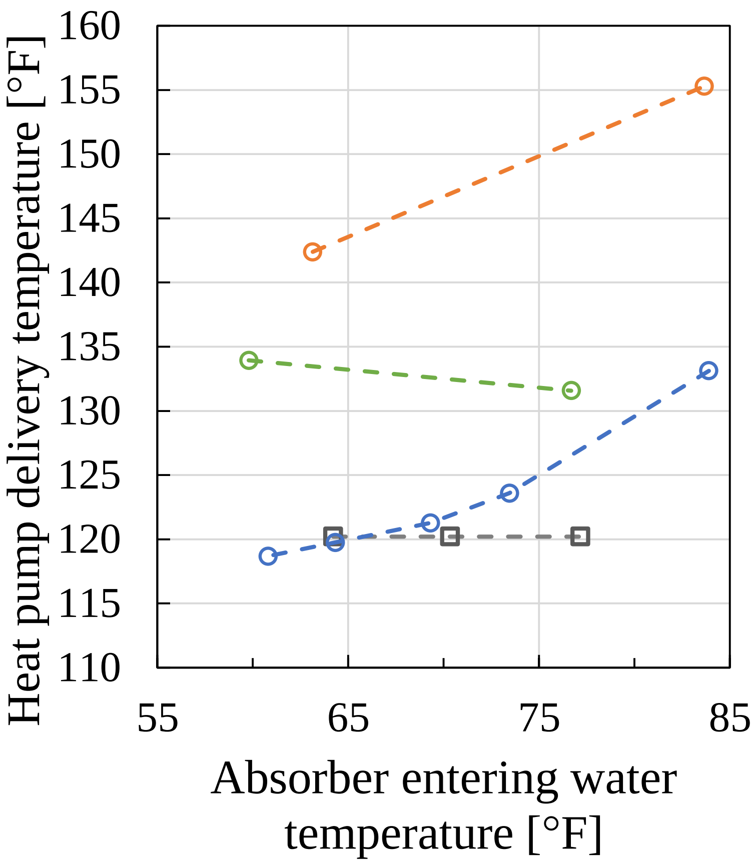


Generation 2:



Experimental Results





- Heating capacity: 700 – 1400 W
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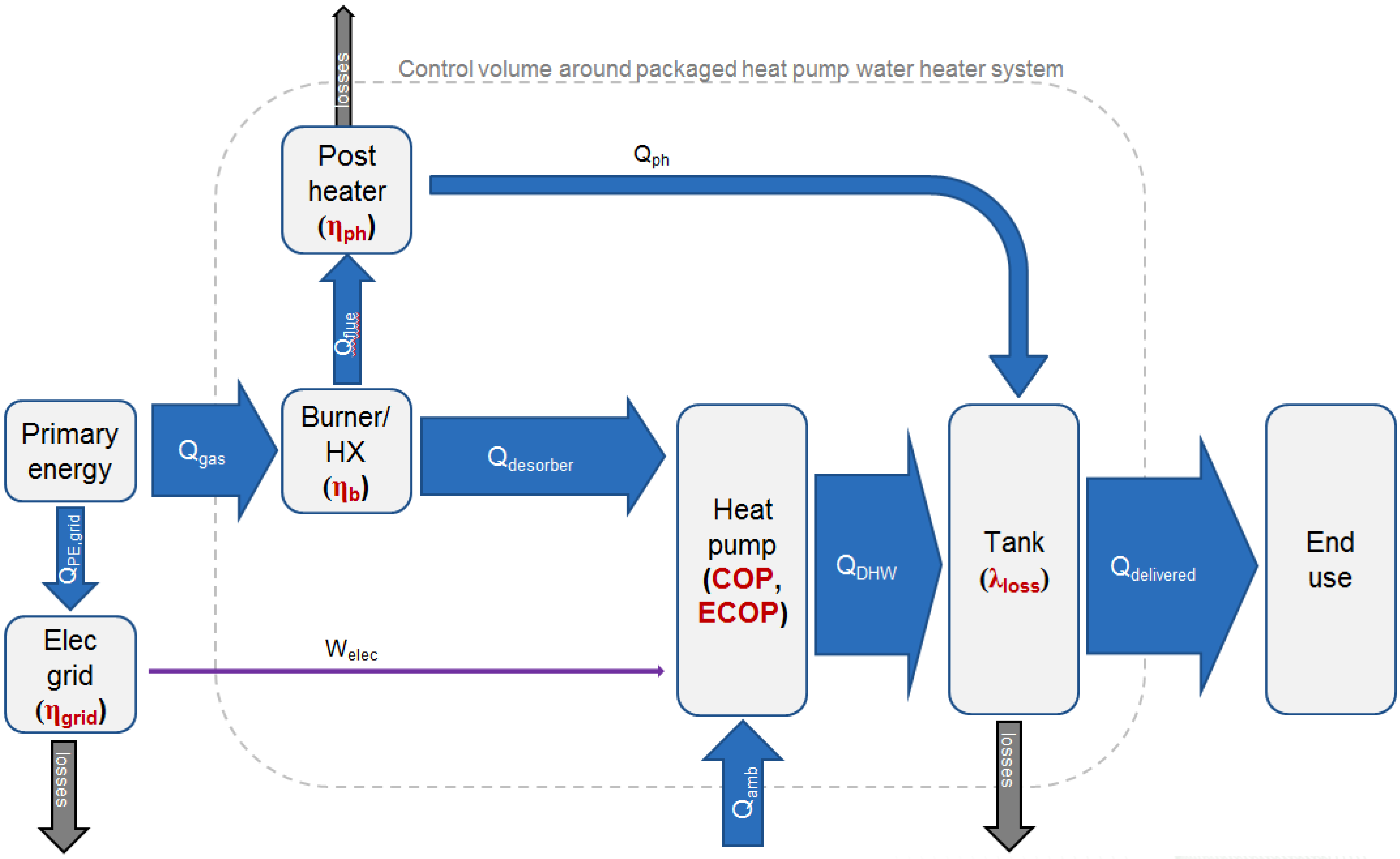
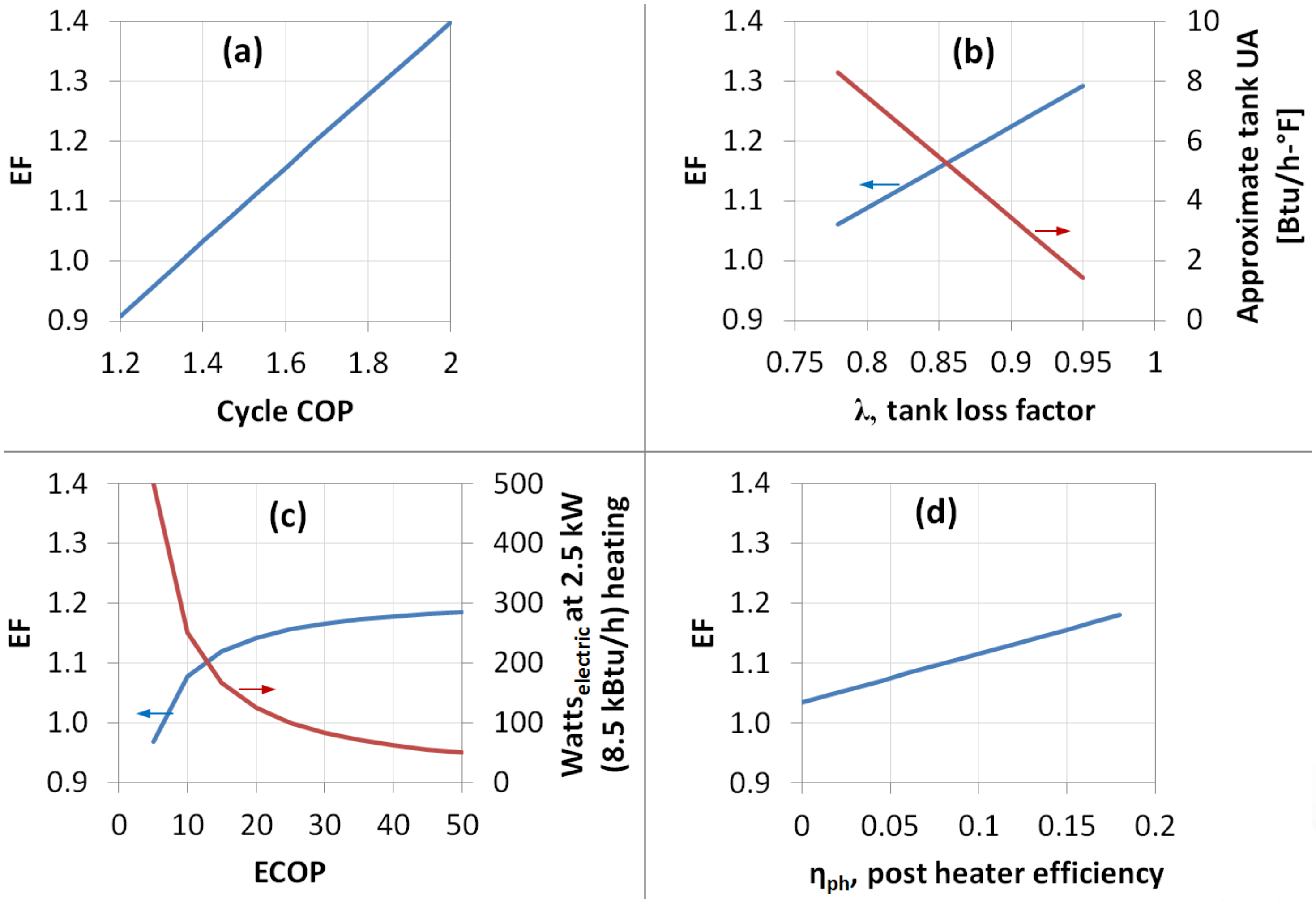
Energy Flows in System



Gluesenkamp, K. (2016). "Energy Factor Analysis for Gas Heat Pump Water Heaters", *ASHRAE Annual Meeting 2016*, June 29, 2016, St. Louis, MO.

COP and UEF

$$\frac{1}{EF} = \frac{1}{\lambda}\left(\frac{1}{\eta_b COP + \eta_{ph}} + \frac{1}{ECOP}\right)$$



Except where explicitly varied along x-axis, parameters values are set to: $\eta_b = 0.8$, $\eta_{ph} = 0.15$, $\lambda = 0.85$, COP = 1.3, and ECOP = 25.

Gluesenkamp, Kyle R.; Yang, Zhiyao; Abdelaziz, Omar. "Translating cycle performance to system-level efficiency for sorption heat pumps." *12th IEA Heat Pump Conference 2017*, Rotterdam, Netherlands, May 15–18, 2017.

Gluesenkamp, K. (2016). “Energy Factor Analysis for Gas Heat Pump Water Heaters”, *ASHRAE Annual Meeting 2016*, June 29, 2016, St. Louis, MO.

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- S. Moghaddam, Thin Film-based Compact Absorption Cooling System, WO Patent 2,013,063,210, 2013.
- S. Moghaddam, D. Chugh, R. Nasr Isfahani, S. Bigham, A. Fazeli, D. Yu, M. Mortazavi, and O. Abdelaziz, Open Absorption Cycle for Combined Dehumidification, Water Heating, and Evaporating Cooling, Patent Application WO/2015/116362, PCT/US2015/010757.
- S. Moghaddam and D. Chugh, Novel Architecture for Absorption-based Heaters, Patent Application UF-14697, 2013.

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Discussion

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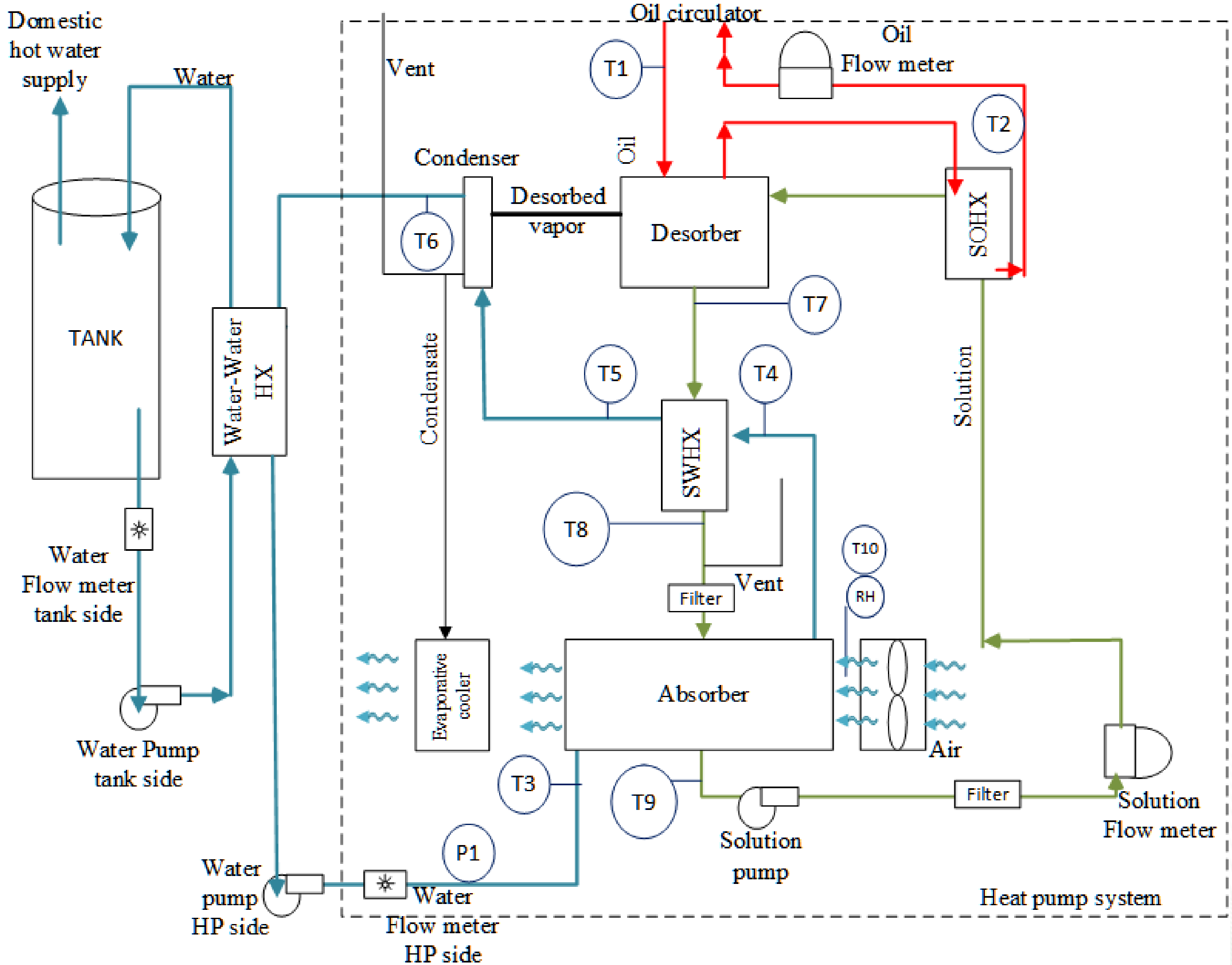
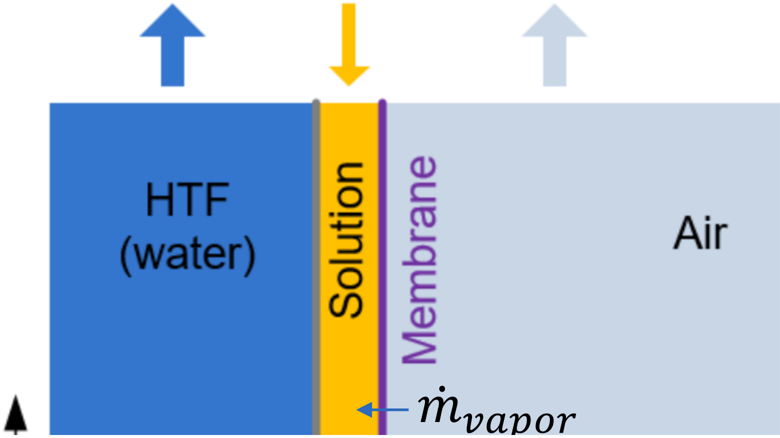
Experimental System Diagram



Theoretical Efficiency Established



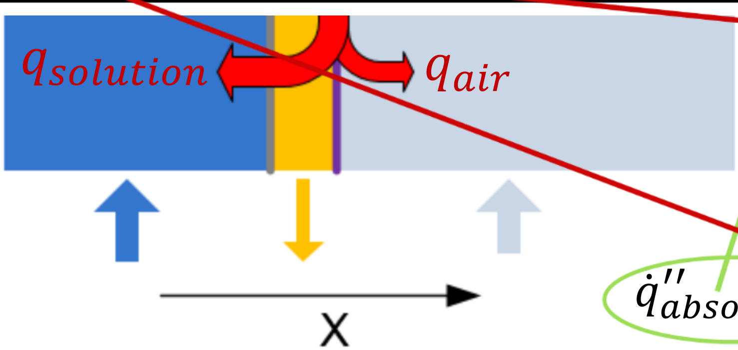
$$COP_{htg} = 1 + \frac{(\alpha - 1)L_{abs} + L_{cond}}{L_{abs} + C_{p,liq}(1 - \varepsilon_{SHX})\Delta T_{D-A}(FR)}$$

$$\alpha \equiv \frac{\dot{q}''_{solution}}{\dot{q}''_{absorption}} = \frac{1}{1 + \dot{q}''_{air} / \dot{q}''_{solution}}$$

Table 4
Experimental results used as empirical values in this work.

Parameter	Measured value
h_m	4.9×10^{-2} g^1 m^{-2} s^{-1} kPa^{-1}
U_{air}	2.67 ± 0.15 W^1 m^{-2} K^{-1}
U_{soln}	28.6 ± 1.7 W^1 m^{-2} K^{-1}

$$\alpha = \frac{1}{1 + \frac{UA_{air}\left(T_{interface} - T^{\infty}_{air}\right)}{UA_{soln}\left(T_{interface} - T^{\infty}_{HTF}\right)}}$$



$$T_{interface} = \frac{\dot{q}''_{absorption} + U_{soln}T^{\infty}_{HTF} + U_{air}T^{\infty}_{air}}{U_{soln} + U_{air}}$$

Only three measured values

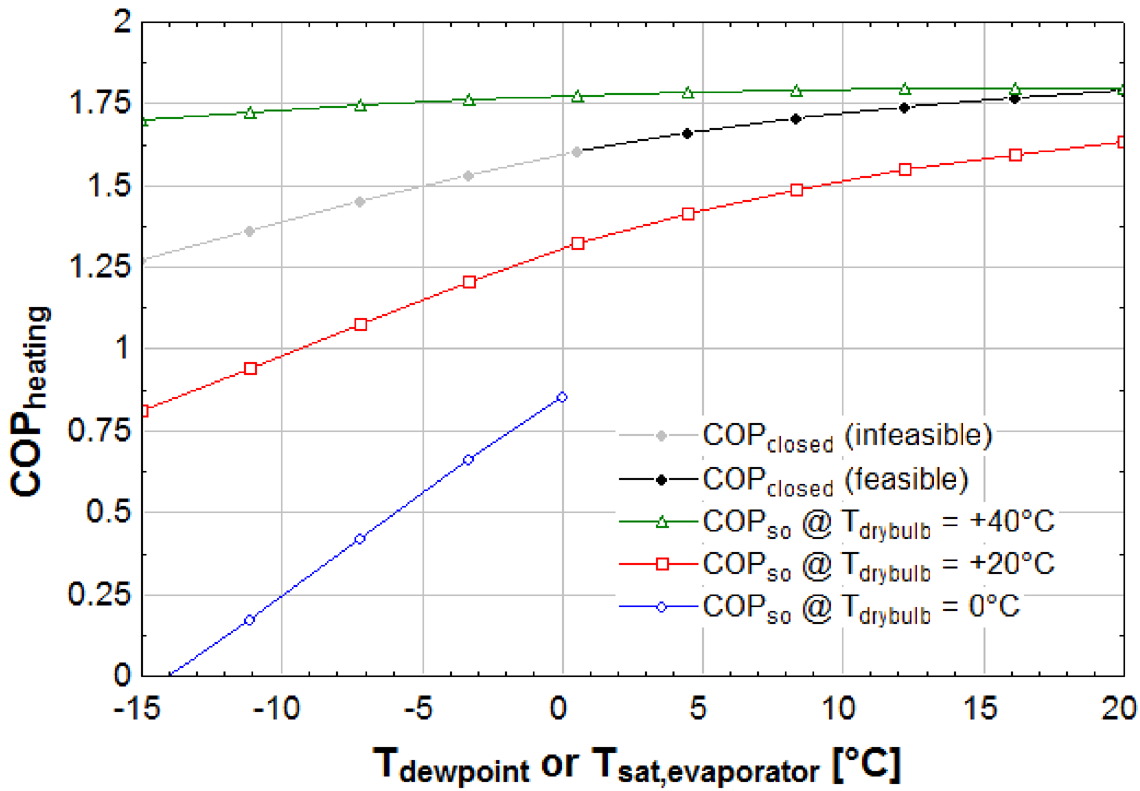
$$\dot{q}''_{absorption} = h_m L_{abs}\left(P_{w,air} - P_{w,soln}\{T_{interface}, X_{soln}\}\right)$$

Gluesenkamp, Kyle R., Devesh Chugh, Omar Abdelaziz, and Saeed Moghaddam (2017). "Efficiency Analysis of Semi-Open Sorption Heat Pump Systems," *Renewable Energy* 110, 95-104.

Efficiency Expected by Theory

Parameter	Measured value in prototype
h_m	4.9×10^{-2} $g^1 m^{-2} s^{-1} kPa^{-1}$
U_{air}	2.67 ± 0.15 $W^1 m^{-2} K^{-1}$
U_{soln}	28.6 ± 1.7 $W^1 m^{-2} K^{-1}$

Efficiency can be lower or higher than conventional closed absorption cycle, depending on ambient temperature



Contours of heating COP for closed and semi-open cycles at various ambient conditions.

Gluesenkamp, K., Chugh, D., Abdelaziz, O., and Moghaddam, S., "Efficiency Analysis of Semi-Open Sorption Heat Pump Systems," *Renewable Energy* (in press).

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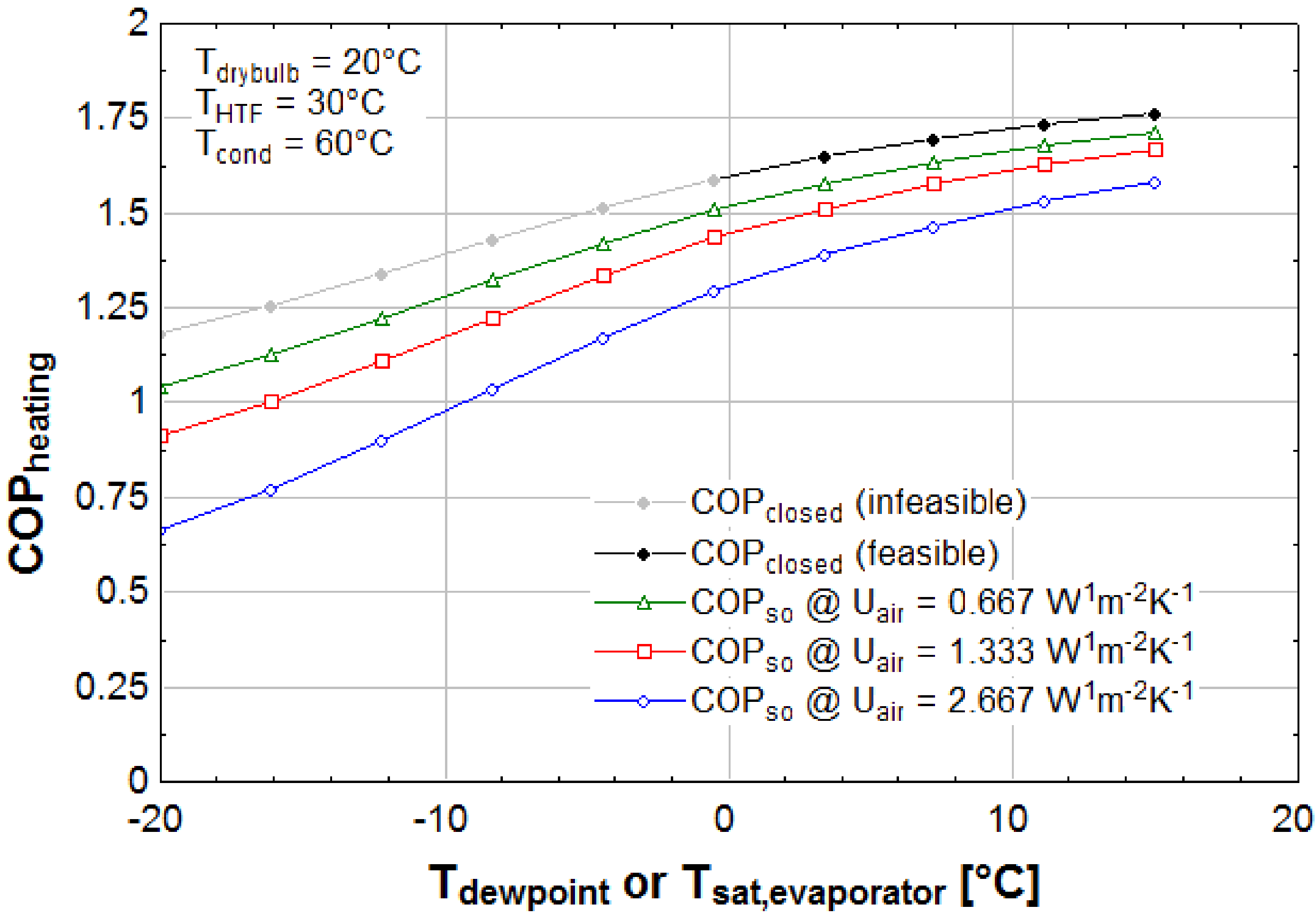
Research Opportunities

Performance improved by **lower** air side heat transfer…

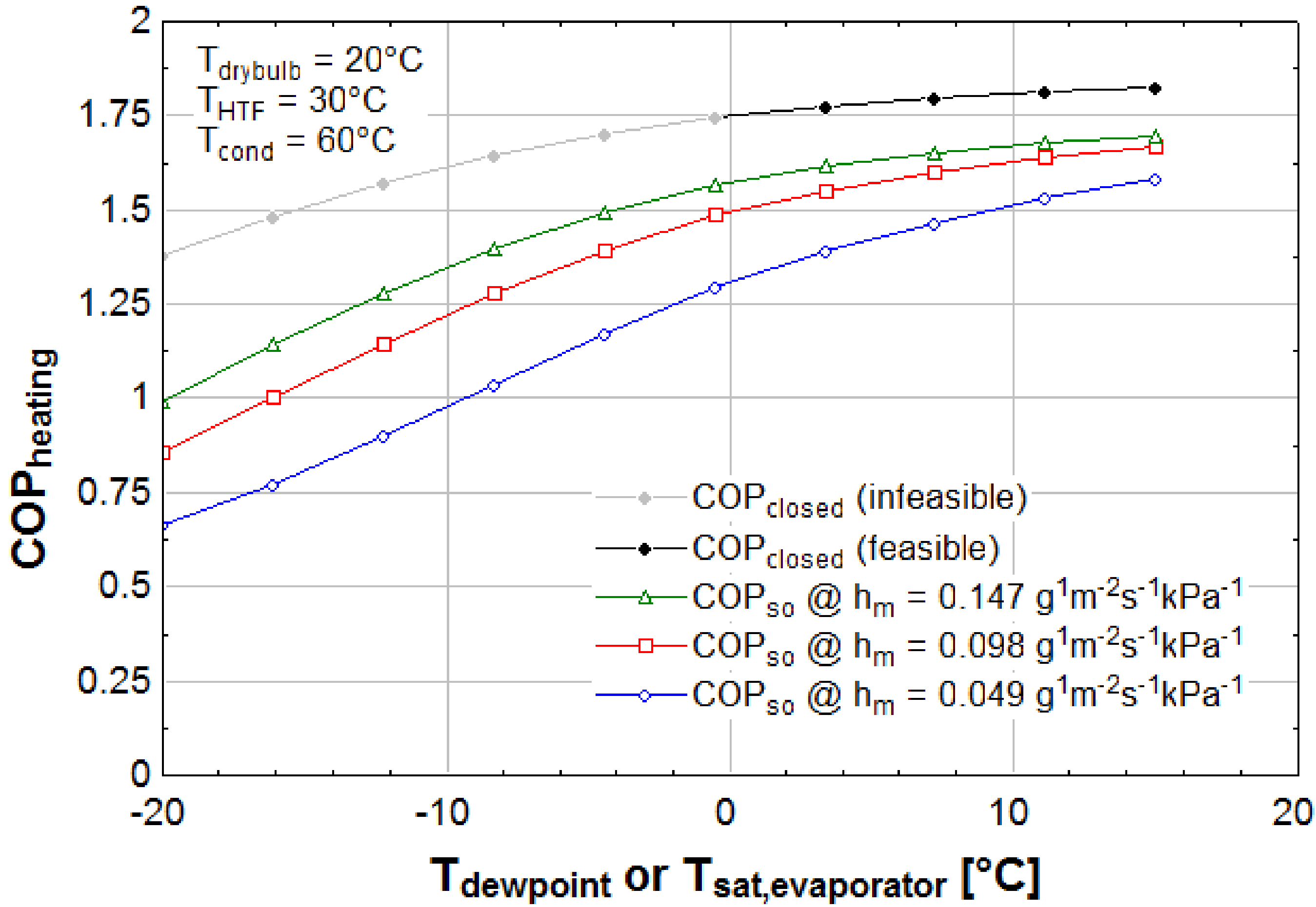


Lower U_{air} values improve performance at fixed permeability (h_m =0.049 $g^1m^{-2}s^{-1}kPa^{-1}$)

Gluesenkamp, K., Chugh, D., Abdelaziz, O., and `Moghaddam, S., *Renewable Energy* (in press).

Research Opportunities

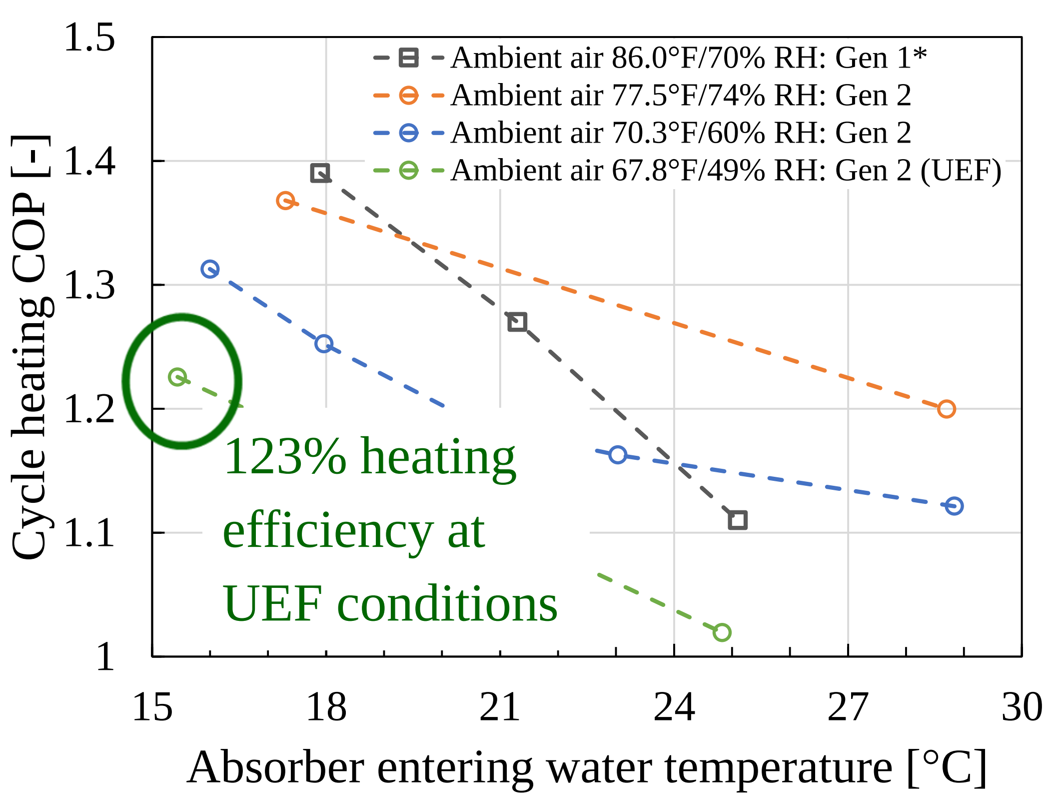
… and **higher** moisture mass transfer.

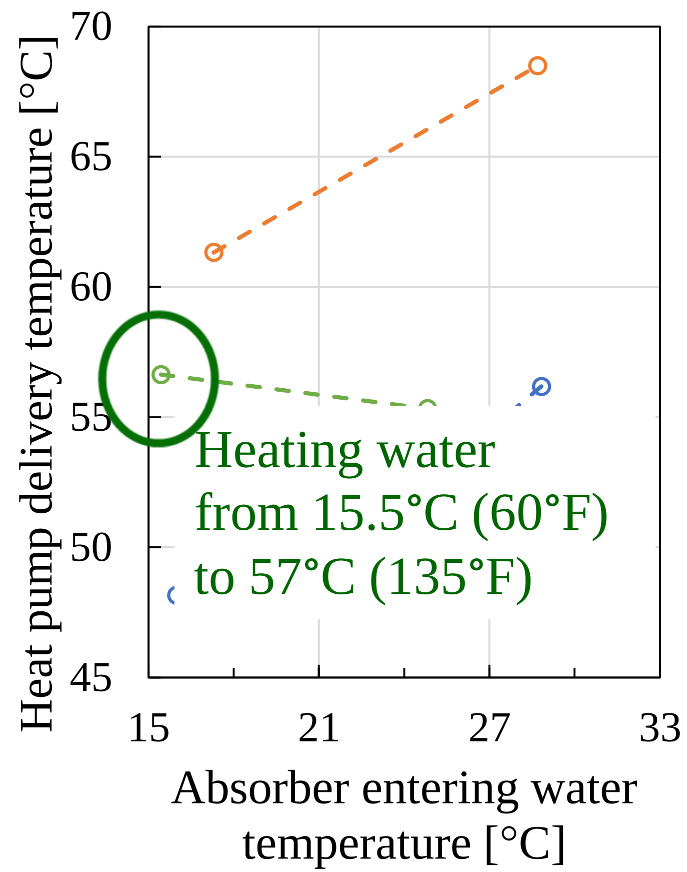


Higher membrane permeability at fixed U_{air} = 2.667 $W^1m^{-2}K^{-1}$ leads to better performance

Gluesenkamp, K., Chugh, D., Abdelaziz, O., and `Moghaddam, S., *Renewable Energy* (in press).

Experimental Results





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