Efficiency improvement of a high capacity transcritical CO_2 heat pump for human comfort in large buildings

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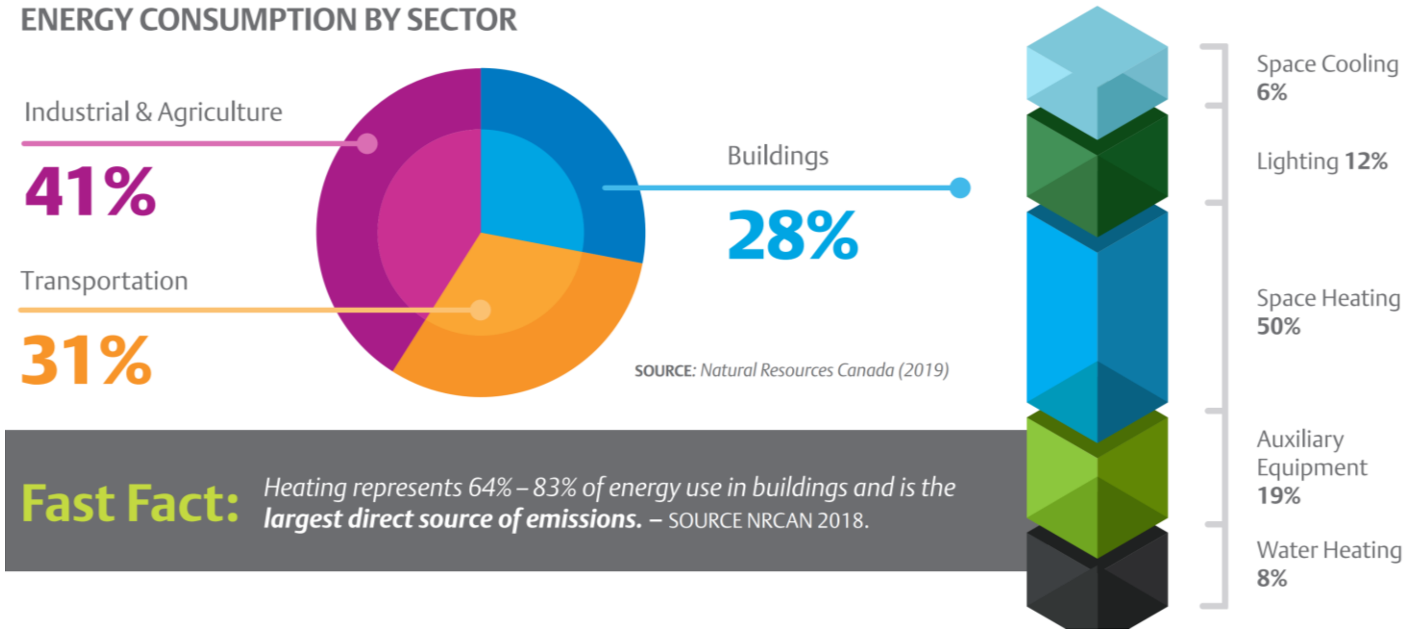
Outlines of the presentation

1. Context
2. Experimental prototype
3. Results and discussion
    1. Discharge pressure
    2. Compressor speed
    3. Heat source temperature
    4. Heat sink temperature
4. Conclusions and perspectives

1. Context



Global Action

Electrification

- Transportation, industrial, building sectors

Deployment of Energy Efficiency Technologies

- Reduce energy demand and provide grid flexibility
- Facilitate transition to renewable energy and decarbonize electricity:
    - Heat pumps
    - Waste heat energy recovery
    - Thermal storage
    - Batteries

Digitization

- IoT and predictive AI to increase efficiency and productivity of systems

1. Context

Department of Energy

Biden-Harris Administration Announces Steps to Electrify and Cut Emissions from Federal Buildings

DECEMBER 7, 2022

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To cut carbon emissions, a movement grows to 'electrify everything'

By Jonathan Mingle | News, US News

JEAN GAGNON WIKIPEDIA C.C. 4.0 — A document prepared for Public Services and Procurement Canada titled Roadmap To Low-Carbon Operations in the National Capital Region advises the federal government on decarbonizing its building stock in the region. Pictured: the Transportation Building on Rideau Street at Sussex Drive.

IISD International Institute for Sustainable Development

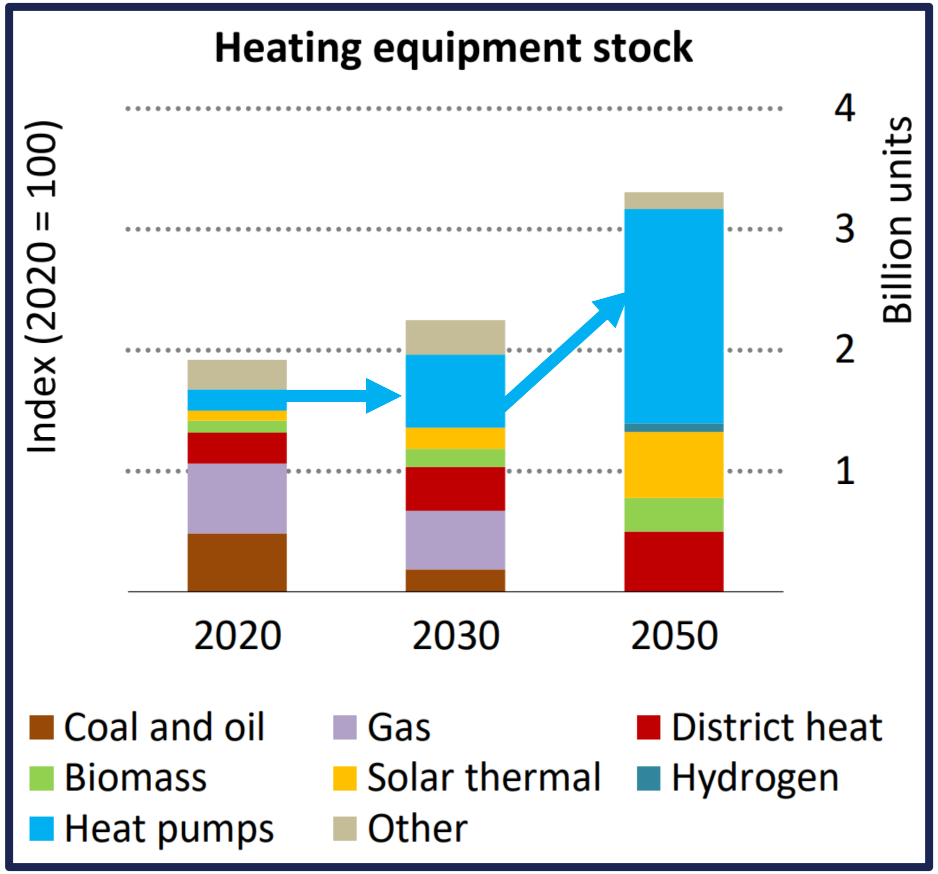
BRIEF

Electrifying Heating in Commercial and Institutional Buildings

Heating buildings is a significant source of greenhouse gas emissions in Canada— emissions that must be mitigated to meet our net-zero targets. About three quarters of this sector's emissions must be eliminated by 2040, and since most heating equipment installed today is likely to still be running then, there is no time to waste.

May 24, 2022

1. Context



Source: International Energy Agency (2022)

BENEFITS OF HEAT PUMP TECHNOLOGY

Building Owners / End Users

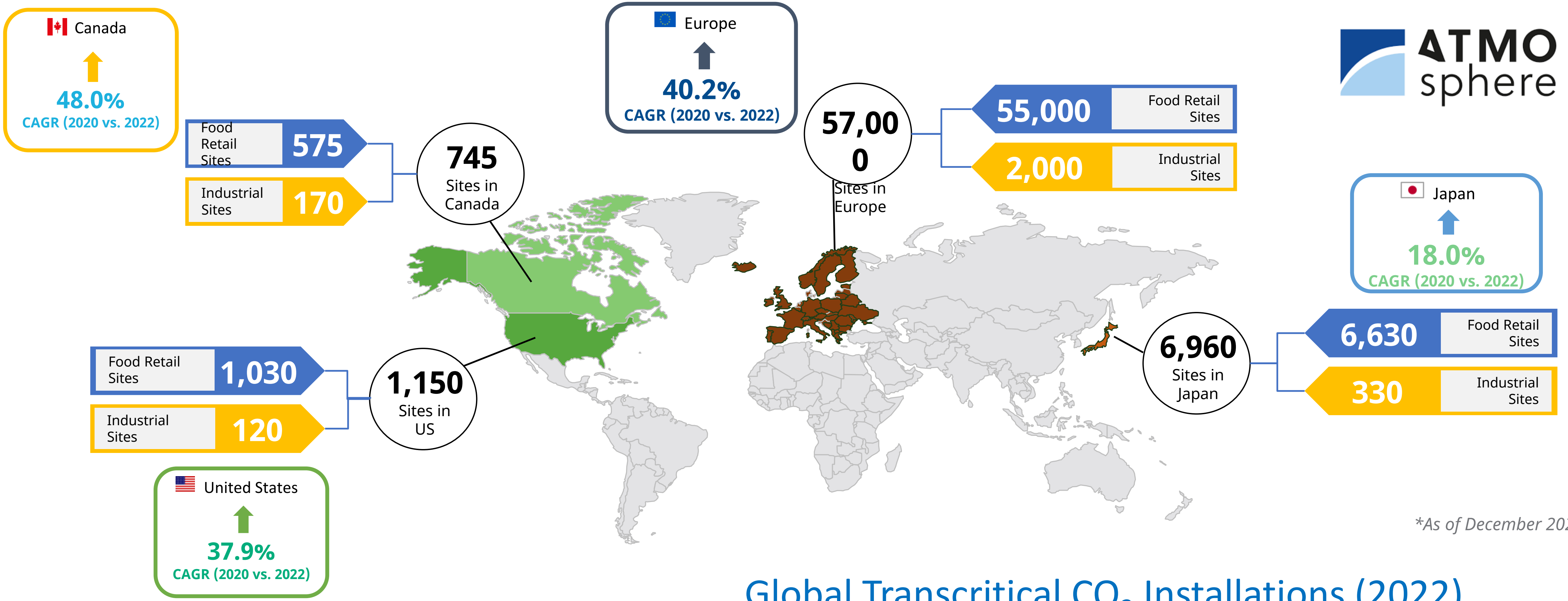
- Energy Efficiency & Peak Demand Mitigation
- Financial Return on Investment & Lifecycle Cost of Ownership
- Greenhouse Gas (GHG) Emissions Reduction

Utilities

- Electricity Network Optimization
- Decoupled Energy Consumption
- Grid Flexibility & Supply / Demand Management

IEA: "50%+ of Global Heating Demand is Met by Heat Pumps in 2045"
Stock of Installed Heat Pumps to Increase from 180M Units in 2020 to 600M Units in 2030

1. Context



*As of December 2022

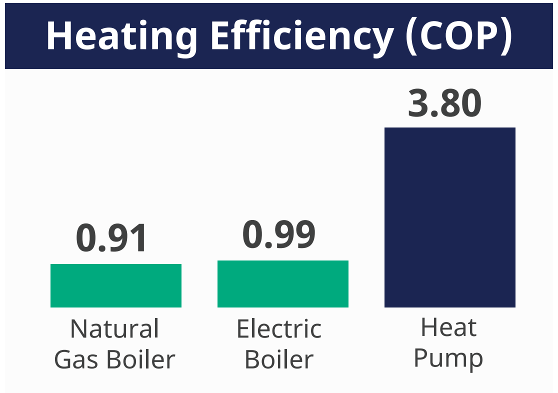
Global Transcritical CO_2 Installations (2022)

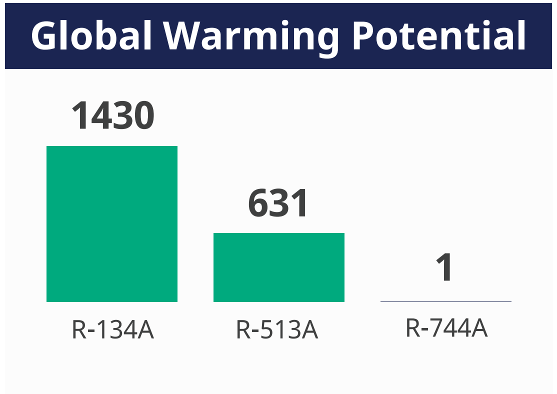
1. Context

Objective: Develop an eco-friendly heat pump solution designed to reduce greenhouse gas emissions and improve energy efficiency while offering load flexibility.

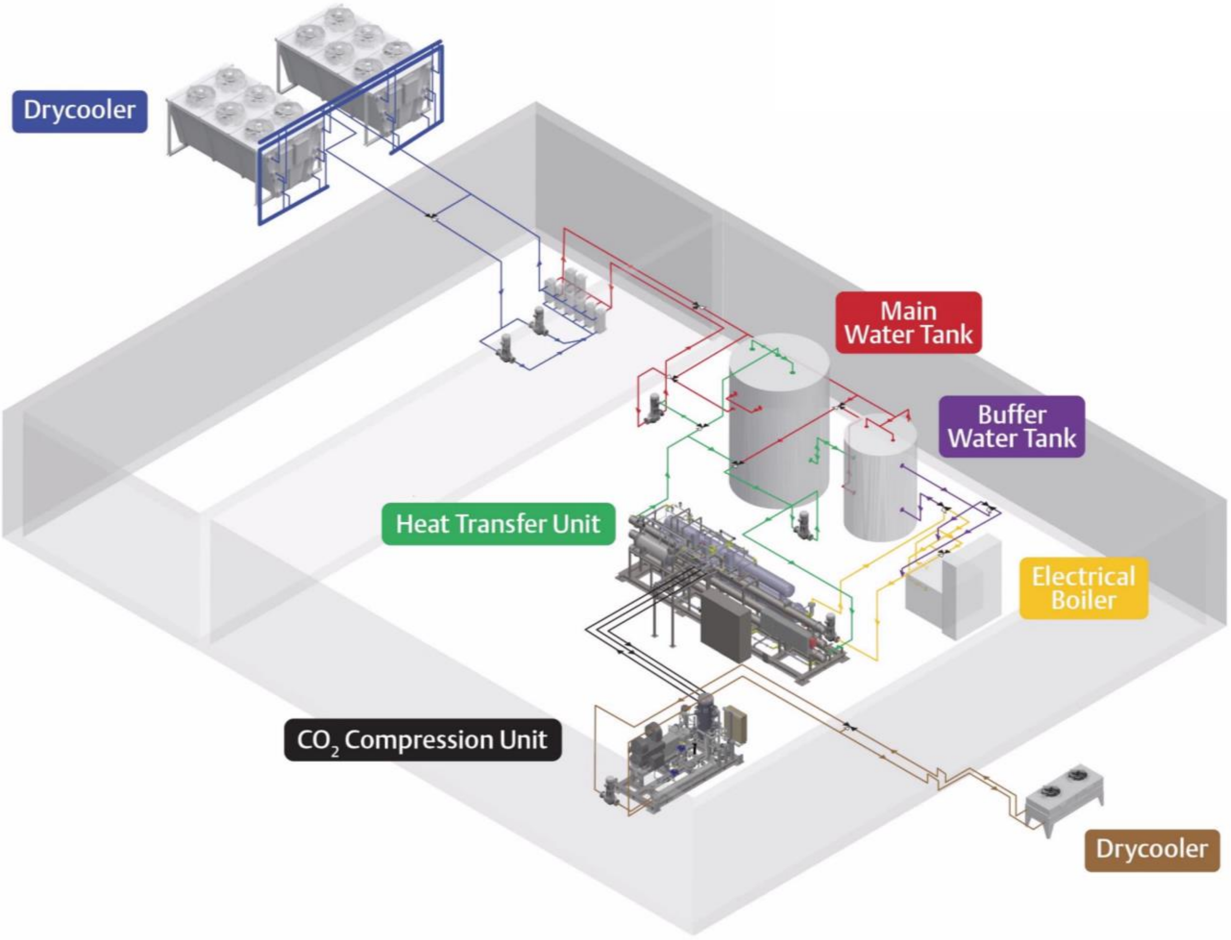
Applications:

- Space Heating
- Domestic Hot Water
- Chilled Water





2. Experimental prototype

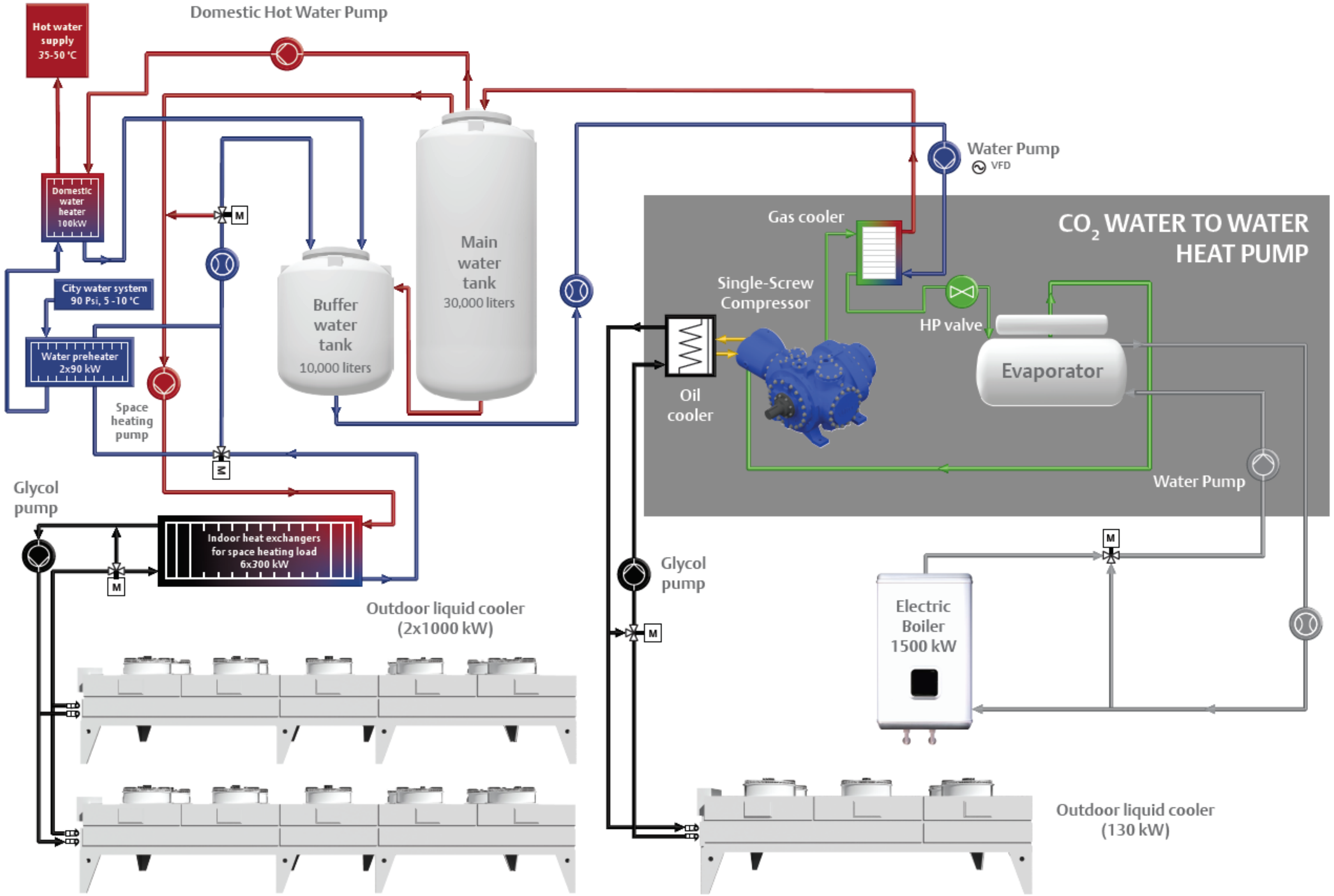


VHP System Overview	(Commissioned in 2020)
System Configuration	Water to Water, Single Stage
Refrigerant	R744 (A1 Safety Class, GWP = 1, ODP = 0)
Controls	Allen Bradley
Compressor	HPLD Single Screw VSS-222 CFM
Maximum Operating Pressure	1,500 psig (103 bar)
Maximum Motor HP / Speed	865 HP (645 kW) / 4,300 RPM
Capacity Modulation	VFD
Certifications	UL & CSA with CRN
Unit Performance	
Heat Source Inlet Temperature	50°F to 70°F (10°C to 21°C)
Heat Sink Outlet Temperature	Up to 160°F (71°C)
Heat Sources	Lake/sea/river, ground, heat recovery, waste heat
Heating / Cooling Capacity	1,362 kW / 0.988 MW
Efficiency (COP)	Up to 4.75 (combined heating and cooling)

12,000+ Hours of Heat Pump Runtime

2. Experimental prototype

2. Experimental prototype



Control

- 3 Allen Bradley PLC, 1 Industrial Computer

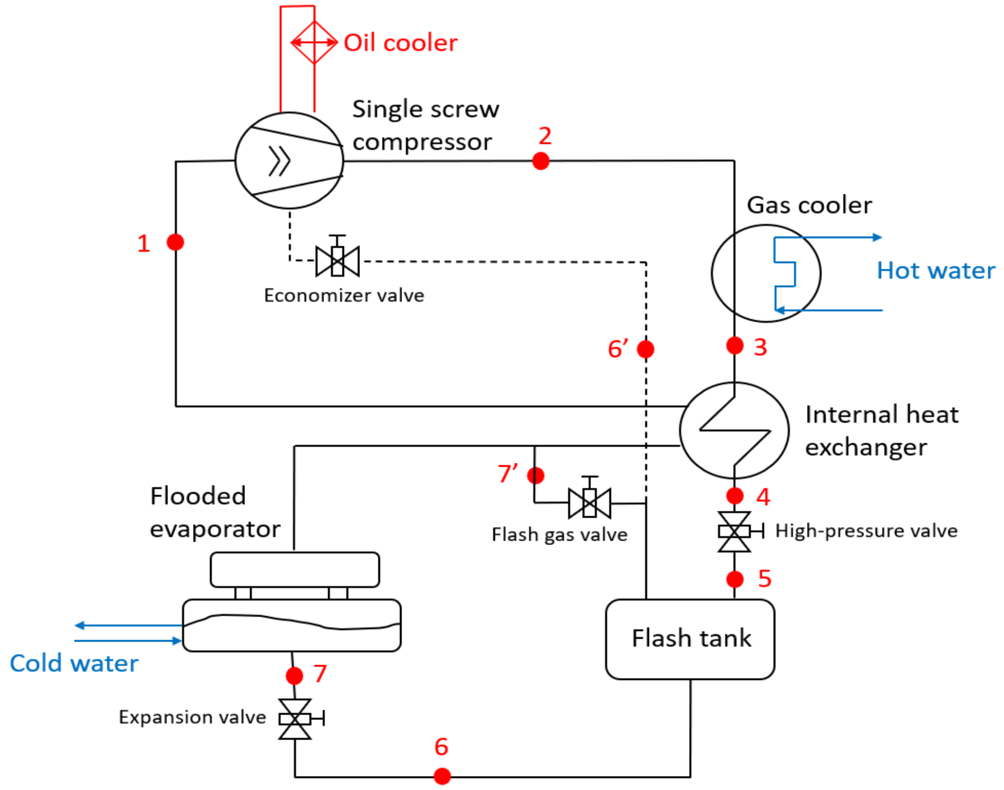
Instrumentation

- Temperatures: 200 pts – accuracy $\pm$0.2°C
- Pression: 50 pts – accuracy $\pm$0.25%
- Flow: 15 pts – accuracy $\pm$0.1% (CO_2) / $\pm$0.5% (water)
- Power: 10 pts
- Others: RPM, Torque, Liquid Level, CO_2 ppm
- Acquisition: Independent Database

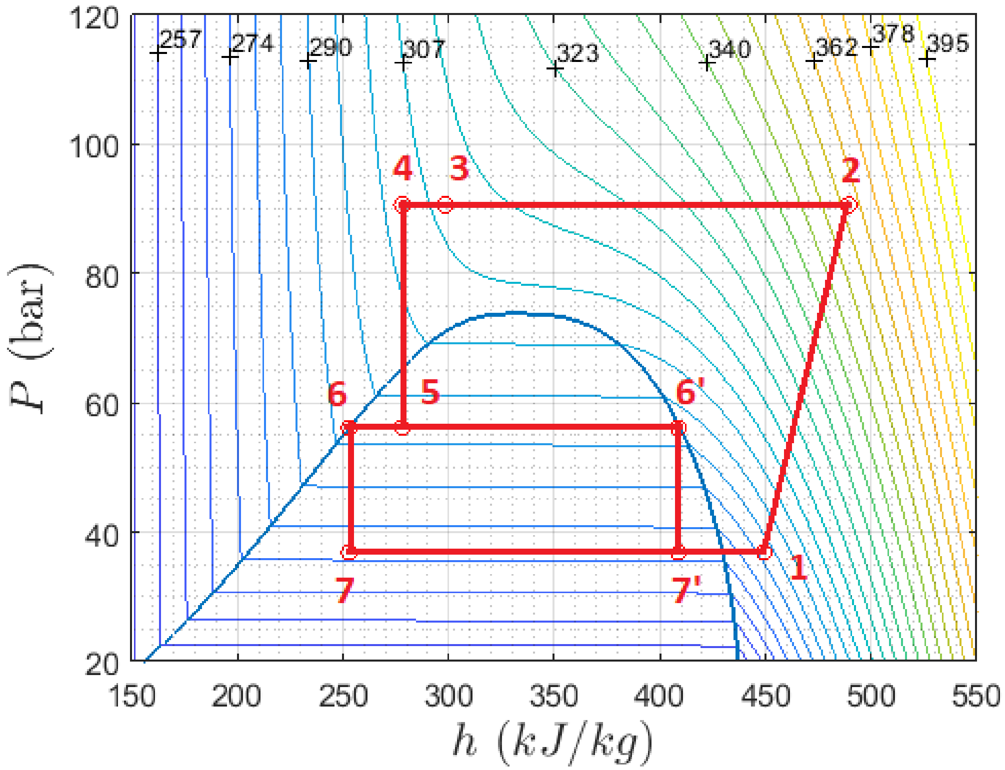
Equipment

- Electrical Boiler (1 boiler x 1.5 MW)
- Thermal Storage:
  - 1 tank x 30 m^3
  - 1 tank x 10 m^3
- Heat Exchangers:
  - 6 exchangers x 300 kW
  - 2 exchangers x 100 kW
  - 1 exchangers x 130 kW
- Outdoor Fluid Coolers:
  - 2 coolers x 1.1 MW
  - 2 coolers x 130 kW
- Compressor: 1 x Single-Screw (222 CFM)

2. Experimental prototype



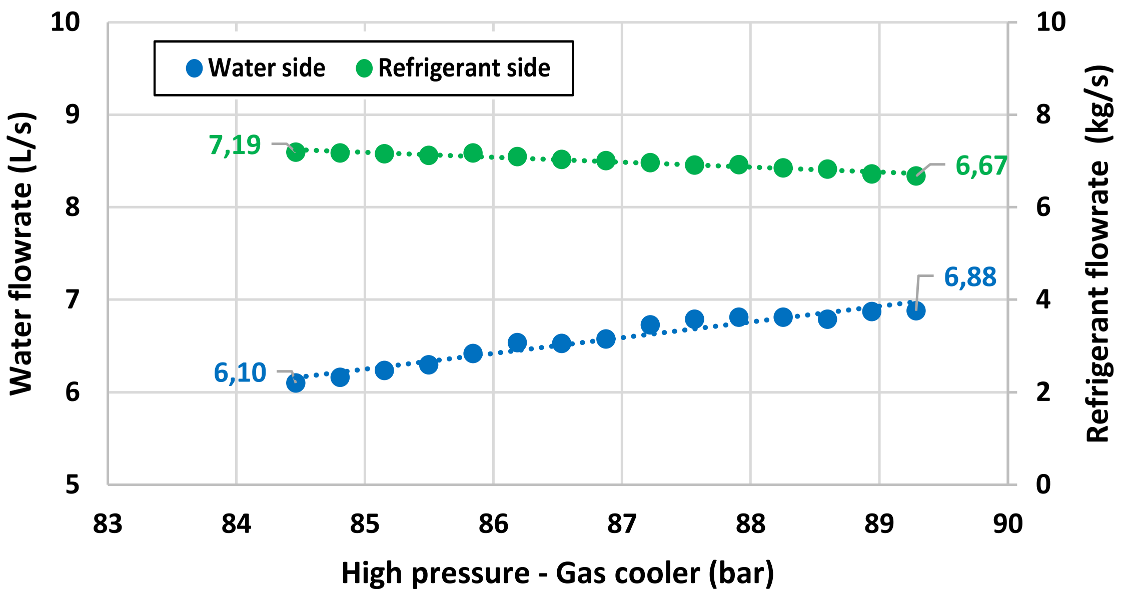
Simplified model of the transcritical CO_2 heat pump

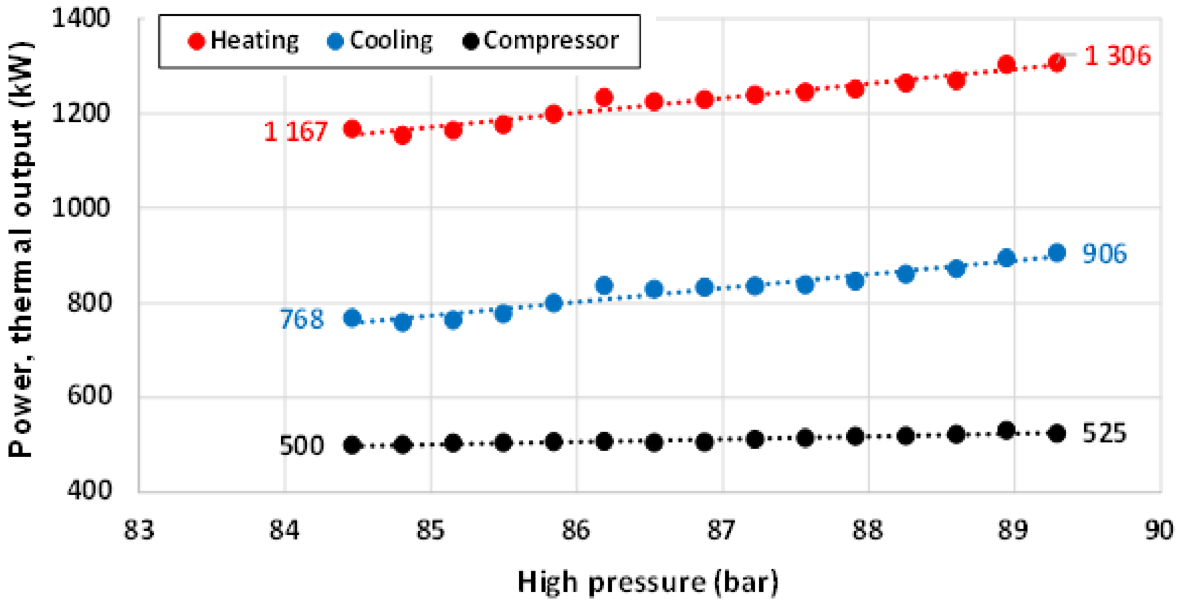


Pressure – enthalpy diagram

3. Results and discussion

Discharge Pressure Effect

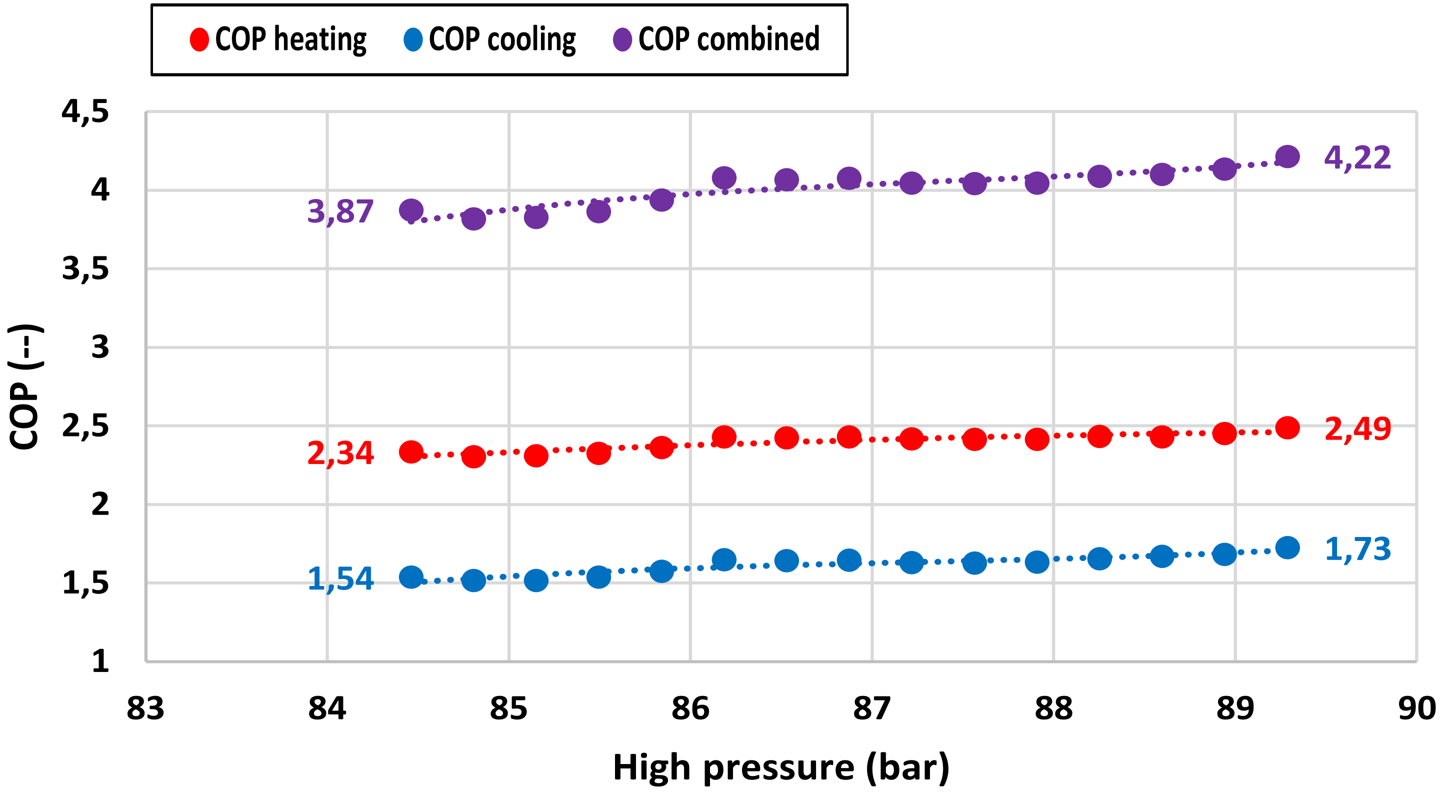




- ❑ When the discharge pressure ↑, the CO_2 mass flowrate gradually ↓ (adjustment of the EEV opening) excessive accumulation of CO_2 in the gas cooler ⇒ the discharge P and T and the heat generated at the gas cooler ↑.
- ❑ When the discharge pressure ↑, the heating and cooling capac. ↑. As the EEV closes, the discharge pressure (and T) ↑, and the suction pressure ↓ (T_{evap} ↓). Thus, water flowrates ↑ in the gas cooler and evaporator to keep the outlet temperatures constant.

3. Results and discussion

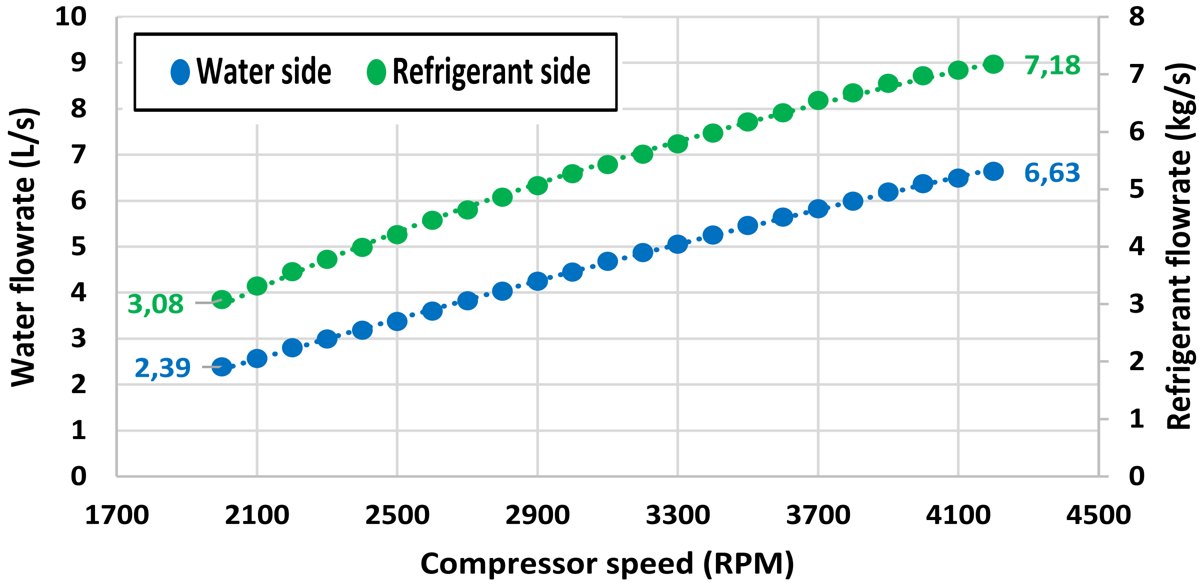
Discharge Pressure Effect

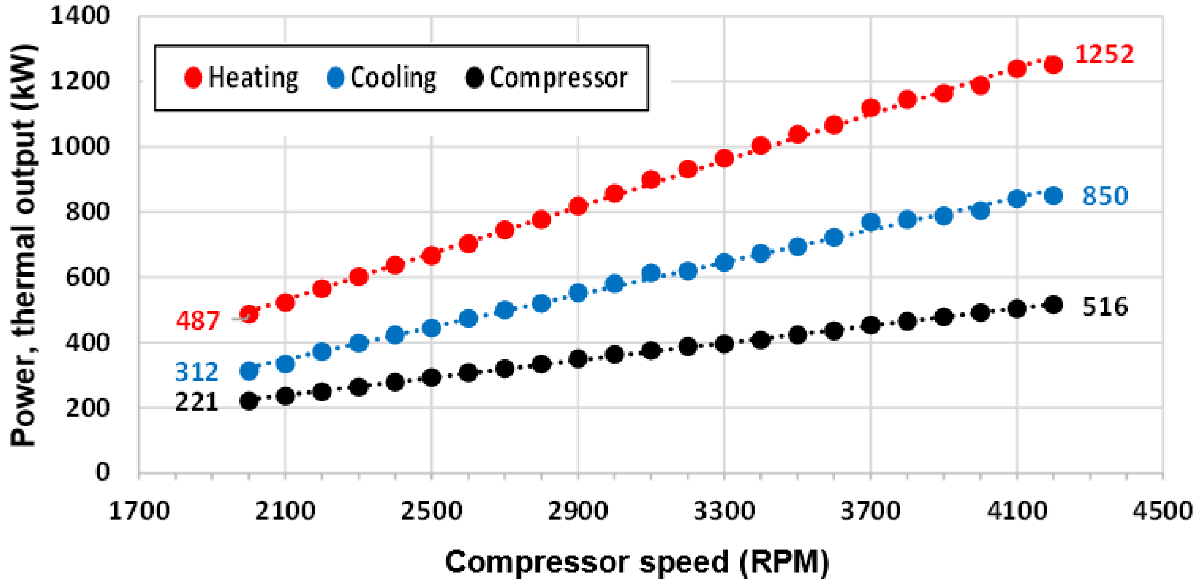


- ❑ When the discharge pressure ↑, the COP ↑ steadily.
- ❑ Since the discharge pressure tested did not exceed 90 bar, its optimum (maximizing the COP) has not been reached.
- ❑ Note that the uncertainty on the COP is 3.92%.

3. Results and discussion

Compressor Speed Effect



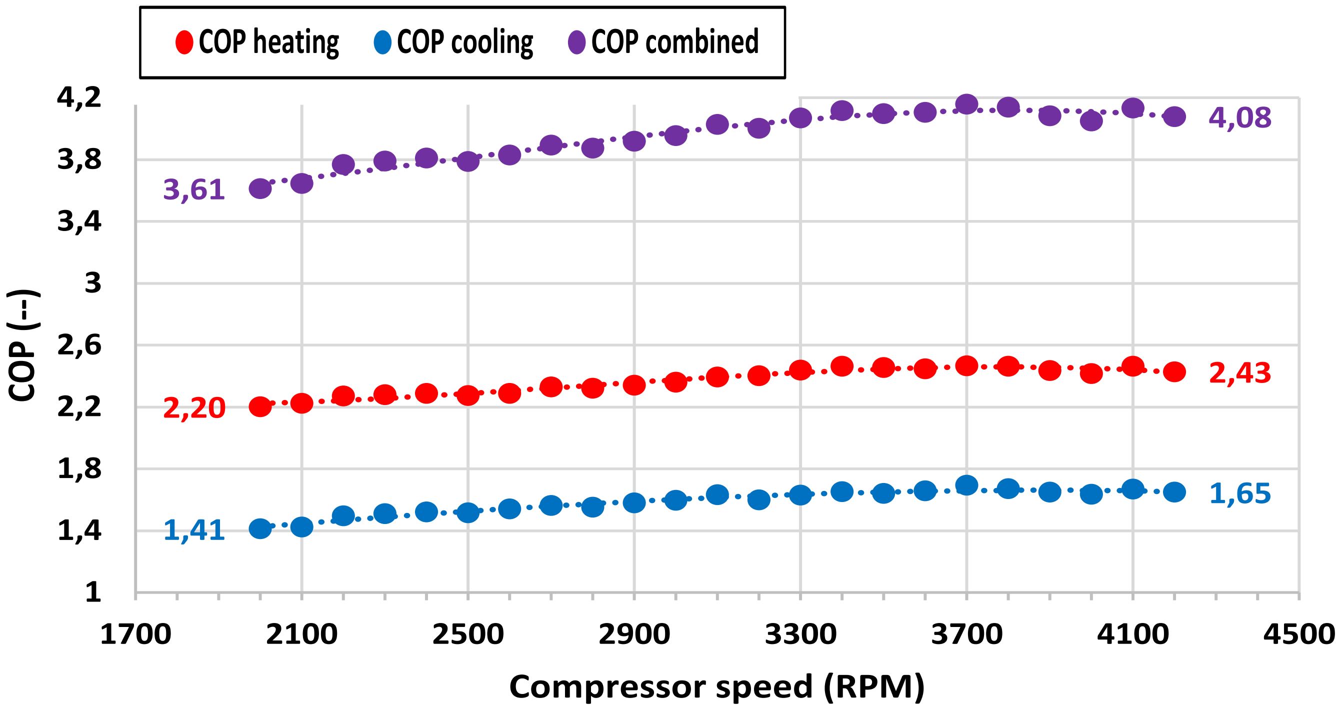


- ❑ As the compressor speed ↑, the EEV opens to maintain the discharge pressure constant. Thus, the refrigerant flowrate ↑ as well as the flowrate of water since more thermal energy must be evacuated.

- ❑ The heating output through the GC ↑ as the compressor speed ↑.
- ❑ When the compressor speed drops from 4200 to 2000 rpm, the power demand is reduced by 57%.

3. Results and discussion

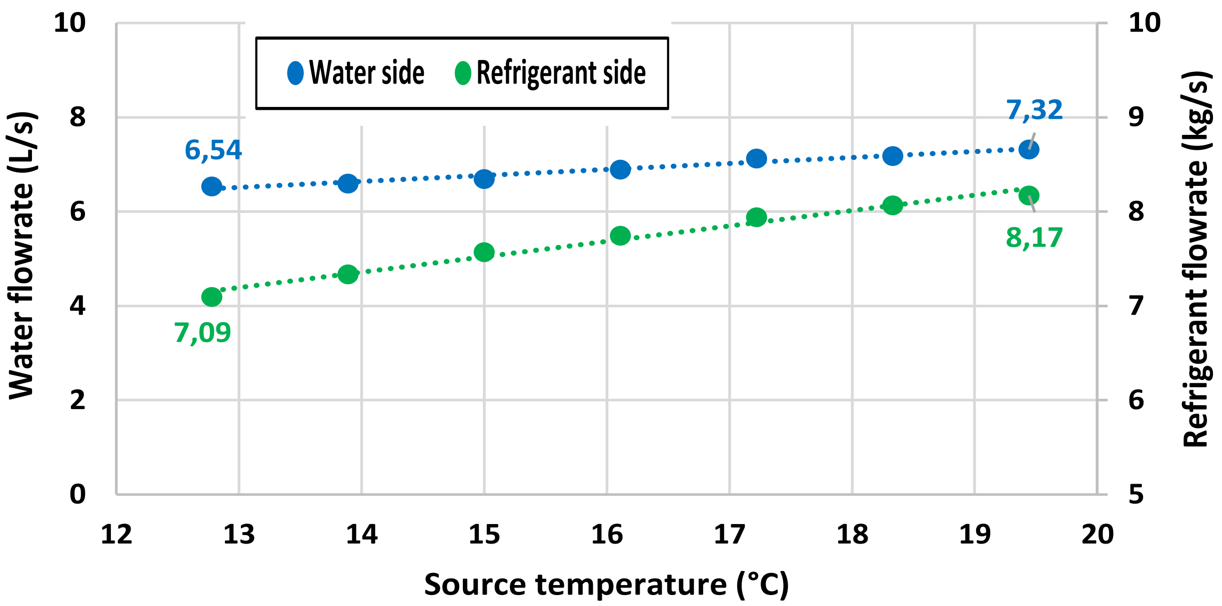
Compressor Speed Effect



- When the compressor speed exceeds 3600 rpm the COP decreases. (60Hz)
- The performance decreases by only 12% when the compressor speed drops from 4200 to 2000 rpm.
- It has an important impact for demand response applications for which the compressor speed variation is an advantage.

3. Results and discussion

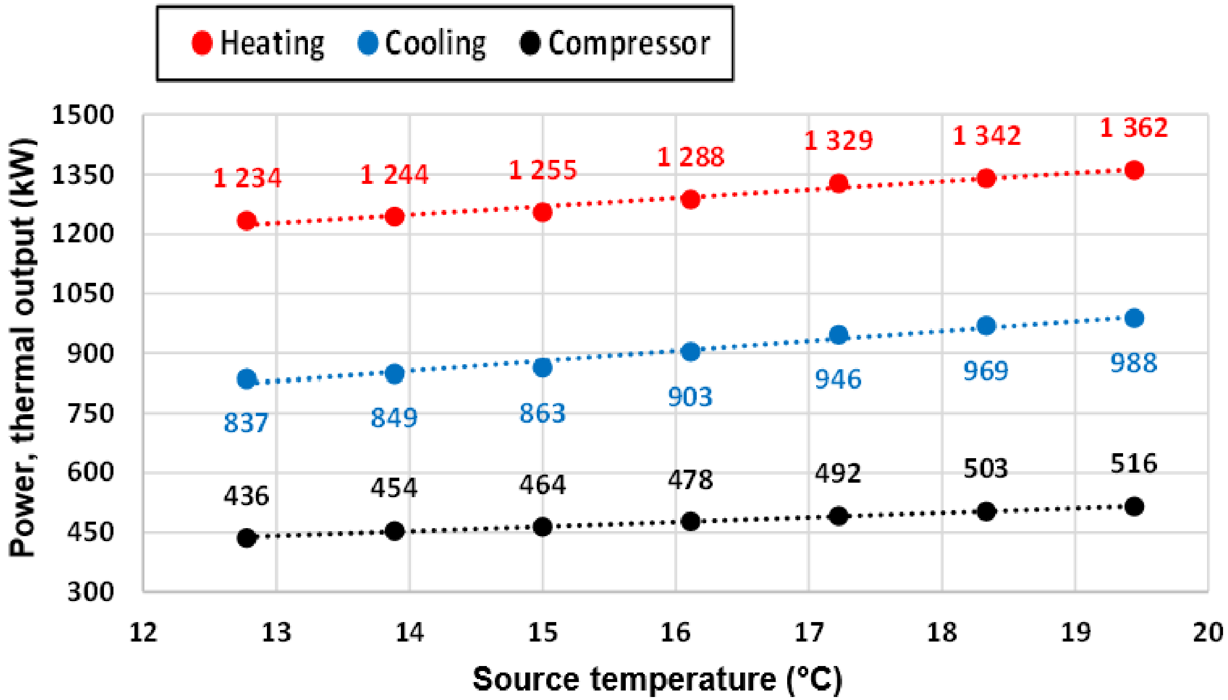
Heat Source Temperature Effect

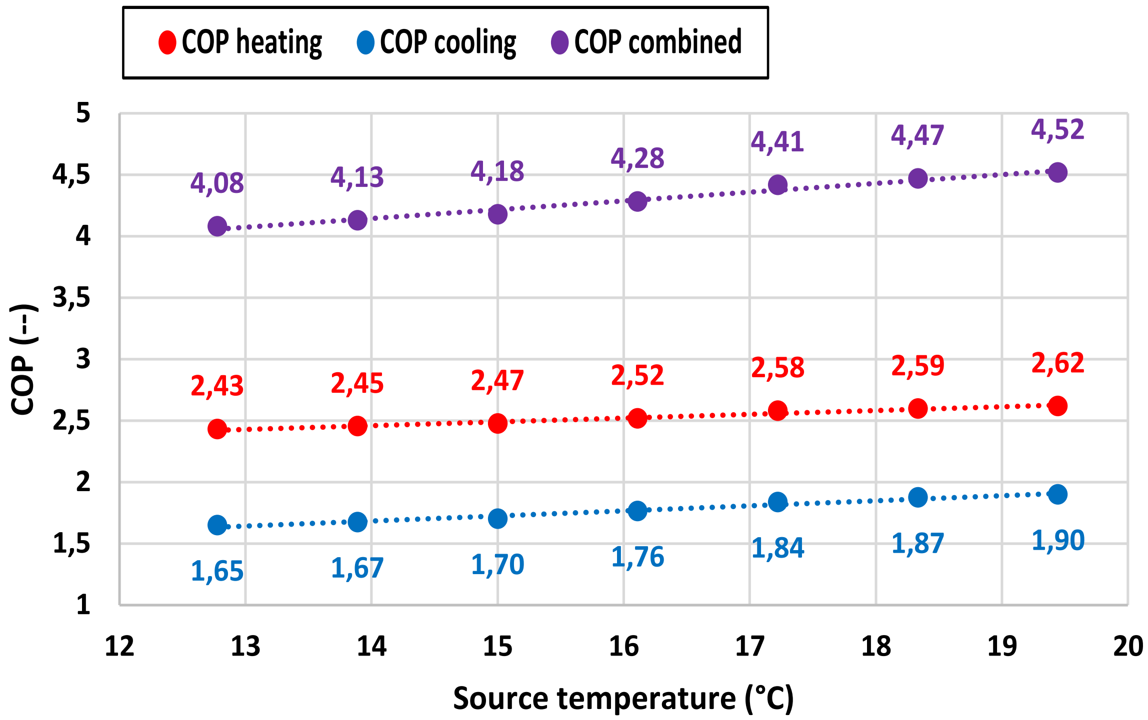


- Heat source temperature is represented by the inlet water temperature at the evaporator. This parameter has been varied from 12°C to 20°C.
- The temperatures at the inlet and outlet of the GC are maintained at 20°C and 60°C, respectively. The compressor speed is set at 4200 rpm and the high pressure is fixed at 86.2 bar.
- When the heat source temperature ↑, the flowrates on both sides of the GC ↑ (enhancement of the evaporating kinetic). Since more heat is absorbed by the evaporator, it is expected that more heat is released at the GC. The water flowrate ↑ to maintain the water outlet temperature at the set-point of 60°C.

3. Results and discussion

Heat Source Temperature Effect

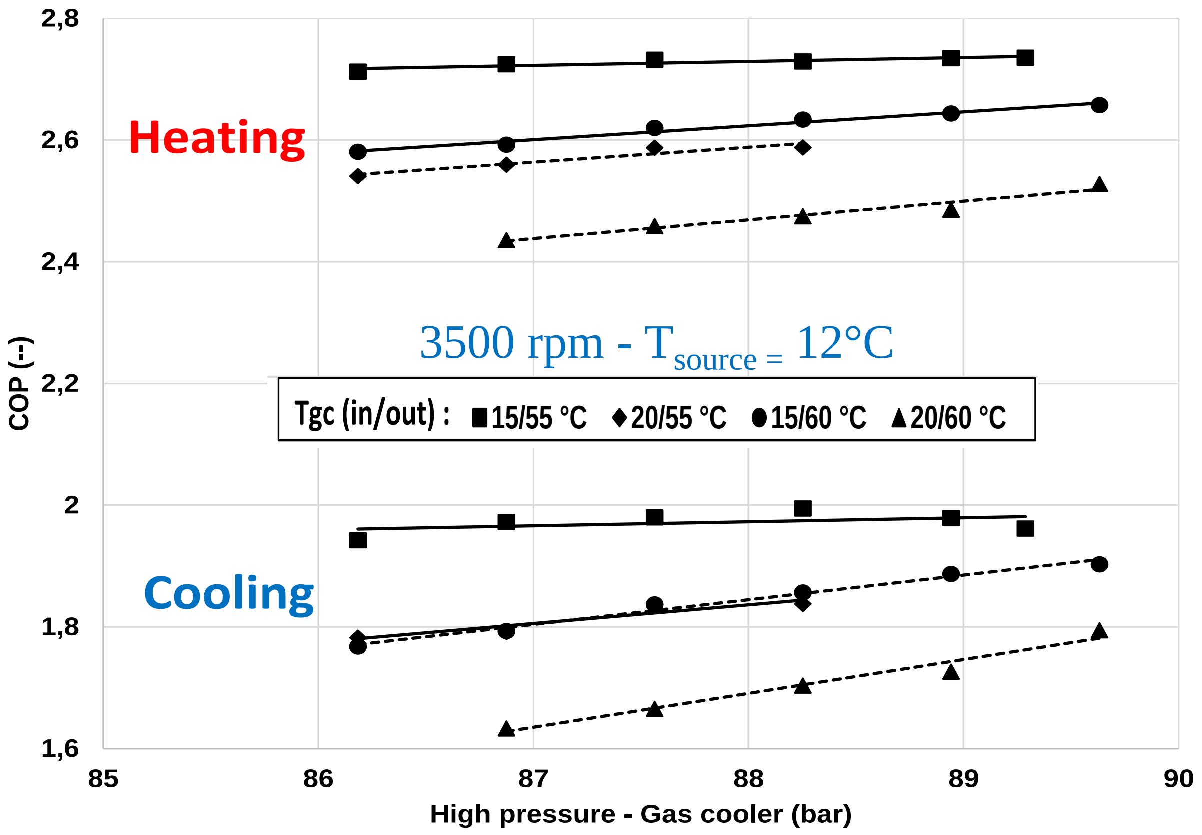




- When the heat source temperature at the evaporator ↑, the heat adsorbed and rejected by the heat pump ↑. The power demand of the compressor ↑ (the refrigerant flowrate ↑ due to an enhancement of the vaporizing process) ⇒ COP ↑.

3. Results and discussion

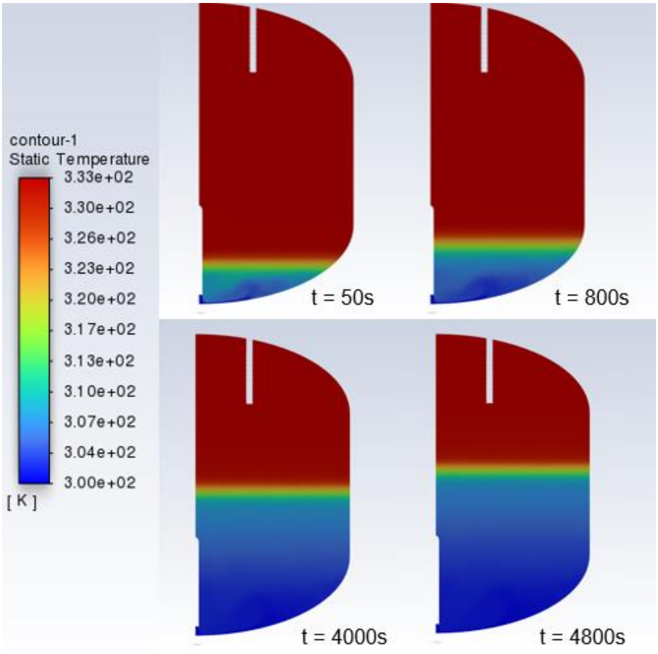
Heat Sink Temperature Effect



- ❑ For a constant outlet temperature at the gas cooler when the inlet temperature ↑, the performance ↓. Since an increase in the inlet temperature results in an increase of the CO_2 temperature at the outlet of the gas cooler, the heat absorbed at the evaporator is less and consequently, the thermal output decreases.
- ❑ When the inlet temperature is kept constant, any reduction in the outlet temperature will lead to an increase of the COP (the water flowrate through the GC ↑ when the outlet temperature ↓).

4. Conclusions and perspectives

- A transcritical CO_2 heat pump has been built at the pilot-scale for heating and cooling of large buildings.
- Thermal storage tanks enable to decouple the thermal load from the heat pump.
- The influences of the discharge pressure, compressor speed, and heat source and sink temperatures on the main performances of the system have been quantified in detail and discussed.
  - Both heating and cooling COPs are increasing as a function of the discharge pressure, compressor speed, and heat source / sink temperatures.
  - The maximum heating and cooling capacities are 1.362 MW and 0.988 MW, respectively.
  - The combined COP is 4.75*. (COP is based on measured heat outputs on the water sides).
    **Managed to reach up to 6.4 combined COP with latest improvements.*
- Future works include:
  - Detailed investigation of the water storage tank and more particularly its optimal design to manage the thermocline.
  - Demand response functionality to provide load flexibility.



Thank you for your attention.

Questions ?