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Seminar 51 - GSHPs using CO_2

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Laboratory Performance of a Prototype CO_2 Ground-Source Air Conditioner (GSAC)

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Session Learning Objectives

- Describe the benefit of using CO_2 as refrigerant in DX-GSHP systems.
- List some important parameters for designing CO_2 DX-GSHP systems.
- For the prototype CO_2 GSAC, discuss the variation of capacity, efficiency, with entering liquid temperature (ELT).
- Compare the efficiency and capacity of the prototype CO_2 GSAC with the R410A GSHP.

this presentation

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Optimized Thermal Systems

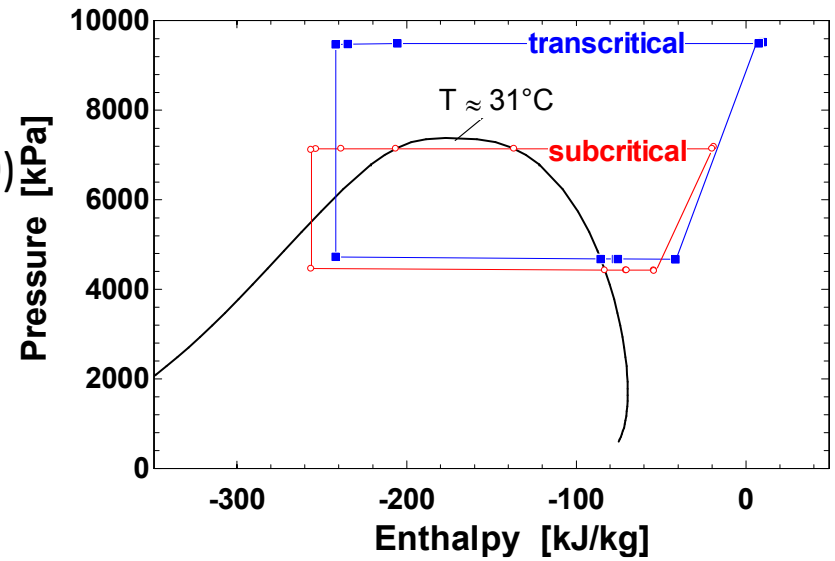
Outline/Agenda

- Using CO_2 as a refrigerant
- Description of prototype CO_2 GSAC
- Test facility & protocol (ISO 13256-1)
- Test results
- Comparison with a R410A GSHP
- Conclusions

Using CO_2 as a refrigerant

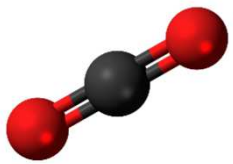
CO_2 as a refrigerant

- Advantages
  - Environmentally friendly (GWP* = 1, ODP* = 0)
  - Non-toxic, non-flammable
  - Low pressure ratio (<2) → high comp. eff.
  - High density → low pressure drop



- Challenges
  - Low critical temperature: $T_c \approx 31$ °C (88 °F)
  - Low thermodynamic cycle efficiency
  - High-pressures: ≈10 000 kPa (1450 psi) @ ELT 40 °C (104 ° F)
  - Subcritical & transcritical operation

    ELT* < 25 °C ELT > 25 °C (77 °F)



***Abbreviations:**

GWP = global warming potential

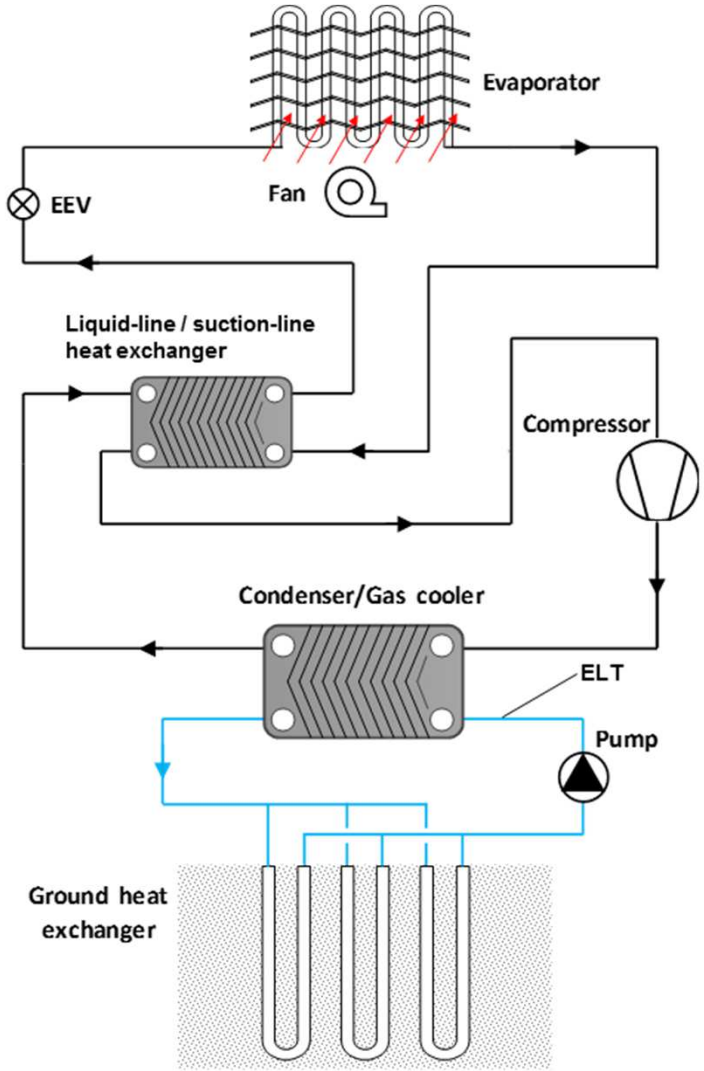
ODP = ozone depletion potential

ELT = entering liquid temperature

Prototype CO_2 GSAC

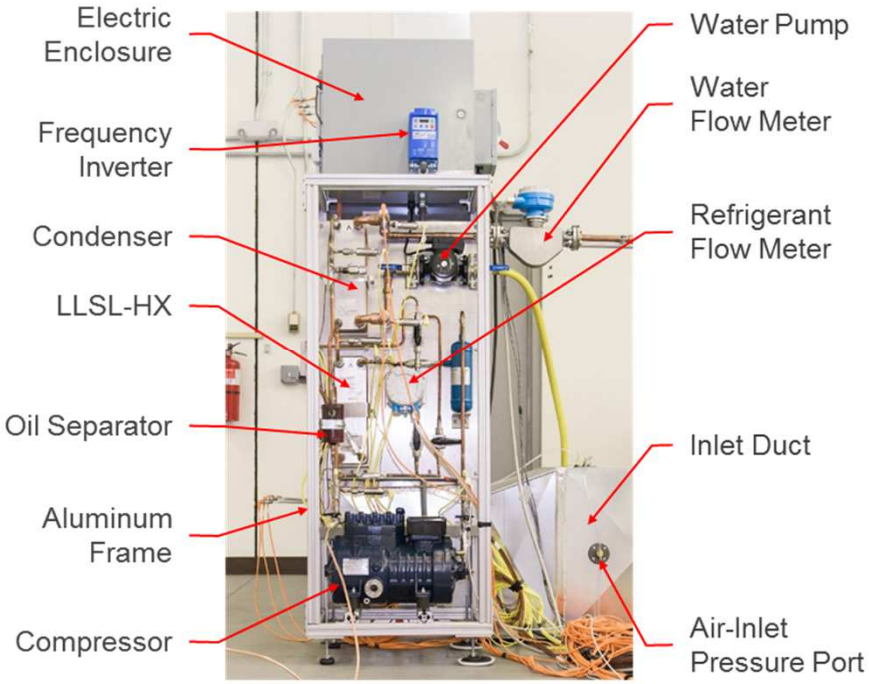
Prototype CO_2 GSAC

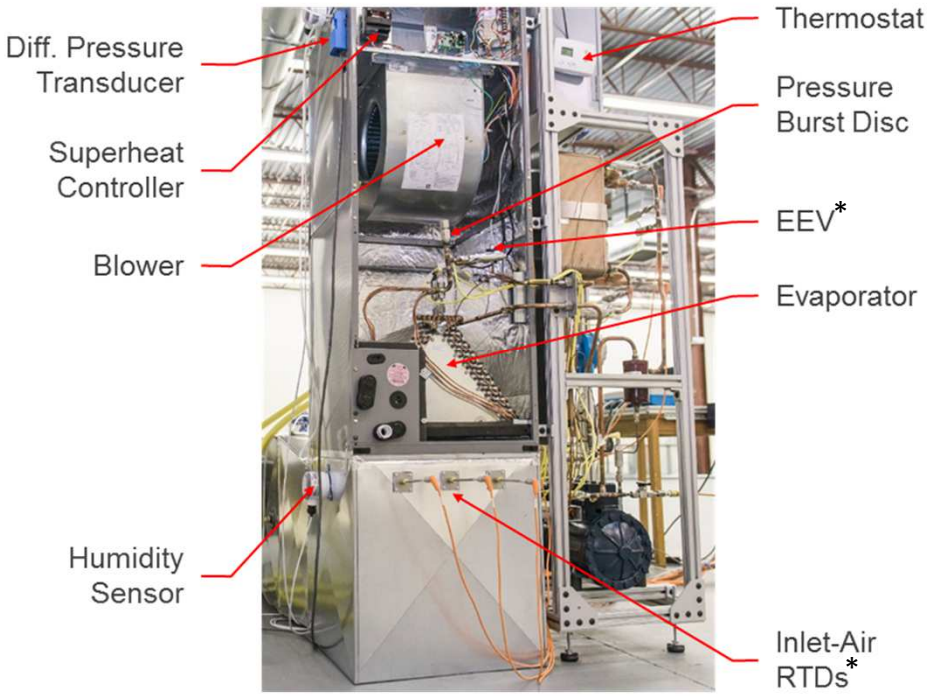
- Residential liquid-to-air GSAC
- Capacity: 5 to 7 kW (1.5 to 2 ton)
- Vapor-compression cycle with liquid-line / suction-line heat exchanger (LLSL-HX)
- Cooling only
- Plate heat exchangers
  - Condenser / gas cooler
  - LLSL-HX
- Fin-tube evaporator
- Reciprocating compressor (semi-hermetic)



Prototype CO_2 GSAC

- MAWP - High side: 12 000 kPa (1740 psi), Low side: 7000 kPa (1015 psi)
- Component specifications available in forthcoming NIST Technical Note [1]





***Abbreviations:**

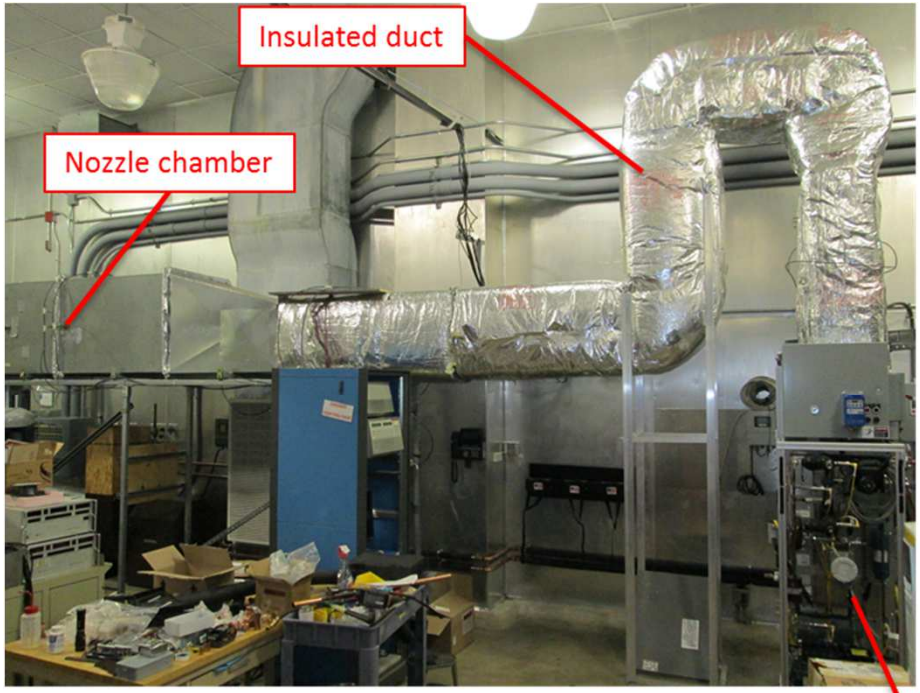
EEV = electronic expansion valve

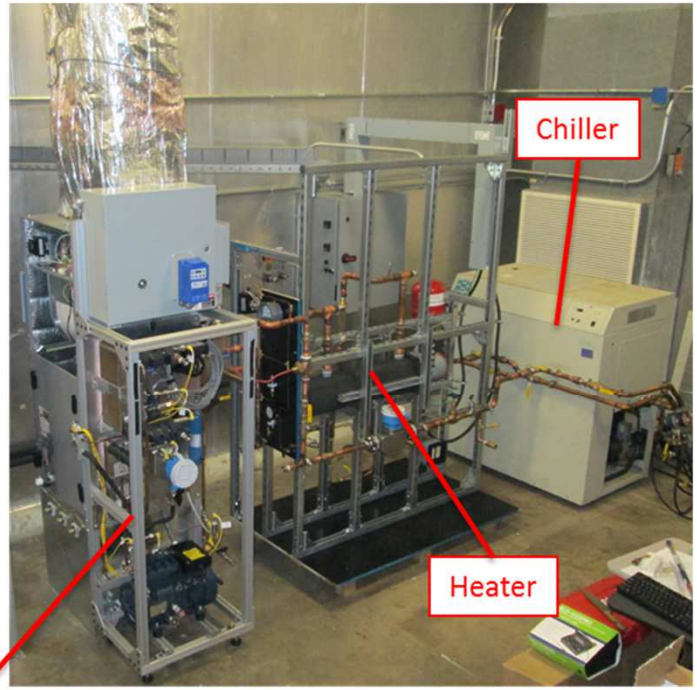
RTD = resistance temperature detector

Test facility & protocol

Test facility

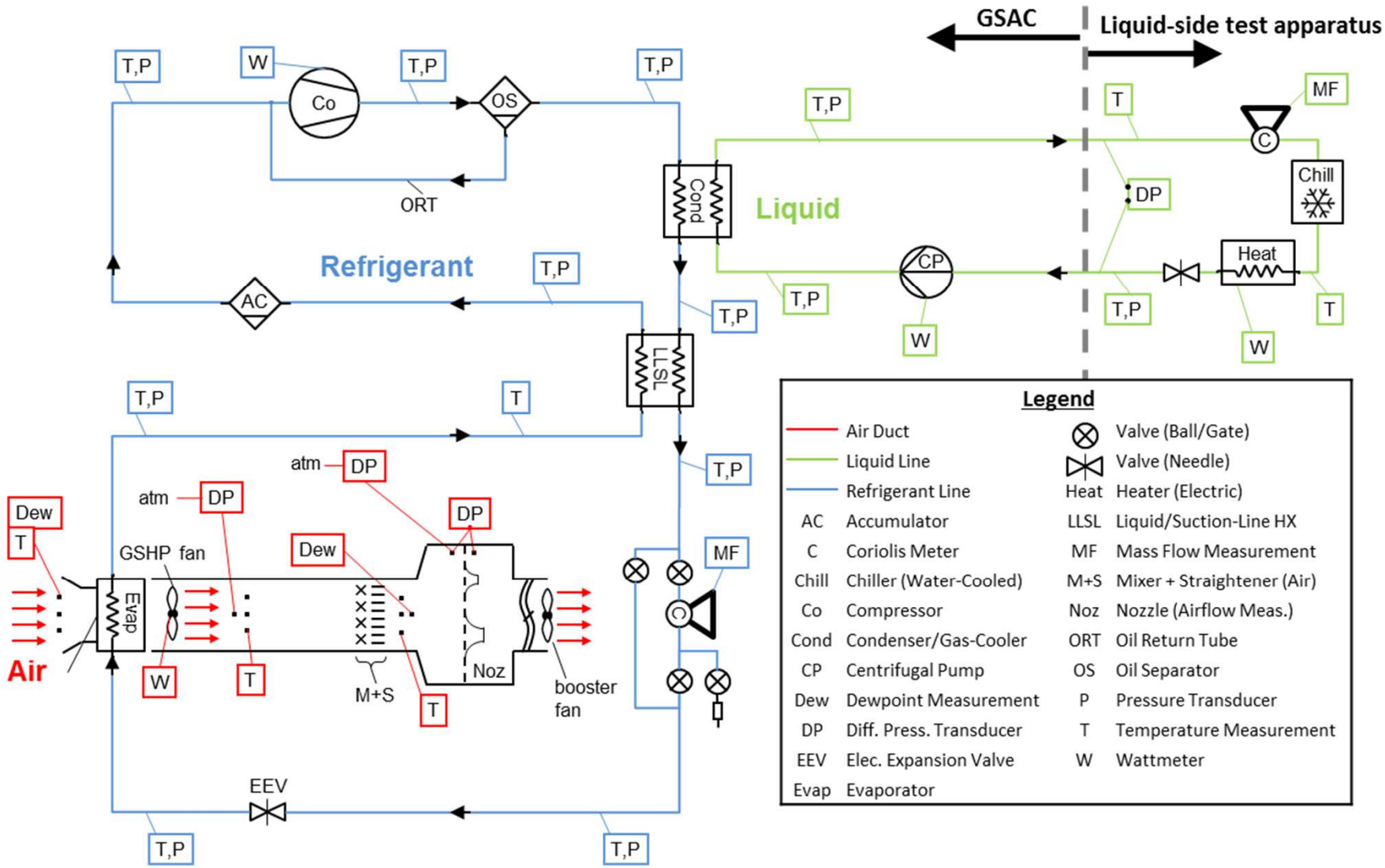
- System tested inside an environmental chamber
- Measured capacity (latent/sensible), electricity, COP
- Controlled airflow, drybulb, dewpoint, liquid flow, entering liq. temp (ELT)





GSAC

Test facility - measurements



Test protocol

- ISO 13256-1: Standard for water-source heat pumps [2]
- Ground loop antifreeze: water/ethanol/isopropanol (70/25/5 %)

Test Conditions

	Standard	Part-load	Maximum	Minimum
Drybulb, °C (°F)	27 (81)		32 (90)	21 (70)
Dewpoint, °C (°F)	14.7 (59)		19.2 (67)	11 (52)
Airflow, L/s (ft^3/min)	342 (725)			
Static pressure, Pa (in H_2O)	58 (0.25)			
Liquid flow, L/min (gal/min)	17 (4.5)			
Entering liq. Temp., °C (°F)	25 (77)	20 (68)	39 (102)	10 (50)

Test protocol

- ‘Extended’ tests - additional liquid temperatures

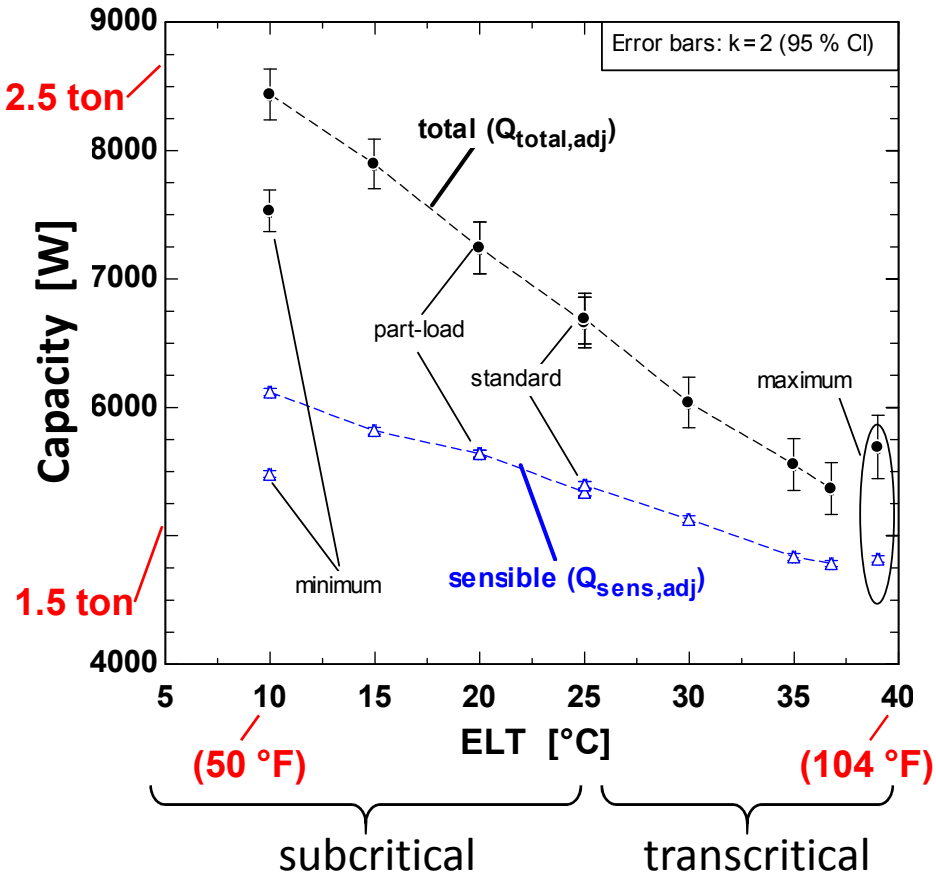
Test Conditions

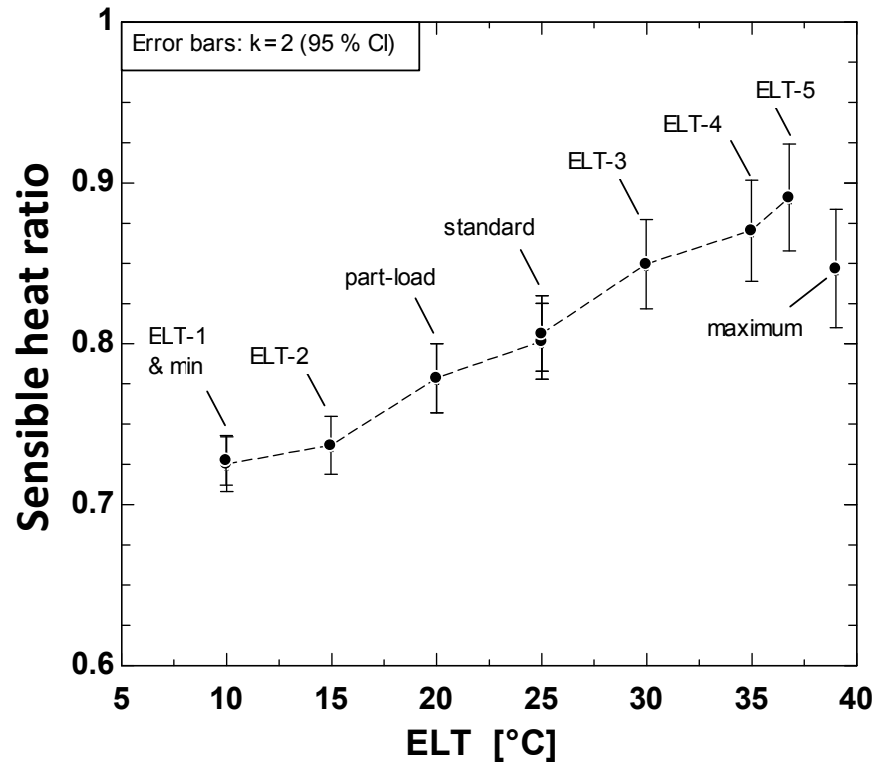
	ELT-1	ELT-2	ELT-3	ELT-4	ELT-5
Drybulb, °C (°F)	27 (81)				
Dewpoint, °C (°F)	14.7 (59)				
Airflow, L/s (ft^3/min)	308 (650)				
Static pressure, Pa (in H_2O)	58 (0.25)				
Liquid flow, L/min (gal/min)	21 (5.5)				
Entering liq. Temp., °C (°F)	10 (50)	15 (59)	30 (86)	35 (95)	36.8 (98)

Test results

Test results - Capacity & Sensible Heat Ratio

- Capacity and SHR include adjustments to fan & pump power, per ISO 13256-1





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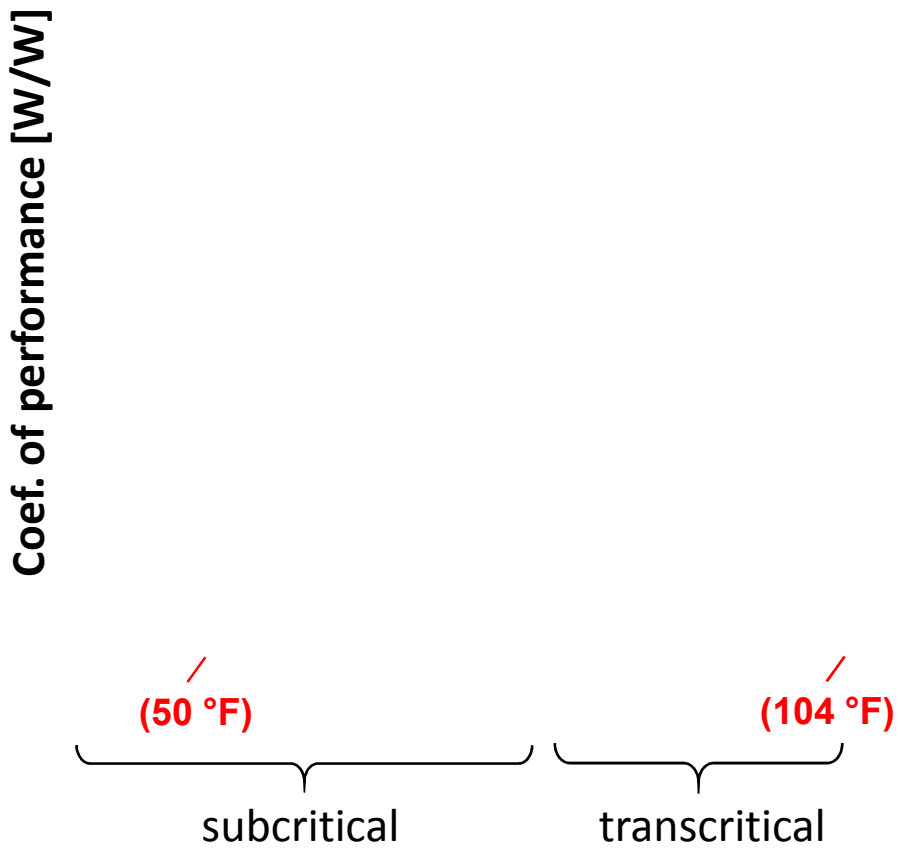
Test results - Coefficient of Performance

- COP includes adjustments to fan & pump power, per ISO 13256-1



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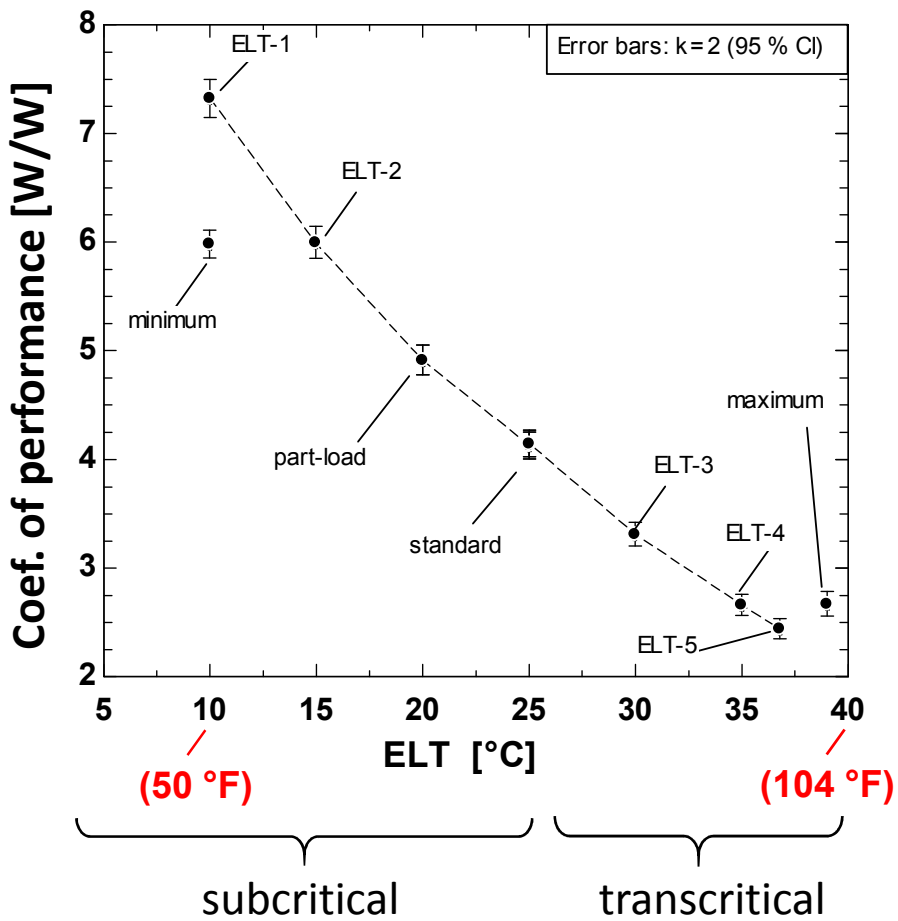
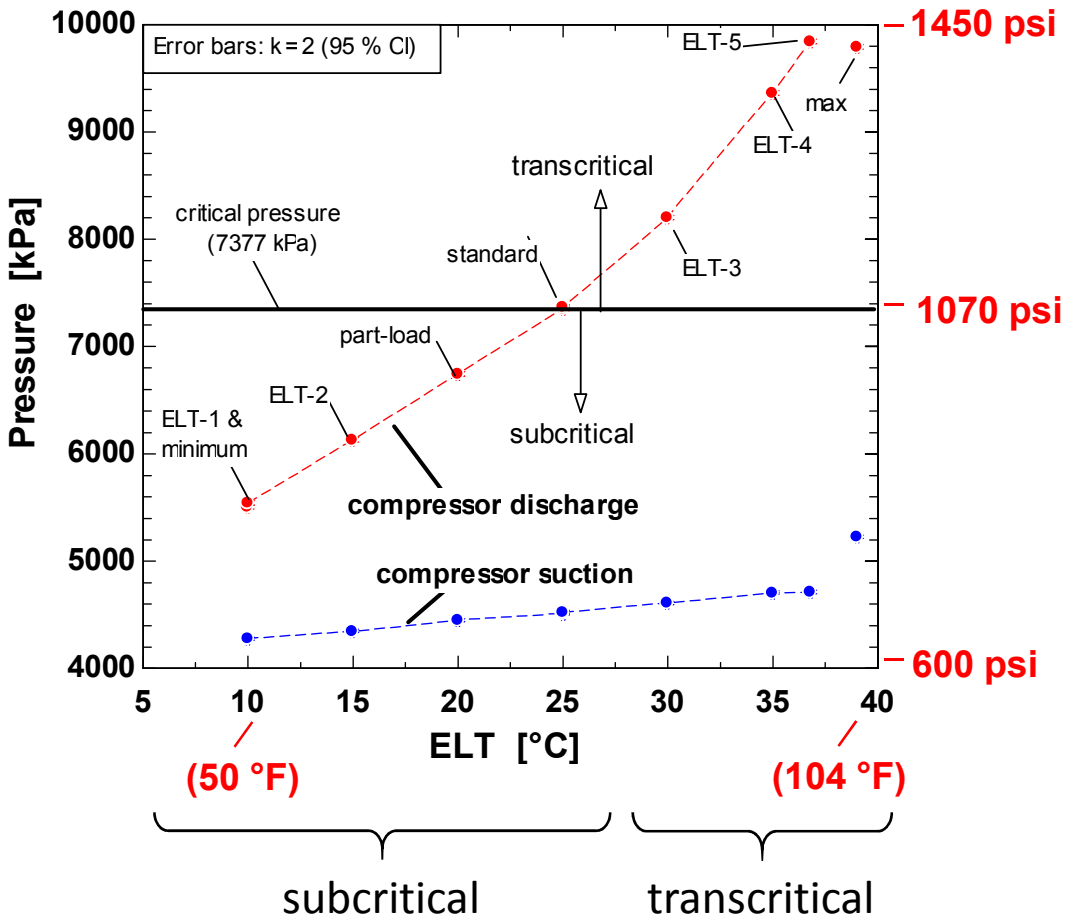
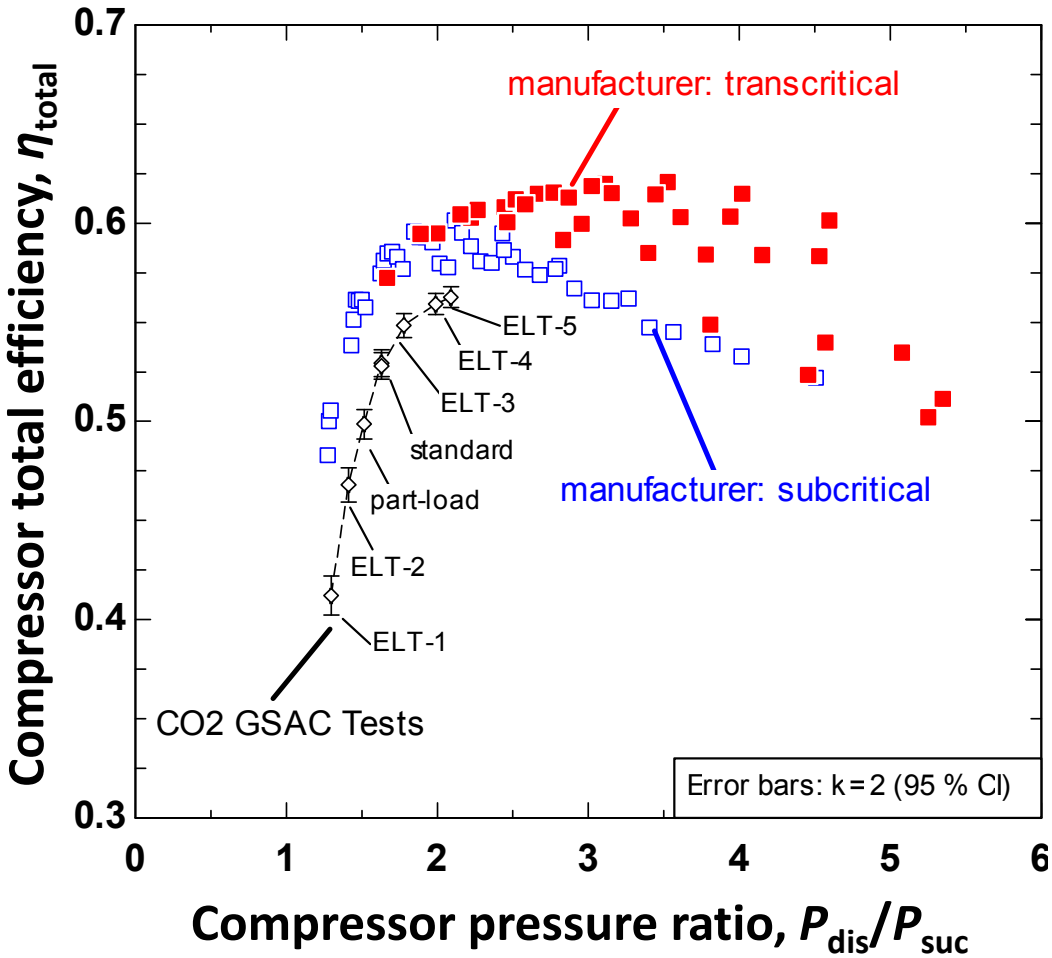


Test results - Pressure



Test results - Compressor Efficiency

- Compressor efficiency $\eta_{total} = m_{ref} \cdot \Delta h_{isen} / W_{elec}$ [3]



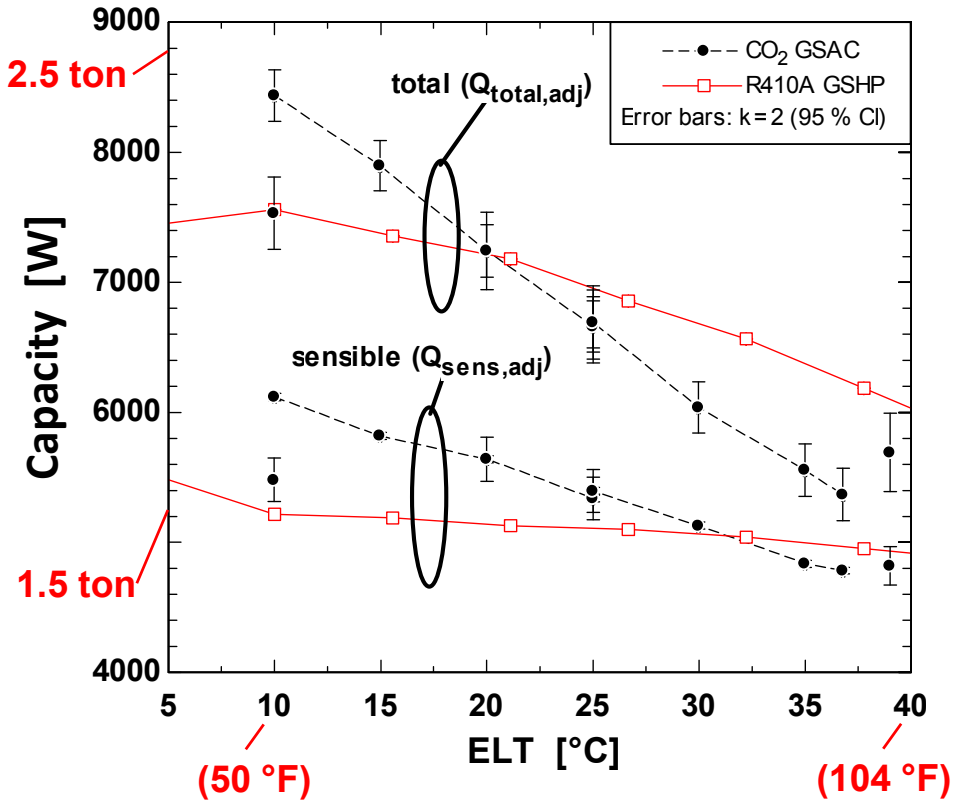
Comparison with R410A GSHP

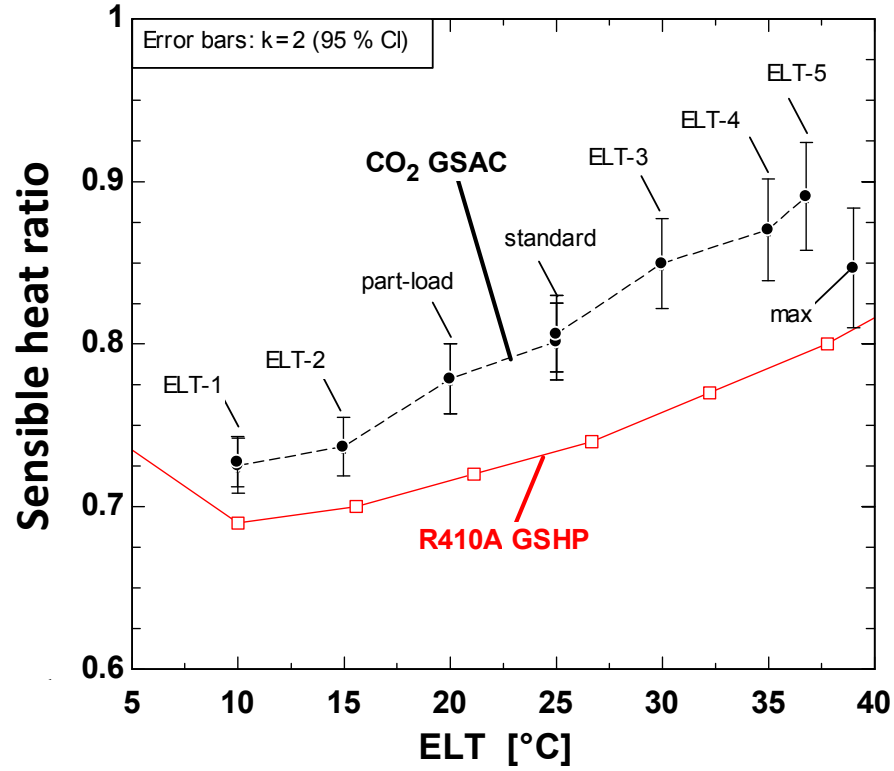
Comparison with R410A GSHP

- Compared CO_2 GSAC with a R410A GSHP
- R410A GSHP
  - Similar size: 7000 W (2 ton)
  - Commercially available
  - Entry-level price (low cost)
  - Data from manufacturer's website [4]

Comparison with R410A GSHP

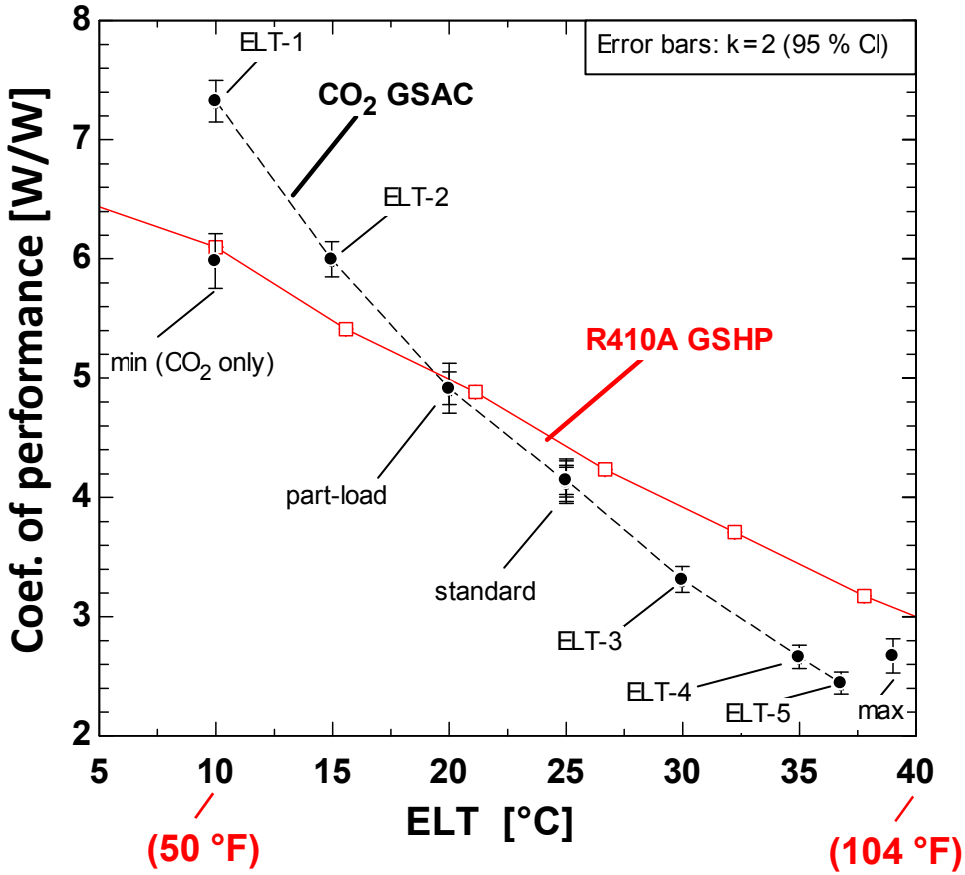
- CO_2 GSAC had lower capacity w/ ELT > 20 °C (68 °F)
- CO_2 GSAC had higher SHR





Comparison with R410A GSHP

- CO_2 system had lower COP w/ ELT > 20 °C (68 °F)



Conclusions & future work

Conclusions

- Tested prototype CO_2 GSAC in cooling, ISO 13256-1
- Measurements: capacity, COP, SHR, pressures, compressor efficiency
- Transcritical cycle when ELT > 25 °C (77 °F)
- CO_2 GSHP vs. R410A GSHP
  - CO_2 GSAC had lower capacity & COP with ELT > 20 °C (68 °F)
  - CO_2 GSAC had higher SHR
- Additional work required to make CO_2 system competitive

Future work

- Increase CO_2 GSAC efficiency
  - Ejector
  - Compressor design (leverage low pressure ratio)
  - Heat exchanger design (leverage low pressure drop)
- CO_2 system in heating mode

Bibliography

[1] Skye, H.M., Wu, W., “Laboratory Tests of a Prototype Carbon Dioxide Ground-Source Air Conditioner”, NIST Technical note, expected publication 2019.

[2] ISO, “ISO 13256-1:1998 Standard for Water-source heat pumps -- Testing and rating for performance -- Part 1: Water-to-air and brine-to-air heat pumps.” International Standards Organization, 1998.

[3] ASHRAE Handbook: HVAC Systems and Equipment. Amer. Soc. Heating, Ref. Air-Conditioning Eng. Inc., p. 38.3, 2016.

[4] Waterfurnace, “Waterfurnace Specifications Catalog: 3-Series 300A11.” 2018.

Questions?

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