Performance Investigation of a Dual-Source Heat Pump for a Swine Nursery Barn in Northern Italy

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Presentation Outline

- Introduction
- System design and description
- Methodology
- Experimental results
- Seasonal Coefficient Of Performance
- Digital capacity operation
- Conclusions

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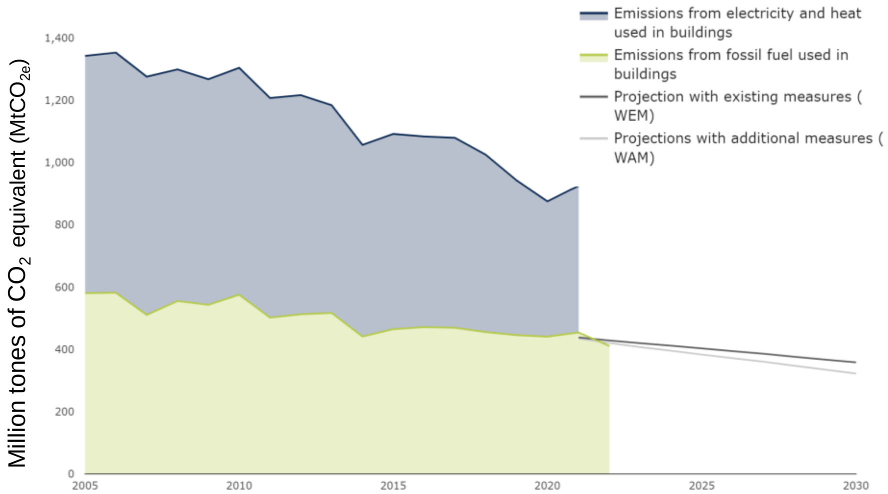
Introduction

General Context



European Environment Agence (EEA). Greenhouse gas emissions from energy use in buildings in Europe. 24 Oct 2023: https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-energy

- **Buildings contribute to ~40% of global carbon emissions – decarbonizing heating is crucial.**

- **Heat pumps (HPs) are efficient electric devices gaining momentum due to government initiatives to more sustainable solution.**

Introduction

Focusing on livestock buildings…

- **Major source of greenhouse gas (GHG) emissions, especially intensive livestock and husbandry facilities due to:**
  - High energy consumption
  - Extensive use of fossil fuels

Replace current technologies with reliable RES solutions to consume less energy and improve the thermal conditions

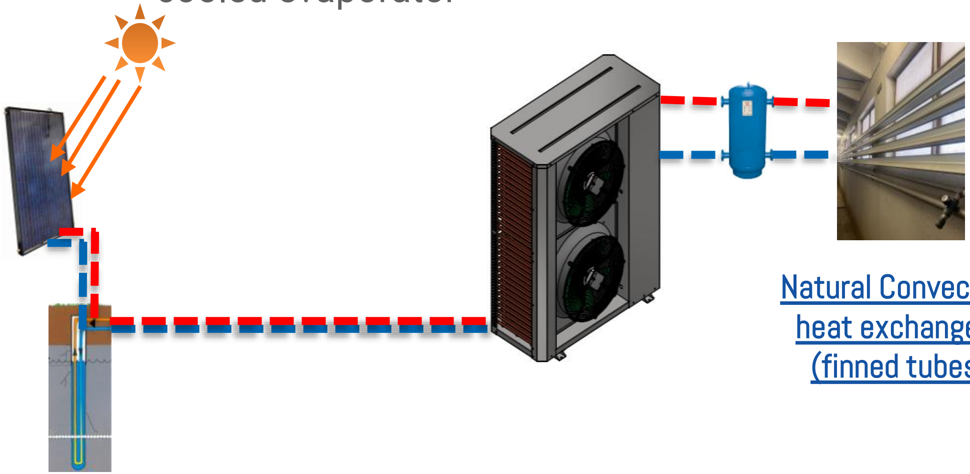
Scope of the work

Replacement of a 35 kW LNG boiler of a nursery barn

With

- Multisource (air/water) heat pump with **hybrid** operation
- Medium temperatures (up to 45 oC) for higher COP
- Sources: Geothermal and solar for water | Air-cooled evaporator

Nursery Barn in Northern Italy



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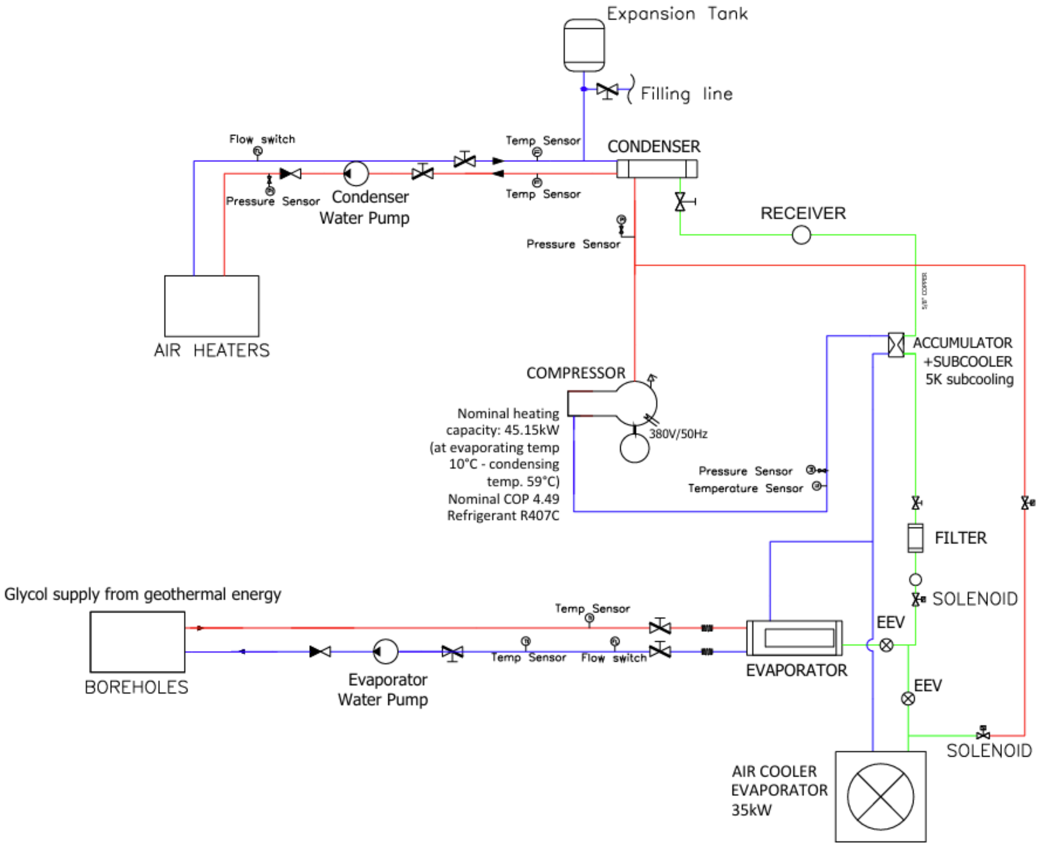
System design and description

Cycle Design Parameters

- **Refrigerant R407C**
- Condensing temperature: 58 °C
- Evaporating temperature: 13 °C
- Superheat / subcooling: 10 K / 5 K
- Pinch point: 3 K
- Specified water flowrates

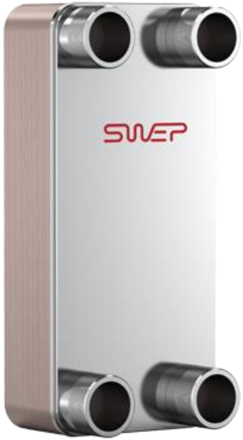
Water/ glycol flow	Temperature (°C)	Flowrate (m3/h)
Evaporator (in / out)	20 / 15	6.4
Condenser (in / out)	45 / 55	3.9



System design and description

Plate HEXs used for efficient heat transfer:

Heat exchanger	Model	Plates	Surface (m^2)
Condenser	B85H	100	5.88
Evaporator	B80H	80	4.68



Design conditions

Condenser

DUTY REQUIREMENTS		Side 1		Side 2
Fluid		R407C		Water
Flow type			Counter-Current	
Circuit		Inner		Outer
Heat load	kW		45,15	
Inlet vapor quality		1,000		
Outlet vapor quality		0,000		
Inlet temperature	°C	70,00		45,00
Condensation temperature (dew)	°C	58,00		
Subcooling	K	2,00		
Outlet temperature	°C	51,83		55,00

Evaporator

DUTY REQUIREMENTS		Side 1		Side 2
Fluid		R407C		Ethylene Glycol - Water (20,0 mass%)
Flow type			Counter-Current	
Circuit		Inner		Outer
Heat load	kW		35,10	
Subcooled liq. temp.	°C	43,00		
Inlet vapor quality		0,268		
Outlet vapor quality		1,000		
Inlet temperature	°C	9,00		20,00
Evaporation temperature (dew)	°C	13,00		
Superheating	K	5,00		
Outlet temperature	°C	18,00		15,00

System design and description

System design

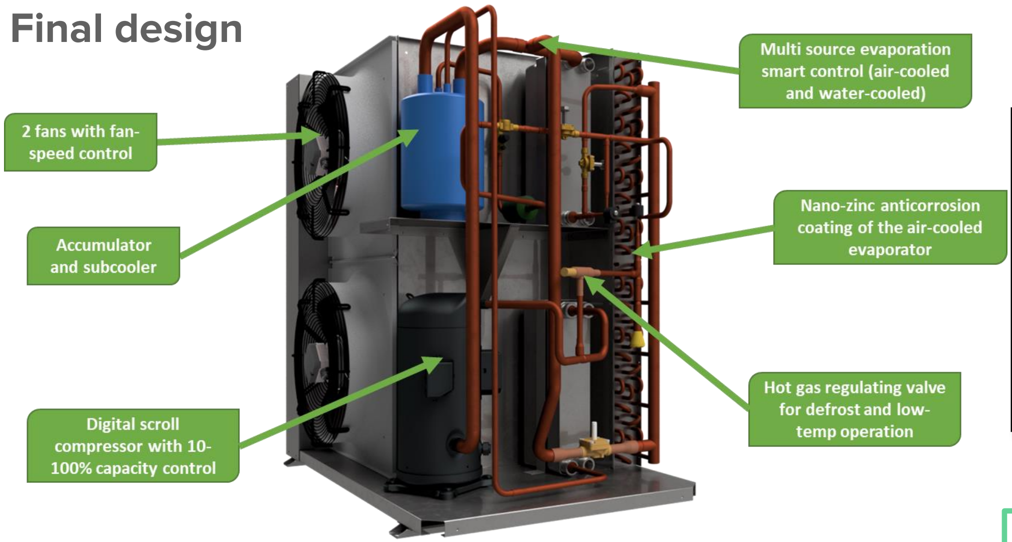
Air heated evaporator

Air of 0°C

CAPACITY OBTAINED	18677	W
EXHANGE SURFACE	60.12	m^2
EXCHANGE GLOBAL COEFFICIENT	46	$W/(m^2K)$
FINS THICKNESS	0.2200	mm
COIL INSIDE VOLUME	7.3	l
TUBES OUTSIDE DIAMETER	12.7	mm
TUBES INSIDE DIAMETER	11.7	mm

System design and description

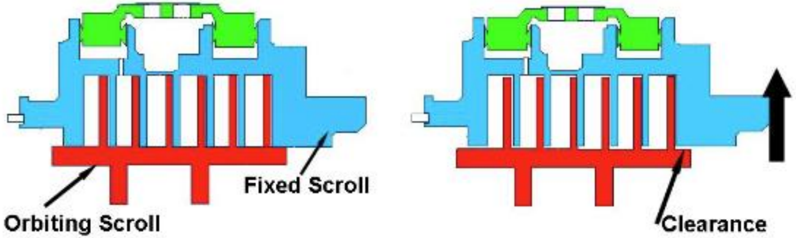
Final design



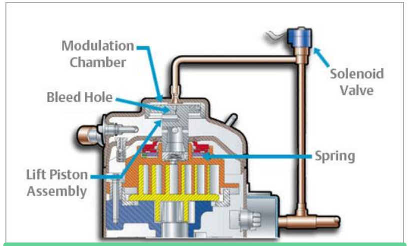
PERFORMANCE AT SPECIFIED OPERATING POINT ZRD125KCE-TFD Data at 50 Hz	
Cooling Capacity, kW	35.10
Power, kW	10.05
COP	3.49
Current at 400 V, A	17.60
Suction Mass Flow, g/s	234.00
Heating Capacity, kW	44.60
Isentropic Eff., %	72.46

Compressor Selected	ZRD125KCE-TFD

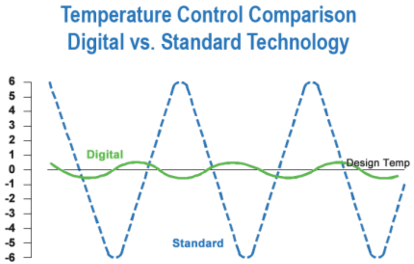
Digital Scroll Technology



20 sec cycle time



Digital Scroll Compressor



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Methodology

Measured values

Parameter (units)	Symbol
Electricity consumption of the compressor (net) (kW)	$\dot{w}_{comp}$
Electricity consumption of the auxiliary parts (kW)	$\dot{w}_{aux}$
Inlet temperature at the water side of the evaporator (°C)	$T_{w,evap,in}$
Outlet temperature at the water side of the evap. (°C)	$T_{w,evap,out}$
Inlet temperature at the water side of the condenser (°C)	$T_{w,cond,in}$
Outlet temperature at the water side of the cond. (°C)	$T_{w,cond,out}$
Refrigerant pressure at the discharge line (bar)	$P_{discharge}$
Refrigerant pressure at the suction line (bar)	$P_{suction}$
Water flow at the evaporator side (m³/h)	$\dot{V}_{w,evap}$
Water flow at the condenser side (m³/h)	$\dot{V}_{w,cond}$
Outdoor temperature (°C)	$T_{outdoor}$

Methodology

Testing conditions

- Water temperatures at evaporator: 8 – 20 °C.
- Water temperatures at condenser: 30 – 50 °C
- Compressor capacity variation: 20 – 100%

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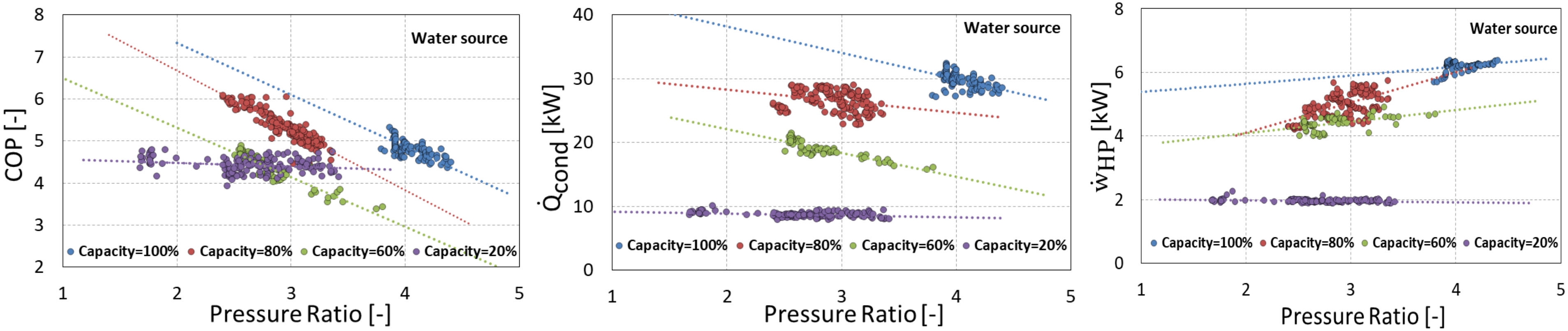
Experimental results – Water source

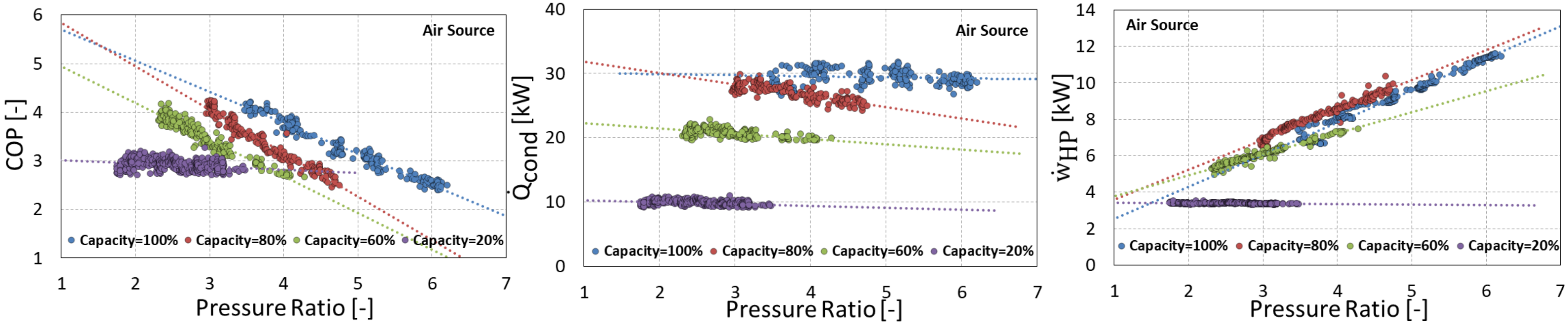
- $T_{evap,in}$ ~10 – 20 °C
- $T_{cond,in}$ ~20 – 50 °C



- Condensation load and COP for capacity variation when pressure ratio is about 4:
  - 100% capacity: Q_{cond}~32 kW, COP=5
  - 80% capacity: Q_{cond}~25 kW, COP=3.9
  - 60% capacity: Q_{cond}~15 kW, COP=3.0
  - 20% capacity: Q_{cond}~9 kW, COP=4.2

Experimental results – Air source

- $T_{outdoor}$ ~15 – 20 ºC
- $T_{cond,in}$ ~20 – 50 ºC

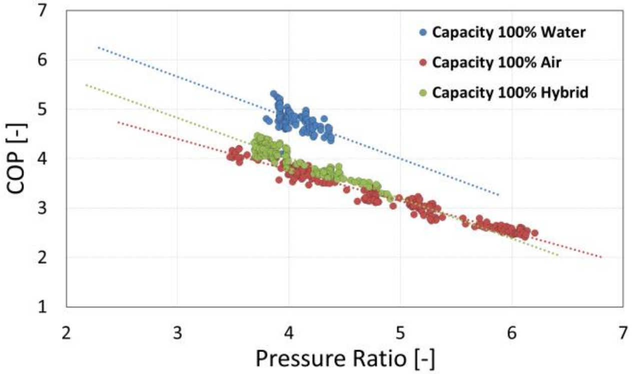


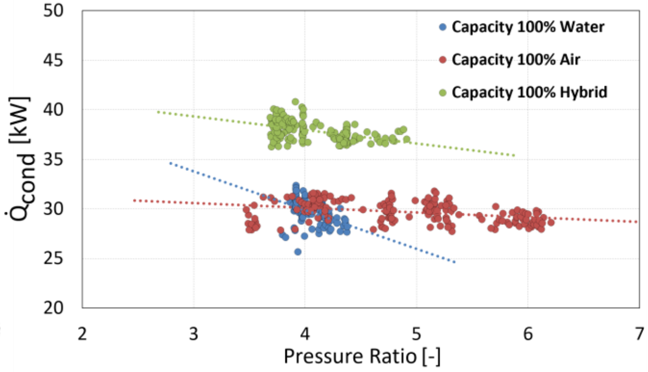
❑ Condensation load and COP for capacity variation when pressure ratio 2 – 5:

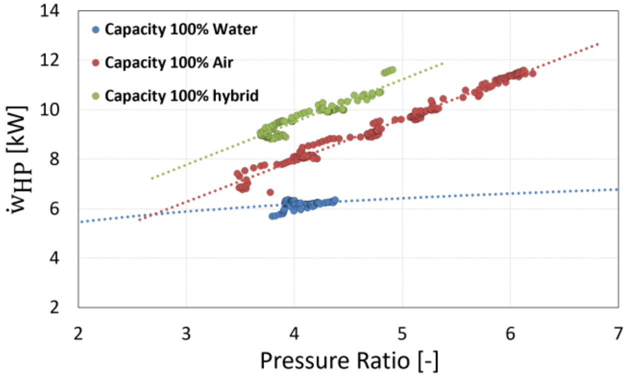
- 100% capacity: $\dot{Q}_{cond} > 30\ kW, COP = 3.0 - 4.3$
- 80% capacity: $\dot{Q}_{cond\ \sim 25\ -\ 30}\ kW, COP = 2.3 - 4.0$
- 60% capacity: $\dot{Q}_{cond\ \sim 20}\ kW, COP = 2.0 - 4.0$
- 20% capacity: $\dot{Q}_{cond\ \sim 9}\ kW, COP = 3.0$

Experimental results – Hybrid mode

- $T_{outdoor}$ ~15 – 20 °C
- $T_{cond,in}$ ~20 – 50 °C
- $T_{evap,in}$ ~10 °C
- **100% Capacity**







- High outdoor temperature during tests, results to modest enhancements in COP between hybrid and air mode: COP 4.5 (hybrid) vs 4.1 (air) in lower pressure ratios (3.5 – 4).
- Hybrid operation → Increased power consumption (fans, pumps etc.)
- Hybrid operation → 8 kWth capacity increment (~25%↑)
- Water operation → Highest COP

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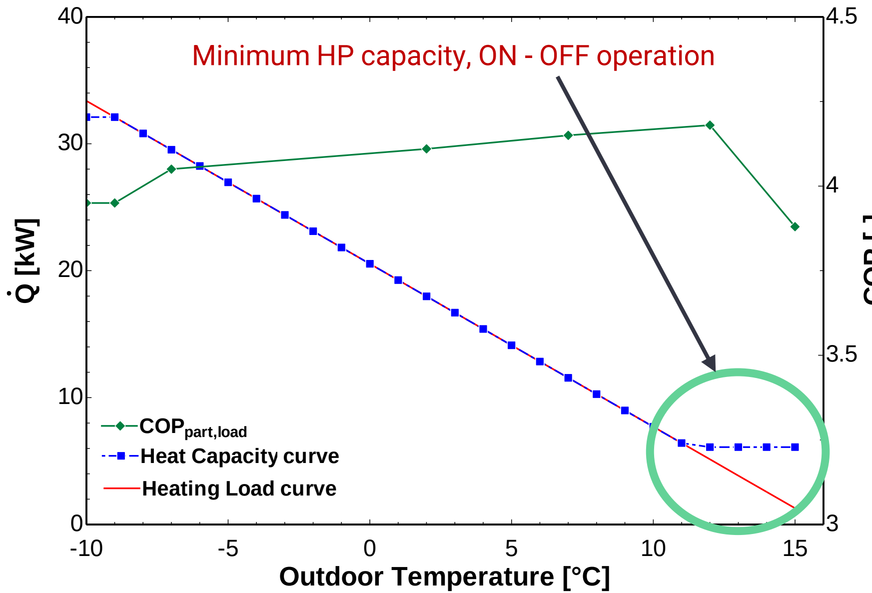
Seasonal COP

- According to EN 14825 for **water-source** (geothermal heat pumps)
- For "Average" temperature zone (Medium temp application)

Evaporator inlet: 10 °C
Condenser outlet: 45 °C

Reference heating season		"A" Average	
Seasonal Efficiency	Reference Heating Season (EN14824), Medium temp. (Fixed outlet 45 °C)	$P_{design}(kW)$	33.38
		$SCOP$	4.08



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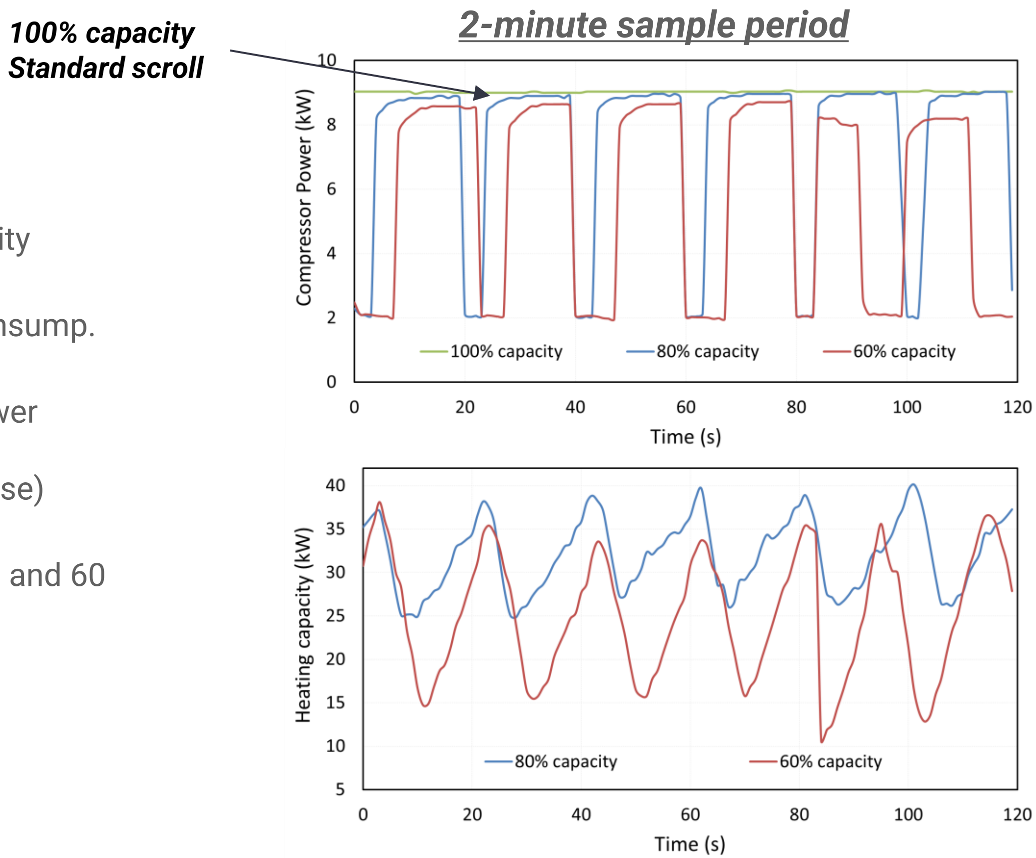
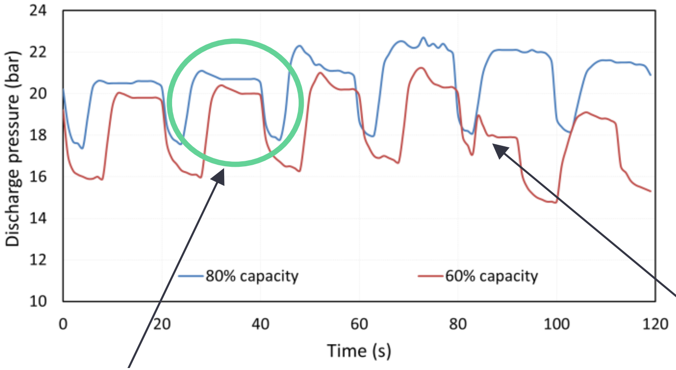
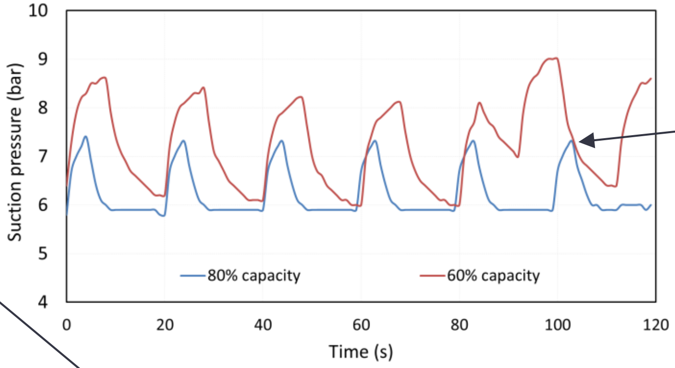
Digital capacity operation

- Loaded phase: 100% capacity
- Unloaded phase: ~2 kW consump.
- 60% Capacity, 4% lower power consumption due to lower pressure ratios (loaded phase)
- 10 kW disparity between 80 and 60 % capacity in heating load



Digital capacity operation



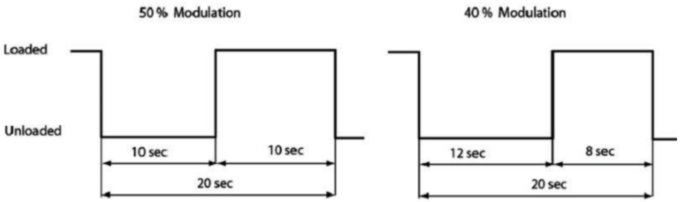


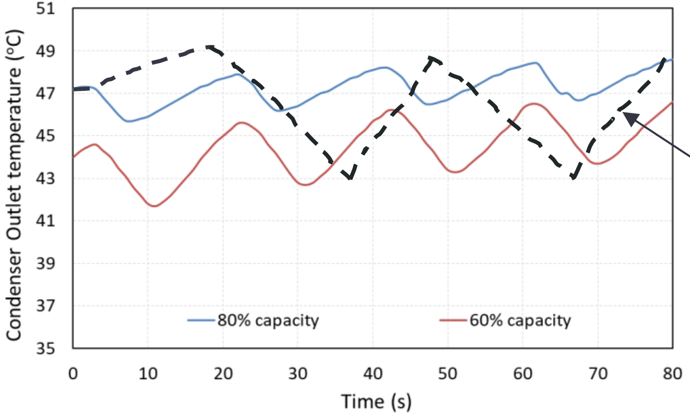
Ample reheat at low loads (Suction pressure increase)

2-minute sample period

Higher discharge pressure at 80% capacity due to ~ 5 °C higher water inlet temperature at condenser

Pressure variations due to load variations





ON – OFF Scroll Compressor

Source: *www.copeland.com*

Conclusions

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Conclusions

- Water source at full load → over 30 kW heating capacity with COP up to 5.
- Air source at full load → 30 kW heating capacity with COP range between 3 and 4 .
- Hybrid mode: Similar COP with air source for temperatures at 15 ˚C but with enhanced heating capacity (>25% compared to Water/Air mode).
- Average climate zone and Medium temperature applications result to a **SCOP of 4.08** for water source operation.
- Digital capacity modulation: Variation of heating capacity between 9 – 32 kW with COP 2 – 5. Enhanced system performance compared to standard scroll due to:
  - ✓ Precise temperature control according to the load – match capacity to demand.
  - ✓ Reduce the on – off cycling, less mechanical stress and effective lubrication.
  - ✓ Efficient part load operation, **reducing the capacity up to 80% without stopping completely**.

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MARINE REFRIGERATION & AIR CONDITIONING

ECOS 2024
RHODES, GREECE

Thank you for your attention!

Acknowledgment

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RES4LIVE
ENERGY SMART LIVESTOCK FARMING
TOWARDS ZERO FOSSIL FUEL CONSUMPTION

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