The 22nd IIR International Congress or Refrigeration – Beijing, China

CO_2 Heat Pump System for Combined Heating and Cooling of Non-Residential Buildings

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Working Fluids in Heat Pumps

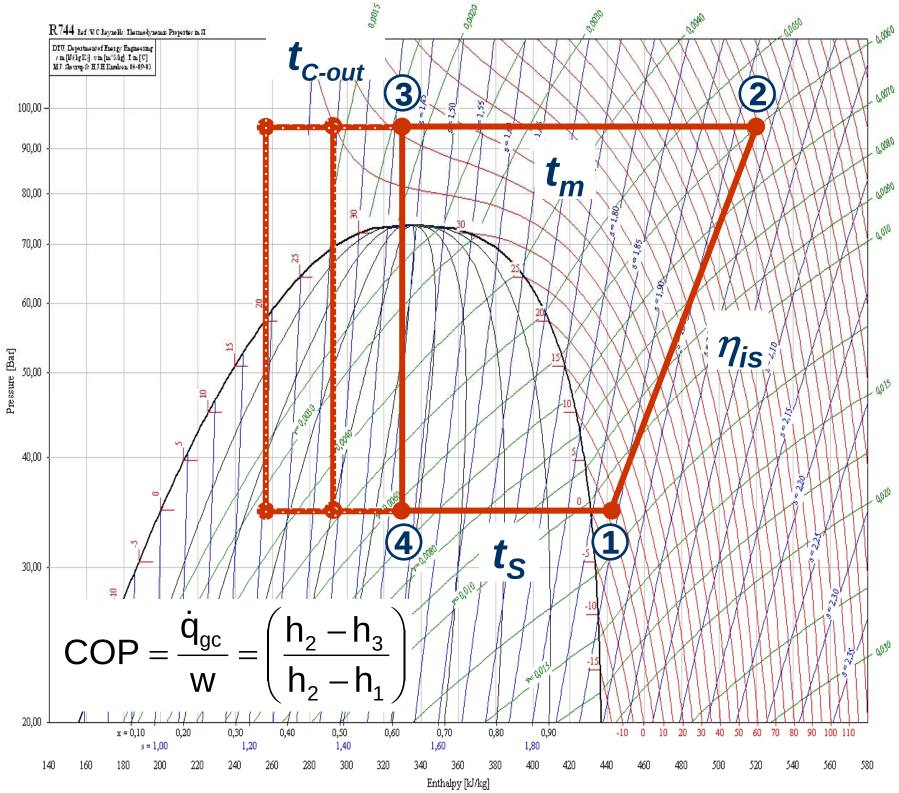
Non-Residential Applications – $V_{suction}$ at -5/55°C, η_{is}=1,0, λ=1.0

R407C	**GWP = 1700**	Non-flammable	Non-toxic
	t_{max} ≈ 50-55°C	$V_{suction}$ = 100%	
R134a	**GWP = 1400**	Non-flammable	Non-toxic
	t_{max} ≈ 70°C	**$V_{suction}$ = 150%**	
R717	GWP = 0	~Non-flammable	**Toxic**
	t_{max} ≈ 50/70°C	$V_{suction}$ = 80%	
R290	GWP = 3	**Flammable**	Non-toxic
	t_{max} ≈ 60°C	$V_{suction}$ = 110%	
R744	**GWP = 1 (0)**	**Non-flammable**	**Non-toxic**
	t_{max} ≈ 90°C	**$V_{suction}$ = 15%**	

CO_2 Heat Pump Energy Efficiency

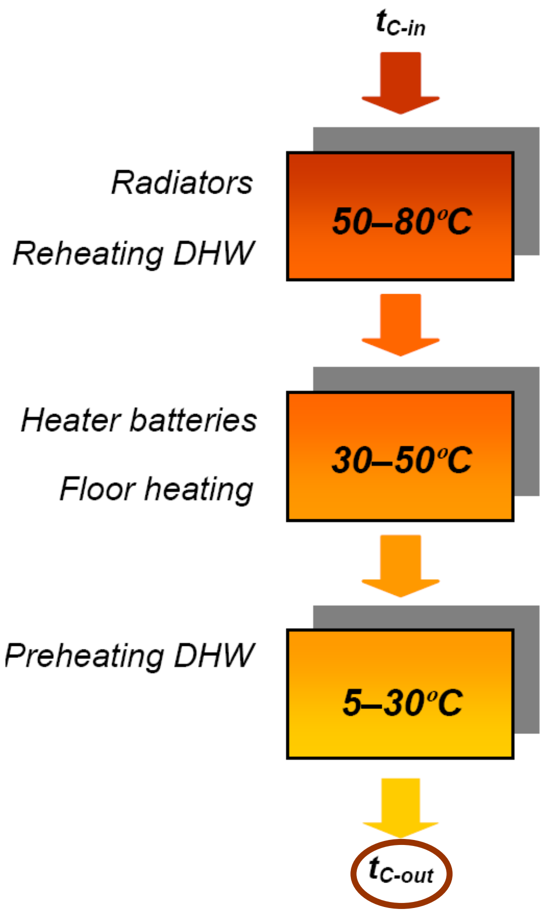
Main Factors that Determine the Coefficient of Performance (COP)

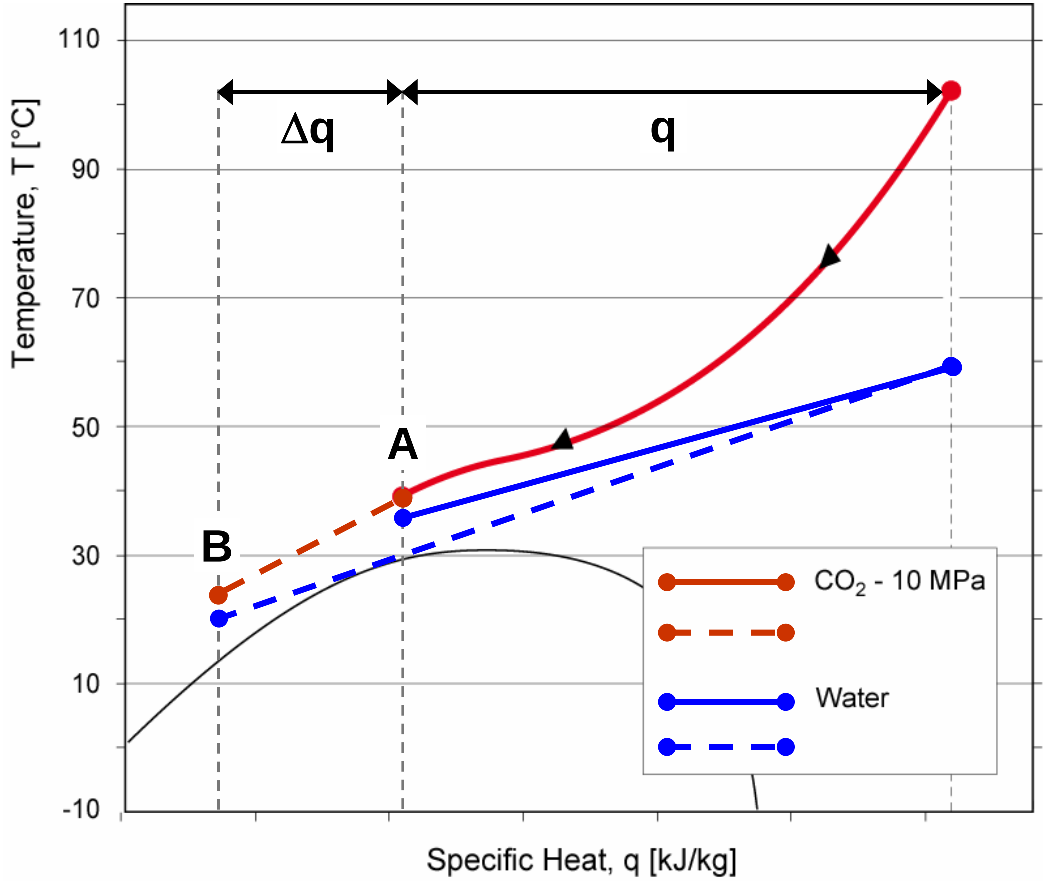
- Heat source temperature, t_s
- Overall isentropic efficiency of the compressor, η_{is}
- Mean temperature during heat rejection, t_m
  - High-side pressure
  - CO_2 outlet temperature from the gas cooler, $t_{C\text{-}out}$
- Possible recovery of expansion energy
  - Ejector
  - Expander



CO_2 Heat Pumps in Non-Res. Buildings

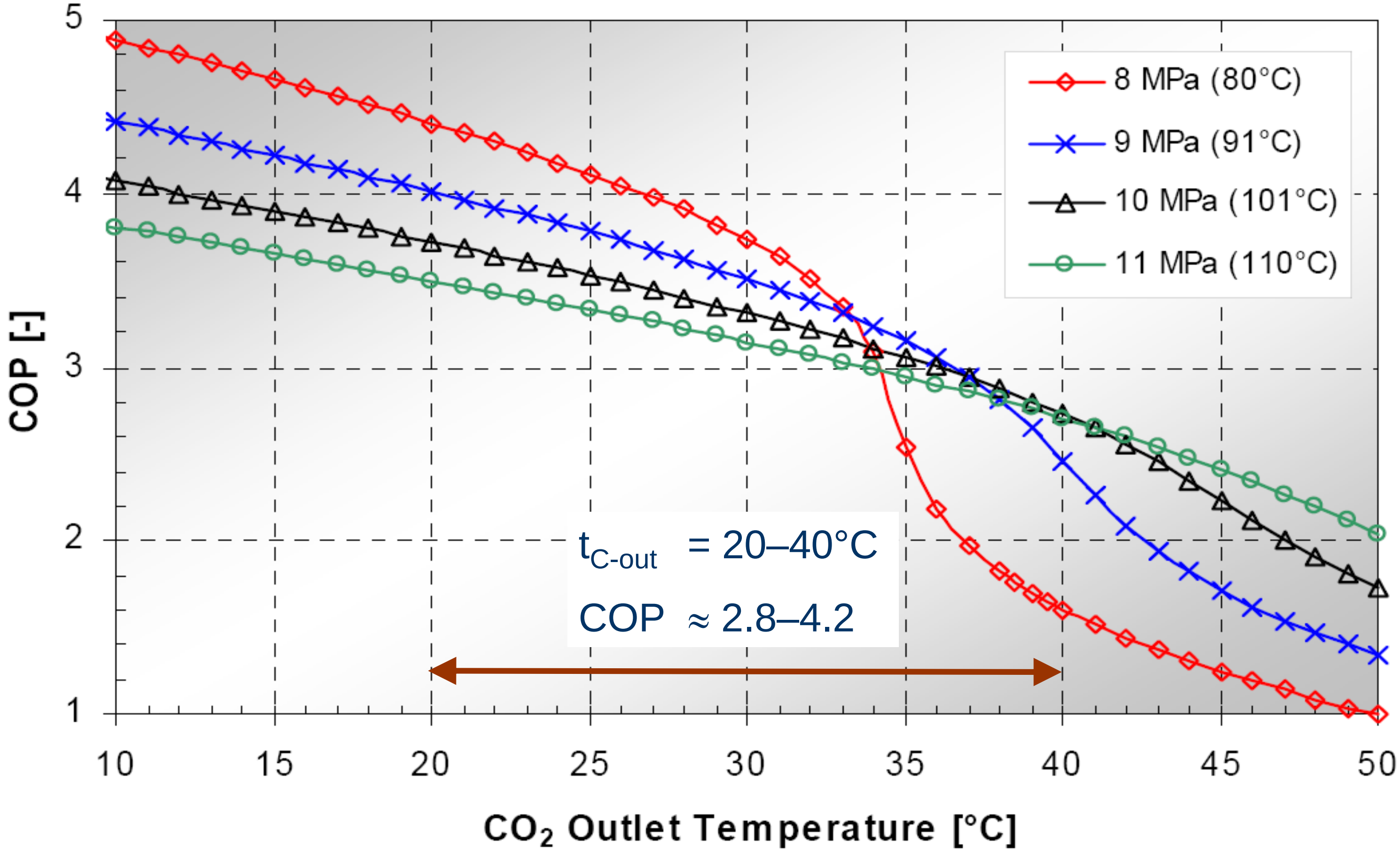
Serial Connection of Heat Loads with Diminishing Temp. Level





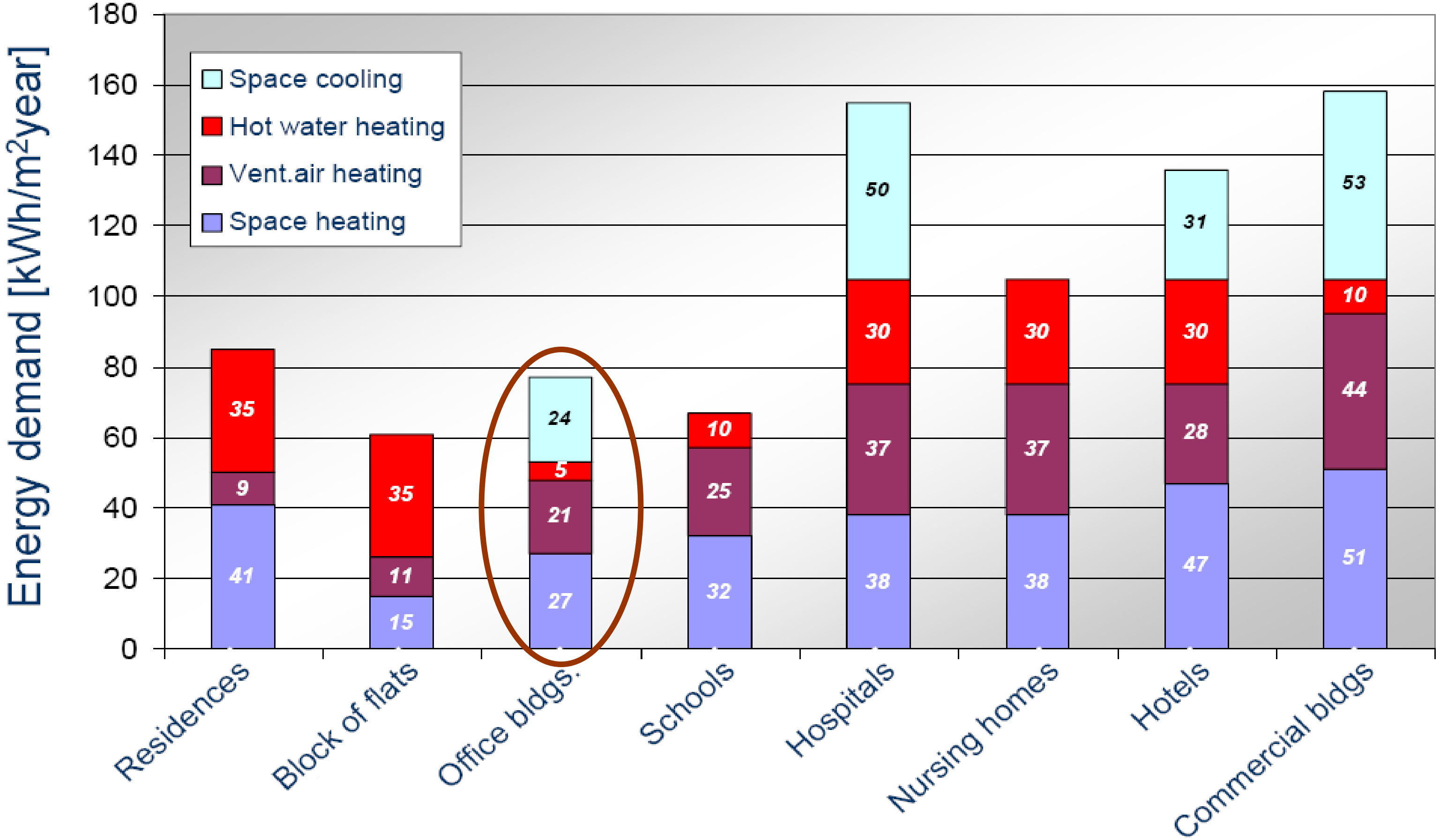
Maximum COP vs. CO_2 Outlet Temperature

Single-Stage Compression, t_0=-5°C, t_{SH}=5 K, η_{is}=75%, Q_{HL}=10%



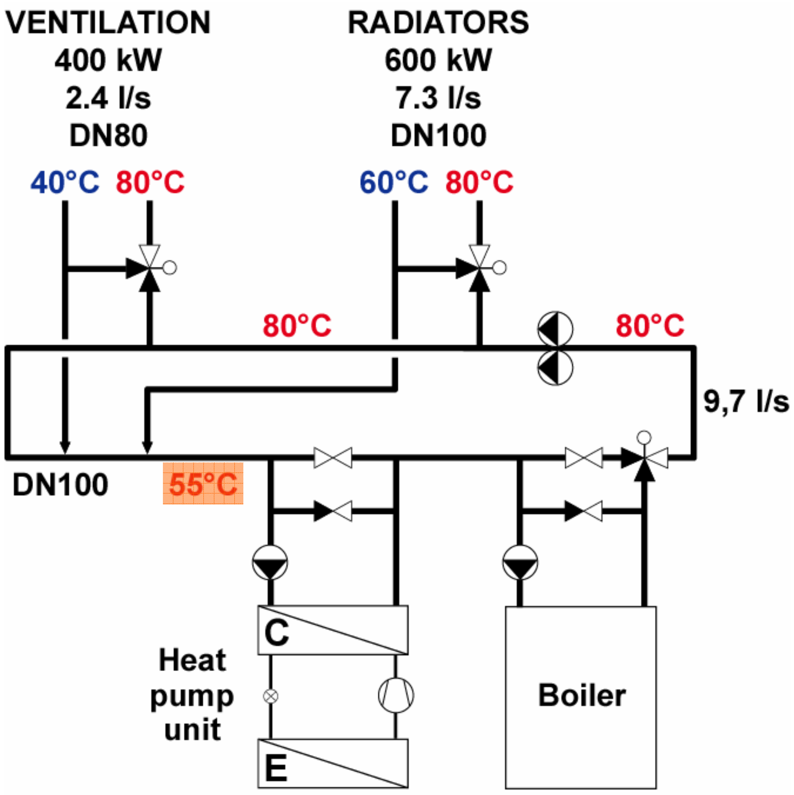
Specific Energy Demands in Buildings

Demands Based on the New Norwegian Building Code – 2007

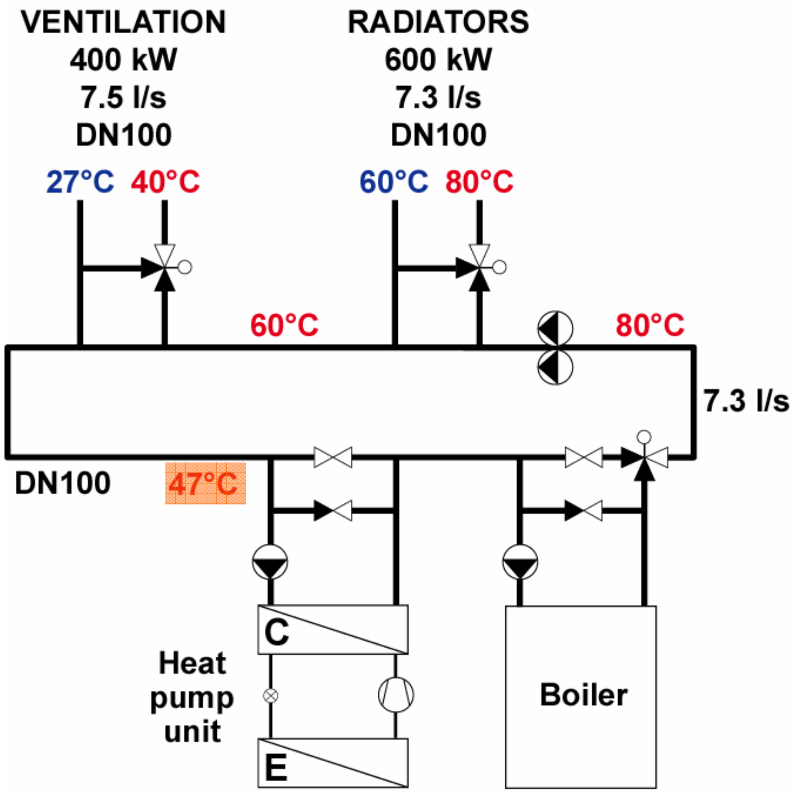


Heating System – Return Temperature

EXAMPLE – New Office Building, Design Conditions



80/60°C – PARALLEL Connection



80/60°C – SERIAL Connection

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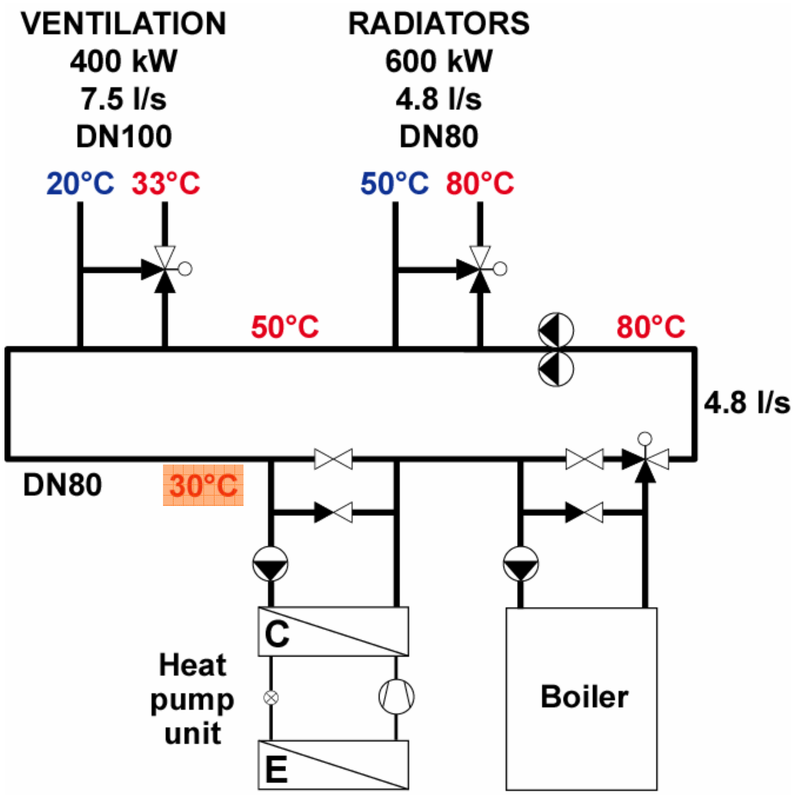
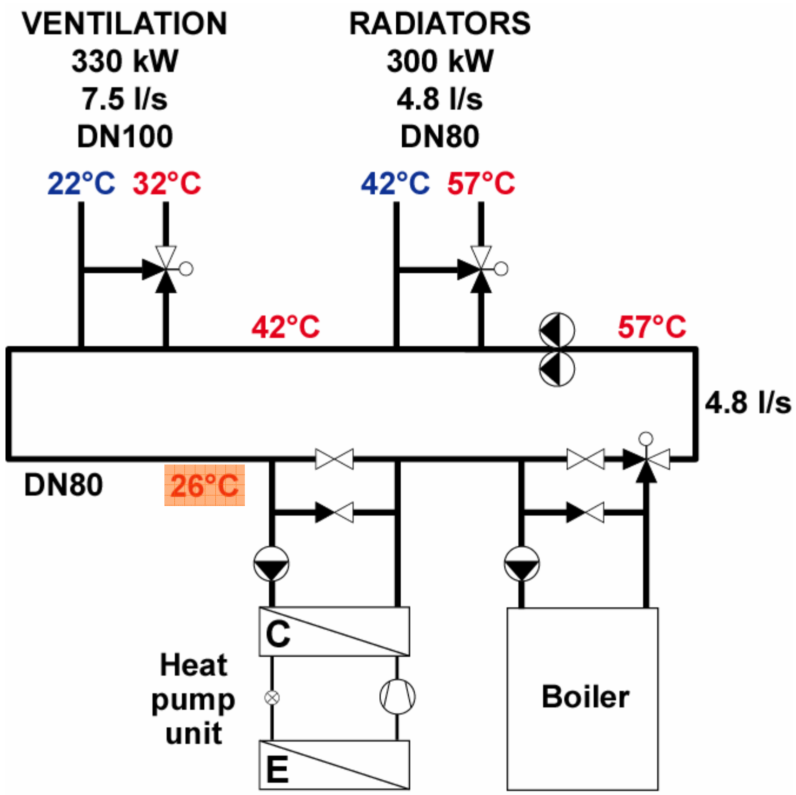
Heating System – Return Temperature

Example – Office Building, Design and Off-Design Conditions



80/50°C – Design conditions



80/50°C – Off-design conditions

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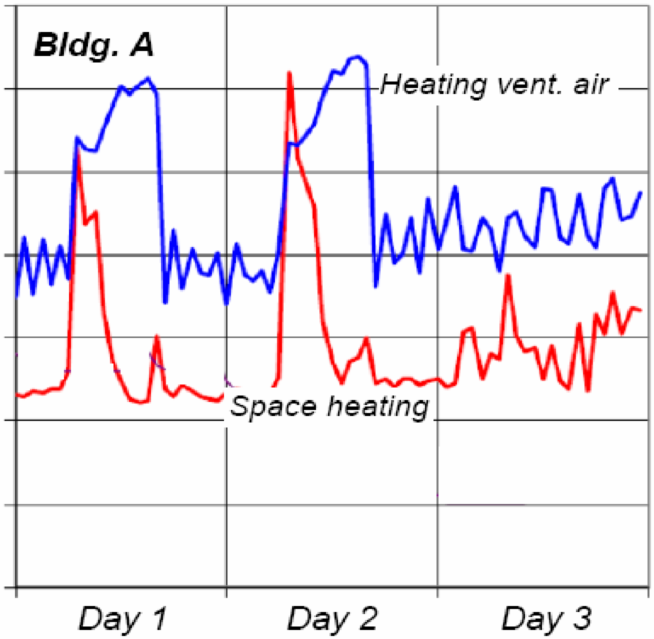
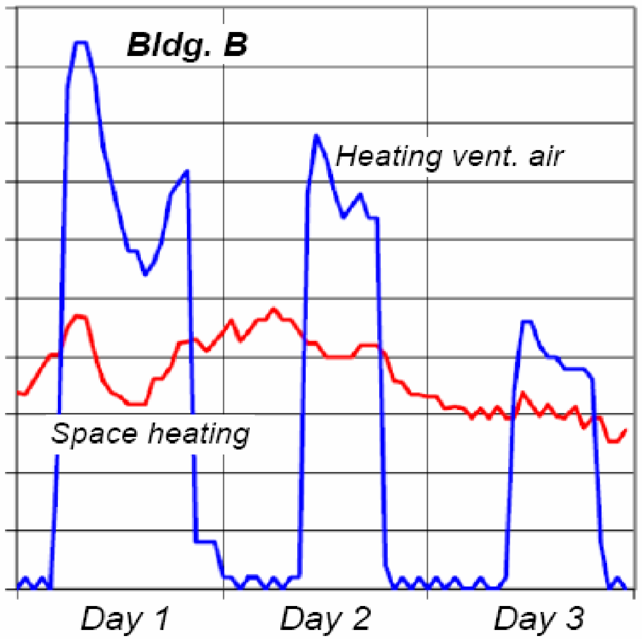
Simultaneousness of Heating Demands

Heat Loads – Space Heating and Heating of Ventilation Air

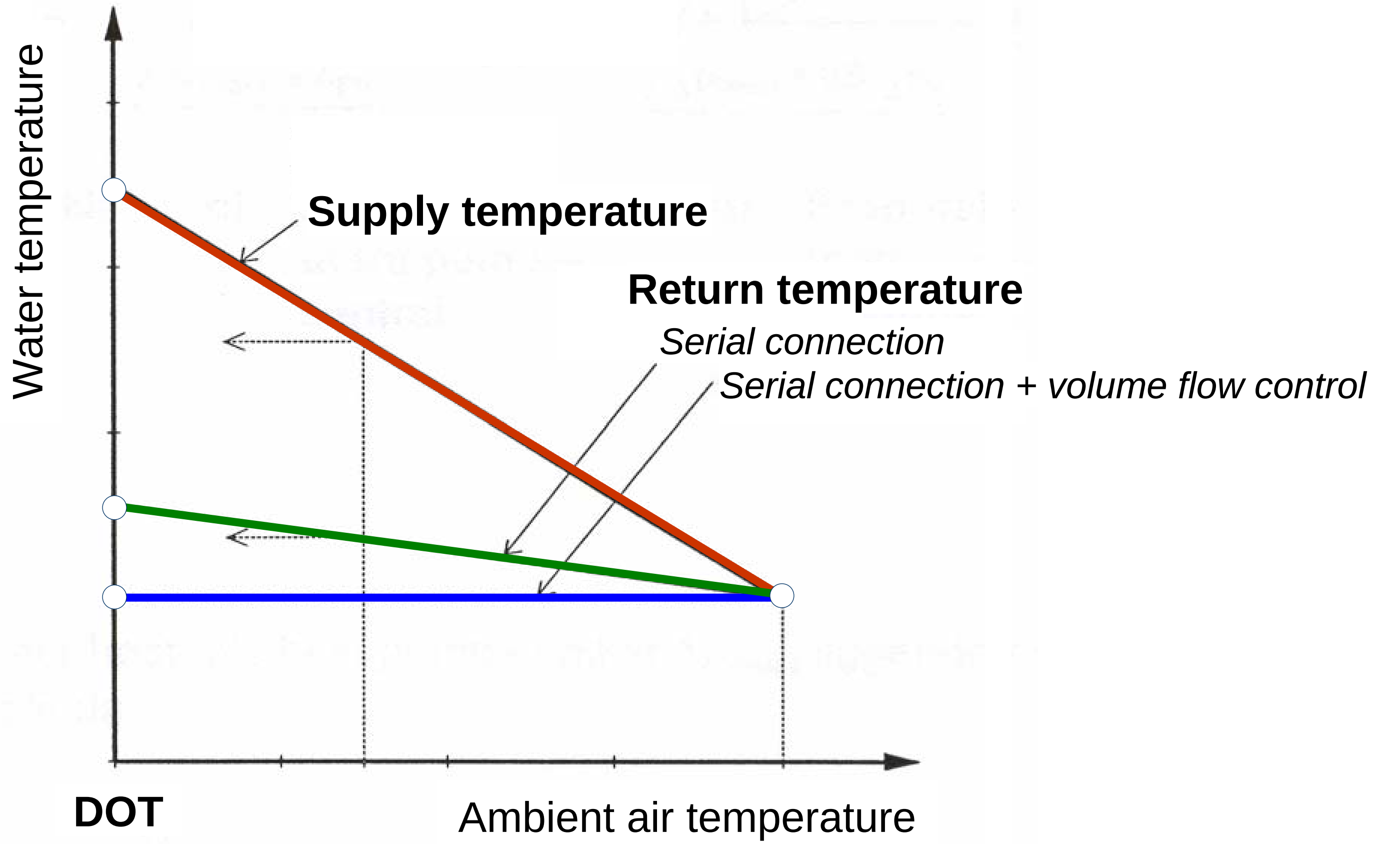
Bldg.	Year of construct.	Heated area	Ventilation system	Heating system
A	2002	850 m^2	Hybrid, VAV, no night stop	Hydronic, radiators
B	1996	24.000 m^2	Mechanical, VAV, night stop	Hydronic, radiators





Focus on Low Return Temperature

Principle Illustration of Different Control Curves



Example – SPF for CO_2 and R134a Systems

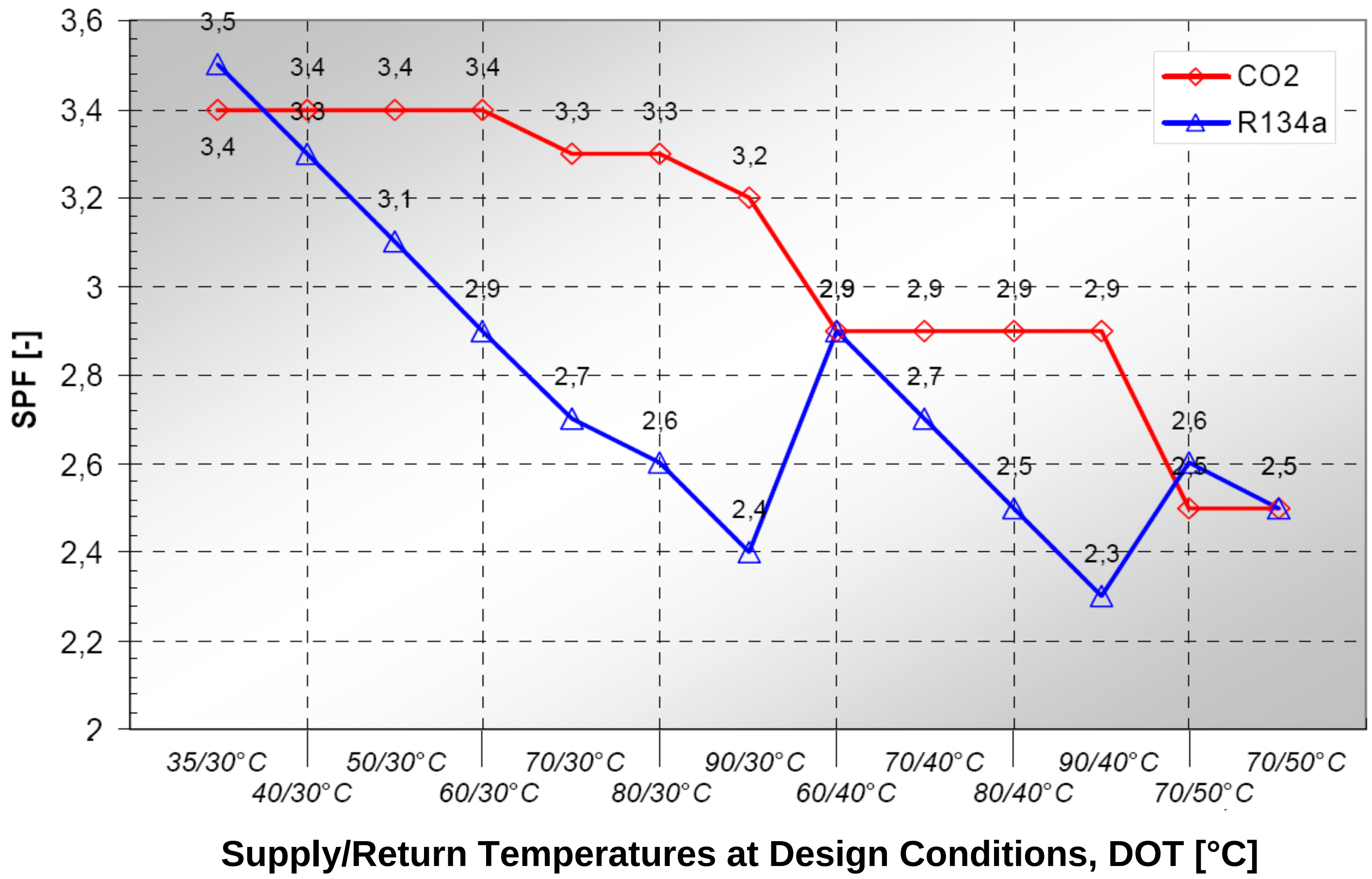
Heating and Cooling of a 7.000 m^2 Office Building, Oslo Climate

- Ambient air as heat source and heat sink – indirect system
- Operation in heating mode or cooling mode
- Compressor swept volume determined by the cooling demand
- Serial connection of radiators and ventilation heater batteries

Design load – space heating / heating of ventilation air	250 kW	300 kW
Design load – space cooling	400 kW	
	CO_2	**R134a**
Overall isentropic efficiency, compressor	75%	70%
LMTD – evaporator (constant)	8 K	8 K
Temperature approach – condenser/gas cooler (constant)	2 K	2 K
Efficiency – peak load unit (electro boiler)	100%	100%

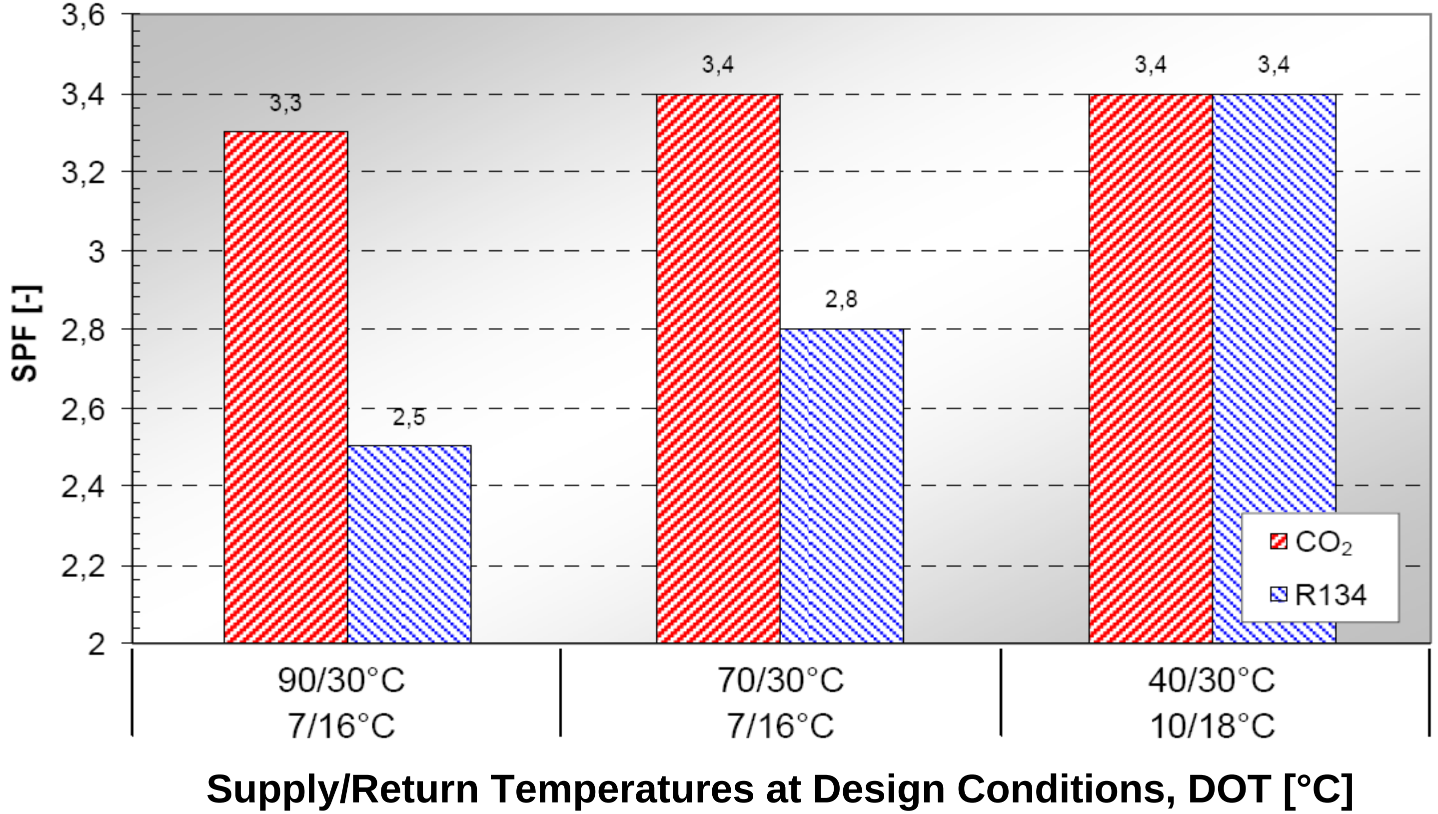
Calculated SPF_H – CO_2 and R134a System

Varying Supply/Return Temperatures in the Heat Distribution Syst.



Calculated SPF_T – CO_2 and R134a System

Varying Supply/Return Temperatures in the Distribution Systems



Prototype CO_2 Heat Pump System

Heating and Cooling of an Office Building

- Project participants (2007-2008)
  - Builder – Teknotherm AS *http://www.teknotherm.no/*
  - Project partner – The Directorate of Public Construction and Property (*Statsbygg*)
  - Project partner – The Norwegian Defence Estates Agency (*Forsvarsbygg*)
  - Funding – The Norwegian Research Council (*NFR*)
- Heating capacity – approx. 75 to 100 kW
- Heat source – energy wells in bedrock or ambient air

TEKNOTHERM
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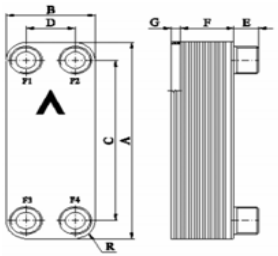
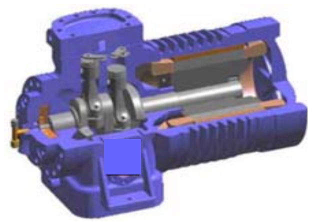
Forsvarsbygg

STATSBYGG

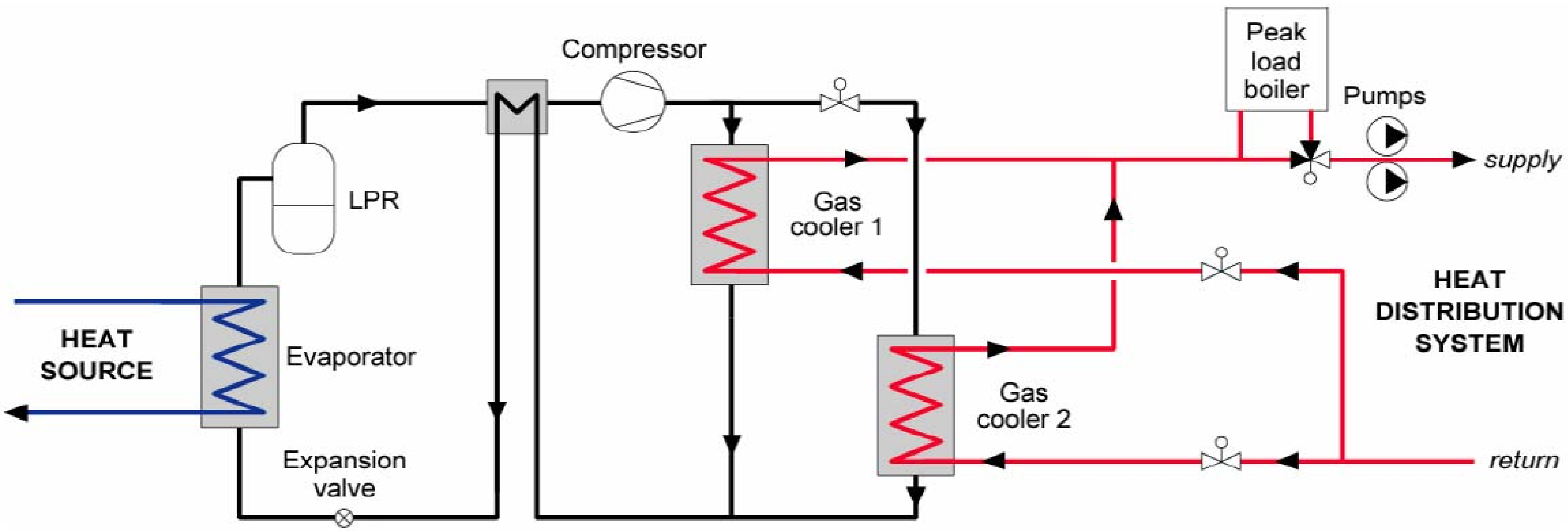
The Research Council of Norway

Prototype CO_2 Heat Pump System

- Bivalent heat pump system with peak load unit (boilers)
- CO_2 heat pump unit
  - Single-stage unit
  - Suction gas heat exchanger (SGHX) and low-pressure receiver system (LPR)
  - Single gas cooler or two gas coolers in parallel
- Components
  - Compressor – reciprocating, inverter controlled
  - Evaporator – PHE (64 bar) or tube-in-fin air cooler
  - Gas cooler – PHE (140 bar) or tube-in-tube heat exchanger
  - Other components – commercially available


Prototype CO_2 Heat Pump System



Conclusions – Further Work

- A single-stage CO_2 heat pump system can achieve the same or higher SPF than state-of-the-art HFC systems in office buildings
- CO_2 heat pumps can meet high-temperature heating demands
- Critical factors wrt. low return temperature and achievable SPF
  - Heat loads for space heating vs. heating of ventilation air
  - Operational time of the ventilation system
  - Design and operation of the hydronic heat distribution system

- Design, install and monitor a prototype CO_2 heat pump system
  - 75 to 100 kW single-stage unit in an office building

Thank you for your attention!

谢谢

More information available at