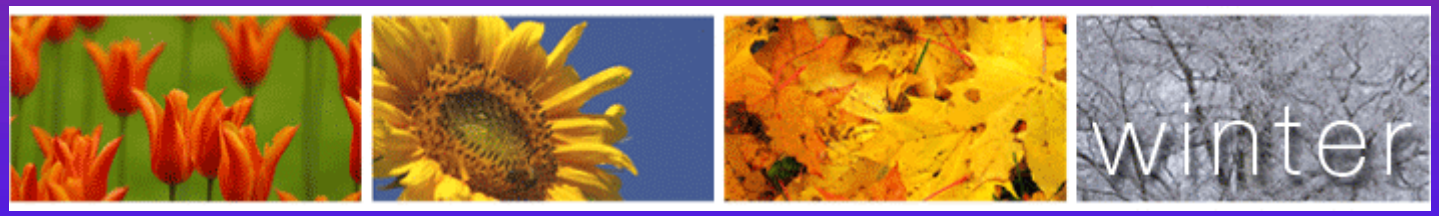
# High-Efficiency Heat Pump Water Heater (HPWH) System for Apartment Buildings of Passive House Standard

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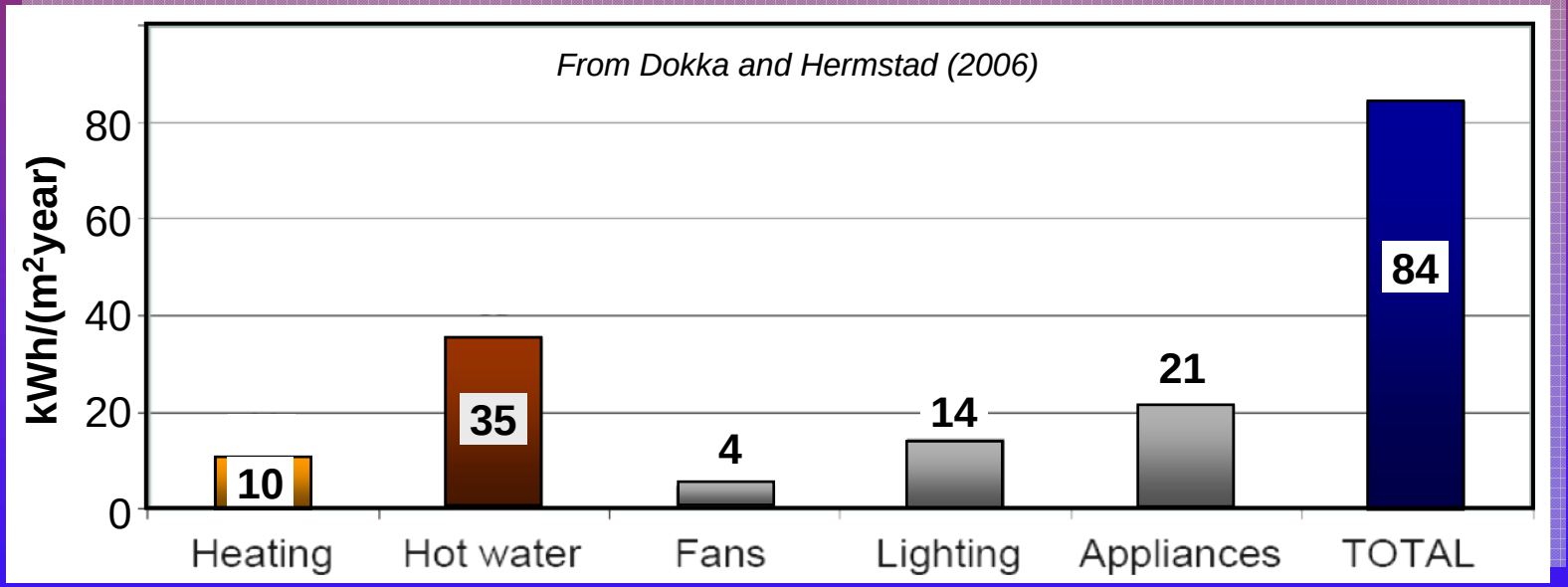
# Heating Demands in Passive Houses

*Example – Block of Flats – 60 m² – Oslo, Norway*




- Total heating demand — 53% of the total energy demand
- Heating of domestic hot water (DHW) — **78%** of the total heating demand
- Space heating + heating of vent. air — **22%** of the total heating demand

# Heating Demands in Passive Houses

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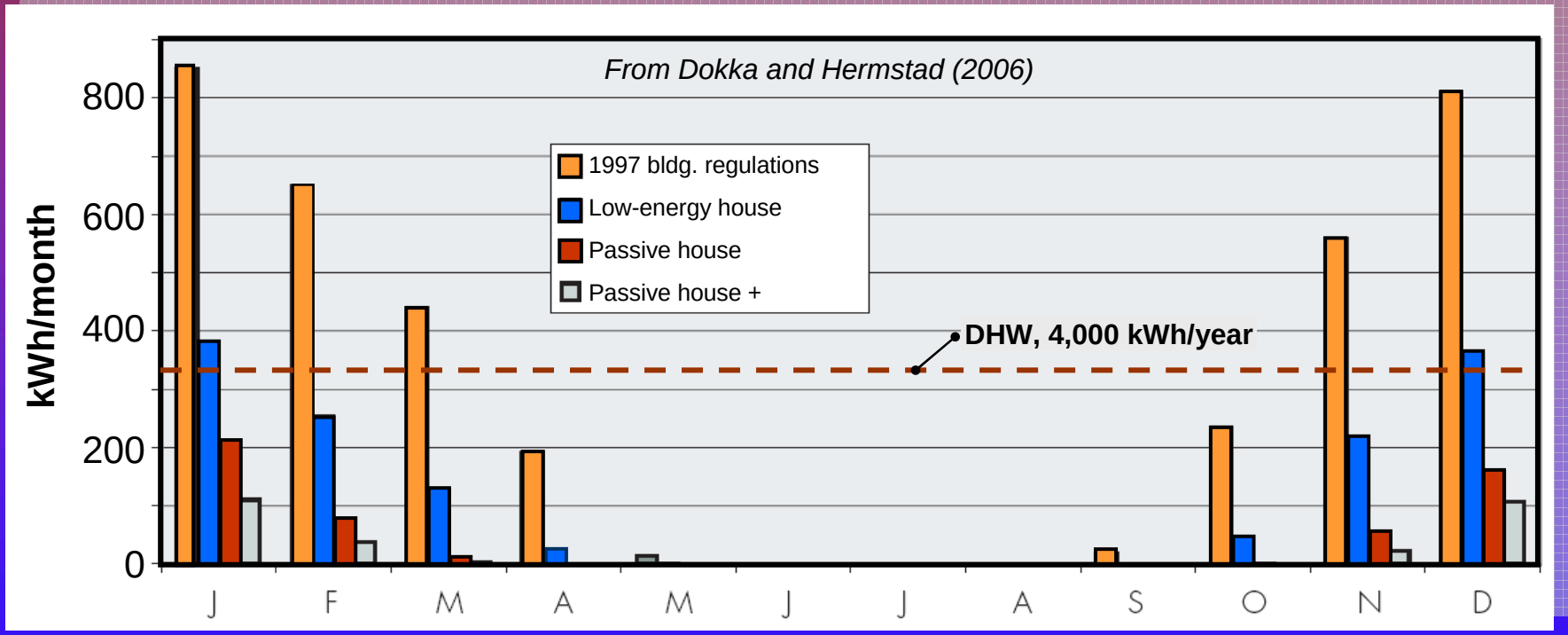
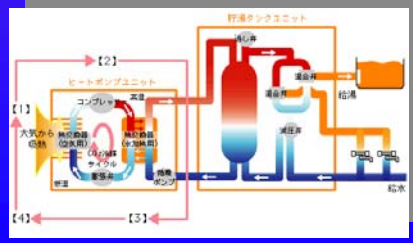



- 1997 bldg. regulations: Space heating demand approx. **8** months/year
- Low-energy house: Space heating demand approx. **6** months/year
- Passive house: Space heating demand approx. **4** months/year

# Heating of Domestic Hot Water (DHW)

*Apartment Buildings & Block of Flats of Passive House Standard*

- Local/unitary DHW systems
  - Electric immersion heaters
  - Solar collectors + electric heater
  - Gas-fired system
  - Heat pump water heater (HPWH)
- Centralized DHW systems
  - Electric immersion heaters
  - Solar collectors + electric heater
  - Pellets-fired boiler
  - Gas-fired boiler
  - Heat exchanger – district heating system
  - Heat pump water heater (HPWH)



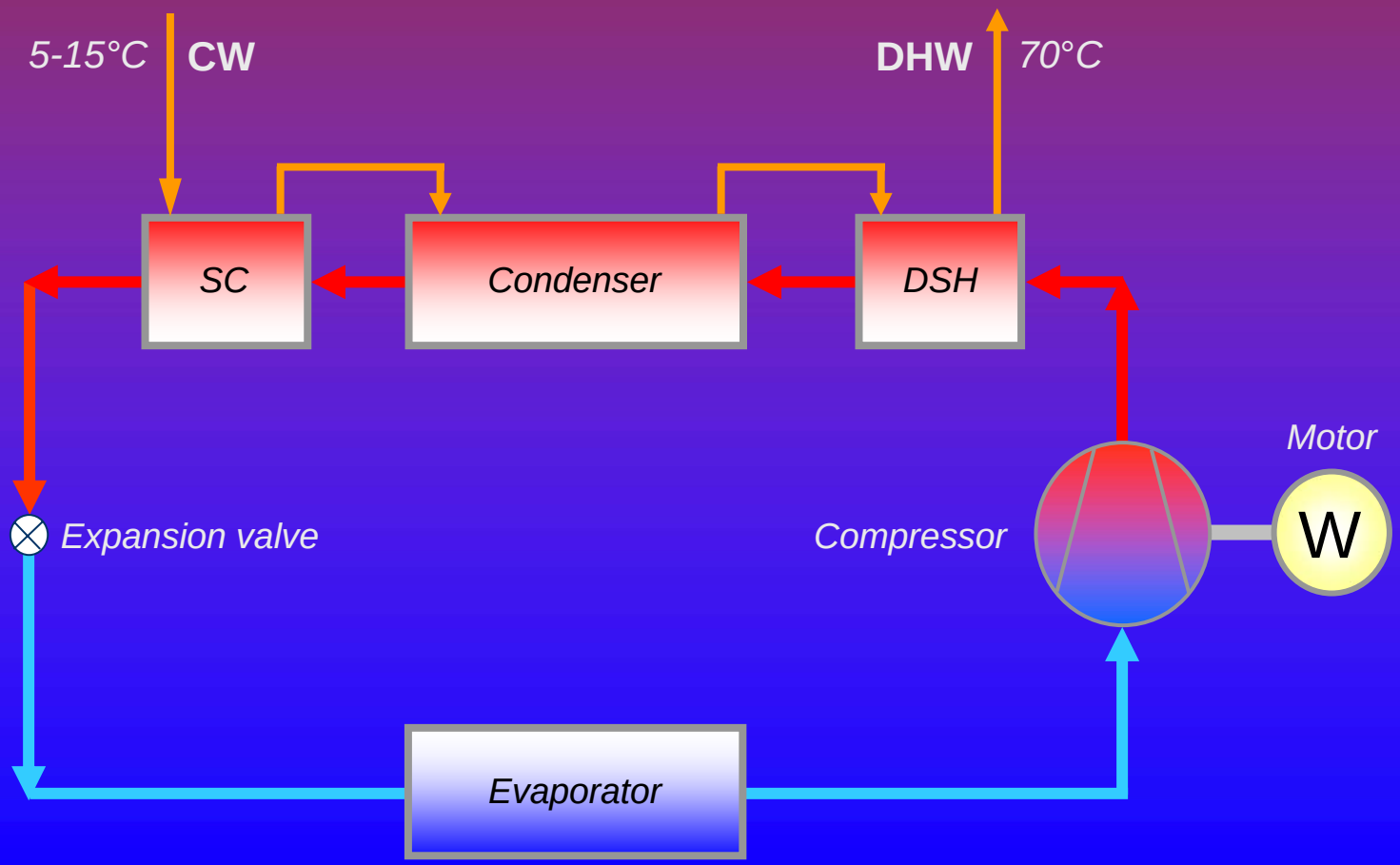
# Heat Pump Water Heater (HPWH) System

*Analysis of Different Design Concepts*

- State-of-the-art heat pump (HP) technology
  - **System 1** – HP with condenser and desuperheater
  - **System 2** – HP with condenser, desuperheater and subcooler
  - **System 3** – HP with condenser, desuperheater, suction gas heat exchanger
  - R134a or R290 (propane) as working fluid (refrigerant)
- New, innovative heat pump technology
  - **System 4** – $CO_2$ heat pump unit with single gas cooler
  - Carbon dioxide ($CO_2$, R744) as working fluid (refrigerant)
  - $CO_2$ technology developed at:
    - *SINTEF Energy Research, Dept. of Energy Processes*
    - *NTNU, Dept. of Energy and Process Engineering*

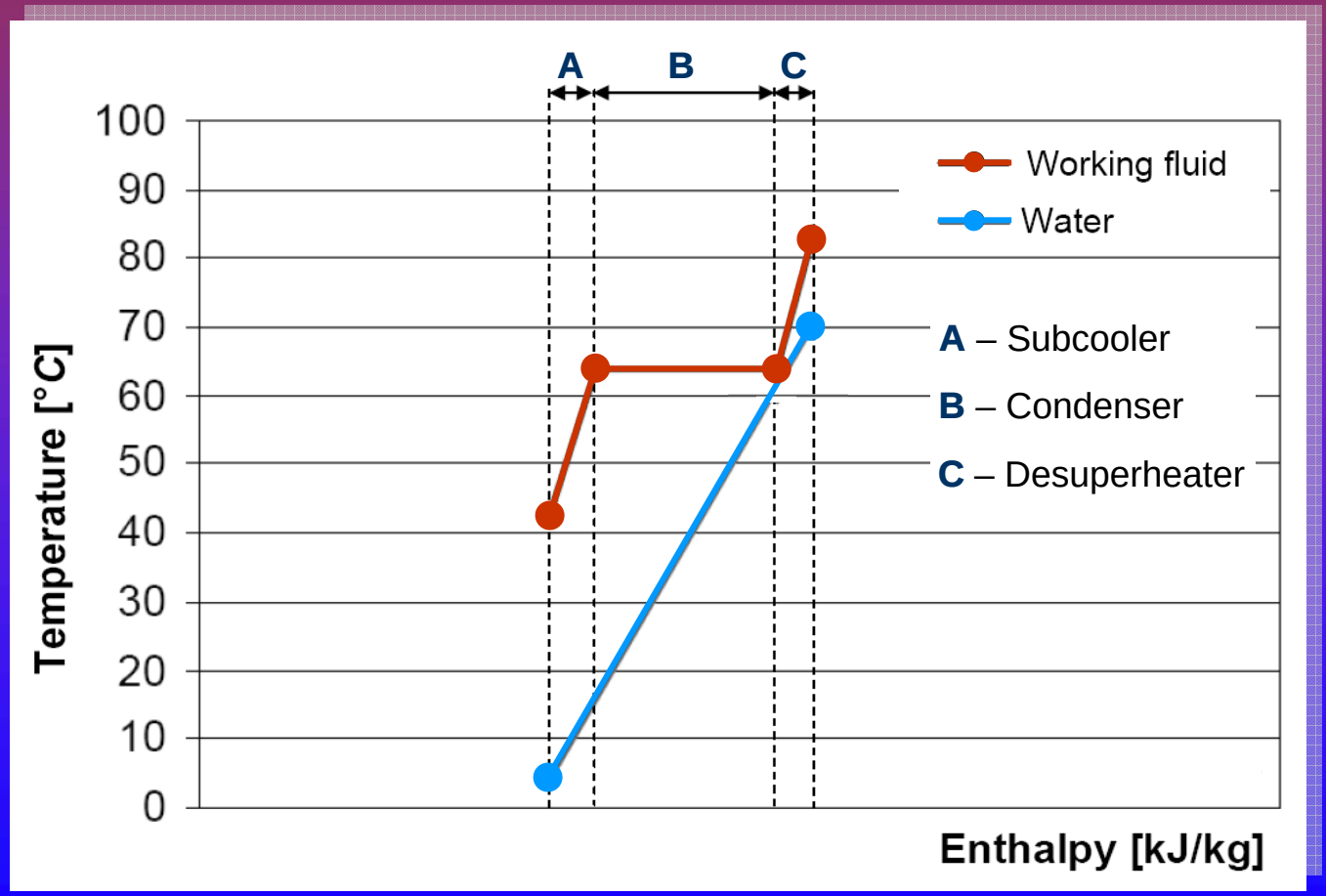
# Heat Pump Water Heater System – Type 2

*Desuperheater (DSH) + Condenser + Subcooler (SC)*



# Heat Pump Water Heater System – Type 2

*Desuperheater (C) + Condenser (B) + Subcooler (A)*

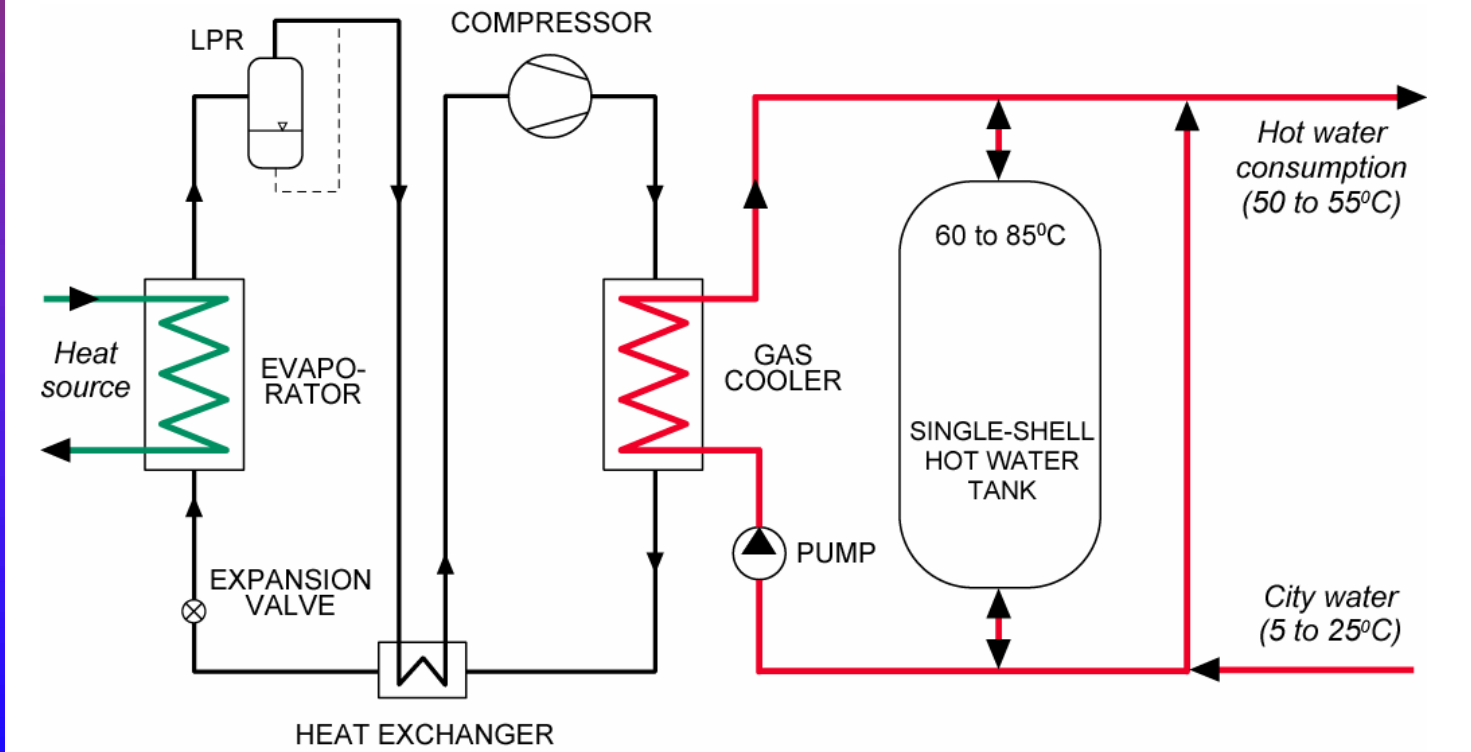


# $CO_2$ as a Working Fluid in Heat Pumps

- Global environmental properties – safety aspects
  - ODP = 0, GWP = 0
  - Non-flammable (fire retardant)
  - Non-toxic
  - Heavier than air
- Characteristic properties
  - High operating pressure – 30 to 110 bar
  - Heat rejection by cooling of $CO_2$ gas – temperature glide
  - Small compressor volume
  - Small dimensions for pipelines and valves
  - High compressor efficiency
  - Excellent heat transfer in heat exchangers

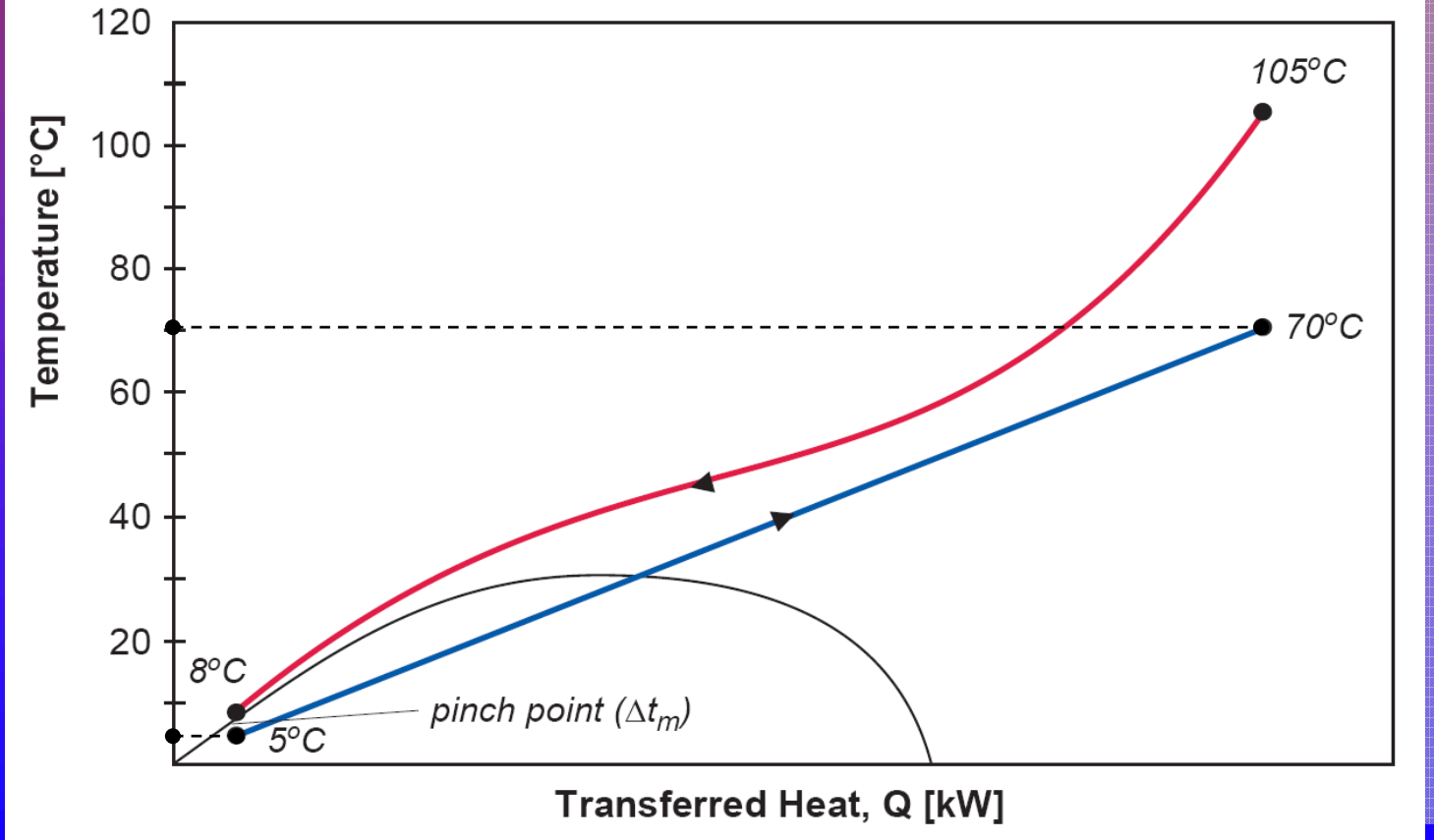
# Heat Pump Water Heater System – 4

*$CO_2$ Heat Pump Unit with a Single Gas Cooler*



# Heat Pump Water Heater System – 4

*$CO_2$ Heat Pump Unit with a Single Gas Cooler*



# Simulations of the HPWH Systems

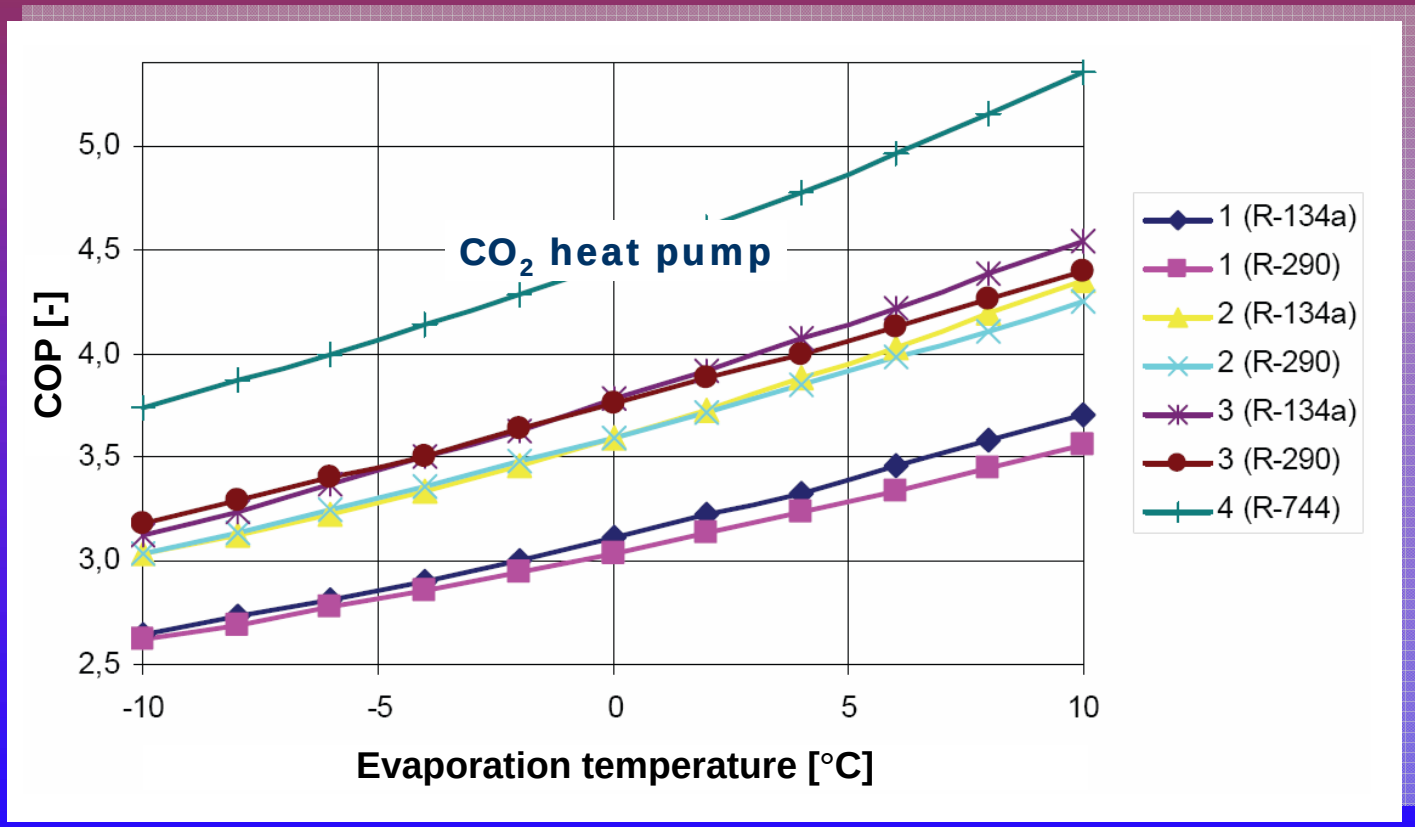
*Coefficient of Performance (COP = Q/P)*

- Simulated systems
  - HPWH design 1 to 3 — **R134a** and **R290** as working fluids
  - HPWH design 4 — **$CO_2$** heat pump water heater
- Equal boundary conditions
  - Total UA-value[1)] — 2,100 W/K
  - Evaporator superheat — 5 K
  - Isentropic compressor efficiency — From laboratory measurements
  - City water temperature — 5°C
  - DHW temperature — 70°C
  - Evaporation temperature — -10°C to +10°C

*1) Total UA-value for the heat exchangers for heat rejection*

# Simulations of the HPWH Systems

*Coefficient of Performance (COP = Q/P)*

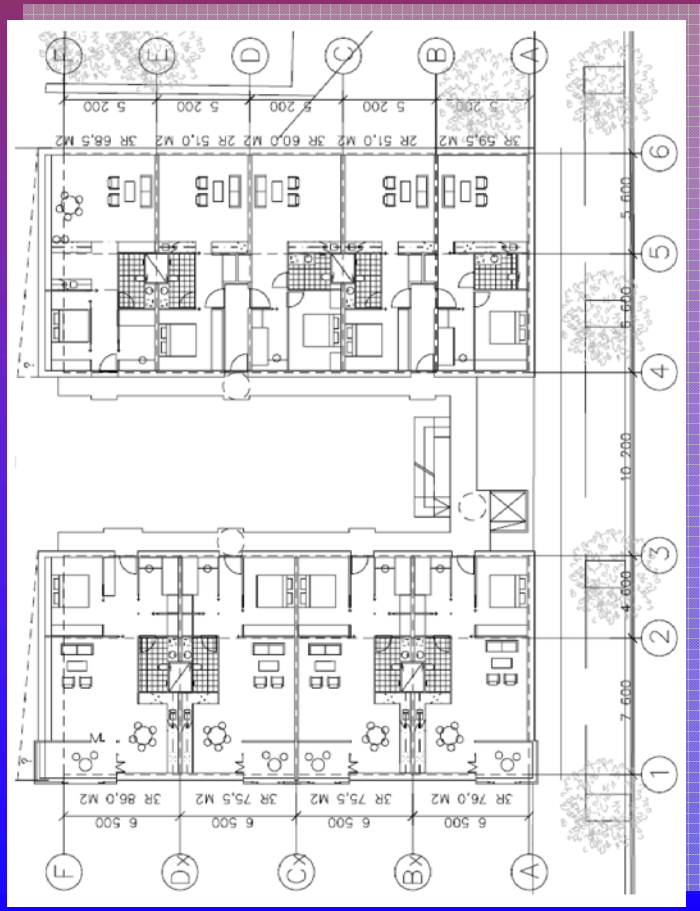



- The $CO_2$ heat pump achieved 20% higher COP than the best R134a/R290 units

# The Damsgård Project

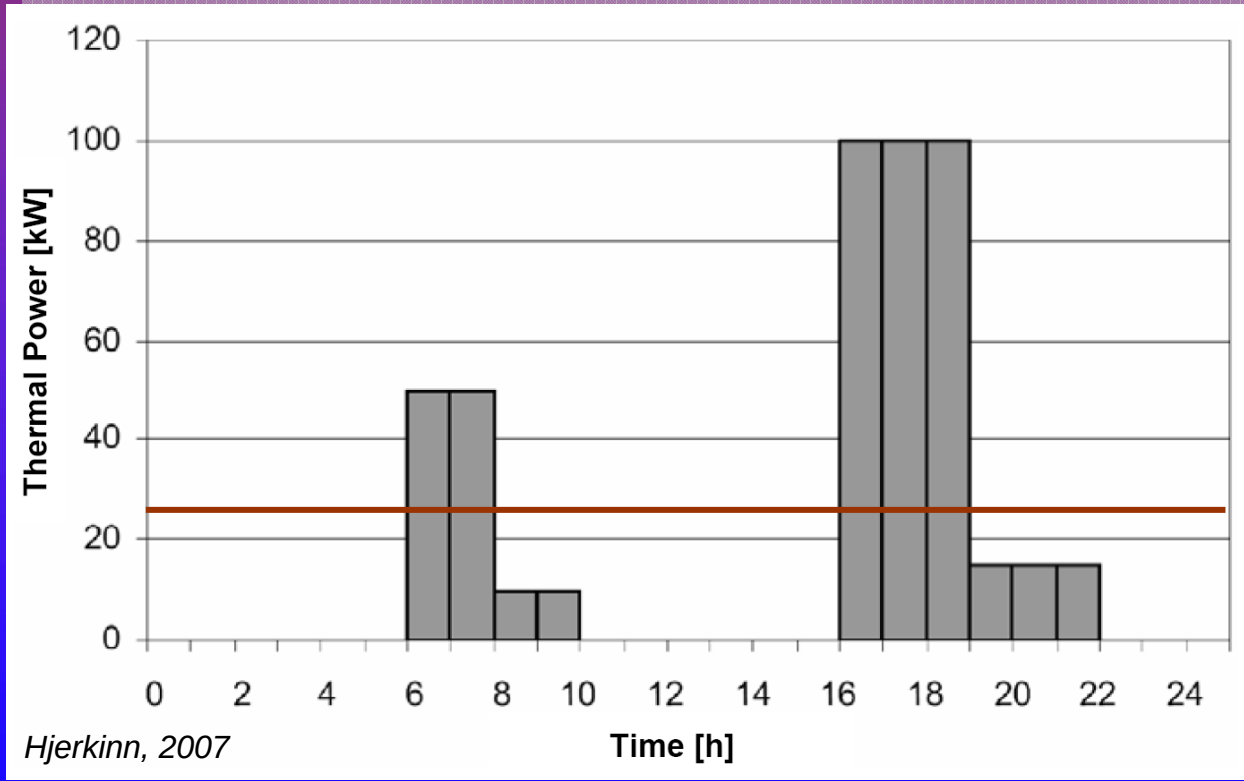
*Building Owner – "Bergen og Omegn Boligbyggelag"*

- Apartment buildings of passive house standard
  - Damsgårdsundet, Bergen (Norway)
- Total project – 300 flats
- DHW heating system
  - In-depth analysis of different heat pump water heater (HPWH) systems for one apartment building with 40 flats
- Heating and storage demands
  - Each flat – approx. 4,200 kWh/year
  - Total – approx. 170,000 kWh/year
  - HPWH – approx. 26 kW heating capacity
  - DHW storage tanks – approx. 3,800 litres



# DHW Heating Demand

*Estimated 24 hours DHW Consumption Diagram*




*Hjerkinn, 2007*

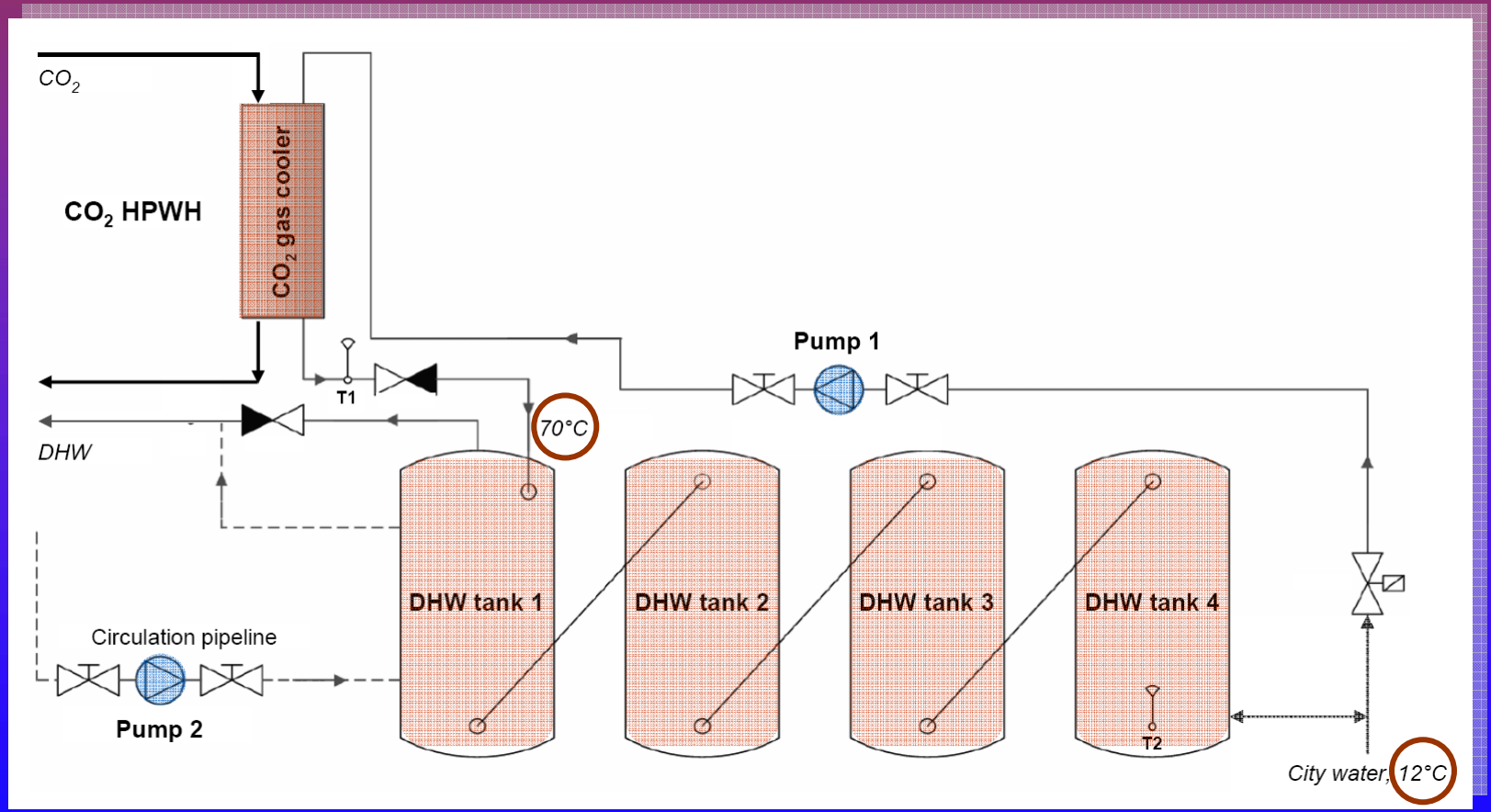
# Design and Analysis of a $CO_2$ HPWH

*Four Different Heat Sources – Different Evaporator Design*

- 26 kW $CO_2$ heat pump unit
  - Gas cooler temperature approach 3 K
  - Isentropic compressor efficiency 0.70 – from measurements
  - Volumetric compressor efficiency 0.75 – from measurements
- DHW temperature conditions
  - DHW 70°C
  - City water 12°C – average temperature in Bergen, Norway
- Different heat sources
  - Ambient air DOT=-10°C, $t_{ave}$=7.8°C
  - Seawater 0°C – indirect system design
  - Groundwater 7°C
  - Grey water 20°C

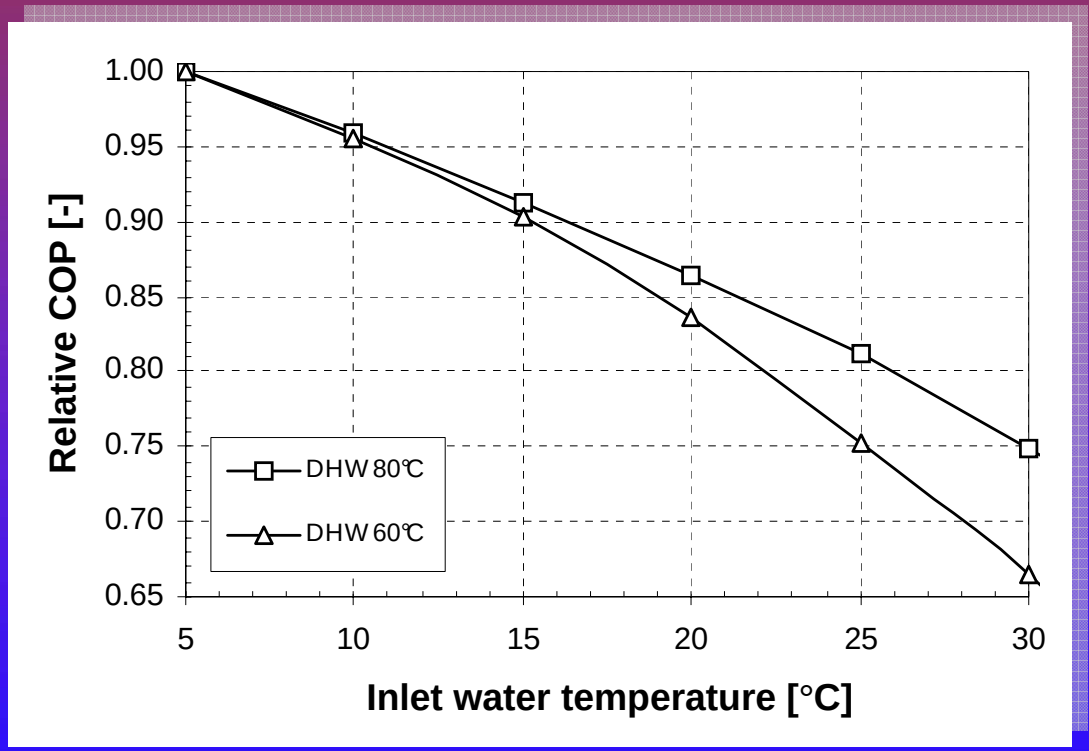
# $CO_2$ Heat Pump Water Heater System

*Principle Sketch of $CO_2$ Heat Pump Unit and DHW Storage Tanks*



# COP vs. Inlet Water Temperature

*Simulations with 60°C and 80°C DHW Temperature*

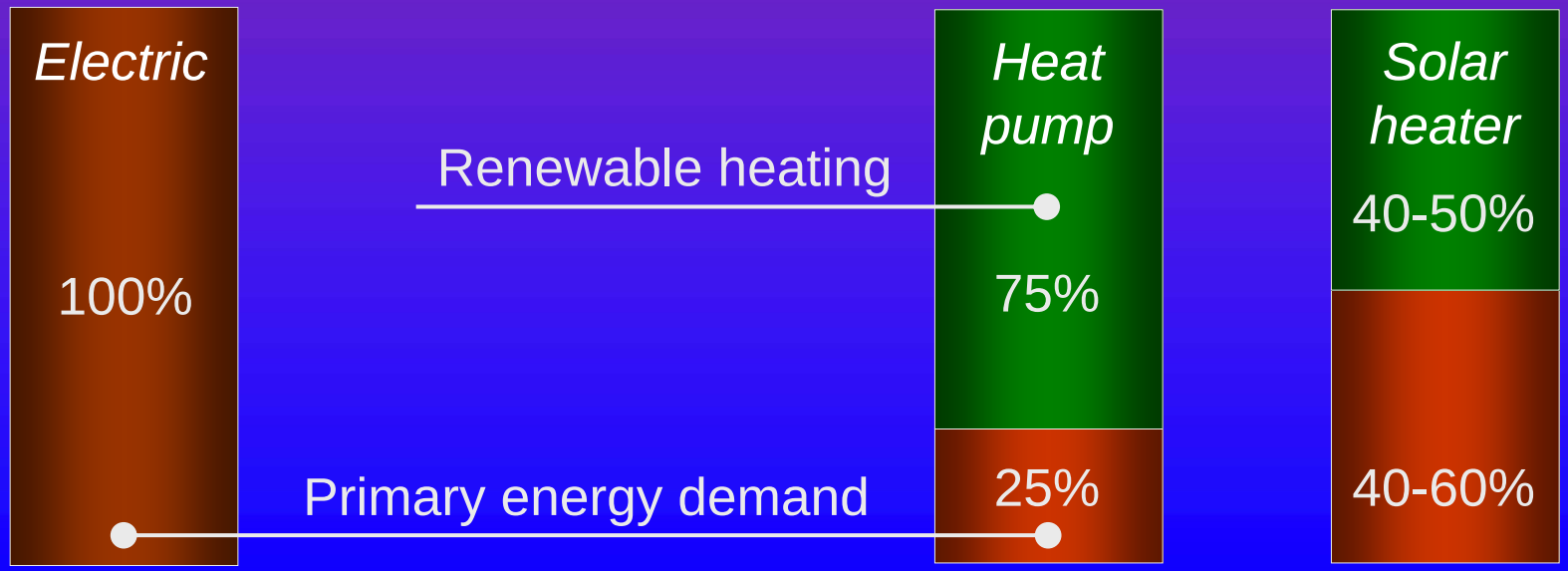



- The higher the inlet water temperature, the lower the COP of the $CO_2$ heat pump
- Recommendation – small diameter DHW storage tanks and efficient diffusers

# Simulation Results – COP, Energy Saving

*Simulation in CSIM – Groundwater as Heat Source (7°C)*

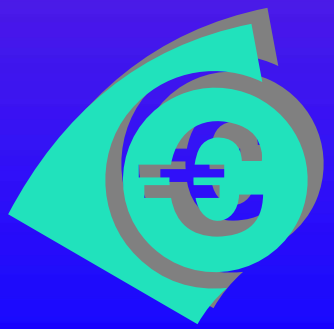
- Coefficient of Performance
  - COP = approx. 3.8 – energy input to pumps not included
- Net energy saving
  - Approx. 70-75% – compared to a direct electric heating system



# Simulation of Profitability

*Maximum Investment Cost (MIC)*

- Boundary conditions
  - Annual heating demand — 170,000 kWh/year
  - Heat pump, average COP — 3.5 – conservative value
  - Real interest rate — 6%
  - Economic lifetime — 15 years
  - Electricity price — 0.1 €/kWh (0.75 NOK/kWh)
  - Reference DHW system — Electric immersion heaters
- Results
  - Maximum investment costs approx. **€125,000 – 4,800€/kW**
  - Very profitable installation



# $CO_2$ Heat Pump Water Heaters – EcoCute

*Japanese Systems Commercially Available in Europe from 2007*


- 1 million residential $CO_2$ air-to-water HPWH sold in Japan during 2002-2008
- Heating capacity range from approx. 4 kW to 30 kW
- $CO_2$ technology developed at SINTEF-NTNU in Trondheim, Norway

# Heat Pump Water Heaters – Conclusions

- Heat pump water heaters represent an environmentally benign and profitable technology for centralized DHW heating in apartment buildings and block of flats
- For heat pump water heaters typically 65-75% of the heat supply comes from a renewable or waste heat source
  - Solar heater systems installed in the Nordic countries cover 40-50% of the heating demand with renewable heat – 50-60% is electricity
- $CO_2$ heat pump water heaters typically achieve 20% higher Coefficient of Performance than state-of-the-art heat pumps
- High-quality air-to-water $CO_2$ heat pump water heaters from Japan have now become commercially available in Europe

# Thank you for your attention!