HEAT PUMP APPLICATIONS AND DEFINITIONS

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APPLICATIONS OF HEAT PUMPS

- **1900s:** Refrigeration, need to chill **food;**
  Survival: → very large application; chilled food comprises 30-40 % of household energy use
  Turnover: Sweden $10 \cdot 10^9$, Europe $200 \cdot 10^9$, Global $1000 \cdot 10^9$ EUR

- **1940s:** Air conditioning, **comfort**
  Wellbeing: Including productivity → large application
  Voted innovation of the century in USA
  Sales: > $20 \cdot 10^6$ RAC per annum (explosive sales in China)

- **1970s:** Heat pumps for heating, **energy savings**
  Economy: Many alternatives for heating → limited application
  Sales: Sweden > $60 \cdot 10^3$ per year, > $600 \cdot 10^3$ total number (half of the European market, but Europe is growing)

APPLICATIONS OF HEAT PUMPS

- **Stationary**
  - Cryogenics
  - Freezers, refrigerators
  - Air conditioners
  - Space heating
  - Industrial processes

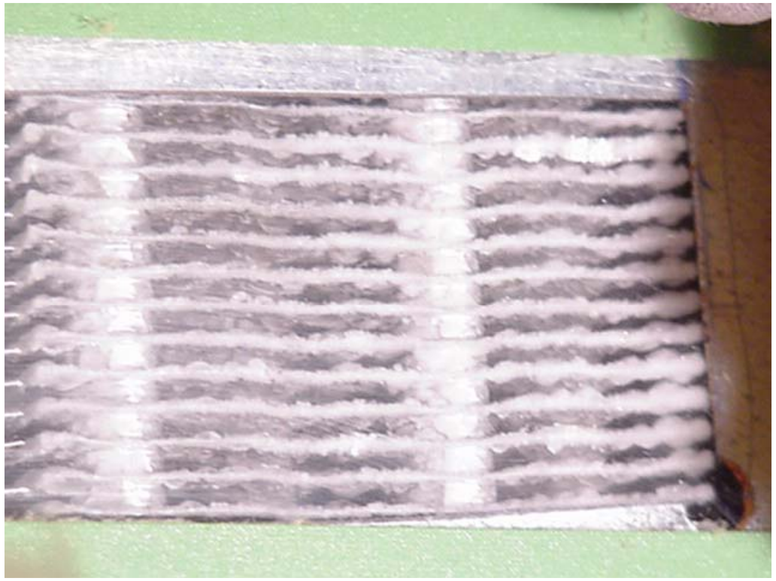
- **Mobile**
  - Reefers, road transport
  - Air conditioning (cars, lorries, buses, trains, airplanes....)

APPLICATIONS OF HEAT PUMPS

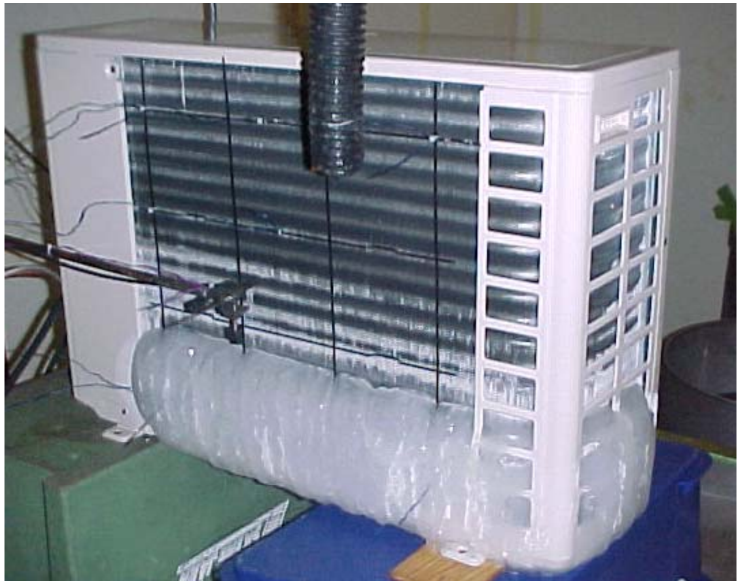
- **Demand** →
  need to move heat from **lower to higher temperature**
- Hence need for **heat pumps** (chillers) →
  basic heat pump theory
- Relation between **demand and process** →
  system aspects
- Most commonly, end task is **air cooling** →
  air coolers
- **Common denominator:** $\dot{Q} = \dot{Q}_S + \dot{Q}_L$
  (condensation and frosting distinguishes air coolers from air heaters)

APPLICATIONS:
Refrigeration and air-source heat pumps

- **Display-case air coil**



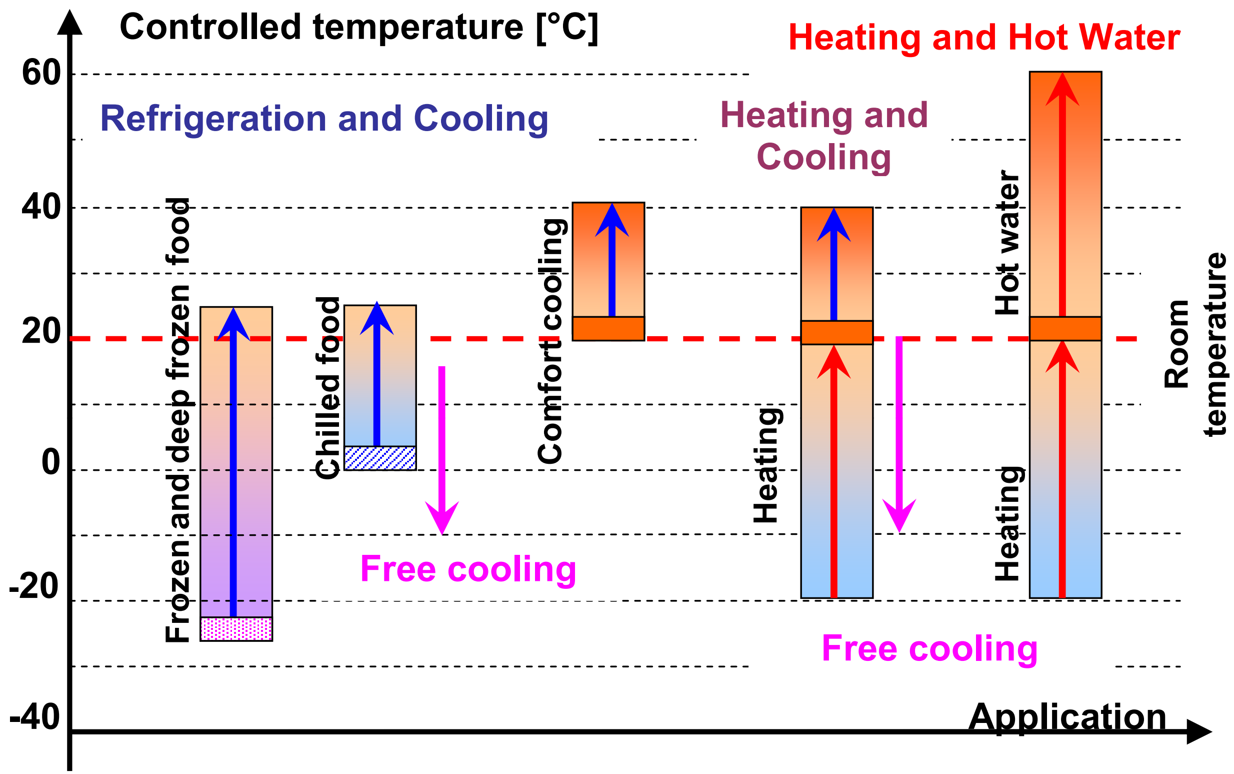
- **A/A heat pump**



- **Air coolers → all transport mechanisms must be considered**

HEAT PUMP APPLICATIONS

- **Frozen and chilled food:** Few alternatives (food hygiene, survival)
- **Space cooling:** Few alternatives (comfort, productivity)
- **Space heating and hot water:** Many alternatives (comfort, productivity)

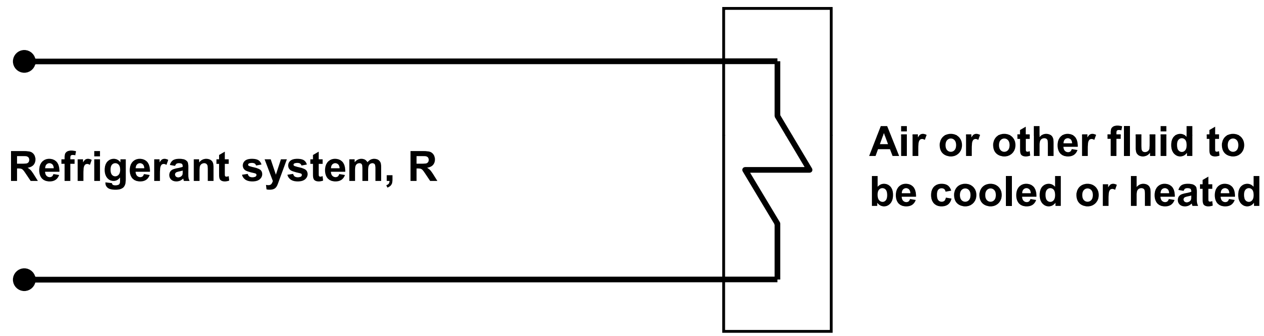


HEAT PUMP APPLICATIONS

- **Outdoor air**
  - "Unlimited" source → high air flows
  - High α, small Δt; frosting at t_{ao} < 5 to 7 °C, 2 < s < 4 mm
  - Thin coils → low Δp, high α, (developing flow)
  - Natural convection units → large area (the "ice stick")
  - Fluidized bed
- **Exhaust air**
  - HRV, mandatory in Sweden since 1980
  - "Limited" source → fixed air flow
  - Moderate α, large Δt (often 20 K); 4 < s < 6 mm
  - Thick coils → long thermal flow path (high η_t)
  - Natural convection units → large area
- **Process air:** Timber drying ….. (usually high temperature)

NOMENCLATURE: Definitions (1)

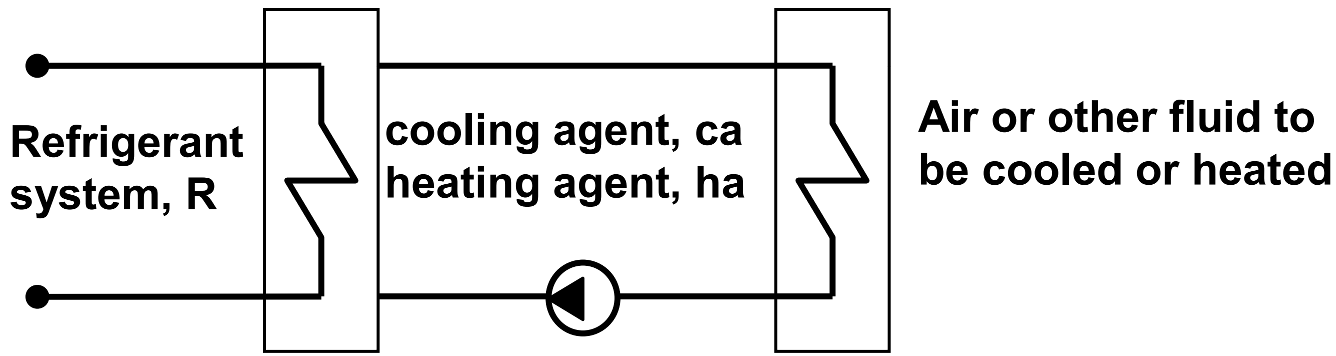
- **Direct (expansion) system**, DX (SS1897)
  A system in which the evaporator, condenser etc.
  is in direct contact with the cooled or heated medium.
  Only the heat exchanger wall separates the refrigerant
  and the cooled or heated medium (see figure below)



NOMENCLATURE: Definitions (2)

- **Indirect system (SS1897)**
  A system in which the evaporator, condenser etc. is not in direct contact with the cooled or heated medium.

  Note: An intermediate heat transfer medium, in this text denoted cooling or heating-agent, transports heat from the refrigerant heat exchanger to a second heat exchanger between the brine and the cooled or heated medium. Only the heat exchanger wall separates the refrigerant and the cooled or heated medium (see figure below).



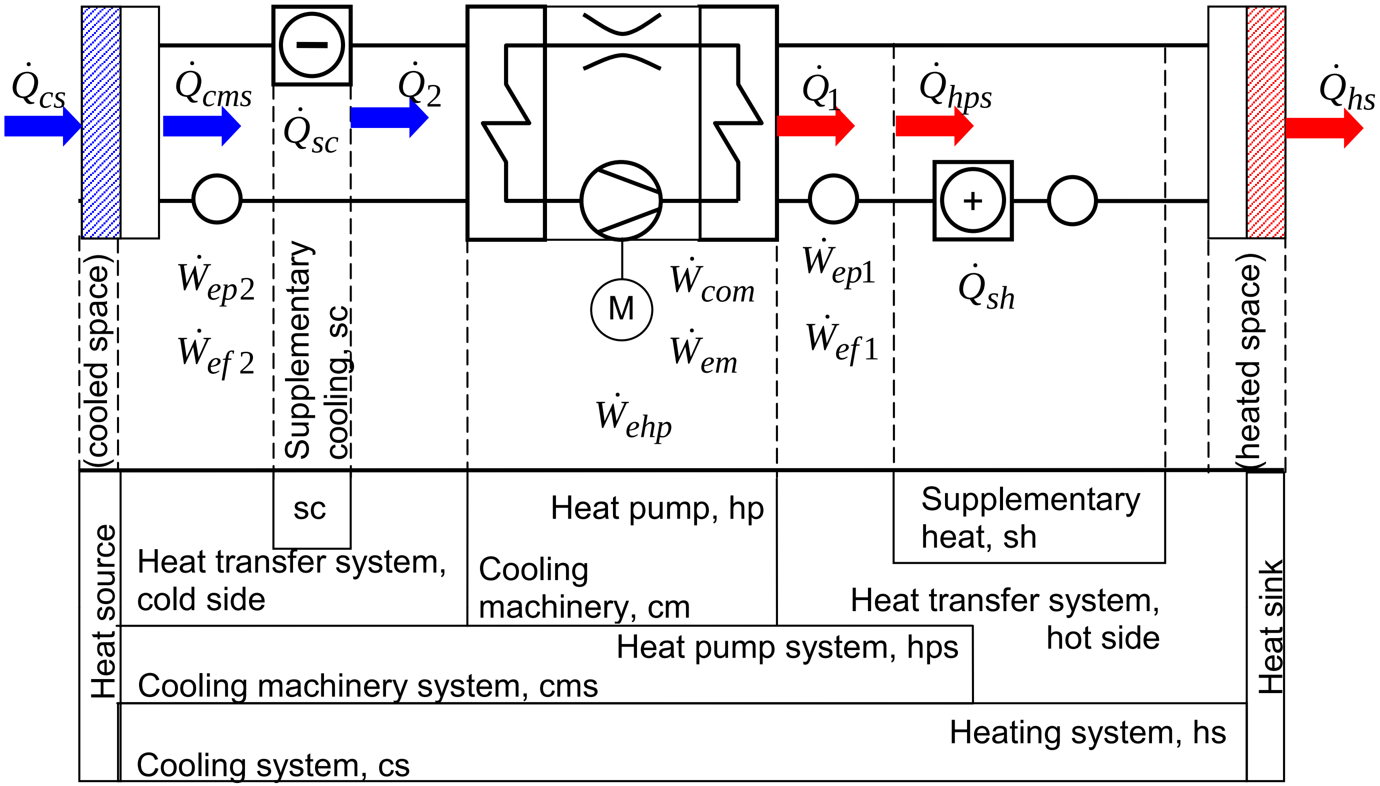
NOMENCLATURE: Definitions (2)

- **Brine, b (EN255)**
  Heat transfer medium that has a freezing point depressed relative to water.
  Comment: Brine is a water-based subgroup of cooling agents (see cooling agent)
- **Condenser coolant, cc**
  Medium (fluid) that transports heat away from the condenser.
- **Cooling agent, ca (SS1897)**
  Medium (fluid) that transports heat from a heat source to a heat pump or from a cooled/refrigerated space to a cooling/refrigeration plant.
  C.f. brine, secondary coolant, secondary refrigerant, cold-side heat transfer medium.
- **Heating agent, ha (SS1897)**
  Medium (fluid) that transports heat from a heat emitter to a point of use (e.g. from a condenser to a heating or hot water system).
  C.f. heating water, heating air, hot-side heat transfer medium.
- **Refrigerant, R (SS 1897)**
  Working medium (fluid) of a refrigeration (heat pump) process.
  The refrigerant absorbs heat at a low temperature and a low pressure and rejects heat at a higher temperature and a higher pressure, usually through a change of state (liquid-to-gas, gas-to-liquid).

NOMENCLATURE: Subscripts

- **Subscripts:** Medium, component, position, function
- **Medium:** a = air, w = water, b = brine, ca = cooling agent, ha = heating agent, g = gas, l = liquid, s = solid
- **Component:** f = fan, cm = cooling machinery, cms = cooling machinery system, sc = supplementary cooling, hp = heat pump, hps = heat pump system, hs = heating system, sh = supplementary heating, p = pump, ‘ = unsaturated, ‘’ = saturated,
- **Position:** 1 or i = inlet, 2 or o = outlet, 1 = condenser, 2 = evaporator
- **Function:** g = gas, l = liquid, s = solid, ‘ = unsaturated, ‘’ = saturated,

NOMENCLATURE: System diagram



1 = condenser side
2 = evaporator side

cs = cooling system
cms = cooling machinery system
sc = supplementary cooling

hp = heat pump
hps = heat pump system
hs = heating system
sh = supplementary heating

e = electric
m = motor
f = fan
p = pump

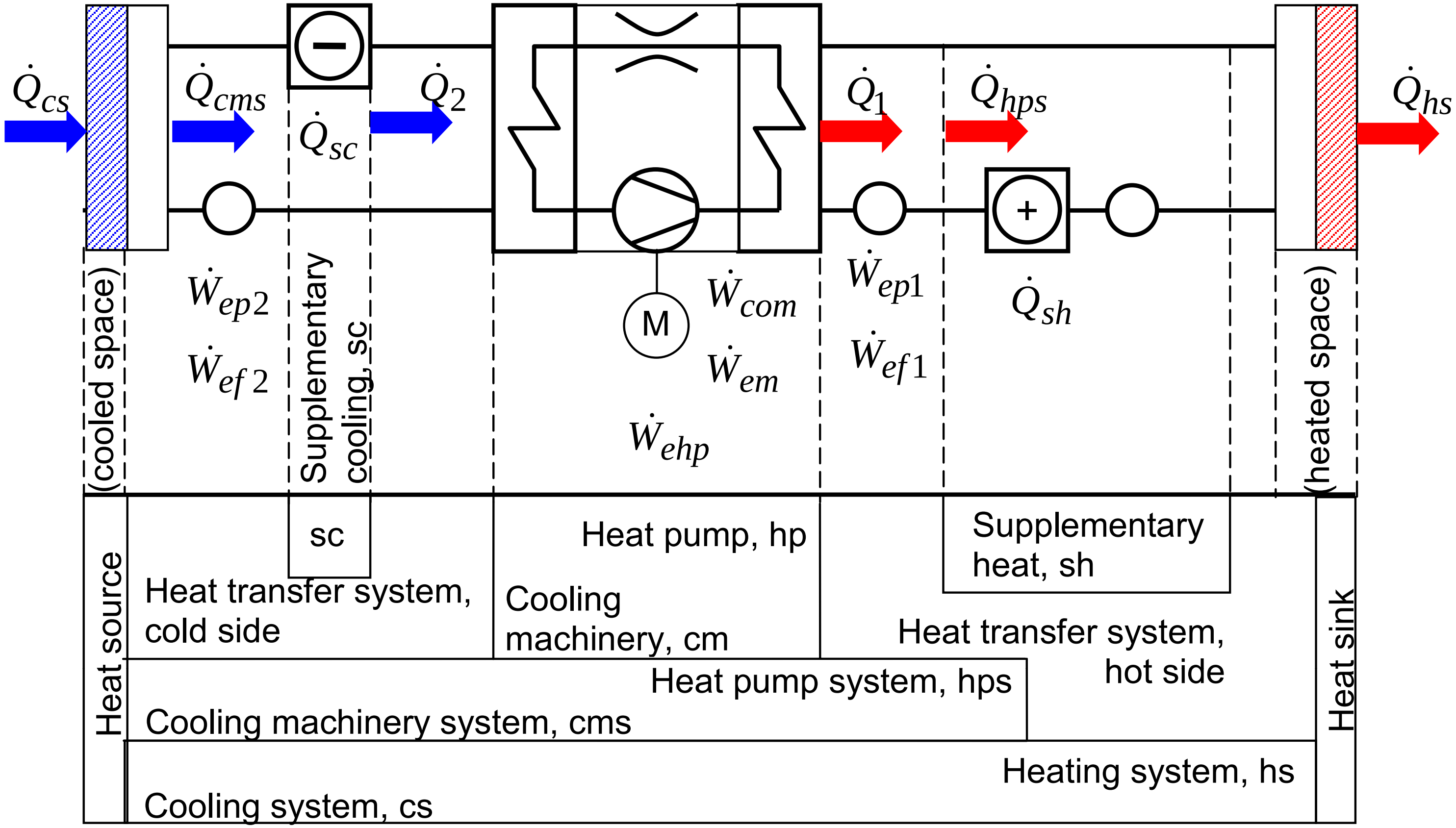
HEAT PUMP EFFICIENCY ASPECTS

IMPROVE *SPF* BY OPTIMAL USE OF FREE ENERGY AND DRIVE POWER, e.g.

- **Reduce use/demand** (load matching and storage)
- **Reduce purchased energy** (natural sources and sinks)
- **Reduce drive energy for:**
  - heat pumping (reduction of temperature lift)
  - heat transfer (heat exchanger design and control)
  - heat transport (system design and flow control)
  - terminal units (design and control)

APPLICATION AND LOCATION → DEMAND

HEAT PUMP SYSTEM BOUNDARIES



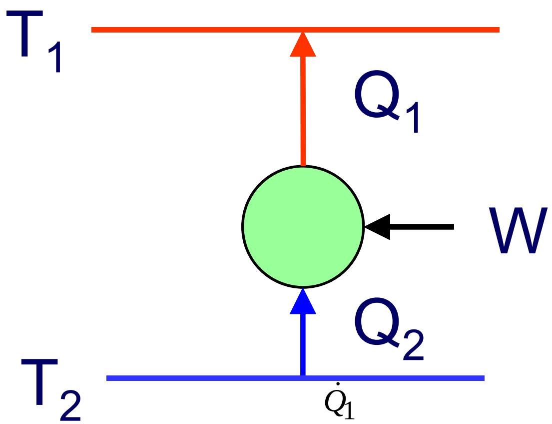
$$W_{ep2} = \sum_{j=1}^{n} W_{ep2,j}$$

$$W_{ehp}$$

$$W_{ep1} = \sum_{i=1}^{n} W_{ep1,i}$$

HEAT PUMP KEY NUMBERS

- **Carnot process**

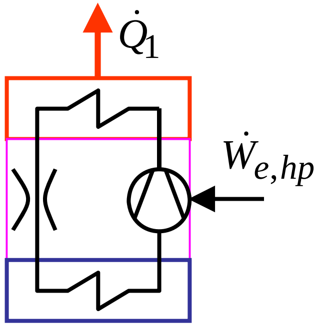


$$COP_{1C} = \frac{Q_1}{W} = \frac{T_1}{T_1 - T_2}$$

$$COP_{2C} = \frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}$$

- **Heat pump**

$$COP_{hp} = \frac{\dot{Q}_1}{\dot{W}_{e,hp}}$$



- **Heat pump system**

$$COP_{hps} = \frac{\dot{Q}_1 + \dot{W}_{e,p1}}{\dot{W}_{e,hp} + \dot{W}_{e,p1} + \dot{W}_{e,p2}}$$

- **Heating or cooling system**

$$COP_{hs} = \frac{\dot{Q}_1 + \dot{W}_{e,p1} + \eta_{sh} \cdot \dot{Q}_{sh}}{\dot{W}_{e,hp} + \dot{W}_{e,p1} + \dot{W}_{e,p2} + \dot{Q}_{sh}}$$

SYSTEM DESIGN AND OPERATION

- **Load matching by Control-On-Demand (*COD*)**
  - Adapt the supply capacity → capacity control
  - Adapt the HVAC system → storage
- **HVAC system design is crucial for**
  - ***Natural sinks*** (free cooling)
  - ***Temperature lift*** compressor (heat pumping)
  - ***Heat transfer*** pumps, fans
  - ***Heat transport*** heat losses, pumps, fans
  - ***Terminal units*** - pumps, fans

$$\frac{\Delta COP_{hp}}{COP_{hp}} \approx \left[\frac{\Delta T_2}{T_1 - T_2} - \frac{T_2}{T_1} \cdot \frac{\Delta T_1}{T_1 - T_2} \right]$$

$$COP_{hps} = COP_{hp} - \frac{\left(COP_{hp} - 1\right) \cdot \dot{W}_{e,p1} + COP_{hp} \cdot \dot{W}_{e,p2}}{\dot{W}_{e,hps}}$$

Parasitic drive energy ratio: $R_{pW} = \dfrac{W_{e,hps} - W_{e,hp}}{W_{e,hp}}$

EN STANDARDS

1. EN255-3Rev, 2007. Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors - Heating mode - Part 3: Testing and requirements for marking for sanitary hot water units.

2. EN378, 2000. Refrigerating systems and heat pumps - Safety and environmental requirements.

3. EN14511, 2004. Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling
   - Part 1: Terms and definitions.

4. - Part 2: Test conditions.

5. - Part 3: Test methods.

6. - Part 4: Requirements.

EN STANDARDS (continued)

7. prEN14825, 2010. Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance.
8. prEN15459, 2006. Heating systems in buildings - Data requirements for standard economic evaluation procedures related to energy systems in buildings, including renewable sources.
9. prEN15879-1, 2008. Testing and rating of direct exchange ground coupled heat pumps with electrically driven compressors for space heating and/or cooling - Part1: Direct exchange-to-water heat pumps.
10. SS-EN12102, 2008. Air conditioners, liquid chilling packages, heat pumps and dehumidifiers with electrically driven compressors - Measurement of air-borne noise - Determination of the sound power level
11. SS-EN15243-2007, 2007. Ventilation for buildings - Calculation of room temperatures and of load and energy for buildings with room conditioning systems.