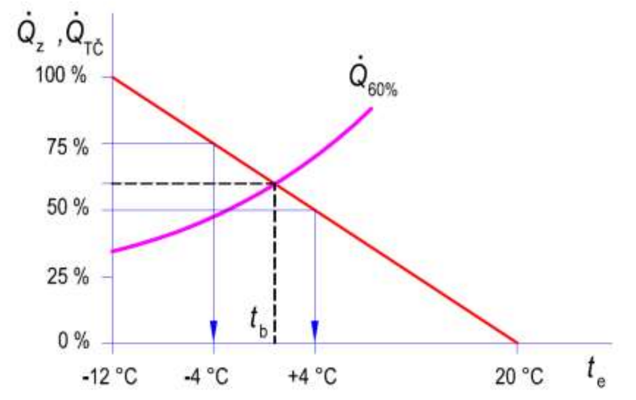
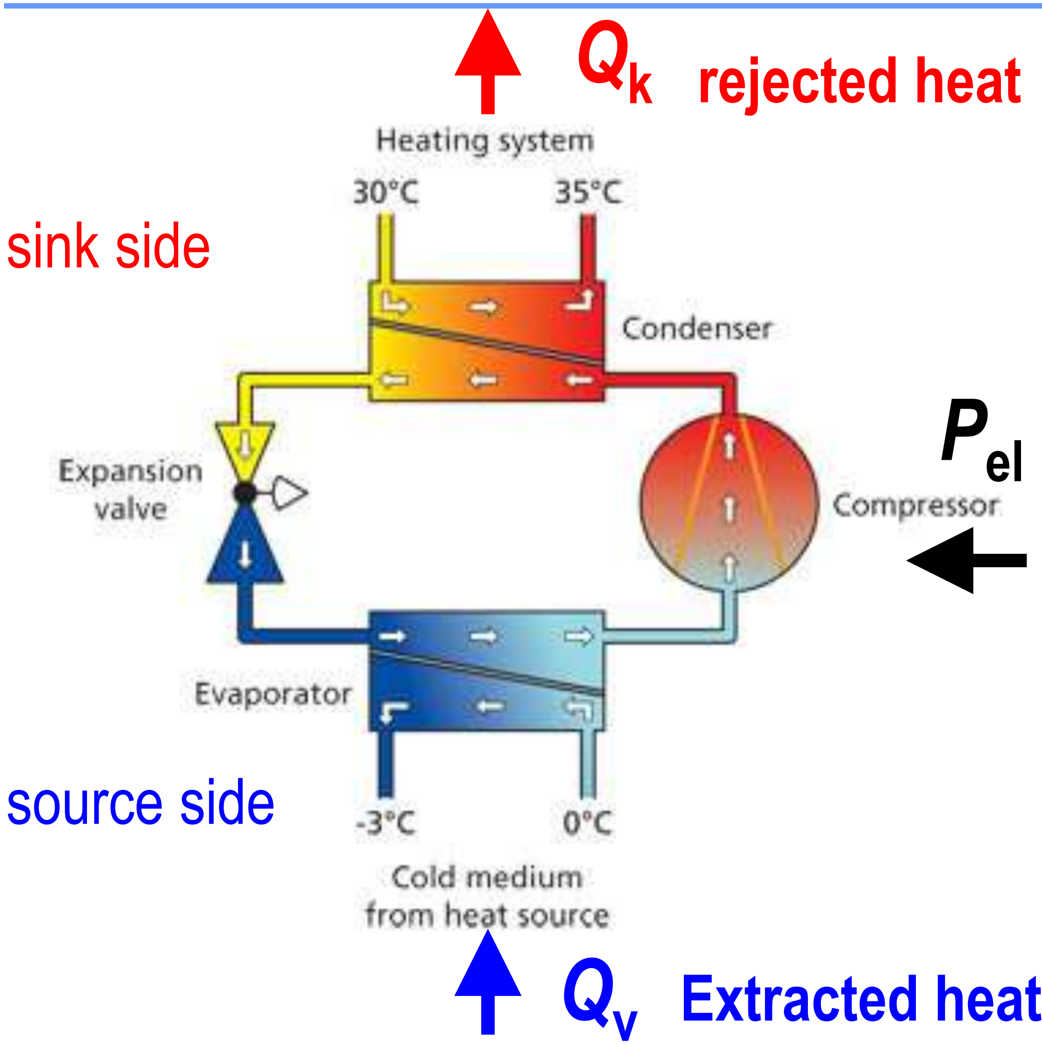
7 Heat pumps sizing

- heat pump characteristics
- testing & operation conditions
- balance point
- storage size
- hydraulics



Heat pump



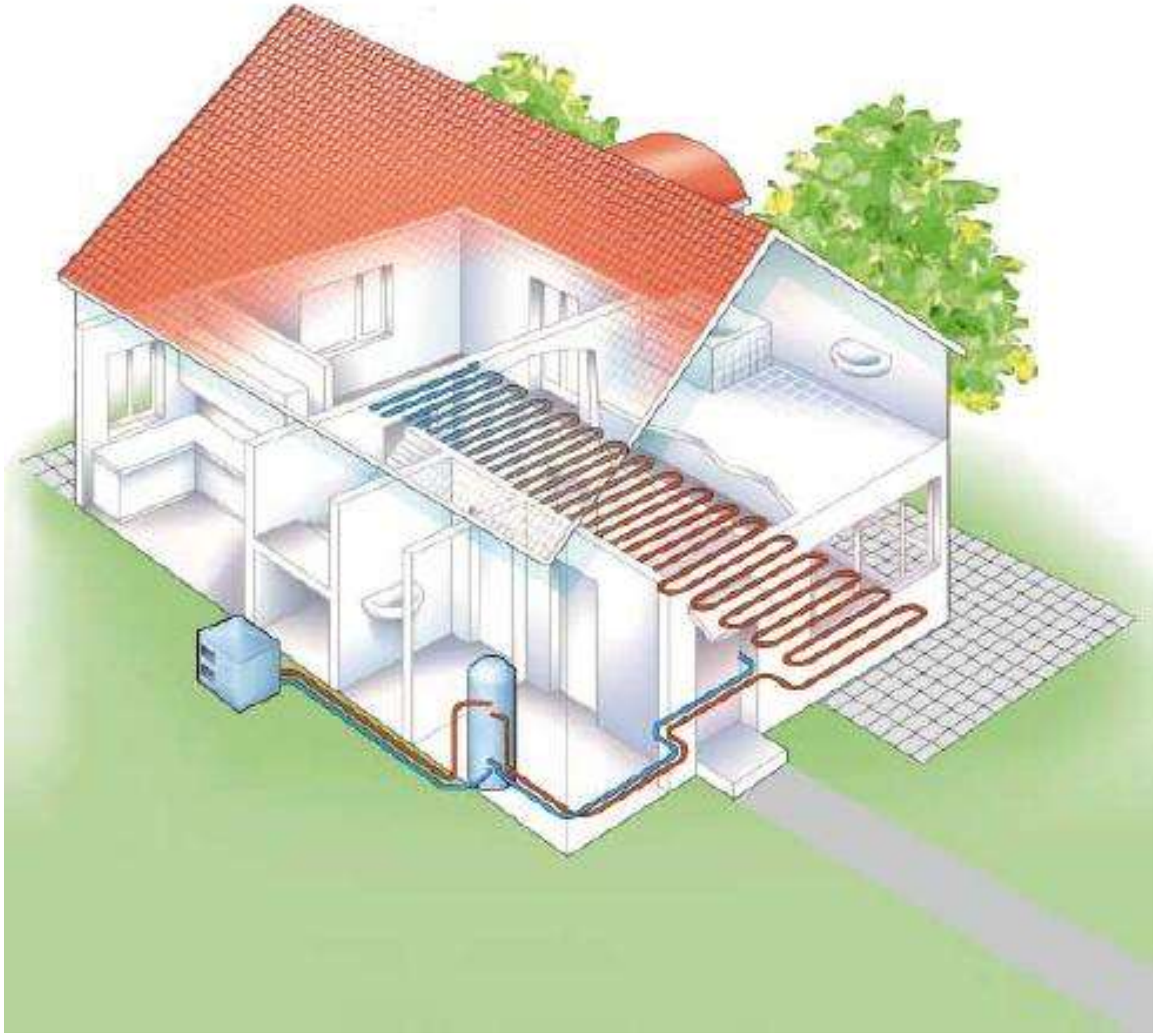
$$\dot{Q}_k = P_{el} + \dot{Q}_v$$

$$COP = \frac{\dot{Q}_k}{P_{el}}$$

$$\dot{Q}_v = \dot{Q}_k - P_{el}$$

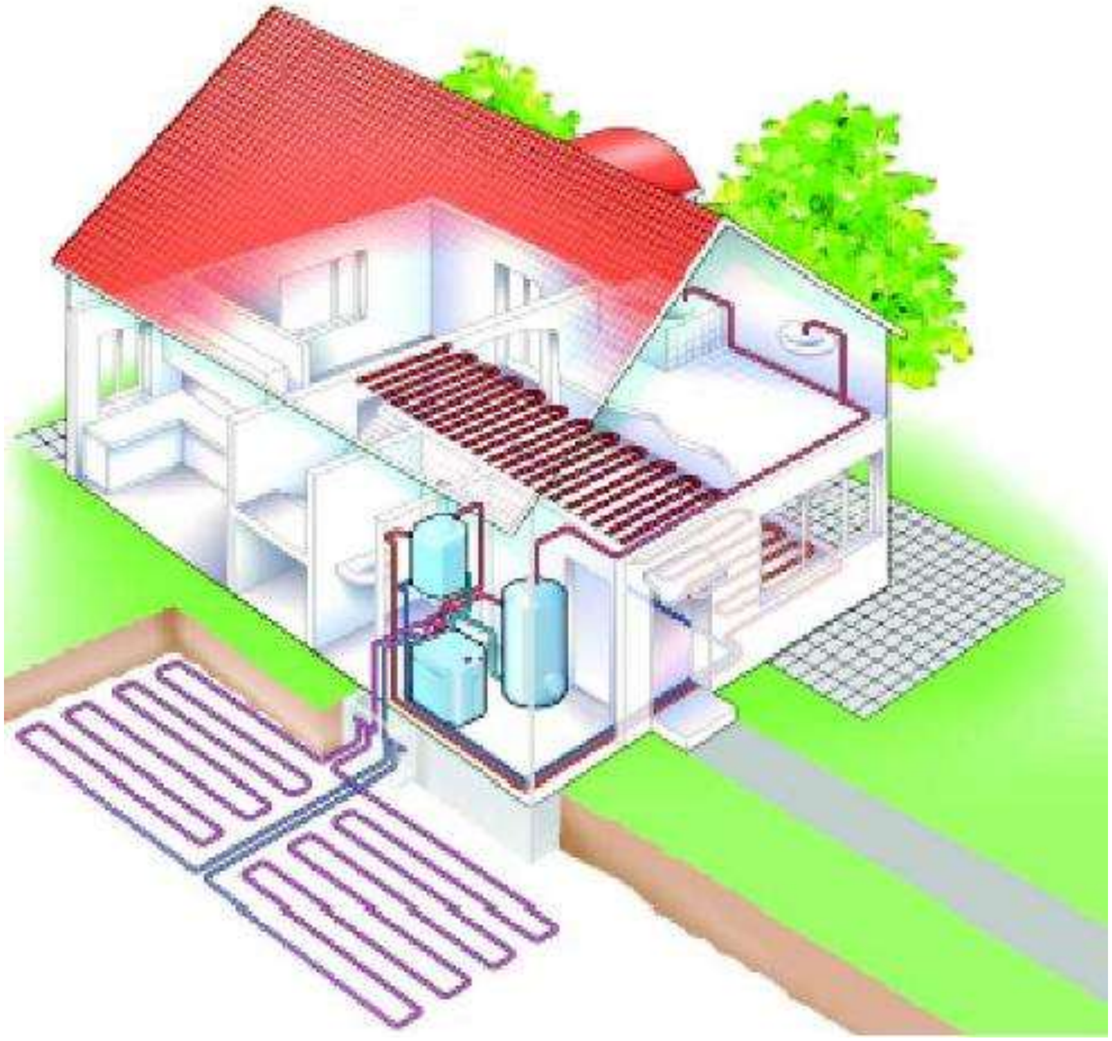
$$\dot{Q}_v = \dot{Q}_k \cdot \left(1 - \frac{1}{COP}\right)$$

Heat pumps: air source (ambient)



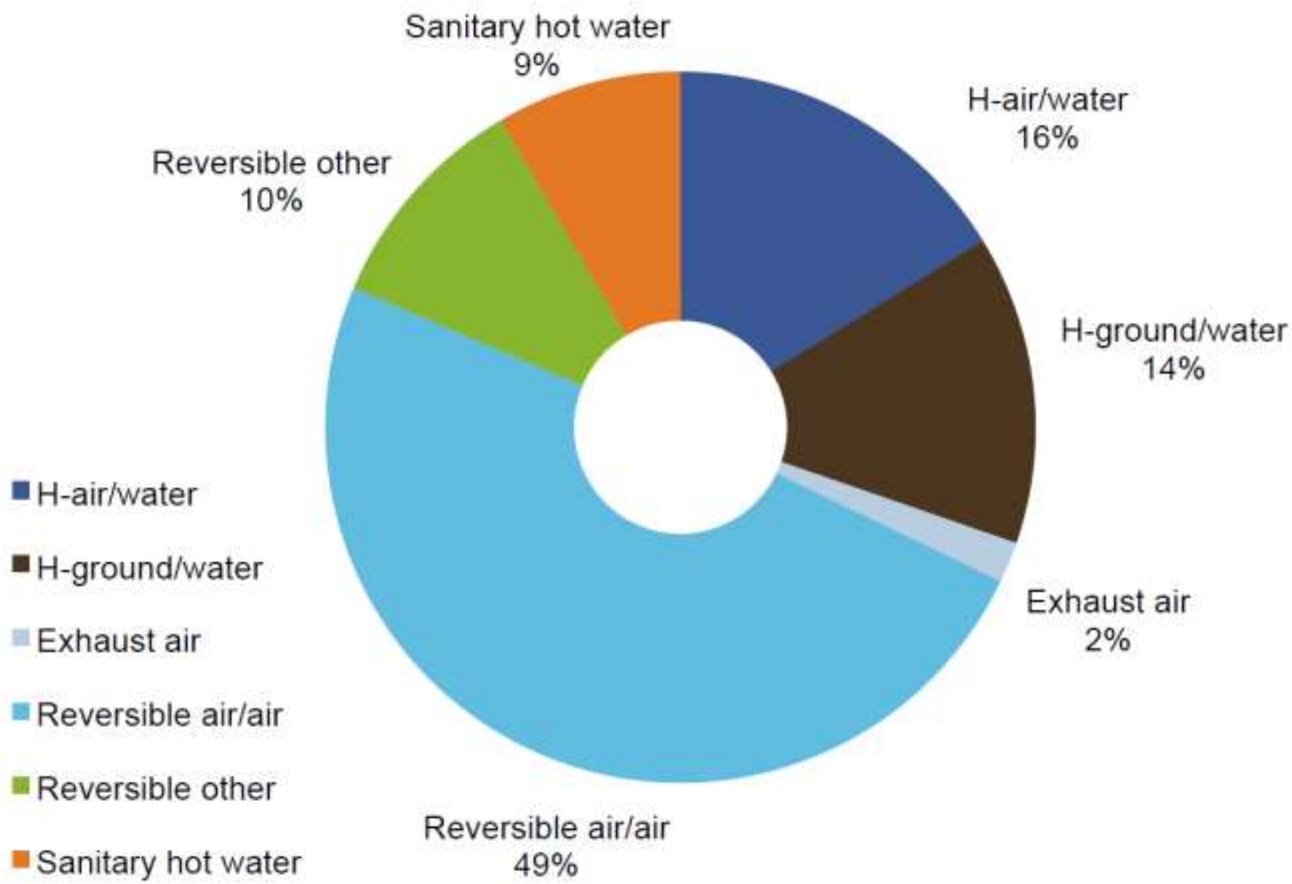
Heat pumps: ground source (borehole)

Heat pumps: ground source (ground HX)

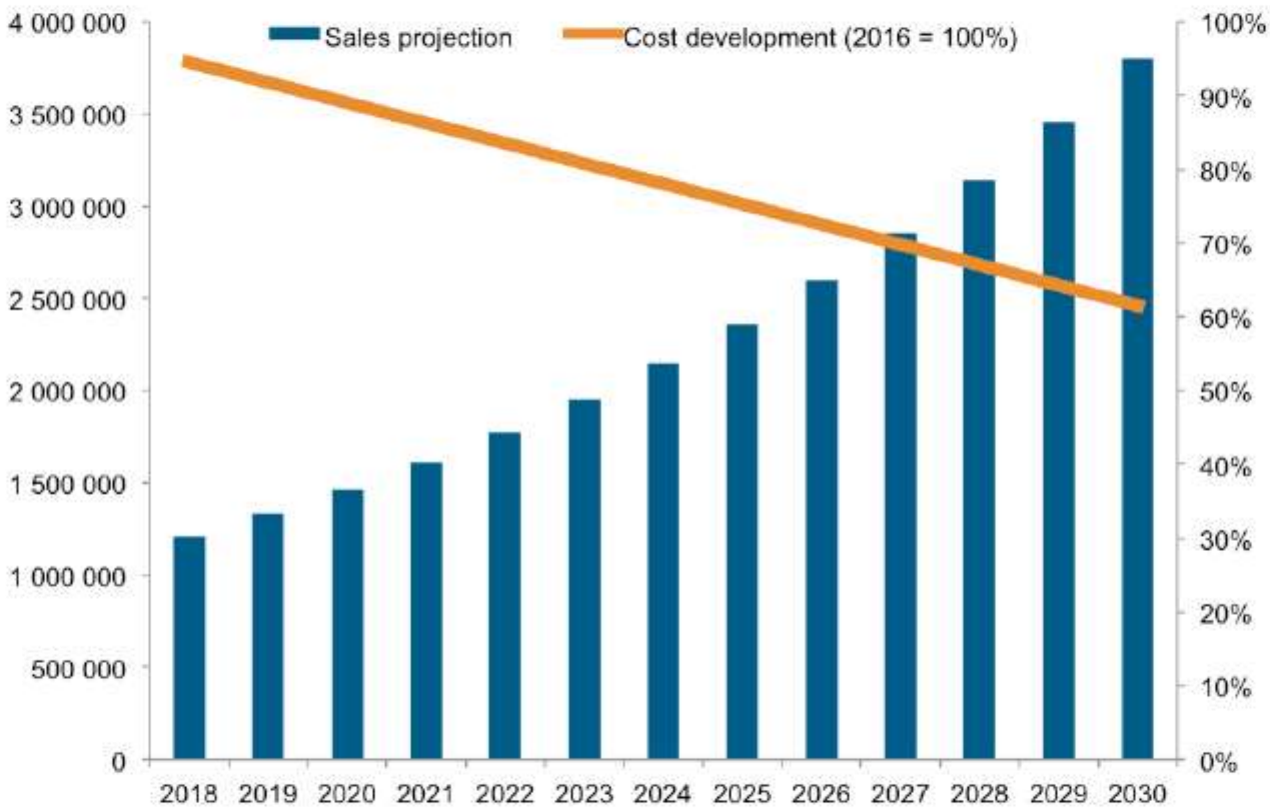


Heat pumps: water source (water well)

Types of heat pumps on the market



Future

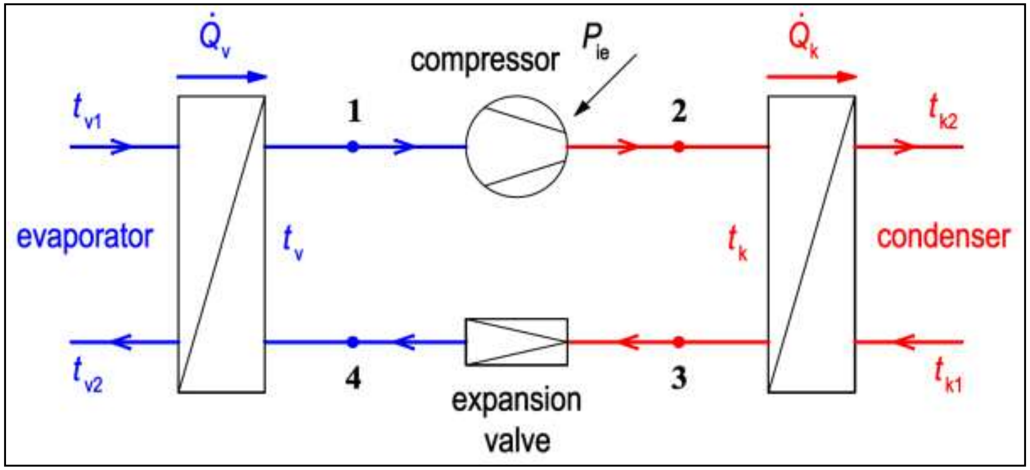


Sales projection
Cost development (2016 = 100%)
4 000 000
3 500 000
3 000 000
2 500 000
2 000 000
1 500 000
1 000 000
500 000
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030

Heat pump parameters

electric power
P_{el} [kW]

evaporator input
Q_v [kW]
= source output



heat output, heat capacity

Q_k [kW]

= heat output from **condenser**

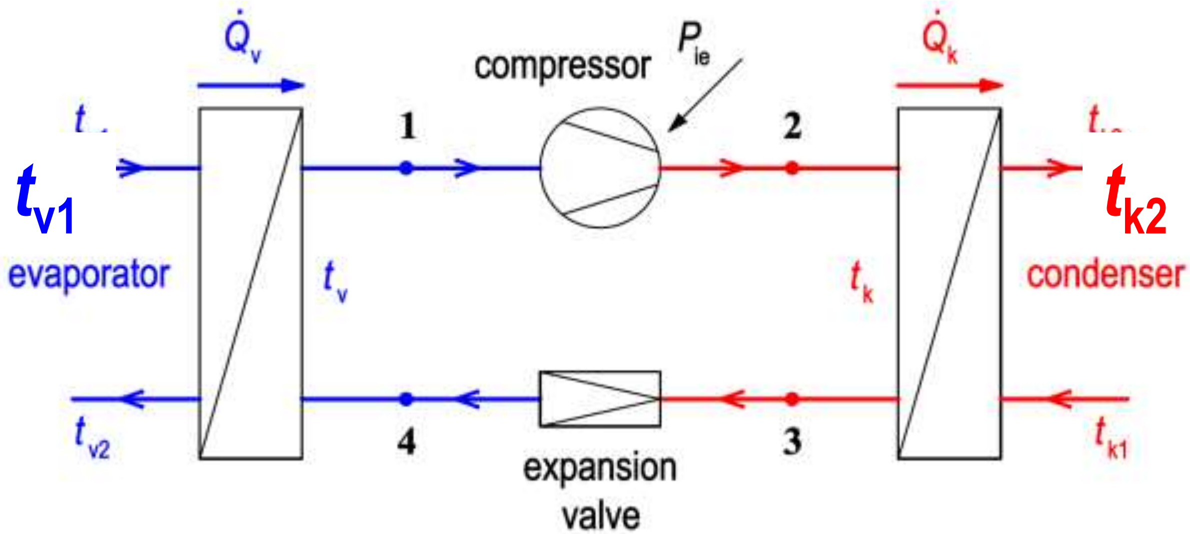
coefficient of performance COP [-]

Heat pump parameters

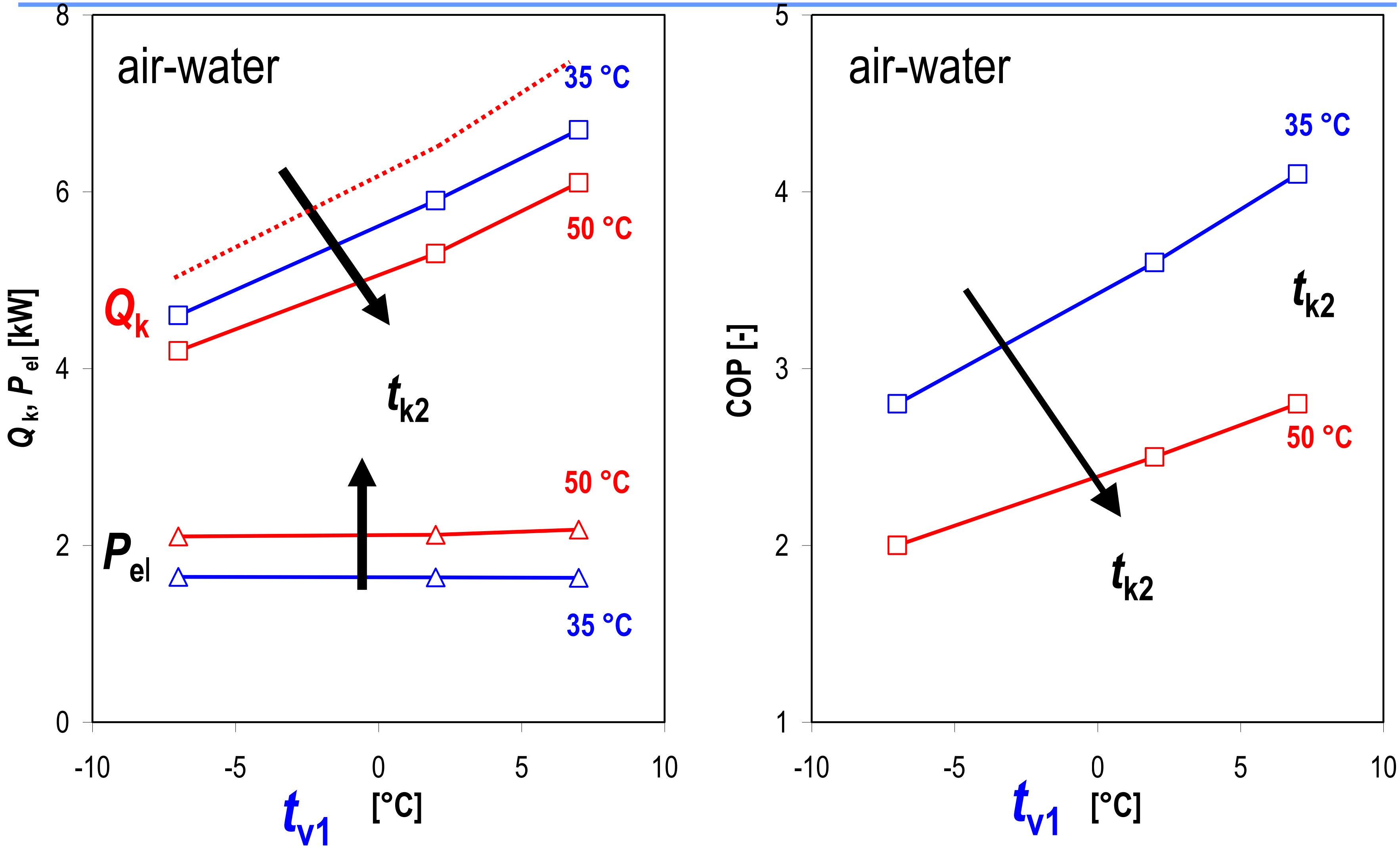
at given boundary conditions

t_{v1} - evaporator input temperature

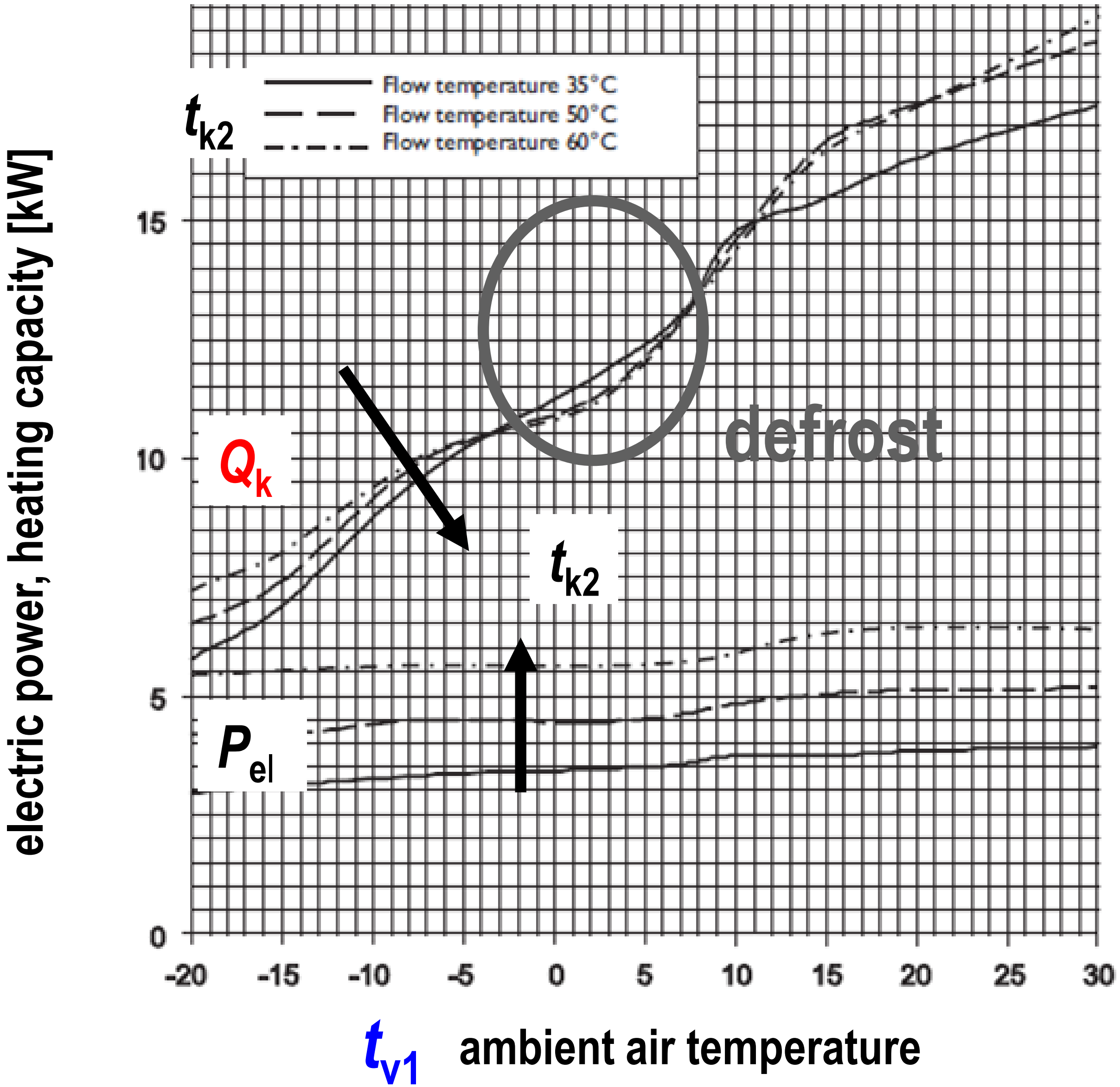
t_{k2} - condenser output temperature



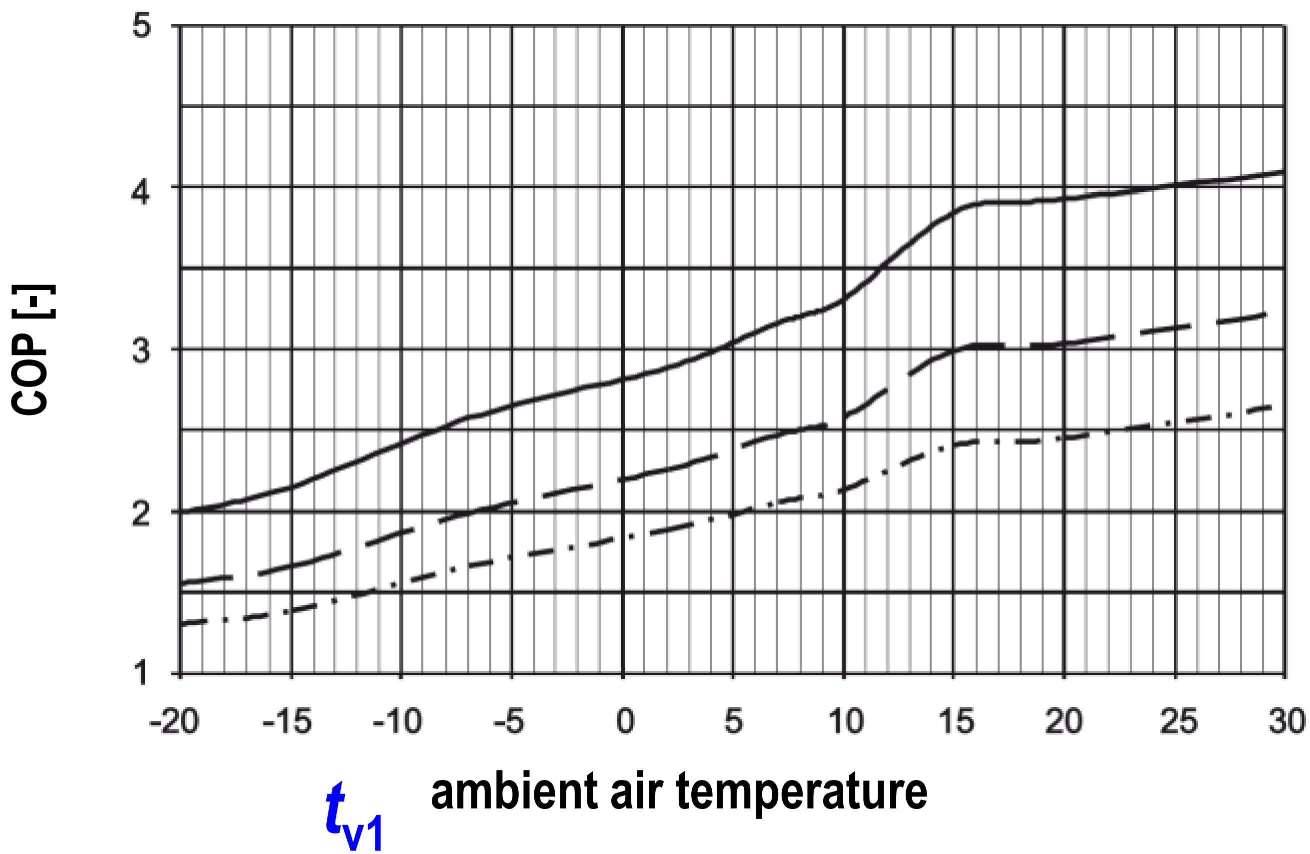
Air-water heat pump characteristics



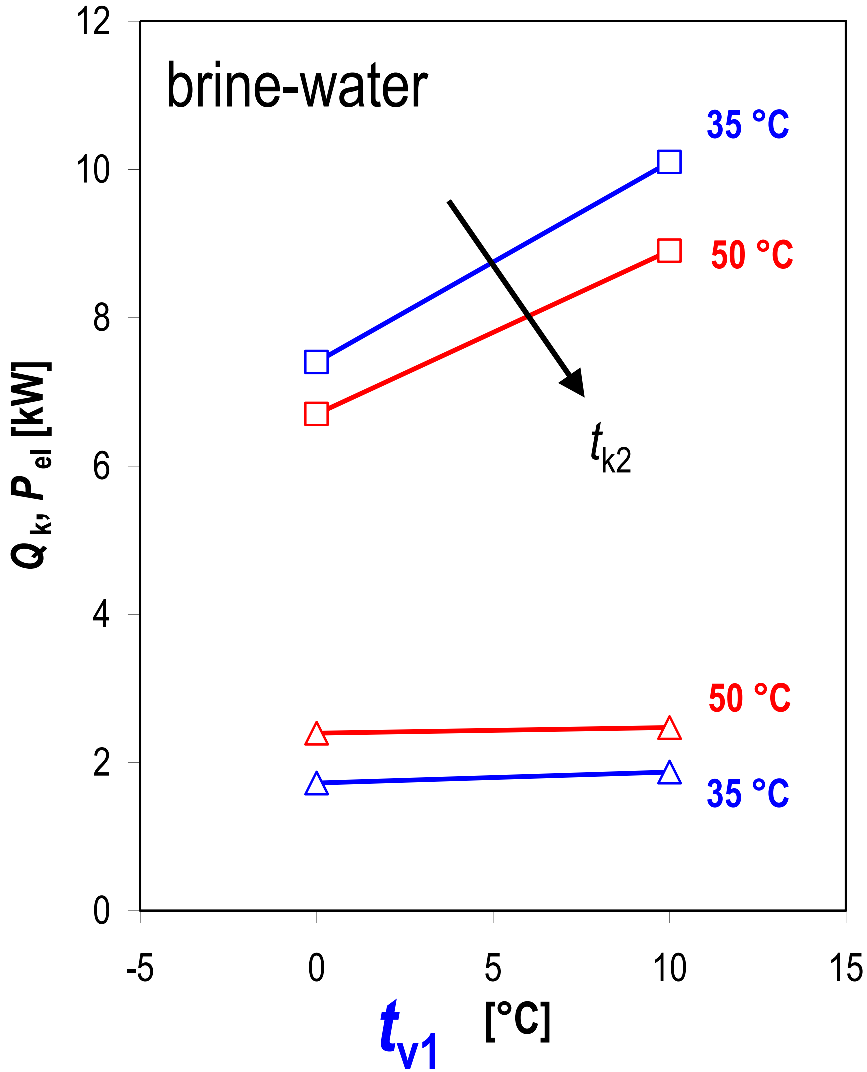
Air-water heat pump characteristics

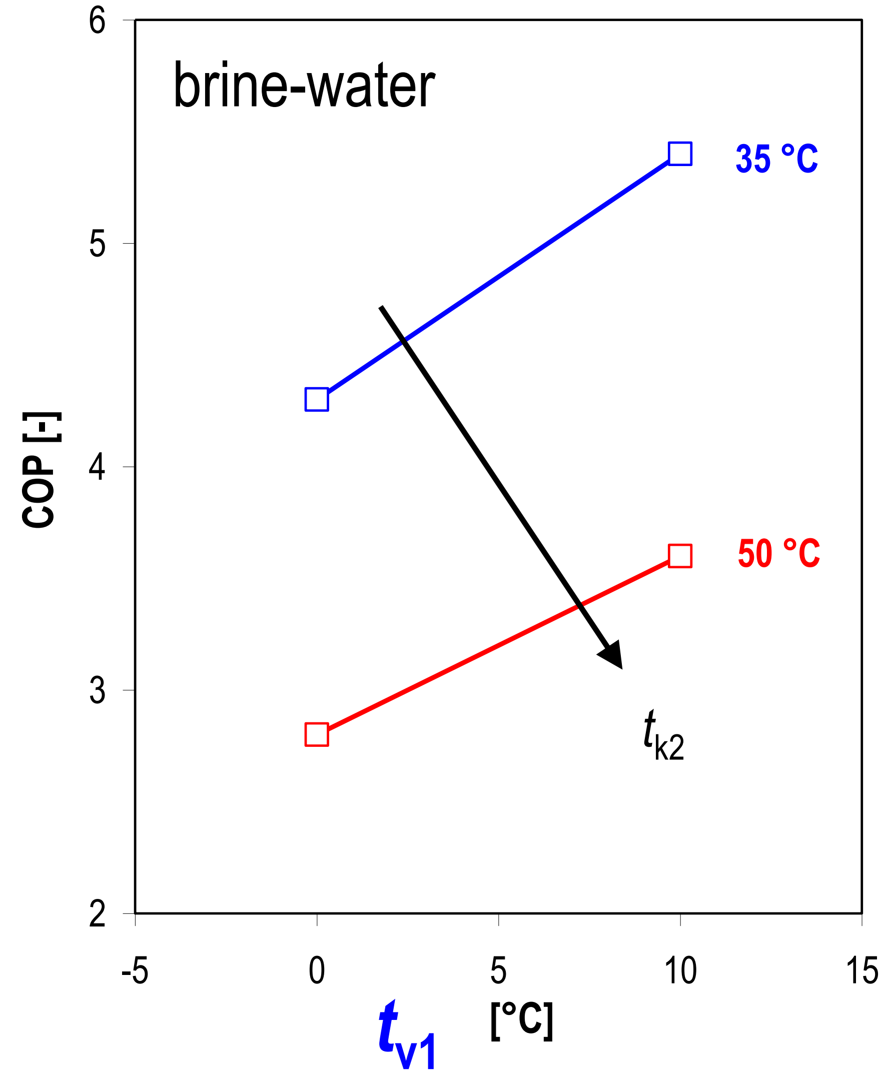


Air-water heat pump characteristics

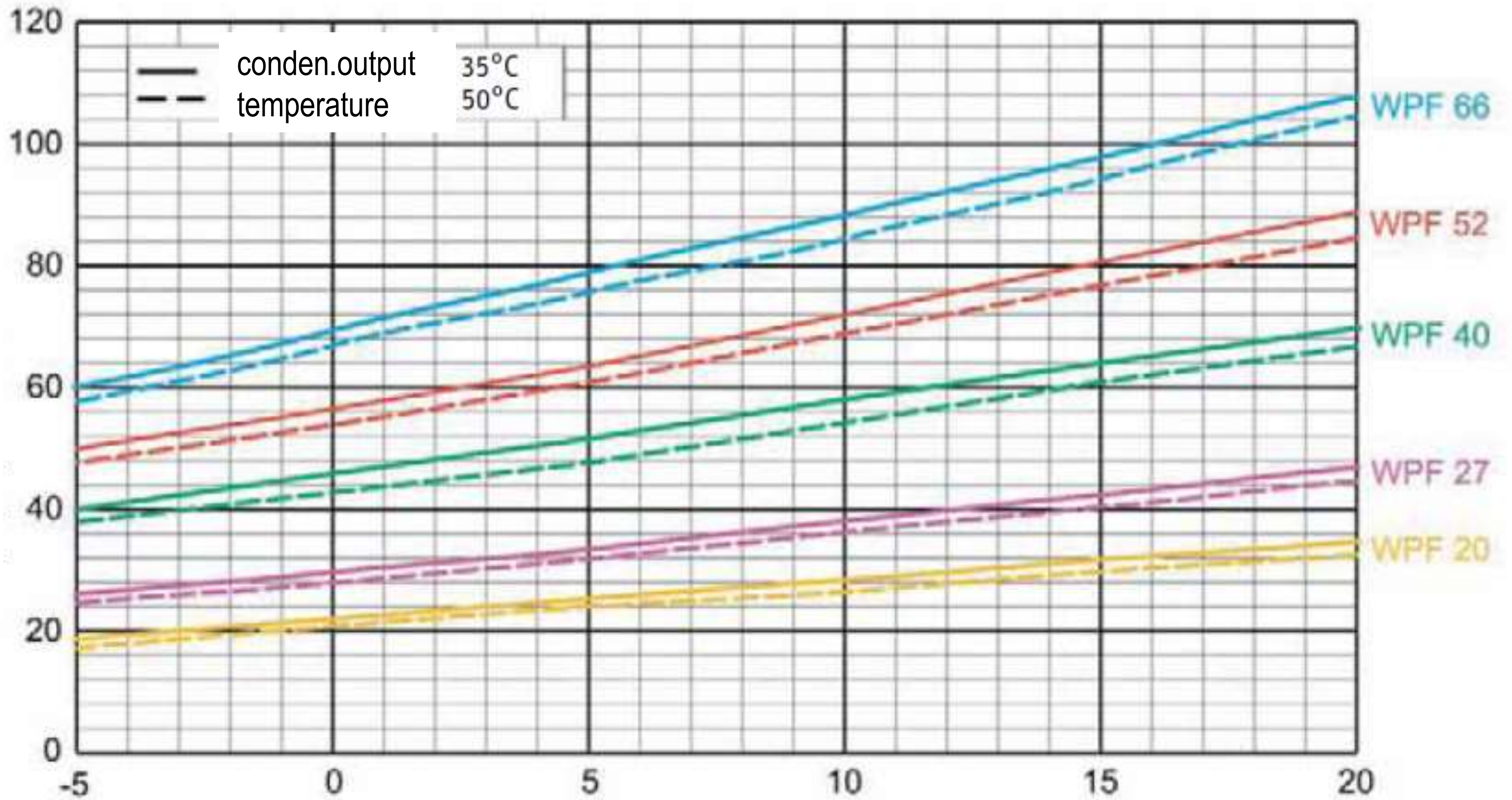


Brine-water heat pump (ground source)





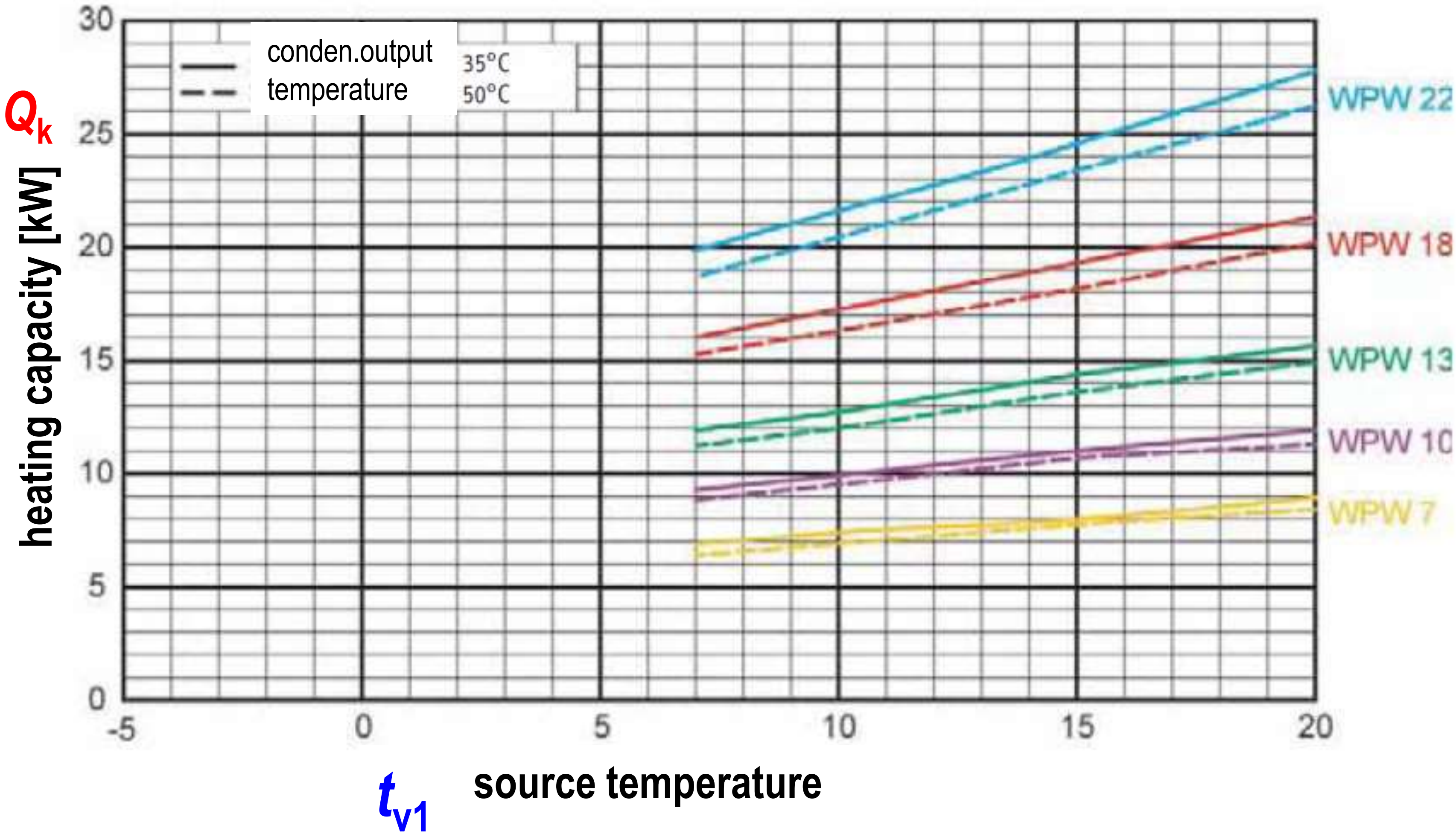
Brine-water heat pump (ground source)



Q_k heating capacity [kW]

t_{v1} source temperature

Water-water heat pump



Testing of heat pumps

- EN **14511** - Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling.
  - EN 14511-1: dtto - Terms and definitions
  - EN 14511-2: dtto - Test conditions
  - EN 14511-3: dtto – Test methods
  - EN 14511-4: dtto - Requirements

- EN **16147** – Heat pumps with electrically driven compressors. Testing and requirements for marking of domestic hot water units

Testing conditions

- EN 14511: water-water **W/W** (W10 / W35)
  - **nominal: 10/35 °C** 10/45 °C
  - operation: 15/45 °C 10/55 °C
- EN 14511: brine-water (ground-water) **B/W** (B0 / W35)
  - **nominal: 0/35 °C** 0/45 °C
  - operation: 5/35 °C 5/45 °C 0/55 °C
    -5/45 °C
- EN 14511: air-water (ambient air) **A/W** (A2 / W35)
  - **nominal: 7/35 °C** 7/45 °C
  - operation: **2/35 °C** 2/45 °C 7/55 °C
    -7/35 °C -7/45 °C -7/55 °C
    -15/35 °C -15/45 °C

Requirements on heat pump

- **Quality label EHPA (European Heat Pump Association)**
- minimum *COP* from testing according to EN 14511 in respected lab

brine-water	**B0/W35**	***COP* > 4.3**
water-water	**W10/W35**	***COP* > 5.1**
air-water	**A2/W35**	***COP* > 3.1**

- declaration of sound power level
- documentation: planning, service and operation guides in local language
- customer service network, 24 h reaction time on customer complaints
- 2 years full warranty, spare parts inventory available for 10 years in stock

Requirements on heat pump – other norms

- **EN 14825(SCOP)**
  - Air to air - Needs to fulfill min. energy efficiency class A according to EU Regulations, i.e. SCOP shall not be lower than 3.4.
- **EN 15879-1**:
  - Direct Exchange ground coupled to Water E4/W35 - 4.30
- **EN 16147**:
  - Domestic Hot Water heat pump

Requirements on heat pump – KEYMARK

- Example … for low temperature heat pumps:

A7/W35;

A20/W35;

B0/W35;

W10/W35 according to EN 14511

bivalent temperature conditions according to EN 14825 for average climate

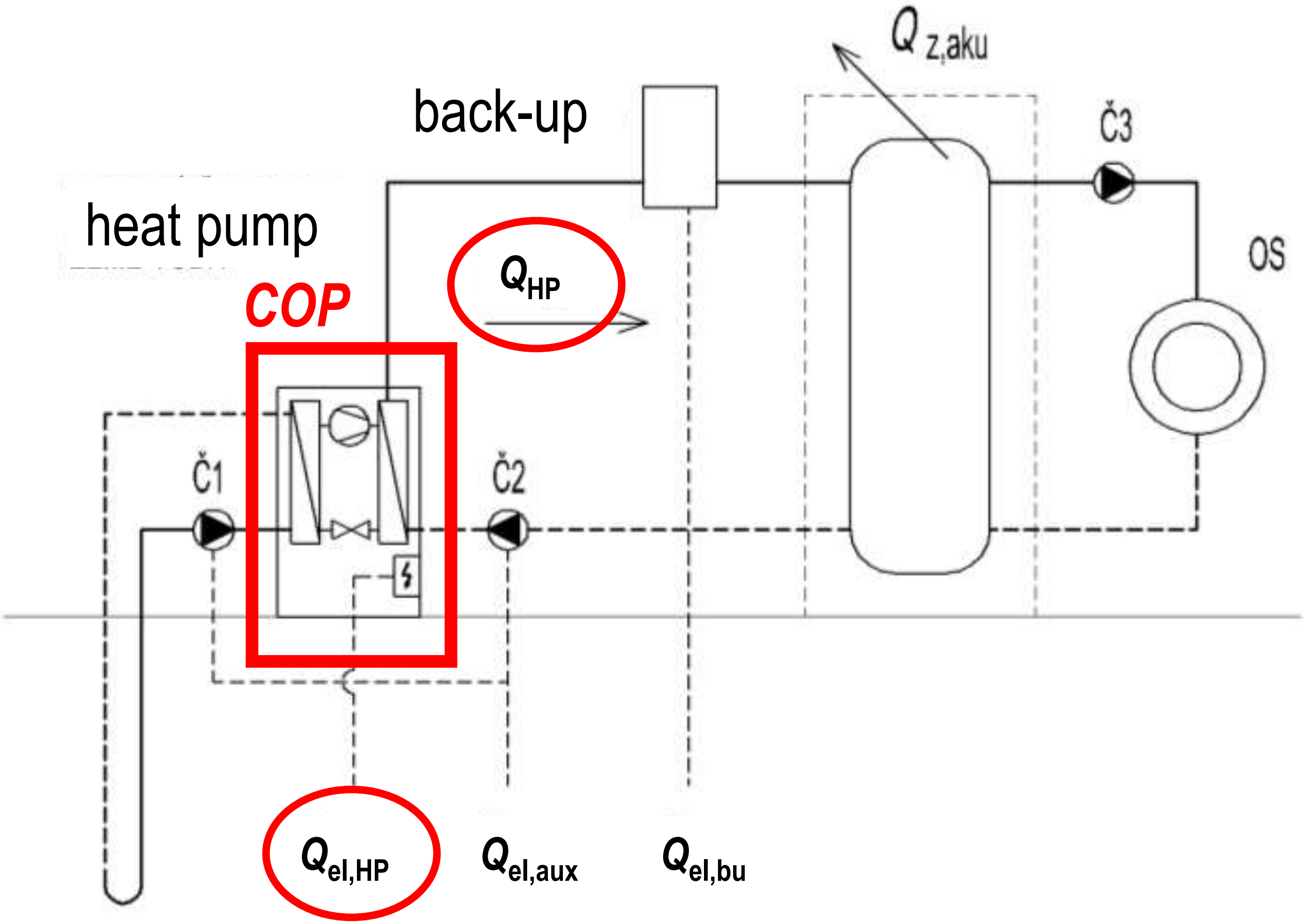
CEN heat pump KEYMARK

performance factor

hot water

space heating

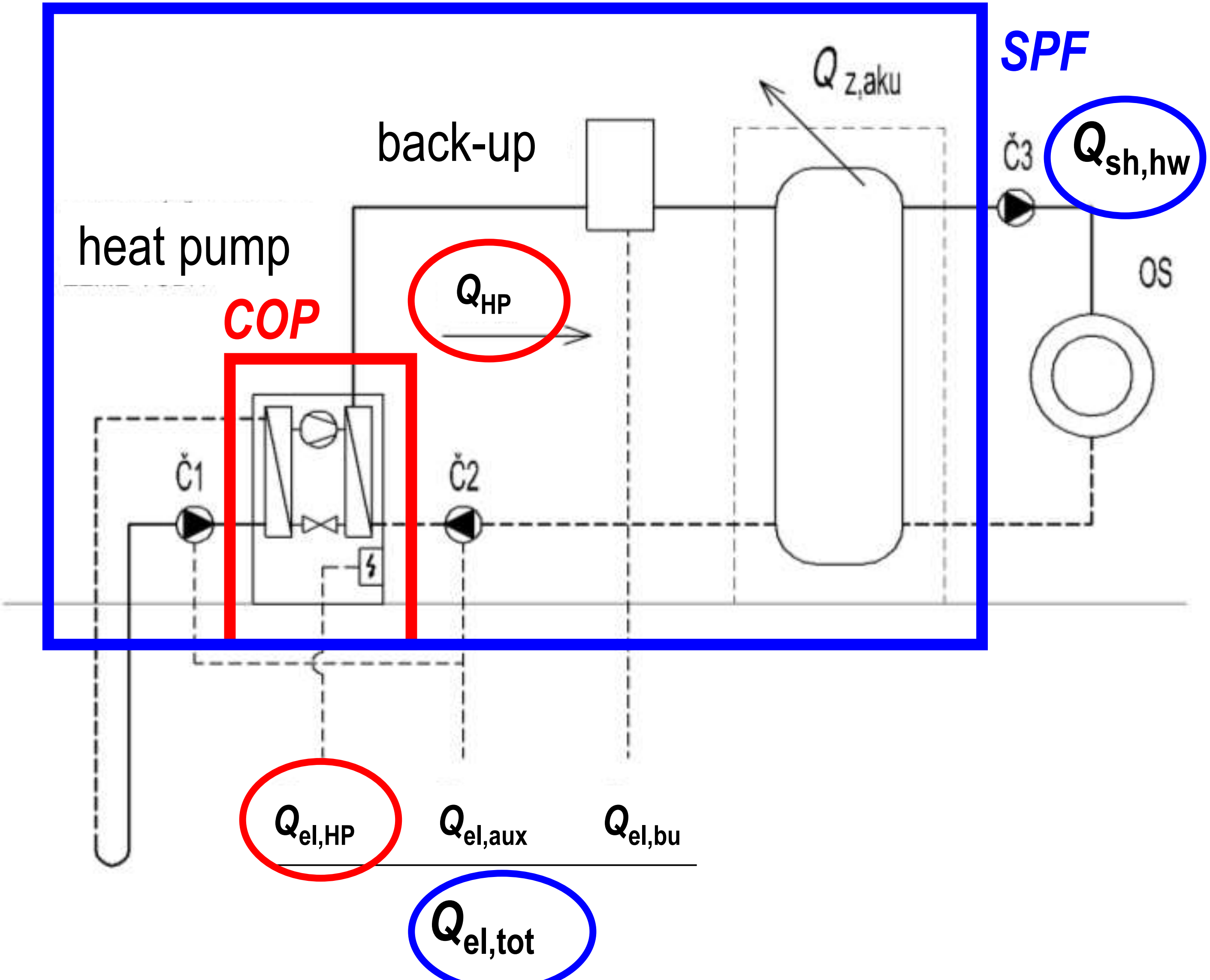
$$COP = \frac{Q_{HP}}{Q_{el,HP}}$$



Seasonal performance factor

hot water

space heating



$$COP = \frac{Q_{HP}}{Q_{el,HP}}$$

$$SPF = \frac{Q_{sh,hw}}{Q_{el,tot}}$$

RES directive, minimum SPF

- **heat pumps consume electric energy**
  - produced mainly from fossil fuels (primary non-renewable energy source)

$$SPF > 1{,}15 \frac{1}{\eta_e}$$

η_e electricity production efficiency
european average 45.5 %

***SPF* > 2.5**

if *SPF* < 2.5 ... better to use fossil fuels directly by combustion

EN 15450 – Annex C (informative)

Table C.1 — Default minimum and target values for SPF for heat pump systems employed for space heating and domestic hot water production in new buildings (typical for Central Europe)

energy source / sink	minimum value for SPF	target value for SPF
air / water	2,7	3,0
ground / water	3,5	4,0
water / water	3,8	4,5

Table C.2 — Default minimum and target values for SPF for heat pump systems employed for space heating and domestic hot water production in retrofit buildings (typical for Central Europe)

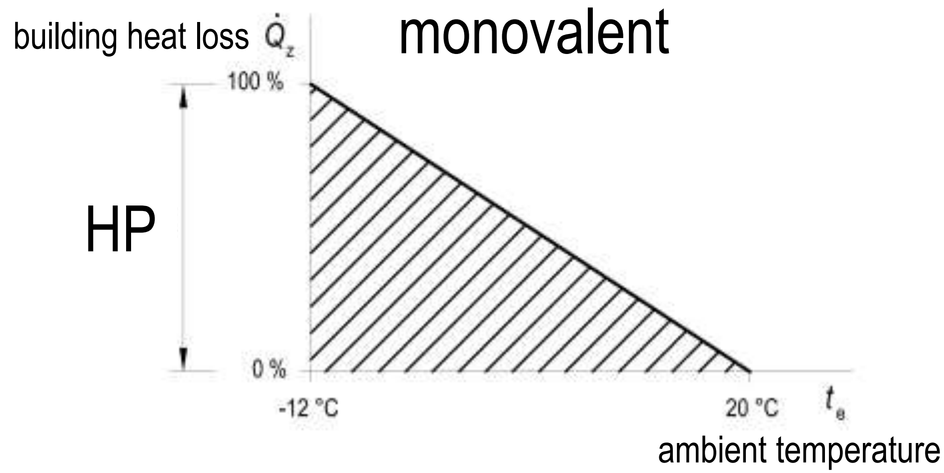
energy source / sink	minimum value for SPF	target value for SPF
air / water	2,5	2,8
ground / water	3,3	3,7
water / water	3,5	4,2

Table C.3 — Default minimum and target values for SPF for heat pump systems employed for domestic hot water production only (typical for Central Europe)

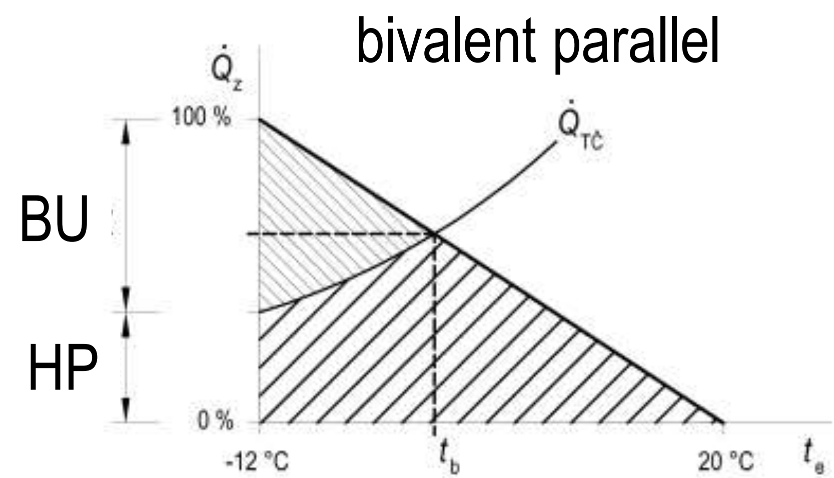
energy source / sink	minimum value for SPF	target value for SPF
air / water	2,3	2,8
ground / water	3,0	3,5
water / water	3,2	3,8

Operation modes

- **monovalent operation**
  - only heating device



- **parallel bivalent operation**
  - under bivalent temperature (**balance point**) back-up heater is switched-on
  - low temperature systems

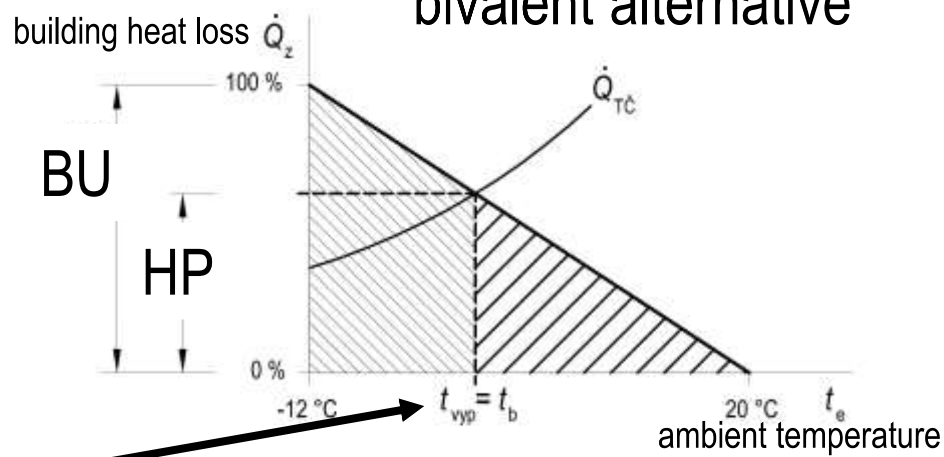


Heat production/loss in function of the outdoor (ambient) temperature

Operation modes

- **alternatively bivalent operation**
  - under bivalent temperature back-up replaced heat pump. for high temperature heating systems

bivalent alternative



the balance point = temperature under which the back-up heater is required

Operation modes

- **monoenergetic operation**
  - e.g. bivalent operation of electric heat pump with electroboiler (integrated in one device)

- **balance point**
  - according to heat output (dimensioning)
  - acc. heating water temperature
    - sufficient heat output from heat pump
    - high temperatures of heating water needed, which couldnt be supplied by heat pump, esp. in extreme winter

Heat pump sizing

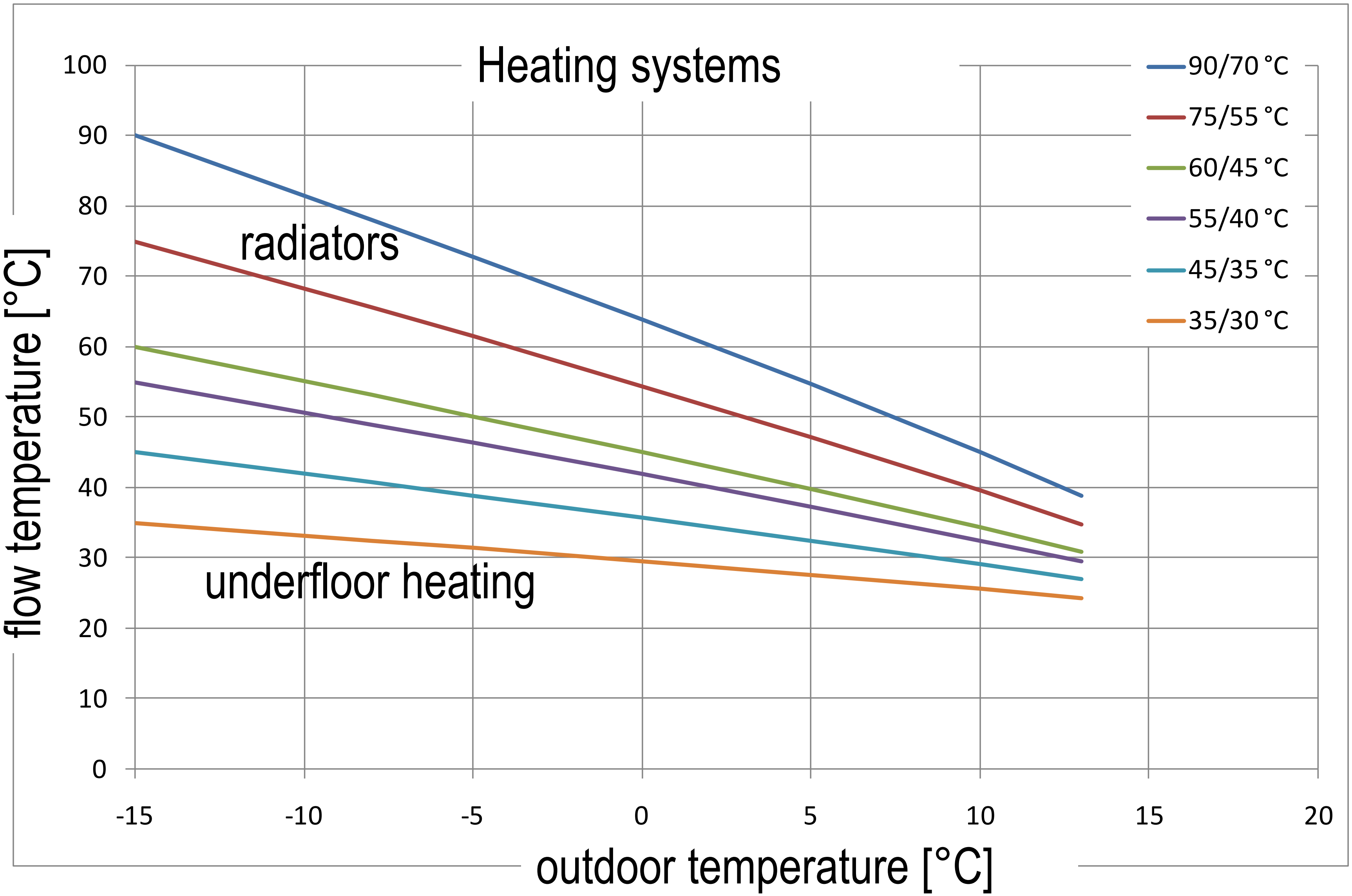
- **determination of heat pump type**
  - available heat source

Heat pump sizing

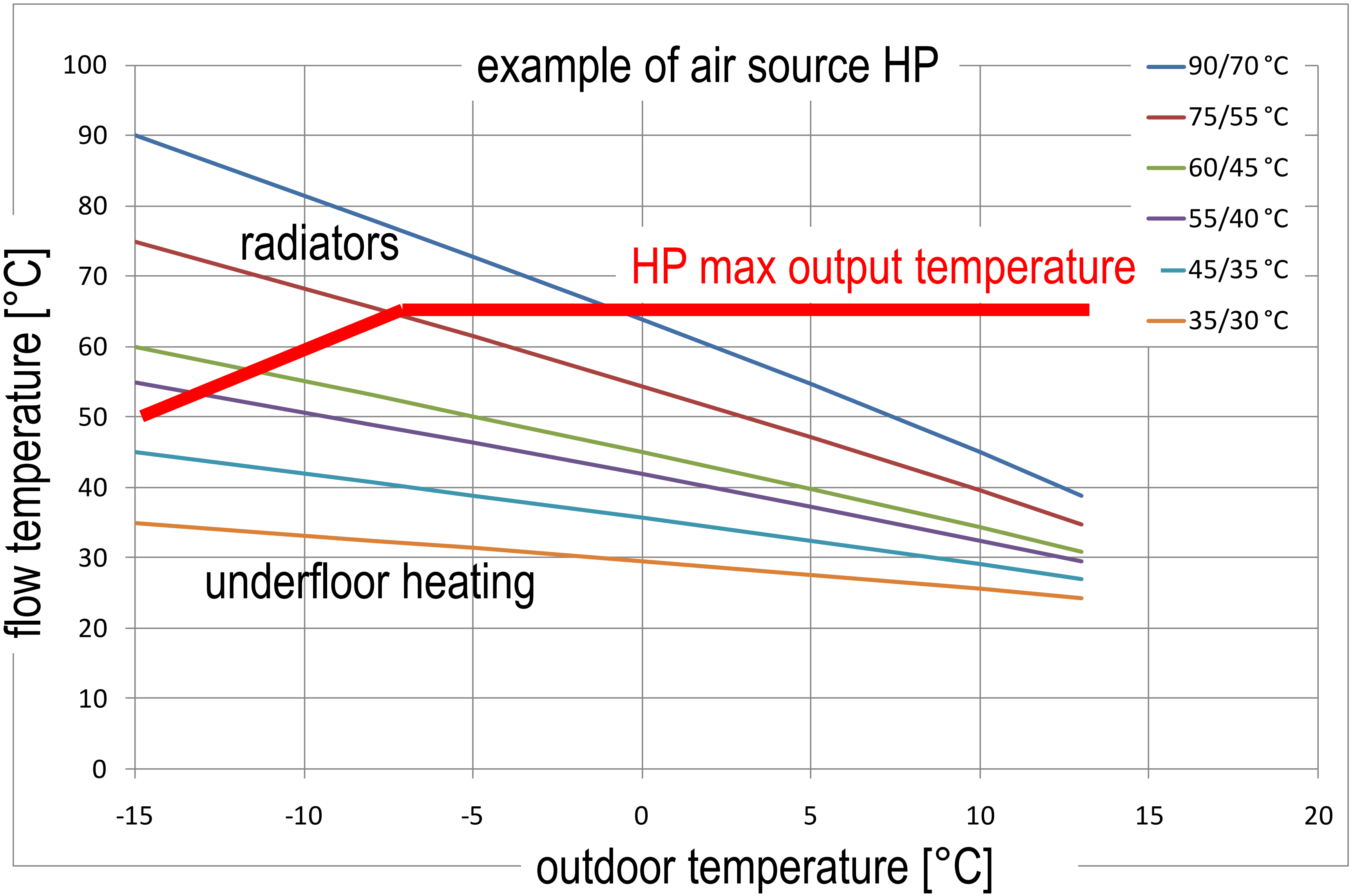
- **determination of heat pump type**
  - available heat source

- **determination of (condenser) heat output Q_k (for space heating)**
  - building heat loss
  - heat output for hot water
  - design flow temperature
  - design source temperature

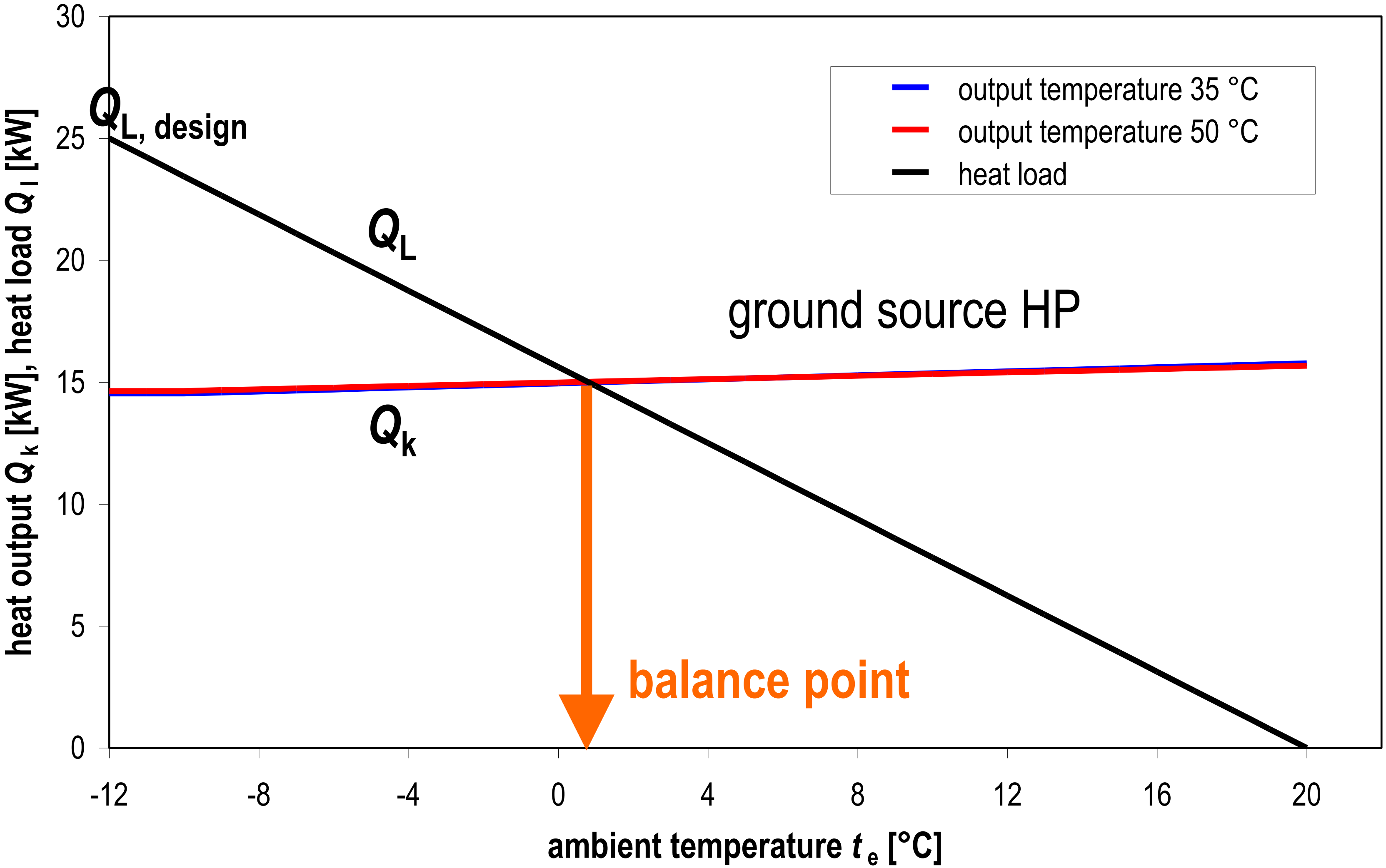
Balance point according to temperature



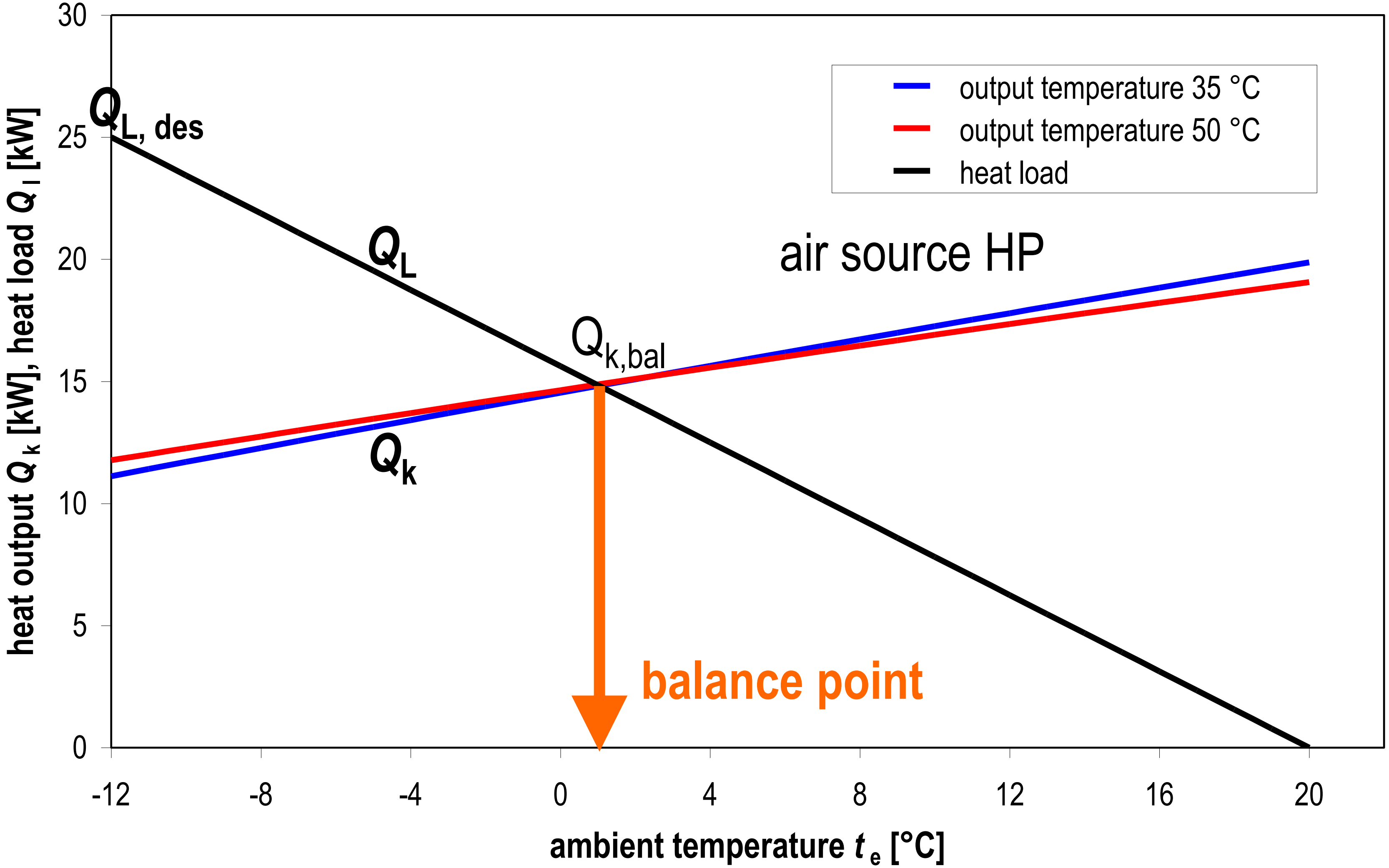
Balance point according to temperature



Balance point according to heat output

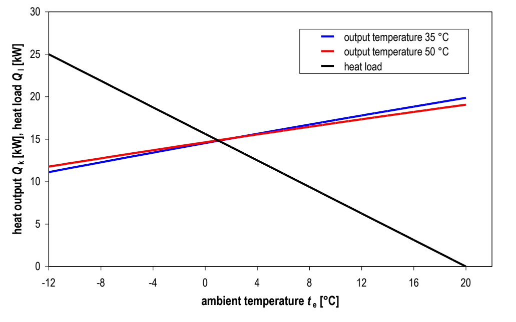


Balance point according to heat output



Balance point determination

- **design heat load $Q_{L,des}$**
  - calculation according to EN 12 831 for design external temperature (e.g. -12 °C, -15 °C, -18 °C in CZ)
- **heat output at balance point $Q_k = Q_L$**
  - e.g. from desired fraction 60 to 100 % $Q_{k,bal} / Q_{L,des}$



$$\frac{Q_{L,des}}{(t_i - t_{e,des})} = \frac{Q_L}{(t_i - t_e)} = \frac{Q_{k,bal}}{(t_i - t_{e,bal})}$$

$$t_{e,bal} = t_i - \frac{Q_{k,bal}}{Q_{L,des}}(t_i - t_{e,des})$$

if Q_k = konst

if $Q_k \neq$ konst - graph

Example

family house

design load 15 kW for

design temperature -15 °C

heat pump (SE WPL18)

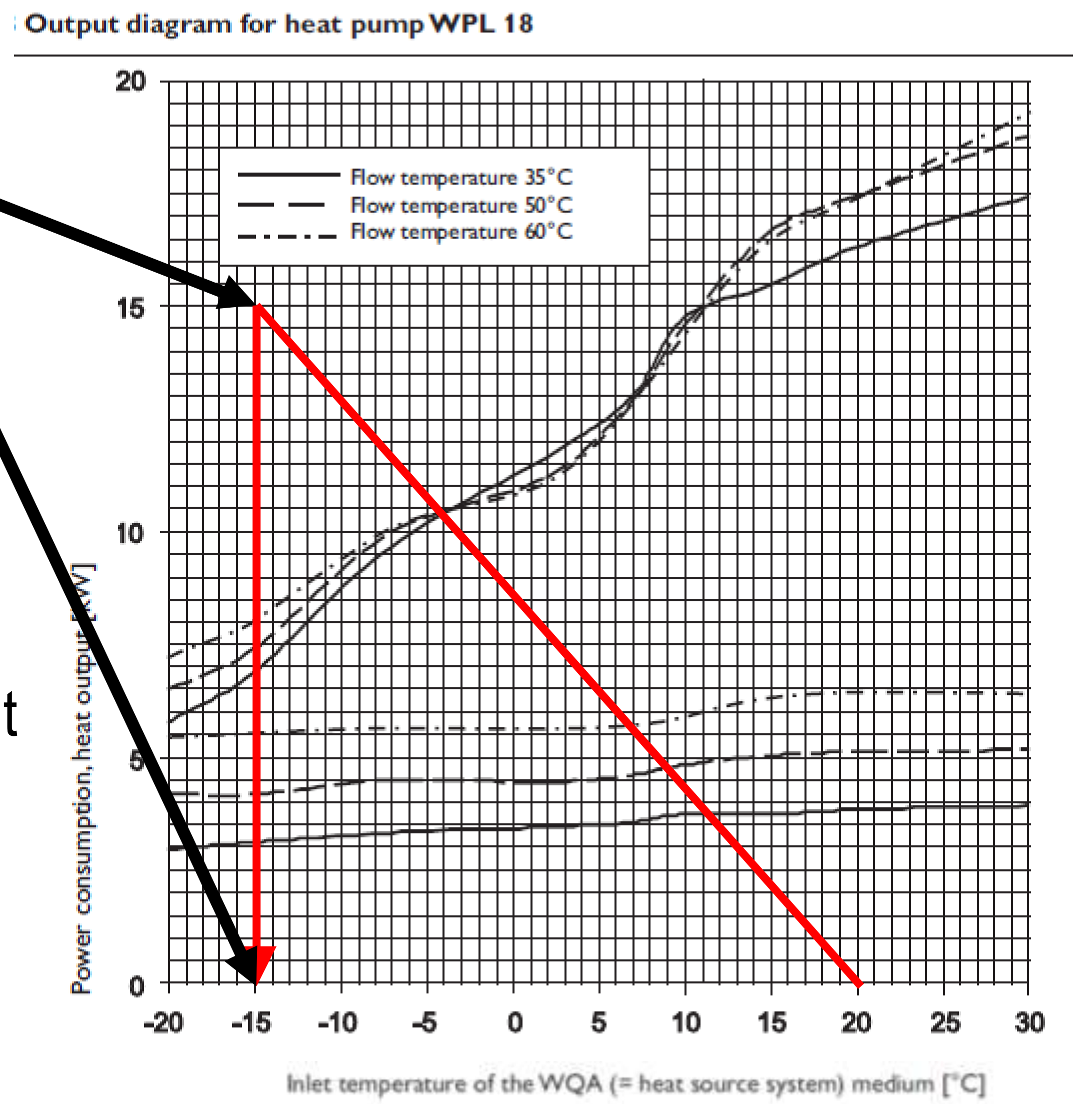
heating system 50/40 °C

determine the balance point

balance point heat output

balance point power input

balance point COP



Example

family house

design load 15 kW for

design temperature -15 °C

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heating system 50/40 °C

determine the balance point

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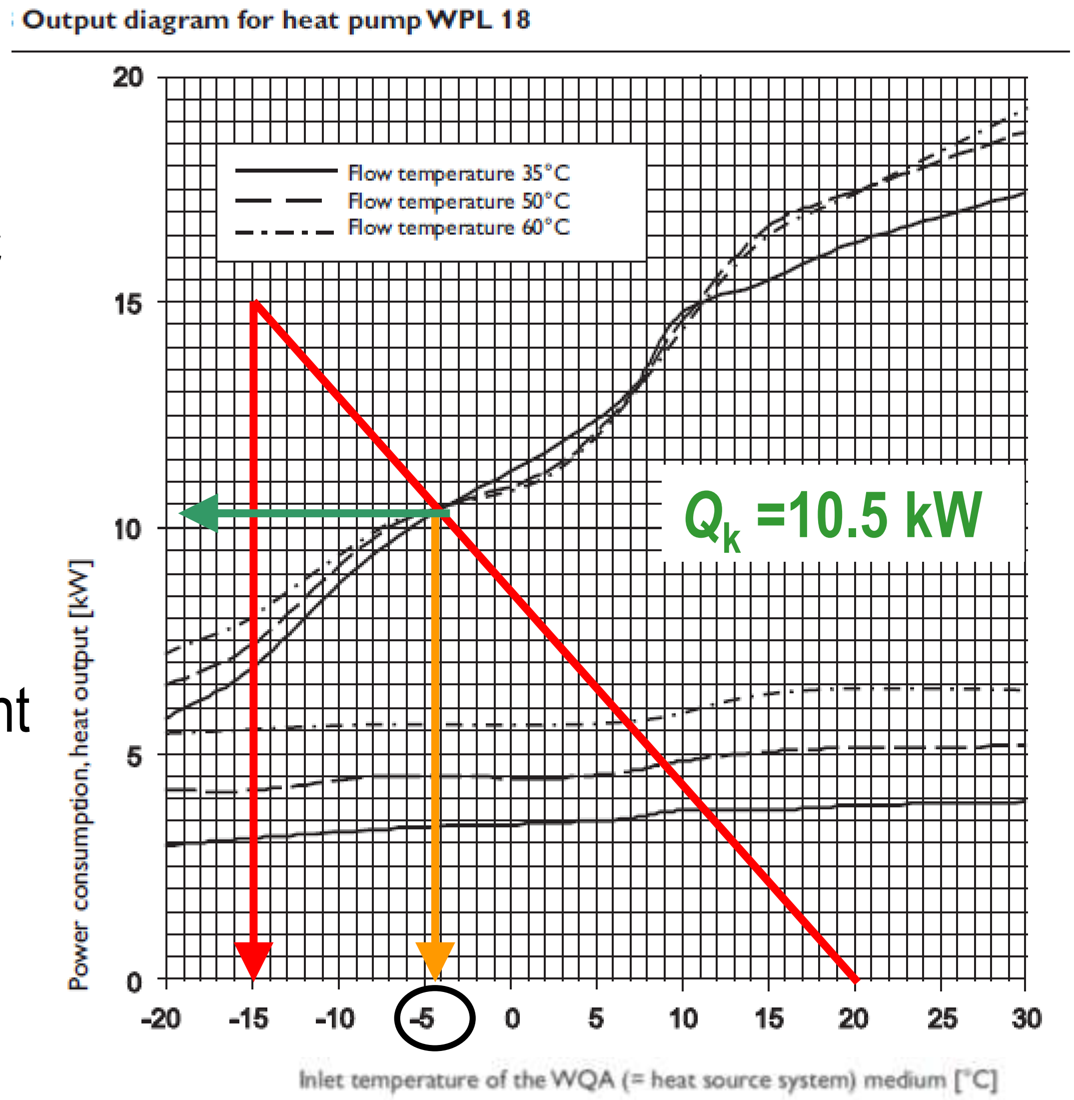
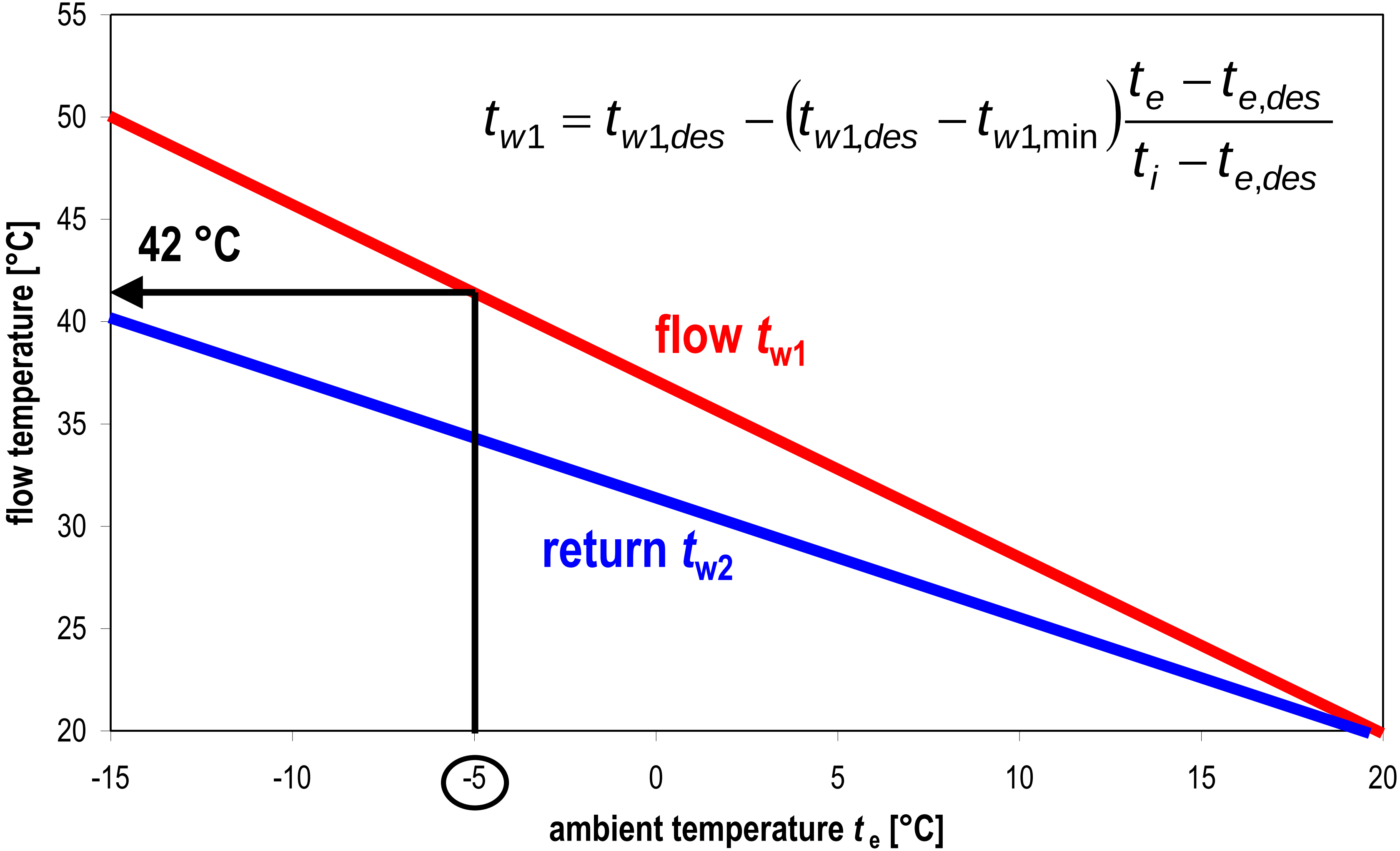
balance point COP



Flow temperature



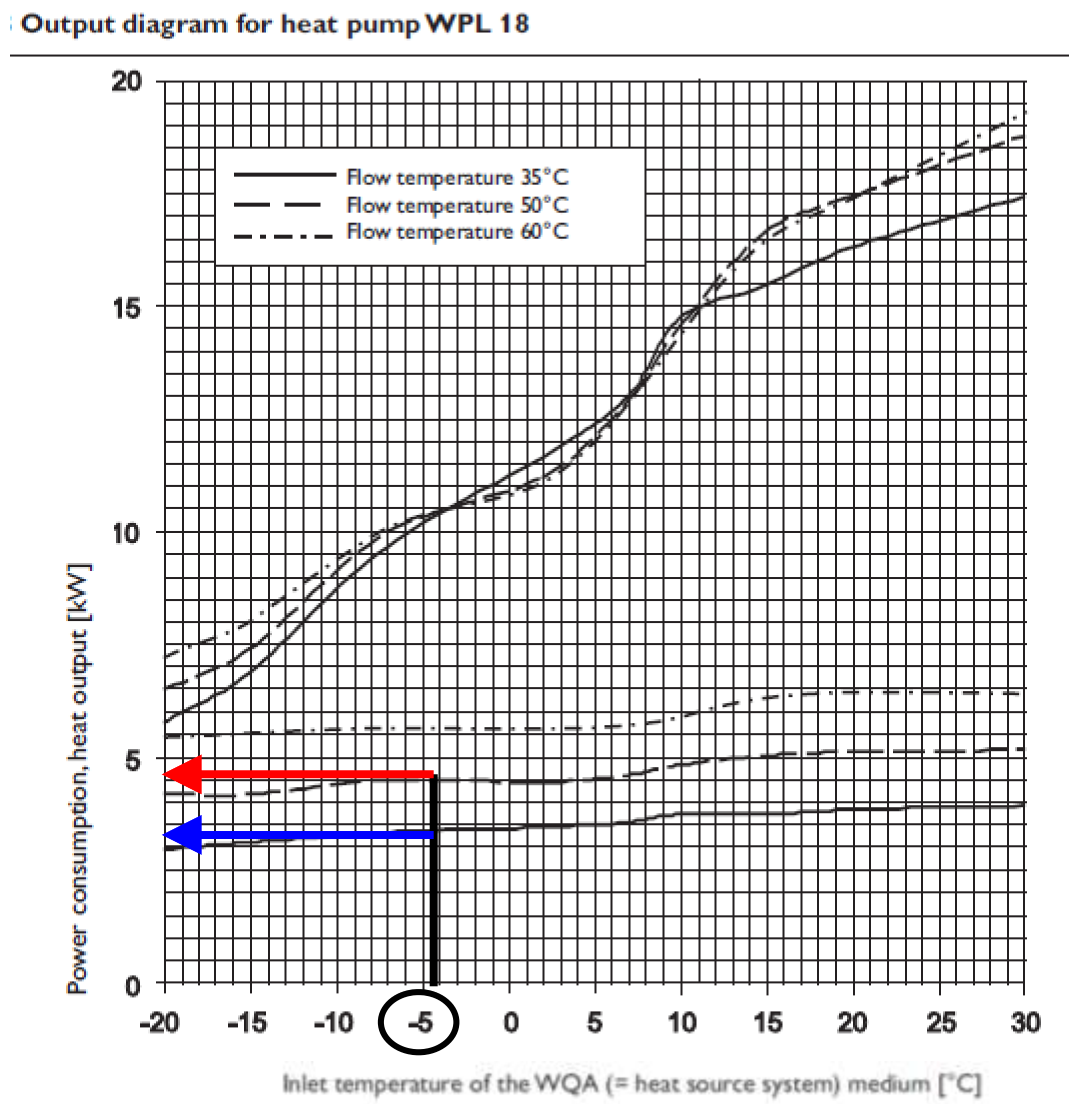
Power input at balance point

for balance power point

t_{v1} = -5 °C, t_{k2} = 42 °C

P_{35} = 3.3 kW

P_{50} = 4.5 kW



Power input at balance point

for balance power point

t_{v1} = -5 °C, t_{k2} = 42 °C

P_{35} = 3.3 kW

P_{50} = 4.5 kW

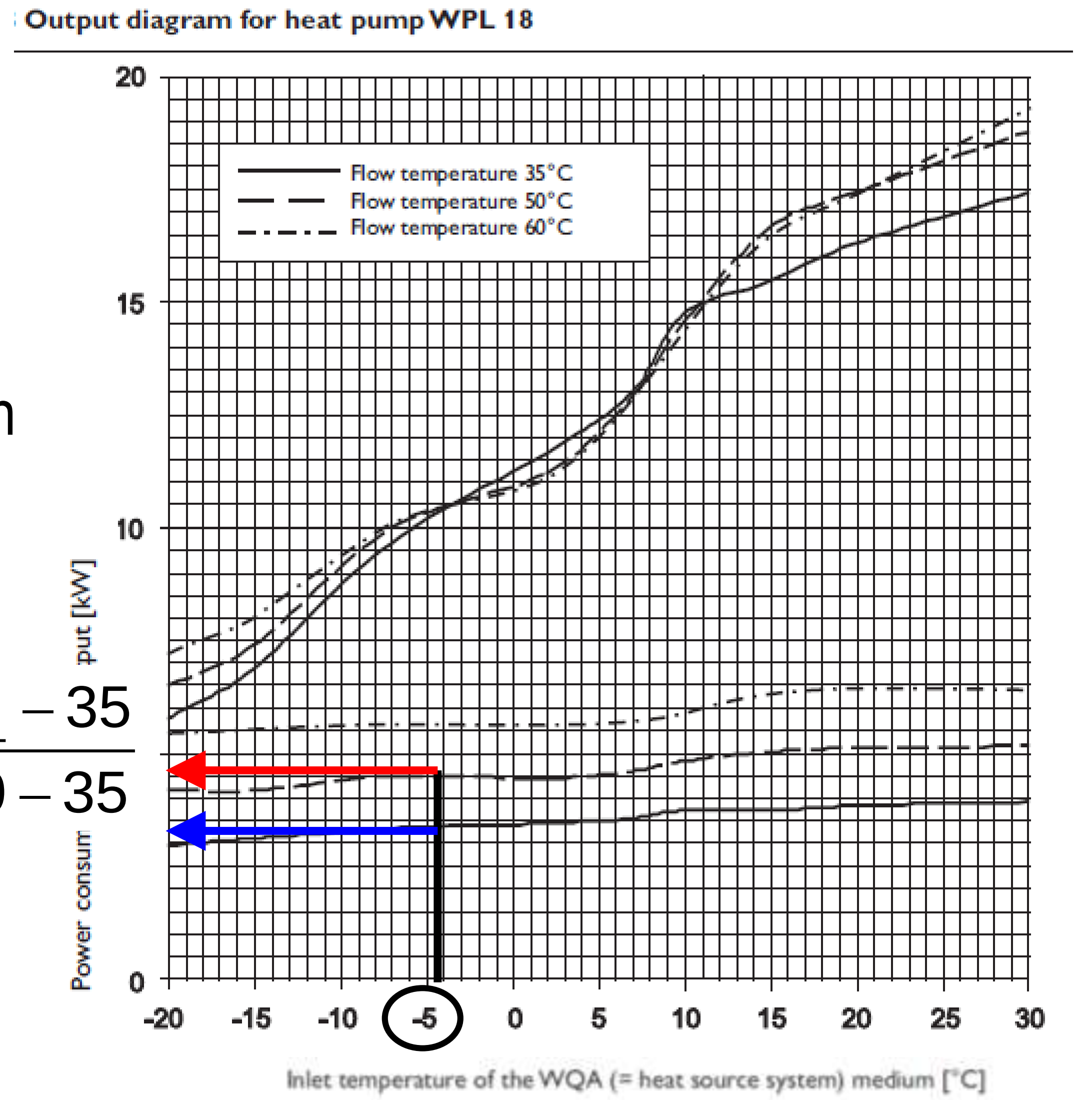
interpolation

$$\frac{P_{tw1} - P_{35}}{t_{w1} - 35} = \frac{P_{50} - P_{35}}{50 - 35}$$

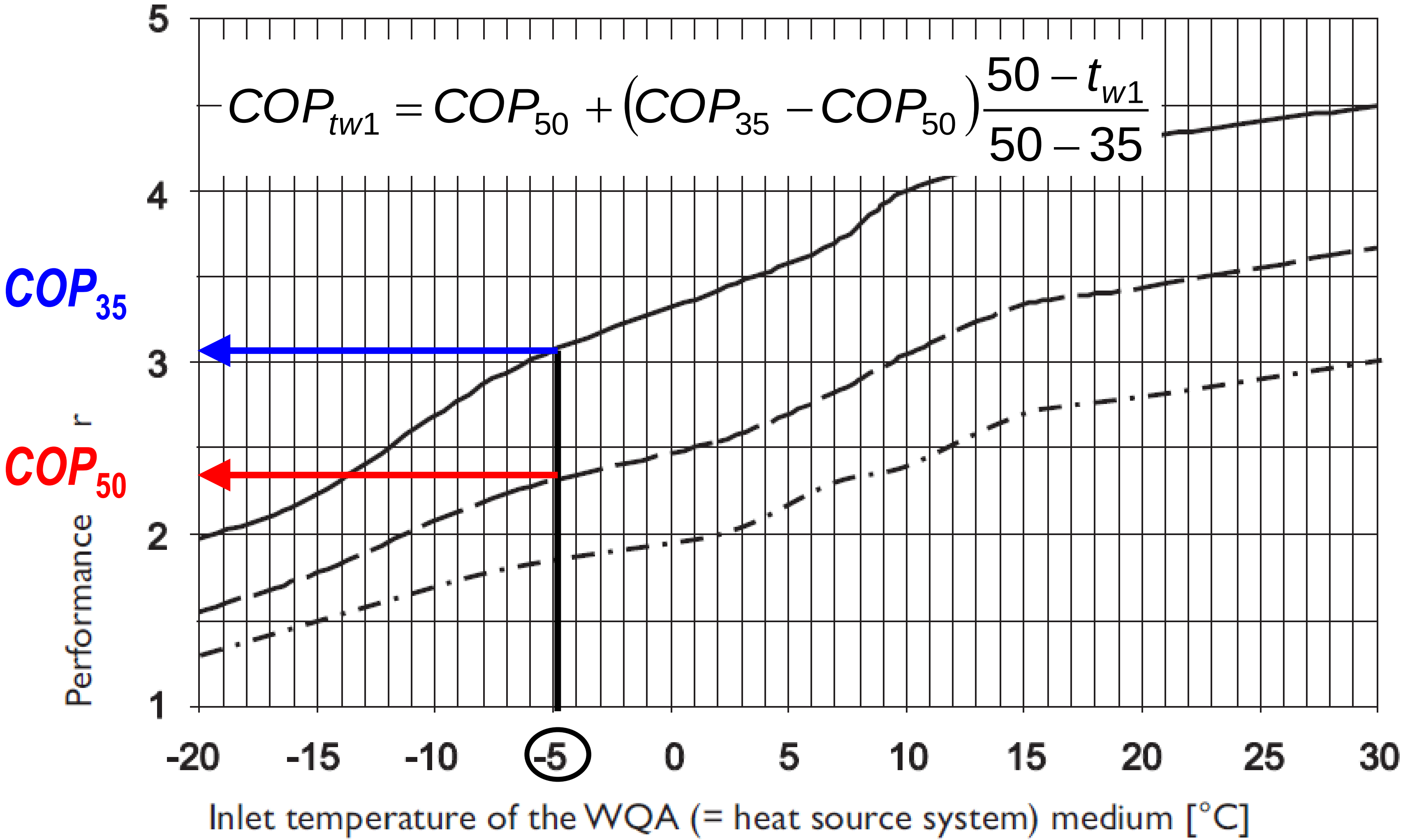
$$P_{tw1} = P_{35} + (P_{50} - P_{35})\frac{t_{w1} - 35}{50 - 35}$$

balance power point

P_{42} = 3.9 kW



Example



$$COP_{tw1} = COP_{50} + \left(COP_{35} - COP_{50}\right)\frac{50 - t_{w1}}{50 - 35}$$

Example

family house

design load 15 kW for

design temperature -15 °C

heat pump (SE WPL18)

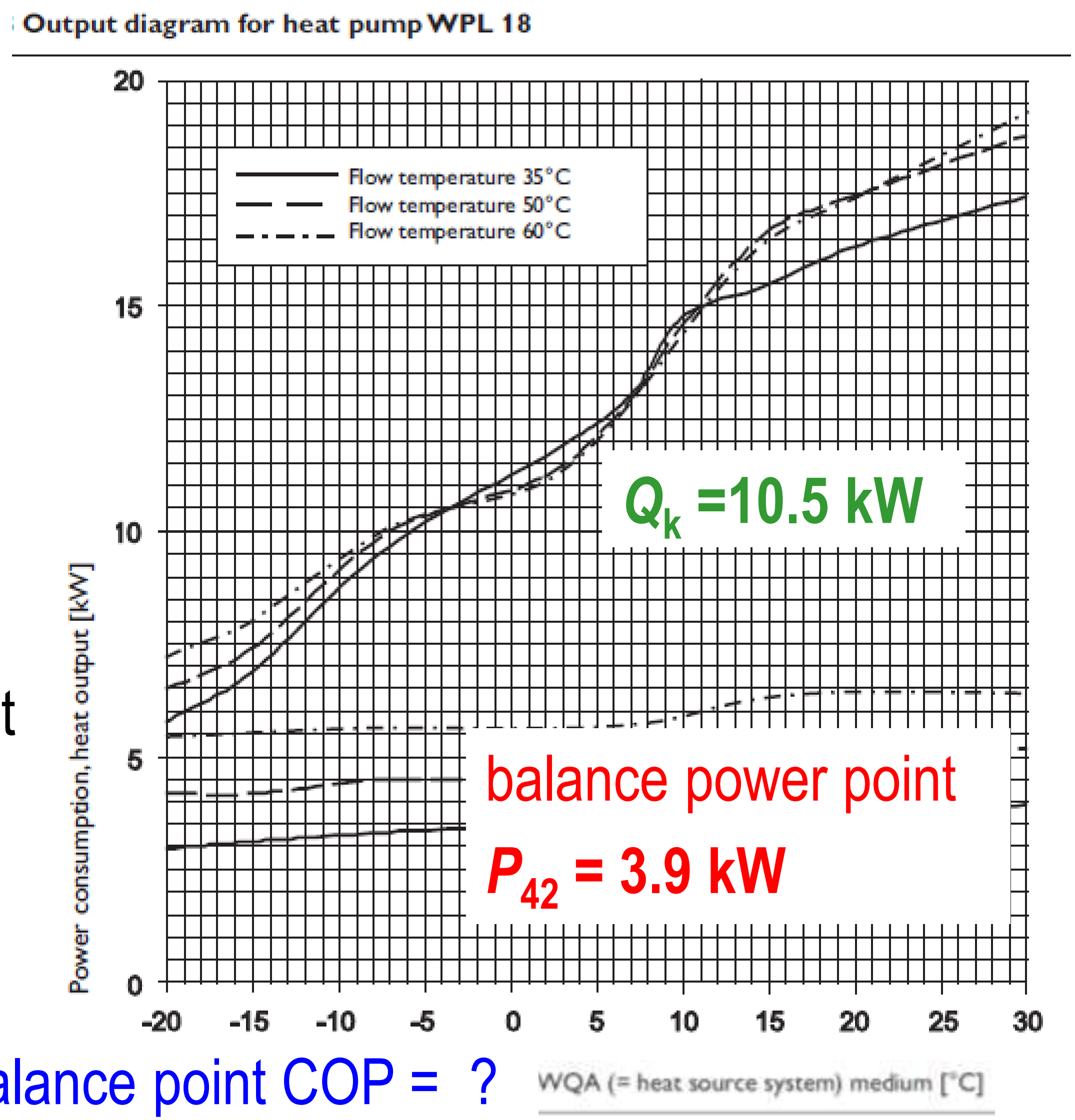
heating system 50/40 °C

determine the balance point

balance point heat output

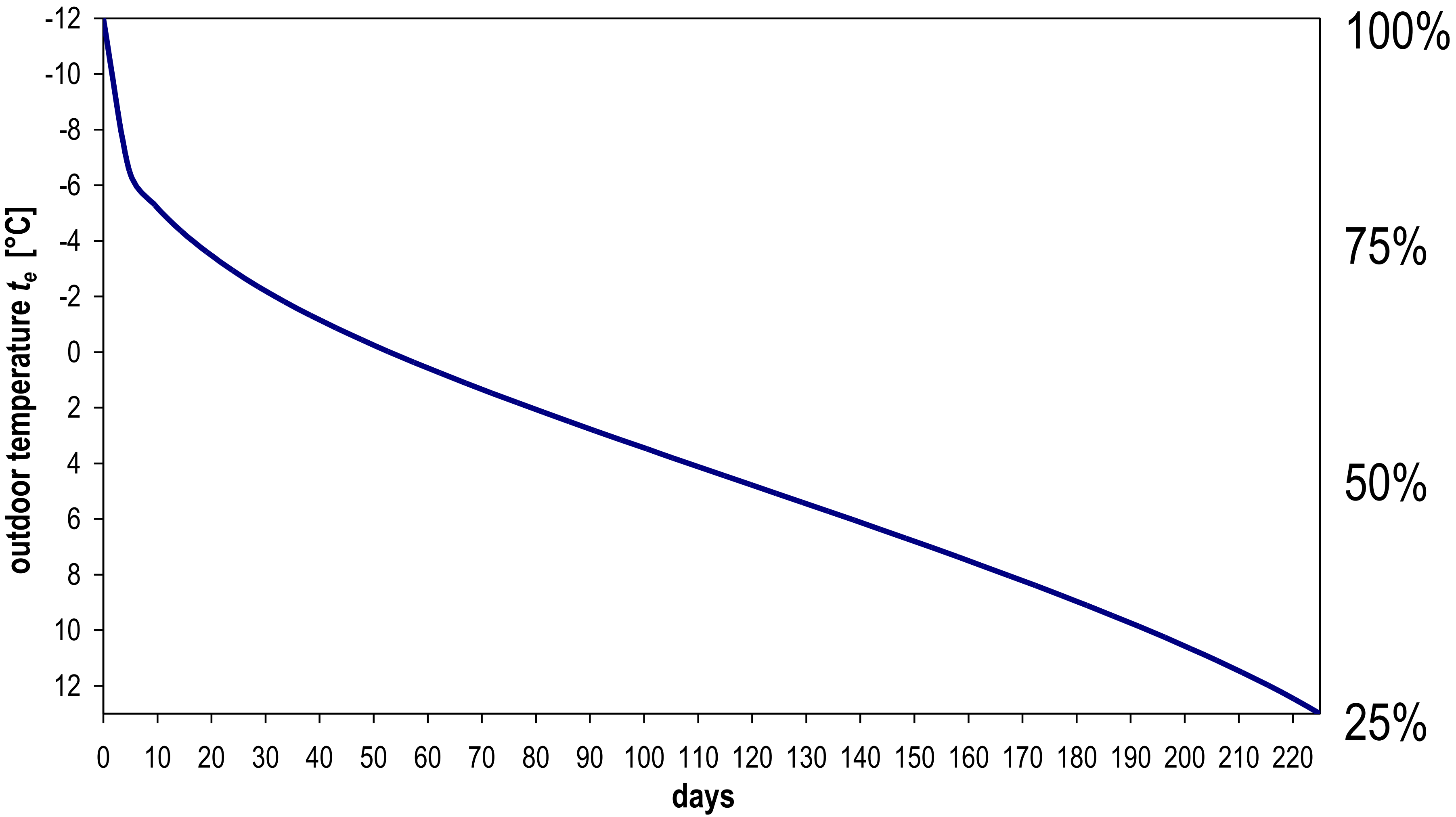
balance point power input

balance point COP

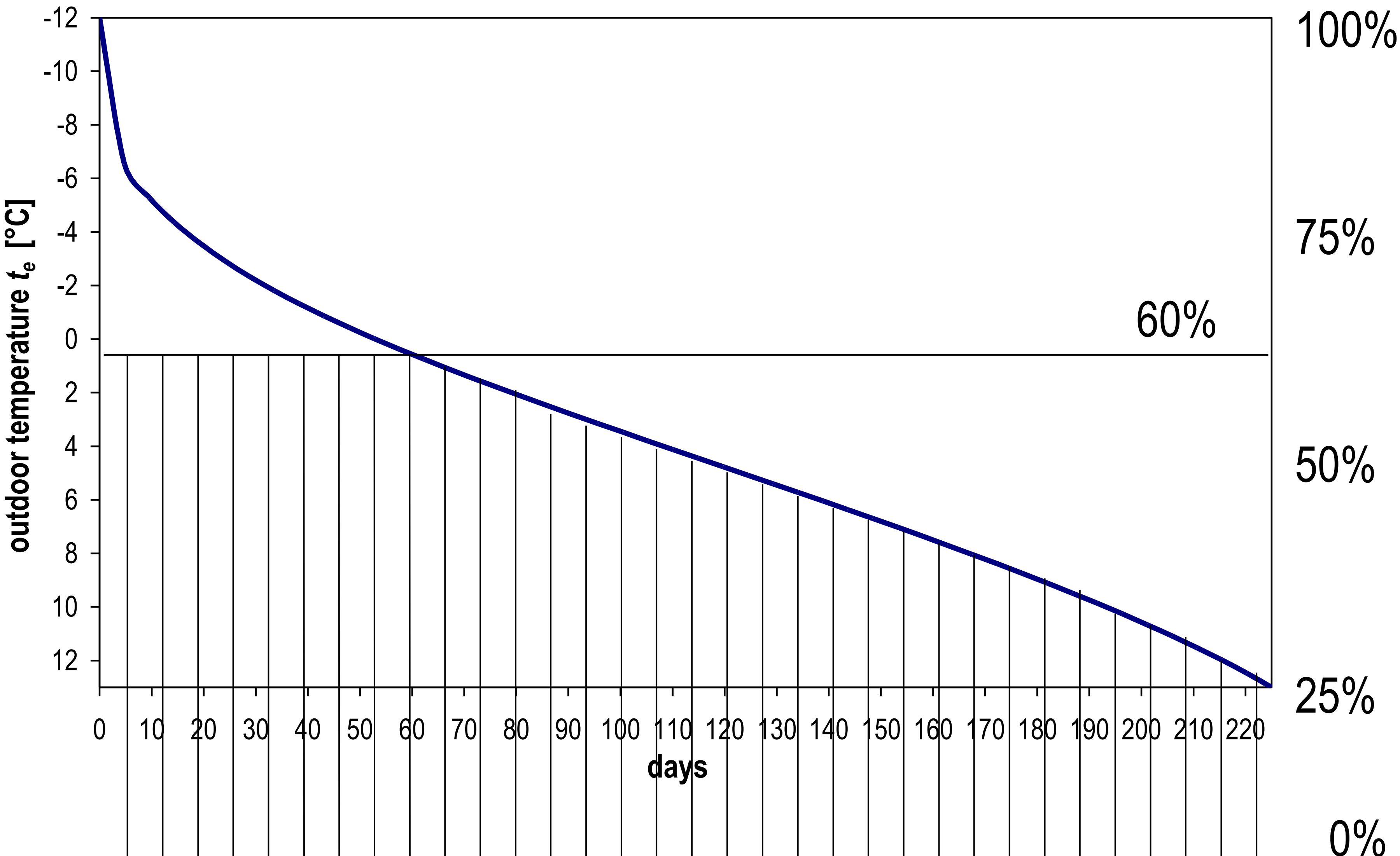


balance point COP = ?

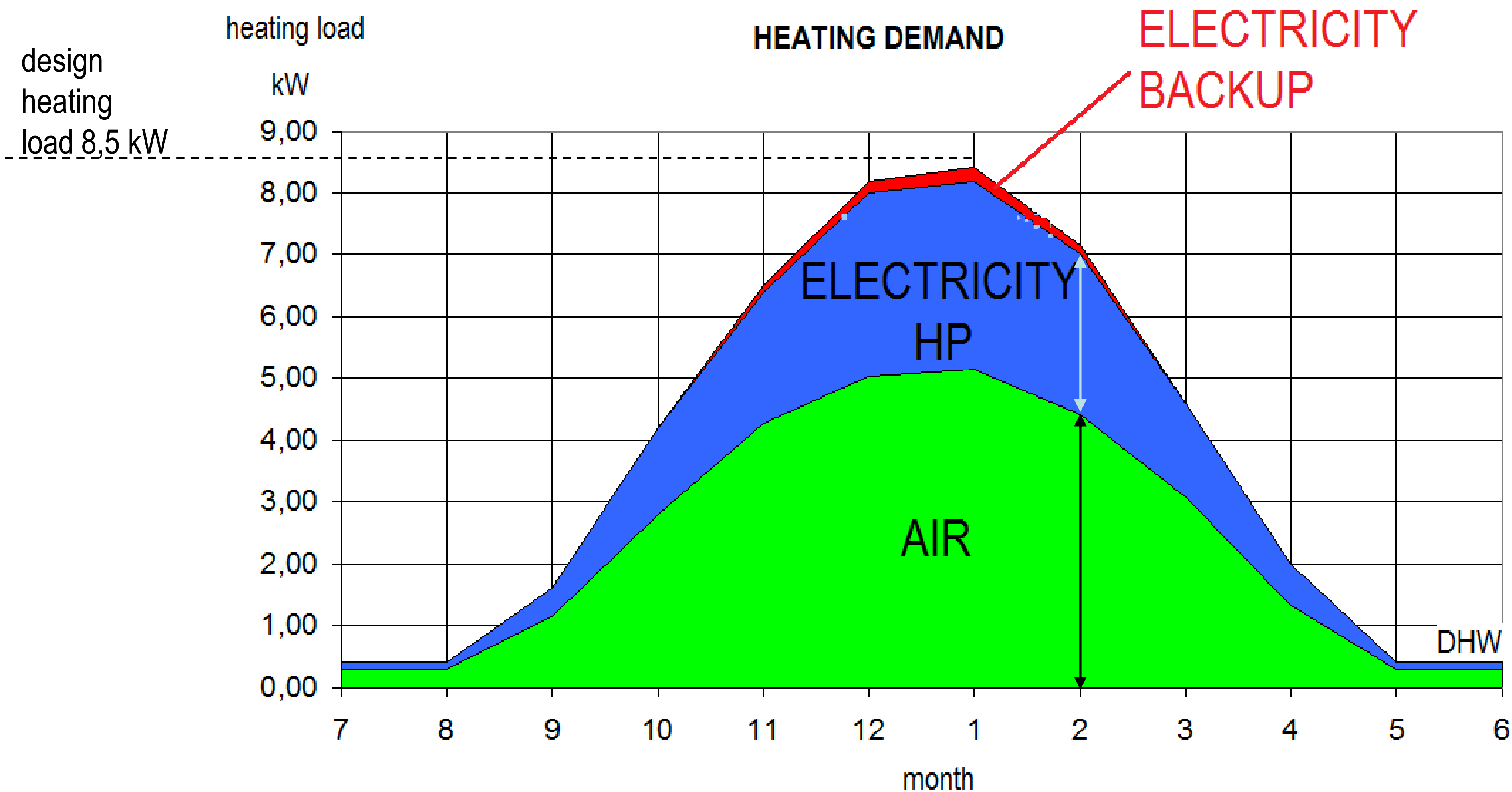
Heat pump sizing – coverage of demand



Heat pump sizing – coverage of demand

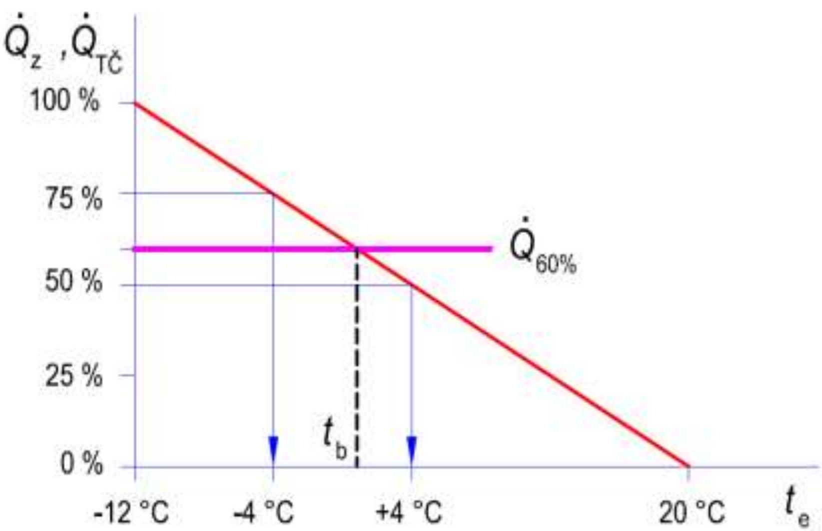


Heat pump sizing – coverage of demand

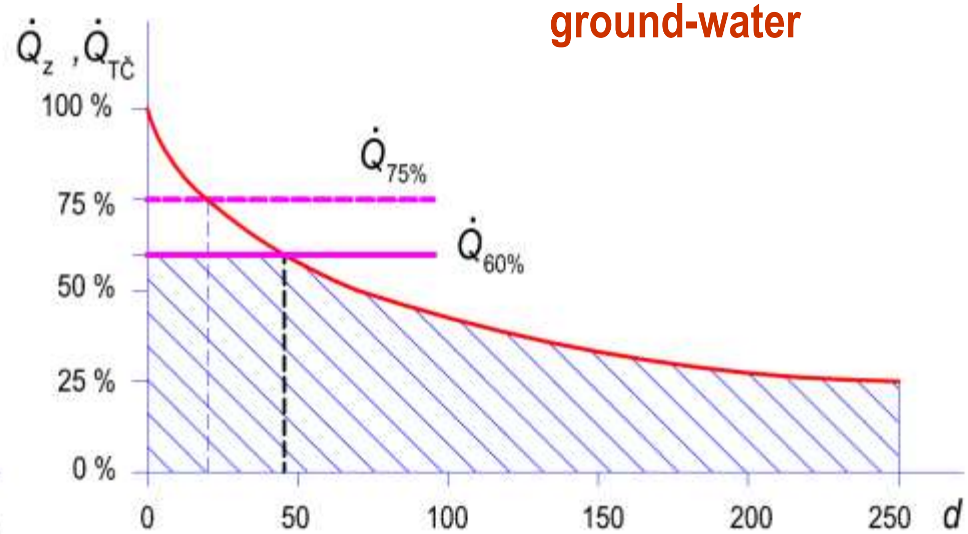


Heat pump sizing (ground source)

- **dimensioning heat output (independent on ambient conditions)**
  - 50 % heat loss - coverage 85 % heat demand
  - 60 % heat loss – coverage 93 % heat demand
  - 70 % heat loss - coverage 97 % heat demand

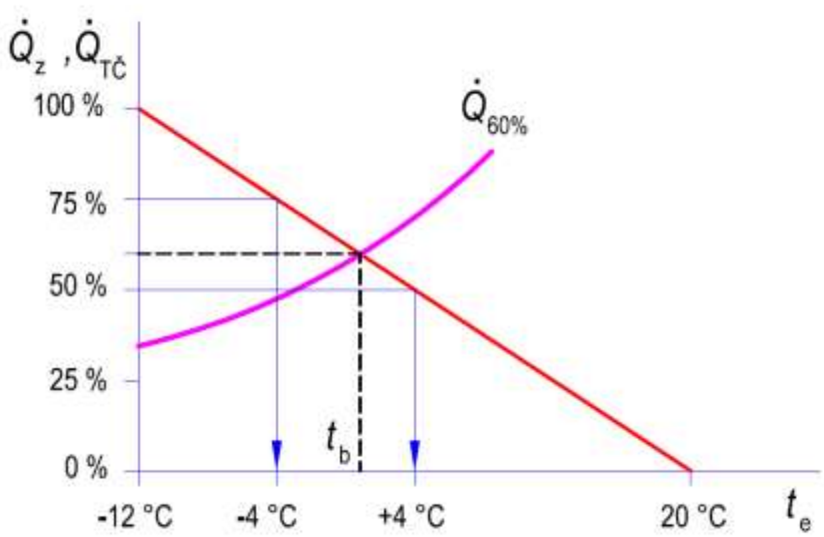


ground-water

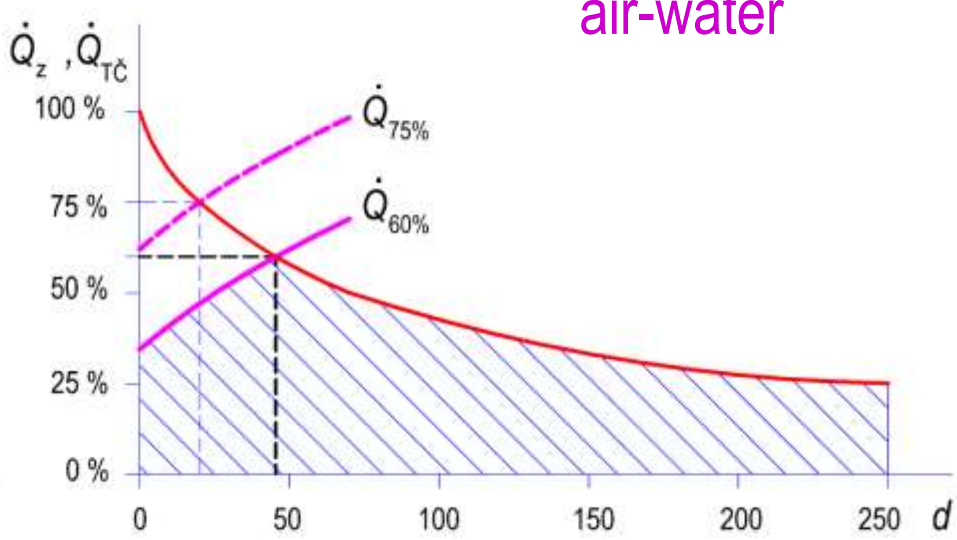


Heat pump sizing (air source)

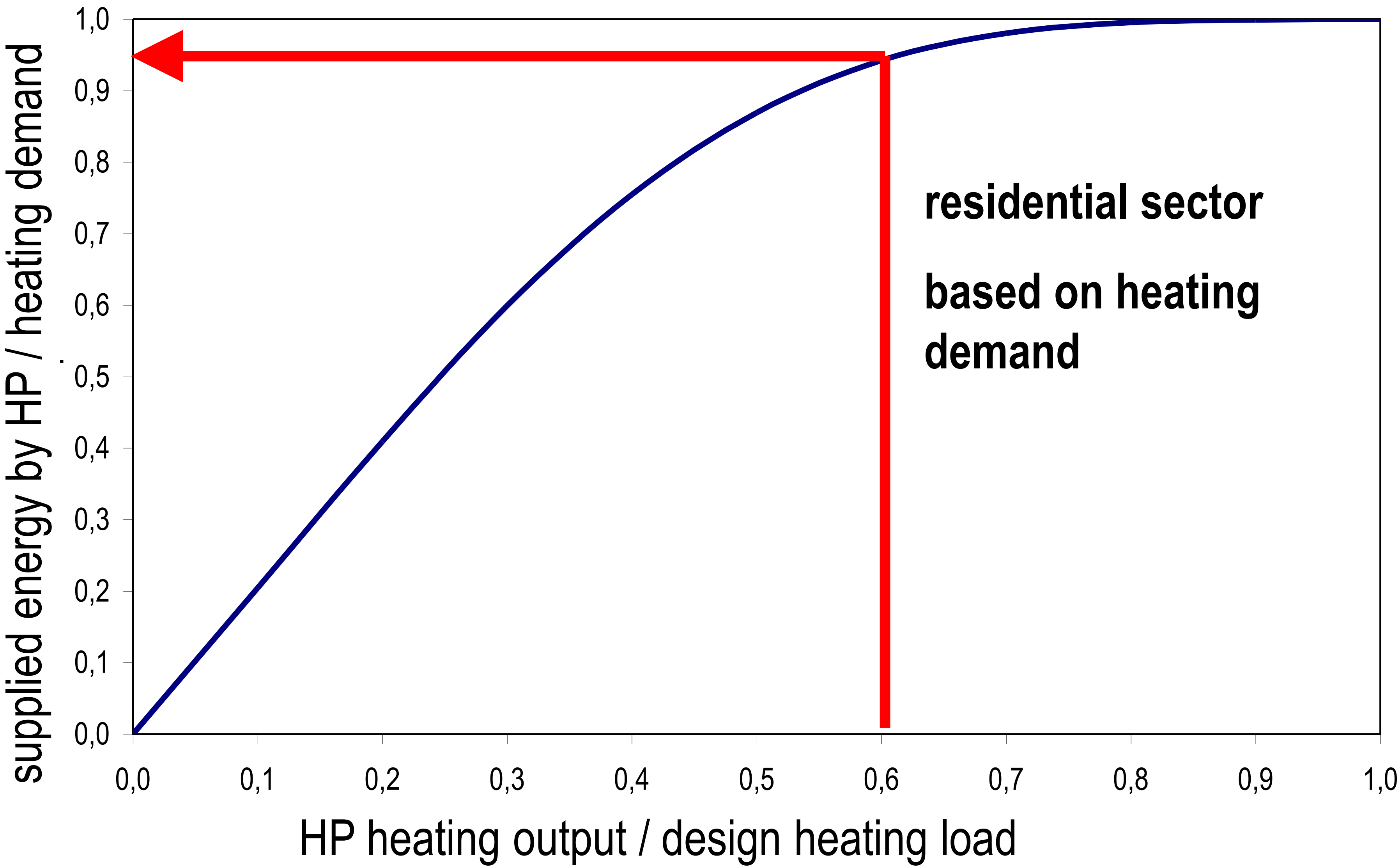
- **dimensioning heat output (dependent on ambient conditions)**
  - 50 % heat loss - coverage 75 % heat demand
  - 60 % heat loss – coverage 85 % heat demand
  - 70 % heat loss - coverage 92 % heat demand



air-water



Heat pump sizing – coverage of demand

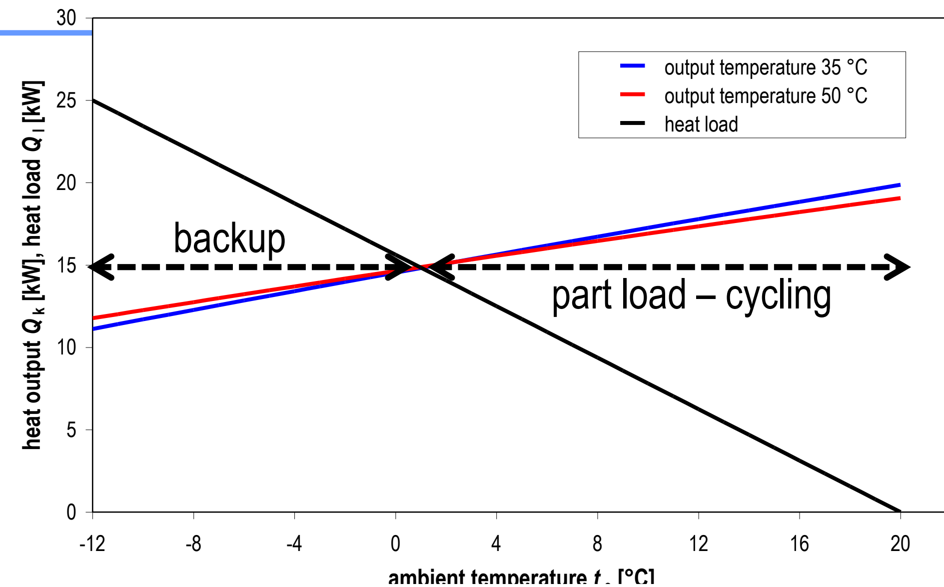


Heating capacity control

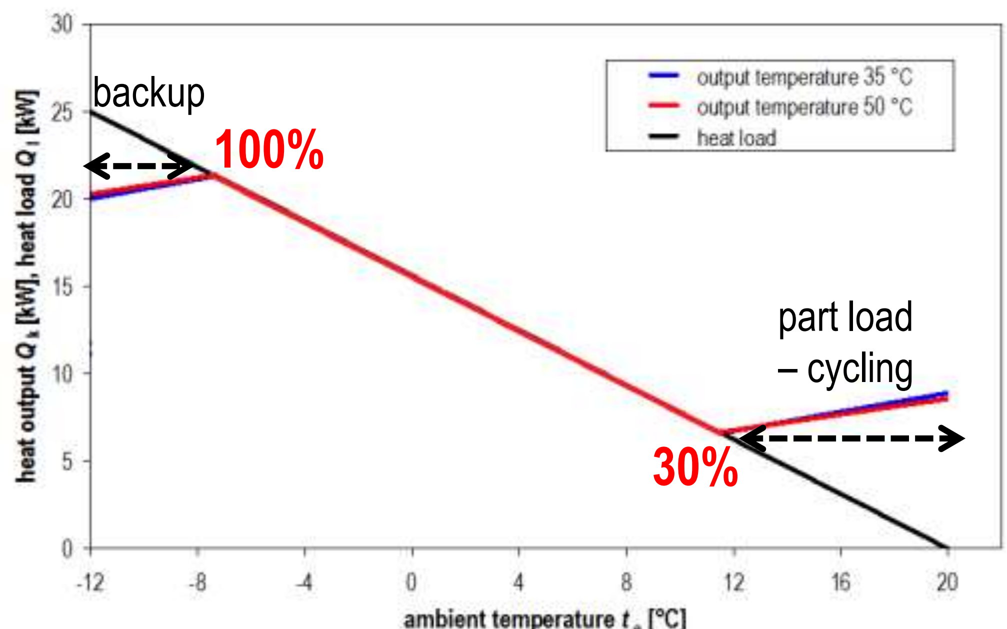
- **start-stop regime heat pumps**
  - cycling = reduction of durability compressor
  - elimination cycling
    - undersizing (possible?)
    - heat storage – sizing of store for minimum operation time of heat pump
- **heat pump with heating capacity control**
  - compressor speed control
  - possibility for monovalent operation

Heating capacity control

Without capacity control



With capacity control

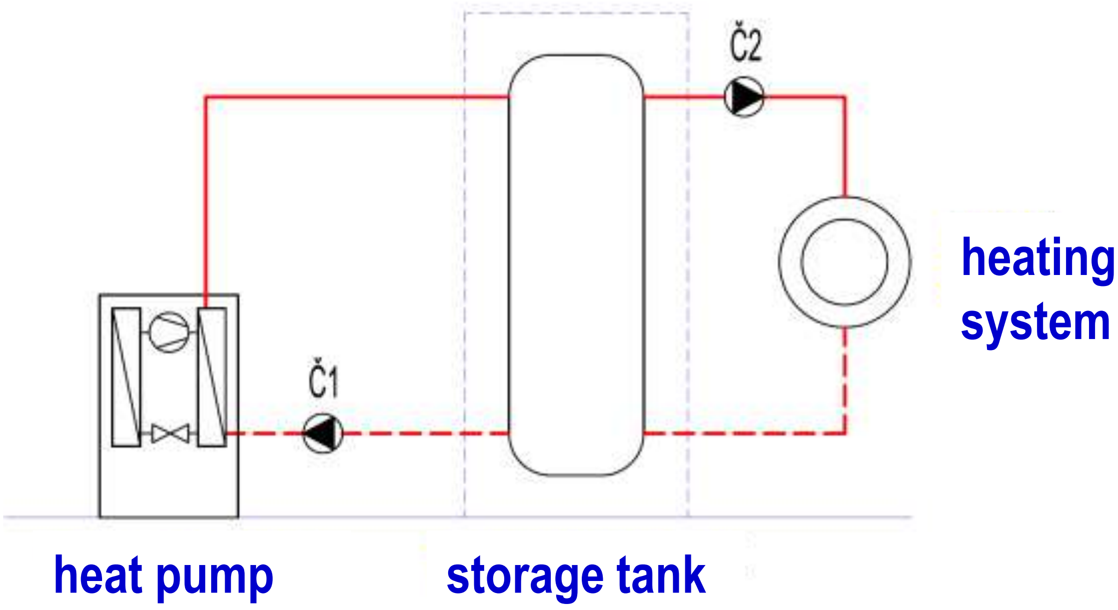


Heat storage for heat pump

- **oversized storage** for most of operation time
  - balancing heat output and heat load
- **reduction of frequency compressor on/off** (1 x 10 min)
  - longer durability of compressor
- **heat source for outdoor units** (air-water)
  - antifreeze protection

Heat storage for heat pump

- **hydraulic decoupling of heat pump** from heating circuit
  - hydraulic shunt
  - heating systems can't influence HP circuit
  - providing required (higher) flowrates at condenser



Sizing of storage tank

- **balance** to reduce on/off frequency
  - minimum operation time period $\Delta\tau$
  - increase of temperature Δt in store during operation of heat pump
- heat stored during operation of heat pump

$$Q_{stored} = \dot{Q}_{HP} \cdot \Delta\tau = V \cdot \rho \cdot c \cdot \Delta t$$

Sizing of storage tank

specific volume

$$\frac{V}{\dot{Q}_{HP}} = \frac{1000 \cdot \Delta\tau}{\rho \cdot c \cdot \Delta t}$$

$\Delta\tau$ [s]	minimum operation time:	15 min
Δt [K]	increase of store temperature:	3 - 5 K

usually **15 to 30 l/kW**

thermal capacity (momentum) of heating system results in lower volume requirement

Example

- **calculate** heat storage volume for balance point heat output **10.5 kW**
  - minimum operation time period $\Delta\tau$ = 15 min
  - increase of temperature Δt in store 3 K

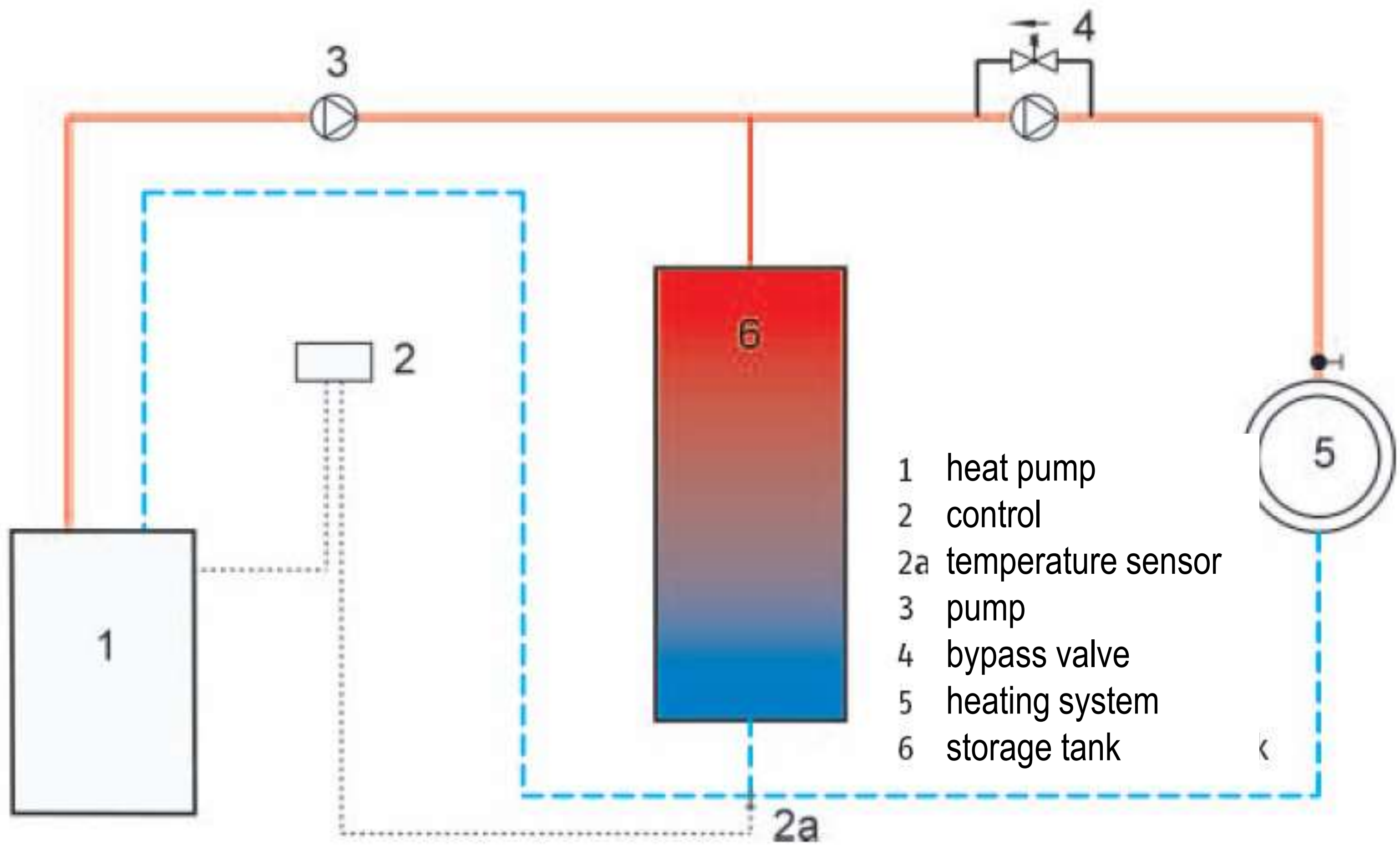
$$V = \dot{Q}_{HP} \frac{1000 \cdot \Delta\tau}{\rho \cdot c \cdot \Delta t}$$

$$V\ [\mathrm{m}^3] = \dot{Q}_{HP}\ [\mathrm{kW}] \cdot \frac{1000 \cdot 15 \cdot 60}{998 \cdot 4187 \cdot 3}$$

***V* = 754 l**

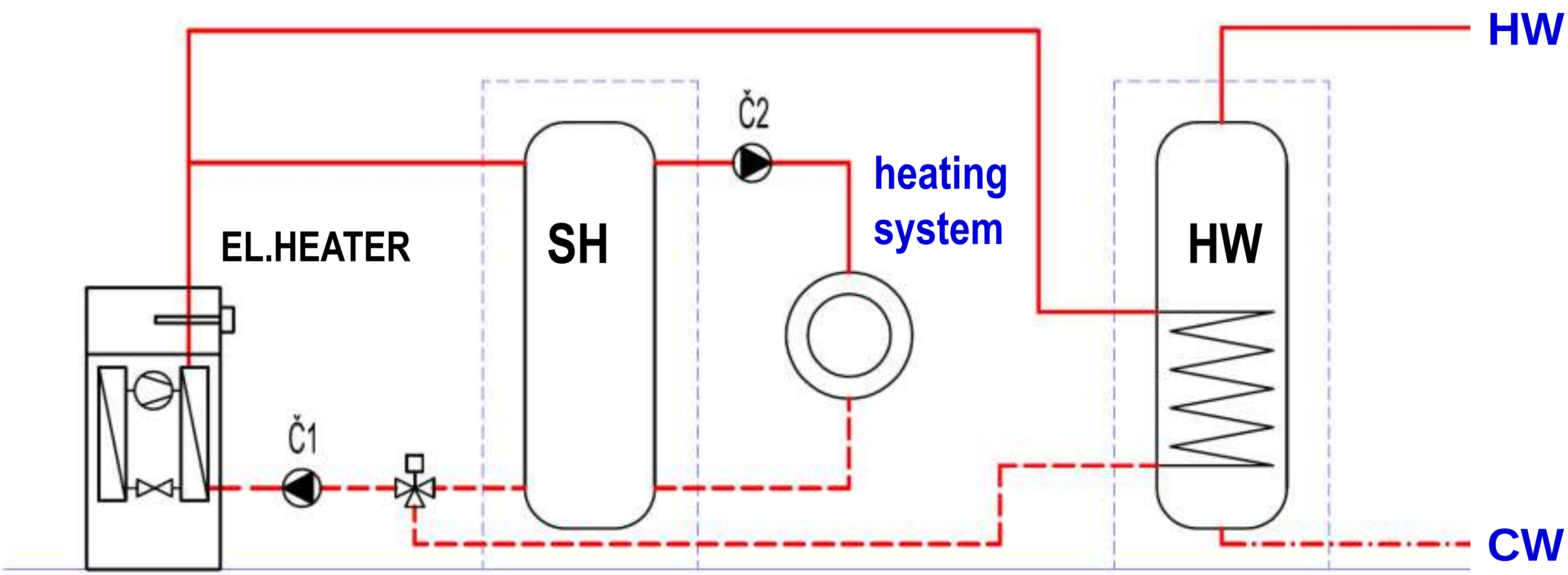
Integration of store

electronically
controlled pump



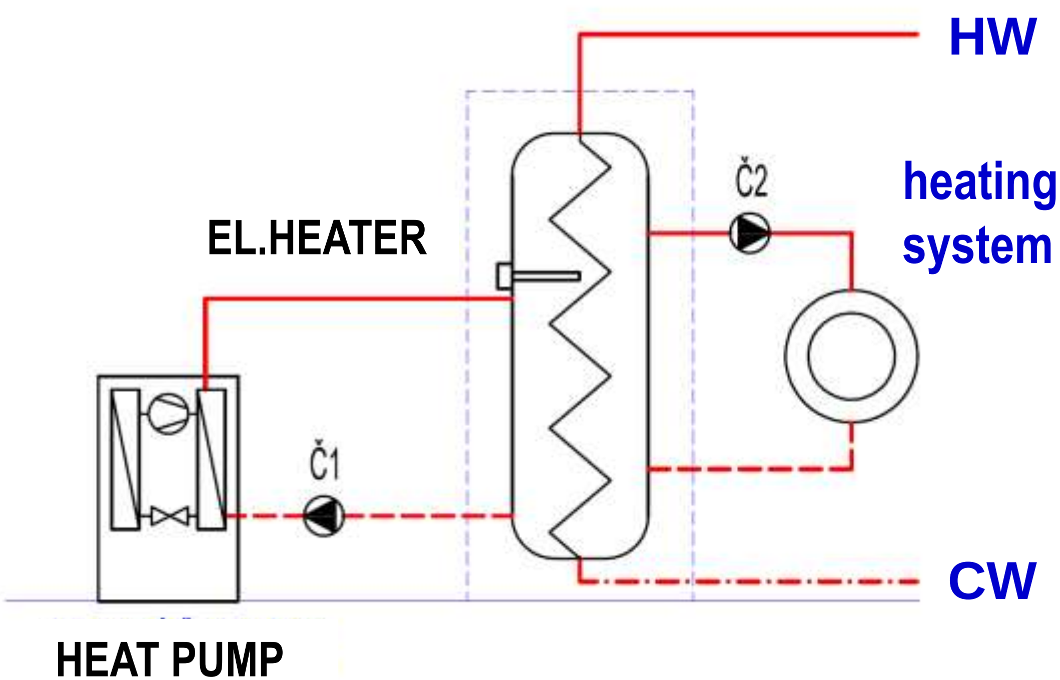
Hydraulics

- **with two stores**
  - heating water store, hot water store
  - bivalent (back-up) heater inside heat pump



Hydraulics

- **with central store**
  - hot water heated in heat exchanger immersed in heating water store volume
  - bivalent (back-up) heater: immersed in store



Guides for design

- **low temperature heating < 45 °C**
  - floor heating, wall heating
  - radiators with larger surface

- **pool water heating**
- **hot water**
  - low temperature 45 °C
  - air-water: advantage in summer, high ambient temperatures
  - brine-water: reduction of borehole regeneration (!)