7 Heat pumps sizing

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

\[ \dot{Q}_k = P_{el} + \dot{Q}_v \]

\[ \text{COP} = \frac{\dot{Q}_k}{P_{el}} \]

\[ \dot{Q}_v = \dot{Q}_k - P_{el} \]

\[ \dot{Q}_v = \dot{Q}_k \cdot \left(1 - \frac{1}{\text{COP}}\right) \]
Heat pumps: ground source (borehole)
Heat pumps: ground source (ground HX)
Heat pumps: water source (water well)
Heat pumps: air source (ambient)
Types of heat pumps on the market

- Reversible air/air: 49%
- Sanitary hot water: 9%
- Reversible other: 10%
- H-air/water: 16%
- H-ground/water: 14%
- Exhaust air: 2%
The trend is air source
... also sanitary hot water HP increase
Heat pumps market in Europe
Top ten countries is the market

674,389 units (89%)
Heat pump parameters

- heat output, heat capacity $Q_k \text{ [kW]}$ – heat output from condenser
- coefficient of performance COP [-]

at given boundary conditions
- $t_{v1}$
- $t_{k2}$
- electric power $P_{el} \text{ [kW]}$
- evaporator input = source output $Q_v \text{ [kW]}$
Air-water heat pump characteristics

Air-water heat pump characteristics include the performance curves for different temperatures. The graphs show the relationship between $Q_k, P_{el}$ and COP as a function of $t_{v1}$ and $t_{k2}$ for 35 °C and 50 °C.

- $Q_k, P_{el}$ vs. $t_{v1}$
- COP vs. $t_{v1}$

The graphs illustrate how the heat pump's performance changes with varying temperatures and conditions.
Air-water heat pump characteristics

electric power, heating capacity [kW]

ambient air temperature

Flow temperature 35°C
Flow temperature 50°C
Flow temperature 60°C
Air-water heat pump characteristics

COP [-] vs. ambient air temperature

The graph illustrates the coefficient of performance (COP) of an air-water heat pump system as a function of ambient air temperature. The COP values increase with higher ambient temperatures, indicating improved heat pump performance in warmer conditions.
Brine-water heat pump (ground source)

Brine-water

- $Q_k, P_{el}$ [kW]
- $t_{v1}$ [°C]
- $t_{k2}$
- 35 °C
- 50 °C

- COP [-]:
- $t_{v1}$ [°C]
Brine-water heat pump (ground source)
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 \( \text{COP} > 4.3 \)
  - **water-water** W10/W35 \( \text{COP} > 5.1 \)
  - **air-water** A2/W35 \( \text{COP} > 3.1 \)

- 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
Seasonal performance factor

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

\[ COP = \frac{Q_{HP}}{Q_{el,HP}} \]
RES directive, minimum SPF

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

\[ SPF > 1.15 \frac{1}{\eta_e} \]

\( \eta_e \) electricity production efficiency
  european average 45.5 %  \( SPF > 2.5 \)

if \( SPF < 2.5 \) ... better to use fossil fuels directly by combustion
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)

<table>
<thead>
<tr>
<th>energy source / sink</th>
<th>minimum value for SPF</th>
<th>target value for SPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>air / water</td>
<td>2.7</td>
<td>3.0</td>
</tr>
<tr>
<td>ground / water</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>water / water</td>
<td>3.8</td>
<td>4.5</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>energy source / sink</th>
<th>minimum value for SPF</th>
<th>target value for SPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>air / water</td>
<td>2.5</td>
<td>2.8</td>
</tr>
<tr>
<td>ground / water</td>
<td>3.3</td>
<td>3.7</td>
</tr>
<tr>
<td>water / water</td>
<td>3.5</td>
<td>4.2</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>energy source / sink</th>
<th>minimum value for SPF</th>
<th>target value for SPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>air / water</td>
<td>2.3</td>
<td>2.8</td>
</tr>
<tr>
<td>ground / water</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>water / water</td>
<td>3.2</td>
<td>3.8</td>
</tr>
</tbody>
</table>
Operation modes

- **monovalent operation**
  - only heating device

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

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

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

- 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

- Flow temperature vs. outdoor temperature

Example of air source HP

Radiators

Max output temperature

Underfloor heating

- 90/70 °C
- 75/55 °C
- 60/45 °C
- 55/40 °C
- 45/35 °C
- 35/30 °C
Balance point according to heat output

**ground source HP**

- Heat output $Q_k$ [kW], heat load $Q_L$ [kW]
- Output temperature $35 \degree C$
- Output temperature $50 \degree C$
- Heat load

**Balance point according to heat output**

- $Q_{L, \text{des}}$
- $Q_L$
- $Q_k$

**Diagram:**

- Ambient temperature $t_e$ [°C]
- Heat output $Q_k$ [kW], heat load $Q_L$ [kW]

**Legend:**

- Blue: Output temperature $35 \degree C$
- Red: Output temperature $50 \degree C$
- Black: Heat load

**Balance point**
Balance point according to heat output

![Graph showing balance point for heat output and load](image)

- **Heat output** $Q_k$ and **heat load** $Q_L$ are plotted against **ambient temperature** $t_e$.
- **Balance point** $Q_{k,bal}$ is indicated where $Q_k$ and $Q_L$ intersect.

**Legend**:
- Blue line: Output temperature 35 °C
- Red line: Output temperature 50 °C
- Black line: Heat load

**Note**: The graph illustrates the balance point for air source HP systems.
Balance point determination

- design heat load $Q_{L,\text{des}}$
  - 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 % $Q_{k,\text{bal}} / Q_{L,\text{des}}$

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

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

if $Q_k = \text{konst}$
if $Q_k \neq \text{konst}$ - 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
Flow temperature

\[ t_{w1} = t_{w1,\text{des}} - \left( t_{w1,\text{des}} - t_{w1,\text{min}} \right) \frac{t_e - t_{e,\text{des}}}{t_i - t_{e,\text{des}}} \]

**Flow temperature**

42 °C

**flow** \( t_{w1} \)

**return** \( t_{w2} \)
Power input at balance point

for balance power point

\[ t_{v1} = -5 \, ^\circ C, \ t_{k2} = 42 \, ^\circ C \]

\[ P_{35} = 3.3 \, kW \]

\[ P_{50} = 4.5 \, kW \]

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

\[ P_{tw1} = P_{35} + \left( P_{50} - P_{35} \right) \frac{t_{w1} - 35}{50 - 35} \]

balance power point

\[ P_{42} = 3.9 \, kW \]
Example

\[
COP_{tw1} = COP_{50} + (COP_{35} - COP_{50}) \frac{50 - t_{w1}}{50 - 35}
\]
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

\[ Q_k = 10.5 \text{ kW} \]

\[ P_{42} = 3.9 \text{ kW} \]

balance point COP =
Heat pump sizing – coverage of demand

Diagram shows the relationship between outdoor temperature ($t_e$ °C) and the number of days for different coverage levels (25%, 50%, 75%, 100%). The coverage levels are indicated at the right side of the graph, with 60% coverage marked at a specific temperature and days value.
Heat pump sizing – coverage of demand

- residential sector
  - based on heating demand

*Graph showing the supplied energy by HP / heating demand vs. HP heating output / design heating load.*
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
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
Heating capacity control

- usual heat pumps
  - start-stop regime
  - cycling = reduction of durability compressor
  - elimination cycling
    - undersizing
    - 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 load 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 \( \Delta t \) in store during operation of heat pump
- heat stored during operation of heat pump

\[
Q_{\text{stored}} = \dot{Q}_{\text{HP}} \cdot \Delta \tau = V \cdot \rho \cdot c \cdot \Delta t
\]
Sizing of storage tank

specific volume

\[ \frac{V}{Q_{HP}} = \frac{1000 \cdot \Delta \tau}{\rho \cdot c \cdot \Delta t} \]

\( \Delta \tau \) [s]  minimum operation time: 15 min

\( \Delta t \) [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 $\Delta t$ in store 3 K

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

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

\[
V = 754 \text{ l}
\]
Integration of store electronically controlled pump

1 heat pump
2 control
2a temperature sensor
3 pump
4 bypass valve
5 heating system
6 storage tank
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

![Diagram of hydraulics system]

- EL.HEATER
- HEAT PUMP
- HW
- CW
- Heating system

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 (!)