Heat sources for heat pumps

- ground
- water
- air
Natural and waste energy

- energy from solar radiation = ambient energy
  - solar radiation: 200 to 1000 W/m²
  - air
  - precipitation, surface water, well water
  - ground
- geothermal water in specific areas
- waste energy
  technology processes, laundry, washing, ventilation
Ground energy

- **specific power**
  - Heat flow from ambient: 10 to 40 W/m² (in average)
  - Heat flow from Earth core: 0.04 to 0.06 W/m²

- **temperature**
  - Under 2-5 m stable conditions: > 10 °C
  - Geothermic temperature gradient: 3 K/100 m

- **thermal conductivity**
  - Dry sand soil: 1.1 W/m.K
  - Wet granite: 3.3 W/m.K
  - Average: 2 W/m.K
Ground temperature

1. temperature curve of 1st of February;
2. temperature curve of 1st of May;
3. temperature curve of 1st of August;
4. temperature curve of 1st of November.
Ground energy extraction

- **vertical bore heat exchangers**
  drilled dry ground boreholes

- **horizontal ground heat exchangers**
  subsurface HX

- **wells**
  extraction of ground water – different technology, different heat pump application
Ground vertical boreholes

- Heat extraction by dry boreholes under 200 m
- Usually under 100 m
- Not space demanding
- 1 or 2 pipe circuits in borehole
- Primary circuit temperatures: from -4 °C to +4 °C
Knowledge of geology!

- design of length and number of boreholes
  thermal properties of the ground
  risk of undersizing – reveals after years
  decrease of heat output and COP, insufficient borehole regeneration

- ecology
  disruption of water horizons
  interconnection of deep horizons with high quality ground water with shallow horizons with low quality
Ground vertical - Thermal resistance of ground

- **Thermal resistance**: $R_z = \frac{1}{2\pi \cdot \lambda_z} \ln \frac{D_z}{d_v} \text{ [m.K/W]}$

- **Diameter of influenced field**: $D_z = 4 \text{ to } 6 \text{ m}$
- **Diameter of borehole**: $d_v = 100 \text{ to } 150 \text{ mm}$
- **HDPE**: DN25, DN32
- **Thermal conductivity**: $\lambda_z = 1.0 \text{ to } 3.0 \text{ W/m.K}$

- **Bore**: $t_z = +12 \text{ °C}$
- **Heat exchanger**: $q_z \text{ [W/m]}$
Ground vertical - Specific heat flow

\[ q_{z,l} = \frac{t_z - t_{v12}}{R_z} \] [W/m]

- borehole temperature \( t_{v12} \) = around 0 °C (+4 to – 4°C)
- ground temperature in stable field \( t_z \) = 12 °C (+3 K/100 m)

<table>
<thead>
<tr>
<th>Ground type</th>
<th>Specific heat flow ( q_{z,l} ) [W/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>granite with water</td>
<td>100</td>
</tr>
<tr>
<td>conductive stone</td>
<td>80</td>
</tr>
<tr>
<td>standard solid stone, average</td>
<td>55</td>
</tr>
<tr>
<td>dry sands, low conductivity</td>
<td>30</td>
</tr>
</tbody>
</table>
Ground vertical - Specific heat flow
EN 15 450 (VDI 4650)

<table>
<thead>
<tr>
<th>Ground type</th>
<th>Specific heat extraction rate</th>
<th>operation period 1 800 h</th>
<th>operation period 2 400 h</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General guidance values:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>poor underground (dry sediment and $\lambda &lt; 1.5$ W/(m K))</td>
<td>25 W/m</td>
<td>20 W/m</td>
<td></td>
</tr>
<tr>
<td>normal underground and water-saturated sediment $1.5 &lt; \lambda &lt; 3.0$ W/(m K)</td>
<td>60 W/m</td>
<td>50 W/m</td>
<td></td>
</tr>
<tr>
<td>consolidated rock with high thermal conductivity $\lambda &gt; 3.0$ W/(m K)</td>
<td>84 W/m</td>
<td>70 W/m</td>
<td></td>
</tr>
<tr>
<td><strong>Individual ground types:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry gravel or sand</td>
<td>&lt; 25 W/m</td>
<td>&lt; 20 W/m</td>
<td></td>
</tr>
<tr>
<td>gravel or sand saturated with water</td>
<td>65 to 80 W/m</td>
<td>55 to 65 W/m</td>
<td></td>
</tr>
<tr>
<td>gravel or sand and strong ground water flow</td>
<td>80 to 100 W/m</td>
<td>80 to 100 W/m</td>
<td></td>
</tr>
<tr>
<td>moist clay</td>
<td>35 to 50 W/m</td>
<td>30 to 40 W/m</td>
<td></td>
</tr>
<tr>
<td>massive limestone</td>
<td>55 to 70 W/m</td>
<td>45 to 60 W/m</td>
<td></td>
</tr>
<tr>
<td>sandstone</td>
<td>65 to 80 W/m</td>
<td>55 to 65 W/m</td>
<td></td>
</tr>
<tr>
<td>siliceous magmatite (e.g. granite)</td>
<td>65 to 85 W/m</td>
<td>55 to 70 W/m</td>
<td></td>
</tr>
<tr>
<td>basic magmatite (e.g. basalt)</td>
<td>40 to 65 W/m</td>
<td>35 to 55 W/m</td>
<td></td>
</tr>
<tr>
<td>diorite</td>
<td>70 to 85 W/m</td>
<td>60 to 70 W/m</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE** values valid for heat pump systems with a heating output up to 30 kW

annual extracted energy should be between 100 and 150 kWh/m
Ground vertical - Depth (length) of borehole

for nominal conditions determine the heat power and COP

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

\[ l_v = \frac{\dot{Q}_v}{q_z} \quad [\text{m}] \]

- final borehole depth given by drilling technology – similar technology to water wells, not more than 100 m
- more boreholes = division of flowrate = lower pressure losses

\[ q_z \text{ considered according to assumed operation time of HP} \]
(1800, 2400 h)
Alternative sizing

- determination of annual heat delivered by HP $Q_{HP,del}$ and $COP$
- determination of annual extracted energy from borehole $Q_v$

$$Q_v = Q_{del} \left(1 - \frac{1}{COP}\right)$$

- operation period $\Delta \tau_{HP}$: 1800 (space heating only), 2400 (space heating and DHW)
- determination of average extraction power (at evaporator)

$$Q_v = \frac{Q_v}{\Delta \tau_{HP}}$$

design power for borehole depth calculation
Borehole construction

- suitable piping: HD-PE, PE-RC (crack resistant), PN16 (100m)
- minimum distance > 5 m to avoid the coupling of influenced fields
- better > 10 m: *drilling is not completely vertical* (deflection 2 m), distance larger than 10% of borehole length
- ground water flow: suitable location of boreholes to avoid mutual cooling
- borehole filling by bentonite (cement mixture) can’t be filled by extracted soil! = insulator
**Borehole construction**

- **injection pipe** – filling the borehole with bentonite
- **reduction** – connection of circuits
- **distance bar** – distance between pipes
- **support bar**
- **U piece** – bottom of borehole
- **anchor**
Example: ground source HP boreholes

- house, heat load 10 kW \( (t_{e,N} = -12 \degree C, t_i = 20 \degree C) \)
- heat pump \( Q_{HP} = 10 \text{ kW}, COP = 4,0 \) (at B0/W35)
- heating season, monovalent operation
  - \( t_{e,av} = 4,3 \degree C, t_{i,av} = 20 \degree C, 225 \text{ days of heating}, \text{correction factor} \ 0,75 \)
- space heating demand \( Q_{SH} = 19,9 \text{ MWh/a} \)
- hot water demand \( Q_{HW} = 3.5 \text{ MWh/a} \)

\[
Q_{SH} = 225 \cdot 24 \cdot \varepsilon \cdot \dot{Q}_N \cdot \frac{t_{i,avg} - t_{e,avg}}{t_{i,N} - t_{e,N}}
\]

\[
Q_{HW} = 365 \cdot \frac{V_{HW,day} \cdot \rho \cdot c \cdot (t_{HW} - t_{CW})}{3,6 \times 10^6}
\]
Example: ground source HP boreholes

- **theoretical approach (power approach)**

- **cooling power of the heat pump** \( Q_v = Q_{HP} \left(1 - 1/COP\right) = 7.5 \text{ kW} \)

- **borehole**

  \[ \lambda_z = 2.5 \text{ W/mK}, \quad d_v = 150 \text{ mm}, \quad D_z = 4 \text{ m}, \quad t_z = 12 \text{ °C}, \quad t_{v1} = +2 \text{ °C}, \quad t_{v2} = -2 \text{ °C} \]

- **thermal resistance of ground** \[ R_z = \frac{1}{2\pi \cdot \lambda_z} \ln \frac{D_z}{d_v} = 0.22 \text{ mK/W} \]

- **specific heat power** \( q_z = \frac{(t_z - t_{v12})}{R_z} = 54 \text{ W/m} \)

- **borehole length (depth)** \( l_v = \frac{\dot{Q}_v}{q_z} \text{ [m]} \quad l_v = 140 \text{ m} \)
Example: ground source HP boreholes

- practical approach (demand approach): heating only 1800 h

- heat extracted by heat pump $Q_{ex} = Q_{SH} \times (1 - 1/COP)$ = 14,9 MWh

- average cooling power of heat pump $Q_v = Q_{ex} / 1800$ h = 8.3 kW

- tables: average soil with $1.5 < \lambda_z < 3.0$ $q_z = 60$ W/m (1800 h)

- borehole length (depth) $l_v = 138$ m
Example: ground source HP boreholes

- practical approach (demand approach): SH+HW 2400 h
  - heat extracted \( Q_{\text{ex}} = (Q_{\text{SH}} + Q_{\text{HW}})(1 - 1/COP) \) = 17,5 MWh
  - average cooling power of heat pump \( Q_v = Q_{\text{ex}} / 2400 \text{ h} \) = 7.3 kW
  - tables: average soil with 1,5 < \( \lambda_z \) < 3,0 \( q_z = 50 \text{ W/m (2400 h)} \)
  - borehole length (depth) \( l_v = 146 \text{ m} \)
Horizontal ground heat exchangers

- heat extraction from subsurface layer (up to 2 m depth)
- possible influence of vegetation
- space demanding excavation
- large land need
- HX temperatures around 0 °C
Horizontal ground heat exchangers

- Depth min. 0.2 m under non-freezing level
  \( h = 0.6 \) to 2 m

- Pipe distance (spacing)
  \( s = \text{min. } 0.8 \text{ m to } 1.1 \text{ m} \)

- HDPE pipes 25 – 40 mm

- Thermal conductivity
  \( \lambda_z = 1.0 \) to 3.0 W/m.K

\[
R_z = \frac{1}{2\pi \cdot \lambda_z} \ln \left[ \frac{2 \cdot s}{\pi \cdot d} \sinh \left( 2\pi \frac{h}{s} \right) \right] \quad \text{[m.K/W]}
\]
Horizontal ground heat exchangers

\[ q_{z,l} = \frac{t_z - t_{v12}}{R_z} \] [W/m]

- **temperature in pipes**
  \[ t_{v12} = \text{around } 0 ^\circ \text{C} \ ( +4 \text{ to } -4 ^\circ \text{C}) \]

- **temperature of ground**
  \[ t_z = 10 ^\circ \text{C} \]

<table>
<thead>
<tr>
<th>Soil type</th>
<th>specific heat flow ( q_{z,l} ) [W/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>dry sands, non cohesive</td>
<td>10 – 15</td>
</tr>
<tr>
<td>dry solid soil</td>
<td>15 – 20</td>
</tr>
<tr>
<td><strong>moist solid soil</strong></td>
<td>20 – 25</td>
</tr>
<tr>
<td>soil saturated with ground water</td>
<td>25 – 30</td>
</tr>
<tr>
<td>soil with ground water flow</td>
<td>35 – 40</td>
</tr>
</tbody>
</table>
Length and area of ground HX

\[ l_v = \frac{\dot{Q}_v}{q_z} = \frac{\dot{Q}_k - P_{el}}{q_z} \quad [\text{m}] \]

\[ S = \frac{\dot{Q}_v \cdot s}{q_{z,l}} = \frac{\dot{Q}_v}{q_{z,A}} \quad [\text{m}^2] \]

for a distance \( s = 1 \) m

\( q_{z,l} \) becomes \( q_{z,A} \)

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<tr>
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<td>soil with ground water flow</td>
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</tr>
</tbody>
</table>
Specific heat flow EN 15 450 (VDI 4650)

<table>
<thead>
<tr>
<th>Ground quality</th>
<th>Specific heat extraction flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>operation period 1 800 h per year</td>
</tr>
<tr>
<td>dry, non cohesive soil</td>
<td>10 W/m²</td>
</tr>
<tr>
<td>moist cohesive soil</td>
<td>20 to 30 W/m²</td>
</tr>
<tr>
<td>water saturated sand or gravel</td>
<td>40 W/m²</td>
</tr>
</tbody>
</table>

annual extracted energy should be between 50 and 70 kWh/m²

- for nominal conditions determine heat power and COP (at B0/W35)

\[
Q_v = Q_k \left(1 - \frac{1}{COP}\right)
\]

\[
S = \frac{Q_v}{q_{z,A}} \quad [m^2]
\]

\(q_{z,A}\) is considered according to assumed operation time of HP (1800, 2400 h)
Alternative sizing

- Determination of annual heat delivered by HP $Q_{HP,del}$ and $COP$
- Determination of annual extracted energy from borehole $Q_v$

\[ Q_v = Q_{del} \left( 1 - \frac{1}{COP} \right) \]

- Operation period $\Delta \tau_{HP}$: 1800 (space heating only), 2400 (space heating and DHW)
- Determination of average extraction power (at evaporator)

\[ Q_v = \frac{Q_v}{\Delta \tau_{HP}} \]

Design power for ground HX area calculation
Construction of ground HX

- Length of circuits should not exceed 100 m for DN25 ... or 400 m for DN40 (pressure loss)
- Distribution of flowrate to number of circuits
- Circuit from one pipe, no junctions
- Surface above HX – permeable for rain (no concrete of asphalt layers) for regeneration
- Mind the roots!
- Documentation of piping location
Construction of ground HX
Connection to house (borehole, HX)

- brines \( (t_F < -10^\circ\text{C}) \): propylenglycol-water (30 / 70 %)
  ethanol-water (40 / 60 %)

- pipe with slope from distributor – deaeration

- similar lengths of circuits – easy hydraulic balancing

- passage into building in insulated protector

- safety distance from building constructions (basements) – pipes under freezing point

- attention for crossing the water installation

- piping inside building in insulation – condensation and freezing
Borehole connection to house
Ground HX connection to house
Distributor

- Distributor located outside:
- Plastic casing
- Concrete casing
Ground water

- chemical quality
- quantity
- stable water temperature = average annual air temperature
Water

- **warm waste water**: cooling processes
  \( t = 20 \text{ to } 25 \, ^\circ\text{C} \)

- **surface water**: rivers, lakes
  \( t = 0 \text{ to } 18 \, ^\circ\text{C} \), temperature influenced by ambient climate

- **ground water**: wells, boreholes
  \( t = 7 \text{ to } 10 \, ^\circ\text{C} \), uniform temperature during the year

- **geothermal water**: deep boreholes
  \( t = 10 \text{ to } 13 \, ^\circ\text{C} \), temperature gradient 3 K/100 m
  \( t > 25 \, ^\circ\text{C} \), geothermal water
Ground water

pumping well (max. 15 m deep: pump power)

drain well (15 m from pumping well)

cooling by 3 to 4 K

for $Q_k = 10 \text{ kW} \sim 1500 \text{ l/h} (0.4 \text{ kg/s})$

water quantity (constant flowrate)

$$\dot{M}_v = \frac{\dot{Q}_v}{c_v (t_{v1} - t_{v2})} \text{ [kg/s]}$$

pumping test: 30 days, or more!
Pumping and drain well

- drain well
- pumping well

Diagram labels:
1. studniční šachta
2. kryt studny
3. uzávěr studny
4. čerpací trubka
5. vsakovací trubka
6. ponorné čerpačelo
7. uzavírací ventil
8. filtr
9. manometr
10. teploměr
11. odběrový kohout
Water quality

- chemical content
  - corrosion (stainless steel) – chlorides, oxygen
  - minerals (heat exchanger fouling)
  - fine particles - filters with automatic cleaning

Table A.1 — Requirements for the quality of extraction water as a heat source

<table>
<thead>
<tr>
<th>components / units of measurement</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>organic material (possibility of sedimentation)</td>
<td>none</td>
</tr>
<tr>
<td>ph – value</td>
<td>6.5 to 9</td>
</tr>
<tr>
<td>electrical conductivity (μS/cm)</td>
<td>50 to 1 000</td>
</tr>
<tr>
<td>chloride (mg/litre)</td>
<td>&lt; 300</td>
</tr>
<tr>
<td>iron and manganese (mg/litre)</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>sulfate (mg/litre)</td>
<td>0 to 150</td>
</tr>
<tr>
<td>O₂ – content (mg/litre)</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>chlorine (mg/litre)</td>
<td>0 to 5</td>
</tr>
<tr>
<td>nitrate (mg/litre)</td>
<td>0 to 100</td>
</tr>
</tbody>
</table>
Example: water well sizing

- heat pump $Q_{HP} = 10$ kW, $COP = 4.0$

- cooling power of the heat pump $Q_v = Q_{HP} \left(1 - \frac{1}{COP}\right) = 7.5$ kW

- $t_{v1} = 10$ °C, $\Delta t = 4$ K

- water flowrate $M_w = 0.45$ kg/s = 27 l/min
Ambient air

- use of ambient heat
- heat power dependent on climate conditions
  - winter: COP < 3
  - summer: COP > 4
- mostly bivalent operation
- removal of condensate
- noise (large flowrates)
The temperature of air is lowest in the time of highest heat demand.
Ambient air – energy content, enthalpy

\[ h = c_a \cdot t + (l_0 + c_D \cdot t) \cdot x = 1010 \cdot t + \left(2,5 \cdot 10^6 + 1840 \cdot t \right) \cdot x \]

- \( c_a \) specific heat of dry air, \( \nu \) J/(kg.K);
- \( t \) air temperature, \( \nu \) °C;
- \( l_0 \) latent heat of water (evaporation), \( \nu \) J/kg;
- \( c_D \) specific heat of water vapour, \( \nu \) J/(kg.K);
- \( x \) specific humidity of air, \( \nu \) kg w/kg da.

\[ \dot{V}_v = \frac{\dot{Q}_v}{\rho \cdot (h_{v1} - h_{v2})} \]
Construction

indoor units

outdoor units
Indoor units
Outdoor units
Condensate

- **condensation of water** content in air at evaporator of heat pump
- **removal of condensate**
  - drainage to ground (outdoor units)
  - connection to sewer system (indoor units)
  - transfer pump

Diagram showing concrete sheet, gravel layer, and condensate removal.
Frost

- **frosting** at evaporator surface
  - reduction of heat transfer
  - decrease of evaporator pressure and temperature, power, COP
  - reduction of cross section, increase of pressure loss, increase of fan power, *operation restriction*

- **defrosting**
  - internal cycle (favourable): hot vapor, reverse cycle
  - outer heating: electric cables at evaporator
    - by air above +3 °C, HP is OFF, fan is ON
Noise protection

- large flowrates at evaporator, big fan - source of noise
  - grass not reflection surfaces
  - noise barriers (walls, green fences)
  - protection by distance
  - antivibrating layers under HP
  - noise reducers for piping (water, air)