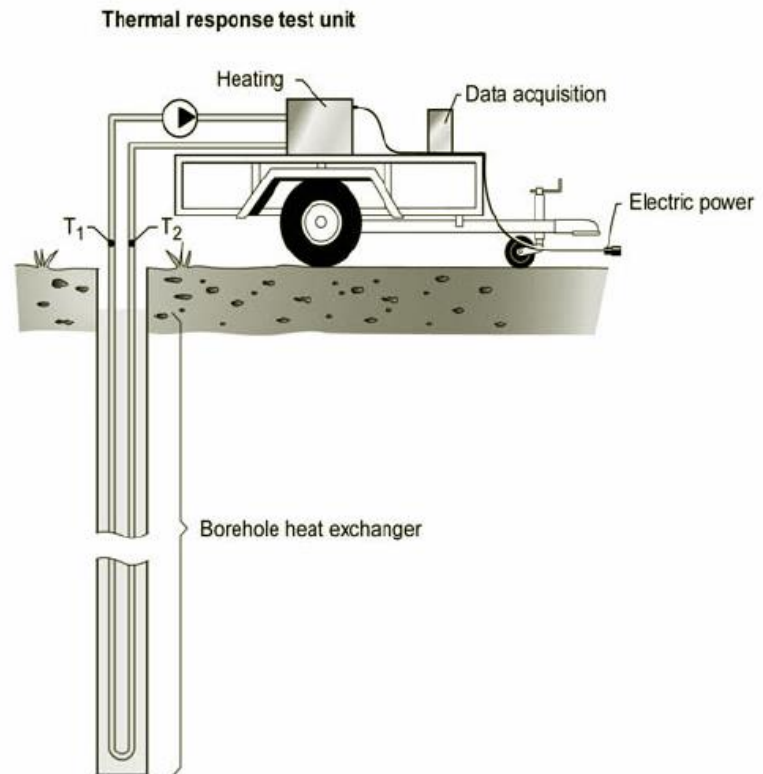




Heat sources for heat pumps

- 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 only

- **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 Only!**

- **temperature**

under 2-5 m stable conditions > 10 °C

geothermic temperature gradient 3 K/100 m

- **thermal conductivity**

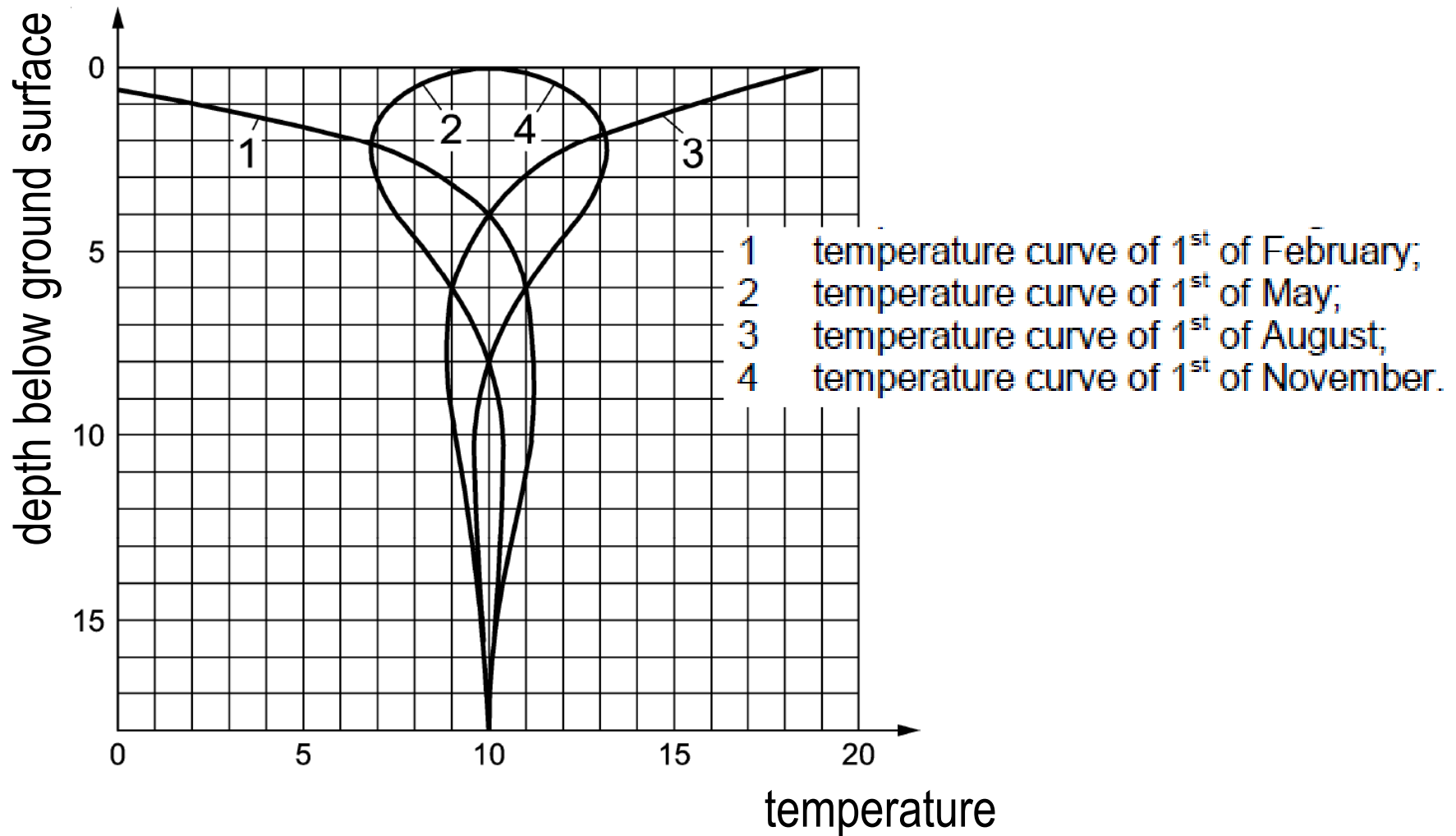
dry sand soil 1,1 W/m.K

wet granite 3,3 W/m.K

average 2 W/m.K



Ground temperature





Ground energy extraction

1. vertical bore heat exchangers

drilled dry ground boreholes

2. horizontal ground heat exchangers

subsurface HX

3. wells

extraction of ground water – different technology, different heat pump application



1 Ground vertical boreholes



- heat extraction by dry boreholes under 200 m
- usually under 100 m
- not space demanding (on ground surface)
- 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

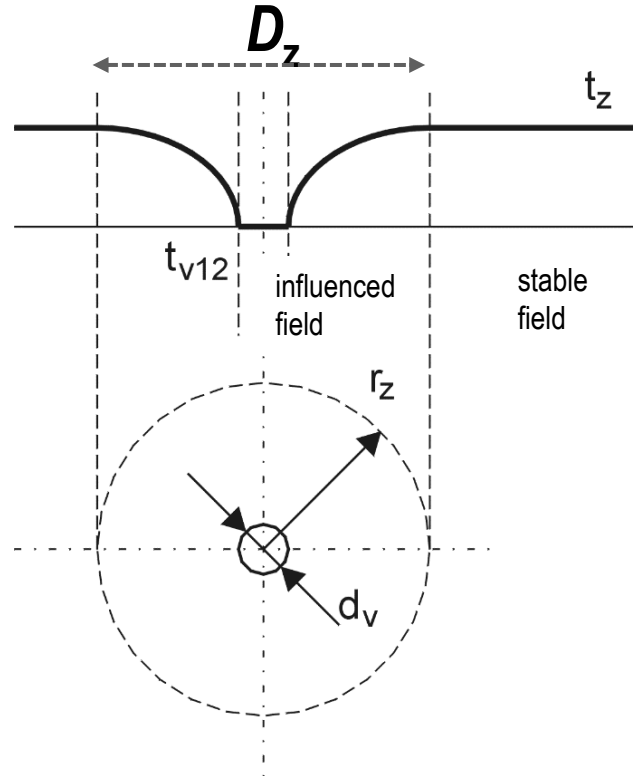
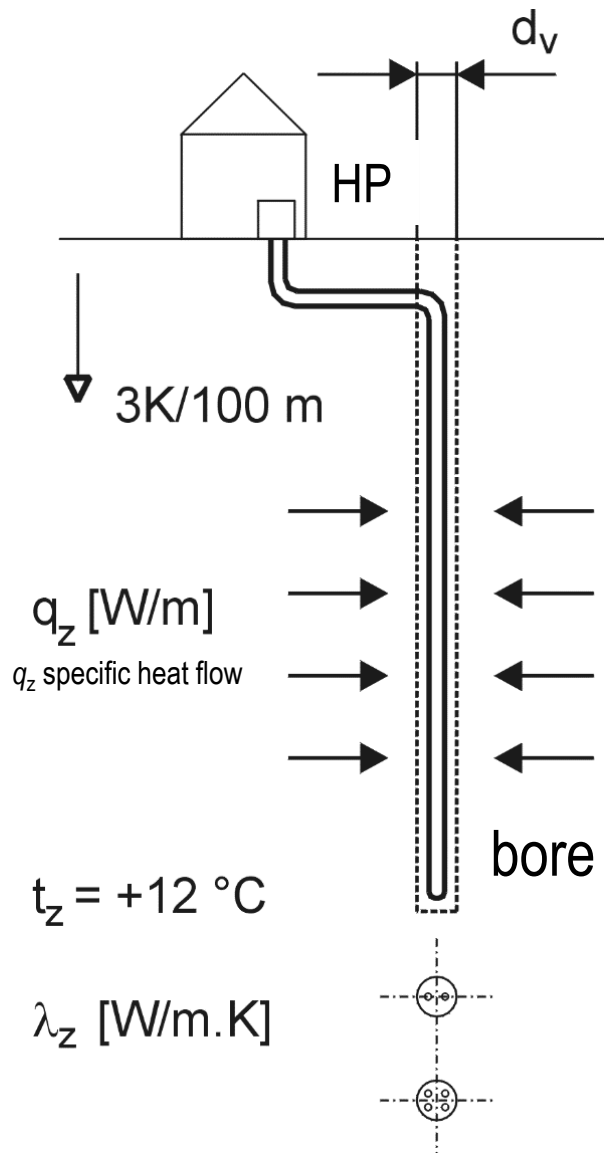
- **ecology**

disruption of water horizons

interconnection of deep horizons with high quality ground water with shallow horizons with low quality water



1 Ground vertical - Thermal resistance of ground



thermal resistance

$$R_z = \frac{1}{2\pi \cdot \lambda_z} \ln \frac{D_z}{d_v} \quad [\text{m.K/W}]$$

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

$\lambda_z = 1,0 \text{ to } 3,0 \text{ W/m.K}$



1 Ground vertical - Specific heat flow

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

borehole temperature

$t_{v12} = \text{around } 0 \text{ }^{\circ}\text{C} \quad (+4 \text{ to } -4^{\circ}\text{C})$

ground temperature in stable field

$t_z = 12 \text{ }^{\circ}\text{C} \quad (+3 \text{ K/100 m})$

Ground type	specific heat flow $q_{z,l}$ [W/m]
granite with water	100
conductive stone	80
standard solid stone, average	55
dry sands, low conductivity	30



1 Ground vertical - Specific heat flow

EN 15 450 (VDI 4650)

Ground type	Specific heat extraction rate	
	operation period 1 800 h	operation period 2 400 h
General guidance values:		
poor underground (dry sediment and $\lambda < 1,5 \text{ W/(m K)}$)	25 W/m	20 W/m
normal underground and water-saturated sediment $1,5 < \lambda < 3,0 \text{ W/(m K)}$	60 W/m	50 W/m
consolidated rock with high thermal conductivity $\lambda > 3,0 \text{ W/(m K)}$	84 W/m	70 W/m
Individual ground types:		
dry gravel or sand	< 25 W/m	< 20 W/m
gravel or sand saturated with water	65 to 80 W/m	55 to 65 W/m
gravel or sand and strong ground water flow	80 to 100 W/m	80 to 100 W/m
moist clay	35 to 50 W/m	30 to 40 W/m
massive limestone	55 to 70 W/m	45 to 60 W/m
sandstone	65 to 80 W/m	55 to 65 W/m
siliceous magmatite (e.g. granite)	65 to 85 W/m	55 to 70 W/m
basic magmatite (e.g. basalt)	40 to 65 W/m	35 to 55 W/m
diorite	70 to 85 W/m	60 to 70 W/m
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



1 Ground vertical - Depth (length) of borehole

for nominal conditions determine the heat power and COP

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

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

q_z considered according to
assumed operation time of HP
(1800 h or 2400 h)
 q_z specific heat flow

- 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



1 Alternative sizing

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

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

inverse value

- operation period $\Delta \tau_{HP}$: 1800 h (space heating only),
2400 h (space heating and DHW)

- determination of average extraction power (at evaporator)

$$\dot{Q}_v = \frac{Q_v}{\Delta \tau_{HP}}$$

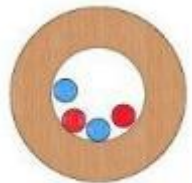
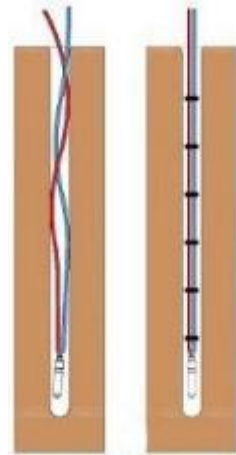


design power for borehole
depth calculation



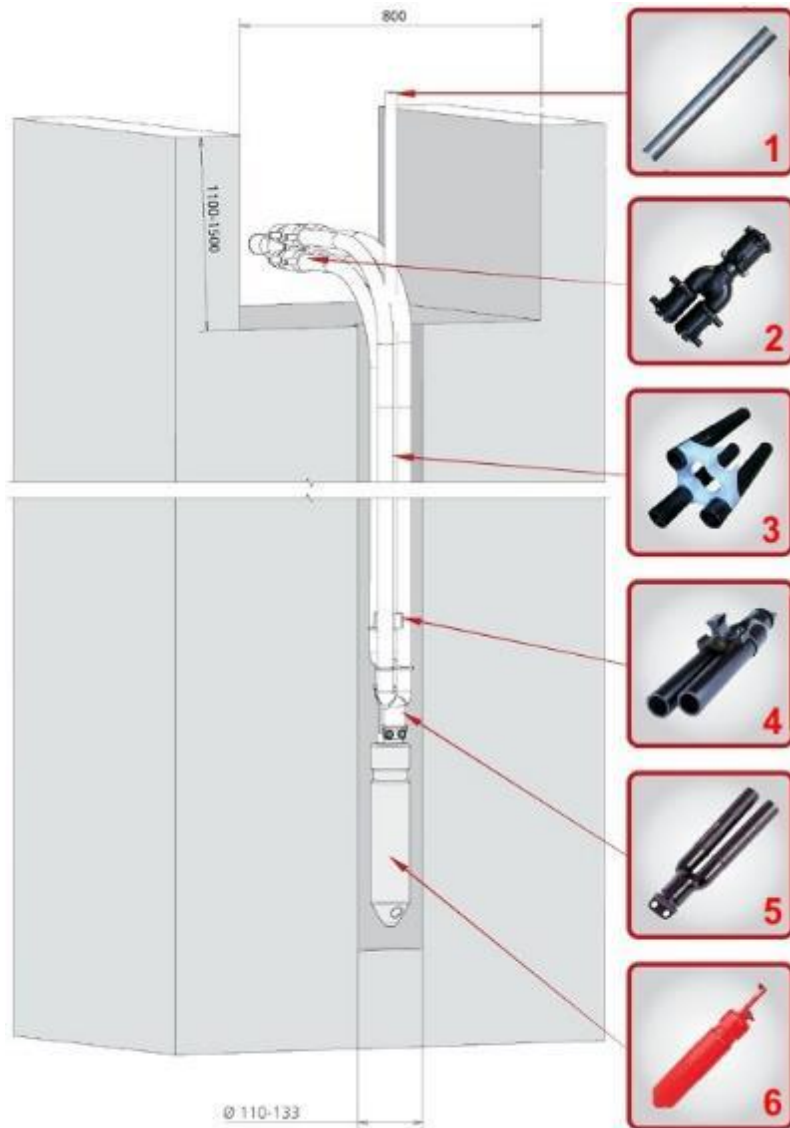
1 Borehole construction

- suitable piping: HD-PE, PE-RC (crack resistant), PN16 (100m)
- minimum distance > 5 m horizontal gap to avoid the coupling of influenced fields
- better > 10 m: ***drilling is not completely vertical*** (deflection could be 2 m), so 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 ! = soil is insulator





1 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





1 Example: ground source HP boreholes

- house, heat load 10 kW ($t_{e,N} = -12\text{ °C}$, $t_i = 20\text{ °C}$)
- heat pump $Q_{HP} = 10\text{ kW}$, $COP = 4,0$ (at B0/W35)
- heating season, monovalent operation
 - $t_{e,av} = 4,3\text{ °C}$, $t_{i,av} = 20\text{ °C}$, 225 days of heating, correction factor 0,75
- space heating demand $Q_{SH} = 19,9\text{ MWh/a}$ $Q_{SH} = 225 \cdot 24 \cdot \varepsilon \cdot \dot{Q}_N \cdot \frac{(t_{i,avg} - t_{e,avg})}{(t_{i,N} - t_{e,N})}$
- hot water demand $Q_{HW} = 3.5\text{ MWh/a}$ $Q_{HW} = 365 \cdot \frac{V_{HW,day} \cdot \rho \cdot c \cdot (t_{HW} - t_{CW})}{3,6 \times 10^6}$



1 Example: ground source HP boreholes

- theoretical approach (power approach)

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

- borehole

thermal conductivity $\lambda_z = 2,5 \text{ W/mK}$, $d_v = 150 \text{ mm}$, $D_z = 4 \text{ m}$,
 $t_z = 12 \text{ }^\circ\text{C}$, $t_{v1} = +2 \text{ }^\circ\text{C}$, $t_{v2} = -2 \text{ }^\circ\text{C}$

- 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 $q_z = (t_z - t_{v12}) / R_z = 54 \text{ W/m}$

- borehole length (depth) $l_v = \frac{\dot{Q}_v}{q_z} \text{ [m]} \quad l_v = 140 \text{ m}$



1 Example: ground source HP boreholes

- **practical approach** (demand approach): heating only 1800 h
- heat extracted by heat pump $Q_{\text{ex}} = Q_{\text{SH}} (1 - 1/\text{COP}) = 14,9 \text{ MWh}$
- average cooling power of heat pump $Q_v = Q_{\text{ex}} / 1800 \text{ h} = 8.3 \text{ kW}$
- tables: average soil with $1,5 < \lambda_z < 3,0$ $q_z = 60 \text{ W/m (1800 h)}$
- borehole length (depth) $l_v = 138 \text{ m}$



1 Example: ground source HP boreholes

- practical approach (demand approach): SH+HW 2400 h
- heat extracted $Q_{\text{ex}} = (Q_{\text{SH}} + Q_{\text{HW}}) * (1 - 1/\text{COP})$ = 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) $l_v = 146 \text{ m}$



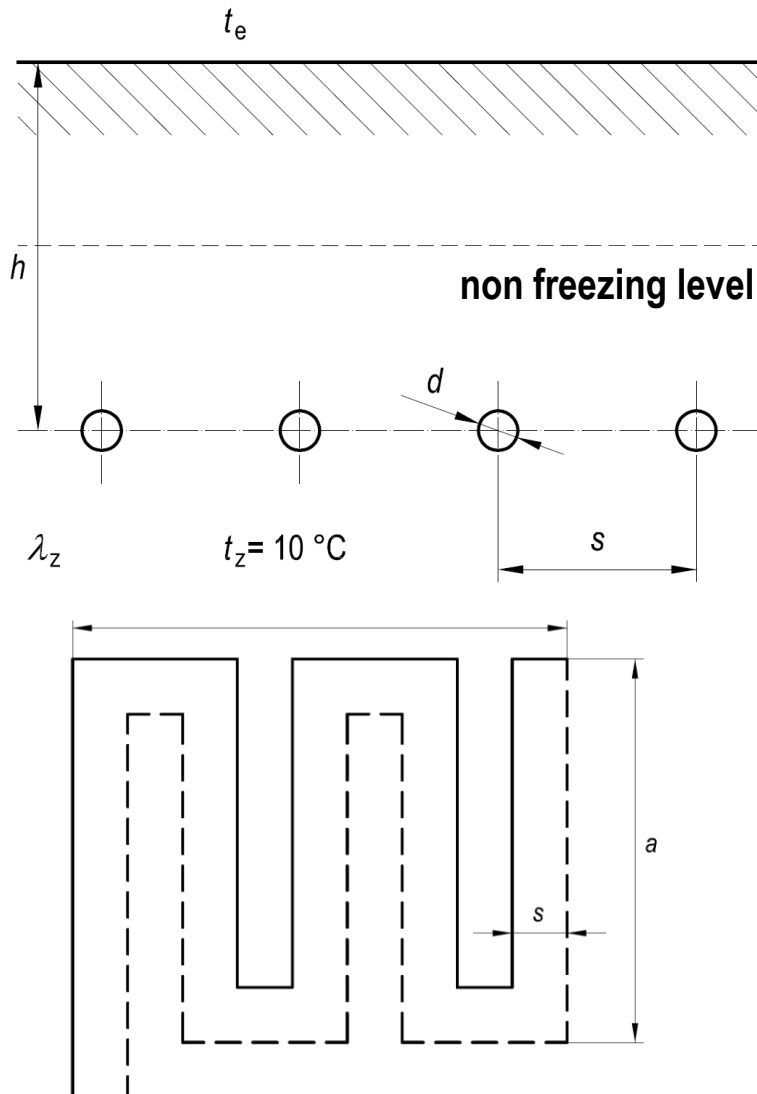
2 Horizontal ground heat exchangers



- 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



2 Horizontal ground heat exchangers



depth min. 0,2 m under non freezing level
 $h = 0,6$ to 2 m

pipe distance (spacing)
 $s = \text{min. } 0,8$ m to $1,1$ m

HDPE pipes, diameter 25 – 40 mm

thermal conductivity
 $\lambda_z = 1,0$ to $3,0$ W/m.K

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



2 Horizontal ground heat exchangers

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

temperature in pipes

$t_{v12} = \text{around } 0 \text{ } ^\circ\text{C} \quad (+4 \text{ to } -4^\circ\text{C})$

temperature of ground

$t_z = 10 \text{ } ^\circ\text{C}$

Soil type	specific heat flow $q_{z,l}$ [W/m]
dry sands, non cohesive	10 – 15
dry solid soil	15 – 20
moist solid soil	20 – 25
soil saturated with ground water	25 – 30
soil with ground water flow	35 – 40



2 Length and area of ground HX

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

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

for a distance $s = 1 \text{ m}$
 $q_{z,I}$ becomes $q_{z,A}$

Soil type	specific heat flow $q_{z,A} \text{ [W/m}^2\text{]}$
dry sands, non cohesive	10 – 15
dry solid soil	15 – 20
moist solid soil	20 – 25
soil saturated with ground water	25 – 30
soil with ground water flow	35 – 40



2 Specific heat flow EN 15 450 (VDI 4650)

Ground quality	Specific heat extraction flow rate	
	operation period 1 800 h per year	operation period 2 400 h per year
dry, non cohesive soil	10 W/m ²	8 W/m ²
moist cohesive soil	20 to 30 W/m ²	16 to 24 W/m ²
water saturated sand or gravel	40 W/m ²	32 W/m ²

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

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

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

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

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



2 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)

$$\dot{Q}_v = \frac{Q_v}{\Delta \tau_{HP}}$$



design power for ground HX
area calculation

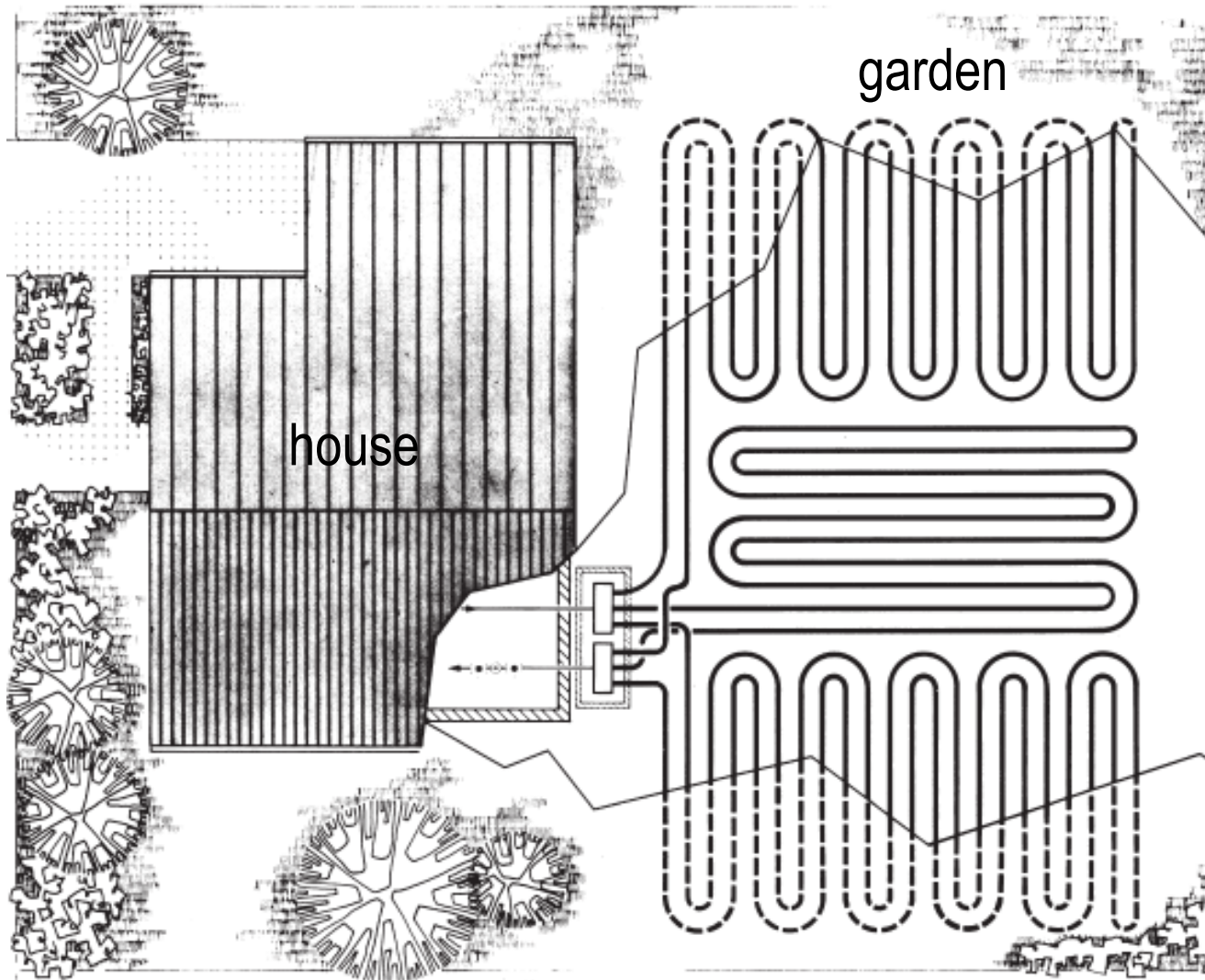


2 Construction of ground HX

- length of circuits should not exceed 100 m for DN25 ... or 400 m for DN40 (pressure loss limitation)
- distribution of flowrate to number of circuits
- circuit from one pipe, no junctions
- surface above HX – permeable for rain (no concrete or asphalt layers) for regeneration
- mind the roots!
- make documentation of piping location



2 Construction of ground HX



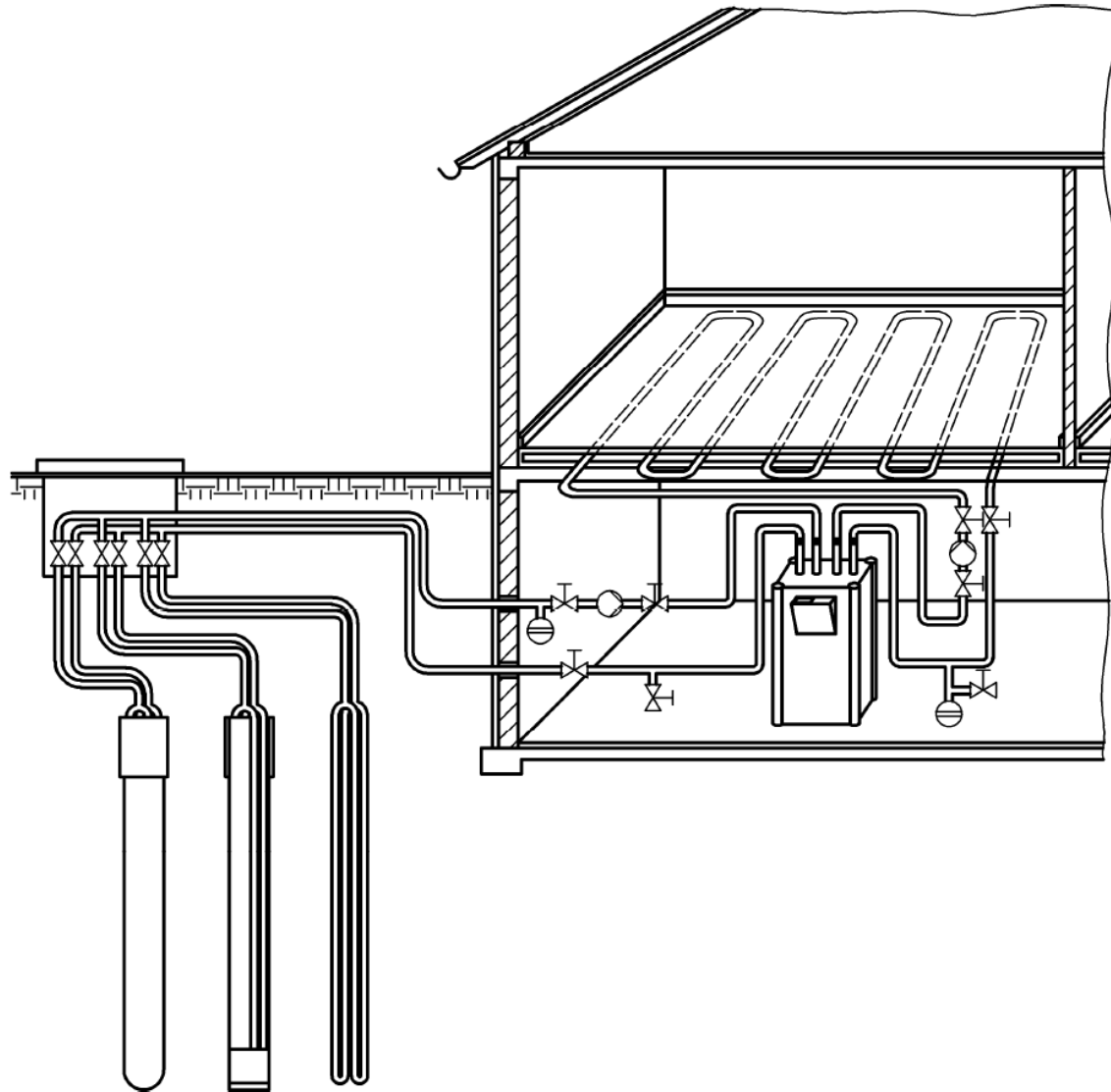


2 Connection to house (borehole, HX)

- 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**



2 Borehole connection to house



The diagram illustrates a hydronic heating system. On the right, a boiler is connected to a network of pipes. Two pumps are shown: one on the supply line to the radiator and another on the return line. The system includes several valves for manual control. The pipes branch out to a radiator in a room above and a coil in a basement. The return line from the coil passes through a filter before returning to the boiler.



2 Distributor



distributor located outside:
 plastic casing
 concrete casing



3 Ground water

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



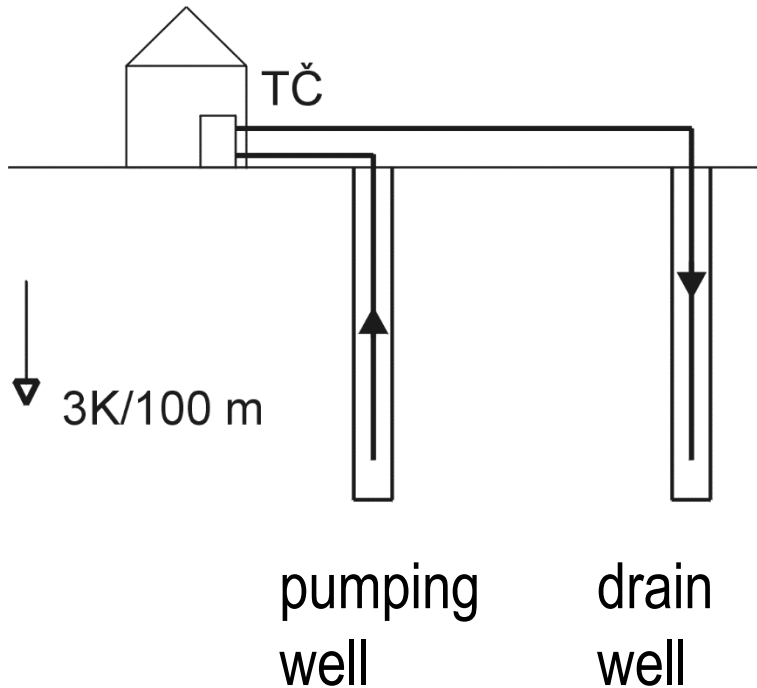


Water

- **warm waste water**: cooling processes
 $t = 20$ to 25 °C
- **surface water**: rivers, lakes
 $t = 0$ to 18 °C , temperature influenced by ambient climate
- **ground water**: wells, boreholes
 $t = 7$ to 10 °C , uniform temperature during the year
- **geothermal water**: deep boreholes
 $t = 10$ to 13 °C , temperature gradient 3 K/100 m
 $t > 25\text{ °C}$, geothermal water



3 Ground water



pumping well (max. 15 m deep:

deeper well means greater pump power)

drain well (15 m horizontally from
pumping well)

cooling by 3 to 4 K

$r Q_k = 10 \text{ kW} \sim 1500 \text{ l/h} (0,4 \text{ kg/s})$

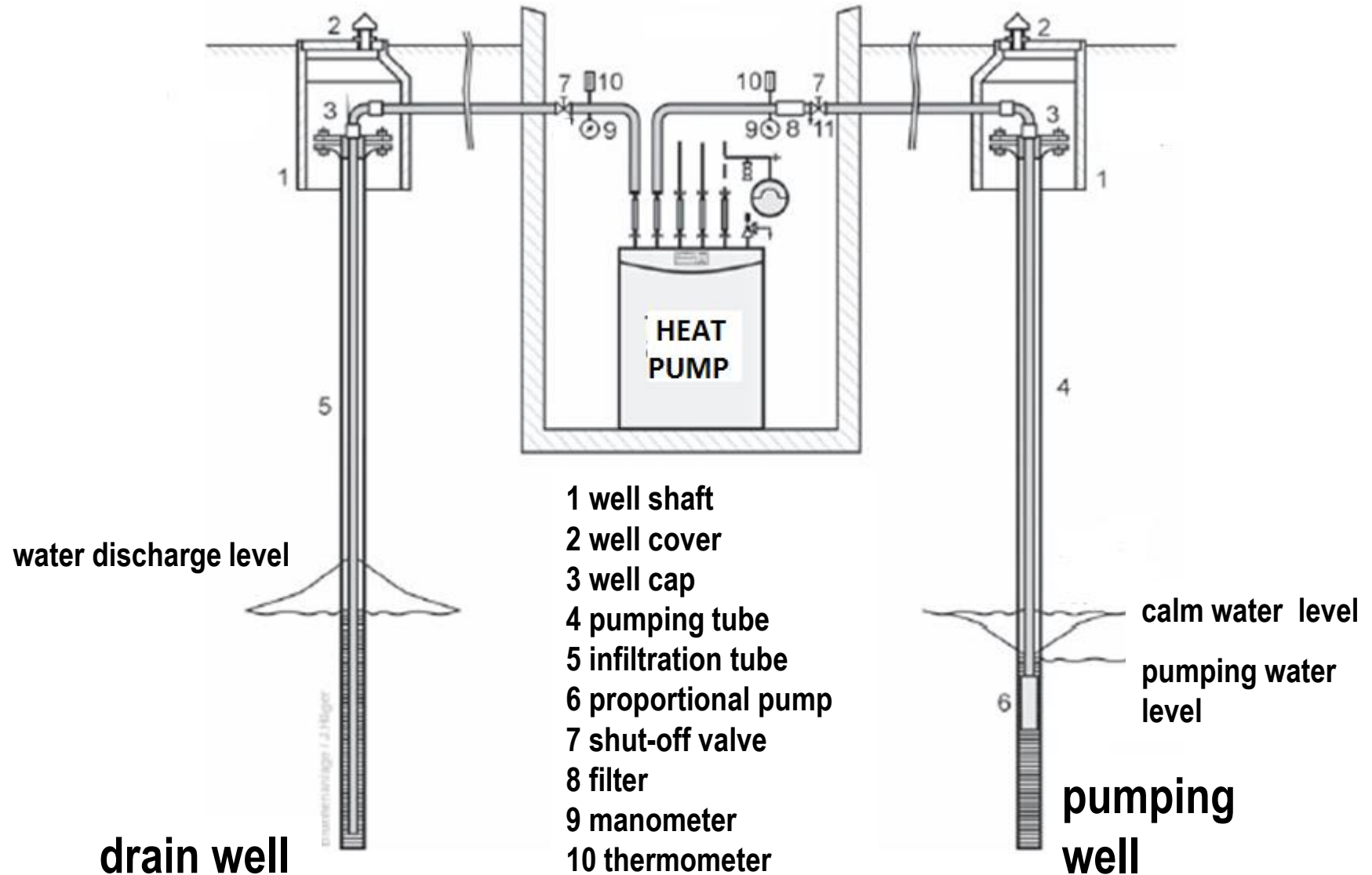
water quantity (constant flowrate)

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

pumping test: 30 days, **or more !**



3 Pumping and drain well





3 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

components / units of measurement	value
organic material (possibility of sedimentation)	none
ph – value	6,5 to 9
electrical conductivity ($\mu\text{S}/\text{cm}$)	50 to 1 000
chloride (mg/litre)	< 300
iron and manganese (mg/litre)	< 1
sulfate (mg/litre)	0 to 150
O ₂ – content (mg/litre)	< 2
chlorine (mg/litre)	0 to 5
nitrate (mg/litre)	0 to 100



3 Example: water well sizing

- heat pump $Q_{HP} = 10 \text{ kW}$, $COP = 4,0$
- cooling power of the heat pump $Q_v = Q_{HP} (1 - 1/COP) = 7.5 \text{ kW}$
- $t_{v1} = 10 \text{ }^\circ\text{C}$, $\Delta t = 4 \text{ K}$
- water flowrate $M_w = 0,45 \text{ kg/s} = 27 \text{ l/min}$

$= 1\,600 \text{ l/hour}$
 $= 39\,000 \text{ l/day}$
 $\dots$



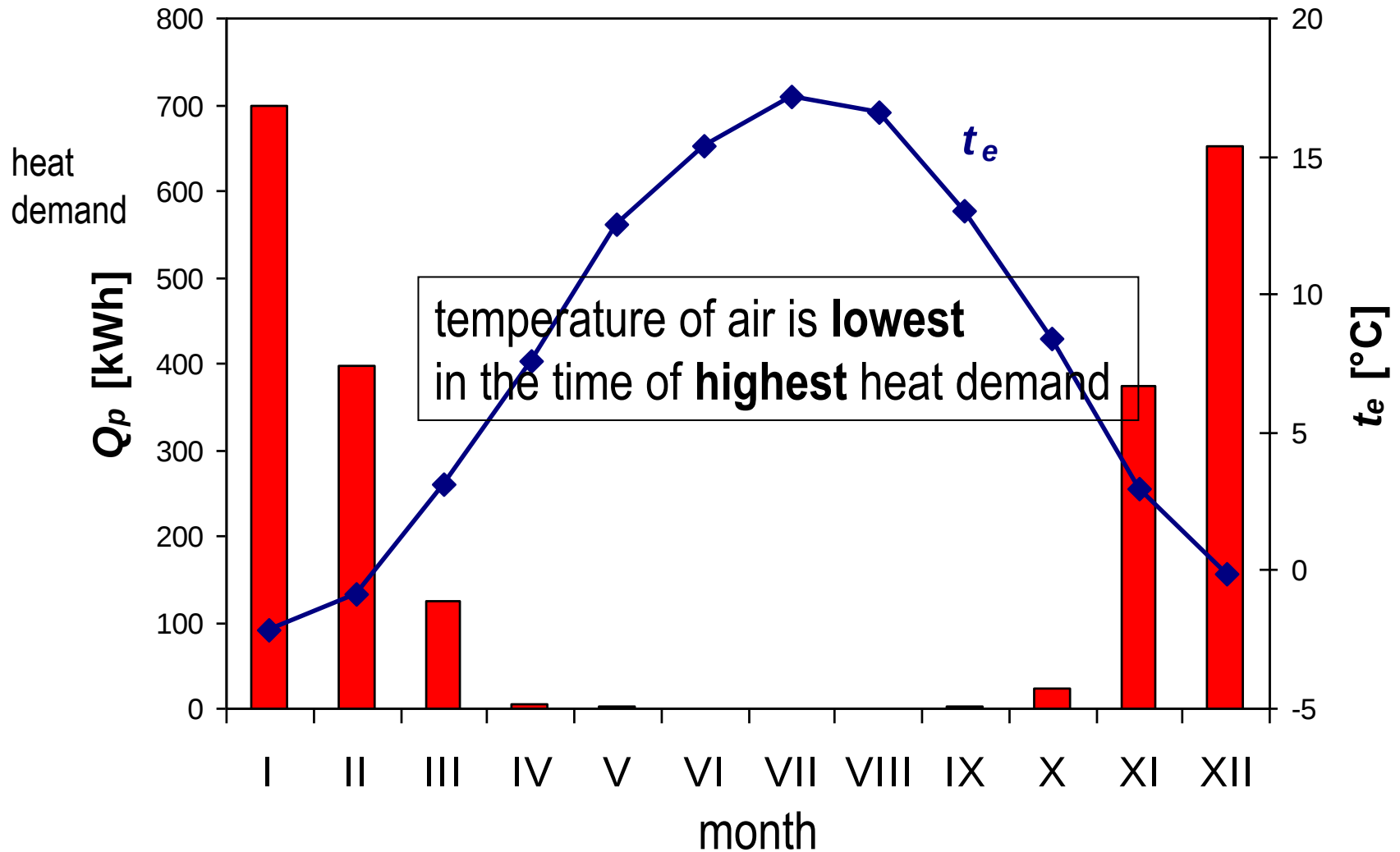
4 Ambient air



- use of ambient heat
- heat power dependent on **climate conditions**
 - winter: $\text{COP} < 3$
 - summer: $\text{COP} > 4$
- mostly **bivalent** operation
- removal of **condensate**
- **noise** (large flowrates)



4 Ambient air





4 Ambient air – energy content, enthalpy

enthalpy

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

c_a specific heat of dry air, v J/(kg.K);

t air temperature, v °C;

l_0 latent heat of water (evaporation), v J/kg;

c_D specific heat of water vapour, v J/(kg.K);

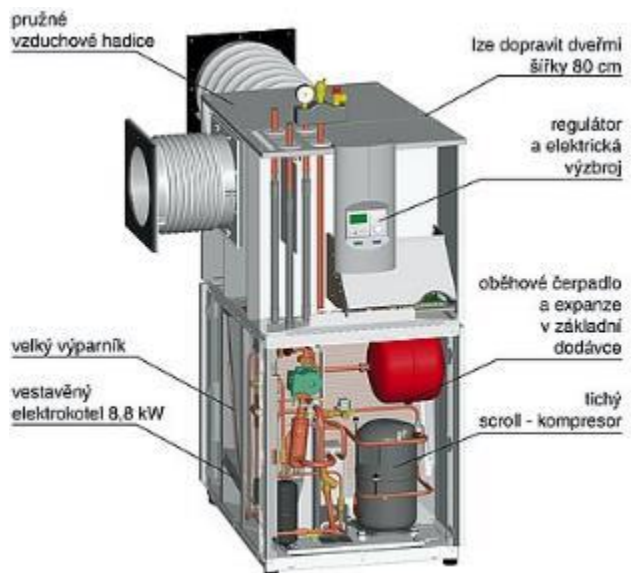
x specific humidity of air, v kg w/kg da.

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



4 Construction

indoor units

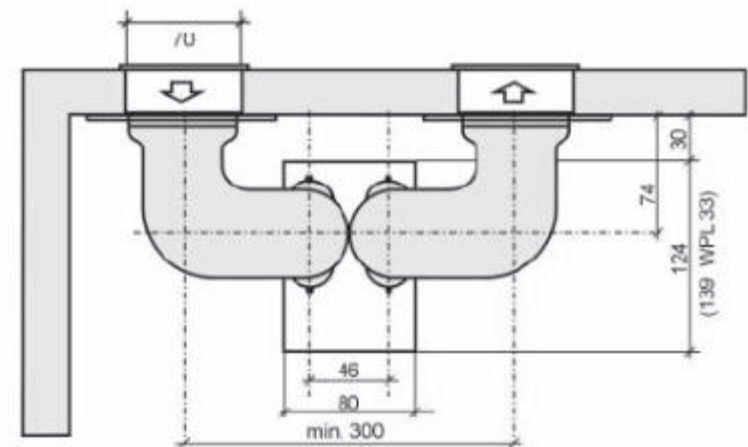
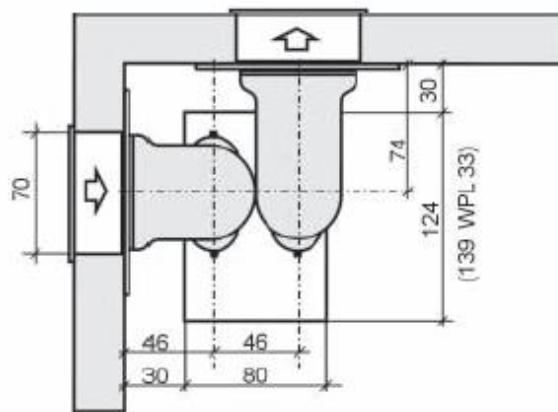
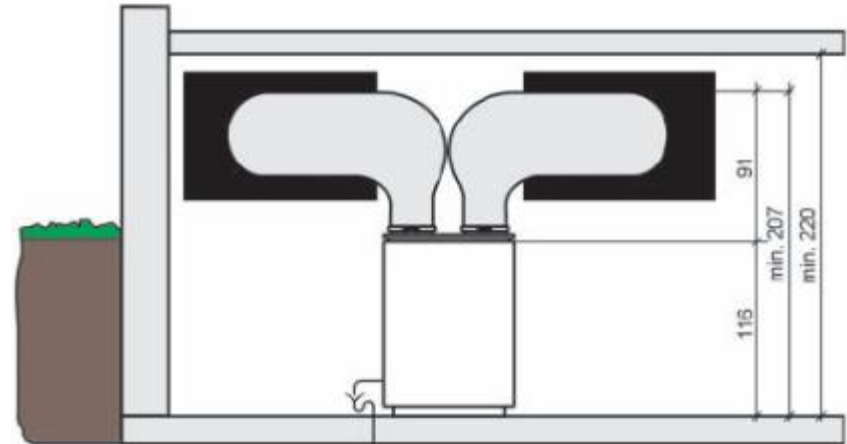
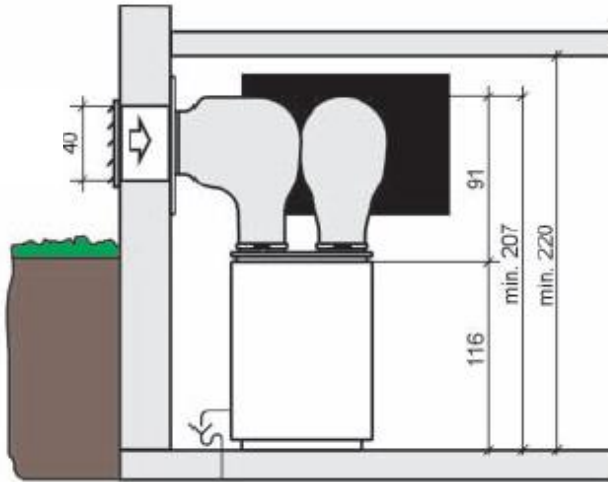


outdoor units





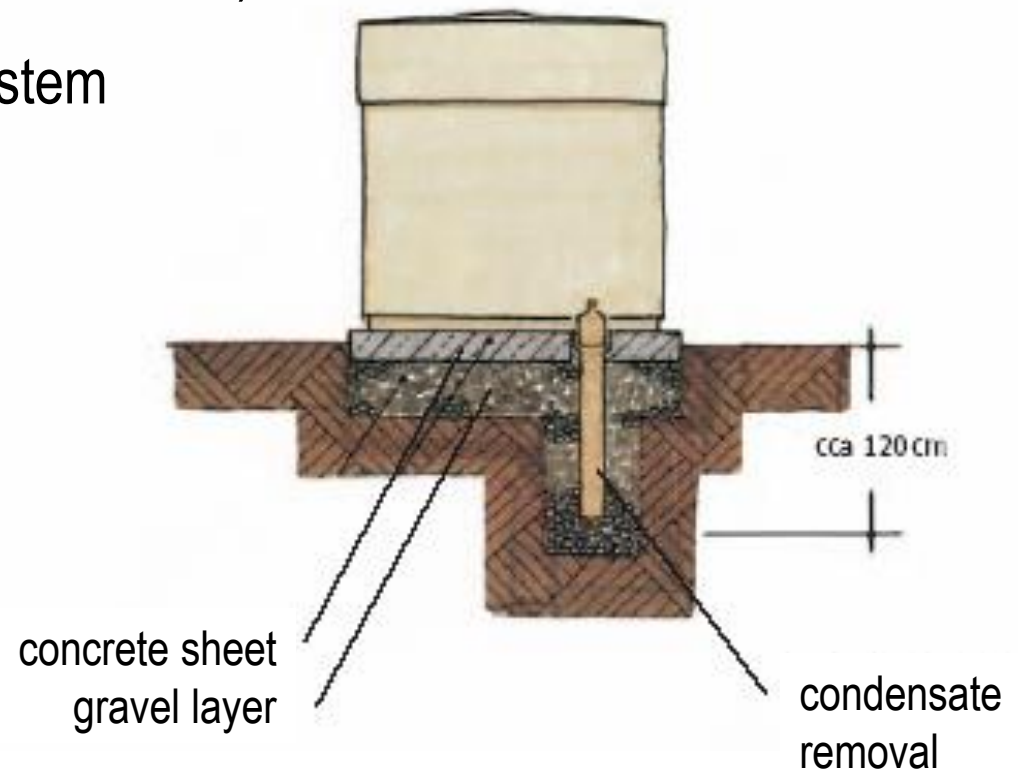
4 Indoor units





4 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





4 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
 - outter heating: electric cables at evaporator
by air above +3 °C, HP is OFF, fan is ON



4 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)

