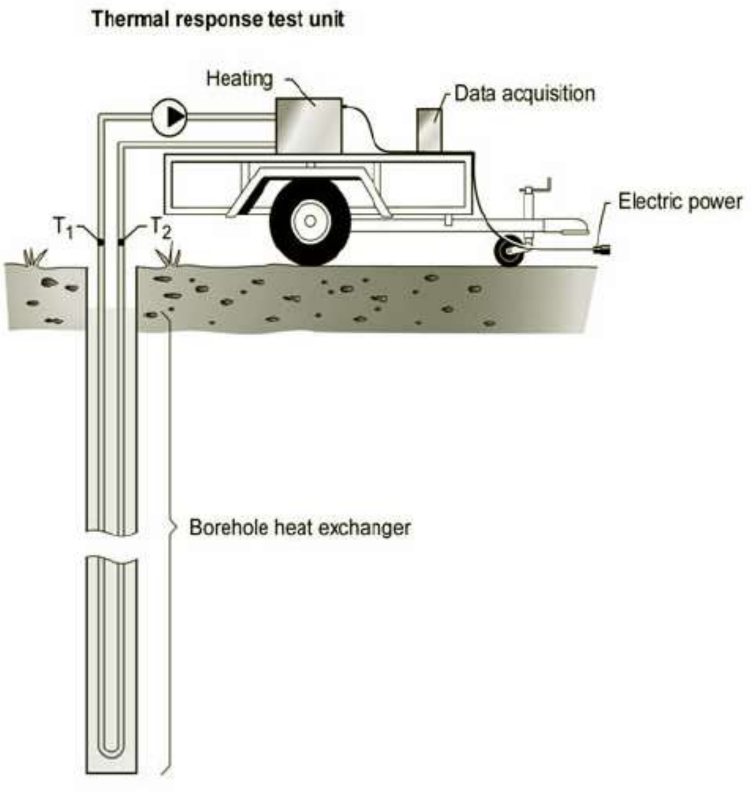
Heat sources for heat pumps

- ground
- water
- air



Natural and waste energy

- **energy from solar radiation = ambient energy**

  - solar radiation: 200 to 1000 W/m^2

  - 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/m^2** (in average)

  heat flow from Earth core **0,04 to 0,06 W/m^2 Only!**

- **temperature**

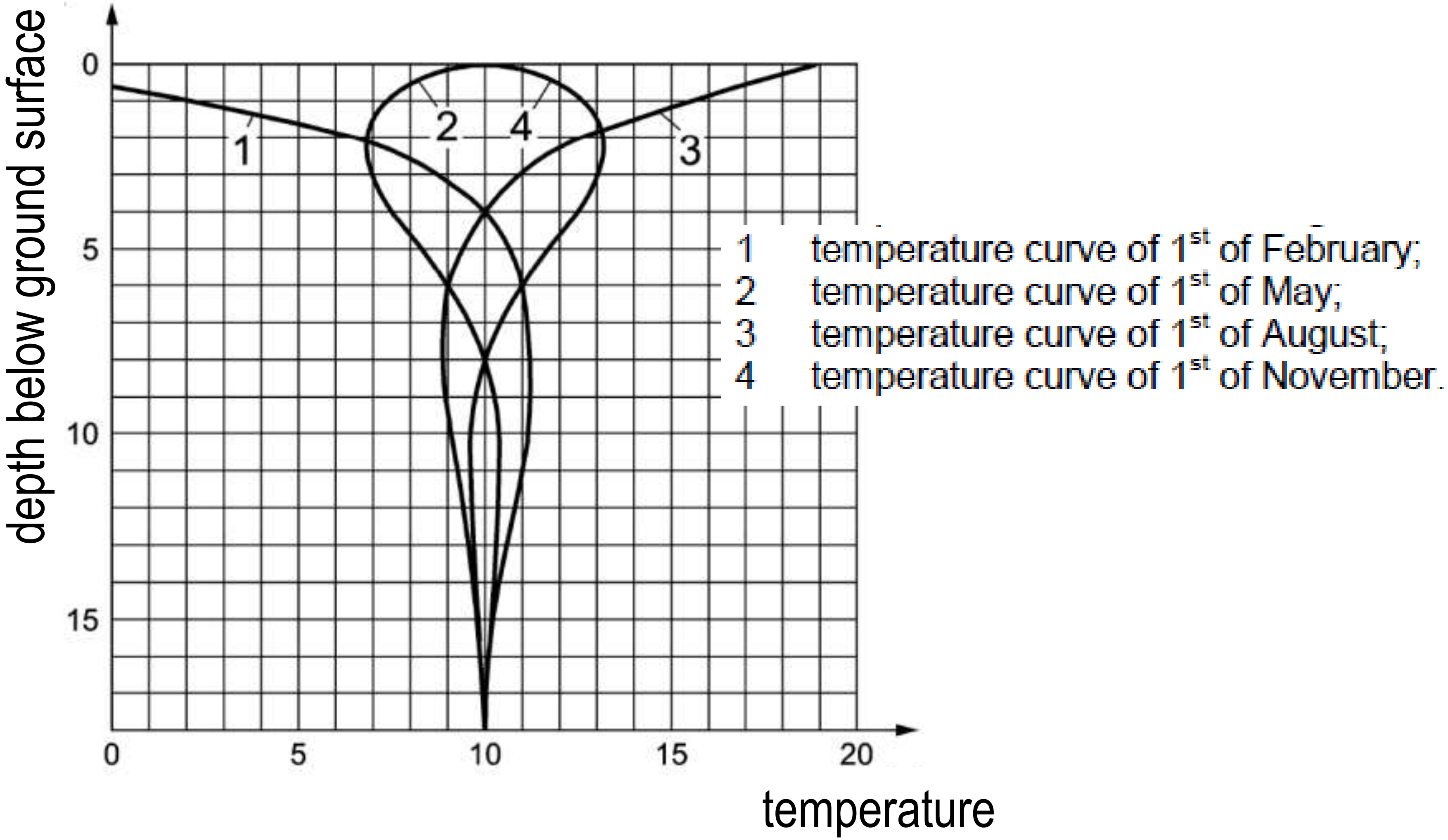
  under 2-5 m stable conditions > 10 °C

  geothermic temperature gradient 3 K/100 m

- **thermal conductivity**

dry sand soil	1,1 W/m.K	average 2 W/m.K
wet granite	3,3 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,

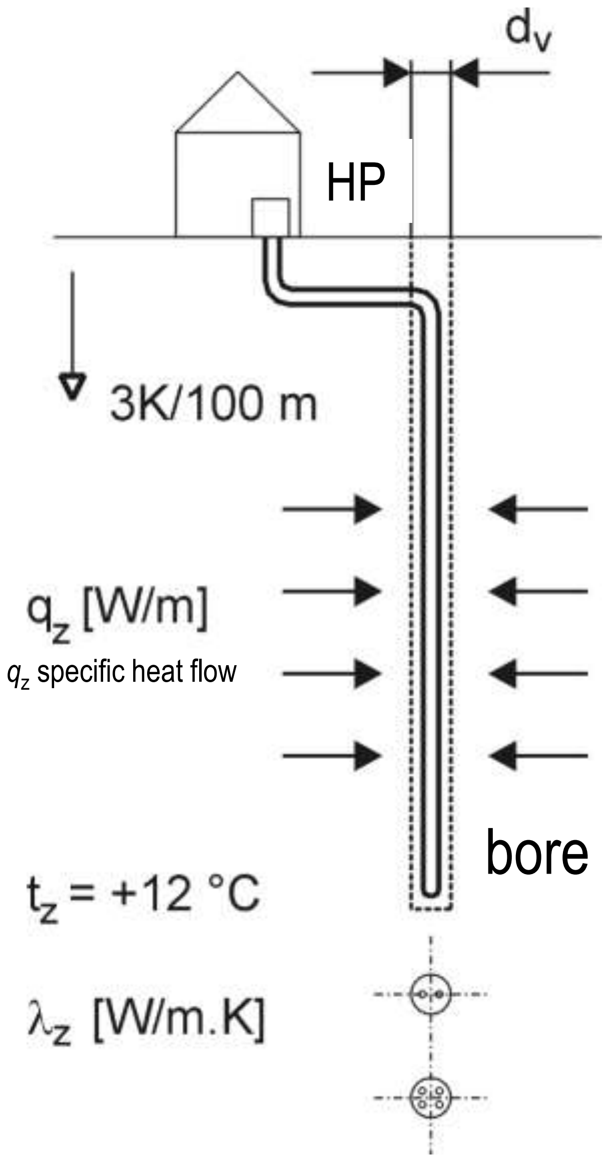
  decrease of heat output and COP, insufficient borehole regeneration

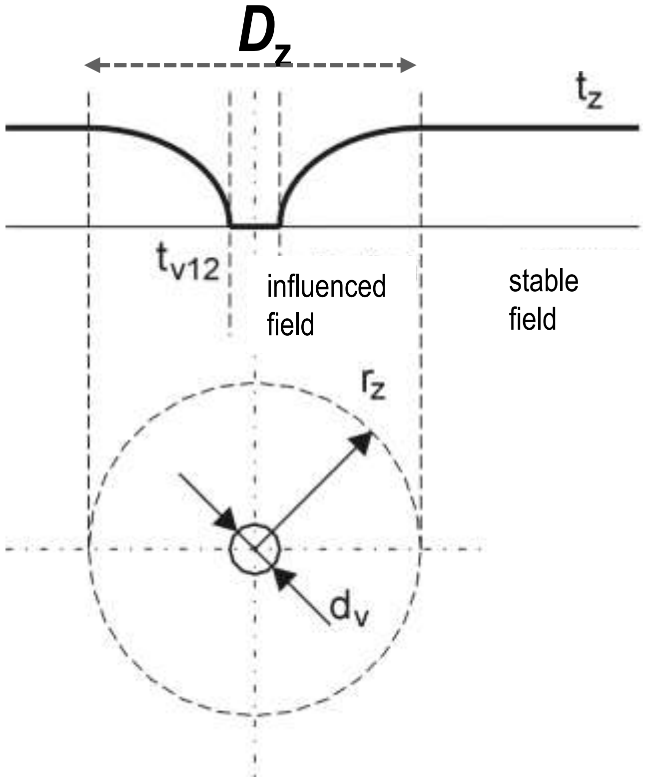
- **ecology**

  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





diameter of influenced field

D_z = 4 to 6 m

diameter of borehole

d_v = 100 to 150 mm

HDPE DN25, DN32

thermal conductivity

λ_z = 1,0 to 3,0 W/m.K

thermal resistance

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

1 Ground vertical - Specific heat flow

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

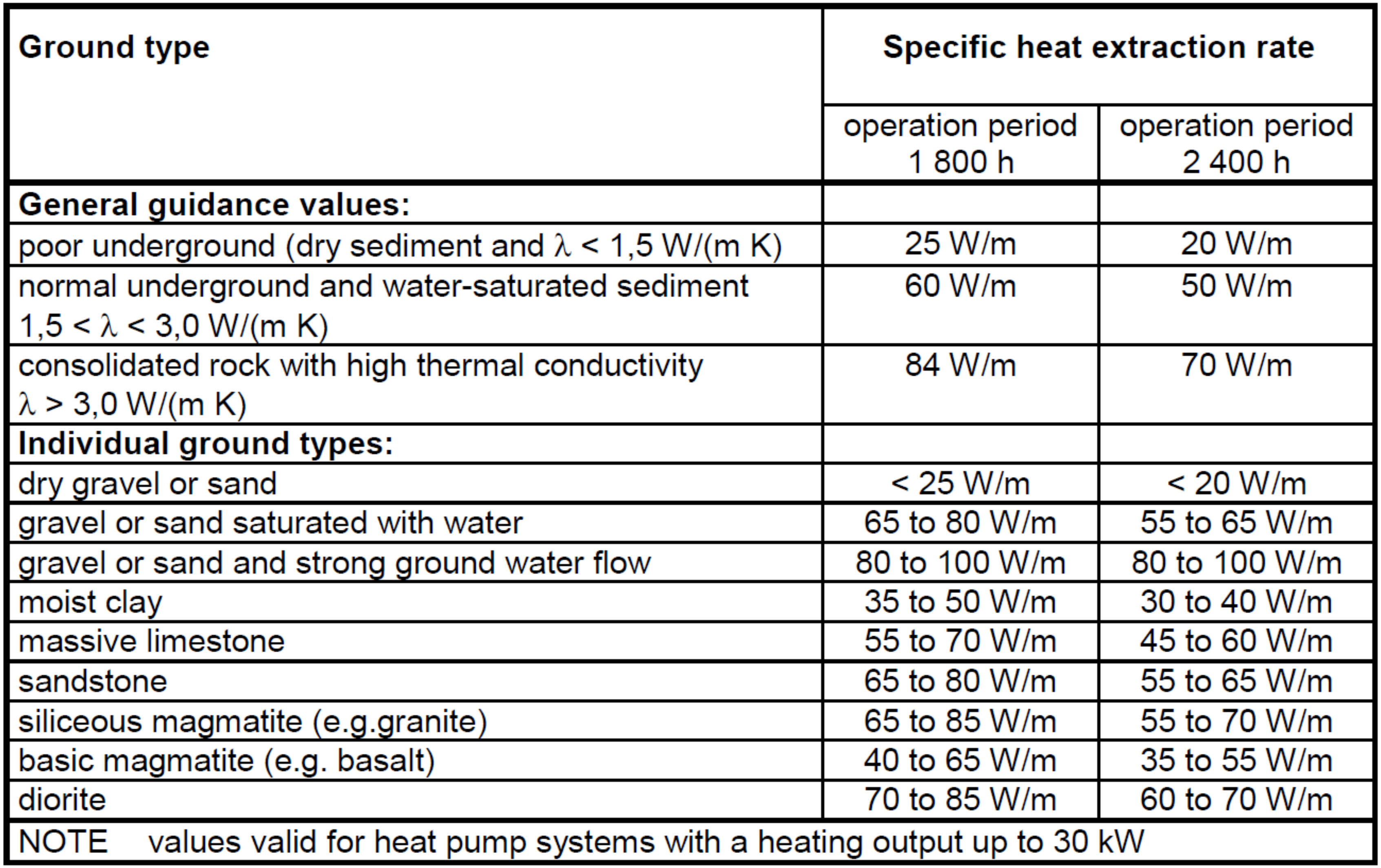
borehole temperature
t_{v12} = around 0 °C (+4 to – 4°C)

ground temperature in stable field
t_z = 12 °C (+3 K/100 m)

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 λ < 1,5 W/(m K)	25 W/m	20 W/m
normal underground and water-saturated sediment 1,5 < λ < 3,0 W/(m K)	60 W/m	50 W/m
consolidated rock with high thermal conductivity λ > 3,0 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 specific heat flow

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

- 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)

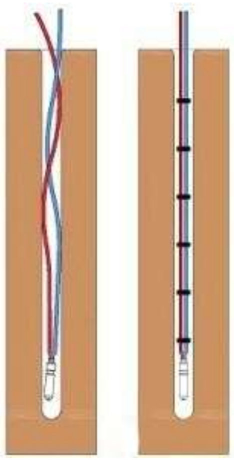
$$\dot{Q}_V = \frac{Q_V}{\Delta\tau_{HP}} \longrightarrow$$

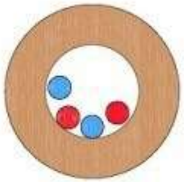
design power for borehole depth calculation

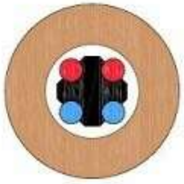
1 Borehole construction

- 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)

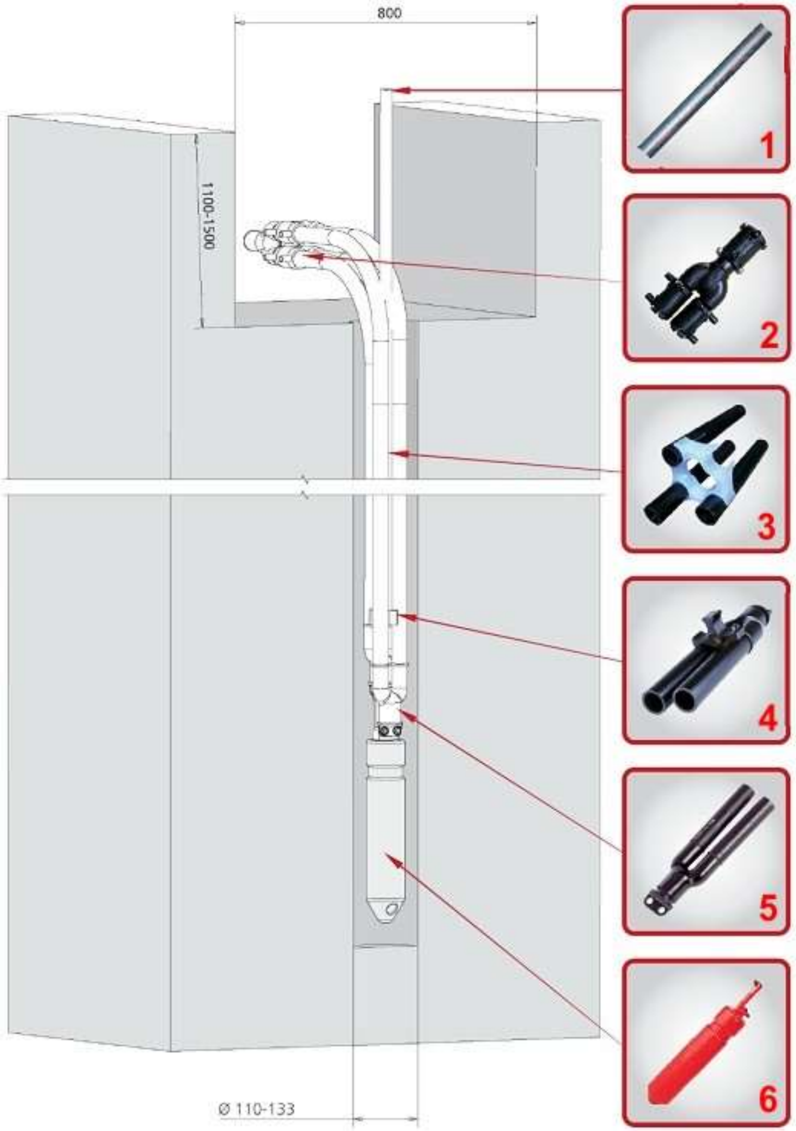
  can't be filled by extracted soil ! = soil is insulator







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 °C, t_i = 20 °C)
- heat pump Q_{HP} = 10 kW, *COP* = 4,0 (at B0/W35)
- heating season, monovalent operation
  - $t_{e,av}$ = 4,3 °C, $t_{i,av}$ = 20 °C, 225 days of heating, correction factor 0,75
- space heating demand Q_{SH} = 19,9 MWh/a

$$Q_{SH} = 225 \cdot 24 \cdot \varepsilon \cdot \dot{Q}_N \cdot \frac{\left(t_{i,avg} - t_{e,avg}\right)}{\left(t_{i,N} - t_{e,N}\right)}$$

- hot water demand Q_{HW} = 3.5 MWh/a

$$Q_{HW} = 365 \cdot \frac{V_{HW,day} \cdot \rho \cdot c \cdot \left(t_{HW} - t_{CW}\right)}{3{,}6 \times 10^{6}}$$

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 kW
- borehole

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

- thermal resistence of ground $R_z = \dfrac{1}{2\pi \cdot \lambda_z} \ln \dfrac{D_z}{d_v}$ = 0,22 mK/W
- specific heat power $q_z = (t_z - t_{v12}) / R_z$ = 54 W/m
- borehole length (depth) $l_v = \dfrac{\dot{Q}_v}{q_z}$ [m] $l_v = 140$ m

1 Example: ground source HP boreholes

- **practical approach (demand approach): heating only 1800 h**
- heat extracted by heat pump $Q_{ex} = Q_{SH}\,(1 - 1/COP)$ = 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

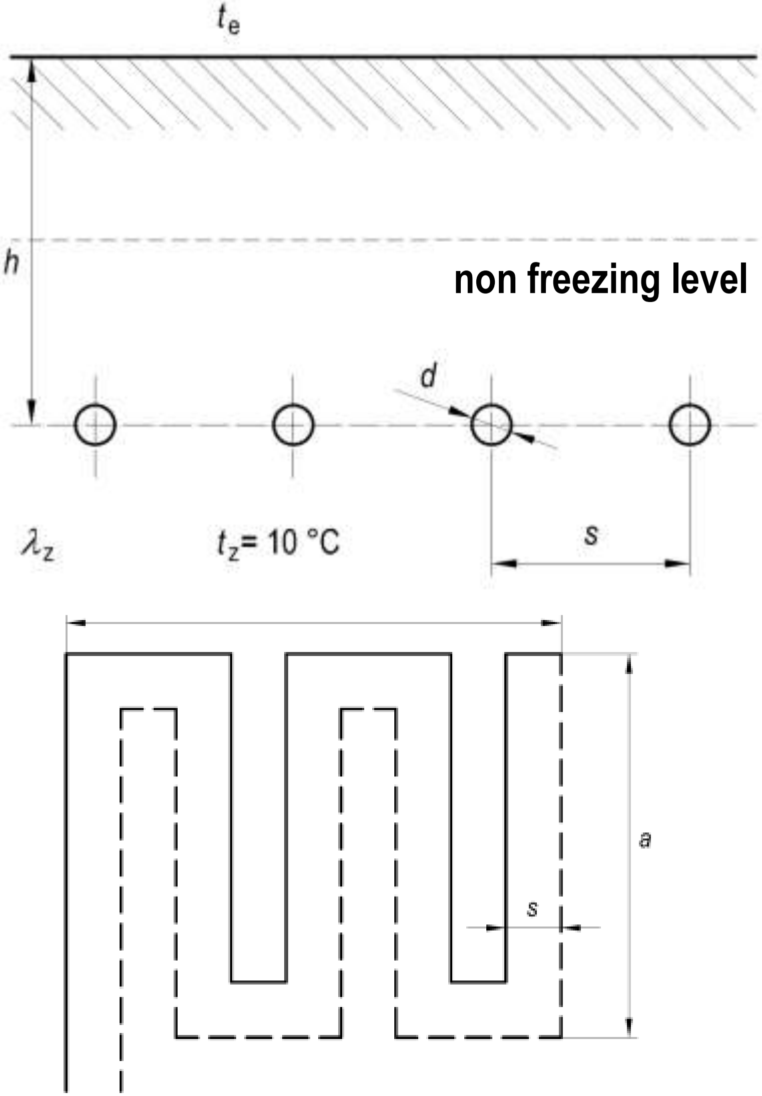
1 Example: ground source HP boreholes

- **practical approach (demand approach): SH+HW 2400 h**
- heat extracted $Q_{ex} = (Q_{SH} + Q_{HW})*(1 - 1/COP)$ = 17,5 MWh
- average cooling power of heat pump $Q_v = Q_{ex} / 2400$ h = 7.3 kW
- tables: average soil with $1{,}5 < \lambda_z < 3{,}0$ $q_z = 50$ W/m (2400 h)
- borehole length (depth) $l_v = 146$ 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* = min. 0,8 m to 1,1 m**

HDPE pipes, diameter 25 – 40 mm

thermal conductivity
λ_z = 1,0 to 3,0 W/m.K

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

2 Horizontal ground heat exchangers

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

temperature in pipes

t_{v12} = around 0 °C (+4 to – 4°C)

temperature of ground

t_z = 10 °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

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

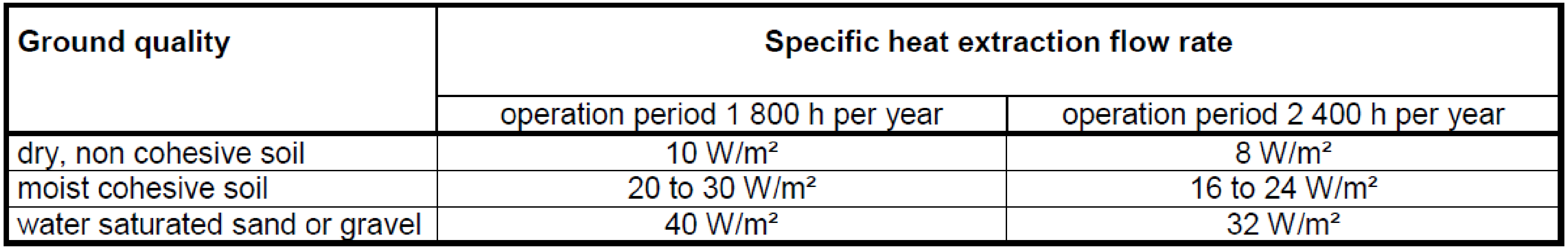
$$S = \frac{\dot{Q}_V \cdot s}{q_{z,l}} = \frac{\dot{Q}_V}{q_{z,A}} \quad [\mathrm{m}^2]$$

for a distance *s* = 1 m

$q_{z,l}$ becomes $q_{z,A}$

Soil type	**specific heat flow** $q_{z,A}$ **[W/m²]**
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/m²	8 W/m²
moist cohesive soil	20 to 30 W/m²	16 to 24 W/m²
water saturated sand or gravel	40 W/m²	32 W/m²

annual extracted **energy** should be between 50 and 70 **kWh/m^2**

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

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

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

$q_{z,A}$ 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)

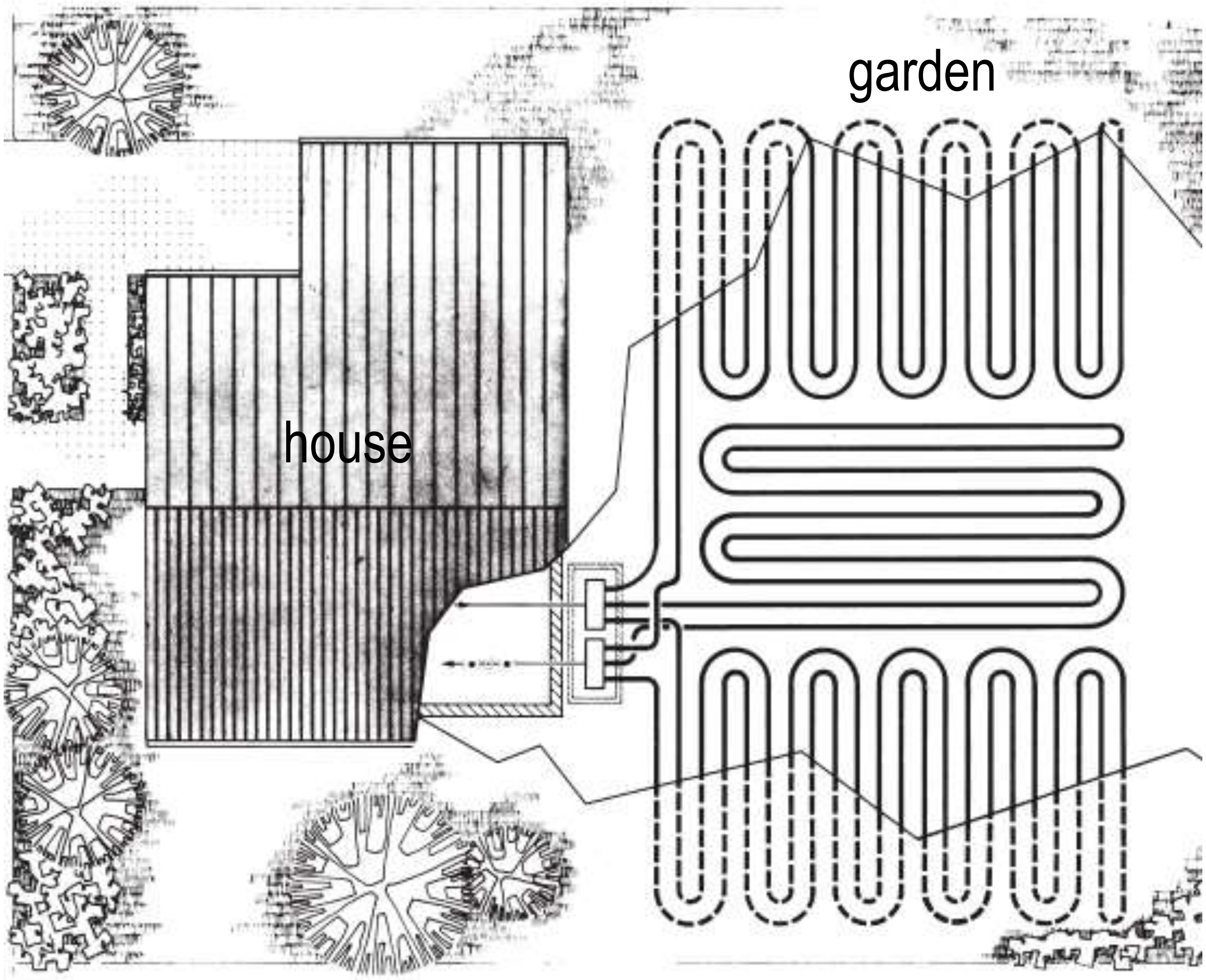
$$\dot{Q}_V = \frac{Q_V}{\Delta\tau_{HP}} \longrightarrow$$

design power for ground HX area calculation

2 Construction of ground HX

- length of cirucits 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 of asphalt layers) for regeneration
- mind the roots!
- make documentation of piping location

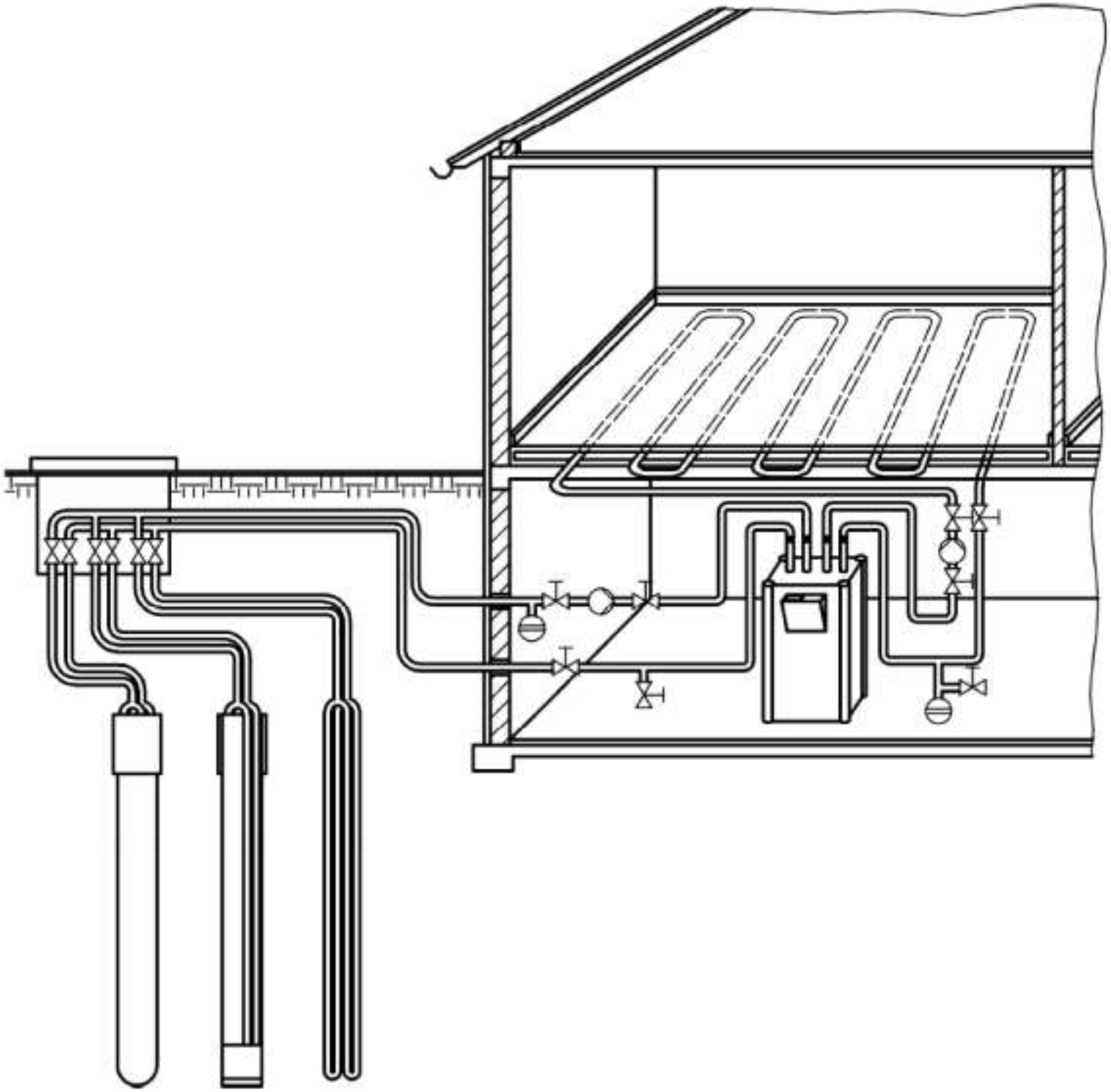
2 Construction of ground HX



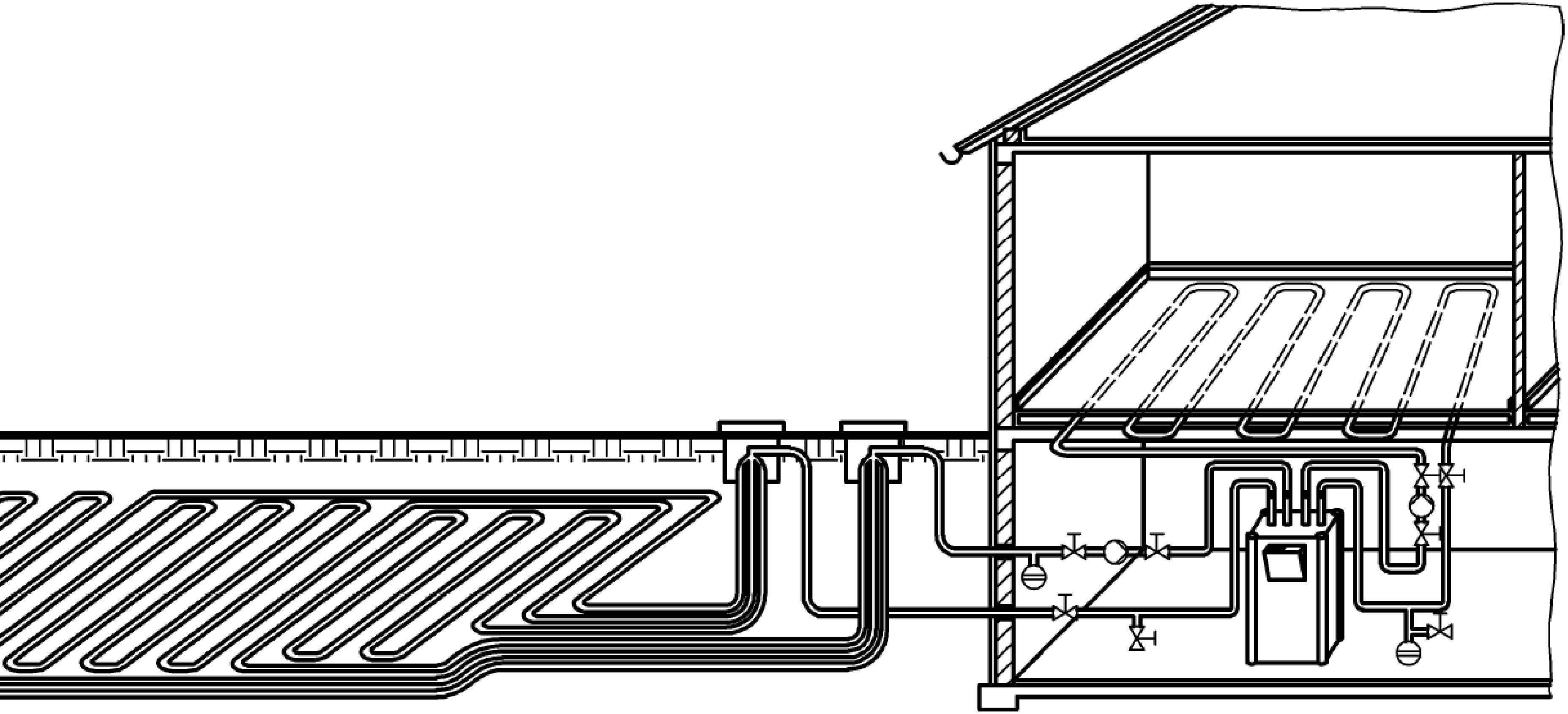
2 Connection to house (borehole, HX)

- brines (t_F < -10°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



2 Ground HX connection to house



2 Distributor

distributor located outside:

- platic casing
- concrete casing

3 Ground water

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

Water

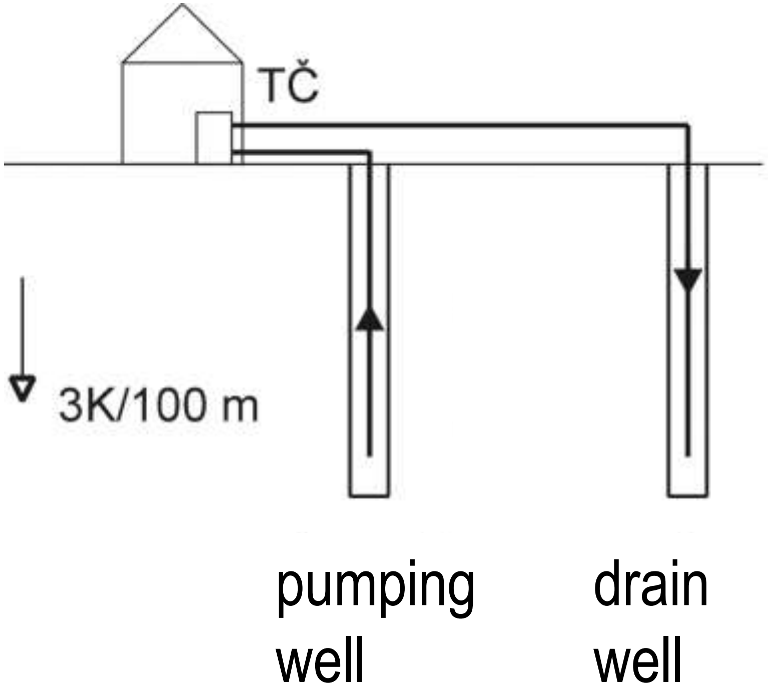
- warm waste water: cooling processes
  t = 20 to 25 °C

- surface water: rivers, lakes
  t = 0 to 18 °C, temperature infulenced 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 °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)

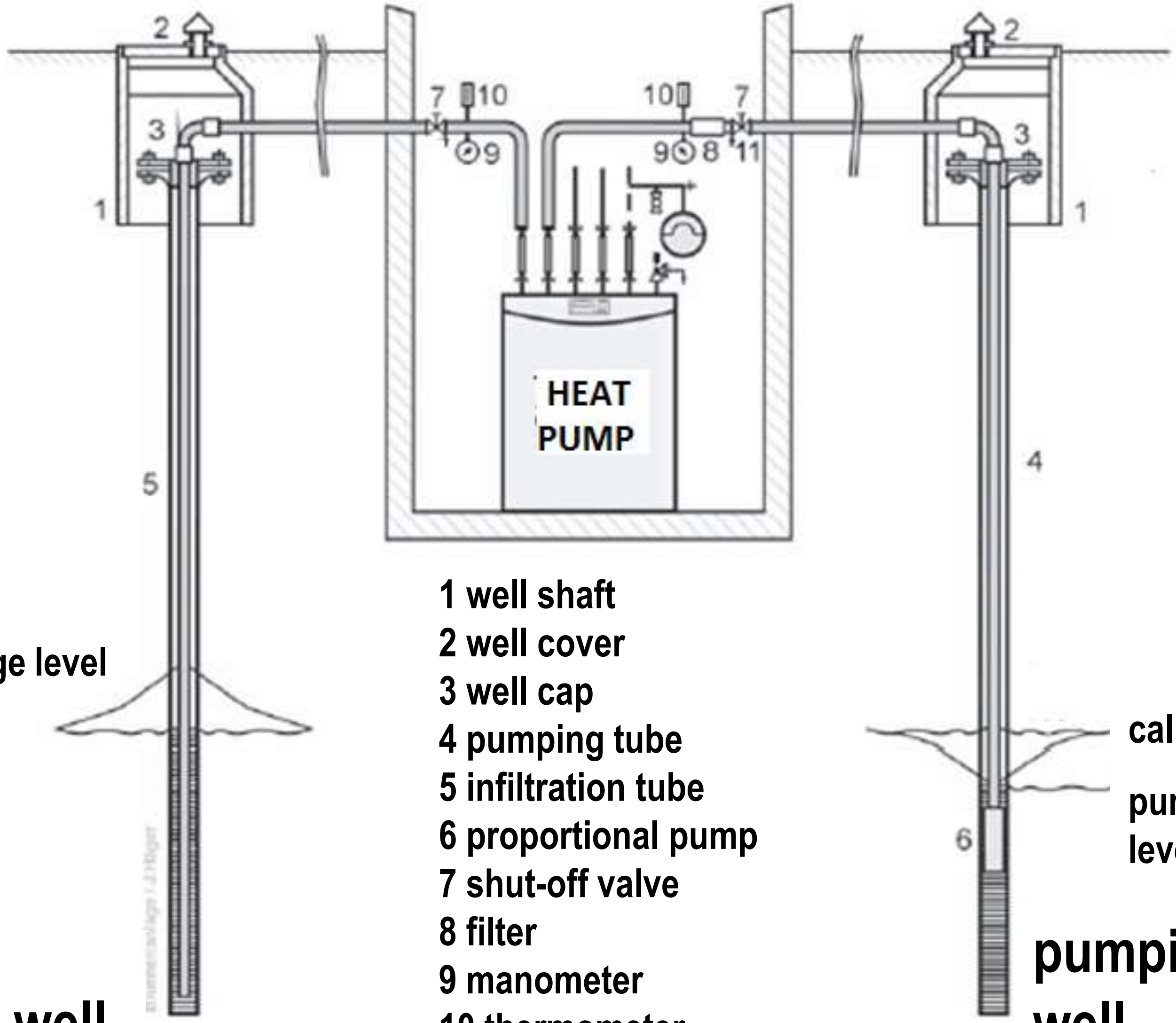
cooling by 3 to 4 K

r Q_k = 10 kW ~ 1500 l/h (0,4 kg/s)

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

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

3 Pumping and drain well



water discharge level

calm water level

pumping water level

1 well shaft
2 well cover
3 well cap
4 pumping tube
5 infiltration tube
6 proportional pump
7 shut-off valve
8 filter
9 manometer
10 thermometer

drain well

pumping well

3 Water quality

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

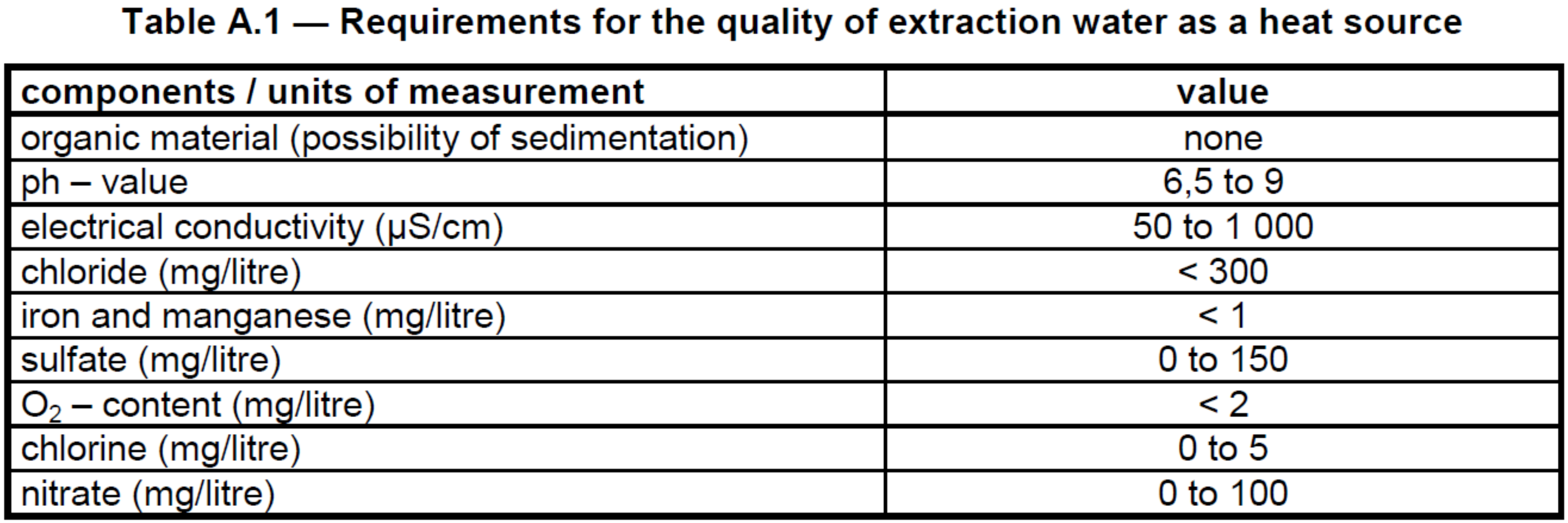


Table A.1 — Requirements for the quality of extraction water as a heat source

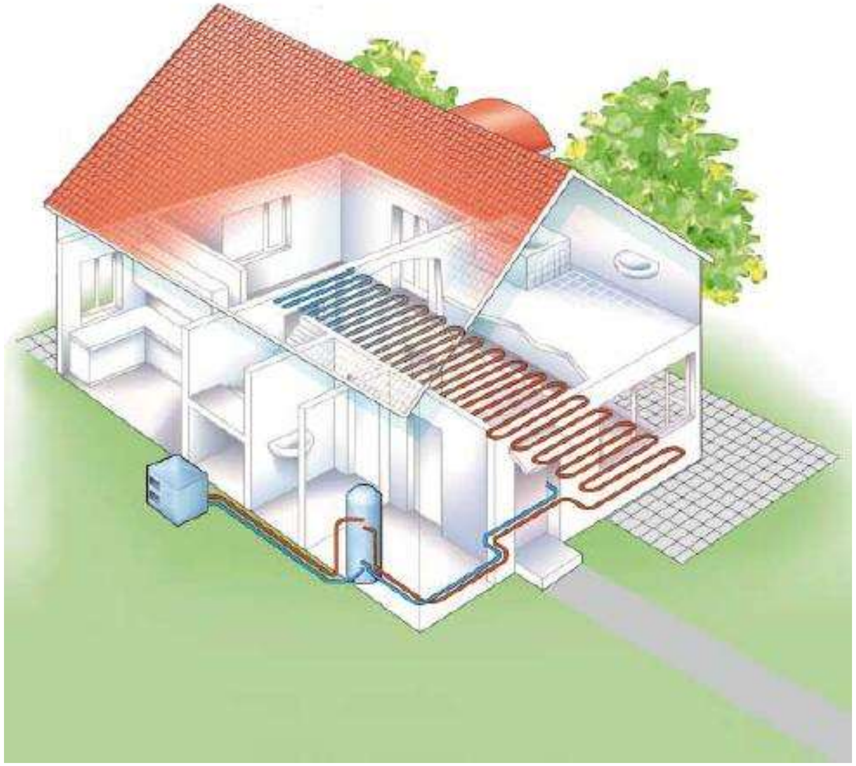
components / units of measurement	**value**
organic material (possibility of sedimentation)	none
ph – value	6,5 to 9
electrical conductivity (µS/cm)	50 to 1 000
chloride (mg/litre)	< 300
iron and manganese (mg/litre)	< 1
sulfate (mg/litre)	0 to 150
O_2 – content (mg/litre)	< 2
chlorine (mg/litre)	0 to 5
nitrate (mg/litre)	0 to 100

3 Example: water well sizing

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

= 1 600 l/hour
= 39 000 l/day
…

4 Ambient air

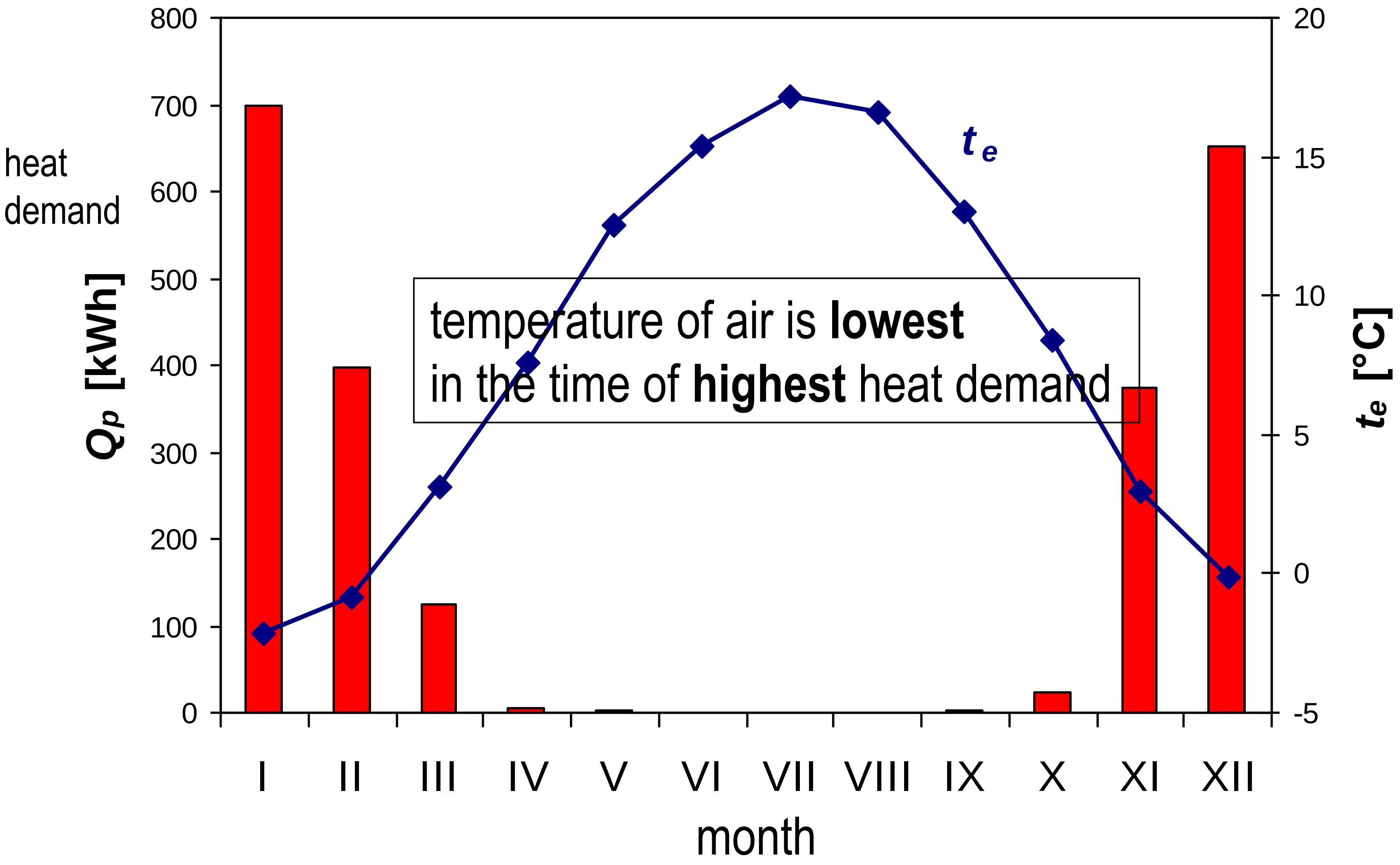


- use of ambient heat
- heat power dependent on **climate conditions**

  winter: COP < 3

  summer: COP > 4
- mostly **bivalent** operation
- removal of **condensate**
- **noise** (large flowrates)

4 Ambient air



temperature of air is **lowest**
in the time of **highest** heat demand

4 Ambient air – energy content, enthalpy

enthalpy

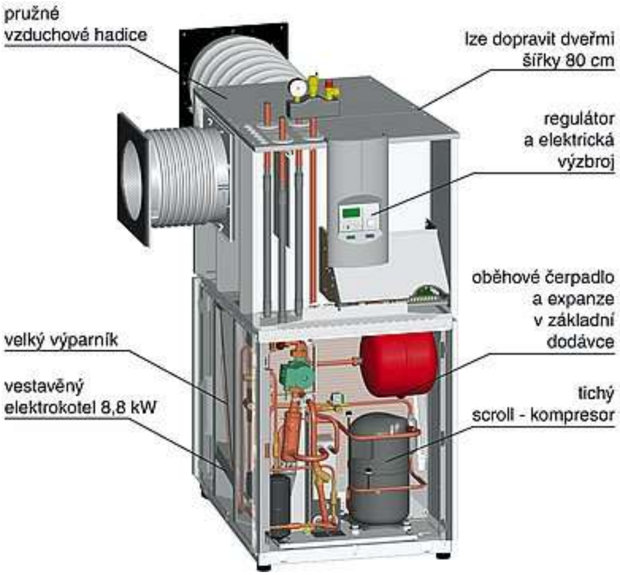
$$h = c_a \cdot t + \left(l_0 + c_D \cdot t\right) \cdot x = 1010 \cdot t + \left(2{,}5.10^6 + 1840 \cdot t\right) \cdot x$$

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.

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

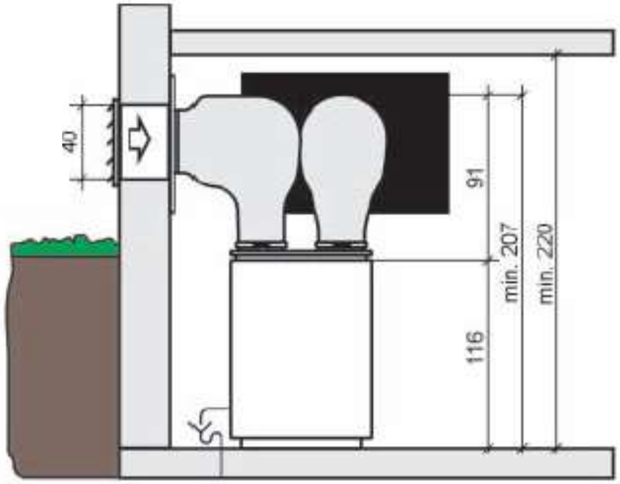
4 Construction

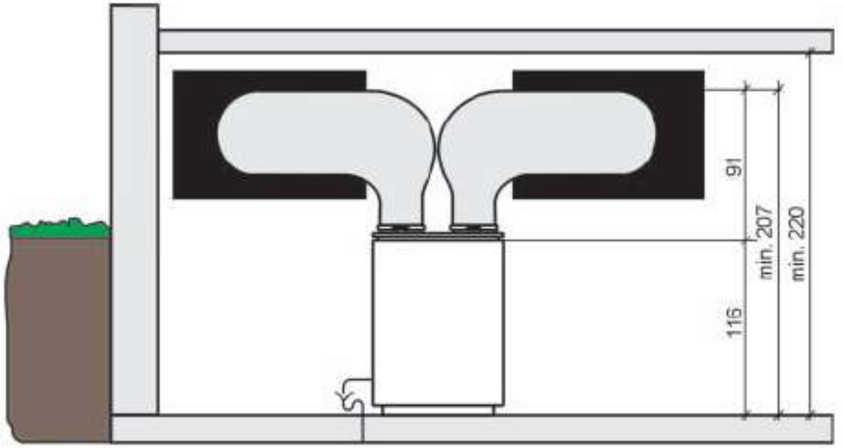
indoor units

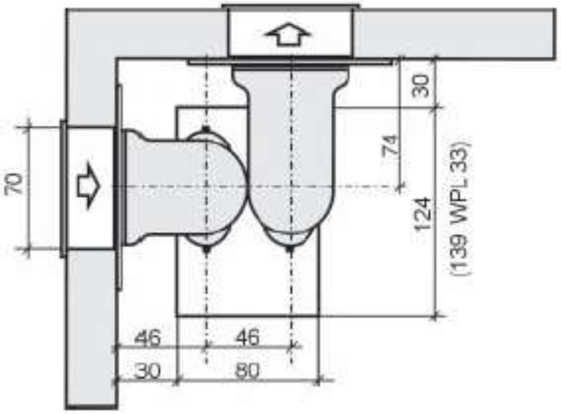


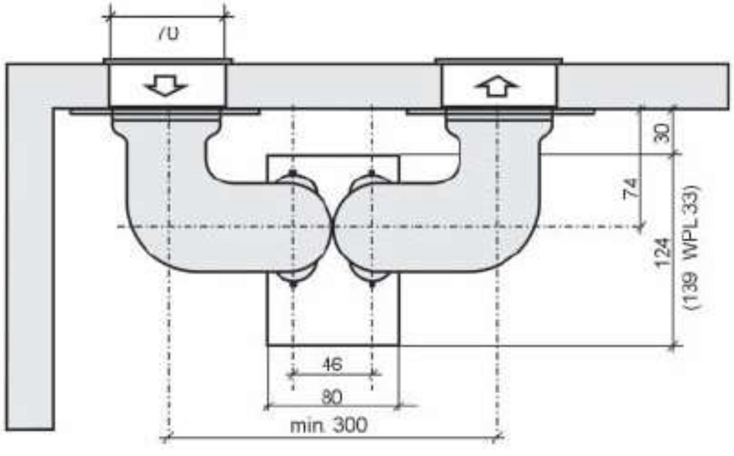
outdoor units

4 Indoor units





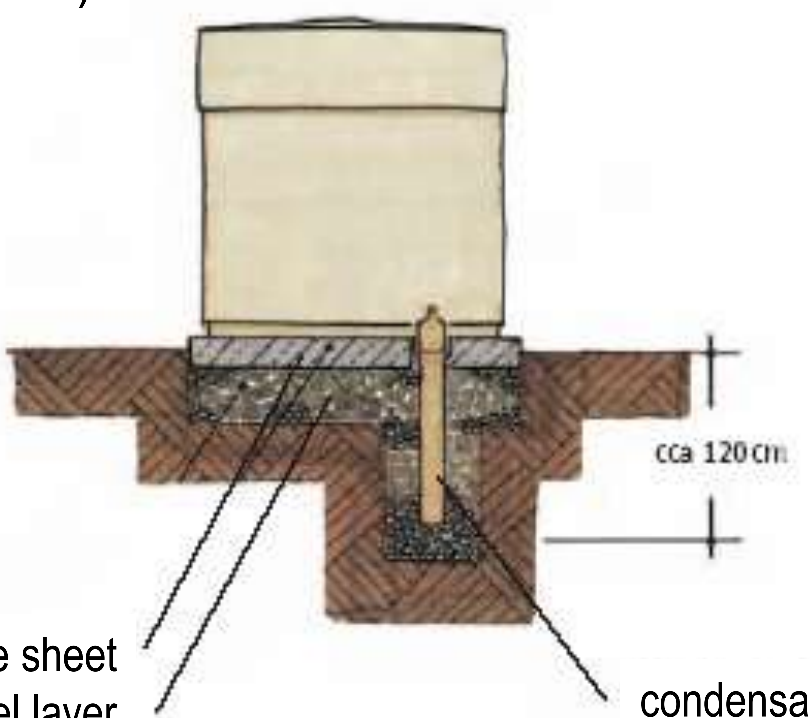




4 Outdoor units

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 refection surfaces
  - noise barriers
    (walls, green fences)
  - protection by distance
  - antivibrating layers under HP
  - noise reducers for piping (water, air)