HEAT PUMPS CALCULATION

Didactic materials

Calculation formulas

- Specific evaporation capacity

$$q_0 = h_1 - h_4 \quad \text{kJ/kg}$$

- Specific condenser output

$$q_c = h_2 - h_3 \quad \text{kJ/kg}$$

- Specific compressor work

$$w_V = h_2 - h_1 \quad \text{kJ/kg}$$

h_1, h_2, h_3, h_4- representative points enthalpy.

Calculation formulas

- Refrigerant mass flow rate

$$m_R = Q_0/q_0 = Q_C/q_C = P_v/w_v \quad \text{kg/s}$$

- Condenser output

$$Q_C = Q_0 + P_v \quad \text{kW}$$

$$Q_C = q_C \cdot m_R = (h_2 - h_3) \cdot m_R \quad \text{kW}$$

Calculation formulas

- Compressor output

$$C = w_v \cdot m_R = P_v \cdot m_R \ \mathrm{kW}$$

- Evaporation output

$$Q_0 = q_0 \cdot m_R = (h_1 - h_4) \cdot m_R \ \mathrm{kW}$$

Calculation formulas

- Coefficient of performance

$$\eta = Q_C/P_v = (h_2 - h_3)/(h_2 - h_1)$$

- Pressure ratio at compressor

$$\Pi = P_C/P_0$$

Calculation and Design of the Heat Pumps

Step 1: Heat Losses Calculations

- Energy required for heating Q_h kW
- Energy required for water heating Q_w kW
- Energy required for ventilation Q_v kW
- Total thermal energy demand for example:

$$Q_\Sigma = Q_h + Q_w + Q_v = Q_0 = 13\ \text{kW}$$

Step 2: Size the Heat Pump

- Total energy demand is equal to condenser output

$$Q_\Sigma = Q_C = 13 \text{ kW}$$

- We need to produce 13 kW to meet the heating demand
- We need to check the product specification sheet to find a heat pump that meets heating demand.

Step 3: Size the Loop Field

- According to our example, we choose a (*Qc)*12 kW heat pump with a (*Pv)* 2 kW compressor motor.
- The quantity of heat supplied from the surrounding environment is equal to the evaporation output.

$$Q_0 = Q_c - P_v \quad \text{kW}$$

$$Q_0 = 12 - 2 = 10\ \text{kW} = 1000\ \text{W}$$

Heat from surroundings

Geothermal

- Ground-source transferring heat between your house and the ground.
- Water-source transferring heat between your house and a nearby water source.
- Air-source heat pump, which transfers heat between your house and the outside air.

Horizontal collectors calculation

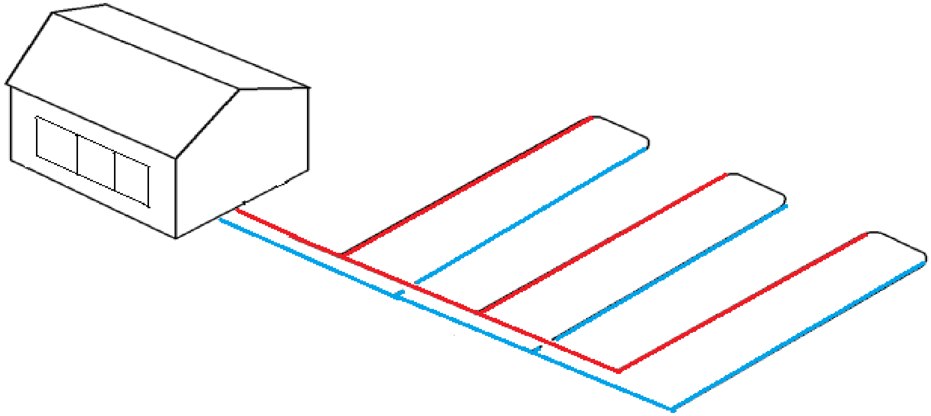

Fig.15. Ground horizontal collector

- This type of installation is generally most cost-effective,where sufficient land is available.Fig15.
- The most common layouts two pipes placed side-by-side at 1.2-1.5 m in the ground in a 0.6m wide trench.
- Horizontal collectors are 0% – 30% cheaper than boreholes as specialist equipment is not required.

- The quantity of heat, the required area of the plot depends largely on the soil specific heat capacity.
- Thermal properties of soil - specific heat and thermal conductivity, are highly dependent on soil composition and condition. The main considerations that affects is humidity the ground water the soil mineral components (eg., Quartz and feldspar) and soil porosity.

Soil specific heat capacity

- Dry sand soil q_E = 10-15 W/m2
- Wet sandy soil q_E = 15-20 W/m2
- Dry clay soil q_E = 20-25 W/m2
- Wet clay soil q_E = 25-30 W/m2
- Soil groundwater q_E = 30-35 W/m2

Horizontal loop calculation

- for example, by selecting the heat capacity of soil $q_E = 25\ W/m^2$
- We calculate the area of the soil.

$$F = Q_0/q_E = 10000/25 = 400\ m^2$$

- The required heat removal pipe length is calculated by estimating the distance between the tube and selecting a diameter of the pipe.

plastic pipe - Ø20 approx (3m pipe to m2 of soil)

plastic pipe - Ø25 approx (2m pipe to m2 of soil)

plastic pipe – Ø32 approx (1,5m pipe to m2 of soil)

In our example F=400 m2 pipe loop length 100 m

- pipe - Ø20, 400·3 =1200m 1200/100 = 12 loop
- pipe - Ø25, 400·2 =800m 800/100 = 8 loop
- pipe – Ø32, 400·1,5=600m 600/100 = 6 loop

- From the calculation, geothermal contour can be formed of different diameters pipes, but the optimal Ø32. You need only 600 meters, the lower the cost of ground works.

Glycolic volume calculation

- Glycolic quantity per meter of pipe:
- plastic pipe - Ø20x2 approx 0,201 ltr/m
- plastic pipe - Ø25x2,3 approx 0,327 ltr/m
- plastic pipe – Ø32x3 approx 0,531 ltr/m
- for example pipe Ø32x3 600m ·

$$V=600 \cdot 0{,}531=318{,}6 \text{ ltr}$$

Double U-tube ground heat exchangers calculation

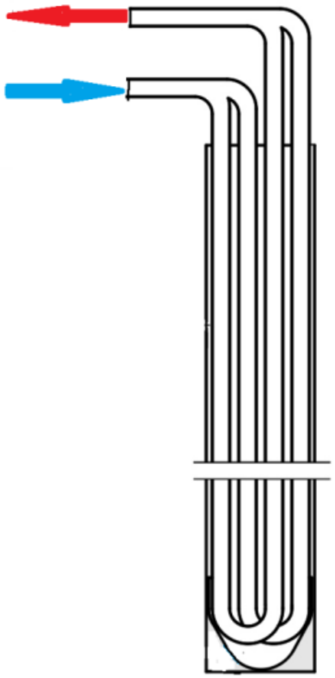

Fig.16. Ground vertical collector

- Vertical closed loops are preferred in many situations. Most large commercial buildings and schools use vertical loops because the land area required for horizontal loops would be prohibitive.

- During a vertical loop field installation a series of holes are drilled, each between 10-150 m. deep.

- Experience shows that the heat flow vary from

  20 W/m to 100 W/m.
- Underground specific heat extraction depend on soil composition thermal conductivity.
- Between the two vertical geothermal probes distance must be 5 m, when the probe 50 m.

Double U-tube underground specific heat extraction

Underground	Conductivity	Specific heat extraction q_E
Poor underground (dry sediment)	Λ<1,5 W/(m·K)	20 W/m
Normal rocky underground and water saturated sediment	Λ<1,5-3,0 W/(m·K)	50 W/m
Consolidated rock with high thermal conductivity	Λ> 3,0 W/(m·K)	70 W/m

- In our example, Q_0 = 12 - 2 =10 kW=10000 W
- We declare that specific heat extraction is q_E50W/m
- The length of the probe will be:

$$L = Q_0/q_E = 10000/50 = 200\text{m}$$

- The selected probe plastic pipe – Ø32x3 approx 0,531 ltr/m

Glycolic volume calculation

- When the probes more than one requires a larger cross-section supply collector.
- Probe double U-tube Ø32 - 0,531 ltr/m, L=200m

$$V=4\cdot L\cdot 0{,}531=4\cdot 200\cdot 0{,}531= 424.8 \text{ ltr}$$

Heat pump (water-water) calculation

Heat pumps (water-water) uses groundwater heat.

- Groundwater temperature constant during the year, from 7 to 12 ° C, so the heat pump to achieve good results.
- It is recommended to keep at least five meters from the supply and return water pipes into the ground.
- Absorption drilling place can be oriented in the direction of flow of the groundwater below the ground water level.

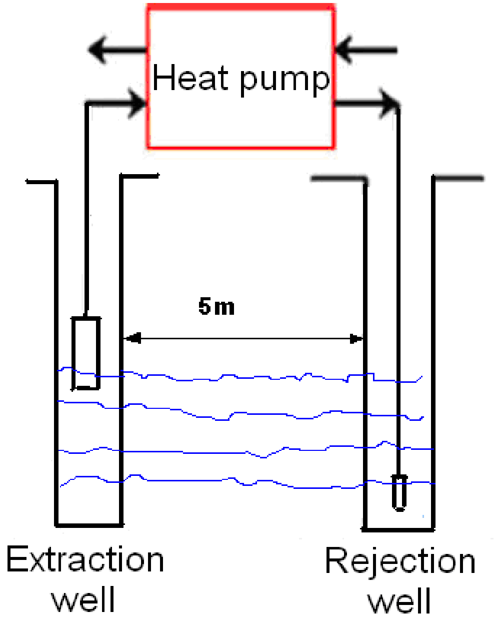

Fig.17. Ground-water heat pump

- Groundwater pump supply water to the heat pump evaporator and transfers its heat.
- Groundwater, depending on the heat exchanger design, is cooled to 5°C difference, the quality of the water remains unchanged.

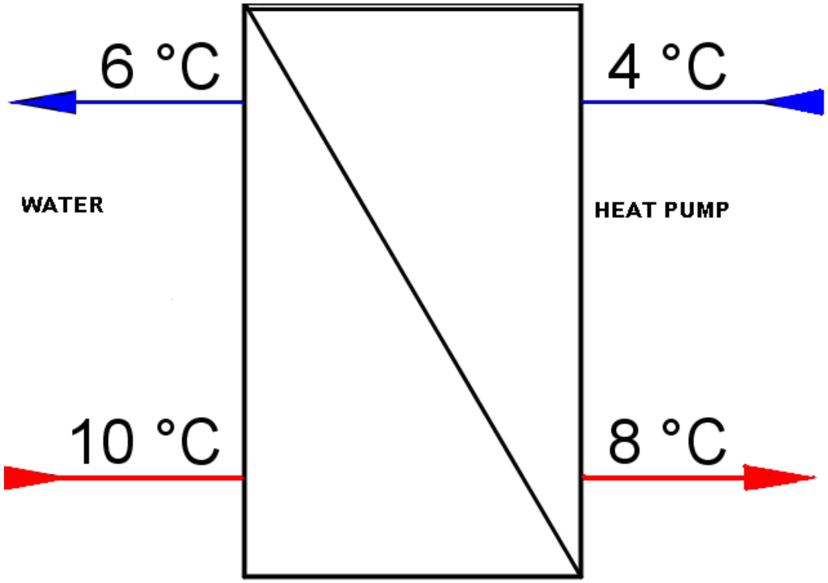

Fig.18. Ground-water heat pump heat exchanger

- Approximately 1 kW heat, supply to 1 m3 of water increasing temperature to one degree.
- If supply to the heat pump water temperature 10 ° C, leaving 6 ° C, then one cubic meter of water gives 4 kW of heat.
- In our example:

$$Q_0 = 12 - 2 = 10\ \text{kW} = 10000\ \text{W}$$

- Amount of water:

$$V = Q_0/4 = 2{,}5\ \text{m3}$$

Step 5: Underfloor heating (UFH) calculations

- The calculation methodology underfloor heating will not be discussed.
- Heat pumps generally supply a maximum water flow temperature of 35-45°C, which is an ideal temperature for Underfloor Heating.
- Using these lower temperatures increases the COP (Coefficient Of Performance) of the heat pump.

- **Step 6: heat pump efficiency calculation using the freon gas phase diagram p-h**

- Calculating the COP the heating temperature of the object (t_c=40°C) constant in both cases:

Example No1 Fig.19, Ground-source t_o=-10°C

Example No2 Fig.20 Heat pump (water-water) transferring heat temperature t_o=5°C

Example No1

- Ground-source transferring heat temperature (p-h diagram freon evaporating)

  t_o=-10°C

- Underfloor heating (p-h diagram freon condensation) temperature t_c=40°C

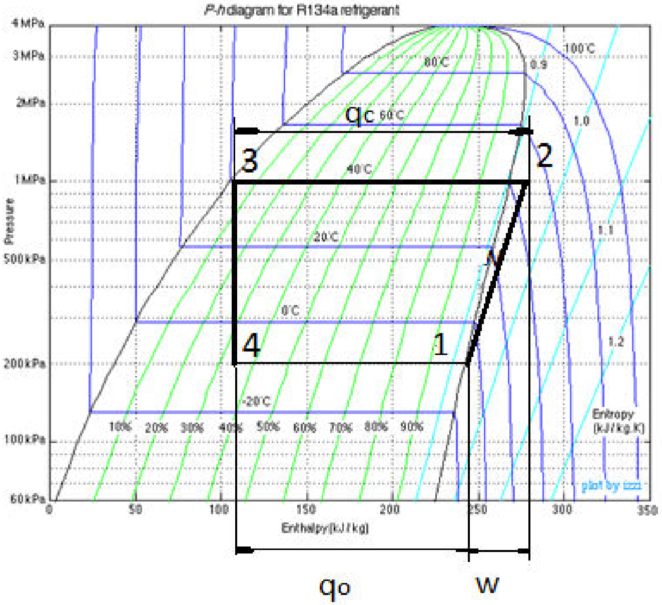

Fig.19. The heat pump cycle in a p-h diagram

From Fig.19 getting enthalpy *h1*, *h2*, *h3*,*h4* values.

$h1 = 240$ kJ/kg

$h2 = 275$ kJ/kg

$h3 = 110$ kJ/kg

$h4 = 110$ kJ/kg

Specific condenser output:

$q_C=h_2 - h_3=275-110=165$ kJ/kg

Specific compressor work:

$w=h_2 - h_1=275-240=35$ kJ/kg

Output coefficient ε:

$$\varepsilon = q_C/w$$

$$\varepsilon = (h_2 - h_3)/(h_2 - h_1)$$

$$\varepsilon = 165/35 = 4.71$$

Example No2

- Heat pump (water-water) transferring heat temperature (p-h diagram freon evaporating)

  t_o=5°C

- Underfloor heating (p-h diagram freon condensation) temperature t_o=40°C

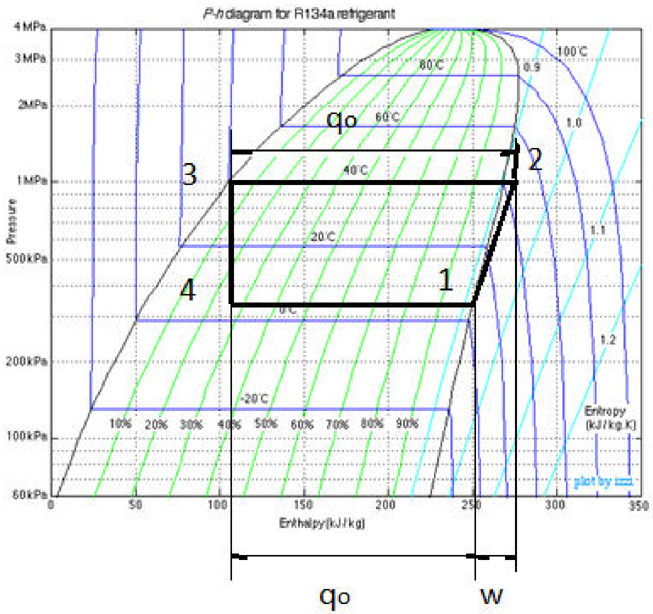

Fig.20. The heat pump cycle in a p-h diagram

From Fig.20 getting enthalpy *h1*, *h2*, *h3*,*h4* values.

h1 =*250* kJ/kg

h2 =*275* kJ/kg

h3 =*110* kJ/kg

h4 =*110* kJ/kg

Specific condenser output:

$q_C = h_2 - h_3 = 275 - 110 = 165$ kJ/kg

Specific compressor work:

$w = h_2 - h_1 = 275 - 250 = 25$ kJ/kg

Output coefficient ε:

$$\varepsilon = q_C / w$$

$$\varepsilon = 165/25 = 6.6$$

- Calculate the COP determine the Ground-source transferring heat temperature (p-h diagram freon evaporating) (t_0=0°C) constant in both cases.

Example No3. Fig.21 heating temperature of the object (t_c=20°C)

Example No4. Fig.22 heating temperature of the object (t_c=40°C)

Example No3.

- Fig.21 heating temperature of the object (t_c=20°C)
- Calculate the COP determine the Ground-source transferring heat temperature (p-h diagram freon evaporating) (t_0=0°C).

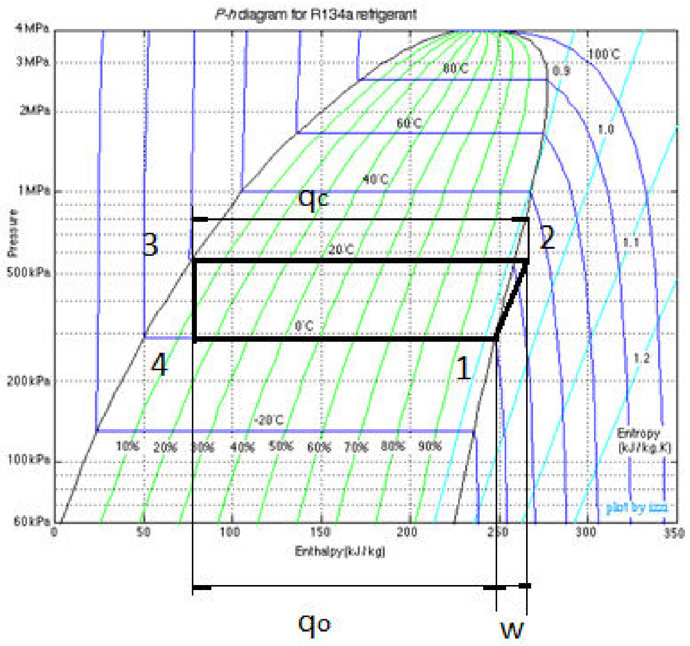

Fig.21. The heat pump cycle in a p-h diagram

From Fig.21 getting enthalpy $h1$, $h2$, $h3$,$h4$ values.

$h1 = 249$ kJ/kg

$h2 = 265$ kJ/kg

$h3 = 76$ kJ/kg

$h4 = 76$ kJ/kg

Specific condenser output:

$q_C = h_2 - h_3 = 265 - 76 = 189$ kJ/kg

Specific compressor work:

$w = h_2 - h_1 = 265 - 249 = 16$ kJ/kg

Output coefficient ε:

$$\varepsilon = q_C / w$$

$$\varepsilon = 189/16 = 11.8$$

Example No 4.

- Fig.22 heating temperature of the object (t_c=40°C)
- Calculate the COP determine the Ground-source transferring heat temperature (p-h diagram freon evaporating) (t_0=0°C).

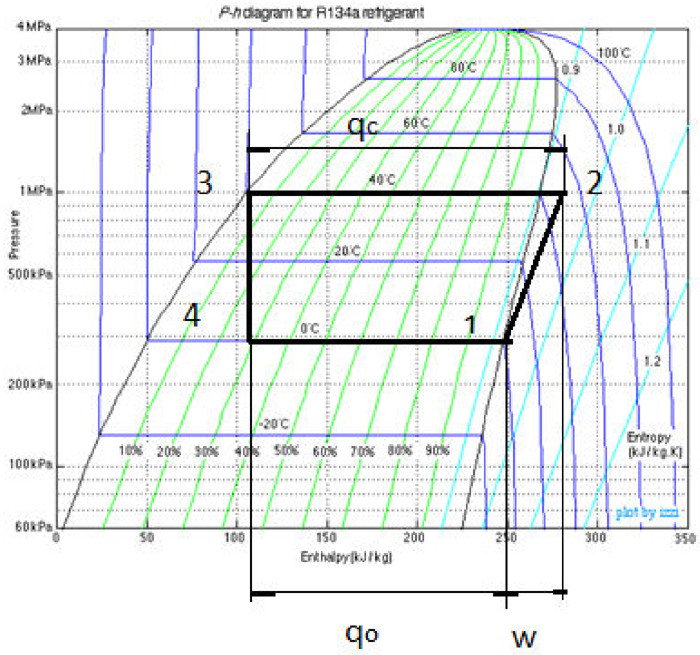

Fig.22. The heat pump cycle in a p-h diagram

From Fig.22 getting enthalpy *h1*, *h2*, *h3*,*h4* values.

$h1 = 249$ kJ/kg

$h2 = 275$ kJ/kg

$h3 = 110$ kJ/kg

$h4 = 110$ kJ/kg

Specific condenser output:

$q_C=h_2 - h_3=275-110=165$ kJ/kg

Specific compressor work:

$w=h_2 - h_1=275-249=26$ kJ/kg

Output coefficient ε:

$$\varepsilon = q_C/w$$

$$\varepsilon = 165/26=6.3$$

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