SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING
LRESE - Laboratory of Renewable Energy Sciences and Engineering

EPFL

Renewable Energy: Geothermal Solution

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1. (a) The mass of the air to be heated is :
   $m_{air} = V \cdot \rho_{air} = 8000 m^3 \cdot 1.29$ kg/m^3 = 10320 kg
   The required energy change:
   $\Delta \dot{E} = m_{air} \cdot c_{air} \cdot \Delta T / \Delta t = 10320 kg \cdot 1000 \frac{J}{kgK} \cdot 7.3 \cdot 10^{-3} K/s = 75336 J/s$
   Installed heating capacity: P_n = 75.3 kW

   (b) COP of heat pump = 4.2
   E = Electrical energy (for pump)
   Q_n = Useful heat
   Q_u = Ambient heat
   $Q_n = Q_u + E$

   Coefficient of power for heat pump is defined as COP $= \frac{Q_n}{E} = \frac{P_n}{P_{el}}$
   This implies electrical power P_{el} = 75.3 kW / 4.2 = 17.9 kW
   Heating power of the probe corresponds to the Q_n and hence $P_n = P_u + P_{el}$ implying P_u = 75.3 kW - 17.9 kW = 57.4 kW

   (c) l is the length of the probe. Using P_u from part b we get: $l \cdot 52 \frac{W}{m}$ = 57.4 kW implies l = 1104m
   we also have : $\frac{Q_u}{l} = \frac{Q_n - E}{l} = \frac{Q_n - \frac{Q_n}{COP}}{l}$
   Insertion of annual heating demand Q_n = 135000 kWh gives:
   $\frac{Q_u}{l} = 93.5 \frac{kWh}{m} < 110 \frac{kWh}{m}$

   (d) $E = \frac{Q_n}{COP}$ = 32143 kWh
   implies the electricity cost = 32143 kWh $\cdot$ 0.13 Fr./kWh = 4178.59 Fr.

   (e) Oil heating:
   Annual heating demand in MJ equal to 135000 kWh = 486000 MJ
   Volume of oil required is $V_{oil} = \frac{486000 MJ}{42.6 MJ/kg \cdot 0.86 kg/L}$ = 13266 litres
   The price of the oil would be 13266 litres . 0.86 Fr./litre =11408 Fr.

(f) CO_2 emission geothermal heat pump : $E \cdot 0.13 \frac{kg}{kWh} = \frac{Q_n}{COP} \cdot 0.13 = 4179$ kg

CO_2 emission oil heating : 486000 MJ $\cdot$ 0.074 $\frac{kg}{MJ} = 35964$kg

Hence reduction in CO_2 emission is $\frac{(35964 - 4179)}{35964} = 88.4\%$

2. (a) Available heat in the geothermal source: $\dot{Q} = \dot{m}c_p(T_{in} - T_{out}) = 50 * 4180 * (190 - 85) =$ 21.945 MW

Exergy available in the geothermal source:

$$T_{logmean} = \frac{T_{h,in} - T_{h,out}}{ln\frac{T_{h,in}}{T_{h,out}}} = \frac{463 - 358}{ln\frac{463}{358}} = \frac{105}{0.2572} = 408.25\text{K}$$

$$Ex_{source} = \dot{Q} * (1 - \frac{T_a}{T_{logmean}}) = 21.945 * (1 - \frac{287}{408.25}) = 21.945 * (1 - 0.703) = 6.52\text{MW}$$

Exergy for district heating:

$$T_{logmean} = \frac{T_{h,in} - T_{h,out}}{ln\frac{T_{h,in}}{T_{h,out}}} = \frac{333 - 313}{ln\frac{333}{313}} = \frac{20}{0.06194} = 322.9\text{K}$$

$$Ex_{heating} = \dot{Q} * (1 - \frac{T_a}{T_{logmean}}) = 12 * (1 - \frac{287}{322.9}) = 12 * (1 - 0.889) = 1.334\text{MW}$$

Energy Efficiency:
- summer: 3.2 MW_e/21.945 MW =14.6%
- winter: (2.4 MW_e+12 MW_{th})/21.945 MW = 65.6%

Exergy Efficiency:
- summer: $\epsilon = \frac{Ex_{electrical} + Ex_{heating}}{Ex_{source}} = \frac{3.2 + 0}{6.52} = 49.1\%$
- winter: $\epsilon = \frac{Ex_{electrical} + Ex_{heating}}{Ex_{source}} = \frac{2.4 + 1.334}{6.52} = 57.3\%$

(b) The marginal electrical efficiency in winter is the elec. production from the residual heat (21.945 MW - 12 MW DH = 9.945 MW), thus 2.4/9.945=24.1%