Assignment 2: water pit heat storage

The aim of the assignment is to calculate thermal performance and cost of heat production of a solar heating plant with water pit heat storage (PTES).

The following questions should be addressed in the assignment:

1) Selection of a district heating plant
   Expected activities: locate a district heating system, find out the annual heat demand, supply temperature, return temperature of the district heating plant
   Calculate degree*hour for the heating system

2) Investigation of a solar district heating plant with a solar fraction of more than 50%
   Expected activities:
   Explain how a solar district heating system with PTES works
   Identify size of the solar district heating system that can cover more than 50% of the annual heat demand of the district heating system obtained in question 1. The configuration of the solar district heating system should be similar to the Marstal solar heating system
   Determine average solar collector efficiency for the solar collector field
   Determine levelized cost of heat for the system

3) Investigation of the PTES and the tank heat storage
   Expected activities:
   Analyse energy balance of the PTES and the tank heat storage calculated by the program SDHCal
   Determine average heat loss coefficient of the heat storages for the top cover, the sides and the bottom surface of the PTES.
   Determine annual heat recovery rate of the heat storages

4) Optimization and recommendation
   Expected activities:
   Carry out parametric investigations for different scenarios, for instance, different fuel price, different system size with an aim to decrease the levelized cost heat.
   Discussion, conclusion and recommendation

Appendix A

The reference solar district heating system in Marstal, Denmark.
For the reference year used in the program, the sum of degree*hour per year is 81834. The yearly solar radiation on a tilted surface of 35º facing south is 1083 kWh/m2. Info about the Marstal Solar heating plant is:

1. District heating net
   The Marstal district heating net has an annual consumption of 32000 MWh. The supply temperature and the return temperature of the district heat net is 75ºC and 35ºC respectively.
2. Solar collector fields

There are three solar collector fields. The tilt of the collector in the three fields is 35º. The distance of between collector rows is 4.5 m. Collector area and efficiency expressions are given as follows.
(1) Solar collector field 1: 9043 m2, efficiency expression of the collector is

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$$\eta = \eta_0 K_\theta - \frac{a_1(T_m - T_a)}{G} - \frac{a_2(T_m - T_a)^2}{G}$$

Η0 = 0.76 [-], a_1= 3.5 [W/m2/K], a_2= 0.002 [W/m2/K2]

(2) Solar collector field 2: 9124 m2, efficiency expression of the collector is
Η0 = 0.81 [-], a_1= 2.57 [W/m2/K], a_2= 0.0079 [W/m2/K2]

(3) Solar collector field 3: 15000 m2, efficiency expression of the collector is
Η0 = 0.85 [-], a_1= 3.07 [W/m2/K], a_2= 0.01 [W/m2/K2]

3. Water pit heat storage

The water pit heat storage used in the plant has a volume of 75000 m3. The height to diameter ratio of the storage is 0.0705. The storage was insulated with 0.24 m PE foam. Thermal conductivity of the PE foam is 0.05 W/m/K.

4. Steel heat storage tank

The steel buffer tank has a volume of 2100 m3 and a height to diameter ratio of 0.6612. The heat loss coefficient of the tank is estimated to be 278 W/K.

5. The other components

The CO2 heat pump has power of 475 kW. The condensing woodchip boiler plus ORC has a total power of 4493 kW. The maximum power of the backup bio-oil boiler is 10 MW.

Financing of the solar heating plant

The cost of collectors is 1200 DKK/m2 solar collector for the collector field 1, 1400 DKK/m2 solar collector for the collector field 2 and 1500 DKK/m2 solar collector for the collector field 3. The water pit storage has a cost of 110 DKK/m3 while it is 700 DKK/m3 for the steel tank. The investment of the Marstal solar heating plant is financed by a 20 year loan with an annual interest rate of 5%. The annual payment for a 20 year loan is given in Appendix A for different interest rates.

The heat produced by the CO2 heat pump is on average 100 DKK/MWh, while it costs 200 DKK/MWh to produce heat by woodchip boiler and 400 DKK/MWh to produce heat by bio-oil.

Appendix B

Table 1 Annual payment of a loan of 20 years for different interest rates

Annual interest rate, %	Annual payment/Amount of loan, %
1.0%	-5.5415%
1.5%	-5.8246%
2.0%	-6.1157%
2.5%	-6.4147%
3.0%	-6.7216%
3.5%	-7.0361%
4.0%	-7.3582%
4.5%	-7.6876%
5.0%	-8.0243%

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