Modeling and optimization of energy systems

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Project description

Part 3 - Optimisation of the EPFL energy system (NLP)

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General Overview

In order to reduce the energy demand of industrial processes, heat recovery represents an attractive solution. Typical heat recovery is performed by placing a heat exchanger between a hot and a cold stream (i.e. a process stream which has to be cooled down and a process stream which has to be heated up, respectively). This decreases both the operating cost and the environmental impact of the process, but additional equipment has to be installed (e.g. a new heat exchanger). Investment costs of heat exchangers depend predominantly on their exchanging surface. Therefore, the goal of this exercise is to define the optimal minimum temperature difference (ΔT_{min}) in such heat exchangers, quantifying the economic potential of the investment.

For the reference scenario consider Figure 1, as well as the information it contains.

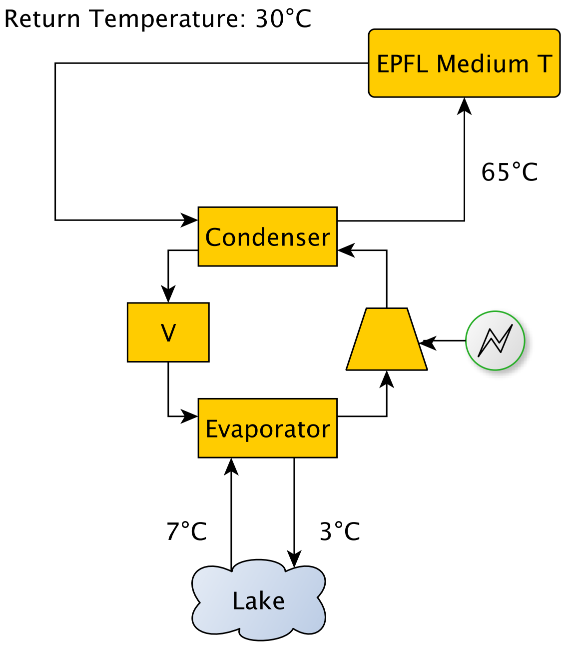

Figure 1: Reference scenario for heat supply

Three heat recovery possibilities are suggested for the EPFL campus.

Besides the usual hypotheses, consider the following list that might be useful.

Hypotheses

- Investment cost equation: Purchase cost (ref. year 2000) $C_p = a_{unit}A^{b_{unit}}$ [CHF], $a_{unit} = 1200$ [CHF/m^2], $b_{unit} = 0.6$
- Overall heat transfer coefficient of the heat exchanger (air-air): $U_{ex} = 0.025$ kW/m^{2}K , (air-water): $U_{ex} = 0.15$ kW/m^{2}K , (water-refrigerant): $U_{ex} = 0.75$ kW/m^{2}K
- Interest rate: 6 %
- Life time of units: 20 years
- Chemical engineering plant cost index (2000): 394.1
- Chemical engineering plant cost index (2015): 605.7 (at the time of purchase)

- Bare module factor: 4.74 for heat exchanger

1 Data Center heat recovery

Integration of the database centre into the heating loop: data centres at EPFL generate 574 kW of heat, which has to be removed. In order to recover the heat generated by them, an heat exchanger is being considered. The intended configuration is depicted in Figure 2, as well as some considerations.

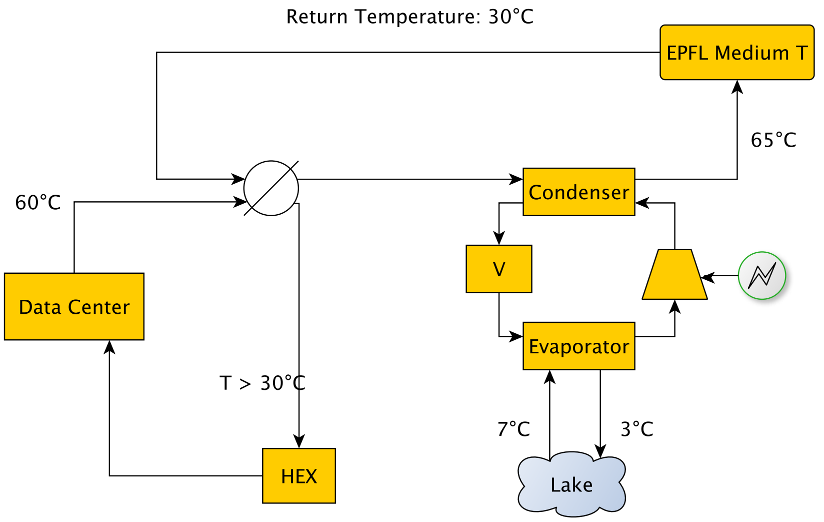

Figure 2: Heat recovery from data center

You have access to 3 files, with the same structure as in the MILP part. A moes2019NLP_sv.mod file that contains the model description; a moes2019NLP_sv.dat file that contains a part of used data; moes2019NLP_sv.run file that loads both .mod and .dat files, specifies the solver and displays specific variables. In this section we are solving a non-linear problem (NLP), so a non-linear solver is needed.

Hint

- Open the .mod file and identify the variables and parameters in the diagram.
- Open the .dat file and identify the values you need to input. Pay attention that in the present situation we are only interested in the medium temperature heat demand. **The values in the .dat file are an example and do not correspond to your data**.
- Consider that the (in place) data centre cooling system is able to cope with changes in the load, and that there is no cost associated.
- The AMPL model contains all the required information. Every parameter, variable and constraint are commented in order to guide you through the problem resolution.

Task

- You should develop the AMPL model for the reference scenario (current situation) and for the suggested heating recovery option.
- You should calculate and present the current energy bill (no integration).
- You should be able to calculate the new energy bill (if you decide to make use of the DC heat), the new heat exchanger area, cost, pay-back time as well as the optimal ΔTmin.

2 Air ventilation heat recovery

Integration of the air ventilation into the heating loop: considering the specifications given in the first part of the project, the incoming air ventilation flow ($T = T_{ext}$) can be preheated by the outgoing air ventilation flow (leaving the building at $T = T_{int}$ =21°C). By preheating the air ventilation flow, the heat demand (and consequently the operating cost) reduces according to (see Equation 1):

$$Q(t) = A_{th} \cdot \{U \cdot (T_{int} - T_{ext}(t)) + m_{air} \cdot c_{p,air} \cdot (T_{int} - T'_{ext}(t)) - k_{sun} \cdot Irr(t) - Q_{people}(t)\} - Q_{el}(t) \quad (1)$$

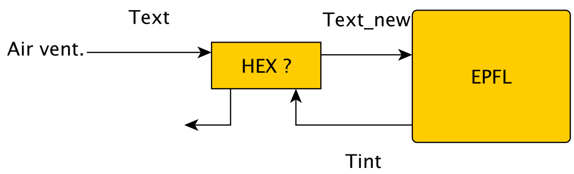

Figure 3: Heat recovery from air ventilation

Similarly to the previous section there are 3 files, .mod, .dat and .run, with the denomination ventilation.

Hint

- Only based in the hypotheses presented initially are you able to comment *a priori* on the viability of this kind of heat exchanger?
- The heat demand is no longer a parameter but a variable, that depends on the external temperature.
- When computing the logarithmic mean temperature, you may want to consider another equation (why?). Check equation 2.

$$\Delta T_{ln} = {\frac{\Theta_1 \cdot \Theta_2^2 + \Theta_2 \cdot \Theta_1^2}{2}}^{1/3} \quad (2)$$

Task

- You should develop the model allowing you to take conclusions.
- If the model is done correctly, operating cost without ventilation should be very close to the reference values of the previous section.
- You should be able to size the ventilation heat recovery (if it is profitable) and indicate the optimal ΔTmin of the installed heat exchanger.

3 Air ventilation and Heat pump integration

Another possibility is to use the exiting air ventilation heat as heat source for the heat pump (Figure 4).

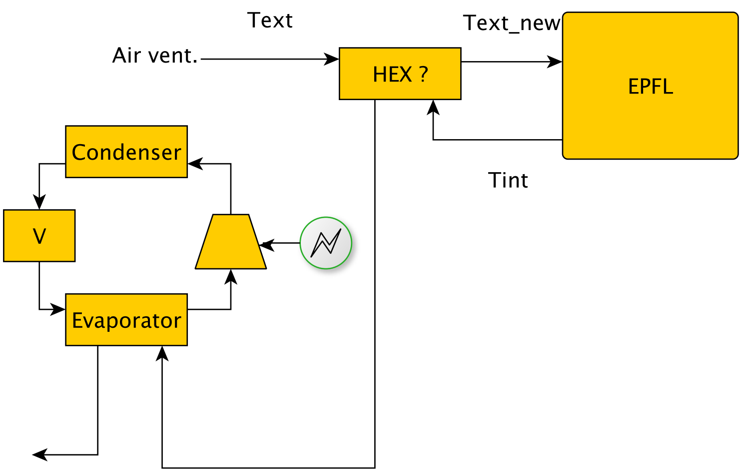

Figure 4: Ventilation and heat pump integration

Hint

- Use the same ampl files as in the previous section and re-use the variables.
- You will now have two ways of supplying heat to EPFL. Besides the conventional HP, you will have to consider this new heat integration. For the sake of simplicity, consider that only the HEX from the previous section has to be bought (meaning that the HP equipment is already in place).
- Make some assumptions if needed but be able to justify them.

Task

- You should have a fully developed model allowing you to take conclusions.
- You should be able to provide operating and investment costs, as well as pay-back time for the ventilation HEX (if profitable) as well as its size.

4 Summary

You should present for the heat recovery system on campus

- The optimum ΔTmin for the Data Center heat recovery and the ventilation recovery unit (if applicable), the heat recovered in each of them and the corresponding area.
- All the relevant economic and performance indicators.

You have learned:

- How to formulate NLP optimization programs for several heat recovery scenarios and how to solve them.
- How to interpret results and which variables/parameters are the most determinant.