Heating demand of a tensile structure

Study case

The object under consideration is a tensile structure serving a sports facility located in Bologna, Italy, made of a metal skeleton and covered with PVC. The aim is to renew the heating system of such, replacing the present methane boiler with a heat pump.

As a first step, an estimate of the structure's heat dispersions was made, going to calculate what are the heat loss coefficients through the structure, the floor and due to ventilation.

From the data analyzed, following the European standards provided for this type of structure, the following coefficients were obtained:

$\boldsymbol{H_s}$ $[\boldsymbol{W/K}]$	$\boldsymbol{H_f}$ $[\boldsymbol{W/K}]$	$\boldsymbol{H_v}$ $[\boldsymbol{W/K}]$
3290.57	71.80	2677.32

An average indoor temperature $\boldsymbol{\theta_{int}} = 18°C$ (from regulations) and a minimum outdoor temperature $\boldsymbol{\theta_{out}} = -5$°C (for the city of Bologna) were then considered. Substituting these two temperatures and the data in Table 1 in the following eq. we obtain the rated output that the new heating system must have, corresponding to the maximum amount of heat to be introduced into the structure Q_c.

$$\boldsymbol{Q_c} = \left(H_s + H_f + H_v\right) * \left(\theta_{int} - \theta_{out}\right) \cong \mathbf{140}\ \boldsymbol{kW}$$

There are already some fan coils in the facility, which require water at 60°C in order to maintain the design indoor temperature. Therefore, in this exercise the installation of a water-to-water heat pump is proposed, which uses groundwater at a temperature of 12°C (for the city of Bologna).

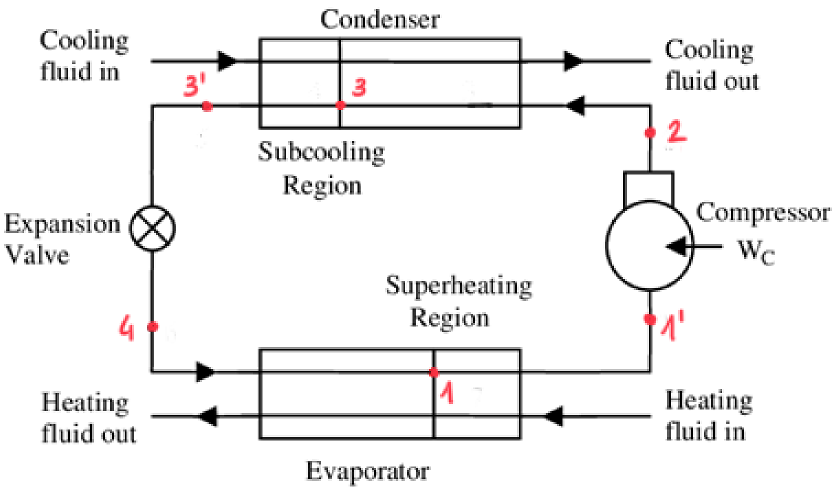
The heat pump has the following characteristics:

- Nominal power: $P_n > 140\ kW$
- Condensation temperature: $T_c = 65°C$
- Evaporation temperature: $T_e = 7°C$
- Refrigerant with low GWP: R1234ze (GWP=7)
- Compressor isoentropic efficiency: $\eta_{is} = 0{,}72$
- Mechanical efficiency: $\eta_{me} = 0.9$

Methodology

To carry out the above analysis, two different simple vapor compression cycles were considered, with sub-cooling (T_3') and superheating (T_1') and without. The temperature difference chosen for sub-cooling and superheating are, respectively:

$$\Delta T_{sc} = -7°C \ , \quad \Delta T_{sh} = 10°C$$



Knowing the maximum heating demand of the structure $Q_c = 140\ kW$, the electrical consumption of the heat pump and thus its efficiency (COP) was evaluated using the following equations:

$$h_2 = \frac{h_{2iso} - h_1 + \eta_{iso} * h_1}{\eta_{iso}}$$

$$\dot{m} = \frac{\dot{Q}_c}{(h_2 - h_3)}$$

$$\dot{Q}_e = \dot{m} * (h_1 - h_4)$$

$$\dot{W}_{cp} = \dot{m} * (h_2 - h_1)$$

$$\dot{W}_c = \frac{\dot{W}_{cp}}{\eta_{me}}$$

$$COP_{cp} = \frac{\dot{Q}_c}{\dot{W}_{cp}}$$

$$COP = \frac{\dot{Q}_c}{\dot{W}_c}$$

Results

Through the implementation of a code, using the CoolProp library, the following results were obtained:

	$\dot{m}$ $[kg/s]$	$\dot{W}_{cp}$ $[kW]$	$\dot{W}_c$ $[kW]$	$\dot{Q}_e$ $[kW]$	COP_{cp} $[-]$	COP $[-]$
With SC and SH	0.89	39.10	43.45	100.90	3.58	3.22
Simple	1.01	42.72	47.47	97.28	3.28	2.95

Based on the results obtained, it can be observed that by subcooling the fluid at the condenser outlet and further heating it at the evaporator outlet, a higher efficiency is achieved compared to the simple cycle. Similarly, the work done by the compressor is reduced, as is the flow rate of the refrigerant, thereby decreasing operational costs. A comparison was also made regarding the use of different refrigerants and how they can influence the efficiency of the cycle.

		Simple	**S-C and S-H**
COP	**R1234ze**	2.95	3.22
	R410a	2.55	2.86
	NH_3	3.33	3.41

From this analysis, it is clear that the refrigerant NH_3 is the best choice for the characteristics of this problem but it is also more dangerous than the others since it's inflammable and toxic.

Finally, for the simple cycle using R1234ze, p-h and T-s diagrams were produced to represent the thermodynamic cycle in question.