2. Heat pumps

A heat pump is a device aimed to transfer heat from a low temperature source to a higher temperature heat sink. In order to move thermal energy in the opposite direction of the thermal gradient external power is required according to the Clausius statement[1] of the second law of thermodynamics (cf Figure 2.1).

In order to enhance the thermal level of the heat to be provided to the hot sink, the fluid (refrigerant) undergoes adiabatic compression (compression heat pumps); in case of a low cost or waste available thermal energy source compression is substituted by a more complex chemical/physical absorption system of a refrigerant in a carrier fluid (absorption heat pumps). The high efficiency of heat pumps is due to the fact that you don't have to produce the energy you need, you just require to spend the amount of energy necessary to move it.

Actually heat pump and refrigeration thermodynamic cycles are analogous, the difference lies in their purpose: while the former is aimed to provide heat to a sink whose temperature is higher than the ambient one, the latter has the purpose to remove heat from a source at a temperature lower than T_{amb}.

The common design of a compression heat pump involves four main components: a condenser, an expansion valve, an evaporator and a compressor as shown in Figure 2.2. The coefficient of performance (COP), defined as the ratio between the useful energy and the energy to be paid, varies from 5-7 for big machines and 2-3 for small ones. In order to compare these values to the efficiency of the most common heating systems, e.g. boilers, the cost of electrical energy needs to be converted to thermal energy basis. Electricity indeed costs about three times the same amount of thermal calories, therefore the aforementioned COP values should be divided by 3. However, being the COP of boilers approximately equal to 0.75, heat pumps still result to be much more profitable.

Heat pumps allow to reduce energetical consumption, atmospheric pollution as well as process heating costs. Moreover they're environmental friendly since they use highly dispersed energy sources such as heat recovery from cooling water or from cold air. Even if heat pumps result to be very effective and to allow high energy savings, they're not a very spread technology due to the high capital costs required that vanish their profitability and to the uncertain maintenance costs. Moreover their use could be limited by the high cost of electrical energy and the replacement of the fuel gas network by this technology is unfeasible due to the inability of the actual power plants and relative distribution network to withstand such a high load.

[1]Clausius, R. (1854). "Über eine veränderte Form des zweiten Hauptsatzes der mechanischen Wärmetheorie". Annalen der Physik. Poggendoff. xciii: 481–506. doi:10.1002/andp.18541691202

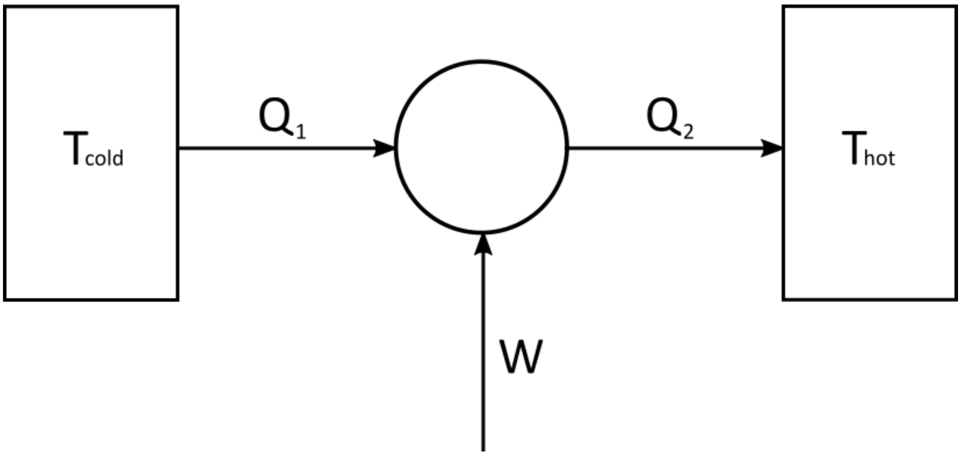

Figure 2.1.: Heat pump thermal machine scheme

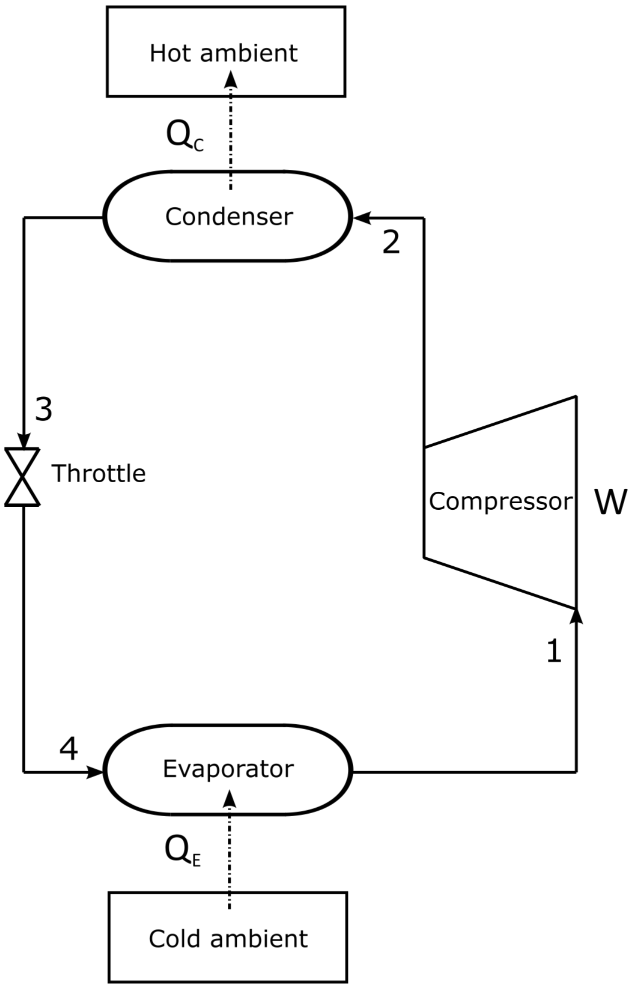

Figure 2.2.: Vapor compression heat pump

	Property	Value	Unit
Antoine coefficients			
	A	3.97183	
	B	1021.864	
	C	-43.231	
Physical properties			
	c_P^L	2.426	$kJ/(kg \cdot K)$
	c_P^V	1.778	$kJ/(kg \cdot K)$
	$\Delta H_{ev}(T_C)$	19940	$kJ/kmol$
	MW	72.15	g/mol

Table 2.1.: Isopentane properties

2.1. Heat pump design

A 7.5 kW vapor compression heat pump to heat up a 95 °C system should be designed. The ambient temperature is 50 °C and a minimum temperature difference $\Delta T_{min} = 5\,°C$ is required for a feasible exchange. The refrigerant is isopentane whose properties are listed in Table 2.1. The Antoine coefficients correspond to the equation expressed as:

$$log_{10}(P_s[bar]) = A - \frac{B}{T[K] + C} \tag{2.1.1}$$

Moreover, given $U_C = 375\,W/(m^2 \cdot K)$ and $U_E = 340\,W/(m^2 \cdot K)$, the equipment sizing is requested.