Heat pumps for many applications

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ABSTRACT

For many people, heat pumps are units that hang outside a window. They can cool in the summer and heat in the winter. But heat pumps offer much more than just this single application. Heat pumps are produced for many applications, with capacities from a few kilowatts to the megawatt class, and for many different temperature levels.

In the industrial sector, heat pumps are used in processes, and are therefore often referred to as process heat pumps. One of the drivers for using heat pumps is the desire to use electricity rather than fossil fuels to generate hot water – which can then be used in many ways. Today heat pumps are available for production of hot water up to 90°C and, in the near future, we will see heat pumps able to deliver hot water or steam at 150°C or even higher.

The purpose of this paper is to describe some applications in which industrial heat pumps can be used. What makes industrial heat pumps interesting is their ability to produce both cold and hot water simultaneously. This possibility has not often been exploited, and a preparation of a good business case can help to analyse all possibilities onsite.

In many industrial applications, there is a need for cooling (supplied by refrigeration plants or chillers) and heating (supplied by steam boilers or hot water boilers) in a facility. The industrial heat pump combines these two requirements, heating and cooling, in one piece of equipment.

1. INTRODUCTION

A heat pump is commonly thought of as being a unit that absorbs heat from ambient air and produces either warm air or hot water. But when it comes to industrial heat pumps, these can be built in the same way as a domestic reversible heat pumps, but they are also so many other things.

Figure 1 shows several different solutions where a heat pump is the central connector. The easiest way to handle the collection of heat is to absorb it in water or air.

In the industrial process, the low-value heat can be relatively warm and yet not useful for general heating purposes in your own processes. It is very common to dump water or air at 30°C or higher into the environment rather than using it as a heat source for a heat pump.

In some countries it is illegal to dump water over 20°C in the environment but dumping water at 10°C is acceptable. Also, from most office buildings, in winter, warm and humid air is rejected to the ambient and then the cool ambient air taken in must be heated.

In cold-climate zones it is very common in domestic houses to heat the air with a heat pump before it is ducted in to a house, and cool the rejected air. Why is it so difficult to do it in office buildings? If it is not difficult, why is it not mandatory?

In industrial processes there are many examples where the refrigeration system is one inventory and the boiler is another, and they are working on the same process. Take dairy as an example.

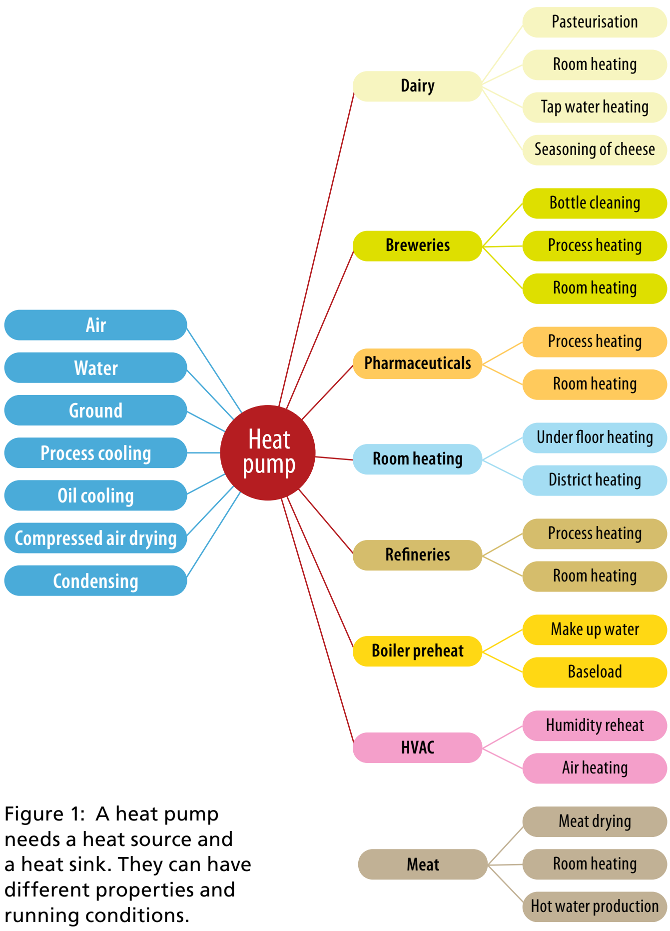


Figure 1: A heat pump needs a heat source and a heat sink. They can have different properties and running conditions.

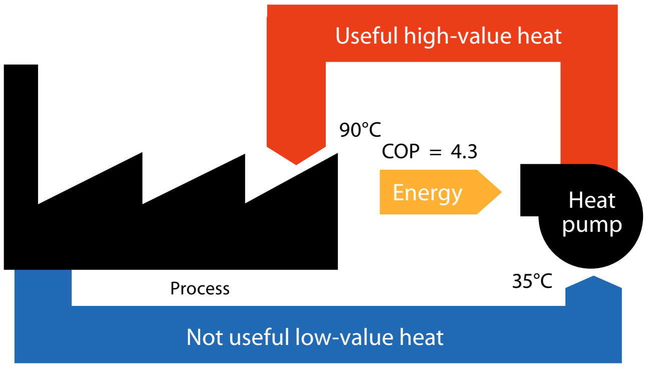


Figure 2: In industrial processes you produce low-value heat that is normally ejected to the ambient. With a heat pump this "waste heat" is transformed in to useful high-value heat, which can be used elsewhere in the process or sold for other uses.

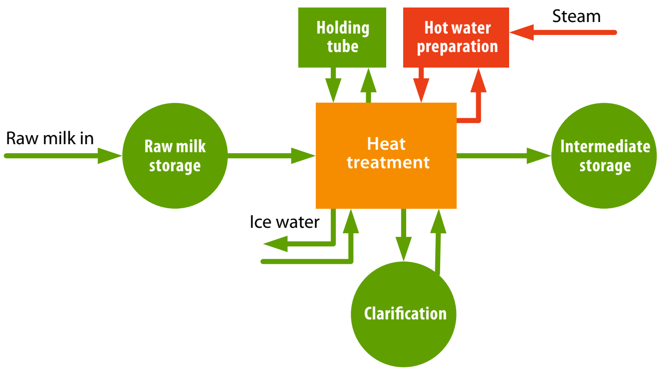


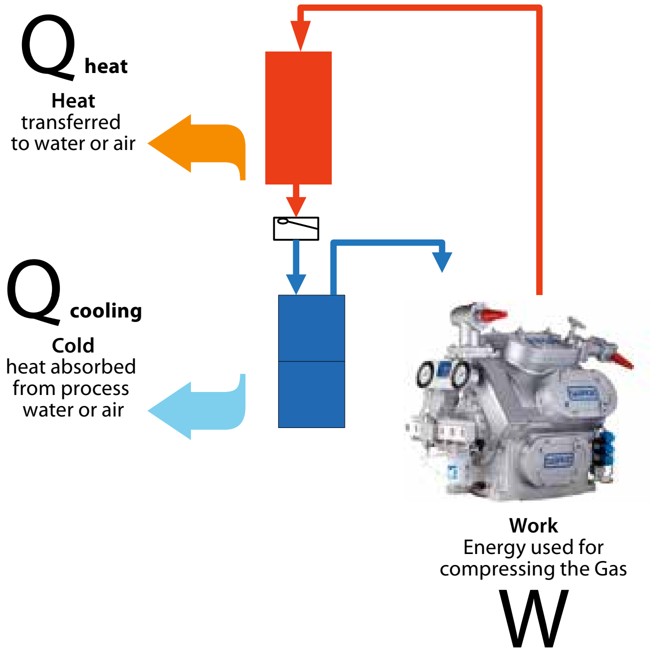
Figure 3: In a typical dairy you cool the milk when it arrives to the dairy and when it is processed. During pasteurisation of milk it is heated to about 80°C using steam produced in a boiler that supplies a hot water loop. This hot water can be heated by a heat pump rather than a boiler.

If we use the principle in Figure 2 and look at the process in Figure 3 we will find the opportunity for reusing heat from before and after the heat treatment (pasteurisation). The ice water production is also prepared using mechanical refrigeration and can provide the heat for a heat pump.

An example: The ice water chiller produces condensing water of 35°C and the heat pump cools it down to 30°C with an evaporation temperature of 28°C. On the warm side the heat pump produces hot water at 90°C. The COP of the HP system at these conditions is 4.3. The best boiler on the market has a COP=0.98 but most are not much over 0.85.

The efficiency of a boiler is in theory up to about 98% for the newest condensing boilers. Real-world tests done in Germany show that the reality is different from the declared efficiency.

$$\text{COP} = \frac{\text{Infired fossil fuel}}{\text{Heat on the user side}}$$



$$\text{COP} = \frac{\text{Qheat+Qcool}}{\text{W}}$$

In many industrial applications you can use both the cooling capacity and the heating capacity, and therefore both capacities must be added to the equation.

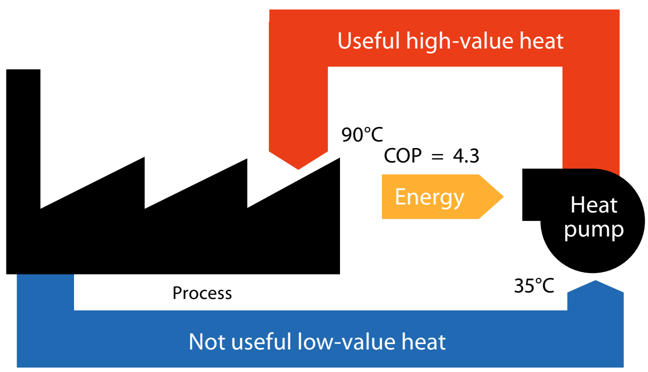


Figure 4: Reusing the low-value heat you can produce hot water with high efficiency compared to a state-of-the-art boiler.

The same exercise can be performed for a variety of industries. A substantial part of the meat industry produces considerable heat when cooling down a freshly killed animal. The heat produced by the cooling and freezing process can be reused in a heat pump system for production of cleaning water. However, in this case the heat source is at its peak capacity earlier in the day while the cleaning in place (CIP) takes place in the late afternoon or evening. Therefore, the hot water produced must be stored in large insulated tanks.

The temperature of the water needs some consideration because there is no reason to warm the water to higher temperatures than necessary. If you warm the water to 90°C you will in many cases not need to add chemicals, whereas if you only heat it to 60°C chemicals must be added. The chemicals can make the water non-potable, and this needs special care. Very warm water can make some types of meat stick to steel, so both types of cleaning have their advantages and disadvantages.

Another application is breweries. Here a lot of hot water is produced, with steam at 160°C for heating water to 90°C, the water then used for cleaning bottles. This is "energy murder". With a heat pump connected you can keep the water at 90°C by using the heat produced in the production for cooling the product and process.

2. SELL THE HEAT

Heat cannot be re-used in the same production process in all cases. However, unless a facility is located a substantial distance away from its neighbours, it's possible to sell off excess heat for others to use in their processes.

A special gas producer in Asia has a facility near the city limits. There was quite a lot of heat at 40°C, which needed to be cooled down to 30°C. The heat was agreed to be sold to the local district heating company at one price in the summer (hot sanitary water production) and another in the winter (including heat) at a higher price. The COP = 5.3 and a simple payback time for the unit was about 1.8 years, a very attractive investment indeed.

Due to seasonal production cycles, some customers do not have the same load year-round. When these are connected to a district heating system, (if this is available) there will also be others with a slightly different cycle. In this case, cycling of the individual system does not influence the grid to a great degree. However, some imbalance will always occur in countries that have high summer loads for summer cooling and lower needs for heat. Yet this can be dealt with by storing hot water in large underground storage basins for later use. This has been practised in cold-climate zones for some years now.

3. MAPPING THE SOURCES

The first couple of times a site or factory is checked, it may be difficult to figure out where to collect the heat. One thing to keep in mind is that cooling towers used for cooling compressed air represent about one-third of the typical heat rejection, so this is a source not to underestimate.

The first thing to consider is if there are refrigeration systems on site and then think about their air conditioning chillers. All these units produce quite a high heat rejection capacity. Compressor oil cooling can often be a good source of low-grade heat for a heat pump input. Also, waste water/sewers can be a good source of low-value heat. In many cities around the world the sewer system is about 20°C or more year-round, and the flows can be stable.

A very valuable source of heat in office buildings is the exhaust air. It is warm and humid, and it is not a problem to cool it down to pull as much energy out of it as possible. One of the sources can be the air from underground metro tunnels, see Figure 5, or tunnels such as the Eurotunnel.

Figure 5: In this case, one can wonder if a heat pump has been used to cool down the air from the subway exhaust.

When discussing new installations with a client it is a good idea to listen very carefully to the description of the factory layout and try to understand on a concept level the system in question.

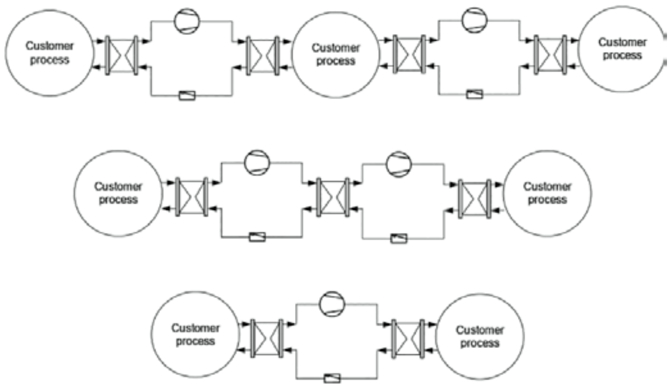


Figure 6: Three system layouts for heat pumps. The imagination sets the limits of how to connect and use heat pumps. Lower temperatures are to the left and the high temperatures to the right of the systems.

In case the temperature lift is too high, consider a two-stage solution or even more stages. The temperature lift is limited by the discharge temperature and the pressure ratio allowed over the compressor. This varies a little between the compressor types.

In Figure 6 at the bottom, there is a simple one-stage heat pump, which is the most commonly used system. If a heat pump is connected to an existing chiller or there is a high-temperature lift, consider the middle system, especially in cold climates using the sea to produce high-temperature water for district heating.

If there is some process water at about 30 to 40°C and a cold source and high temperature is required, consider the top solution. It is also used for district cooling and heating.

4. NATURAL SOURCES

Air and ground water are popular sources, especially in cooler parts of the world; however, for industrial applications, it is not always very practical. Yet for air conditioning and space heating these options can be enough. If ground source is considered, there is a limit to how much heat is available. This depends on the water flow of the ground and the temperature. Air is also an option, but for the industrial application, there will need to be very high-volume flows, and noise can be a real limitation.

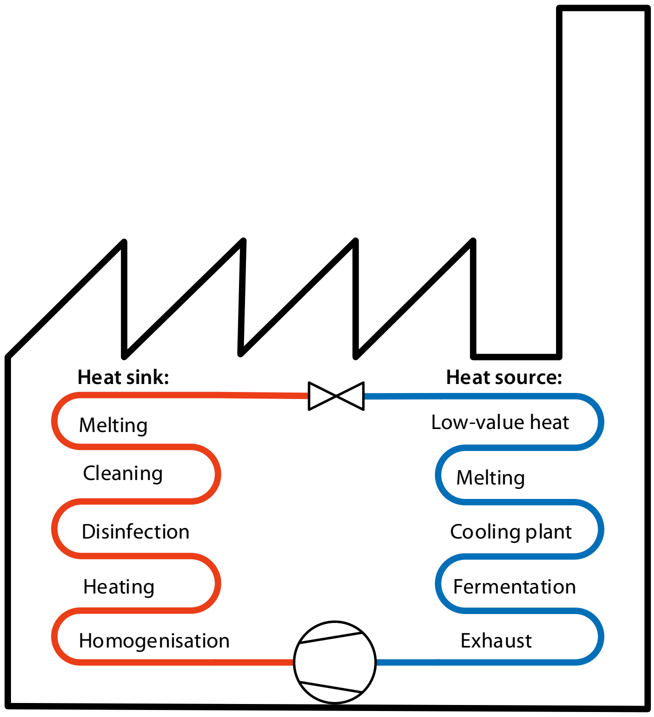


Figure 7: In industrial process heat pumps, the cold side is used for recovering heat or cooling a product. As shown in figure 6, the heating can be gained at a low level and sent to the right, where the temperature level is higher. If you cannot use the cooling or heating capacity internally then consider the possibility of selling the capacity to others in the neighbourhood.

Other more obvious solutions can be rivers, lakes, the seabed and the sea. The problem with ground sources is the sensitivity of the ground-source water, especially if it is potable water. Also, in most cases, it is not allowed to take so much heat out that there is a change of temperature to either side of the natural temperature. In some countries, it is also not allowed to change the temperature of the seawater or the salt concentration. This eliminates using the sea as source of heat or dumping heat in to it.

Rivers are a good solution when they are flowing all year. In some countries there is a requirement to have a body of closed-off neutral water between the seawater and the refrigerant side. This has many benefits but of course also introduces a little loss to the system due to extra pumping power and extra heat exchange. But it does provide good protection against contamination of either cycle.

In the past, it was not possible to classify exhaust air from buildings as a sustainable solution, but that has changed recently in Europe. The argument was that when a building is no longer there, the source is also no longer there. However, the counter-argument was that when the building is not there you also do not need the heating.

Cooling towers and evaporative condensers can serve as a good heat source for a heat pump. When a refrigeration system or air compressor is running, it is possible to reuse the heat from the connected systems. In warmer climates, when refrigeration and AC chillers are not used, the ambient air can re-heat the cold water. It is still necessary to keep an eye on the water quality, especially where the air pollution is high.

If there is a saline atmosphere, it will be necessary to select a cooling tower that is not sensitive to saline water and air.

CONCLUSIONS

With industrial heat pumps, there are many options to produce hot air or water in order to reduce the use of fossil fuels in production processes. Sustainability is improved through better overall efficiency and lower CO_2 emissions from energy production. Heat pumps are more economical to use. The benefits will drive the development once the industry has understood "what's in it for me".

Short pay-back and lower energy consumption are the main drivers for those who only understand the economic argument. At the same time, using industrial heat pumps is safer, and the financial risks are less than using fossil fuels such as oil and coal.

ABOUT THE AUTHORS

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