New ways of combining Heat Pumps and District Heating

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In the Swedish research project Heat Pumps in District Heating Systems new combinations of heat pumps and district heating systems have been investigated. The project group has looked into three different way to combine heat pumps and district heating. Firstly, focusing on the combination of heat pumps and district heating in the manufacturing industry, secondly, hybrid heat pumps with the possibility to alternate between a heat pump and district heating depending on the energy prices, and thirdly, the combination of low temperature district heating and heat pumps for production of domestic hot water.

Introduction

Heat Pumps in District Heating Systems has been a Swedish national research project founded by the Swedish Energy Agency through the research program Effsys Expand. The project has also had an exchange of knowledge with IEA HPT TCP Annex 47, Heat Pumps in District Heating and Cooling Systems. The project has run for three years and was completed this summer.

The overall aim of the project was to investigate new combinations for heat pumps integrated in district heating systems. In three sub-projects, new possibilities have been explored for combining heat pumps and district heating. We have looked into the combination of heat pumps and district heating in the manufacturing industry, hybrid heat pumps that can alternate between heat pumps and district heating depending on the energy prices, and the combination of low temperature district heating and heat pumps for production of domestic hot water (DHW).

RISE Research Institutes of Sweden has been the coordinator, and the project was conducted together with five project partners from the industry: the heat pump manufacturers Nibe, Bosch Thermoteknik and Thermia, the district heating company Borås Energy and Environment, and the manufacturing company Volvo Cars.

Heat pumps in Swedish district heating grids today

Traditionally in Sweden there is a strong competition between the heat pump and district heating industries. By finding new applications, the two industries both can benefit from coexisting. Today, four heating technologies dominate the Swedish heating market: district heating, heat pumps, electrical heating and biofuel boilers. District heating covers over half of the total heating demand, while heat pumps and electrical heaters together have one third of the market. District heating is dominating for multi-family houses and premises, while heat pumps dominate for single-family houses [1]. District heating is well developed in Sweden and there are district heating grids in 285 of the county's 290 municipalities [2]. Also, no other country has the same or a larger amount of heat pumps installed in their district heating grids. 2013 the total installed heat pump capacity was 1.2 GW, and 4.5 TWh heat was produced with heat pumps for production of district heating in 2016 [3, 4]. This represents 7 % of the total heat delivered to the Swedish district heating grids. The main part of the energy is supplied to a few grids. The five largest producers of district heating via heat pumps deliver 85 % of the total amount of heat produced via heat pumps in the Swedish district heating grids [5].

Heat pumps in the manufacturing industry

One part of the project has focused on heat pumps combined with district heating in the manufacturing industry. Volvo Cars in Gothenburg, Sweden, uses heat pumps to recover heat from process cooling water. The heat pumps are used in combination with district heating for space heating and production of DHW. During winter, when the heating system requires high supply temperatures, the heat pump capacity is not enough and a district heating boost is required to reach a sufficiently high supply temperature. Since cooling water, of about 25 °C, can be used as heat source for the heat pumps, the COP is relatively high over the year, and a Seasonal Performance Factor (SPF) of 5.2 has been achieved.

The building where the heat pumps are installed is primarily used for development within Volvo Cars, which means that the building includes offices as well as test rigs. The two heat pumps installed have been running since 2011, and deliver around 10 GWh/year; in the same time the use of district heating is about 13 GWh/year.

Current connection of the heat pumps and district heating substation is made with heating in series. The return flow of the secondary heating system is first heated by the heat pump, then by district heating. The heat pump constitutes a base load during the heating

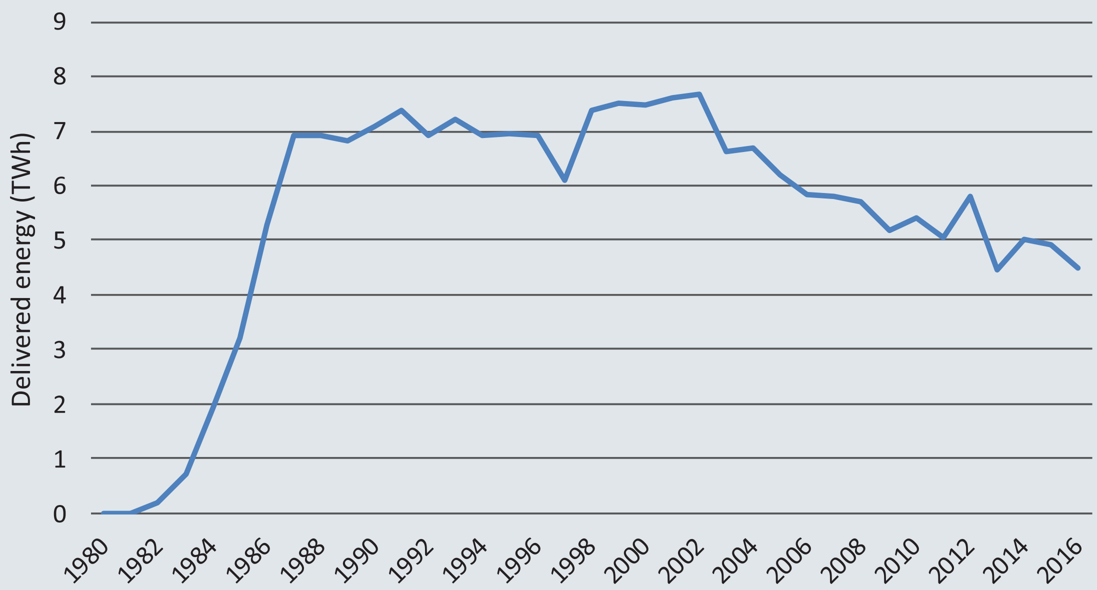

Fig. 1: Delivered heat from heat pumps to the Swedish district heat grids.

season, and district heating covers the peaks. During the summer, when the heating demand is lower, the heat pumps are shut off and all heating is produced by district heating. This is mainly due to seasonal variations in the district heating price, giving low energy prices during the summer. In the same time Volvo Cars evaluates the environmental burden from the district heating to be low during summer when the mix mainly consist of industrial excess heat and waste incineration.

The evaluation of the heat pumps at Volvo Cars shows that the best compromise for combining heat pumps and district heating is to make the connection in parallel instead of in series, since this gives a high COP for the heat pump and a low return temperature for district heating. The drawback is that the control strategy will be more complex compared to a series connection.

Hybrid heat pumps

Another part of the project has studied hybrid heat pumps with the possibility to alternate between heat pump and district heating for production of space heating and domestic hot water. In facilities and multi-family houses in Sweden with an installed heat pump there are often, for historical reasons, also a connection to district heating, and when needed district heating is often used as auxiliary heat. For the house owner it would be a benefit if it was possible to alternate between the two alternatives of heating depending on the lowest cost. This could also be used to reduce greenhouse gas emissions by using electricity or district heating when the share of renewables is high in each grid.

In a future smart grid, it would be a benefit to have the possibility to alter the technology for the heat production based on the demand and supply for electricity and district heating at the moment. Here a hybrid heat pump

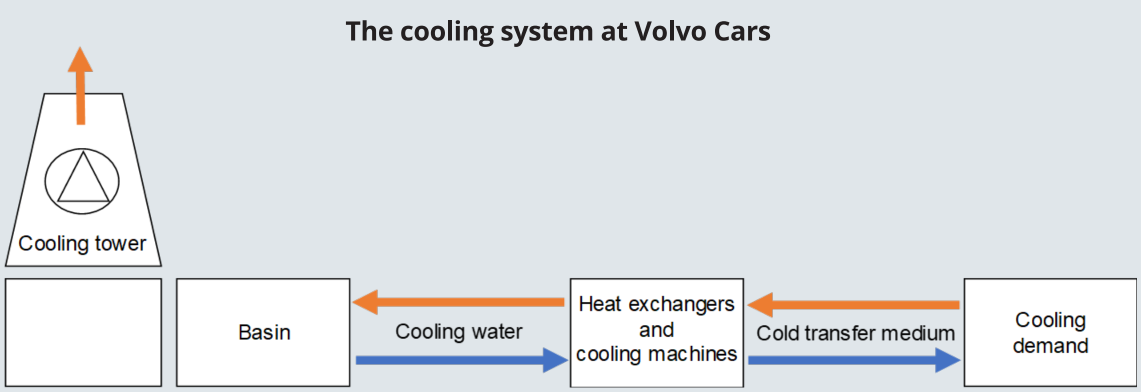

Fig. 2: The cooling system at Volvo Cars. Source: Volvo Cars

increases the flexibility. Today there are already existing hybrid heat pumps on the European market, but with a possibility to alter between a gas or oil boiler and a heat pump.

An algorithm was developed within the project, calculating the variable cost related to the choice of heat pump or district heating, depending on current operating conditions and energy prices, as well as selecting the energy production with the lowest hourly cost.

The algorithm has been tested in a case study based on a multi-family house in Linköping with both district heating and an exhaust air heat pump installed. Based on electricity and district heating prices in Linköping in 2015 [6, 7], the algorithm will mainly choose the heat pump during the autumn, winter and spring, while district heating dominates in the summer. The main reason is the seasonal energy prices for district heating in Linköping, with low prices during the summer month and higher during the rest of the year. Figure 3 shows the calculated variable cost for heating the model house in the case study.

In table 1, it is shown how the energy demand of space heating and DHW will be distributed when the hybrid heat pump in the case study makes an active choice based on the lowest variable cost for the model house in the case study. Since the heat pump cannot cover the total heating demand of the building during a large part of the year auxiliary heat, based on district heating, will be needed. With the heat pump used in the study it is possible to make an active choice for approximately 60 % of the energy demand.

In order to evaluate the financial conditions for using double systems, including both variable and fixed costs for heating, the life cycle costs were calculated using the net present value method. Based on the case study, the result shows that with a payback time of five years, depending on the energy prices, the investment of a hybrid heat pump can be 4,000-9,500 Euro higher than a traditional installed heat pump, cover as much as possible of the heating demand, and still have the same payback time (discount rate of 6 %/year). With a payback time of 10 years, the investment can be 7,000-17,000 Euro higher.

Heat Pumps for DHW production

For the future, low temperature district heating grids in combination with heat pumps can be an interesting solution. Using a low temperature in the grid has several benefits, such as lower losses to the surroundings and possibilities to use excess heat of lower temperatures as a heat source. Depending on the temperature in the grid, heat pumps will be needed primarily for production of DHW. The same approach can be used for using the district heating return flow as a heat source. The temperature in the return flow is often high enough for space heating, but for production of DHW a heat pump is needed to increase the temperature.

The project has studied how a heat pump solution for production of DHW should be designed, using district heating return flow as a heat source. One challenge with using the return flow as a heat source is the temperature variations, which affect the working conditions for the heat pump. One can also see that due to the temperature levels of the return flow, the use of the heat source for space heating directly requires floor heating in order to work. Thus, for multi-family houses in Sweden, this is

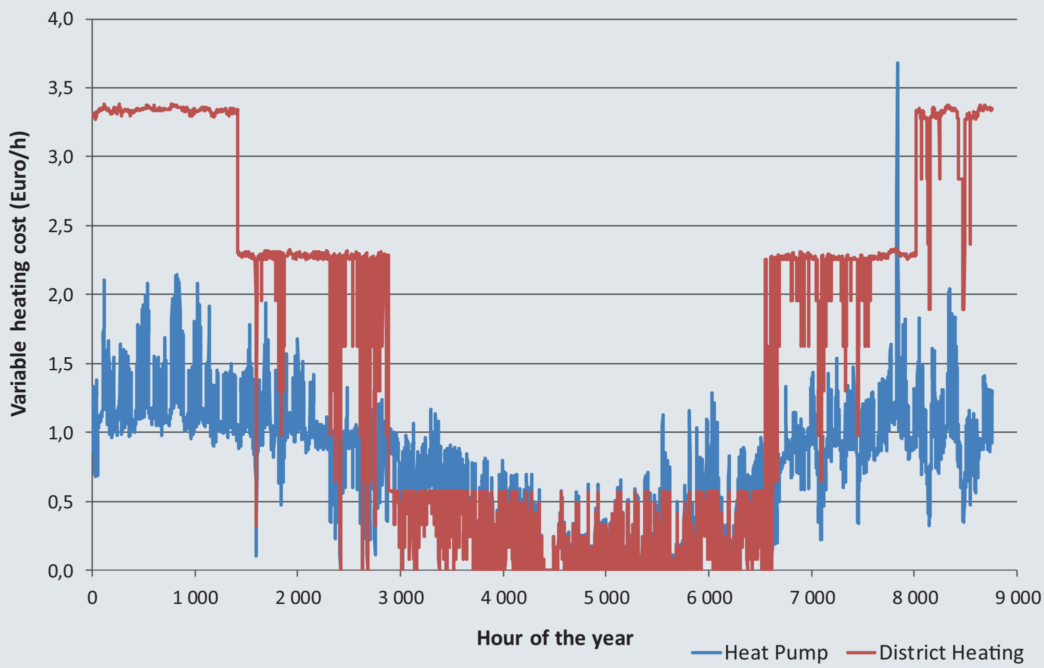

Fig. 3: Variable cost for space heating for the model house heated with exhaust air heat pump and district heating. Based on data for 2015. Costs for auxiliary heating excluded.

	Space Heating (MWh/year)	DHW (MWh/year)	Total (MWh/year)
Heat Pump (lowest variable cost)	378	10	388
District Heating (lowest variable cost)	116	63	179
District Heating (auxiliary heating)	316	117	433
Total heating demand	810	190	1 000

Table 1: Energy demand of the model house based on data for 2015, divided into heat pump and district heating

only applicable in new built houses, since more or less all existing multi-family houses today have radiators. The higher price for installing floor heating requires low energy prices of the return flow to make the alternative economically interesting.

The study has also shown that a storage tank for DHW is required for individual apartments or villas; direct heating of DHW without a tank requires a high power output from the heat pump and the Swedish building regulation (BBR) will not be fulfilled. It has also been shown that, for multi-family houses, a centrally placed heat pump is preferable compared to small heat pumps for each apartment, even though it leads to larger heat losses from the DHW circulation.

Acknowledgement

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