Hybrid Heat Pumps in Combination with District Heating

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Abstract

In Sweden the two most common ways to heat a building is either by heat pumps or by district heating. In many facilities and multifamily houses with an installed heat pump there are many times, by historical reasons also a connection to district heating. The prices for both electricity and district heating often vary over time. For the building owner it would be cost efficient if he had the possibility to combine the two heating facilities and switch between the two systems in order to choose the one with the lowest operating cost for the moment. One step closer to such a solution is to develop a method on how to calculate and chose the most cost efficient combination of heat pump and district heating operation depending on the operating conditions at the moment.

The main object with the study have been to develop an algorithm to calculate when it is best according to price to use district heating and when to use a heat pump for facilities that have both district heating and heat pump installations. In addition, life cycle cost calculations (LCC) have been performed in order to evaluate the costs related to using double systems. The method developed is based on Swedish conditions and takes into account running costs for electricity and district heating as well as the heat pumps performance at current conditions such as outdoor temperature and the type of heating system. The method also differentiates between domestic hot water production and space heating operation.

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Keywords: hybrid heat pump; district heating, cost

1. Introduction

1.1. Background

In facilities and multifamily houses in Sweden with an installed heat pump there are many times, by historical reasons also a connection to district heating. For the house owner it would be a benefit if there was a possibility to alter between the two alternatives of heating depending on the lowest cost. In a future smart grid it would be a benefit if it was possible to alter the technology for the heat production based on the demand and supply for district heating and electricity at the moment. Here a hybrid heat pump, with its possibility to vary the heating facility, increases the flexibility in the energy system.

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A hybrid heat pump is a heat pump with a possibility to differ between different way of heating, either to use a heat pump solution or another heating system. Today there are already existing hybrid heat pumps on the European market. Several heat pump suppliers offer a heat pump solution with a possibility to alter between a gas or oil boiler and a heat pump [1]. This article investigates the possibilities to alter between heat pump and district heating.

1.1.1. The Swedish heating market

The most common way to heat a building today in Sweden is to use district heating followed by electricity either by heat pump or electrical heaters, on third place come biofuel-boilers. More than 50% of the Swedish heating demand is covered by district heating [5]. Electric heaters and heat pumps are most common in single-family-houses, while district heating dominates in multi-family-houses. One third of the heating demand in Sweden is covered by heat pumps or electrical boilers. Today there are over 1 million installed heat pumps in Sweden, mainly in single family-houses. [6]

1.1.2. District heating prices in Sweden

The cost for district heating in Sweden varies from one municipality to another, the Swedish district heating association has published prices for different Swedish grids for three model houses [7]. In Figure 1 below the district heating prices related to a lager multifamily house are shown. As one can see the yearly cost for district heating varies from 40 to 80 Euro/MWh depending on where your building is located. There is also a large variation between different grids in how the tariff is built up, which makes it difficult to compare the prices easily.

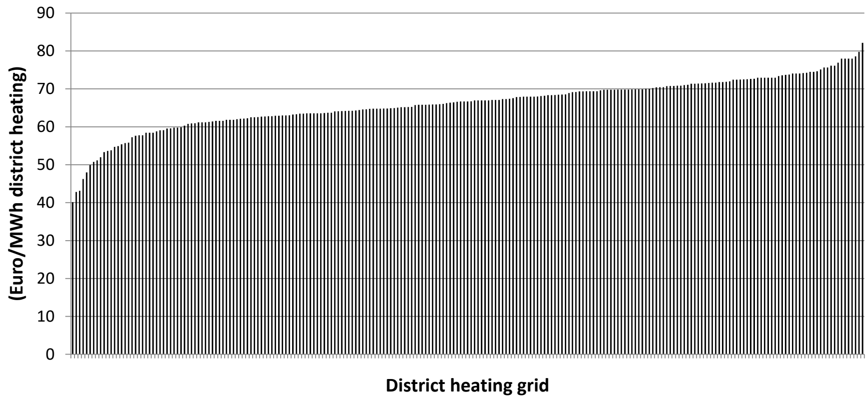

Figure 1. Variation in district heating prices 2016 for a building with a heating demand of 1000 MWh/year, based on at which district heating grid in Sweden the building is located, prices in Euro, VAT excl.

1.1.3. Electricity prices in Sweden

The Swedish electricity mix consist of mainly hydro- and nuclear power, together they represented 81% of the electricity production in Sweden 2015. The share of wind power is increasing and 2015 11% of the electricity came from wind power.

The Swedish electricity grid is divided in four “elspot areas”. I general the most of the electricity is produced in the north of Sweden, while the demand is largest in the south. The Sweden’s electricity market is a part of Nord Pool, which includes the Nordic and Baltic countries [8]. Nord pool is owned by the Nordic and Baltic transmission system operators. At Nord Pool the electricity spot price is set ones an hour. In Figure 2 below the daily average spot prices for electricity in “elspot area 3 – Stockholm” for 2015, is shown.

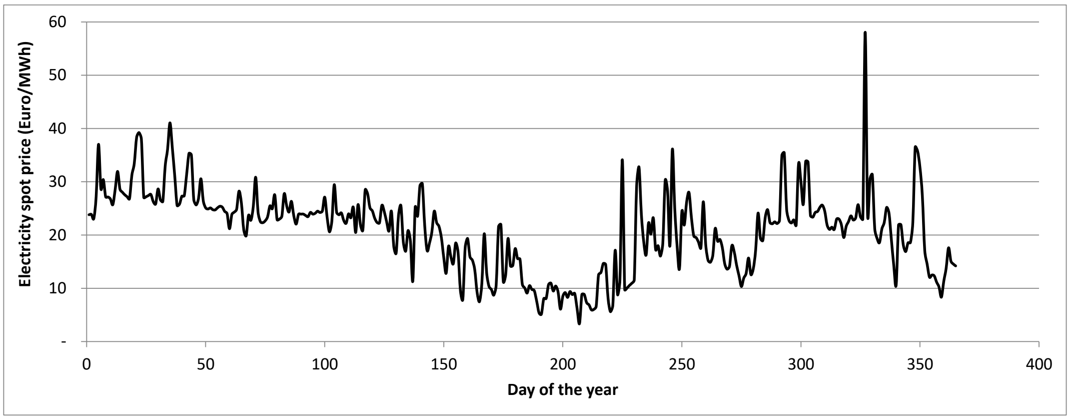

Figure 2. Variation of the electricity spot price for “elspot area SE3 -Stockholm” during 2015, based on data from Nord pool [8].

1.2. Scope

The main objective with the project described in this article is to develop an algorithm that can be used for smart control in a hybrid heat pump combined with district heating. The algorithm shall calculate the variable heating cost for the two alternatives and select the heating alternative that at the moment gives the lowest variable cost for the house owner. This is done for both space heating and domestic hot water (DHW) production.

The performance of the developed algorithm has been verified in a case study. The case study shows how the algorithm selects between a heat pump and district heating and includes a number of sensitivity analyses. The economic potential will also be discussed.

1.3. Delimitations

The article focuses on the Swedish situation. Other countries are not included in the analysis. Also for Sweden there is a large variation in how different price models are built up, both for district heating and electricity. The case study focuses on one the variable cost in one price model.

Only the economical aspect are analysed and the algorithm described focus on minimizing the variable cost for the building owner. Other aspects such as for example environmental burden are not included.

2. Method

A method of how to calculate the variable cost for space heating and DHW production for heat pump and district heating and selects the heating facilities with the lowest variable cost has been developed. The algorithm has to take the actual price for electricity as well as district heating into account. The smart control also needs to include the actual operating condition for the heat pump.

2.1. Construction of an algorithm for smart control

The algorithm makes an update of the current situation once every hour. Each hour the algorithm calculates whether a heat pump or district heating should be used to cover the heat demand of the building in order to minimize the cost for the building owner. The algorithm has to take the following parameters into account:

- Current electricity price
- Current district heating price
- Outdoor temperature

The calculations are made both for space heating and for domestic hot water production. The decision is based on the lowest running cost for the two ways of producing the amount of heat needed. This project have focused on minimizing the variable cost, but it would be possible to use the same algorithm in order to optimize based on another parameter, such as greenhouse gas emissions or primary energy use. The algorithm will work in the same way. The difference is related to the figures for the price or environmental burden of the energy.

Below follows a short description of how the algorithm works, step by step:

1. The first step for the algorithm is to update the current outdoor temperature.
2. Based on the outdoor temperature and information regarding the heating system the heat pump COP is known, both for space heating and production of domestic hot water.
   a. Note that the supply temperature and thereby the heat pump performance depends on the outdoor temperature. Therefor the outdoor temperature is important also for a heat pump not using outdoor air as a heat source.
3. In case the capacity of the heat pump cannot cover heat demand for both space heating and DHW, the heat pump prioritizes the production with the highest COP.
4. Heat pump: Based on the COP-value and the heating demand the electricity needed to produce the heat is calculated.
5. District heating: The demand of district heating is assumed to be equal to the heating demand.
6. In case there is a need for auxiliary heating it is assumed to be covered either by district heating or an electric heater.
7. Current prices for electricity and district heating are updated and the cost for producing the requested amount of heat is calculated for the two alternatives. This is made both for space heating and for DHW production.
8. The heating alternative with the lowest variable cost is prioritized, for space heating and DHW-production respectively.

3. Case studies

In order to evaluate the function of the algorithm cases studies have been made using the algorithm described in chapter 2 above. The case studies are based on a model house developed in the project. Data for the model house is based on an existing multifamily house located in Linköping, Sweden. The building has been investigated in a master thesis written by Gustafsson and Karlsson [11] and is a typical example of a building with both heat pump and district heating installed. Based on data given in the master thesis in combination with typical data for a house of that type and age a model house has been developed.

The house is built in 1961 and includes 93 apartments distributed on 11 floors. Based on measurements [11] the yearly heating demand of the building is 915 MWh. For the model house the heating demand is assumed to valid for a year with an average climate for Linköping, based on data from Meteonorm [18]. The heating system includes district heating in combination with two exhaust air heat pumps. In the model house only one exhaust air heat pump is assumed, with a maximum capacity of 75-80 kW. The model shows that the heat pumps can cover approximately 60% of the annual heating demand. The rest of the heating demand is covered with district heating. The DHW demand is set to 130 MWh/year and the heat losses related to the hot water circulation to 60 MWh/year, giving a total heating demand related to DHW-production of 190 MWh/year.

The performance of the heat pump is not based on a specific heat pump model but have been generated based on input from two heat pump producers of exhaust air heat pumps [12][13] in order to make sure that realistic values have been used. The heating system in the building is assumed to follow the medium temperature application with variable outlet temperature for the cold climate according to EN14825:2016 [17]. The performance data can be seen as typical data for a new exhaust air heat pump of that size. The maximum capacity is set to 75-80 kW and COP for space heating is set to 4.0 at -7°C and to 5.0 at +7°C. COP for DHW-production is set to 3.0.

3.1. Case study, lowest variable cost based on energy prices 2015 in Linköping

In the base case the variable cost for covering the heat demand either with district heating from the city Linköping or with an exhaust air heat pump has been investigated. In this case the actual prices and climate from 2015 have been used. The electricity prices are based on hourly statistics from Nord pool during 2015, while the district heating prices are based on price tariff from the district heating supplier Tekniska Verken 2015 [10]. Linköping is located 200 km southwest of Stockholm and is Sweden's fifth largest city, with 153 000 inhabitants

[14]. Hourly climate data for 2015 have been used based on statistics from the Swedish Meteorological and Hydrological Institute, SMHI [15].

3.1.1. Electricity price

The electricity price is based on hourly statistics from Nord pool 2015 [8] for the electrical market area SE3, where Linköping is located. To the spot prices costs for electric certificates, taxes, cost for electricity transmission in the net and the electric company's mark-up is added. VAT is not included. Fixed costs, such as a yearly fee based on the size of main fuse, is not included.

3.1.2. District heating price

The district heating prices in Linköping are based on three levels depending on the month of the year. The prices have large differences in price between the summer- and winter period, see Table 1 below.

Table 1. District heating prices in Linköping 2015 [10].

Month	Price district heating (SEK/kWh)	Price district heating (Euro/kWh)†
Dec-Feb	0.395	0.040
Mar-Apr, Oct-Nov	0.255	0.026
May-Sep	0.078	0.008

In addition there is a cost related to district heating flow calculated to approximately 0.05 SEK/kWh for the model house [10]. According to statistics from the Swedish district heating association regarding district heating prices in Sweden the yearly prices for Linköping is slightly below the average in the country [7].

3.1.3. Analysis of lowest variable cost distribution for a model house in Linköping

In Table 2 below the annual heat demand is shown for the model house based on climate statistic from SMHI, for 2015 [15]. Note that 2015 was a relatively warm year and the buildings heating demand for 2015 (810 MWh) is lower than the heating demand for an average year, based on Meteonorm data (915 MWh). The table shows how the heat demand is covered by the two heating alternatives when the algorithm makes an active choice. It also shows the amount of auxiliary heat needed, in this case covered by district heating. Since the capacity of the heat pump is smaller than the model houses heating demand at lower temperatures additional heating is needed during a large part of the year. The bivalent temperature, where the heat pump can cover the whole heat demand of the model house without auxiliary heat, is calculated to +9°C.

Table 2. The model house´s heating demand 2015 broken down by heating facilities

	Space heating (MWh/year)	**DHW production** (MWh/year)
Heat pump (lowest variable cost)	378	10
District heating (lowest variable cost)	116	63
District heating (auxiliary heat)	316	117
Total heating demand	**810**	**190**

Figure 3 below shows a summary of the results regarding how the algorithm prioritizes between district heating and the exhaust air heat pump, based on data from 2015 on an hourly basis. The figures show the percentage of hours each month when district heating or the heat pump has the lowest variable cost. The heat pump capacity is too small to cover the whole demand of both space heating and DHW production and have to prioritize. Since the COP for the space heating is higher than for the DHW production in this case, the heat pump will prioritize space heating. Only the hours when the heat pump has the capacity to produce DHW, there will be an active evaluation of the lowest cost between the two heating alternatives. For hour when the heat pump cannot cover the DHW production auxiliary heating (district heating in this case) will be used. In the diagram to the right in Figure 3 these hours are showed as “HP prioritizes space heating”.

† 1 Euro = 9.87 SEK [16]

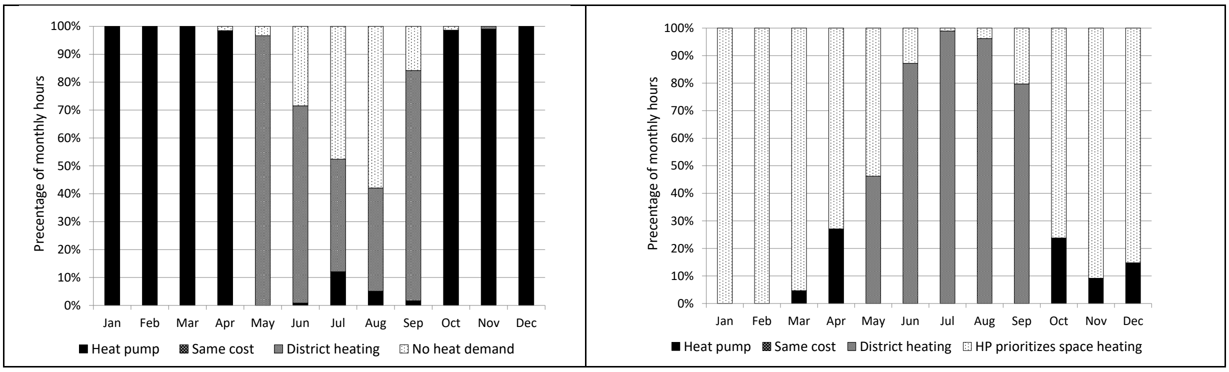

Figure 3.Percentage of hours with lowest variable cost for the Linköping scenario, space heating (left) and DHW-production (right). Auxiliary heat excluded.

In Figure 4 below the variations over the year for the variable cost related to the space heating of the model house is shown.

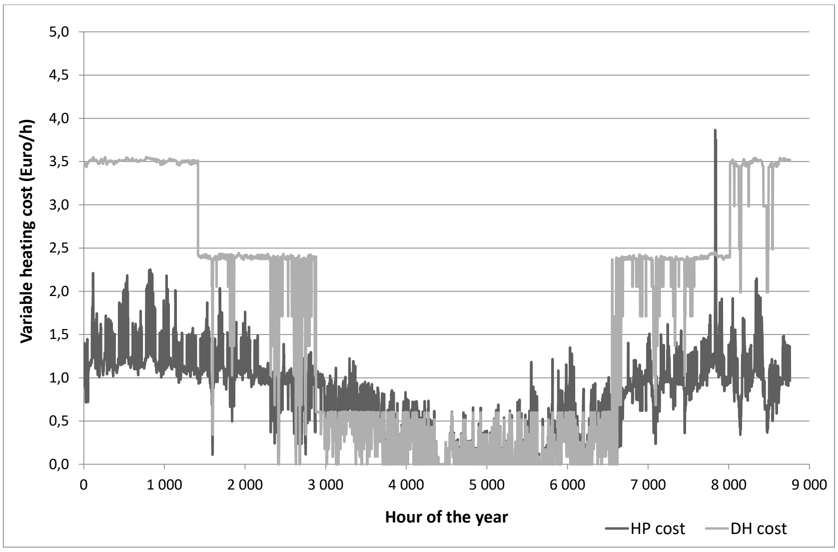

Figure 4. Variable space heating cost for the model house heated with a exhaust air heat pump or district heating, based on data for 2015.

The general trend is clear. The heat pump has the lowest running cost from October to April when the district heating prices are high. This is the case for both space heating and DHW-production. During the summer month with a low price on district heating, district heating is preferred most of the hours. The difference in cost between the heat pump and district heating is anyhow small during the summer months. Small changes in the energy prices might have a large impact on how the smart control priorities.

3.2. Sensitivity analysis, variation of price ratio

In the sensitivity analysis the ratio between the electricity- and the district heating price is varied in order to investigate how large difference in price that is needed for the algorithm to switch from district heating to the heat pump and back. The case study is based on the same model house as described above with climate data from 2015.

The electricity price has been fixed at 100 Euro/MWh while the district heating price has been varied. At a district heating price of 35Euro/MWh the variable cost is lowest for the exhaust air heat pump 100% of the time for both space heating and DHW-production. At 30 Euro/MWh the algorithm choses the heat pump technology for space heating while DHW-production is covered with district heating. If the price for district heating is getting lower also the space heating starts to be covered by district heating. Table 3 and Figure 5 below show the situation with a district heating price of 20 Euro/MWh.

Table 3. The model house´s heating demand broken down by heating facilities with a fixed energy price of 100 Euro/MWh for electricity and 20 Euro/MWh for district heating

	Space heating (MWh/year)	DHW production (MWh/year)
Heat pump (lowest variable cost)	186	0
District heating (lowest variable cost)	308	73
District heating (auxiliary heat)	316	117
Total heating demand	**810**	**190**

Here the heat pump is preferred at higher outdoor temperatures when the COP is high, while district heating is used at colder temperatures for space heating. The DHW-production is totally covered by district heating. If the district heating price is lowered to 15 Euro/MWh, district heating is chosen all hours of the year.

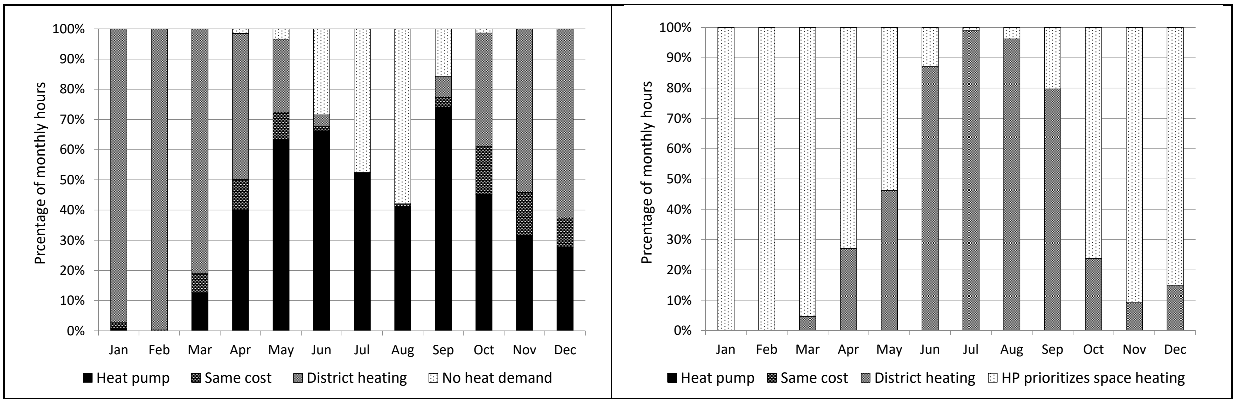

Figure 5. Percentage of hours with lowest variable cost with fixed energy price of electricity 100 Euro/MWh, district heating 20 Euro/MWh, space heating (left), DHW-production (right). Auxiliary heat excluded.

3.3. Sensitivity analysis, variation of heat pump COP

It has also been analyzed how the results are affected related to the efficiency of the heat pump. In the base case scenario typical data for a modern exhaust air heat pump have been used. Based on the performance data for the heat pump in the base case the COP-values have been increased and decreased in order to see the differences in result. No changes have been made to the district heating production.

In the first case the COP values for both space heating and DHW-production have been increased with 20%. This can for instance represent a future improved heat pump. The effect of increasing COP can be seen in Table 4 and Figure 6 below, the base case is show in Table 2 and Figure 3.

Table 4. The model house´s heating demand broken down by heating facilities, result based on a heat pump with an increased COP of 20%

	Space heating (MWh/year)	DHW production (MWh/year)
Heat pump (lowest variable cost)	410	10
District heating (lowest variable cost)	84	63
District heating (auxiliary heat)	316	117
Total heating demand	**810**	**190**

For space heating the heat pump now dominates most of the year, except for May and September. The summer month, June, July and August that in the base case was dominated by district heating will now be dominated by the heat pump. In the base case district heating was dominating from May to September. The difference in price for the two energy alternatives is anyhow small during the summer period. A small change in the energy prices can lead to large changes regarding what energy alternative that has the lowest costs. For the DHW-production there is no difference in result. As for the base case May to September district heating will give the lowest variable costs while the rest of the year the heat pump solution will give the lowest variable costs.

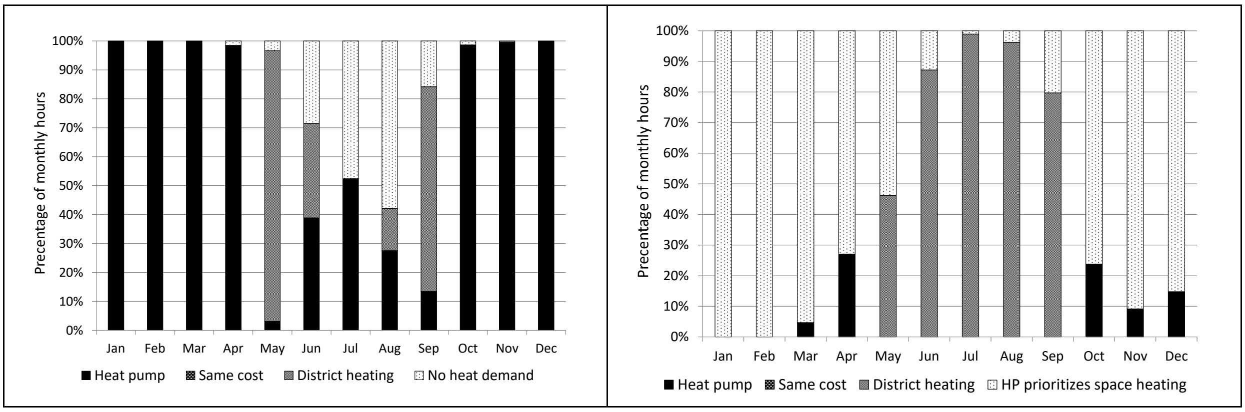

Figure 6. Percentage of hours with lowest variable cost for Linköping scenario with heat pump COP <u>increased</u> 20%, for space heating (left) and DHW-production (right). Auxiliary heat excluded.

In Table 5 and Figure 7 below the opposite situation is shown. The heat pumps COP values have been decreased with 20%. A situation with 20% lower COP values can for instance represent older technology or a badly installed heat pump system. For space heating the period from May to September will be totally dominated by district heating. In the base case a smaller amount of the hours was covered by the heat pump. During the winter month the decrease in COP has no effect on the result. With the high winter price for district heating in Linköping the heat pump solution will dominate from October to April. For DHW-production the general tendency is similar to the base case, but for hours with a high electricity price in March and November one can see that district heating now have a lower variable cost and is prioritized.

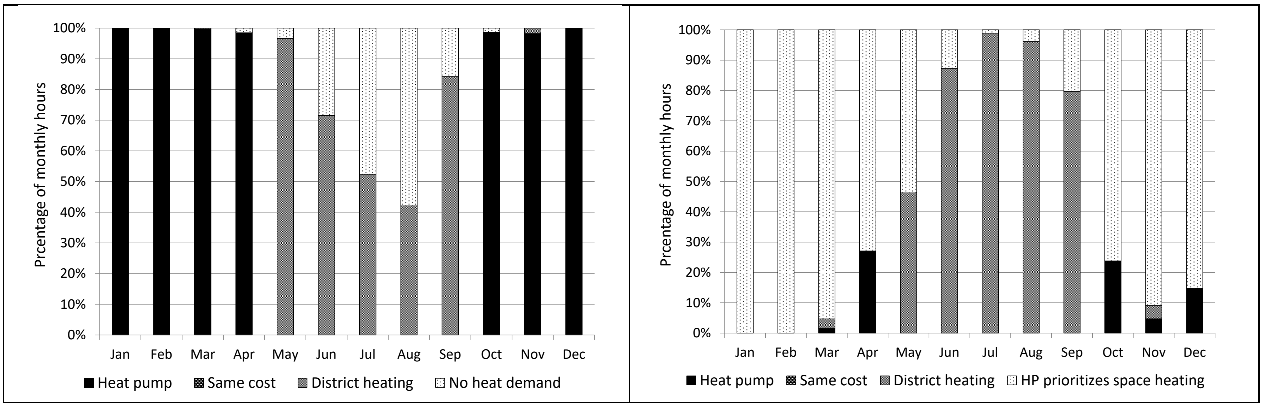

Figure 7. Percentage of hours with lowest variable cost for a scenario with heat pump COP <u>decreased</u> 20%, for space heating (left) and DHW-production (right). Auxiliary heat excluded.

In general the impact related to the variation of the COP values are relatively small, the impact on the result related to the price is much larger.

Table 5. The model house´s heating demand broken down by heating facilities with a heat pump with a decreased COP of 20%

	Space heating (MWh/year)	**DHW production** (MWh/year)

Heat pump (lowest variable cost)	373	9
District heating (lowest variable cost)	121	64
District heating (auxiliary heat)	316	117
Total heating demand	**810**	**190**

4. Cost saving potential

For the base case with the model house located in Linköping and energy prices for 2015 a calculation of the potential cost savings related to an implemented algorithm has been done. For a building with both exhaust heat pumps and district heating installed the potential cost savings related to have the possibility to select the heating technology with the lowest variable cost are 500-1000 Euro/year depending on how one assumes the heat pump to operate for the case where one has both heat pump and district heating installed but without a smart control.

If one uses data for 2010 for electricity prices and outdoor temperatures the cost saving potential will increase to approximately 2000 Euro/year (calculated with the same district heating prices as 2015). The winter 2010 was cold in the south of Sweden and the electricity prices were high all year. The average electricity price at Nord Pool was approximately 2.6 times higher 2010 compared to 2015. This makes the variable costs for the heat pump solution higher, both since the electricity prices are higher but also since the lower temperature will decrease the heat pump COP. The effect of the higher heating cost for the heat pump is that the variable cost for the heat pump gets closer to the cost for district heating. The variation of the electricity price from hour to hour makes sometimes the heat pumps solution preferable and sometimes the district heating, thereby the benefits of a smart control increase.

Based on data for 2015 the heat pump has a capacity to cover approximately 60% of the yearly heating demand of space heating and DHW for the model house. Thereby a large part has to be covered by district heating. The annual savings related to installing a heat pump is approximately 8000 Euro/year compared to a case with district heating only. If a smart control based on the algorithm is installed additional 500-1000 Euro/year can be saved. Using data for 2010 (with higher electricity prices) the annual saving related to installing a heat pump are smaller, approximately 3000 Euro/year. But the saving potential related to the smart control increases to approximately 2000 Euro/year. How much of the potential cost saving that is related to the installation of the heat pump and how much that is related to a smart control depends on the energy prices and how they are variating.

5. Discussion

With the energy prices today in Sweden the economical saving related to the use of a smart control is moderate but not negligible. The case study for a multi-family house in Linköping shows that the potential annual savings are approximately 500-1000 Euro/year. With a total heating cost of 24 000 Euro/year for the model house it gives a saving of 3-4%. 2010 was a cold year and even if the annual saving related to the smart control increased to approximately 2000 Euro that year also the heating costs increased, giving an cost saving related to the smart control of 5%.

With larger variations in the energy prices and a situation when it often differs which heating alternative that has the lowest variable cost the benefits related to the smart control increase. In the model the electricity prices have been varied each hour. Many times the contract with the electricity supplier gives a fixed price each month or for a longer period. The district heating prices in the case studies vary on a monthly base. The befit of the algorithm will increase the more the prices vary.

The smart control is designed to minimize the energy cost for the building owner, but with a price model where the energy companies more actively varies the energy price depending on the actual situation also the energy company will benefit. One example is to avoid starting expensive plants for marginal production of district heating, plants that many times also have a production with a high environmental burden. With a number of buildings that switch from district heating to heat pumps when the energy company increases the district heating prices the demand of district heating will decrease and the start of the marginal plant might be avoided. The same arguments can be used for electricity, the difference is that the electricity system is much larger and more buildings with smart control are needed before one sees a difference. Another example is during periods with a high supply of district heating compared to the demand e.g. when district heating production is based on the waste incineration plant but the demand for district heating is low. Here the prices can be lowered and customers switch from heat pump to district heating.

In an electric grid with a larger share of electricity from wind and sun the supply of electricity will differ more. The larger variations in electricity supply will probably lead to larger variations in the electricity prices. In a future smart grid the possibility to vary the heating technology based on the actual supply and demand of electricity increases the flexibility for the system and can help cutting of the power peaks.

6. Conclusions

- The article describes how an algorithm for smart control of a hybrid heat pump that can alter between a heat pump and district heating for production of both space heating and domestic hot water can be designed.
- The profit from installing a smart control increases when there are larger variations in the energy prices. In the same time the variable heating cost for the two heating facilities should be close enough to each other to make the heating alternative with the lowest variable cost alternate.
- The case study shows that with the energy prices today in Sweden it is profitable to have the possibility to alter between the two heating alternatives if the building has both district heating and a heat pump already installed. The potential cost saving according to the case study is 3-5% of the total energy cost.
- The case study shows that with today's electricity and district heating prices in Linköping the algorithm will mainly choose the heat pump for heat production from October to March, while district heating is chosen for the period May to September. This includes both space heating and DHW production.
- Based on the situation in the case study a variation of the cost ratio between district heating and electricity was done. The analysis shows that the breakpoint when district heating has the lowest variable cost happens with a district heating price of 20-30% of the electricity price.
- The impact on the result related to a variation of the heat pump COP is much smaller than the impact related to the prices for electricity and district heating.

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