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LAB TEST ON AN ACTIVE CONTROLLED RESIDENTIAL HEAT PUMP

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Abstract

Since an increasing number of unpredictable and undispatchable local renewable energy sources like pv-installations or wind turbines are coupled to the electrical distribution grids, balancing of these grids become more and more challenging. Demand response is seen as a way to deal with this problem.

To assess the demand response performance of a residential heat pump, a lab setup was built. This setup consists of an 11 kW heat pump, combined with two buffers: one for storage of domestic hot water and one for storage of space heating. In addition, the house also has a building integrated pv-installation or a small scale wind turbine and some uncontrollable load. By means of a market-based multi-agent system (MAS), the heat pump is controlled. The ambition was to enable the heat pump when local renewable electricity production was available and to switch the heat pump off at times when there already was a high electricity demand from the household (peak shaving). The tests were performed for both the coldest winter week and an average winter week in a Belgian climate, whereby first the heat pump was controlled by means of a standard heat driven control algorithm and afterwards by means of active control.

The tests show that active control is able to reduce the peak power extraction from the grid significantly. Also the self-consumption of local produced electricity of the house increased by 8 to 30%. However, the results also indicate that the active controlled heat pump consumes more electricity (8-12%).

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1. Introduction

Over the last years, the consumption of electricity has drastically grown [1]. This trend is expected to be continued and even is going to increase in the coming years, due to expanding comfort demands (e.g. air conditioners) and a strong market growth of energy efficient technologies (e.g. heat pumps and electric plug-in cars). On the other hand, also more and more electricity from local renewable energy sources, like wind mills and photovoltaic panels, will be injected in the grid. Certainly in Belgium, the installed capacity of photovoltaic power has developed rapidly. In 2011 this small country had the ninth largest market worldwide, due to favourable subsidy mechanisms [2].

Without measures, this increase in both consumption and local production of electrical power can lead to grid capacity problems and unwanted shutdowns of renewable energy sources [3]. Reinforcement of the power lines is an option, but studies show that investments in flexible loads would be less expensive [4–6] . Off-peak operation or load shifting is a form of flexibility. Heat pumps, in combination with thermal storage, are interesting devices for load shifting purposes and for supporting the (smart) electrical grid.

To assess the performance of a heat pump for load shifting, a lab setup was built. This paper presents the first results of the active controlled heat pump. In these tests, the aim was to switch the heat pump on when renewable solar electricity is available. Therefore the heat demand of a single household during a winter week was

emulated by a heat exchanger. The heat pump was controlled by means of a market-based multi-agent control mechanism.ere introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 10 pt. Here follows further instructions for authors.

2. Methods

The lab setup represents a heat pump installation for a single-household residence. The heat pump provides heat for space heating and for production of domestic hot water. Two water storage buffers are included to store the heat produced at times when no or few heat is needed. The domestic hot water storage has a capacity of 300 l while the space heating buffer has a capacity of 400 l. A schematic overview of the installation is shown in Figure 1.

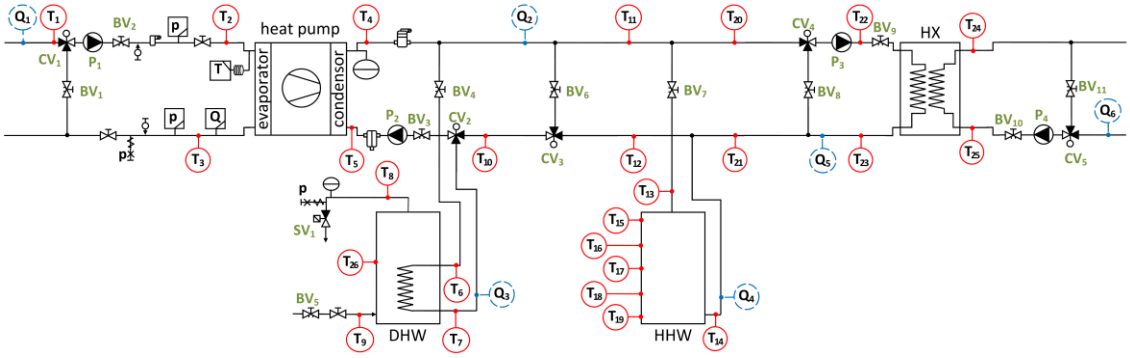


Figure 1: Schematic overview of the heat pump setup

The evaporator of the heat pump is coupled to the lab infrastructure. This allows controlling the temperature and flow to the evaporator. In this way the source of the heat pump can be emulated.

The heat pump can deliver its heat to either the domestic hot water ('DHW') vessel or the heating hot water ('HHW') vessel. The heat exchanger ('HX') is used to emulate the space heating demand of the building. The secondary side of this heat exchanger is coupled to the lab, through which the heat extraction can be controlled. An electronic valve (SV_1) is used to simulate hot water draw from the DHW-buffer. 26 temperature sensors (red) and 6 flow sensors (blue) are used to fully survey the state of the installation.

Next to the heat pump, the household obviously has other electricity consumers. These were assumed not to be controllable and are included in the experiments as 'dumb' loads. A profile for this dumb load was recorded in a real household. During the studied week, the electricity consumption of this household was 76 kWh, excluding the heat pump installation.

The photovoltaic power production profile was obtained by a TRNSYS-simulation [7]. The aim was to get a net-zero energy building, which means that the PV-installation produces as much electricity as is consumed during a whole year. Therefore, a 7.7 kWp installation was needed, with an annual production of 6 673 kWh. During the tested week, this installation produced 123 kWh of electrical energy.

To decide when the heat pump may switch on, a market-based multi-agent system (MAS) was developed. In this system, each device has its own agent. By means of bidding curves, these agents communicate the willingness of a device to switch on or off to a controller called 'prioritizer'. A bidding curve described the power demand/supply of a device (y-axis) in relation to the priority to switch (x-axis). The priority can be seen as a virtual electricity price. Applied to the heat pump, when the buffers are almost full, the heat pump will only be willing to operate when the priority/price is low. If the buffers run empty, this threshold will shift towards higher priorities.

The bidding curve from the agent for the grid has an opposite progress: when priority/price is low, the grid wants to deliver only little energy; when the priority increases, the grid is willing to deliver more electrical power.

For the dumb load, the bidding curve is flat: no matter what the priority is, the demand of electricity must always be met. Same for the photovoltaic panels: regardless the priority the panels will deliver its power at any time.

After communicating all biding curves to the prioritizer, equilibrium for traded energy and priority/price is calculated. The whole idea of MAS control is shown in Figure 2.

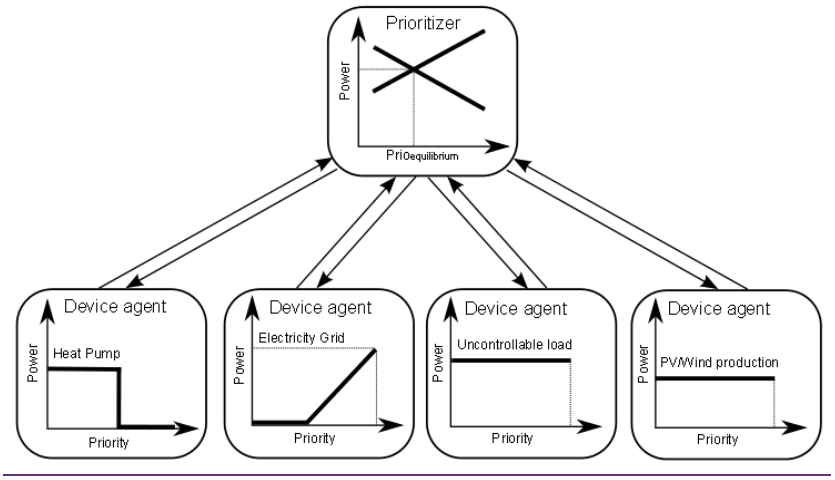


Figure 2: The market-based multi-agent system

In the business case that we describe in this paper, the goal is to keep the electrical demand of the building within variable limits. This is a concrete question from the distribution system operators (DSO): to guarantee the reliability of the electrical grid, the power consumption of a building should stay within a certain bandwidth, adapted to the amount of renewable electricity available. To be able to emulate this business case, the power bandwidth profile is inserted as an input. To maintain the electricity consumption in this bandwidth, both peak shaving and maximization of own-consumption of PV-power will be imposed on the house by the control algorithm.

3. Results and discussion

In these first set of tests, the aim was to check if the suggested MAS strategy actually worked properly. Therefore a comparison was made between a heat pump with and without active control. The first analysis determined the normalized on-time of the heat pump in relation to the electricity flow of the house (Figure 3). On the horizontal axis, the dumb load of the household minus the production of PV-panels is shown. The vertical axis shows the time that the heat pump is active: 0% means that the heat pump is always off for that power frame, 100% means the heat pump is on. It is clear that when abundant electricity production is present (low x-axis values), the heat pump is enabled more often than in case of absence of renewable electricity (high x-axis values).

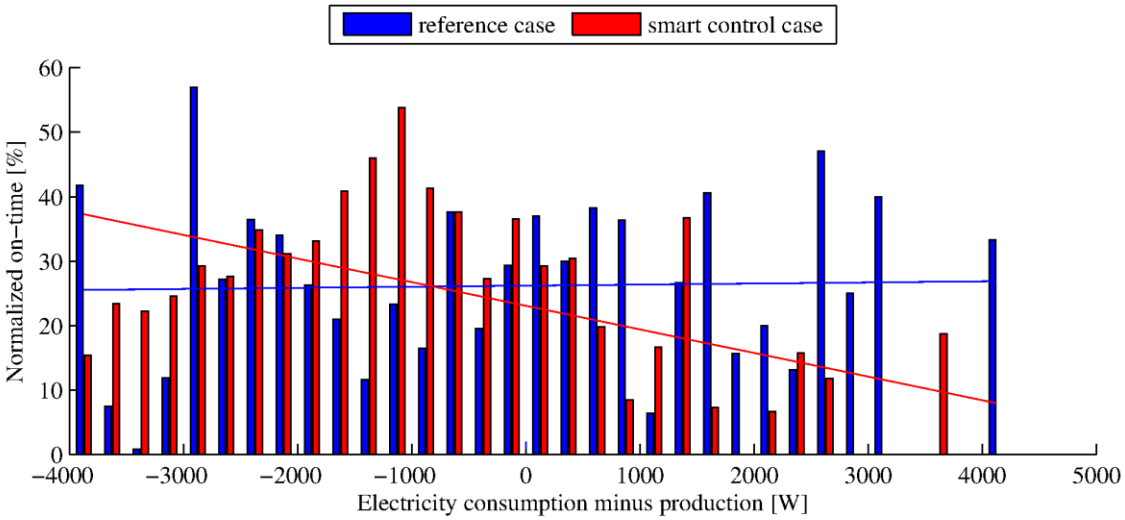


Figure 3: Normalised on-time for the heat pump installation

This can also be seen in Figure 4, showing the electricity consumption of the heat pump and the uncontrollable load, during one day. The heat pump is switched on when the dumb load is low. Only when the buffers run empty, the upper consumption limit is sometimes violated. The reason therefore is that the thermal comfort of the building must be guaranteed at all time.

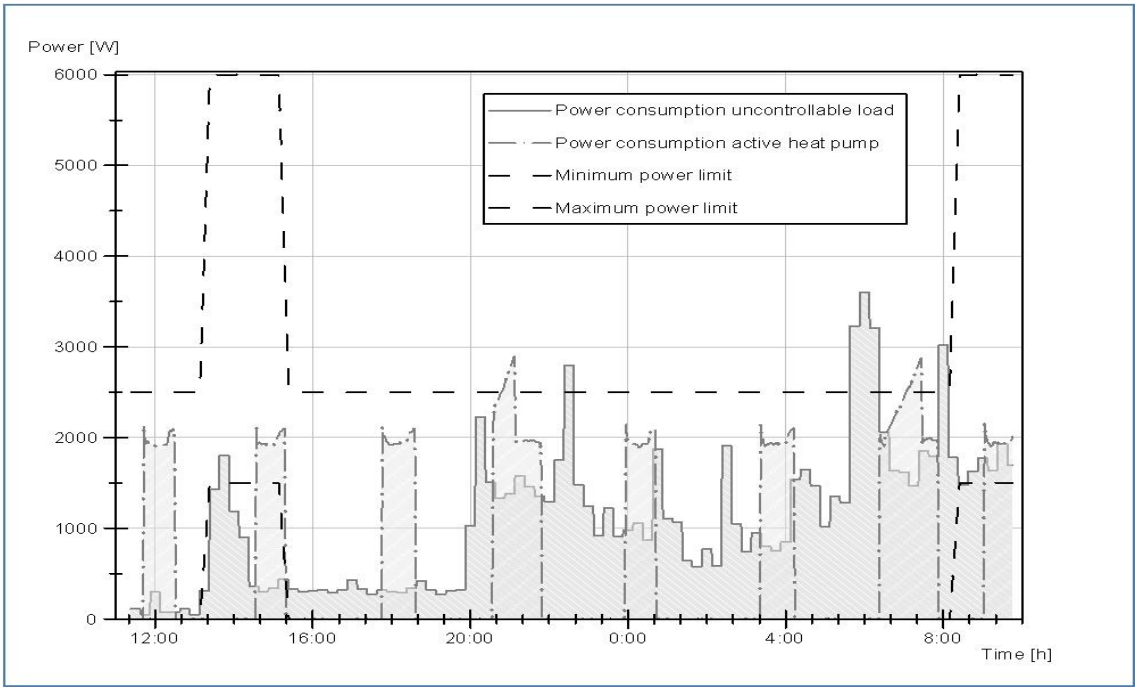


Figure 4: Electrical power consumption of the uncontrollable load and the heat pump and the power bandwidth

The tests however also show an extra electricity consumption of the active controlled heat pump installation in comparison to the reference. While in the reference case the heat pump installation only consumed 84.4 kWh, for the active controlled case this was 94.4 kWh (+11.8%). This can mainly be attributed to the number of switches of the installation. In the reference case the number of switches is minimal: only when the buffers are totally empty, they are fully charged. During the week, the heat pump was activated 46 times. In the active case the heat

pump is switched more often, namely 161 times. Therefore an active controlled installation implies more start-up losses.

To investigate the effectiveness of active control, Baetens et al. [8] suggested the use of cover factors γ_D and γ_{PV}. These factors are a measure for the correlation between power demand and production by the PV-installation. γ_D is defined as the ratio to which the power demand is covered by the PV-installation. The higher this ratio, the more of the household electricity demand is covered by the photovoltaics. Analogously, γ_{PV} is defined as the ratio to which the PV-supply is covered by the power demand of the household.

Both factors should be as high as possible. A building with year-round γ_D^{year} and γ_{PV}^{year} of both 100% would mean that the PV-installation production profile would exactly match the demand profile. If γ_D^{year} is high but γ_{PV}^{year} is low, than the demand of electricity is mostly covered by the PV-installation but a large share of the produced electricity would be injected in the grid. A building with a low γ_D^{year} and a high γ_{PV}^{year} is a building which does not inject much energy to the grid, but also does not cover much of the own demand of electricity.

In the reference case, the cover factors are calculated as γ_D^{year} = 26.9% and γ_{PV}^{year} = 30.8%. These rather low factors indicate that the distribution grid is often used as a virtual storage. With active control, these factors increase to γ_D^{year} = 35.2% and γ_{PV}^{year} = 42.8%. Both factors increase, but the difference is not dramatic. There are some explanations for this. One is that there is still a large share of uncontrollable load in the household. Another reason is that, because of the limited storage capacity in the heat pump installation, the flexibility of the installation is often small.

4. Conclusions

To deal with local capacity problems in electrical distribution grids, the demand of electricity should be matched to the production of renewable electricity. Heat pumps are excellent candidates for demand response due to its large share in the household electricity consumption. To assess the performance of an active controlled heat pump, a lab test setup was built. The aim of the test setup was to operate the heat pump as much as possible when photovoltaic power is available.

The first test show that the heat pump is working properly: the heat pump is operated when renewable power is available, however due to comfort reasons, the boundary limits are sometimes violated.

The analysis of the results also shows that an active controlled heat pump consumes more energy than the reference heat pump. This is mainly attributed to the larger number of switches of the installation.

Investigation of the cover factors of the photovoltaic panels show that these factors increase when the heat pump is controlled actively. These factors could even increase further by adding more controllable devices to the household or by increasing the storage capacity of the installation.

References

[1] IEA. Key world energy statistics 2010. OECD Publishing, 2010.
[2] European Photovoltaic Industry Association (EPIA). Market report 2011. 2011.
[3] Verschueren T, Mets K, Meersman B, Strobbe M, Develder C, Vandevelde L. Assessment and mitigation of voltage violations by solar panels in a residential distribution grid. In: 2011 ieee international conference on smart grid communication. Brussels, 17-20 Oct. 2011: 2011.
[4] Østergaard PA. Ancillary services and the integration of substantial quantities of wind power. Applied Energy 2006;83(5):451-463.
[5] Lund H. Large-scale integration of wind power into different energy systems. Energy 2005;30(13):2402-2412.
[6] Barth R, Brand H, Swider DJ, Weber C, Meibom P. Regional electricity price differences due to intermittent wind power in germany: impact of extended transmission and storage capacities. International Journal of Global Energy Issues 2006;25(3/4):276-297.
[7] Klein SA, Beckman W, Mitchell J, Duffie J, Duffie N, Freeman T. Trnsys 16 - a transient system simulation program 2004.

[8] Baetens Ruben, De Coninck Roel, Van Roy Juan, Verbruggen Bart, Driesen Johan, Helsen Lieve, Saelens Dirk. Assessing electrical bottlenecks at feeder level for residential net zero-energy buildings by integrated system simulation. Applied Energy 2012:13 pages.