# Grid Flexible Control of Heat Pumps

**Markus Lindahl, Sweden**

**Within the EU project Flexible Heat and Power (FHP), RISE Research Institutes of Sweden has, together with the other project partners, evaluated the possibilities and limitations for external control of today's and tomorrow's heat pumps. This in order to control the power consumption, as well as providing demand response. Both indirect control, via temperature sensor override, and direct control of the compressor speed has been evaluated by laboratory tests of a ground source heat pump. Direct control gives the best accuracy, while indirect control works on more or less all heat pumps.**

## Introduction

The European power system is undergoing a major transformation driven by a steadily increasing share of power from renewable intermittent energy sources, such as wind and sun. Heat pumps, with their possibility to convert power to heat, can support the transformation of the power system. Making use of the building's thermal inertia in combination with controlling the heat pump´s power consumption makes it possible to also provide demand response.

The EU project Flexible Heat and Power (FHP) was completed during fall 2019, and included partners from seven different research institutes and companies in Europe. RISE Research Institutes of Sweden has, together with the other project partners, evaluated the possibilities and limitations for external control of today's and tomorrow's heat pumps, with focus on space heating of buildings. By external control of the heat pumps and their power consumption, demand response can be offered to the power grid. The term "demand response" includes controlling the power consumption to better match the consumption with the power supply. Demand response can be used to avoid power peaks, balance the power consumption, avoiding curtailment of power production from intermittent renewable sources, etc. The aim of the FHP-project is to use demand response to secure that electricity from intermittent, renewable sources, such as wind and sun, can be used. In the FHP project this is done by making dynamic clusters of heat pumps, giving higher flexibility when controlled together.

## The Flexible Heat and Power project

Within the FHP project, the demand response possibilities of heat pumps have been investigated. The benefit with heat pumps, when it comes to demand response, is their possibility to transform power to heat. In combination with the thermal inertia in buildings, or thermal storages, it gives a possibility to control, within certain limits, when the building needs to be heated and still maintain a good indoor climate. By controlling the power consumption of the heat pump, it is possible to help balancing the power systems variations in supply and demand. However, controlling the power output from a single heat pump gives low flexibility to the grid, so in order to provide a useful scale of demand response, a coalition of heat pumps needs to be controlled. In order to do this in an efficient and functional way, several steps are needed.

The first step is to calculate the available thermal flexibility from the individual buildings. This is done by dynamic thermal models, calibrated with data from existing buildings, using machine learning. The models are used to create a plan, a so called "Flex Graph", including when and how much power the heat pump will need for heating the building. It also shows available flexibility for heating. The "Flex Graphs" for each individual building are sent to a central "Dynamic Coalition Manager" used for gathering the available flexibility for a number of heat pumps in a community or a neighbourhood. The aggregated plan can for example be used in collaboration with the local Distribution System Operator (DSO) in order to avoid local grid problems or in cooperation with the Balance Responsible Party (BRP) to offering balancing services. Finally, the selected control of the heat pump coalition will be disaggregated and dispatched to the individual heat pumps, where the contribution from each single heat pump, most probably, will vary over time, based on the local situation at the moment. This is done by an iterative process made by a distributed optimization algorithm called ADMM.

## Control of heat pumps

One important step in the chain to provide demand response is to be able to control the heat pump based on external signals in order to make the heat pump use the amount of electricity asked for, in this case the power consumption "negotiated" by the ADMM-algorithm. The heat pumps on the market today are developed to give high comfort with as high efficiency as possible. External control of a heat pump can be divided into two main categories, direct or indirect control. Within the FHP project RISE has tested both of these possibilities on a ground source heat pump. The aim was to evaluate different strategies for external control and to give recommendations regarding the best way to control a grid flexible heat pump.

## Indirect control

The heating demand of a building is dependent on the outdoor temperature and a heat pump is programmed to adjust its heat production based on the outdoor temperature. Most heat pumps are equipped with an outdoor temperature sensor, giving information about current temperate, used to estimate the heating demand of the building. A lower outdoor temperature gives a higher heating demand, which causes the inverter heat pump to increase its compressor speed and thereby the heat production, and the power consumption will increase. At low winter temperatures, the backup heater may need to start in order to cover the total heating demand of the building.  Manipulating the temperature sensor and sending a fake outdoor temperature to the heat pump is a possible way to indirect control the heat pump's heat production and power demand. An alternative way to control the heat pump indirectly is to adjust the heat pump's heating curve. In the tests related to this project the outdoor temperature sensor was replaced with an adjustable precision potentiometer and thereby it was possible to manually set the outdoor temperature desired.

## Direct control

During direct control the heat pump's ordinary, internal control, which sets the compressor speed and switches between space heating and production of domestic hot water, is bypassed, and the compressor is controlled directly. This makes it possible to control the heat pump's power consumption quicker and with better accuracy. To make this work, it is necessary that the heat pump is prepared for external control and that it is possible to communicate with it. No heat pump on the market has this functionality today.

During the laboratory tests at RISE with direct control, a program developed by the heat pump manufacturer of the tested heat pump was used. The program is normally used for internal testing by the manufacturer. Via a computer connected to the heat pump, the program makes it possible to set the compressor frequency directly. As a complement to the program, RISE developed an add-on which makes it possible to create a test sequence that automatically changes the compressor speed at desired times, making it easier to test longer sequences with varying compressor speed or to make fast changes.

## Test cycle for grid-flexible heat pumps

In order to standardise testing and evaluate the control of a grid-flexible heat pump, an eight-hour test cycle for laboratory testing was developed. The purpose with the test cycle is partly to evaluate how close the heat pump in combination with the external control manages to follow a specified test profile, and partly to test if the heat pump control manages to handle a number of functions, such as start and stop or varying the compressor speed, see Figure 1.

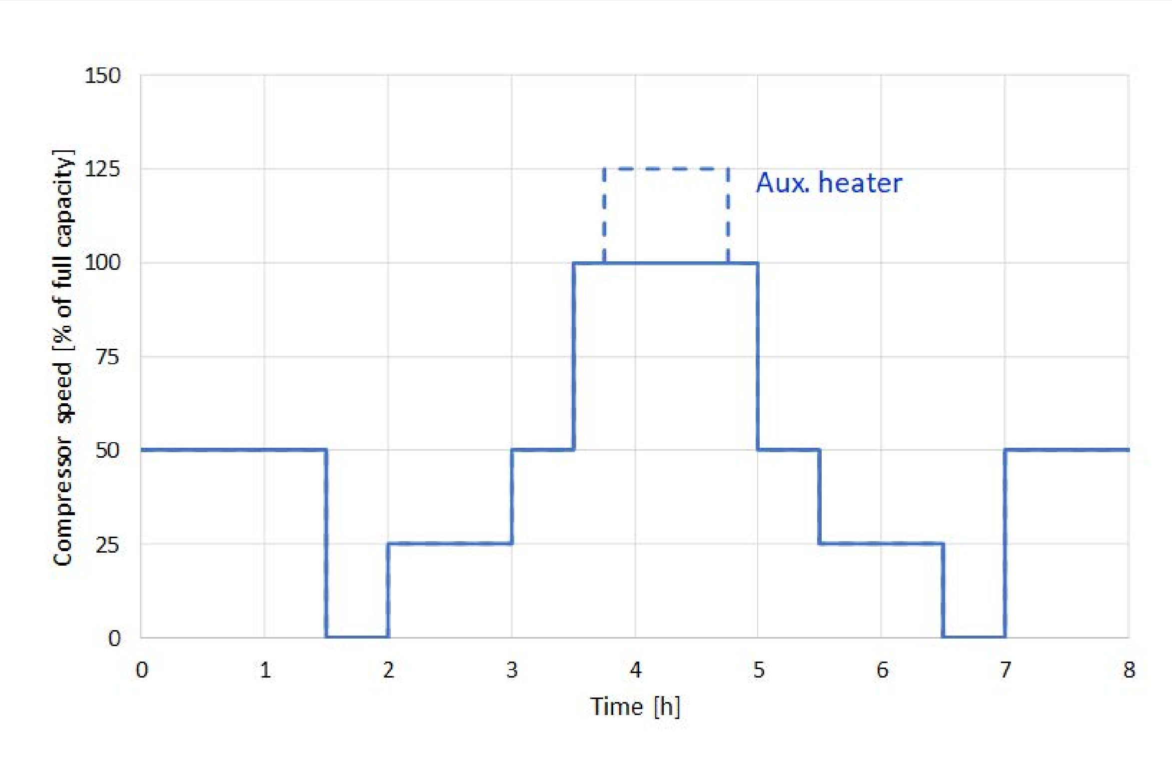


*Fig. 1: Test cycle for evaluation of a grid flexible heat pump*

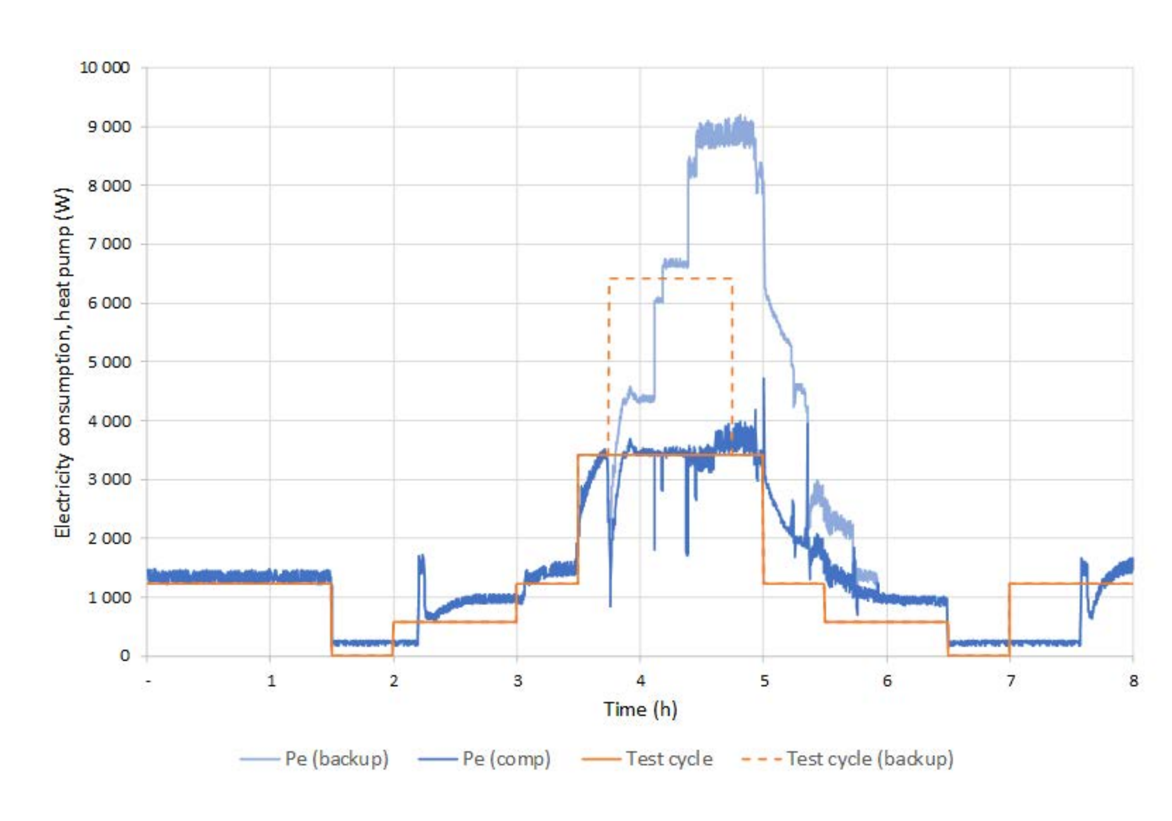


*Fig. 2: Test results, indirect control of the heat pump*

In Figure 2 the results for indirect control is shown, focusing on the power consumption. The results from the test shows that it is possible to follow changes in the test cycle by manipulating the outdoor temperature sensor. The heat pump cannot follow the test cycle in detail, but the general trend is followed relatively well, especially focusing on the control of the compressor without the backup heater. In average, the part load of the compressor deviates with 370 W from the test cycle and during 64% of the time the deviation from the test cycle is within ±10%. A self-learning algorithm can probably improve the agreement with the test cycle further.

Direct control of the heat pump's compressor speed, and thereby its power consumption, gives better possibilities to control the heat pump in detail. The results from the laboratory test with direct control of the compressor shows that it is possible to follow the test cycle with very high accuracy, see Figure 3. However, the tested version of the program for direct control has no functionality for controlling the backup heater, and thus the backup heater could not be started during the test. The power consumption of the compressor is on the average 100 W from the values of the test cycle, and for 97% of the time the heat pump is within ±10%.

The laboratory tests show that the COP often is affected negatively by the active external control; exactly how much the COP decreases depends on the shape of the profile. The lower COP value can be explained by the fact that the heat pump is forced to operate at less optimal conditions in order to provide demand response. In laboratory tests based on other load profiles and using direct control we have seen that the COP decreases with 0-10%, depending on the shape of the profile. For the test cycle described above, the COP decreased with 11% with direct control and with 13% with indirect control, focusing on the operation of the compressor. In real installations, the decrease in COP may be higher, since the test rig cannot fully simulate a real heat pump installation. If the profile forces the heat pump to start the backup heater, the efficiency will decrease significantly. In a practical context, the reduction in COP would have to be compensated by cost savings and service incentive earnings resulting from the demand response control.

## Conclusions and recommendations for external control

To be able to overrule the internal control and instead control the heat pump externally, the heat pumps of today need an individually tailor-made solution for each model. In order to get a general solution for external control, a standardised way to externally control the heat pump needs to be part of the manufacturers' standard protocol, as a complement to the internal control, based on temperature. For the future, direct control of the heat pump will give the best option to an accurate control of the heat pump's power consumption. To make this happen, the heat pump control system needs to be updated, to make it easier to use it for demand response. This

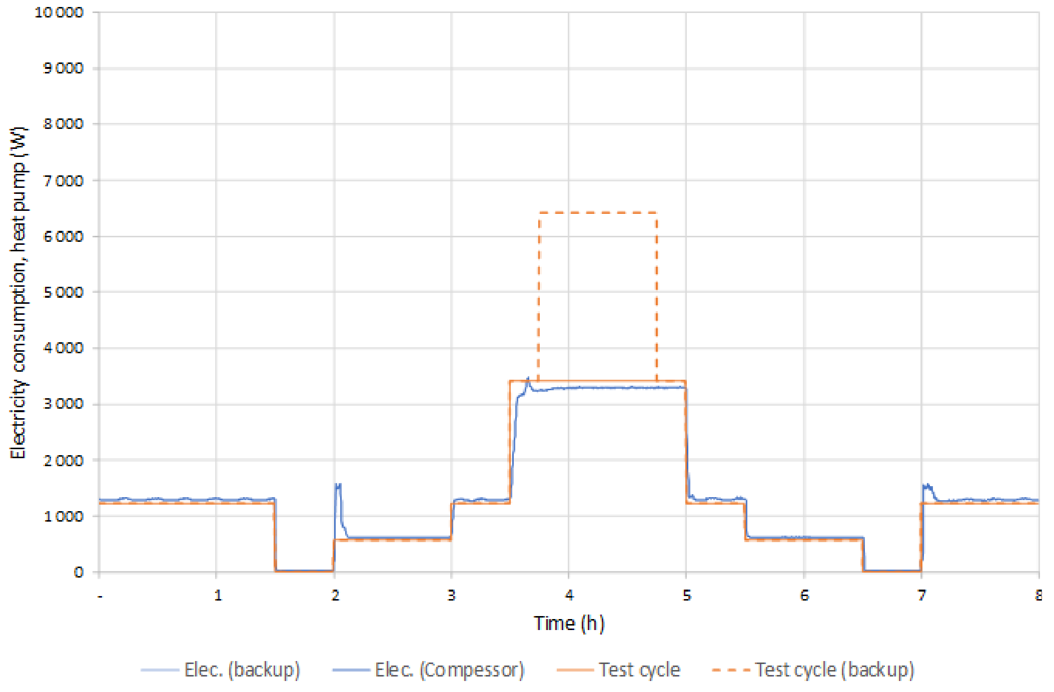


*Fig. 3: Test results, direct control of heat pump*

solution is, at least partly, in the hands of the heat pump manufacturers. From a strategic point of view, with all the external control, the heat pump alone will no longer have the full control of the indoor climate.

If there is a need to control heat pumps that are already installed, it is recommended to use indirect control by manipulating the temperature sensor. The benefit is that the solution will work on almost all heat pump models, both old and new. The downside is partly that the control will not have the same accuracy as with direct control, and partly that there is a need for an installation on site for each heat pump, to make it possible to take over the outdoor temperature sensor. An alternative in order to avoid an expensive installation can be to work with indirect control by actively changing the heating curve or similar by a web-API. Many premium heat pumps sold today give the owner the possibility to control the heat pump from a distance, for example via an app, a feature that may be used for controlling the heat pump without any installations of equipment at each individual heat pump.

## Acknowledgments

The FHP project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731231, and includes the following partners: Vito (project leader), Tecnalia, Noda, Honeywell, Ecovat, RISE and Karlshamn Energi. For more information about the project see: http://fhp-h2020.eu/

**MARKUS LINDAHL**
**M. Sc.**
**RISE Research Institutes of Sweden**
Sweden
markus.lindahl@ri.se
https://doi.org/10.23697/b2fb-mx59