IEA HPT Annex 55 / ECES Annex 34 “CCB”

Task 1 report - Sweden

Date:	2020-04-30
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Status:	Final

This report has been made available as part of the work under the double Annex HPT55/ECES34 on heat pumps and storage. The opinions expressed herein do not necessarily reflect a consensus within the working group from Annex 55/34.

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1.1 The Comfort & Climate Box concept

The central concept in this Annex is the Comfort and Climate Box, CCB. This concept denotes a combined package, consisting of a heat pump, an energy storage and controls. This package may form an actual physical unit but can also consist of separate modules that form an integrated “virtual package”. A CCB should not just be a set of components that have been put together. Rather, all components of the CCB should be designed to work together in a modular fashion and should be operated under a dedicated and optimal integrated control strategy. The package solution could, but will not automatically, take the shape of a single physical “box” providing all functions.

This annex is concerned with improving the integration between HP, storage and controls, as judged by nine quality criteria.

1.2 General background on heat pump and storage deployment

The Swedish market for space heating and domestic hot water (DHW) to housing and premises is about 90 TWh/year and represents a fourth of Sweden’s total energy use. Four heating technologies are dominating the market: district heating, heat pumps, electrical heating and biofuel boilers. District heating covers more than half of the total heating demand, while heat pumps and electrical heaters together have one third of the market. District heating dominates for multi-family houses and premises, while heat pumps dominates for single-family houses [28].

Sweden’s electricity mix (including export) relies primarily on hydro power (65 TWh) and nuclear power (63 TWh), with smaller contributions from wind power (18 TWh) and CHP plants (15 TWh). Non-electricity supply (heating, industry, transports etc.) relies primarily on biofuels (143 TWh) and crude oil and other petroleum products (154 TWh) [27].

1.2.a Electricity prices, tariffs and structure

In Sweden there is an ongoing transformation from an electrical system where the power was produced in a few large plants to a system where the traditional electricity production is complemented with production in many, small and scattered plants (e.g. windmills or micro producers of solar PV). There is also a transition from a system of almost only hydro and nuclear power – which both can be controlled and planned, to increasingly weather-dependent power from sun and wind [29][30].

The Swedish power grid is divided in four “elspot areas” from the north to the south of Sweden. I general most of the electricity is produced in the north of Sweden, while the demand is largest in the south. Sweden’s electricity market is a part of Nord Pool, where the electricity spot price is set ones an hour [31]. Approximately one hundred Swedish electricity suppliers purchase electricity from Nord Pool and sell to their customers. The suppliers sell electricity on the free market, in competition with other electricity suppliers. An electricity supplier can also have a balance responsibility, meaning that the electricity supplier has a financial responsibility to ensure that there is always a balance in the amount of electricity added and withdrawn at the infeed and outtake points that fall under the balance responsibility [32].

In addition to the electricity price from Nord Pool there is a number of other costs for the final user. Some of the costs are fixed and some are variable. There are large differences in prices structure from one power supplier to another and the share of fixed costs in relation to variable costs variates. Even though the electricity price from Nord Pool variated every hour very few Swedish consumers has an electricity contract giving price variations per hour. More normal is to have a variable price based on the monthly average or a fixed electricity price for 1-3 years (both shorter and longer periods exist). Examples on additional costs to the electricity price set on Nord Pool are electricity certificates (approximately 0.05 SEK/kWh) and costs for the electricity distribution and peak outtake. The energy tax on electricity is 0.331 SEK/kWh and finally VAT is added.

The cost structure for the electricity distribution used in Sweden has traditionally included two parameters, a fixed cost related to the subscribed fuse size complemented with an energy transfer fee based on the energy used (kWh/month). During the last years some grid owners have changed their price structure to also include a cost related to the maximal capacity used (kW) based on the maximal power outtake each month (highest hourly average). Some grid owner makes this in two steps and have separate fees for the capacity cost during high and low load hours. In Figure 1 the price structure for six Swedish grid owners are summarised, based on calculation for a fictive villa with a heat pump installed. Note that the price structures represented by Alingsås and Göteborg to the right in the figure below still is the most common structure in Sweden.

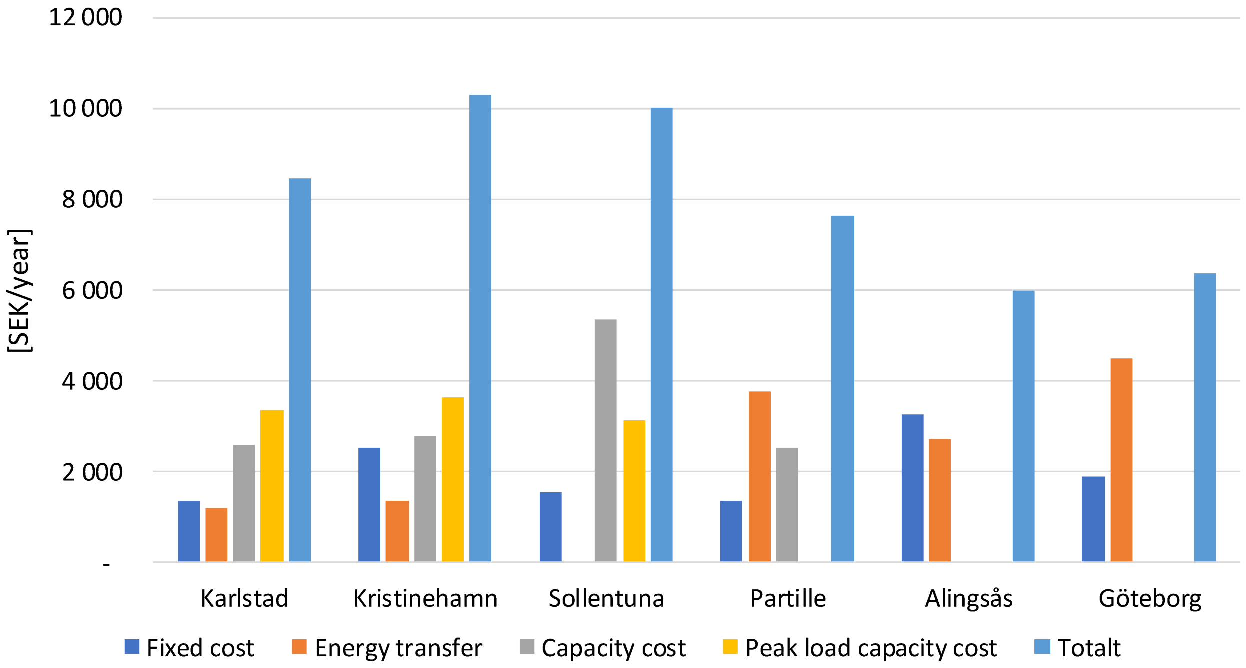

Figure 1. Price structure for electricity distribution fee for six Swedish grid owners based on calculations for a fictive villa with an installed heat pump. A fuse of 20A and an annual power demand of 16 000 kWh is assumed.

1.2.b Heat pump market

Sweden is a mature heat pump market with over 1,6 million heat pumps in operation. Approximately 50% of the heat pump systems sold during the last 10 year are hot-water systems for radiators or under floor heating including ground source (GSHP), exhaust air (EAHP) or air to water (AWHP) heat pumps producing both space heating and domestic hot water (DHW). The other 50% is air-to-air heat pumps producing mainly space heating, see Figure 2.

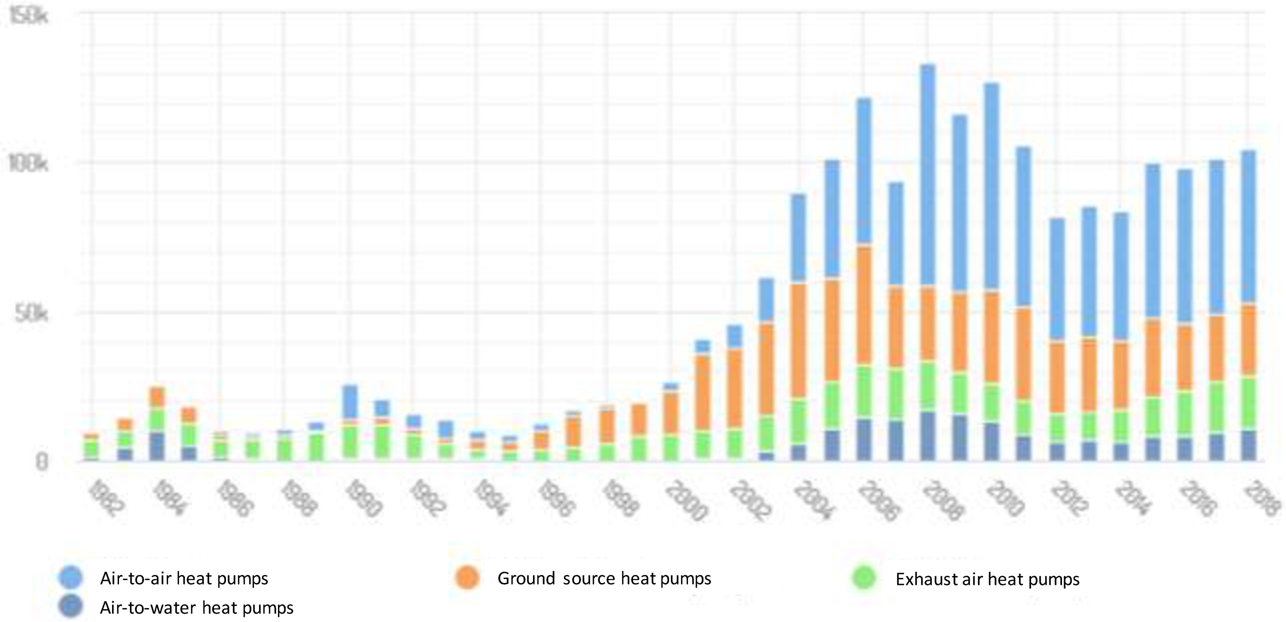

Figure 2. Heat pump sales development per year in Sweden (Source: Svenska Kyl &Värmepumpsföreningen [26])

Fossil Free Sweden initiative

Fossil Free Sweden was initiated by the Swedish government ahead of the COP21 climate change conference in Paris in 2015. Based on the decision by the Swedish parliament to make Sweden climate neutral by 2045 [59], the Fossil Free Sweden initiative [60] has encouraged different business sectors to draw up their own roadmaps in order to be fossil free.

One of the road maps relevant to heat pumps are related to the Swedish power industry [61]. In the roadmap they point out that the demand for fossil free electricity will most probably increase as other industrial sectors are relying on increase electrification in order to be fossil free. Thereby the roadmap for the power industry foresees an increased power demand from todays 140 TWh to 190 TWh 2045. They also point out an increasing need for services offering demand response and power peak optimisation in order to avoid power deficit. In the roadmap for the heating industry [62] it is pointed out that the heat pump industry will focus on e.g. increasing the efficiency of heat pump solutions and make it possible to control the energy use in order to minimize the peak power demand. House owner and builders point out (among other things) that they will focus on low temperature heating systems, heating solutions including smart control in order to reduce peak power demand, energy storage, solar PV and solar thermal.

1.2.c Swedish energy policies

The central Swedish government is responsible for the development of energy policies in Sweden, supported by several national and local authorities. Since 1995 Sweden is a member state of EU and thereby follows EU´s framework regarding legal requirements related to the energy policies [33].

The Swedish government has high ambitions, the country should be a pioneer and become the first fossil free welfare society and a global role model. The following climate and energy goals has been defined [71]:

- 50% more efficient energy use by 2030
- 100% power from renewable sources by 2040
- Zero net greenhouse gas emissions by 2045

Achieving zero net emissions of greenhouse gases means that the emissions of greenhouse gases from activities in Sweden shall be at least 85 per cent lower in 2045 compared to 1990 [58][59]. There are also three milestone targets towards the long-term goal to have zero net greenhouse gas emissions. The milestone targets are:

- By 2020 emissions are to be 40 per cent lower than 1990
- By 2030 emissions are to be 63 per cent lower than 1990
- By 2040 emissions are to be 75 per cent lower than 1990

Note that the goal to have 100% electricity from renewable sources also includes the replacement of electricity from nuclear power, today representing approximately 40% of the Swedish electricity mix. Which thereby should be replaced to 2040. In the same time the power industry foresees an increased power demand from todays 140 TWh to 190 TWh 2045.

Policies related to the growth of the Swedish heat pump market

In Sweden energy and CO_2 is heavily taxed. Energy sources were first taxed in Sweden in the 1920s and a carbon tax was instituted in 1991 as a complement to the already existing energy tax. The carbon tax has been increased in steps since it was introduced in 1991. 2020 the tax is SEK 1190 (EUR 110) per tonne fossil CO_2 emitted [63]. The taxes favours efficient heat pump systems compared to heating systems based on fossil fuel, such as oil or gas burners. In addition, or party as a consequence, the gas grid in Sweden is limited to some areas in the very south of Sweden. Historically there have also been subsidies for homeowners to convert the heating system to a heat pump. Between 2006 and 2010, homeowners could receive up to 30% of material and labour costs up to a maximum level per household for replacing direct electric heating with a heat pump, district heating or biomass [64]. This has led to large-scale replacement of oil heaters in one/two-family houses with heat pumps.

The heat pump market in Sweden has been further supported by technical standards, certification and labelling schemes for heat pumps such as the “P-mark” and the “EHPA quality label”, the environmental label the “Swan”, as well as installer certification trainings etc [65][66][69], even though these schemes have been completely voluntary. During the last years these schemes have almost entirely been replaced by the CEN HP Keymark. The Swedish Energy Agency has also made and published performance tests of heat pumps [67]. Today, EUs energy labelling of heat pumps [70] gives information to customers about the heat pump performance. This has helped to raise the consumer awareness and confidence about heat pumps and have been important drivers to build confidence in the technologies and dispelling negative public perceptions.

Some policy success factors for the Swedish heat pump market are:

- The Swedish Energy Agency have had a 25-year R&D programme [68] focussed on heat pumps that led to many improvements of today’s heat pumps and their performance.
- High taxes on energy and CO_2 disfavour alternative heating systems based on fossil fuel, such as oil or gas burners.
- Investments in information campaigns, to large extent based on results from laboratory tests of heat pumps, technological evaluations etc. have given public acceptance of high energy taxes and the use of heat pumps.

Electricity certificates

Electricity certificates is an instrument to increase the production and use of renewable electrify, mainly from wind, water, biofuels and sun. The producer of renewable energy gets “electricity certificates”, that can be sold to power suppliers and others that need certificates representing a certain quota of sold or used electricity. The aim with electricity certificates is to increases the possibilities for renewable sources to compete with non-renewables. [37]

Micro producer of power from renewable sources

As a micro producer of power from renewable sources the producer has the right to get a tax reduction of 0,6 SEK/kWh produced and transferred electricity to the grid, up to the amount of power that has been taken from the grid (maximum of 30 000 kWh/year). The tax reduction is valid for installations with a maximum fuse of 100 A. For installations with an installed max capacity bellow 255 kW no energy taxes are paid, and no VAT has to be included for a yearly production below 30 000 kWh. [38]

1.2.d Energy use in dwellings

The specific brought energy used for heating and domestic hot water in dwellings has declined during the last 20 years. The main contributing factors to this are installations of heat pumps and building stock with increasing energy efficiency due to renovation and new construction, see Figure 3 below.

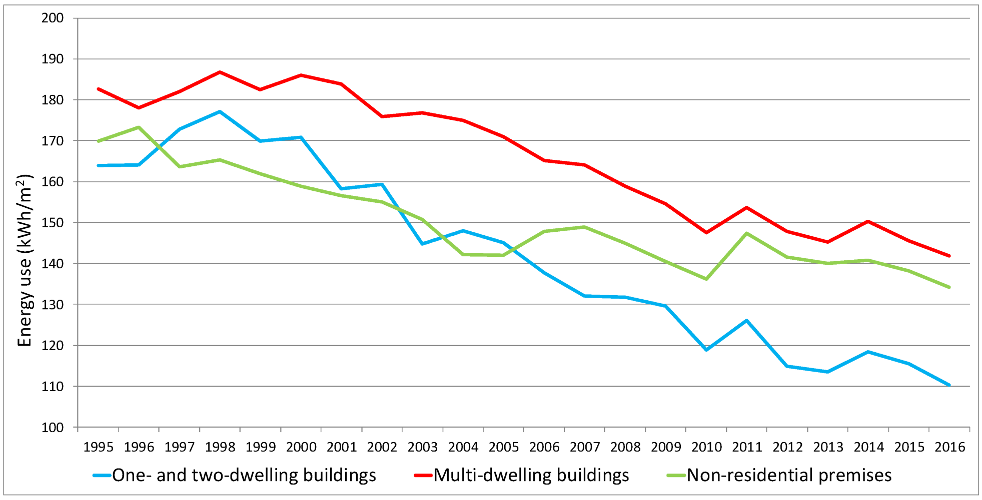

Figure 3. Specific brought energy for heating and DHW in dwellings and non-residential premises, 1995–2016. Data source: Swedish Energy Agency [39]

1.3 CCB Quality criteria

The status of the quality criteria for a comfort and climate box solution in Sweden depends on what is supposed to be included in the concept. Below follow two versions of the criteria based on different number of functions included in the concept “comfort and climate box”. First a box with focus on space heating (SH) and domestic hot water (DHW), second a more complex box including more functions.

1.3.a Heat pumps for space heating and domestic hot water

The first version of the comfort and climate box includes space heating and production of DHW. In this case the DHW tank is the only heat storage (except for the water in the space heating distribution system). These two functions are normally included in a Swedish heat pump with a water-based distribution system for ground source heat pumps (GSHP), air source heat pumps (ASHP) or exhaust air heat pumps (EAHP). In these systems the integrated control is normally altering between the different operation modes. For this relatively simple comfort and climate box concept, there are relatively few barriers identified on the Swedish market, see Figure 4 below.

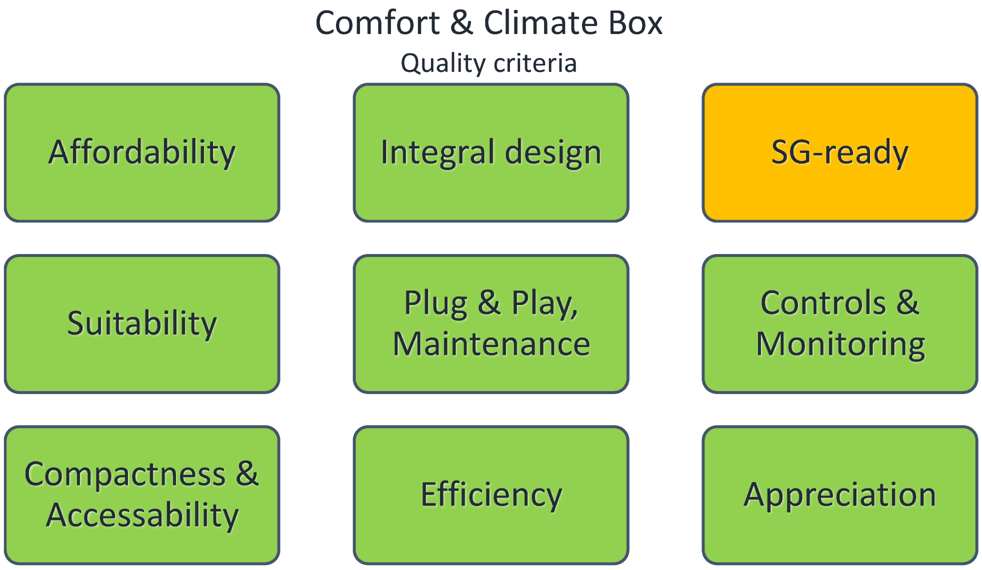

Figure 4. CCB quality criteria, status indicator for Sweden. Heat pumps for space heating and DHW.

Below follows a short description of the status for each box.

Affordability

Heat pumps for space heating and domestic hot water are today common products in Swedish dwellings, especially in single family houses. The investment cost is considerable but on the other hand the running cost, due to relatively low electricity prices, is low. This gives an accaptable life cycle cost. There are also possibilities to get some tax reduction for installation cost.

Suitability

Heat pumps exist within a large capacity range, well suited for most houses.

Compactness

GSHP, EAHP and indoor part of ASHP normally consist of a "box" (L: 60* B: 60* H: 200 cm) including the heat pump and the DHW tank. This more or less standardised format gives a small indoor footprint.

Integral design

The space heating and domestic hot water functions are well integrated, and the switch between the functions works well. For exhaust air heat pumps the ventilation of the house is integrated as well.

Plug & play, maintenance

GSHP, EAHP and monobloc ASHP offer "plug and play" installation that can be made by a plumber (with adapted training). Split ASHP require refrigeration competence and certification.

Efficiency

The heat pumps are efficient enough to offer a low running cost.

SG-ready

Some premium heat pumps can receive external signals from the electricity grid and can adjust the heat production according to the signals, but this functions is seldom applied due to lack of drivers and incentives to do so. One reson for this is the relatively small variations in electricity price today and small difference between feed in and feed out tariffs for on site produced electricity.

Controls & monitoring
Control is normally well functioning and straight forward. More advanced control start to appear on the market. Most heat pumps are not monitored, but such service is normally offered when buying a premium product. Paramters related to safety functions are normally monitored while parameter related to efficiency are not.

Appreciation
Heat pumps can be considered a well known and appriciated "heater" in Sweden, which has a mature heat pump market.

1.3.b Heat pumps for SH, SC, DHW, storage and control for PV and smart grid

The second version of the comfort and climate box includes additional built in functions compared to today's heat pumps, which focus on space heating (SH) and domestic hot water (DHW). The following functions are assumed to be included in this version of the comfort and climate box: space heating (SH), space cooling (SC), domestic hot water (DHW), electric or heat storage, integrated control for solar PV (photovoltaic) and smart grid. In Figure 5 follows a summary of barriers identified for this kind of product.

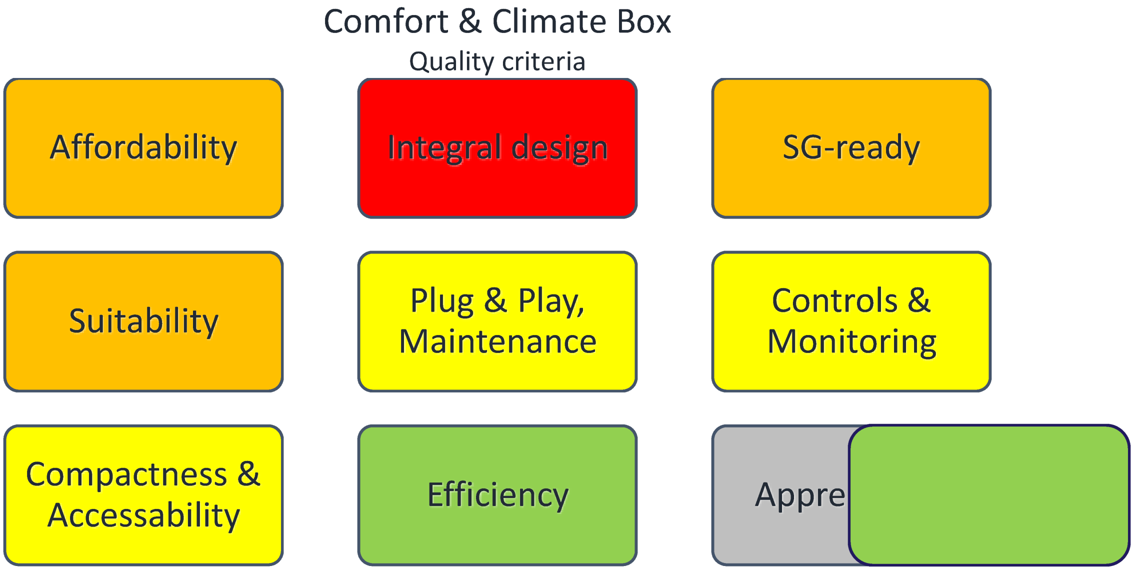

Figure 5. CCB quality criteria, status indicator for Sweden. Heat pumps for SH, SC, DHW, storage and control for PV and smart grid.

Below follows a short description of the status for each box.

Affordability

The heat pump itself is normally a cost effecitive product, but adding energy storage increases the pay back time for the investment with the Swedish electricity pricing of today.

Suitability

Heat pumps and energy storages of varying sizes exist, but incentives and control system to combine them are more rare. Solutions for distributing (free) cooling from the heat pump to the whole house are not very common.

Compactness

The heat pump itself has normally a small indoor footprint (L: 60* B: 60* H: 200 cm), including a DHW tank, which is sort of an energy storage. However, adding on extra energy storage might add on indoor footprint.

Integral design

Except for the integration of the storage related to the DHW tank, heat pumps are seldom integrated with energy storage, nor with an integrated control for the storage. The cooling function is not very often well integrated.

Plug & play, maintenance

It is rare with plug and play solutions where energy storage and/or cooling is combined with a heat pump.

Efficiency

The efficiency of the separate functions are good enough.

SG-ready

Many heat pumps are prepared for recieving signals from the grid or PV-panels but this function is seldomly applied today. One reson for this is the relatively small variations in electricity price today and small difference between feed in and feed out tariffs for on site produced electricity.

Controls & monitoring

Some brands can offer integrated control for heat pumps in combination with solar PV and some brands offer monitoring of new premium products. Still very few heat pumps on the market are operated with an integrated control of the with the solar PV or monitored.

Appreciation

This is difficult to know since full "Comfort&Climate Box" solutions do not exist on the market yet. As long as the life cycle cost for the new product is not higher than for existing heat pump solutions, the potential for high appreciation is good.

1.4 CCBs in your country

Three development areas for a Swedish “Comfort&Climate Box” have been pointed out:

1. **Integrated design and control related to flexibility to the power grid**.
   The share of power from intermittent, renewable sources such as wind and sun is increasing in the Swedish power system, as well as in many other European countries. This leads to larger variations in the power supply. Heat pumping technology can help decreasing the impact of the variations by offering demand response. In order to do that, today´s heat pumps need further development related to the design parameters integrated design and control.

2. **Integrated design and simple installation related to cooling**.
   There is an increasing demand for space cooling also in Sweden. Here a heat pump has the possibility to offer an efficient solution for cooling, either by passive cooling via the bore hole or active cooling by using the cool side of the heat pump cycle. This is today only used to limited extent and the products would benefit of a further development related to integrated design and simple installation.

3. **Cost efficiency for increased sales in other countries**.
   In order to be able to increase the sales in other countries the Swedish heat pump manufacturers would benefit from a development of the design parameter cost efficiency. In many countries heat pumps compete with gas boilers for heating. The gas boilers have a lower investment cost and, in some countries, also lower running cost when the gas prices are low compared to the power price.

2 CCB Market status

Below follows an overview of heat pump systems presently on the Swedish market or close to commercialization including one or several of the functions related to the Comfort and Climate Box concept.

2.1 Control systems for heat pump operation and power consumption

Below six different systems related to the control of the heat pumps operation and control of the power consumption are described.

2.1.a Smart price adaption/ Smartgrid Ready

Several of the large heat pump manufacturers today, e.g. Nibe and Bosch/IVT, has the function to make their premium heat pump models communicate with Nord Pool in order to get information about hourly electricity prices the next day. Based on this, the heat production can be planned in order to minimize the heating cost by making the heat pump work the most when the prices are low. To make this work the house owner also needs an hourly power contract [20]-[23].

2.1.b Maximal power consumption

Most heat pump manufacturers, e.g. Nibe and Thermia, have a function that makes it possible to set the maximal power consumption of the building and reduce the power outtake of the heat pumps back up heater if needed to avoid overload on a phase. This is done in combination with measurements of the buildings instantaneous power demand. During the installation the maximum power consumption for the building, depending on the main fuse, is set. Based on the measured power the heat pump can decrease the backup heaters power consumption when the total consumption is higher than the set value. First the power is redistributed between the phases, second the power used by the backup heater is reduced in steps to finally be completely switched off.

2.1.c German “Smart grid ready” standard

“Smart grid ready” is a standard for smart control of heat pumps in Germany. The standard is not actively used in Sweden, but the heat pumps are prepared for this since the same models are sold in the two countries. The standard for smart control is defined by the German Bundesverband Wärmepumpe e.V.[16] and makes it possible to send a signal to the heat pump that activates one of four predefined modes. The activation of each mode is done based on how two terminals are open (0) or closed (1). The setting of the terminals activates different setting of the heat pump control. When one of the modes is activated, the heat pump is programmed to respond in a certain way. The exact response for each mode is not defined by the standard and can vary from one heat pump model to another.

The four defined heat pump working modes are [17]:

1. Blocking mode: HP is switched off, until storage reaches its lower threshold temperature level. (1:0)
2. Normal mode: HP operates with normal set-points. (0:0)
3. Low price mode: HP is switched on. (0:1)
4. Over capacity mode: HP is switched on, storage temperatures increased to the maximum temperature allowed by the HP. (1:1)

2.1.d Remote control and monitoring

The large heat pump manufacturers in Sweden all have a solution to remotely control and monitor the heat pump via a cloud-based service. The solution has different names depending on the manufacturer, IVT Anywhere, CTC Connect+, Nibe Uplink or Thermia Online. The functions available in the remote control might differ from one supplier to another but according to the manufacturers, more or less all control functions, like changing temperatures for space heating or DHW, producing extra DHW etc. is integrated in the cloud-based services. The remote-control system includes a gateway for communication and an app. The remote-control option is today available or included in the manufactures premium heat pumps but in some cases, it can also be installed as an additional gadget for other HP models. [1]-[10]. For most HP models there is a need to connect the heat pump via a cable to the building's router, alternatively to use a wireless bridge or a mobile router, for the internet connection. Nibe S-series is the only model identified with a built-in wifi-connection.

2.1.e Nibe UpLink and IFTTT

Nibe Uplink is a cloud-based service that makes it possible to connect the heat pump to a smart home system. The user can control connected Nibe products via an app and thereby control heating, cooling, ventilation or production of DHW from a distance.

IFTTT stands for If-This-Than-That and is a technology to easily connect "smart devices" to each other. Nibe uses the standard and can in this way connect different Nibe products with each other or to other products using the same standard. The standard makes it possible to program a smart device to act in a specific way depending on the conditions or how other products are reacting. In the IFTTT system there are already a number of built-in smart features but new can also be made.

2.1.f Ngenic

Ngenic tune is a smart thermostat marketed as a self-learning system that helps you save energy and money. It is a product for the retrofit market controlling the heat pump via a fictive outdoor temperature. The connection to the heat pump is done by cutting the cord to the outdoor sensor and instead connect the Ngenic equipment to the heat pump via the sensor cord. Ngenic tune controls the heat pump via the outdoor temperature signals sent to the heat pump and includes other parameters in the optimisation of the operation, such as indoor- and outdoor temperature, insulation and historical data. [11]

2.2 Control systems for heat pumps combined with solar PV

The decreased investment cost for installing solar PV in Sweden has resulted in increased interest for combining solar PV and heat pumps. Today hundreds of packages including the combination of solar PV and a heat pump are sold, especially in connection to sale of single-family houses. [57]

2.2.a Nibe PV

The heat pump manufacturer Nibe are also selling PV panels for end consumers. The PV panels are prepared for connection with a Nibe heat pump via a communication module. The communication module can also be connected to Nibe Uplink. This makes it possible to show information from the inverter in you heat pump menu and via Nibe UpLink and thereby make it a part of the smart home solution. There is also a function that makes it possible to adjust the heat pumps heat production to follow the power production of the PV panels and thereby maximize the internal use of the power produced by the PV panels [24][25].

2.2.b Bosch Smart Home controller and Bosch Energy Manager

The Bosch Energy Manager controls the flow of locally produced solar power. The Energy Manager makes it possible to connect the photovoltaic system to the building and control the distribution of the produced solar power automatically in order to ensure an optimal distribution of the power. Household appliances are prioritized followed by the heat pump, if there is a remaining surplus it goes to the batteries for storage. The Energy manager makes it possible for the user to internally consume a larger part of the solar power generated [12].

2.3 Control systems for heat pumps combined with solar thermal

There are several benefits with a combination of solar thermal energy and a heat pump, since it can increase the efficiency of the heat pump, decrease the running time of the compressor and reduce the amount of brought energy, but the possibilities and synergy with these combinations also requires a well thought out system solution [57].

There are some Swedish examples on mainly smaller heat pump manufacturers that have focused on the combination heat pump and solar thermal heating. The heat pump´s control function will operate the system differently depending on the weather conditions and the possibilities to use solar thermal for heating or preheating. Below follow two examples from different manufacturers:

2.3.a EVI Heat, GeoSun

The ground source heat pumps from EVI Heat are developed and sold in combination with a solar collector [1]. The tank used for DHW is sold separately and can thereby variate in size, but is normally of 500 l. Depending on the weather the heat pump and solar thermal system will operate in four different modes [2]:

1. The solar collectors produce all energy for heating: Space heating and DHW production is done without starting the compressor.
2. The sun produces some of the energy for heating: The sun is used to increase the brine temperature, which improves the heat pumps COP.
3. The sun produces a surplus of energy for heating: When there is no need for space heating or DHW, the energy surplus is used to reload the borehole storage.
4. The sun produces no energy for heating: Space heating and DHW is produced by conventional heat pump technology only.

2.3.b Free Energy, HYSS

HYSS (Hybrid Solar System) combines conventional heat pumping technology with solar thermal production to boost the heat pump performance. Thermal energy from the solar collector are utilized in three different ways depending on the temperature and the systems operation. If high temperatures are fed from the solar collectors, the energy is stored in the storage tank directly. When solar thermal energy is produced during heat pump operation, the heat is used to preheat the brine to boost the heat pumps performance. If the temperature from the solar collectors is too low, or if the storage tank is fully charged, the excess heat is fed into the bore hole storage and acts as a seasonal storage which energizes and preserves the bore hole(s). Excess solar thermal energy can also be used for seasonal storage via the bore hole(s). The system is also prepared for passive cooling through an external ventilation unit where the cooling is provided from the bore hole storage [40].

The system is supplemented with a web interface that lets the user get an overview of the current working status and performance. It allows the user to see where the energy is supplied from (heat pump, solar thermal or a combination) at any instance. The interface also summarizes the performance (COP, $SCOP_{Combi}$), energy from the solar collector and ground and an overview of the economic and environmental savings.

2.4 Heat pumps used for cooling

The demand for comfort cooling is increasing in Sweden. Even though the energy consumption related to cooling is low compared to the heating demand the peak demand can be high. Heat pumps (ASHP, GSHP) can provide cooling actively by using the cold side of the heat pump cycle, or in case of GSHP passively by using cooling directly from the bore hole. For single family houses the cooling is, in most cases, distributed to the building by fan coils. An alternative is to distribute the cooling via the ventilation system or via the floor "heating system". Traditional radiators without a fan are not suitable for distribution of comfort cooling.

2.4.a Active cooling

GSHP and ASHP can produce active cooling by using the cold side of the heat pump cycle for cooling production. This increases the power consumption compared to passive cooling, which have very small power demand compared to the cooling output. Some heat pump models (mainly ASHP) have an already built in function for active cooling, e.g. the air source heat pumps Thermia iTec or Nibe 2040. Others have it as an additional module such as the GSHPs Thermia Diplomat Optimum G3 or Nibe S1255. An active cooling mode makes it possible for the heat pump to produce both heating and cooling and thereby increases the possibilities to keep a stable room temperature.

2.4.b Passive cooling with ground source heat pumps

Several of the Swedish heat pump manufactures has additional cooling modules for their GSHP in order to provide cooling [13]-[15]. There are also heat pump models (e.g. Thermia Atlas [72]) with a built-in passive cooling function. In this way the heat pump can be used for both heating and cooling. For ground source heat pumps the cooling can be either passive or active. In case of passive cooling the brine is used to transport cooling from the bore hole to the building directly or via a heat exchanger. In this case the compressor is not needed for cooling production and the power consumption related to cooling the building is mainly related to the distribution, which is small compared to the compressors power consumption Using the heat pump for cooling, passive or active, also helps reload the bore hole with energy, increasing the COP of the heat pump when it is used for heat production.

2.5 Existing CCB use cases and CCB best practice examples

Heat pumps for space heating and domestic hot water are today common products in Swedish dwellings, especially in single family houses and there are serval manufacturers providing these products. They have a high efficiency, a standardised size (L: 60* B: 60* H: 200 cm) including the DHW tank and are relativly simple to installed.

Two good example of best practise comfort and climate boxes on the Swedish market today is the Nibe S-series, including both ground source and air-to-water heat pumps [41] and Thermia Atlas ground source heat pumps [72]. As many other heat pumps on the market the heat pumps produce both space heating and DHW with a high efficiency and both have a solution to remotely control and monitor the heat pumps via a cloud-based service.Thermia Atlas has a built-in control and function for passive cooling by default and Nibe S-series have focused on smart control including an integrated wifi-connection and can be a part of a smart home system using the IFTTT standard. It also has other functions for smart control like the smart price adaption function, making it possible to plan and minimize the heating cost based on hourly electricity prices from Nord Pool. Another function is a weather-based control taking in data from the weather forecast into the heat planning. The Nibe heat pump is also prepared to be connected to PV-panels and to control the heat pump based on the information about the internal power production from the panels.

3 Projects overview

Below has a number of research projects with relevance for the comfort and climate box concept been described.

3.1 Flexible Heat and Power

Title	Flexible Heat and Power (FHP) [42][43]
Parties involved	VITO (project leader), RISE, Noda, Karlshamn Energi, Honeywell, Tecnalia, Ecovat
Location (for field trials)	Karlshamn (Sweden), Uden (Netherlands)
Start date	Nov 2016
End date	Oct 2019
Status	Finished

3.1.a Project goal

The overarching objective of the project was defined as “secure mitigation of RES curtailment in the electric distribution grid by dynamic coalitions of power-to-heat resources”.

3.1.b Project setup

The project work was divided in seven work packages:
WP1: FHP Business Cases, Business Models and FHP Platform definition
WP2: FHP Building Level Agent development and innovation
WP3: Dynamic Coalition Manager and Multi-Agent Integration and Testing
WP4: Pilot Validation
WP5: Dissemination and Exploitation
WP6: Project Management
WP7: Ethics requirements

Especially relevant for the CCB project is deliverable 2.3 with focus on heat pump design optimized for flex services. Also, the field tests in WP4 are of relevance for the CCB-project.

3.1.c Summary of main results

The FHP has investigated solutions and technologies in order to decarbonizing the EU building stock and reducing emissions through three pillars:
1) Improving heat pump’s capabilities to offer flex services,
2) Making heat pumps more attractive and therefore increase their deployment rate,
3) Facilitate effective HP flex activations with a flexibility trading concept connecting “Flex Needers” with “Flex Providers” in a grid secure manner.

Laboratory testing of direct control of a ground source heat pump following a test cycle shows that it is possible to control the heating capacity and electricity consumption of the heat pump in a good way. Six 24h-profiles based on different scenarios was tested in laboratory using direct control. The results show that the profiles in general can be followed with high accuracy. The compressor speed in the profile can be followed with ±1-2rps and the heat pumps total power consumption with approximately ±100W.

Laboratory test was also done using indirect control of the heat pump. The results show that it is possible to control the heating capacity and electricity consumption of the heat pump via outdoor temperature sensor override, but not as accurate as with direct control. For 75% of the time the test cycle was followed within ±10% looking at the compressor speed only and for 62% of the time including the auxiliary heater. The average deviation from the specified test cycle was 9rps, or 370W power consumption, looking at the operation of the compressor.

Results from laboratory tests with the flex test cycle indicates that COP will decrease using the heat pump for flex services. The tested 24h-profiles with direct control show a decrease in COP with 0-10% depending on the profile. In real installations COP might decrease further, since the test rig cannot fully simulate a real heat pump installation.

3.1.d Lessons learned

- The results related to the Grid Flex Heat Pump concept can improve the level of granularity and determinism that can be reached in the heat pumps' actual energy consumption versus its planned/requested energy consumption.
- Results from laboratory tests with the flex test cycle indicates that COP will decrease using the heat pump for flex services. The tested 24h-profiles with direct control show a decrease in COP with 0-10% depending on the profile. In real installations COP might decrease further, since the test rig cannot fully simulate a real heat pump installation.
- Despite the decrease in COP using heat pumps for flex services can reduce their Total Cost of Ownership, thereby making them more attractive to install.
- A heat pump with a fast response variable speed compressor should be chosen. A survey to a few manufacturers shows a built-in limit between 4.5 and 80 minutes to go from compressor off to maximum capacity for heat pumps with variable speed compressors.

Recommendations for external control of the heat pumps electricity consumption can be summarized as:

1. For older heat pumps or non-premium heat pumps sold today:
   Outdoor temperature sensor override: This is a solution that will work on more or less all heat pumps, but the accuracy of the heat pumps electricity consumption is not as good as for other alternatives. There is also a need for a physical installation on the heat pump which is costly.
2. For premium heat pumps sold today and future heat pumps:
   Indirect control of the temperature settings by adjustments of the heating curve or similar via web-API. Many premium heat pumps sold today are connected to the internet and a web interface or an app makes it possible for the owner to make changes related to the heat pump settings at a distance.
3. For future heat pumps:
   Direct control of the heat pump will give the fastest control of the power consumption and have the best accuracy. To make this happening it needs to be part of the manufacturers standardized protocol for controlling the heat pump.

3.2 Grid flexible heat pumps

Title	Grid flexible heat pumps (Nätflexibla värmepumpar) [44]
Parties involved	RISE, Nibe, Noda, Vattenfall,
Location (for field trials)	-
Start date	Jan 2017
End date	Dec 2018
Status	Finished

3.2.a Project goal

The project goal was to increase the knowledge and estimate the potential for demand response based on coalitions
of heat pumps in apartment buildings.

3.2.b Project setup

The work in the project was organized in five work packages:

1. Development of power consumption models for multi-family building.
2. Development of algorithms for dynamic coalitions of large heat pumps and agent-based system models.
3. Case studies: Demand response from heat pumps
4. Possibilities and constrains for demand response (interview and literature study)
5. Project management

3.2.c Summary of main results

Grid flexible heat pumps is a national Swedish research project funded by the Swedish Energy Agency through their research program Samspel. The project aim is to contribute to a better picture of the conditions and potentials of demand response from coalitions of heat pumps in apartment buildings. The potential has been evaluated both quantitatively through estimated load flexibility and financial value, and qualitatively in an interview study with stakeholders. The project goal is to increase the knowledge and estimate the potential for demand response based on coalitions of heat pumps in apartment buildings.

In a future energy system, demand response can be used to balance the differences between supply and demand of electricity by taking advantage of the thermal inertia in larger buildings with installed heat pumps. The project has evaluated the potential to automatically control the electricity load in apartment buildings, which could contribute to such flexibility. In this case, a larger flexibility could be achieved through forming dynamic coalitions of heat pumps in apartment buildings.

In the project, a model library to describe loads for apartment buildings with heat pumps has been developed. The models have been used to simulate the technical potential for demand response.

3.2.d Lessons learned

Through simulations, the project has showed available flexibility, duration and repetition for demand response in apartment buildings heated with heat pumps. Simulations show that it is possible to aggregate 10 MW of demand response during one hour in a distribution grid area with 174 apartment buildings through turning off the heat pumps collectively. This would correspond to 170 MW for a price area with approximately 10 000 apartment buildings.

Based on the simulations of demand response, the project has calculated the market potential in Sweden and the financial conditions for balance responsible parties and distribution grid operators. The results show that with the system and prices in Sweden today the saving potential is relatively modest. However, the saving potential might increase in the future when a larger share of renewable energy lead to greater variations in the power supply, which would lead to an increased need for demand response.

Based on today’s electricity prices, the largest financial potential for the distribution grid operators are to reduce the power tariff costs. The project results shows a saving potential in a distribution grid corresponds to 2800 SEK/building and year. For balance responsible parties within a price area, there is an estimated saving potential of 2.7 MSEK per year (or 270 SEK/building and year) from participating in the mFRR market and control market. The final profit needs to take into account any costs for maintaining the system, and for initial installation costs for equipment.

The qualitative interview study with building owners shows that they do not find the current financial incitement strong enough to participate in demand response programs with heat pumps. Both building owners and balance responsible parties believe that demand response solutions need to be combined with other services in a more holistic solution in order to create value. In addition, balance responsible parties are skeptical to the flexibility from coalitions of apartment buildings, as they consider it too limited and thus of limited value and interest.

3.3 TESHP (Test of solar heat pump systems)

Title	TESHP (Test of solar heat pump systems) [45][46]
Parties involved	Dalarna University, Nibe, Ferroamp
Location (for field trials)	Stockholm
Start date	Jan 2017
End date	June 2020
Status	Some results produced

3.3.a Project goal

To increase the knowledge of both academia and companies on how the control of systems with PV and heat pump can be optimized and how such systems can be tested in the lab so that the operational functionality can be verified and performance determined in a quick and efficient manner using the so called accelerated quasi-field testing of the whole system. A compact exhaust air heat pump system for a single-family house is used for the studies.

3.3.b Project setup

One research group (Dalarna University) developing the control algorithms and test method. One heat pump company and one power electronics company for integrating the complete prototype system including battery storage as well as advanced control.
WP1 – Development of control algorithms and testing for range of boundary conditions.
WP2 – Prototype development
WP3 - Development accelerated quasi-field test for PV-heat pump systems
WP4 – Field test

3.3.c Planning (if ongoing project)

One prototype system is being tested in the lab, with and without battery storage and with and without advanced control. One system is being tested in the field during 2020.

3.3.d Summary of main results

Rule based control using thermal (building and DHW store) as well as electrical storage for storing excess PV power has been developed. Additionally, price control based on the future spot market price has been developed using thermal storage. These have been simulated for 6 different countries, for a range of different sizes of PV systems, plug and DHW loads as well as indoor set temperatures. Both heat pump and plug loads are considered. No additional hot water storage was considered, only the 180l integrated hot water store and the indoor temperature is only varied by up 1.5 °C. The results show that there are significant variations in energy and cost savings between the countries, assuming that both the tariff for bought and sold electricity is tied to the spot market price and there are no subsidies. Germany and Spain show greatest cost savings, with Sweden showing least.

3.3.e Lessons learned

Exhaust air heat pumps have limited capacity due to the limited air change rate, and the electrical heater is often needed for buildings that are not low energy buildings. Intelligent control of the electrical heater is required to avoid unnecessary use of this heater, which otherwise can undermine the gains of the advanced control.

System testing of such complex systems is demanding, with high requirements for the test rig. It is still common to find “unexpected” functional problems in the system being tested.

3.4 Probabilistic Forecasting for Battery Management

Title	Probabilistic Forecasting for Battery Management
Parties involved	RISE Research Institutes of Sweden (RISE), Uppsala University, Chalmers University, Cell Solar, Herrljunga Elektriska AB and TMF[1]
Location (for field trials)	RISE Research Villa in Borås, Sweden
Start date	Jan. 2019
End date	Dec. 2020
Status	Probabilistic forecast model for solar photovoltaic (PV) generation has been developed by Uppsala University together with a machine learning algorithm to forecast electrical load demand. RISE has modelled the grid impact for a small electrical grid with full penetration of PV and domestic battery storage. Furthermore, RISE has begun to study the economical pay-back-period for the investment in a PV and battery system for households. Within this study, detailed characteristics have been made on the battery characteristics to determine its dynamic behavior. During 2020, a demonstration of the probabilistic PV forecast and load prediction is scheduled for Q2-Q4 2020 in RISE’s Research Villa in Borås

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[1] The Swedish Federation of Wood and Furniture Industry - Trä- och Möbelföretagen (TMF)

3.4.a Project goal

Analyze how a probabilistic forecast of PV generation and a machine learning algorithm can be used to enhance the battery dispatch for a single-family household with the objective to maximize the economical profit. The operation and functionality of these models will be demonstrated in a real-life case of RISE's Research Villa that is equipped with a PV system, battery storage and a ground-source heat pump.

Different PV and battery system designs, with regards to sizing, and battery dispatch algorithms will be analyzed to find optimal design and functionality with regards to its pay-back-period.

To enhance the investment profitability, the battery's ability to act on the grid balancing market (e.g. frequency regulation) is investigated to increase the system's revenue.

3.4.b Project setup

This project consists of six work packages:

1. Project management and dissemination
2. Data collection and clustering
3. Load prediction and PV forecasting
4. Modelling of PV and battery system including battery dispatch algorithms
5. External grid services for household batteries
6. Demonstration of load prediction and PV forecasting algorithm for battery management

3.4.c Planning (if ongoing project)

So far, individual electrical load profiles for the grid in Herrljunga, Sweden have been collected, processed and clustered into a few clusters. Where each cluster represents typical user profiles in terms of daily load profile. This data has then been analysed in a first step to see which of these clients are more suited for battery storage, given their daily usage and co-existence with available PV generation.

A load predictive algorithm has been developed that uses historical measured data and an artificial intelligence algorithm to give predictions on the up-coming usage [47]. This is used together with a forecasting model for the PV generation to have the predicted net grid interaction. These models are then to be used in WP6 for the demonstration where it will be tested in RISE's Research Villa in Borås.

Work is also on-going related to what external grid services a household battery could offer to increase its revenue. Current legislations have been mapped and a modelling have been done to see how well the need for frequency regulation coincides with available battery storage capacity.

A modelled have been developed in MATLAB to evaluate the energy flows and system performance for a PV and battery system that will be used later together with the cluster profiles from WP2 to find "optimal" system configurations for each cluster profile.

In WP6 an external communication has been established with the battery system in RISE's Research Villa for remote controlling using MQTT.

3.5 From photovoltaic generation to end-users with minimum losses – a full-scale demonstration

Title	From photovoltaic generation to end-users with minimum losses – a full-scale demonstration
Parties involved	RISE Research Institutes of Sweden (RISE), Asko Appliances AB, Derome Hus AB, Ferroamp, Herrljunga Elektriska AB, Johanneberg Science Park AB, Metrum Sweden AB, NIBE AB, Systemair Sweden AB, TMF, Wallenstam AB, Västra Götalandsregionen
(for field trials) Location	RISE Research Villa in Borås, Sweden
Start date	Jan. 2017
(projected) End date	Dec. 2020
Status	A model has been developed in MATLAB to analyse the performance of a PV and battery system with regards to its grid interaction, self-consumption of PV and energy efficiency gains of a low-voltage direct-current (LVDC) distribution system. Prototypes of a ground-source heat pump (GSHP) and ventilation system has been developed by NIBE and Systemair that operates directly on direct-current (DC) supply. A full-scale demonstration of an LVDC distribution network has been up and running for 36 months with a GSHP and ventilation system running directly on DC supply.

3.5.a Project goal

A demonstration of a LVDC distribution system in a net-zero energy building (NZEB) with PV, battery storage and an internal DC distribution network.

Study how different battery dispatch algorithms impact the system's performance with regards to self-consumption (of PV) and peak shaving [48] .

A modelling comparison of the potential energy efficiency gains when using an LVDC distribution network, together with PV and battery storage, for a single-family NZEB in Sweden.

3.5.b Project setup

This project consists of six main parts:

A. **Literature review** – establishing of state-of-the-art regarding LVDC distribution and energy usage in buildings.
B. **Preparations prior to the demonstration** – prototyping of DC compatible appliances and purchasing of components
C. **Installation and commissioning of LVDC** – done in RISE's Research Villa in Borås, Sweden
D. **Demonstration** – full-scale demonstration of the LVDC system in RISE's villa together with a battery storage and PV system
E. **Evaluation** – system and component evaluation and characterization from modelling and laboratory measurements.
F. **Demonstration showcase and result dissemination** – study visits at RISE's villa and dissemination of project results.

3.5.c Planning (if ongoing project)

The full-scale demonstration of the LVDC system in RISE’s Research Villa was commissioned in Q2 2018 and have since then been up and running together with the battery storage, PV array and two modified direct DC loads – heat pump and ventilation system. There has been numerous study visits and publicity since then.

A model has been developed in MATLAB to analyse the system performance of the LVDC network to enable a comparison with a conventional AC system. This model uses the measured performance characteristics from measurements of power electronic converters and a battery cell performed in the laboratory to have an accurate representation of the dynamic performance.

Two scientific articles are near completion with the focus on – (i) detailed battery modelling and its impact on system performance and (ii) modelling of potential energy savings from an LVDC network.

3.5.d Summary of main results

The impact of different battery dispatch algorithm has been modelled for an NZEB in Sweden and the resulting system performance [48].

Two conventional installation products – heat pump and ventilation unit – have been modified to enable direct operation on DC and have been up and running in the demonstration since Q2 2018.

3.5.e Lessons learned

One of the goals with this project was to install, commission and operate a full-scale demonstration of an LVDC network with battery storage, PV array and DC compliant products with the aim of showcasing this system topology. From the communication with the companies involved in the DC modification of the products, it was known that the modification was easy to perform without the need for any advance power electronic components.

From the modelling of the impact of different battery sizes and dispatch algorithms it was shown that the size and chosen dispatch should be selected carefully to avoid over-sizing of the battery capacity. The characterization of the battery’s performance also showed that there is a large discrepancy in the battery’s losses depending on the modelled used.

3.6 IRIS – Smart Cities

Title	IRIS – Smart Cities [49]
Parties involved	Consortium consisting of 43 partners from 9 countries, for a full overview – see here.
Location (for field trials)	Lighthouse cities – Utrecht (NL), Nice (FR) and Gothenburg (SE). Follower cities – Vaasa (FIN), Alexandroupolis (GR), Santa Cruz de Tenerife (ESP) and Focsani (RO)
Start date	Oct. 2017
End date	2022
Status	Ongoing

3.6.a Project goal

The overall concept of IRIS is the Transition Strategy comprising five tracks that together provide a universal yet versatile framework to address both common and district specific challenges. Within these five tracks, IRIS envisions to demonstrate a set of integrated solutions built on top of both mature and innovative technologies.

The European Innovation Partnership on Smart Cities and Communities (EIP-SCC) brings together cities, industry and citizens to improve urban life through more sustainable integrated solutions, including applied innovation, better planning, a more participatory approach, higher energy efficiency, better transport solutions, intelligent use of Information and Communication Technologies (ICT).

The IRIS project is developed by the “Lighthouse cities” of **Utrecht** (The Netherlands, coordinator), **Nice** (France), and **Gothenburg** (Sweden), who will act as a good example of replication for **Vaasa** (Finland), **Alexandroupolis** (Greece), **Santa Cruz de Tenerife** (Spain) and **Focsani** (Romania) the four “Follower cities” and an additional high number of linked EU cities through a well prepared dissemination and exploitation planning of IRIS actions foreseen.

3.6.b Project setup

The five tracks forming the project are,

1. **Renewable and energy positive districts**; integrating the following aspects
    a. high share of locally produced and consumed renewable energy at district level,
    b. energy savings at building level reducing the citizens’ energy bills,
    c. energy savings at district level.
2. **Flexible energy management and storage**. Integrating smart energy management and renewable energy storage for:
    a. maximum profits of renewables power/heat/gas,
    b. maximum self-consumption reducing grid stress and curtailment,
    c. unlocking the financial value of grid flexibility.
3. **Intelligent mobility solutions**. Integrating electric vehicles and e-cars sharing systems in the urban mobility system offering:
    a. local zero-emission mobility,
    b. lower household mobility costs,
    c. smart energy storage in V2G car batteries.
4. **Digital transformation and services**. Cutting edge information technology and data framework enabling:

    a. the above-mentioned solutions maximizing cost-effectiveness of the integrated infrastructure.

5. **Citizen Engagement and Co-creation**. Design and demonstration of feedback mechanisms and inclusive services for citizens to achieve that they are intrinsically motivated to:
    a. save energy,
    b. shift their energy consumption to periods with redundant renewables,
    c. use electric vehicles,
    d. change the vehicle ownership culture towards a use or common mobility assets culture.

3.6.c Summary of main results

An interesting publication available related to this project is:

- **D1.3: User, Business and Technical requirements of T.T.#2 Solutions** [50] The report provides detailed requirements and specifications of the corresponding solutions, and recommendations capable of allowing a smarter and more efficient grid balancing, not only as concerns the electricity, but also additional energy streams distribution as those of heating/cooling on a city level basis. Including the interaction between heat pump(s) and district heating in the two user-cases – Campus Johanneberg and Medical campus in Gothenburg.

For a complete list of publicly available reports, see project web page - https://irissmartcities.eu/public-deliverables.

3.7 Optimization of combined solar hybrid and geothermal systems

Title	Optimization of combined solar hybrid and geothermal systems [51][2]
Parties involved	RISE Research Institutes of Sweden (RISE) and Energiförbättring Väst
Location (for field trials)	Housing cooperative "Vårlöken" in Kungälv, Sweden
Start date	Sep. 2016
End date	Dec. 2017
Status	Finished

3.7.a Project goal

This project aims were to study how different factors linked to control parameters affect the energy efficiency of these systems and studying different borehole configurations and how these affect the possibility for seasonal heat storage.

The project combined simulations at several system levels with measurements in the existing installation which created a unique opportunity to study both the optimal design and to evaluate the results based on actual measurements. The projected resulted in increased knowledge on factors influencing the effectiveness of these and similar systems.

3.7.b Project setup

The project consisted of two main work packages:

1. **Optimizing the system performance through modelling and field measurements**. A model of the entire energy system, including bore hole storage, PVT collectors, heat pump, hot water storage

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[2] This was a continuing of the separate project "*Solhybrid och bergvärme - Förnybart med ny systemlösning*" where the performance of the existing system was evaluated through field measurements.

tanks, electrical boilers, etc. were developed in Polysun to enable a modelling comparison of different energy management systems.

2. **Bore hole storage analyze** – the existing bore hole configuration was analyzed using EED and alternative configurations were investigated.

3.7.c Summary of main results

In Polysun, several operating strategies to maximize solar heat exchange was tested. The conclusion was that solar heat can be increased by about 50%. Unnecessary operation of the solar hybrids can also be avoided by an addition to the control conditions of the circuit.

A few different cases with regards to solar heat and borehole configurations was studied. Analysis of the results strengthens the benefit of increased solar heat production which lead to an improvement of the SPF (Seasonal Performance Factor) by two tenths. The results from EED also showed that for a new system, fewer and deeper boreholes are recommended, placed in one line to achieve a lower investment cost but equivalent performance. A seasonal heat store is not applicable because the solar heat is not large enough.

The self-consumption of solar electricity in the system is 62%. The tenants can increase its own consumption by excess charging of their heat storage tanks for heat and hot water if there is enough excess of solar electricity production. An energy-efficient solution is to reduce the main fuse size and receive a better profit for the sold electricity.

Available data for the system for three years shows that the heat pump performance is constant with SPF H1[3] of 3.1 for the entire period. The electric boiler is required during cold periods because the heat pump system is not designed to cover the entire energy and power demand. For a cold period e.g. January 2016, a lot of electricity is bought for the system and SPF H4 is 2.6 for that period. The losses in culverts between the houses are large and with improved insulation, some of the bought electricity can be avoided.

3.7.d Lessons learned

With proper energy management and system planning, the energy efficiency and self-consumption of the system can be improved. Excess PV energy could, due to legal requirements, only be used to supply common loads for the building cooperation. With planning, this excess energy could also be used to supply the household loads of the occupants and thus increase the self-consumption and economic of the investment.

The bore hole storage configuration could also be improved with proper planning and modelling of the performance to increase the systems energy efficiency and possibility for increased seasonal storage.

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[3] ”H1-H4” were different system boundary defined in the project. For more information, see [51].

3.8 FED – Fossil-free Energy Districts

Title	FED – Fossil-free Energy Districts [52]
Parties involved	Göteborg Stad, Johanneberg Science Park AB, Göteborg Energi AB, Business Region Göteborg AB, Chalmersfastigheter AB, Akademiska hus AB, Chalmers University of Technology, RISE Research Institutes of Sweden AB and Ericsson AB
Location (for field trials)	Chalmers Campus in Gothenburg, Sweden
Start date	Nov 2016
End date	Oct 2019
Status	Finished

3.8.a Project goal

The FED-project aims to deliver a grid-connected local energy system with demand and supply in balance, integrating electricity, heating and cooling, and a local energy market and trading system functioning in symbiosis with the existing energy market.

The environmental improvements, with the FED-system in place, will lead to a local energy production that is 100% fossil-free, decreased energy-peaks with 80%, and imported energy into the grid with 30%.

The FED local energy market leads to new business and revenues for the real-estate owners and users, utility companies, and 3rd party suppliers. The new energy marketplace will demonstrate and evaluate at least 10 000 business transactions.

FED creates cost effective energy improvement solutions, thus avoiding higher rental cost for economically disadvantaged citizens.

3.8.b Project setup

FED aims to develop, demonstrate and replicate a novel district level energy system, integrating electric power, as well as heating and cooling. This solution embraces and enhances the use of technologies such as PVs, heat-pumps and wind into larger system. The solution will drastically reduce peak loads and the use of fossil primary energy to such an extent that Gothenburg has the possibility to be a no-carbon city if deployed on a greater scale.

To overcome the main challenges, the proposed solution contains advancements in system development and operation, business logistics, legal framework as well as stakeholders’ acceptance.

The FED solutions consist of three cornerstones:

1. **FED demonstrator area** – The selected demonstration is located at a campus with about 15 000 end-users. It has a well-balanced set of property owners, energy infrastructure, and users, including prosumers as well as buildings with different needs and usage profiles. The area is exempted from the law of concession for electricity distribution, providing the opportunity to test and validate a local energy market. The prerequisites to optimize the use of primary and secondary energy using intermediate storage are well developed, as they are for generation, storage and distribution.
2. **FED System solution** – Our solution will optimize the use of low-grade energy to replace primary energy. Adding fossil-free energy sources while optimizing different buildings usage profiles; one building’s energy needs will be balanced with the surplus of another. Intermediate storage, fundamental to be success, consists of heating/cooling storage in the building’s structure,

accumulation tanks or geothermal heat pumps, and batteries for electricity. An ICT service will support future volatile energy markets.

3. **FED Business solution** – Create new sustainable markets. The success of FED depends on cooperation and energy exchange between several stakeholders. To make it happen, a local energy market creating business value for each stakeholder will be developed.

3.9 EnergyMatching

Title	EnergyMatching [53]
Parties involved	The consortium is represented by 17 partners operating in 7 European Countries: Italy, Spain, France, Germany, Spain, The Netherlands and Sweden. For complete partner list, see project web page - https://www.energymatching.eu/partners/.
Location (for field trials)	Saint Aubin Sur Scie, France; Comune di Campi Bisenzio, Italy and Ludvika, Sweden
Start date	Oct. 2017
End date	March 2022
Status	On-going

3.9.a Project goal

The overall objective of the project is to maximize the RES harvesting in the built environment by developing and demonstrating cost-effective active building skin solutions as part of an optimised building energy system, being connected into local energy grid and managed by a district energy hub implementing optimised control strategies within a comprehensive economic rationale balancing objectives and performance targets of both private and public stakeholders. The scope of the project is for existing urban areas with multi-family buildings and to a limited extent other buildings. The methodology can also be applied in the design process for new housing areas, but the demonstration sites are all retrofit.

The expected results are divided into three main areas, each with sub-goals:

- Methodological framework and business vision
    - Energy Harvesting business enhancer platform
    - Energy Matching optimization tool (techno-economic optimization of size and placement of PV based on hourly electrical loads)
- Adaptable and adaptive skin technologies
    - Versatile click&go substructure for different cladding systems
    - Solar windows package
    - Modular appealing BIPV envelope solutions
- Building and district energy LAN
    - Renewable harvesting package to heat and ventilate (heat pump and energy storage)
    - Building and district energy harvesting management system (sharing of electricity between buildings)

3.9.b Project setup

The project has three objectives:

1. Definition of adaptive envelope solutions for energy harvesting at building level
2. Integration of the energy harvesting solutions into the building and district energy concept
3. Geoclusterisation of solutions and replication potential

3.9.c Summary of main results

The results so far include two peer-reviewed articles [54][55] with results relevant to the CCB project. The cost-optimum size for PV is generally much larger when optimizing for the aggregated load of several buildings rather than the sum of the sizes for cost optimization of PV for each building independently. Battery storage is nearly always optimized to zero show no profitability. In the Swedish demo case extra water storage will be built into the system enabling a much larger cost optimal PV system.

More results so far can be found here: https://cordis.europa.eu/project/id/768766/reporting

3.9.d Lessons learned

The three demonstration sites show that there are large differences in both the buildings themselves, and thus potential for different types of heat pumps, but also space for HVAC equipment and possibility for extra water storage. Overheating of the building is also difficult as the tenants generally control the indoor temperature of their flat themselves. The differences make it difficult to have pre-engineered standard system solutions. As the methodology used is cost optimization, the improvements in system design and control of the HP result in larger optimal PV sizes and not increased self-consumption.

3.10 MacSheep

Title	**MacSheep** - New Materials and Control for a next generation of compact combined Solar and heat pump systems with boosted energetic and exergetic performance [56]
Parties involved	Institut für Solartechnik SPF of the University of Applied Sciences Rapperswil (**HSR**), Solar Energy Research Center of Högskolan Dalarna (**SERC**), French National Institute for Solar Energy (**CEA INES**), Department of Environmental Engineering of the Czech Technical University Prague (**CTU Prague**), Institute of Thermal Engineering of Graz University of Technology (**IWT TUG**), **REGULUS** spol. s.r.o., **VIESSMANN** Faulquemont S.A.S., **Ratiotherm** Heizung+Solartechnik GmbH & Co. KG and Energie Solaire SA (**ESSA**).
Location (for field trials)	Systems were tested using the accelerated quasi-field-testing method that was developed in the project
Start date	Jan. 2012
End date	Dec. 2015
Status	Finished

3.10.a Project goal

The objective of this project was to develop new innovative products and advanced test methods for a next generation of compact combined renewable energy systems based on solar thermal and heat pump technology for space heating and hot water preparation, using breakthroughs in ICT, new materials and technology.

The goal was to achieve 25% energy savings compared to current state of the art systems, with still competitive prices on the market. Thus, the work proposed aims for a seasonal performance factor of the system (solar and heat pump) of e.g. 6 as compared to 4.5 for the current state of the art. This will be possible by using new materials, components and ICT in an integrative approach for new system concepts where the focus is on the overall system's cost and performance.

3.10.b Project setup

A systematic approach was used to evaluate new breakthroughs for heat pumps, collectors, storage and control were evaluated in a first step via literature study and following analysis. The four separate design teams then chose desirable breakthroughs to evaluate using detailed system simulations and cost analysis. Based on this a final design was made and a prototype was built. This system was simulated for a range of boundary conditions as well as tested in the lab with the test method developed in the project.

3.10.c Summary of main results

The four design teams all produced prototypes that were significantly better than the state-of-the-art systems tested at the start of the project. Three reached the goal of 25% improvement for one or more of the four boundary conditions (climate and building type) defined in the project.

At the start of the project there were three different whole system testing methods, and during the project the three labs agreed on a joint set of boundary conditions (lab setup and weather/loads) and then developed a new 6-day test sequence. The test method for dynamic quasi-field testing has a 6-day test sequence for which the electricity use of the system during the 6 days is 6/365 that for a complete year, ie the result of the test is representative for the whole year.

3.10.d Lessons learned

The systematic approach and work in four separate teams worked very well and produced interesting differences but also good synergy effects in the development process. The simulation model (TRNSYS) used in the project was very good, but unfortunately is not available commercially.

3.11 Further development of heat pump systems for Nearly Zero Energy Buildings (NZEB)

Title	Further development of heat pump systems for Nearly Zero Energy Buildings (NZEB) (Vidareutveckling av värmepumpssystem för NNE-hus) [18]
Parties involved	RISE, Bosch Thermoteknik, Danfoss värmepumpar, Nibe, Skanska, TMF
Location (for field trials)	Borås, Varberg (Sweden)
Start date	July 2015
End date	June 2018
Status	Finished

3.11.a Project goal

The goal with the project is to develop new knowledge regarding a number of parameters related to the heat pump design and the operation and installation of the heat pump for a NZEB:

- Increased knowledge about heating demand and heat pumps in NZEB.
- Increased knowledge about variable speed HP compared to on-off HP.
- Increased knowledge about how the connection to a tank impacts the operating parameters.
- Increased knowledge about tapping profiles and production of DHW in relation to the space heating demands in a NZEB.
- Increased knowledge about integration of heat pumps with ventilation, heat recovery and passive cooling.

3.11.b Project setup

The project work was divided in six work packages:

1. Evaluation of a heat pump system based on an on-off heat pump in RISE research villa.
2. Evaluation of a heat pump system based on a variable speed heat pump in the Varberg villa.
3. Summary and analysis of DHW profiles from 30 NZEB.
4. Development of a proposal for a test method for HP producing Space heating and DHW simultaneous.
5. Integration of heat pump system and FTX
6. Development and evaluation of a newly developed heat pump system based on results from the project.

3.11.c Summary of main results

Heat pumps are frequently used as heating system in Swedish single-family buildings, but in most cases, they are used in buildings with higher heating demand than the nZEBs of tomorrow. In the project, operation parameters such as heating water and brine temperatures were analyzed in detail in real operation in two very similar nZEBs, but with different types of control of the heat pumps system.

The results from the project showed that the brine temperatures were often considerably higher than the test conditions described in EN14825 in the evaluated nZEB-buildings. It was also shown that on-off control and a tank in the system results in higher working temperatures for the heat pump compared to variable capacity control which must be accounted for when calculating projected use of energy, especially in “oversized” heat pumps in houses with low energy demand.

Earlier field measurements in nearly Zero Energy Buildings (nZEB) have shown that excess temperatures can easily occur during summertime in well-insulated houses, also in Sweden. In a heating system with a ground source heat pump the borehole can be used for passive cooling in summertime. If the house has a bidirectional ventilation system, the chilled air can easily be distributed throughout the building. The aim of this part of project was therefore to investigate the potential for such a system to curb excess temperatures. First, a simulation of a single family nNEB was conducted. Several different cases investigating the effect of window opening, ventilation air flow rate and installation of a free cooling system was simulated. To validate the simulation results, a prototype was installed in a real nZEB. The measurements confirmed that it is possible to lower the indoor temperature considerably by passive cooling by use of the borehole and supply via the air system, even though the cooling capacity is limited due to restrictions on ventilation rates and supply air temperature.

3.11.d Lessons learned

The lessons learnt with main interest for the CCB-project are finding related to passive cooling, this described in a paper by Gustafsson et.al [19].

- It is possible to lower the indoor temperature significantly with passive cooling connected to the borehole of a ground source heat pump and a bidirectional ventilation.
- The IDA model used in this study shows reasonable predictions of indoor thermal conditions for a typical summer based on the comparison results with the measurement data.
- Since the cooling capacity is limited in the free cooling system a good control scheme is required i.e. one must start cooling before the actual cooling need (high indoor temperatures) to prevent overheating.
- Increasing the ventilation flow rate is efficient to reduce the number of hours of overheating. Therefore, this should be the first step, if possible, before installing the cooling system.

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