Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 42

Heat Pumps in Smart Grids

Case scenarios per country

Appendix to the Final report

Operating Agent: The Netherlands

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Case scenarios

Sweet spots for flexible heat pump applications

Abstract

This appendix provides a list of 'typical' case scenarios for smart heat pump applications in each participating country in Annex 42.

Table of contents

1 Introduction

For each country, the role of smart grids within the energy system will be different. To gain a deeper understanding of the country-specific drivers and circumstances, *case scenarios* have been compiled for each country. These typical scenarios show at a glance which *sweet spots* exist in each regional market situation. These case scenarios have also been the basis for the simulation studies that have been carried out by the Annex 42 participants.

2 Case scenarios by country

2.1 AT – Austria

2.1.1 Considerations

In the last 5 years, there has been a strong tendency to install A/W heat pump systems, due to

1. Their relatively simple installation process for retrofitting applications and
2. The investment costs for new buildings with low heating demand are quite low. The second most common systems in Austria are B/W heat pumps. In 2014 58 % of the installed systems were A/W and 31% B/W systems. Therefore, the case scenarios are equipped with A/W and B/W heat pump systems to cover the most common systems.

In addition, the single-family building categories of passive house, new building, existing building and renovated building have been selected to have a representative cross section of the Austrian building stock. For each building category, a typical heating system design -- considering the need for buffer thermal storage for space heating (SH) and DHW and the heat distribution system and the temperature level -- has been selected. In Austria, it is common to have buffer storages for SH only with radiators or air source heat pumps with reverse cycle defrost mode, for systems with floor heating the mass of the screed is used as thermal storage. The following case scenarios have been defined:

- Case scenario I – passive house with A/W system for SH and DHW
- Case scenario II-A – new building with A/W system for SH and DHW
- Case scenario II-B – new building with B/W system for SH and DHW
- Case scenario III – existing building with B/W system for SH and DHW
- Case scenario IV – existing building renovated with A/W system for SH and DHW

2.1.2 Case scenario definitions

CASE SCENARIO I 2014 – PASSIVE HOUSE WITH AIR SOURCE HEAT PUMP

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	140 m²
	Annual heating demand	around **15 kWh/m²**
Heat pump	Heat source	**Outside air**
	Operation modes	Space heating and DHW
	Conventional Control	• heating temperature (max. about **30 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 21 °C) • DHW set-temperature around **55 °C** considering typical hysteresis
	Smart Control	Rising heating temperature and DHW temperature according an external signal
	El. Back up heater	**Yes, parallel operation below bivalence temperature (around -7°C)**
Heating system	Medium	Water
	Heat transfer	**Floor heating**
	Buffer storage	**no**
Domestic hot water	Annual energy demand	around 3000 kWh/a, taken into account to have 3 to 4 persons per household
	Load	Typical tapping behaviour (energy and temperature) for average family (e.g. according certification standards)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	No
	active use of building mass	Yes, but restrictions to full fill room comfort conditions
Optimization/Problem	Goal	Optimization of heat pump operation for load shifting /peak shaving under consideration of heat pump system´s efficiency
	Realization	Pooling of heat pumps by centralized control (aggregator) in two cases 1) no feedback from heat pump and 2) feedback from heat pump to aggregator
	Communication with heat pump	Heat pump receives a continuous signal as a live signal (constantly one-way communication, uni-directional) from aggregator and in one further use case aggregator sends control signal, but local MPC controls heat pump system (bi-directional)
	Expected results	Load shift potential of the individual heat pump system and efficiency losses (heat pump efficiency and storage losses
	Observation periods	2014

CASE SCENARIO II-A 2014 – NEW BUILDING WITH AIR SOURCE HEAT PUMP

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	140 m²
	Annual heating demand	around **45 kWh/m²**
Heat pump	Heat source	**Outside air**
	Operation modes	Space heating and DHW
	Conventional Control	• heating temperature (max. about **35 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 21 °C) • DHW set-temperature around **55 °C** considering typical hysteresis
	Smart Control	Rising heating temperature and DHW temperature according an external signal
	El. Back up heater	**Yes, parallel operation below bivalence temperature (around -7°C)**
Heating system	Medium	Water
	Heat transfer	**Floor heating**
	Buffer storage	**300 l-700l (combined)**
Domestic hot water	Annual energy demand	around 3000 kWh/a, taken into account to have 3 to 4 persons per household
	Load	Typical tapping behaviour (energy and temperature) for average family (e.g. according certification standards)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	for thermal simulations
	Battery	No
	Gas/oil boiler	No
	active use of building mass	Yes, but restrictions to full fill room comfort conditions
Optimization/Problem	Goal	Optimization of heat pump operation for load shifting /peak shaving under consideration of heat pump system´s efficiency
	Realization	Pooling of heat pumps by centralized control (aggregator) in two cases 1) no feedback from heat pump and 2) feedback from heat pump to aggregator
	Communication with heat pump	Heat pump receives a continuous signal as a live signal (constantly one-way communication, uni-directional) from aggregator and in one further use case aggregator sends control signal, but local MPC controls heat pump system (bi-directional)
	Expected results	Load shift potential of the individual heat pump system and efficiency losses (heat pump efficiency and storage losses
	Observation periods	2014

Case scenario II-B 2014 – New building with ground source heat pump

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	140 m²
	Annual heating demand	around **45 kWh/m²**
Heat pump	Heat source	**Ground source, BHE**
	Operation modes	Space heating and DHW
	Conventional Control	• heating temperature (max. about 35 °C) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 21 °C) • DHW set-temperature around 55 °C considering typical hysteresis
	Smart Control	Rising heating temperature and DHW temperature according an external signal
	El. Back up heater	**no**
Heating system	Medium	Water
	Heat transfer	**Floor heating**
	Buffer storage	**300 l-500 l (combined)**
Domestic hot water	Annual energy demand	around 3000 kWh/a, taken into account to have 3 to 4 persons per household
	Load	Typical tapping behaviour (energy and temperature) for average family (e.g. according certification standards)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	No
	active use of building mass	Yes, but restrictions to full fill room comfort conditions
Optimization/Problem	Goal	Optimization of heat pump operation for load shifting /peak shaving under consideration of heat pump system´s efficiency
	Realization	Pooling of heat pumps by centralized control (aggregator) in two cases 1) no feedback from heat pump and 2) feedback from heat pump to aggregator
	Communication with heat pump	Heat pump receives a continuous signal as a live signal (constantly one-way communication, uni-directional) from aggregator and in one further use case aggregator sends control signal, but local MPC controls heat pump system (bi-directional)
	Expected results	Load shift potential of the individual heat pump system and efficiency losses (heat pump efficiency and storage losses
	Observation periods	2014

CASE SCENARIO III 2014 – EXISTING BUILDING WITH GROUND SOURCE HEAT PUMP

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	120 m²
	Annual heating demand	around **150 kWh/m²**
Heat pump	Heat source	**Ground source, BHE**
	Operation modes	Space heating and DHW
	Conventional Control	• heating temperature (max. about **55 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 21 °C) • DHW set-temperature around **55 °C** considering typical hysteresis
	Smart Control	Rising heating temperature and DHW temperature according an external signal
	El. Back up heater	**No**
Heating system	Medium	Water
	Heat transfer	**Radiators**
	Buffer storage	**500 l – 1000 l**
Domestic hot water	Annual energy demand	around 3000 kWh/a, taken into account to have 3 to 4 persons per household
	Load	Typical tapping behaviour (energy and temperature) for average family (e.g. according certification standards)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	No
	active use of building mass	Yes, but restrictions to full fill room comfort conditions
Optimization/Problem	Goal	Optimization of heat pump operation for load shifting /peak shaving under consideration of heat pump system´s efficiency
	Realization	Pooling of heat pumps by centralized control (aggregator) in two cases 1) no feedback from heat pump and 2) feedback from heat pump to aggregator
	Communication with heat pump	Heat pump receives a continuous signal as a live signal (constantly one-way communication, uni-directional) from aggregator and in one further use case aggregator sends control signal, but local MPC controls heat pump system (bi-directional)
	Expected results	Load shift potential of the individual heat pump system and efficiency losses (heat pump efficiency and storage losses
	Observation periods	2014

CASE SCENARIO IV 2014 – EXISTING BUILDING RENOVATED WITH AIR SOURCE HEAT PUMP

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	120 m²
	Annual heating demand	around **70 kWh/m²**
Heat pump	Heat source	**Outside air**
	Operation modes	Space heating and DHW
	Conventional Control	• heating temperature (max. about **45 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 21 °C) • DHW set-temperature around 5**5 °C** considering typical hysteresis
	Smart Control	Rising heating temperature and DHW temperature according an external signal
	El. Back up heater	**Yes, parallel operation below bivalence temperature (around -7°C)**
Heating system	Medium	Water
	Heat transfer	**Radiators**
	Buffer storage	**500 l**
Domestic hot water	Annual energy demand	around 3000 kWh/a, taken into account to have 3 to 4 persons per household
	Load	Typical tapping behaviour (energy and temperature) for average family (e.g. according certification standards)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	No
	active use of building mass	Yes, but restrictions to full fill room comfort conditions
Optimization/Problem	Goal	Optimization of heat pump operation for load shifting /peak shaving under consideration of heat pump system´s efficiency
	Realization	Pooling of heat pumps by centralized control (aggregator) in two cases 1) no feedback from heat pump and 2) feedback from heat pump to aggregator
	Communication with heat pump	Heat pump receives a continuous signal as a live signal (constantly one-way communication, uni-directional) from aggregator and in one further use case aggregator sends control signal, but local MPC controls heat pump system (bi-directional)
	Expected results	Load shift potential of the individual heat pump system and efficiency losses (heat pump efficiency and storage losses
	Observation periods	2014

2.2 CH – Switzerland

2.2.1 Considerations

Existing buildings that are or will be renovated have the highest potential for decreasing the energy demand and for contributing significantly to gain flexibility in smart grids. Therefore, two of the four case scenarios (Case scenarios I and II) refer to existing renovated single family houses (reference building SFH100 with 100kWh/m^2/a). The other two cases refer to newer buildings. SFH45 (45kWh/m^2/a) (Case III) represents a renovated building reaching good insulation quality of the building envelope and SFH15 (15kWh/m^2/a) (Case IV) represents a current building envelope with low energy demand. It fits the Swiss Minergie-P (Minergie 2010). These three reference buildings have been defined within IEA SHC Task 44 / HPP Annex 38 [1]. Two different control options are considered for heat pumps, i.e. On/Off-control and capacity control. On/Off-control (Case II, III and IV) is the commonly used way in Switzerland to run the heat pump. Capacity control (Case I) of an air/water heat pump includes an immense potential in smart grids. It guarantees more flexibility by means of a higher heat-range decoupled from the ambient-temperature and higher efficiencies for the heat pump itself. Additionally, thermal storages for hot water generation, for the heating system and the thermal mass of the building itself are considered in the defined cases. In all cases, the use of the building mass within the storage control concept is considered. The common Swiss heating systems types, i.e. radiator or floor heating, are chosen within the discussed cases.

2.2.2 Case scenario definitions

SCENARIO I EXISTING BUILDING (RENOVATED) WITH AIR SOURCE HEAT PUMP (CAP. CONTROL)

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	140 m²
	Annual heating demand	around **100 kWh/m²** (according average Swiss weather conditions)
Heat pump	Heat source	Outside air
	Operation modes	Space heating and DHW
	Conventional Control	• **Capacity control** • heating temperature (max. about **55 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C) • DHW set-temperature around **50 °C** considering typical hysteresis
	Smart Control	
	El. Back up heater	no
Heating system	Medium	Water
	Heat transfer	**Radiators**
	Storage	**Yes (range of 2000l)**
Domestic hot water	Annual energy demand	
	Load	Tapping behaviour (energy and temperature) for average family according DHW-calc (IEA-SHC Task 26)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	Yes (building mass incorporated in overall model)

Optimization/Problem	Goal	Increasing load shifting potential (flexibility of running heat pump) with highest possible efficiency of heat pump. This is quantified by:
		• Objective function consisting of two parts:
		  ○ Maximizing COP of heat pump
		  ○ Maximizing flexibility for smart grid (quantified in first approach by minimizing costs according to EpexSpot prices)
		• Weighing between these two objective functions to be defined.

	Realization	Optimization of the combination of heat pump (Capacity control) and innovative thermal energy storage for typical renovated buildings (heating and domestic water heating).
	Communication with heat pump	**Input of heating power as a function of time, supply temperature**
	Expected results	**In particular, for this case sensitivity analysis of using capacity control for heat pumps on objective function.**
	Observation periods	Coldest average week, Typical Week in Spring, Entire year

Scenario II EXISTING BUILDING (RENOVATED) WITH AIR SOURCE HEAT PUMP (ON/OFF-CONTROL)

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	140 m²
	Annual heating demand	around **100 kWh/m²** (according average Swiss weather conditions)
Heat pump	Heat source	Outside air
	Operation modes	Space heating and DHW
	Conventional Control	• **On/Off-control** • heating temperature (max. about **55 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C) • DHW set-temperature around **50 °C** considering typical hysteresis
	Smart Control	
	El. Back up heater	no
Heating system	Medium	Water
	Heat transfer	**Radiators**
	Storage	**Yes (range of 2000l)**
Domestic hot water	Annual energy demand	
	Load	Tapping behaviour (energy and temperature) for average family according DHW-calc (IEA-SHC Task 26)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	Yes (building mass incorporated in overall model)

Optimization/Problem	Goal	Increasing load shifting potential (flexibility of running heat pump) with highest possible efficiency of heat pump. This is quantified by:
		• Objective function consisting of two parts:
		  ○ Maximizing COP of heat pump
		  ○ Maximizing flexibility for smart grid (quantified in first approach by minimizing costs according to EpexSpot prices)
		• Weighing between these two objective functions to be defined.

	Realization	Optimization of the combination of heat pump (Capacity control) and innovative thermal energy storage for typical renovated buildings (heating and domestic water heating).
	Communication with heat pump	**Input of on/off signal for heat pump, supply temperature**
	Expected results	**In particular effect of thermal storages and thermal mass of building on objectives.**
	Observation periods	Coldest average week, Typical Week in Spring, Entire year

Scenario III NEW STANDARD BUILDING WITH AIR SOURCE HEAT PUMP (ON/OFF-CONTROL)

Category	*Item*	*Details*

<table>
<tr><td rowspan="3">Building</td><td>Type</td><td>Single family house</td></tr>
<tr><td>Heated area</td><td>140 m²</td></tr>
<tr><td>Annual heating demand</td><td>around 45 kWh/m² (according average Swiss weather conditions)</td></tr>
<tr><td rowspan="5">Heat pump</td><td>Heat source</td><td>Outside air</td></tr>
<tr><td>Operation modes</td><td>Space heating and DHW</td></tr>
<tr><td>Conventional Control</td><td>• On/Off-control
• heating temperature (max. about 45 °C) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C)
• DHW set-temperature around 50 °C considering typical hysteresis</td></tr>
<tr><td>Smart Control</td><td></td></tr>
<tr><td>El. Back up heater</td><td>no</td></tr>
<tr><td rowspan="3">Heating system</td><td>Medium</td><td>Water</td></tr>
<tr><td>Heat transfer</td><td>Floor heating</td></tr>
<tr><td>Storage</td><td>Yes (1000l)</td></tr>
<tr><td rowspan="3">Domestic hot water</td><td>Annual energy demand</td><td></td></tr>
<tr><td>Load</td><td>Tapping behaviour (energy and temperature) for average family according DHW-calc (IEA-SHC Task 26)</td></tr>
<tr><td>Storage</td><td>Typical size (around 300 l)</td></tr>
<tr><td rowspan="4">Additional technologies or storages</td><td>PV</td><td>no</td></tr>
<tr><td>Battery</td><td>no</td></tr>
<tr><td>Gas/oil boiler</td><td>no</td></tr>
<tr><td>active use of building mass</td><td>Yes (building mass incorporated in overall model)</td></tr>
<tr><td rowspan="5">Optimization/Problem</td><td>Goal</td><td>Increasing load shifting potential (flexibility of running heat pump) with highest possible efficiency of heat pump. This is quantified by:
• Objective function consisting of two parts:
  ○ Maximizing COP of heat pump
  ○ Maximizing flexibility for smart grid (quantified in first approach by minimizing costs according to EpexSpot prices)
• Weighing between these two objective functions to be defined.</td></tr>
<tr><td>Realization</td><td>Optimization of the combination of heat pump (Capacity control) and innovative thermal energy storage for typical renovated buildings (heating and domestic water heating).</td></tr>
<tr><td>Communication with heat pump</td><td>Input of on/off signal for heat pump, supply temperature</td></tr>
<tr><td>Expected results</td><td>In particular effect of thermal storages and thermal mass of building on defined goals.</td></tr>
<tr><td>Observation periods</td><td>Coldest average week, Typical Week in Spring, Entire year</td></tr>
</table>

Scenario IV Passive house with air source heat pump (On/Off-control)

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	140 m²
	Annual heating demand	around **15 kWh/m²** (according average Swiss weather conditions)
Heat pump	Heat source	Outside air
	Operation modes	Space heating and DHW
	Conventional Control	• **On/Off-control** • heating temperature (max. about **35 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C) • DHW set-temperature around **50 °C** considering typical hysteresis
	Smart Control	
	El. Back up heater	no
Heating system	Medium	Water
	Heat transfer	**Floor heating**
	Storage	**Yes (1000l)**
Domestic hot water	Annual energy demand	
	Load	Tapping behaviour (energy and temperature) for average family according DHW-calc (IEA-SHC Task 26)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	Yes (building mass incorporated in overall model)

Optimization/Problem	Goal	Increasing load shifting potential (flexibility of running heat pump) with highest possible efficiency of heat pump. This is quantified by:
		• Objective function consisting of two parts:
		  ○ Maximizing COP of heat pump
		  ○ Maximizing flexibility for smart grid (quantified in first approach by minimizing costs according to EpexSpot prices)
		• Weighing between these two objective functions to be defined.

	Realization	Optimization of the combination of heat pump (Capacity control) and innovative thermal energy storage for typical renovated buildings (heating and domestic water heating).
	Communication with heat pump	**Input of on/off signal for heat pump, supply temperature**
	Expected results	**In particular effect of thermal storages and thermal mass of building on objectives.**
	Observation periods	Coldest average week, Typical Week in Spring, Entire year

2.3 DE – Germany

2.3.1 Considerations

Four case scenarios have been developed that deal with several of the fields discussed in the German country report for part I. The optimization goal for all four case scenarios will be load shifting to balance the residual load: **Matching heat pumps load with times of low residual load to reduce the challenges for the remaining power plants and avoiding peak loads (capacity problems, electricity prices)**

The case scenarios will differ in terms of the building and the heat pump system. Since heat pump applications in commercial and the industry sector are excluded from the project, the case scenarios deal with domestic buildings. According the building type single family houses were chosen as the heat pumps in large multifamily houses are still focus of research. As mentioned in the market report (part I) 59 % of living space in Germany is represented by one- and two-family houses. Currently in Germany the typical heat pump application is the heat pump for space heating and DHW in new single family houses (SFH). About 30 % of all buildings of this type are equipped with heat pumps. For this reason, a standard new SFH (Case II) and a passive SFH (Case I) with very low energy demand were chosen. Both are equipped with an air-to-water heat pump as the share of this type in the heating heat pump market has risen continuously and comes to 63 % in 2012. Compared to the whole building stock new buildings represent a small share. The annual new building ratio in Germany is about 0.5 %. About 18 % of the existing buildings were built after 1995, 33 % between 1969 and 1994 and 49 % even before 1969. Now, the share of heat pumps in existing buildings is low and unclear for the future. The German Heat Pump Association (BWP) estimates a market share in existing buildings between 3 % and 10 % in 2020. We expect a rising share and consequently our case scenarios III and IV represent heat pump applications in existing buildings. Case IV considers a renovation and is equipped with an air source heat pump and case III represents an existing building with a ground coupled heat pump.

2.3.2 Case scenario definitions

SCENARIO I 2014/2024 – PASSIVE HOUSE WITH AIR SOURCE HEAT PUMP

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	150 m²
	Annual heating demand	around **15 kWh/m²** (according average German weather conditions)
Heat pump	Heat source	**Outside air**
	Operation modes	Space heating and DHW
	Conventional Control	• heating temperature (max. about **30 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C) • DHW set-temperature around **50 °C** considering typical hysteresis
	Smart Control	Rising heating temperature and DHW temperature according an external signal
	El. Back up heater	**Yes, parallel operation below bivalence temperature (around -5 °C)**
Heating system	Medium	Water
	Heat transfer	**Floor heating**
	Buffer storage	**no**
Domestic hot water	Annual energy demand	According design standards around 12,5 kWh/m²
	Load	Typical tapping behaviour (energy and temperature) for average family (e.g. according certification standards)
	Storage	Typical size (around 250 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	no
Optimization/Problem	Goal	Optimization of heat pump operation time for load shifting to periods with low residual load for matching heat pump operation with wind/PV and decrease the challenge (high load gradients) for conventional power plants under consideration of heat pump system´s efficiency
	Realization	Creating a signal which includes information about the current residual load
	Communication with heat pump	Heat pump receives a continuous signal as a live signal (constantly one-way communication, no feedback) which practically could be realized with smart meters (realization with price signal every 15 minutes)
	Expected results	Load shift potential of the individual heat pump system and efficiency losses (heat pump efficiency and storage losses)
	Observation periods	2014 and 2024 (current time horizon of the German Grid Development Plan)

Scenario II 2014/2024 – New building with air source heat pump

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	150 m²
	Annual heating demand	around **50 kWh/m²** (according average German weather conditions)
Heat pump	Heat source	**Outside air**
	Operation modes	Space heating and DHW
	Conventional Control	• heating temperature (max. about **35 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C) • DHW set-temperature around **55 °C** considering typical hysteresis
	Smart Control	Rising heating temperature and DHW temperature according an external signal
	El. Back up heater	**Yes, parallel operation below bivalence temperature (around -5 °C)**
Heating system	Medium	Water
	Heat transfer	**Floor heating**
	Buffer storage	Typical size (**around 500 l**), installed parallel
Domestic hot water	Annual energy demand	According design standards around 12,5 kWh/m²
	Load	Typical tapping behaviour (energy and temperature) for average family (e.g. according certification standards)
	Storage	Typical size (around 250 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	no
Optimization/Problem	Goal	Optimization of heat pump operation time for load shifting to periods with low residual load for matching heat pump operation with wind/PV and decrease the challenge (high load gradients) for conventional power plants under consideration of heat pump system´s efficiency
	Realization	Creating a signal which includes information about the current residual load
	Communication with heat pump	Heat pump receives a continuous signal as a live signal (constantly one-way communication, no feedback) which practically could be realized with smart meters (realization with price signal every 15 minutes)
	Expected results	Load shift potential of the individual heat pump system and efficiency losses (heat pump efficiency and storage losses)
	Observation periods	2014 and 2024 (current time horizon of the German Grid Development Plan)

SCENARIO III 2014/2024 – EXISTING BUILDING WITH GROUND SOURCE HEAT PUMP

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	150 m²
	Annual heating demand	around **150 kWh/m²** (according average German weather conditions)
Heat pump	Heat source	**ground**
	Operation modes	Space heating and DHW
	Conventional Control	• heating temperature (max. about **55 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C) • DHW set-temperature around **55 °C** considering typical hysteresis
	Smart Control	Rising heating temperature and DHW temperature according an external signal
	El. Back up heater	**no**
Heating system	Medium	Water
	Heat transfer	**Radiators**
	Buffer storage	Typical size (**around 800 l**), installed parallel
Domestic hot water	Annual energy demand	According design standards around 12,5 kWh/m²
	Load	Typical tapping behaviour (energy and temperature) for average family (e.g. according certification standards)
	Storage	Typical size (around 250 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	no
Optimization/Problem	Goal	Optimization of heat pump operation time for load shifting to periods with low residual load for matching heat pump operation with wind/PV and decrease the challenge (high load gradients) for conventional power plants under consideration of heat pump system´s efficiency
	Realization	Creating a signal which includes information about the current residual load
	Communication with heat pump	Heat pump receives a continuous signal as a live signal (constantly one-way communication, no feedback) which practically could be realized with smart meters (realization with price signal every 15 minutes)
	Expected results	Load shift potential of the individual heat pump system and efficiency losses (heat pump efficiency and storage losses)
	Observation periods	2014 and 2024 (current time horizon of the German Grid Development Plan)

Scenario IV 2014/2024 – Existing Building (renovated) air source heat pump

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	150 m²
	Annual heating demand	around **80 kWh/m²** (according average German weather conditions)
Heat pump	Heat source	**Outside air**
	Operation modes	Space heating and DHW
	Conventional Control	• heating temperature (max. about **45 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C) • DHW set-temperature around **55 °C** considering typical hysteresis
	Smart Control	Rising heating temperature and DHW temperature according an external signal
	El. Back up heater	**Yes, parallel operation below bivalence temperature (around -5 °C)**
Heating system	Medium	Water
	Heat transfer	**Floor Heating**
	Buffer storage	Typical size (**around 500 l**), installed parallel
Domestic hot water	Annual energy demand	According design standards around 12,5 kWh/m²
	Load	Typical tapping behaviour (energy and temperature) for average family (e.g. according certification standards)
	Storage	Typical size (around 250 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	no
Optimization/Problem	Goal	Optimization of heat pump operation time for load shifting to periods with low residual load for matching heat pump operation with wind/PV and decrease the challenge (high load gradients) for conventional power plants under consideration of heat pump system´s efficiency
	Realization	Creating a signal which includes information about the current residual load
	Communication with heat pump	Heat pump receives a continuous signal as a live signal (constantly one-way communication, no feedback) which practically could be realized with smart meters (realization with price signal every 15 minutes)
	Expected results	Load shift potential of the individual heat pump system and efficiency losses (heat pump efficiency and storage losses)
	Observation periods	2014 and 2024 (current time horizon of the German Grid Development Plan)

2.4 FR – France

2.4.1 Considerations

The case scenarios for France focus on three possible electric load shifting benefits from heat pumps

- Case scenario I – Hybrid A/W heat pump in existing single family house to **reduce the average load in winter**
- Case scenario II – A/W heat pump without buffer storage in existing single family house to **shave the daily peak**
- Case scenario III – Air to air (A/A) reversible heat pump in new single family house ("positive" energy building) to **reduce the peak of PV injection** on the grid
- Case scenario IV – Heat pump dedicated to the production of domestic hot water in new single family house to **reduce the peak of PV injection** on the grid and to flatten the national load curve

2.4.2 Case scenario definitions

CASE SCENARIO I EXISTING BUILDING WITH HYBRID HEAT PUMP

Category	*Item*	*Details*
Building	Type	single family house
	Heated area	100 m²
	Annual heating demand	around 180 kWh/m²
Heat pump	Heat source	outside air
	Operation modes	space heating and DHW
	Conventional Control	• heating temperature according outside air temperature (heating curve {-20/60; -7/52; 0/43; 7/37; 20/20}) - Room temperature aimed to be constant on 20 °C • DHW set-temperature around 55 °C considering typical hysteresis • minimize the energy bill of the customer (electricity and gas) with a standard day and night tariff
	Smart Control	minimize the energy bill of the customer (electricity and gas) with a day and night tariff **together with a day ahead critical peak pricing signal**
	El. Back up heater	No
Heating system	Medium	water
	Heat transfer	radiators
	Buffer storage	no
Domestic hot water	Annual energy demand	around 1800 kWh/year (e.g. according 2012 thermal regulation)
	Load	typical tapping behaviour (energy) for average family
	Storage	typical size (around 250 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	yes
	active use of building mass	no
Optimization/Problem	Goal	optimization of heat pump and boiler operation time to decrease the challenge for conventional power plants under consideration of heat pump system´s efficiency
	Realization	creating a price signal which includes information about the cost of electricity sourcing
	Communication with heat pump	heat pump receives a price signal which can be realized with smart meters
	Expected results	load shift potential of the individual heat pump system and efficiency losses
	Observation periods	one year

Case scenario II Existing building with air to water heat pump

Category	*Item*	*Details*
Building	Type	100 m²
	Heated area	around 180 kWh/m²
	Annual heating demand	around 180 kWh/m²
Heat pump	Heat source	outside air
	Operation modes	space heating and DHW
	Conventional Control	• Heating temperature according outside air temperature (heating curve {-20/60; -7/52; 0/43; 7/37; 20/20}) - Room temperature aimed to be constant on 20 °C • DHW set-temperature around 55 °C considering typical hysteresis
	Smart Control	minimize the energy bill of the customer with a time of use tariff **including peak prices between 18:00-20:00**
	El. Back up heater	yes
Heating system	Medium	water
	Heat transfer	radiators
	Buffer storage	no
Domestic hot water	Annual energy demand	around 1800 kWh/year (e.g. according 2012 thermal regulation)
	Load	typical tapping behaviour (energy) for average family
	Storage	typical size (around 250 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	no
Optimization/Problem	Goal	optimization of heat pump to decrease the challenge for conventional power plants under consideration of heat pump system´s efficiency
	Realization	creating a price signal which includes information about the cost of electricity sourcing
	Communication with heat pump	heat pump receives a price signal which can be realized with smart meters
	Expected results	load shift potential of the individual heat pump system and energy savings
	Observation periods	one year

Case scenario III New building with air to air heat pump

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	91 m²
	Annual heating demand	around 35 kWh/m² (according simulation)
Heat pump	Heat source	air
	Operation modes	space heating and cooling
	Conventional Control	room temperature aimed to be: • constant on 19 °C/26°C on week-ends • reduced to 16°C/30°C between 8:00 and 18:00 on week-days (10:00 and 18:00 on Wednesdays)
	Smart Control	room temperature set-point
	El. Back up heater	no
Heating system	Medium	air
	Heat transfer	grilles
	Buffer storage	no
Domestic hot water	Annual energy demand	around 1800 kWh/year (e.g. according 2012 thermal regulation)
	Load	typical tapping behaviour (energy) for average family
	Storage	typical size (around 260 l)
Additional technologies or storages	PV	yes – 3 kW
	Battery	no
	Gas/oil boiler	no
	active use of building mass	no
Optimization/Problem	Goal	minimize the peak of PV injection on the grid
	Realization	creating a signal which includes information about the current PV production
	Communication with heat pump	heat pump receives a continuous signal as a live signal (constantly one-way communication, no feedback) which practically could be realized with future HEMS
	Expected results	impact on PV residual energy injection on the grid
	Observation periods	one year

CASE SCENARIO IV NEW BUILDING WITH THERMODYNAMIC WATER HEATER

Category	*Item*	*Details*
Building	Type	Single family house
	Heated area	91 m²
	Annual heating demand	around 35 kWh/m² (according simulation)
Heat pump	Heat source	air
	Operation modes	DHW
	Conventional Control	• DHW set-temperature around 55 °C considering typical hysteresis • minimize the electricity bill of the customer with a standard day and night tariff
	Smart Control	shifting the heat pump operation time to limit the peak of PV injection on the grid during summer
	El. Back up heater	yes
Heating system	Medium	water
	Heat transfer	heat exchanger
	Buffer storage	yes
Domestic hot water	Annual energy demand	around 1800 kWh/year (e.g. according 2012 thermal regulation)
	Load	typical tapping behaviour (energy) for average family
	Storage	typical size (around 260 l)
Additional technologies or storages	PV	yes – 3 kW
	Battery	no
	Gas/oil boiler	no
	active use of building mass	no
Optimization/Problem	Goal	minimize the peak of PV injection on the grid
	Realization	creating a signal which includes information about the current PV production
	Communication with heat pump	heat pump receives a continuous signal as a live signal (constantly one-way communication, no feedback) which practically could be realized with future HEMS
	Expected results	impact on PV residual energy injection on the grid
	Observation periods	one year

2.5 NL – Netherlands

2.5.1 Considerations

The NL case scenarios have been selected based on the characteristics of the Dutch housing market in 2012.

- Case I involves a free-standing residence of 150 m^2 floor area equipped with an A/W hybrid heat pump. This is representative of ~14% of the Dutch housing stock.
- Case II involves a free standing or duplex (2 under one roof) residence of 130 m^2 floor area equipped with an A/W hydronic heat pump. Together these types are representative of ~25% of the Dutch housing stock.
- Case III involves a terraced building residence of 105 m^2 floor area equipped with an A/W hydronic heat pump. This is representative of ~42% of the Dutch housing stock.
- Case IV involves a residence of 70 m^2 floor area located in a 20-unit multi-family building. A hydronic (B/W) GSHP is assumed. This is representative of ~32% of the Dutch housing stock.

2.5.2 Case scenario definitions

CASE SCENARIO I FREE STANDING SINGLE-FAMILY BUILDING WITH HYBRID HEAT PUMP

Category	*Item*	*Details*
Building	Type	Free standing, single family house
	Heated area	150 m²
	Annual heating demand	50 GJ
Heat pump	Heat source	outside air
	Operation modes	space heating by hybrid heat pump; DHW by gas boiler only
	Conventional Control	Typical of current installation for both space heating and DHW temperature set point
	Smart Control	Energy price signal communicated to heat pump via smart meter; heat pump responds to use least cost fuel source
	El. Back up heater	No; gas boiler used for backup
Heating system	Medium	Water
	Heat transfer	Radiators or hydronic floor with 40°C supply temperature
	Buffer storage	Yes – 300 L capacity (25 MJ or 7 kWh)
Domestic hot water	Annual energy demand	10.5 GJ
	Load	
	Storage	300 L; 50°C water temperature when fully loaded; 60°C supply water from boiler
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	Yes; gas
	active use of building mass	No
Optimization/Problem	Goal	The control strategy is lowest possible energy cost for the families in the building. Which means responding to price signals, which contain the aspect that if renewables are abundant, price will be low, but also if demand is high, price is high
	Realization	creating a price signal which includes information about the cost of electricity sourcing
	Communication with heat pump	heat pump receives a price signal which can be realized with smart meters
	Expected results	Minimize customer operating costs; facilitate utilization of renewable electricity supply resources
	Observation periods	one year

CASE SCENARIO II FREE STANDING OR DUPLEX (2 UNDER 1 ROOF) BUILDING WITH AIR-WATER HYDRONIC HEAT PUMP

Category	*Item*	*Details*
Building	Type	Free standing or duplex, single family house
	Heated area	130 m²
	Annual heating demand	25 GJ
Heat pump	Heat source	outside air; 3 kW max output heat pump only, 9kW with back up heater
	Operation modes	space heating and DHW by heat pump
	Conventional Control	Typical of current installation for both space heating and DHW temperature set point
	Smart Control	Energy price signal communicated to heat pump via smart meter; heat pump responds to use least cost fuel source
	El. Back up heater	Yes
Heating system	Medium	Water
	Heat transfer	Hydronic floor with 35°C supply temperature
	Buffer storage	Yes – 300 L capacity (25 MJ or 7 kWh)
Domestic hot water	Annual energy demand	10.2 GJ
	Load	
	Storage	300 L; 50°C water temperature when fully loaded; 50°C supply water from heat pump
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	No
	active use of building mass	No
Optimization/Problem	Goal	The control strategy is lowest possible energy cost for the families in the building. Which means responding to price signals, which contain the aspect that if renewables are abundant, price will be low, but also if demand is high, price is high
	Realization	creating a price signal which includes information about the cost of electricity sourcing
	Communication with heat pump	heat pump receives a price signal which can be realized with smart meters
	Expected results	Minimize customer operating costs; facilitate utilization of renewable electricity supply resources
	Observation periods	one year

Case scenario III   Terraced house with air-water hybrid heat pump and small buffer storage

Category	*Item*	*Details*
Building	Type	Terraced house
	Heated area	105 m²
	Annual heating demand	25 GJ
Heat pump	Heat source	outside air; 3 kW max output heat pump only, 9kW with back up heater
	Operation modes	space heating by heat pump; DHW by gas boiler
	Conventional Control	Typical of current installation for both space heating and DHW temperature set point
	Smart Control	Energy price signal communicated to heat pump via smart meter; heat pump responds to use least cost fuel source
	El. Back up heater	No
Heating system	Medium	Water
	Heat transfer	Radiators or hydronic floor with 40°C supply temperature
	Buffer storage	Yes – 100 L capacity (2.3 kWh)
Domestic hot water	Annual energy demand	9.8 GJ
	Load	
	Storage	100 L; 50°C water temperature when fully loaded; 60°C supply water from boiler
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	No
	active use of building mass	No
Optimization/Problem	Goal	The control strategy is lowest possible energy cost for the families in the building. Which means responding to price signals, which contain the aspect that if renewables are abundant, price will be low, but also if demand is high, price is high
	Realization	creating a price signal which includes information about the cost of electricity sourcing
	Communication with heat pump	heat pump receives a price signal which can be realized with smart meters
	Expected results	Minimize customer operating costs; facilitate utilization of renewable electricity supply resources
	Observation periods	one year

CASE SCENARIO IV 20-UNIT MULTIFAMILY BUILDING WITH CENTRAL GSHP AND PARAFFIN THERMAL STORAGE

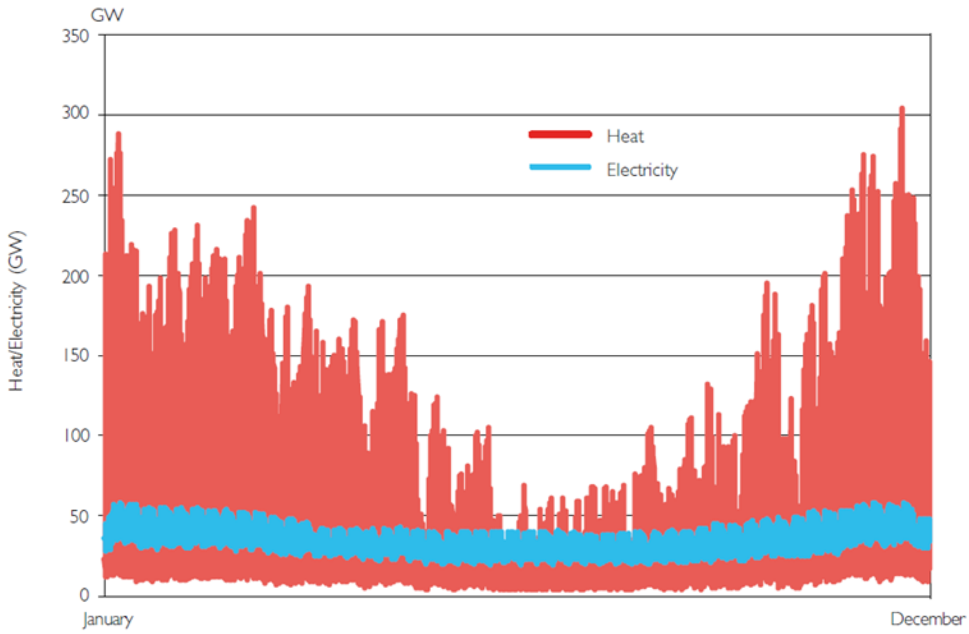
Category	*Item*	*Details*
Building	Type	Residence in 20-unit multifamily building
	Heated area	70 m²
	Annual heating demand	15 GJ per unit – 300 GJ total
Heat pump	Heat source	ground; 30 kW max output heat pump only,36kW with back up heater
	Operation modes	space heating and DHW by heat pump
	Conventional Control	Typical of current installation for both space heating and DHW temperature set point
	Smart Control	Energy price signal communicated to heat pump via smart meter; heat pump responds to use least cost fuel source
	El. Back up heater	No
Heating system	Medium	Water
	Heat transfer	Radiators with 50°C supply temperature
	Buffer storage	Yes – 10 m^3 capacity (525 kWh)
Domestic hot water	Annual energy demand	9.8 GJ per unit; 196 GJ total
	Load	
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	Yes
	active use of building mass	No
Optimization/Problem	Goal	The control strategy is lowest possible energy cost for the families in the building. Which means responding to price signals, which contain the aspect that if renewables are abundant, price will be low, but also if demand is high, price is high
	Realization	creating a price signal which includes information about the cost of electricity sourcing
	Communication with heat pump	heat pump receives a price signal which can be realized with smart meters
	Expected results	Minimize customer operating costs; facilitate utilization of renewable electricity supply resources
	Observation periods	one year

2.6 UK - United Kingdom

2.6.1 Considerations

The UK has a legally binding target to reduce total CO_2 emissions by 80% (from 1990 baseline) by 2050. To achieve this, both the electricity supply and domestic heating will have to be almost fully decarbonised.
Heat pumps have been identified by BEIS as a key technology to contribute to achieving these aims [2]. BEIS has estimated that between 6-9 million heat pumps may be required by 2030 to meet these carbon reduction trajectories.
Figure 1 below illustrates the annual, half-hourly energy demand for both heat and electricity. It illustrates well the potential impact of the electrification of heat. It is estimated that the potential increase in peak electricity demand because of heat pumps in 2030 is between 17-24 GW depending on the levels of deployment.

Figure 1 – Heat and electricity demand in the UK across a year. Courtesy of Imperial College. For illustrative purposes only, and based on actual half-hourly electricity demand from the National Grid and an estimate of half-hourly heat demand.



The primary issue therefore for the UK is that with a large-scale electrification of the heating system, the impact on peak demand at the coldest point in winter, i.e. when all heating systems are running at full capacity, will be substantial.

Case I

This study therefore aims to explore whether the domestic heat pump system (60% of additional peak demand) can be developed with an in-built flexibility or back up capacity to **reduce the demand during this annual peak period**. It is assumed that flexibility should be provided for 7 days i.e. a typical cold snap in the weather (Dec 2010 is a good example of this).
The systems that can be employed to manage an extended period of high capacity will be fundamentally different to those employed for daily shifting of demand. It will not be assumed that the entire period must be reduced to zero demand but more practically to a level at which would not exceed typical daily demand for the grid.
Options to be tested would include fuel switching through hybrid solutions. This may include back-up hybrid solutions e.g. gas canisters rather than a permanent hybrid system. Other temporary storage methods like batteries to switch to reduce the load. Other community scale options could be considered.
Implementation of these systems would require a much more integrated energy system and most likely changes to the way heat pumps are sized (currently to meet 99% of annual heat load).

Case II

2030 – High heat pump deployment; reduce daily peak demand (6-8pm)

This scenario is in effect the same as scenario I. The difference being that the system is designed to reduce the **daily** peak demand rather than annual. This therefore required shorter time periods of flexibility.

Several different demand response services are to be assessed, based on the requirements of the electricity grid operator (National Grid) and the Distribution Network Operators (DNOs). These different services range in responsiveness, length of time, and capacity reduction. It will be important therefore to look at scaling up the potential to community scale for domestic heat pump systems or distributed systems but connected through a common DSR (Demand Side Response) aggregator to provide enough reduction in capacity to be valuable for the electricity grid operators.

The number of system options is much wider for this scenario with the building fabric playing a much bigger role in short term DSR events. Therefore, a key variable to be tested will be the heat loss rate of the building. This will either be specifically varied or varied through different house types with different heat loss parameters. The potential variation in internal temperature will also be analysed, i.e. dropping from 21°C to 19°C. Other options will mirror scenario 1 such as heat and electrical storage and hybrid fuel sources. These, however, are likely to be permanent hybrid solutions that can switch fuel sources dynamically depending on external signals.

2.6.2 Case scenario definitions

Case scenario I 2030 – High heat pump deployment; reduce the annual peak demand (winter)

Category	*Item*	*Details*
Building	Type	Average 3-bed semi-detached house as described in section “System details” on p. 35 below.
	Conditioned area	See section “System details” on p. 35 below
	Annual cooling/heating demand (estimate)	See section “System details” on p. 35 below
Heat pump	Baseline	See section “System details” on p. 35 below
	Operation modes	Space heating (DHW provided by heat pump supplemented by gas back up)
	Conventional Control	See section “System details” on p. 35 below
	Smart Option	See section “System details” on p. 35 below
	El. Back up heater	See section “System details” on p. 35 below
Heating and cooling system	Medium	See section “System details” on p. 35 below
	Heat transfer	See section “System details” on p. 35 below
	Buffer storage	See section “System details” on p. 35 below
Domestic hot water	Annual energy demand	See section “System details” on p. 35 below
	Load	
	Storage	
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	Yes; gas grid connected for space heating and water heating back up
	active use of building mass	No
Optimization/Problem	Goal	Reduce annual winter peak demand
	Realization	Develop/deploy domestic heat pumps with in-built capability to reduce demand over extend cold-snap periods (up to 7 days). May involve fuel-switching via hybrid heat pumps, back-up hybrid solutions, temporary storage approaches (batteries, etc.), or other options (community scale for instance).
	Communication with heat pump	Smart meters with 2-way communication capability, Home Energy Management Systems
	Expected results	Expanded heat pump deployment without increasing average annual winter electric peak demand
	Observation periods	2014 and 2030

CASE SCENARIO II 2030 – HIGH HEAT PUMP DEPLOYMENT, REDUCE DAILY WINTER PEAK (6-8PM)

Category	*Item*	*Details*
Building	Type	Average 3-bed semi-detached house as described in section “System details” on p. 35 below.
	Conditioned area	See section “System details” on p. 35 below
	Annual cooling/heating demand (estimate)	See section “System details” on p. 35 below
Heat pump	Baseline	See section “System details” on p. 35 below
	Operation modes	Space heating (DHW provided by heat pump supplemented by gas back up)
	Conventional Control	See section “System details” on p. 35 below
	Smart Option	See section “System details” on p. 35 below
	El. Back up heater	See section “System details” on p. 35 below
Heating and cooling system	Medium	See section “System details” on p. 35 below
	Heat transfer	See section “System details” on p. 35 below
	Buffer storage	See section “System details” on p. 35 below
Domestic hot water	Annual energy demand	See section “System details” on p. 35 below
	Load	
	Storage	
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	Yes; gas grid connected for space heating and water heating back up
	active use of building mass	No
Optimization/Problem	Goal	Reduce daily winter peak demand
	Realization	Building heat loss rate will be key variable; also, potential variation in indoor temperature over peak period (e.g. 2 °C or so). Develop/deploy domestic hybrid heat pumps with capability to switch fuel sources dynamically based on external signals, temporary storage approaches (batteries, etc.), or other.
	Communication with heat pump	Smart meters with 2-way communication capability, Home Energy Management Systems
	Expected results	Minimized electric heat pump induced daily maximum peak demand
	Observation periods	2014 and 2030

System details

The UK team plan to commission a modelling study which will explore case scenarios I and II, and the potential solutions available now and in the future, based on assumptions on technological development, cost reduction etc.

One example option (for Scenario II) is described below. The modelling study will not choose which system options that will be deployed in each case, but rather comparing each potential option on a like-for-like basis to determine the best solution in terms of CAPEX, OPEX and CO_2 emissions. One such modelled scenario is based on the average 3-bed semi-detached house type.

Percentage of Total Housing Stock	7.8%
Average floor area	88m^2
Average Heat Loss per Degree per Unit Area	3.41W/K.m^2
Average Space Heating Use	11,450 kWh
Average Water Heating Use	3,190 kWh

Proposed system with current and future technology assumptions:

Variables	*Current*	*Future*
Heat Pump system	Air-water heat pump	High temperature air source heat pump
Heating distribution system	Hydronic distribution	Hydronic distribution
Storage type / capacity	200 L water storage tank	Compact thermal storage
Heating pattern	Diurnal	Diurnal
Heat emitter type / temperature	Medium – high temperature radiators ~50 - 60°C	Low temperature radiators ~30 – 40°C
On/off gas grid	Gas grid connection	Gas grid connection
Smart connectivity	Limited smart connectivity	Smart meter with two-way communication facility, Homes Energy Management System (HEMS).
Internal temperature variation	0°C	2°C

These assumptions will set the technical potential in terms of flexibility. This will then determine which DSR scenarios can be utilised and how many systems will need to be aggregated to provide the service.

DSR scenario	*Time of demand reduction*	*Response time*
Strategic Time of Use Reserve (STOR)	120 mins +	20 – 240 mins
Frequency Response	10 - 30 mins	2 – 30 secs
Fast Reserve	15 mins	2 mins

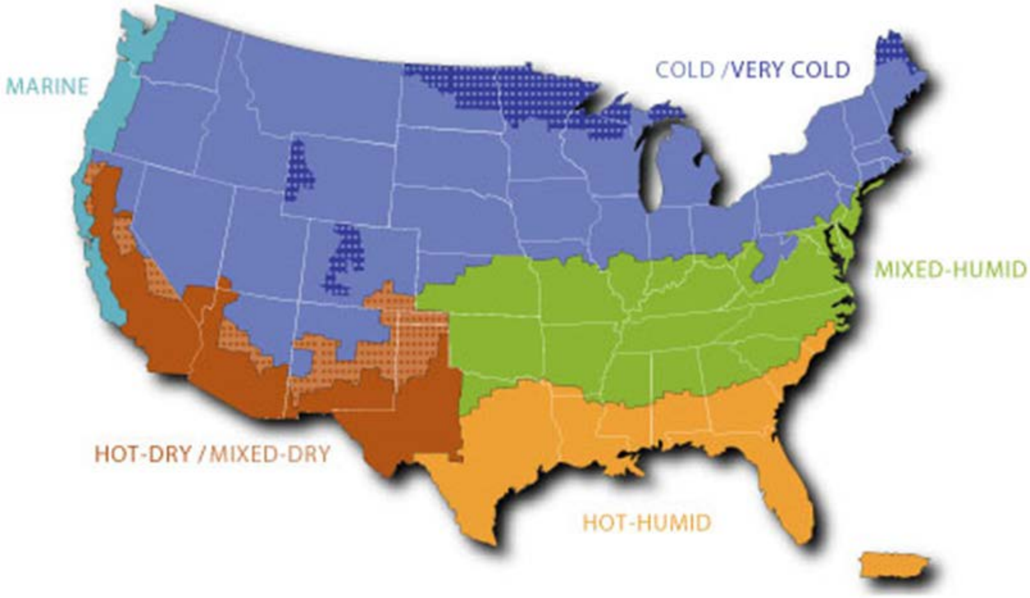
This scenario is one example of many that will potentially be modelled through in a future study.

2.7 US - United States

2.7.1 Considerations

The United States has many different climate conditions and therefore many different heat pump load characteristics. Figure 2 illustrates these variations in climate/weather defined under the US DOE Building America Program (BAP) [3]. In the south (Florida, southern Georgia, Alabama, Mississippi, Louisiana and Texas), cooling load dominates electrical energy consumption, but the space heating demand often causes the most severe peak demand problems for utilities in this region, generally the hot-humid climate zone.

Figure 2 – US climate zones recognized by BAP [3].



An ASHP alone is typically sufficient to maintain indoor set point for much of the time in this region. However, for the occasional periods (may not happen every year) when outdoor temperatures dip below freezing, significant amounts of electric 2nd stage heat are engaged, causing a system power peak. This effect is particularly acute after a multi-day cold spell in the waking morning hours. Utility companies must have provisions for accommodating these infrequent peak periods in the form of installed capacity or the ability to purchase marginal power on the open market. They must also have the transmission & distribution capacity to deliver the power. There is significant capital and expense required to build and maintain this capacity which may only be required once per several years for a brief period of several hours. Scenario I will investigate strategies to mitigate this problem.

Scenarios II and III will examine the use of standalone heat pump water heaters (HPWH) for load levelling (#2) and control of grid frequency and voltage level, or ancillary services (#3). HPWHs are basically air-to-water heat pumps coupled to a hot water storage tank (typically 50-80 gal or 190-300 l).
Scenario IV is similar to Scenario I except that the focus or goal is to achieve daily load levelling for both heating and cooling load dominated locations utilizing variable-speed or capacity systems.

2.7.2 Case scenario definitions

CASE SCENARIO I 2014/2024 – PEAK DEMAND CONTROL FOR WINTER PEAKING UTILITIES IN DEEP SOUTHERN US WITH AIR SOURCE HEAT PUMP

Category	*Item*	*Details*
Building	Type	Single family house
	Conditioned area	223 m² (2400 ft²)
	Annual cooling/heating demand (estimate)	around **78 kWh/m² cooling & 16 kWh/ m² heating** (according to average weather conditions in Houston, TX location) – estimated based on annual energy use of 6269 kWh (cooling) and 2660 kWh (heating) for base heat pump as computed for prototype residential houses by DOE [4],[5] using EnergyPlus **Error! Reference source not found.** model.
Heat pump	Baseline	Single-speed, single capacity level heat pump with outside air heat source and sink
	Operation modes	Space heating and space cooling (DHW provided by conventional electric storage water heater)
	Conventional Control	Simple thermostat controlling indoor air temperature ● heating set point temperature **20 °C (68 °F)** ● cooling set point temperature **~26 °C (78 °F)** ● DHW set-temperature around **50 °C** considering typical hysteresis
	Smart Option	Variable-speed heat pump, outside air heat source and sink with thermostat controlling indoor air temperature level
	El. Back up heater	Yes, 8 kW capacity, parallel operation with heat pump below house balance point (around -5 °C for baseline, varies for variable-speed heat pump case)
Heating and cooling system	Medium	Air
	Heat transfer	Central heated/cooled air distribution
	Buffer storage	no
Domestic hot water	Annual energy demand	About 12,5 kWh/m² (2793 kWh total)
	Load	Tapping behaviour as defined in DOE computations
	Storage	Typical size (around 190 l or 50 gal)
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	No
	active use of building mass	No
Optimization/Problem	Goal	Eliminate sharp winter peak demand during occasional periods of cold weather
	Realization	Utility signal to heat pump of impending cold weather period
	Communication with heat pump	Heat pump receives utility signal (via a smart meter or other)
	Expected results	Heat pump switches to highest speed/capacity and back up electric heat disabled during pre-defined peak period
	Observation periods	2014 and 2024

Case scenario II 2014/2024 – Heat Pump Water Heating with Demand Response

Category	*Item*	*Details*
Building	Type	Single family house
	Conditioned area	223 m² (2400 ft²)
	Annual water heating demand (estimate)	Varies by location (exact locations for analyses still to be determined) – demand will be as computed for prototype residential houses by DOE [4],[5] using EnergyPlus **Error! Reference source not found.** model.
Heat pump – DHW only	Baseline	**Baseline 1 is conventional electric storage; Baseline 2 is electric storage heat pump water heater with rated energy factor of 2-2.4**
	Operation modes	DWH only
	Conventional Control	Simple thermostat controlling hot water storage temperature • DHW set-temperature around 50 °C
	Smart Option	**Electric storage heat pump water heater as in Baseline 2 but with control system set up to receive & respond to utility demand control signals**
	El. Back up heater	Yes, 4.5 kW capacity
Heating and cooling system	Medium	NA
	Heat transfer	NA
	Buffer storage	NA
Domestic hot water	Annual energy demand	Varies by location (exact locations for analyses still to be determined) – demand will be as computed for prototype residential houses by DOE [4],[5] using EnergyPlus **Error! Reference source not found.** model
	Load	Tapping behaviour as defined in DOE computations
	Storage	50-80 gal (190-300 l)
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	No
	active use of building mass	No
Optimization/Problem	Goal	Load levelling &/or peak reduction
	Realization	Utility signal or automatic sensing of load shedding or load adjustment
	Communication with heat pump	Heat pump water heater receives utility signal (via a smart meter or other)
	Expected results	Enabling of peak load management and load shifting ~within a 24-hr period.
	Observation periods	2014 and 2024

Case scenario III 2014/2024 – Grid Frequency and/or Voltage Control (Ancillary Services)

Category	*Item*	*Details*
Building	Type	Single family house
	Conditioned area	223 m² (2400 ft²)
	Annual water heating demand (estimate)	Varies by location (exact locations for analyses still to be determined) – demand will be as computed for prototype residential houses by DOE [4],[5] using EnergyPlus **Error! Reference source not found.** model.
Heat pump – DHW only	Baseline	**Baseline 1 is conventional electric storage; Baseline 2 is electric storage heat pump water heater with rated energy factor of 2-2.4**
	Operation modes	DWH only
	Conventional Control	Simple thermostat controlling hot water storage temperature • DHW set-temperature around 50 °C
	Smart Option	**Electric storage heat pump water heater as in Baseline 2 but with control system set up to receive & respond to utility demand control signals**
	El. Back up heater	Yes, 4.5 kW capacity
Heating and cooling system	Medium	NA
	Heat transfer	NA
	Buffer storage	NA
Domestic hot water	Annual energy demand	Varies by location (exact locations for analyses still to be determined) – demand will be as computed for prototype residential houses by DOE [4],[5] using EnergyPlus **Error! Reference source not found.** model
	Load	Tapping behaviour as defined in DOE computations
	Storage	50-80 gal (190-300 l)
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	No
	active use of building mass	No
Optimization/Problem	Goal	Provide grid frequency and/or voltage regulation control via managed operation of heat pump water heaters
	Realization	Communication with a fleet of enabled HPWHs following a protocol appropriate for specific utility ancillary service needs. These needs vary by the specific ancillary service program offerings of utilities or independent service operators (ISOs).
	Communication with heat pump	Communication should be 2-way, according to an appropriate protocol commensurate with providing necessary telemetry to meet utility or ISO requirements.
	Expected results	Variation of real-time load of installed heat pumps to affect desired load adjustment over an appropriate time period.
	Observation periods	2014 and 2024

CASE SCENARIO IV LOAD LEVELLING CONTROL (WINTER AND SUMMER) FOR RESIDENCES USING VARIABLE-CAPACITY OR VARIABLE-SPEED HEAT PUMP SYSTEMS

Category	*Item*	*Details*
Building	Type	Single family house
	Conditioned area	223 m² (2400 ft²)
	Annual cooling/heating demand (estimate)	Varies depending on location. About **78 kWh/m² cooling & 16 kWh/ m² heating** (according to average weather conditions in Houston, TX location); About **14 kWh/m² cooling & 66 kWh/ m² heating** (according to average weather conditions in Albany, NY location) – estimated based on annual energy use for base single-speed heat pump as computed for prototype residential houses by DOE [4],[5] using EnergyPlus **Error! Reference source not found.** model.
Heat pump	Baseline	Single-speed, single capacity level heat pump with outside air heat source and sink
	Operation modes	Space heating and space cooling (DHW provided by conventional electric storage water heater)
	Conventional Control	Simple thermostat controlling indoor air temperature ● heating set point temperature **20 °C (68 °F)** ● cooling set point temperature **~26 °C (78 °F)** ● DHW set-temperature around **50 °C** considering typical hysteresis
	Smart Option	Variable-speed heat pump, outside air heat source and sink with thermostat controlling indoor air temperature level; demand-response ready according to anticipate future AHRI standard; DHW by separate standalone small HPWH or integrated with space heating/cooling functions in single heat pump system (potential future option)
	El. Back up heater	Yes: for baseline heat pump. Optional for variable-speed heat pump (depending on location may or may not be needed), parallel operation with heat pump below house balance point (around -5 °C for baseline, varies for variable-speed heat pump case)
Heating and cooling system	Medium	Air
	Heat transfer	Central heated/cooled air distribution
	Buffer storage	Optional – California exploring potential options
Domestic hot water	Annual energy demand	Varies with location - about 12.5 kWh/m² (2793 kWh total) in Houston; about 19.5 kWh/m² (4320 kWh total) in Albany for baseline electric storage WH
	Load	Tapping behaviour as defined in DOE computations
	Storage	Typical size (around 190 l or 50 gal)
Additional technologies or storages	PV	No
	Battery	No
	Gas/oil boiler	No
	active use of building mass	No
Optimization/Problem	Goal	Reduce or eliminate peak demand (summer and winter); achieve more equivalent electric demand throughout day – subject to meeting end-use customer heating/cooling needs (customer override capability a must)
	Realization	Demand-response-capable “next generation” heat pump – variable-speed capability, cold-climate applicable, improved back-up heat controls (load-based or staged, etc.)

	Communication with heat pump	Demand response protocols OpenADR, SEP 2.0, CEA-2045, etc. (in compliance with future AHRI standard). Heat pump receives utility signal (via a smart meter or other)
	Expected results	Winter: heat pump controls lock out electric back up during utility peak periods; ramp up compressor speed during utility peak, possibly preheat space just before utility peak using compressor at high speed and staged backup. Summer: prior to utility peak time ramp up compressor speed & adjust room thermostat to pre-cool space; reduce compressor speed to minimum or shut off during peak periods. Actions subject to customer emergency override capability
	Observation periods	2014 and 2024

A References

[1] R. Dott, M. Haller, J. Ruschenburg, F. Ochs, J. Bony: The Reference Framework for System Simulations of the IEA SHC Task 44 /HPP Annex 38. 2013.

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[3] United States Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Office, 2012, March. *Building America Best Practices Series, Volume 7.1, High-Performance Home Technologies: Guide to Determining Climate Regions by County.*

[4] Taylor, Z.T., N. Fernandez, and R.G. Lucas, 2012-April. *Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes*, PNNL-21294.

[5] United States Department of Energy, 2014a. Residential Prototype Building Models, **http://www.energycodes.gov/development/residential/iecc_models.**

www.heatpumpingtechnologies.org

Heat Pump Centre
c/o RISE - Research Institutes of Sweden
PO Box 857
SE-501 15 BORÅS
Sweden
Tel: +46 10 516 5512
E-mail: hpc@heatpumpcentre.org

www.heatpumpingtechnologies.org

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