Heat pumps for cooling and heating

Subtask 5, Report n:o 3

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in co-operation with the country experts

International Energy Agency Demand-Side Management Programme

Task XVII: Integration of Demand Side Management, Distributed Generation, Renewable Energy Sources and Energy Storages

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EXECUTIVE SUMMARY - Heat pumps for cooling and heating

TASK XVII: INTEGRATION OF DEMAND SIDE MANAGEMENT, DISTRIBUTED GENERATION, RENEWABLE ENERGY SOURCES AND ENERGY STORAGES

Task extension: The effects of the penetration of emerging DER technologies to different stakeholders and to the whole electricity system

Background

Energy policies are promoting distributed energy resources such as energy efficiency, distributed generation (DG), energy storage devices, and renewable energy resources (RES), increasing the number of DG installations and especially variable output (only partly controllable) sources like wind power, solar, small hydro and combined heat and power.

Intermittent generation like wind can cause problems in grids, in physical balances and in adequacy of power.

Thus, there are two goals for integrating distributed energy resources locally and globally: network management point of view and energy market objectives.

Solutions to decrease the problems caused by the variable output of intermittent resources are to add energy storages into the system, create more flexibility on the supply side to mitigate supply intermittency and load variation, and to increase flexibility in electricity consumption. Combining the different characteristics of these resources is essential in increasing the value of distributed energy resources in the bulk power system and in the energy market.

This Task is focusing on the aspects of this integration.

Objectives

The main objective of this Task is to study how to achieve a better integration of flexible demand (Demand Response, Demand Side Management) with Distributed Generation, energy storages and Smart Grids. This would lead to an increase of the value of Demand Response, Demand Side Management and Distributed Generation and a decrease of problems caused by intermittent distributed generation (mainly based on renewable energy sources) in the physical electricity systems and at the electricity market.

Approach

The first phase in the Task was to carry out a scope study collecting information from the existing IEA Agreements, participating countries with the help of country experts and from organized workshops and other sources (research programs, field experience etc), analyzing the information on the basis of the above mentioned objectives and synthesizing the information to define the more detailed needs for the further work. The main output of the first step was a state-of-the art report.

The second phase (Task extension) is dealing with the effects of the penetration of emerging DER technologies to different stakeholders and to the whole electricity system.

The main subtasks of the second phase are (in addition to Subtasks 1 – 4 of the phase one):

Subtask 5: Assessment of technologies and their penetration in participating countries

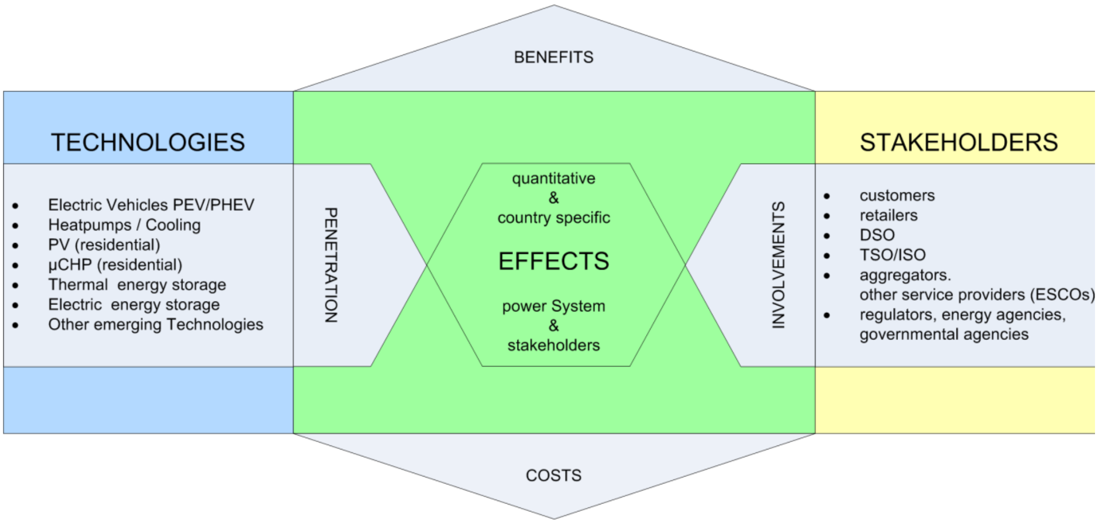
Subtask 6: Pilots and case studies

Subtask 7: Stakeholders involved in the penetration and effects on the stakeholders

Subtask 8: Assessment of the quantitative effects on the power systems and stakeholders

Subtask 9: Conclusions and recommendations

The figure below describes the concept of this extension.



Results

The report summarizes the heat pump technologies and their prospective for demand response purposes. In addition to that the situation of heat pumps in participated countries are described.

Heat pumps and demand response

In principle heat pumps are suitable for demand response for several reasons:

- the penetration rates of different types of heat pumps for heating and cooling are high and increasing in most countries
- demand response needs during the system peaks fits well with the high use of heat pumps either for cooling in summer peak or heating in winter peak situations, similarly local peaks at network level can be decreased; on the other hand, in very low temperatures the COPs of heat pumps are low and additional heating systems are needed (electricity or gas)
- from the customer's comfort point of view heat pumps can be controlled similar way as electric heating and other air-conditioning systems: due to the natural (building mass) and artificial heat storages the heating/hot water production and cooling can be switched off for certain time periods
- from the technical point of view the total switching-off the heat pumps or the thermostat set-point adjustments are possible in short term because heat pumps usually have remote control capabilities

However, some obstacles exist for the use of heat pumps for demand response like

- there are not much experiences from the use of heat pumps for demand response and therefore also technical solutions have not been developed
- after the control period of heat pumps their load will be high and this "pay-back" has to be taken into account in the control strategy
- starting current of heat pumps after switch-off or blackouts can be high and problematic to the networks; this has to be taken into account in the control strategy

Summary on situation in participating countries

The table below shows roughly the penetration of heat pumps at the moment and in 2020 and/or 2030 in participating countries.

	2010		2020		2030
	number	total electric power (MW)	number	total electric power (MW)	number
Austria	175 000	350	250000	508	343000
Finland	390 000	> 2000	1 000 000		
France	950 000		2 000 000		
Netherlands	?		1 500 000		
Spain	6.3 % of houses in 2008	share of summer peak 2.24 %	9 300 000		

The shares of different types of heat pumps are different in different countries:

- In Finland roughly 20 % were ground source based in 2010, but the air/air heat pumps have been very popular during the recent years
- In France the share of geothermal (ground source) is recently about 40 %
- In Spain in practice all heat pumps are air-based

The penetration of heat pumps are partly related to the energy policies, regulations and incentives related to heat pumps: in many countries heat pumps are seen as a way to increase energy efficiency and to reduce CO2-releases:

- In Finland there is financial support (max 20 %) for the renovation investments as well as income tax reduction for labor costs
- In France an income-tax credit permits to deduce from one's tax return a percentage of the investments made in different sustainable development installations. For geothermal heat pump, the tax credit was of 40% in 2010, and is of 36% in 2011. For air/water heat pump, the tax credit was of 40% in 2009, 25% in 2010, and is of 22% in 2011. The government also allows "eco"-loans at 0% interest for ecological installations. In the case of heat pumps, construction work such as drilling for geothermal heat pump for example can benefit from this loan. Renovation work can also benefit from the loan but only if there is a substantial energy saving with the new equipment. Also the VAT is reduced to 5.5% instead of

19.6% for heat pumps installations.

- In the Netherlands applying heat pump systems in homes and utility buildings is taken up in the design time energy performance index (EPC), to which newly built homes in the Netherlands have to comply. This makes it easy to compare heat pumps to other measures to conserve energy. Heat pumps in the Netherlands in existing homes are also subsidized on a per investment basis. For home owners the amount of money is approximately 5000 euro for water/water heat pumps and 2000 euro for air/water heat pumps. Allocated budgets change in time depending on the policy.
- In Spain there are trend to increase the share of geothermal heat pumps. At the moment this market is still very small in Spain. However Spanish regions are subsiding up to 20% of the total cost of geothermal heat pumps.

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1 Heat pumps for heating [1]

1.1 Heat Pump Technology

Heat flows naturally from a higher to a lower temperature. Heat pumps, however, are able to force the heat flow in the other direction, using a relatively small amount of high quality drive energy (electricity, fuel, or high-temperature waste heat). Thus heat pumps can transfer heat from natural heat sources in the surroundings, such as the air, ground or water, or from man-made heat sources such as industrial or domestic waste, to a building or an industrial application. Heat pumps can also be used for cooling. Heat is then transferred in the opposite direction, from the application that is cooled, to surroundings at a higher temperature. Sometimes the excess heat from cooling is used to meet a simultaneous heat demand.

In order to transport heat from a heat source to a heat sink, external energy is needed to drive the heat pump. Theoretically, the total heat delivered by the heat pump is equal to the heat extracted from the heat source, plus the amount of drive energy supplied. Electrically-driven heat pumps for heating buildings typically supply 100 kWh of heat with just 20–40 kWh of electricity.

1.2 The two main heat pump types

Almost all heat pumps currently in operation are either based on a vapour compression, or on an absorption cycle. These two principles will be briefly discussed in the following.

Theoretically, heat pumping can be achieved by many more thermodynamic cycles and processes. These include Stirling and Vuilleumier cycles, single-phase cycles (e.g. with air, CO_2 or noble gases), solid-vapour sorption systems, hybrid systems (notably combining the vapour compression and absorption cycle) and thermoelectric and acoustic processes. Some of these are entering the market or have reached technical maturity, and could become significant in the future. These processes are not discussed in this report.

1.2.1 Vapour compression heat pumps

The great majority of heat pumps work on the principle of the vapour compression cycle. The main components in such heat pump systems are the compressor, the expansion valve and two heat exchangers referred to as evaporator and condenser. The components are connected to form a closed circuit, as shown in Figure 1. A volatile liquid, known as the working fluid or refrigerant, circulates through the four components.

In the evaporator the temperature of the liquid working fluid is kept lower than the temperature of the heat source, causing heat to flow from the heat source to the liquid, and the working fluid evaporates. Vapour from the evaporator is compressed to a higher pressure and temperature. The hot vapour then enters the condenser, where it condenses and gives off useful heat. Finally, the high-pressure working fluid is expanded to the evaporator pressure and temperature in the expansion valve. The working fluid is returned to its original state and once again enters the evaporator. The compressor is usually driven by an electric motor or sometimes by a combustion engine.

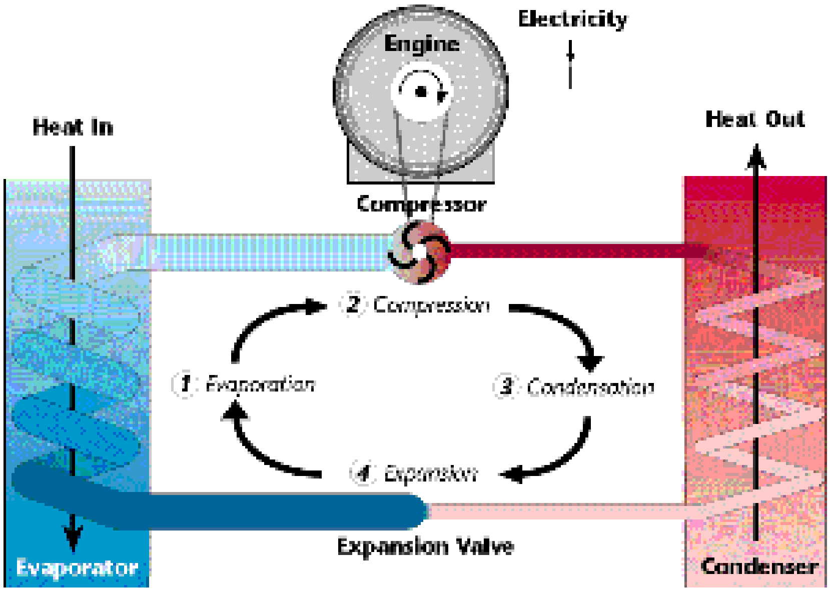


Figure 1. Closed cycle, electric motor-driven vapour compression heat pump

An electric motor drives the compressor with very low energy losses. The overall energy efficiency of the heat pump strongly depends on temperature levels of the heat source and heat sink. This is discussed in the section on Heat pump performance.

When the compressor is driven by a gas or diesel engine, heat from the cooling water and exhaust gas is used in addition to the condenser heat.

1.2.2 Absoption heat pumps

Absorption heat pumps are thermally driven, which means that heat rather than mechanical energy is supplied to drive the cycle. Absorption heat pumps for space conditioning are often gas-fired, while industrial installations are usually driven by high-pressure steam or waste heat.

Absorption systems utilise the ability of liquids or salts to absorb the vapour of the working fluid. The most common working pairs for absorption systems are:

- water (working fluid) and lithium bromide (absorbent); and
- ammonia (working fluid) and water (absorbent).

In absorption systems, compression of the working fluid is achieved thermally in a solution circuit which consists of an absorber, a solution pump, a generator and an expansion valve as shown in Figure 2. Low-pressure vapour from the evaporator is absorbed in the absorbent. This process generates heat. The solution is pumped to high pressure and then enters the generator, where the working fluid is boiled off with an external heat supply at a high temperature. The working fluid (vapour) is condensed in the condenser while the absorbent is returned to the absorber via the expansion valve.

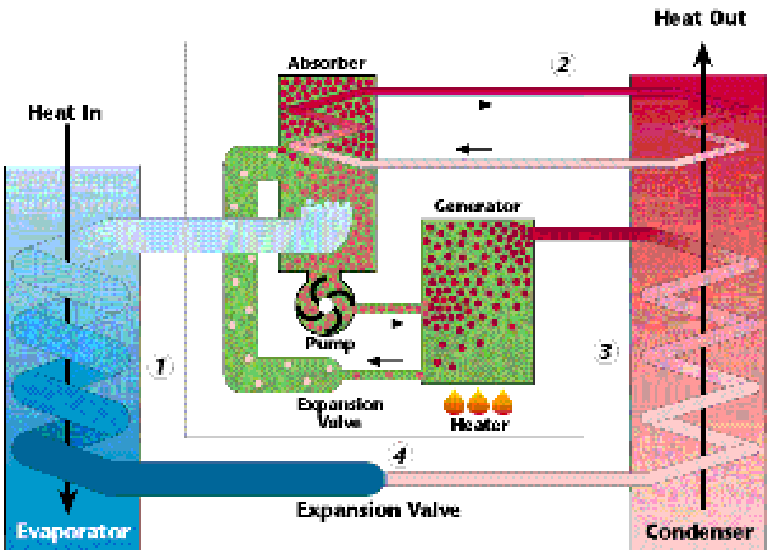


Figure 2. Absorption heat pump

Heat is extracted from the heat source in the evaporator. Useful heat is given off at medium temperature in the condenser and in the absorber. In the generator high-temperature heat is supplied to run the process. A small amount of electricity may be needed to operate the solution pump. For heat transformers, which through the same absorption processes can upgrade waste heat without requiring an external heat source, refer to the section on Heat pumps in industry.

1.3 Heat sources

The technical and economic performance of a heat pump is closely related to the characteristics of the heat source. An ideal heat source for heat pumps in buildings has a high and stable temperature during the heating season, is abundantly available, is not corrosive or polluted, has favourable thermophysical properties, and its utilisation requires low investment and operational costs. In most cases, however, the availability of the heat source is the key factor determining its use. Table 1 presents commonly used heat sources.

Table 1. Commonly used heat sources

Heat Source	Temperature Range (°C)
ambient air	-10 – 15
exhaust air	15 – 25
ground water	4 – 10
lake water	0 – 10
river water	0 – 10
sea water	3 – 8
rock	0 – 5
ground	0 – 10
waste water and effluent	>10

Ambient and exhaust air, soil and ground water are practical heat sources for small heat pump systems, while sea/lake/river water, rock (geothermal) and waste water are usually used for large heat pump systems.

Ambient air is free and widely available, and it is the most common heat source for heat pumps. Air-source heat pumps, however, achieve on average 10–30% lower seasonal performance factor (SPF) than water-source heat pumps, depending on the climate. This is mainly due to the rapid fall in capacity and performance with decreasing outdoor temperature, the relatively high temperature difference in the evaporator and the energy needed for defrosting the evaporator and to operate the fans.

In mild and humid climates, frost will accumulate on the evaporator surface especially in the temperature range 0–6 °C, leading to reduced capacity and performance of the heat pump system. Coil defrosting is achieved by reversing the heat pump cycle or by other, less energy-efficient means. Energy consumption increases and the overall coefficient of performance (COP) of the heat pump drops with increasing defrost frequency. Using demand defrost control rather than time control can significantly improve overall efficiencies.

Exhaust (ventilation) air is a common heat source for heat pumps in residential and commercial buildings. The heat pump recovers heat from the ventilation air, and provides water and/or space heating. Continuous operation of the ventilation system is required during the heating season or throughout the year. Some units are also designed to utilise both exhaust air and ambient air. For large buildings exhaust air heat pumps are often used in combination with air-to-air heat recovery units.

Ground water is available with stable temperatures (4–10°C) in many regions. Open or closed systems are used to tap into this heat source. In open systems the ground water is pumped up, cooled and then reinjected in a separate well or returned to surface water. Open systems should be carefully designed to avoid problems such as freezing, corrosion and fouling. Closed systems can either be direct expansion systems, with the working fluid evaporating in underground heat exchanger pipes, or brine loop systems. Due to the extra internal temperature difference, heat pump brine systems generally have a lower performance, but are easier to maintain. A major disadvantage of ground water heat pumps is the cost of installing the heat source. Additionally, local regulations may impose severe constraints regarding interference with the water table and the possibility of soil pollution.

Ground-source systems are used for residential and commercial applications, and have similar advantages as (ground) water-source systems, i.e. they have relatively high annual temperatures. Heat is extracted from pipes laid horizontally or vertically in the soil (horizontal/vertical ground coils), and both direct expansion and brine systems can be used. The thermal capacity of the soil varies with the moisture content and the climatic conditions. Due to the extraction of heat from the soil, the soil temperature will fall during the heating season. In cold regions most of the energy is extracted as latent heat when the soil freezes. However, in summer the sun will raise the ground temperature, and complete temperature recovery may be possible.

Rock (geothermal heat) can be used in regions with no or negligible occurrence of ground water. Typical bore hole depth ranges from 100 to 200 metres. When large thermal capacity is needed the drilled holes are inclined to reach a large rock volume. This type of heat pump is always connected to a brine system with welded plastic pipes extracting heat from the rock. Some rock-coupled systems in commercial buildings use the rock for heat and cold storage.

River and lake water is in principle a very good heat source, but has the major disadvantage of low temperature in winter (close to 0°C). Great care has to be taken in system design to avoid freezing of the evaporator.

Sea water is an excellent heat source under certain conditions, and is mainly used for medium-sized and large heat pump installations. At a depth of 25–50 metres, the sea temperature is constant (5–8 °C), and ice formation is generally no problem (freezing point -1 °C to -2 °C). Both direct expansion systems and brine systems can be used. It is important to use corrosion-resistant heat exchangers and pumps and to minimise organic fouling in sea water pipelines, heat exchangers and evaporators, etc.

Waste water and effluent are characterised by a relatively high and constant temperature throughout the year. Examples of possible heat sources in this category are effluent from sewers (treated and untreated sewage water), industrial effluent, cooling water from industrial processes or electricity generation, condenser heat from refrigeration plants. The major constraints for use in residential and commercial buildings are, in general, the distance to the user, and the variable availability of the waste heat flow. However, waste water and effluent serve as an ideal heat source for industrial heat pumps to achieve energy savings in industry.

1.4 Heat pump performance

The heat delivered by a heat pump is theoretically the sum of the heat extracted from the heat source and the energy needed to drive the cycle. The steady-state performance of an electric compression heat pump at a given set of temperature conditions is referred to as the *coefficient of performance* (COP). It is defined as the ratio of heat delivered by the heat pump and the electricity supplied to the compressor.

For engine and thermally driven heat pumps the performance is indicated by the primary energy ratio (PER). The energy supplied is then the higher heating value (HHV) of the fuel supplied. For electrically driven heat pumps a PER can also be defined, by multiplying the COP with the power generation efficiency.

The COP or PER of a heat pump is closely related to the temperature lift, i.e. the difference between the temperature of the heat source and the output temperature of the heat pump. The COP of an ideal heat pump is determined solely by the condensation temperature and the temperature lift (condensation - evaporation temperature).

Figure 3 shows the COP for an ideal heat pump as a function of temperature lift, where the temperature of the heat source is 0°C. Also shown is the range of actual COPs for various types and sizes of real heat pumps at different temperature lifts.

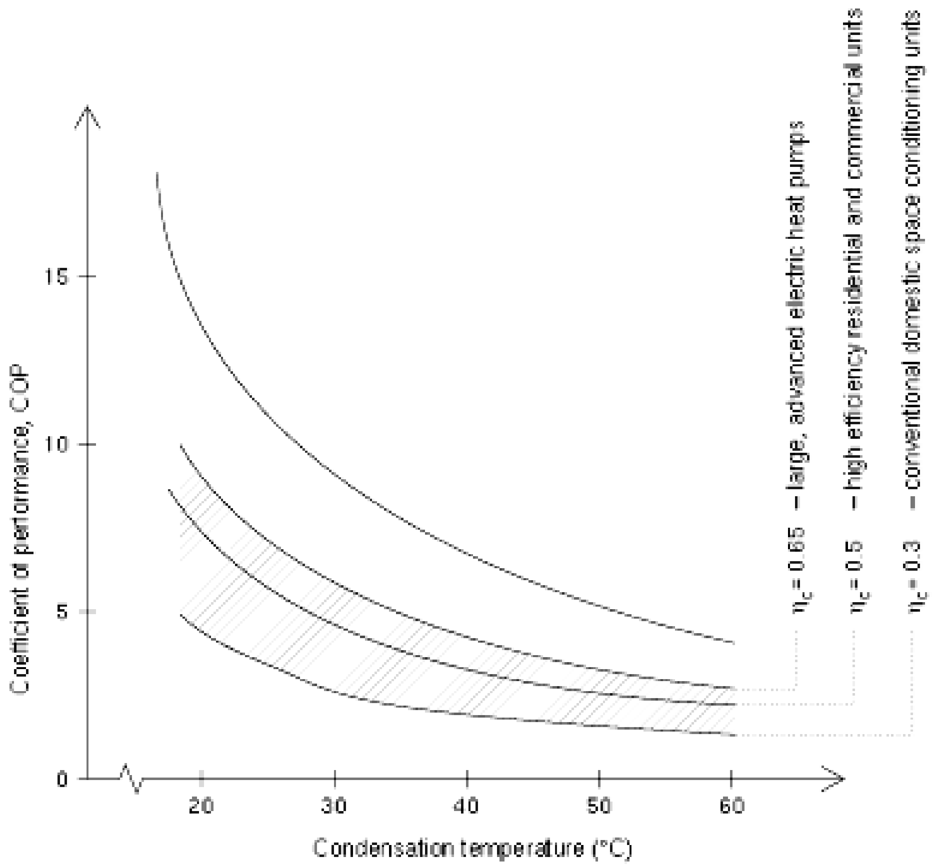


Figure 3. Heat pump performance as function of condensation temperature. Here the temperature of the heat source is 0 °C.

The ratio of the actual COP of a heat pump and the ideal COP is defined as the Carnot-efficiency. The Carnot-efficiency varies from 0.3 to 0.5 for small electric heat pumps and 0.5 to 0.7 for large, very efficient electric heat pump systems.

An indication of achievable COP/PERs for different heat pump types at evaporation 0 °C and condensing temperature 50 °C is shown in 0.

Table 2. Typical COP/PER range for heat pumps with different drive energies

Heat pump type	COP	PER
Electric (compression)	2.5 - 5.0	
Engine (compression)		0.8 - 2.0
Thermal (absorption)		1.0 - 1.8

The operating performance of an electric heat pump over the season is called the seasonal performance factor (SPF). It is defined as the ratio of the heat delivered and the total energy supplied over the season. It takes into account the variable heating and/or cooling demands, the variable heat source and sink temperatures over the year, and includes the energy demand, for example, for defrosting.

The SPF can be used for comparing heat pumps with conventional heating systems (e.g. boilers), with regards to primary energy saving and reduced CO_2 emissions. For evaluating electric heat pumps the power generation mix and the efficiencies of the power stations must be considered.

Factors affecting heat pump performance

The performance of heat pumps is affected by a large number of factors. For heat pumps in buildings these include:

- the climate - annual heating and cooling demand and maximum peak loads;
- the temperatures of the heat source and heat distribution system;
- the auxiliary energy consumption (pumps, fans, supplementary heat for bivalent system etc.);
- the technical standard of the heat pumps and refrigerants;
- the sizing of the heat pump in relation to the heat demand and the operating characteristics of the heat pump;
- the heat pump control system.

1.5 Heat pumps in residential and commercial buildings

1.5.1 General definitions

Heat pumps for heating and cooling buildings can be divided into four main categories depending on their operational function:

- **Heating-only heat pumps, providing space heating and/or water heating.**
- **Heating and cooling heat pumps, providing both space heating and cooling.** The most common type is the reversible air-to-air heat pump, which either operates in heating or cooling mode. Large heat pumps in commercial/institutional buildings use water loops (hydronic) for heat and cold distribution, so they can provide heating and cooling simultaneously.
- **Integrated heat pump systems, providing space heating, cooling, water heating and sometimes exhaust air heat recovery**. Water heating can be by desuperheating only, or by desuperheating and condenser heating. The latter permits water heating when no space heating or cooling is required.
- **Heat pump water heaters, fully dedicated to water heating.** They often use air from the immediate surroundings as heat source, but can also be exhaust-air heat pumps, or desuperheaters on air-to-air and water-to-air heat pumps. Heat pumps can be both monovalent and bivalent, where monovalent heat pumps meet the annual heating and cooling demand alone, while bivalent heat pumps are sized for 20-60% of the maximum heat load and meet around 50-95% of the annual heating demand (in a European residence). The peak load is met by an auxiliary heating system, often a gas or oil boiler. In larger buildings the heat pump may be used in tandem with a cogeneration system (CHP).

In residential applications room heat pumps can be reversible air-to-air heat pumps (ductless packaged or split type units). The heat pump can also be integrated in a forced-air duct system or a hydronic heat distribution system with floor heating or radiators (central system).

In commercial/institutional buildings the heat pump system can be a central installation connected to an air duct or hydronic system, or a multi-zone system where multiple heat pump units are placed in different zones of the building to provide individual space conditioning. Efficient in large buildings is the water-loop heat pump system, which involves a closed water loop with multiple heat pumps linked to the loop to provide heating and cooling, with a cooling tower and auxiliary heat source as backup.

1.5.2 Heat and cold distribution systems

Air is the most common distribution medium in the mature heat pump markets of Japan and the United States. The air is either passed directly into a room by the space-conditioning unit, or distributed through a forced-air ducted system. The output temperature of an air distribution system is usually in the range of 30–50 °C.

Water distribution systems (hydronic systems) are predominantly used in Europe, Canada and the north eastern part of the United States. Conventional radiator systems require high distribution temperatures, typically 60–90 °C. Today's low temperature radiators and convectors are designed for a maximum operating temperature of 45–55 °C, while 30–45 °C is typical for floor heating systems. Table 3 summarizes the typical temperature requirements for various heat and cold distribution systems.

Table 3. Typical delivery temperatures for various heat and cold distribution systems.

Application		Supply temperature range (°C)
Air distribution	Air heating	30 – 50
	Floor heating; low temperature (modern)	30 – 45
Hydronic systems	radiators	45 – 55
	High temperature (conventional) radiators	60 – 90
	District heating - hot water	70 – 100
Distict heating	District heating - hot water/stream	100 – 180
	Cooled air	10 – 15
Space cooling	Chilled water	5 – 15
	District cooling	5 – 8

Because a heat pump operates most effectively when the temperature difference between the heat source and heat sink (distribution system) is small, the heat distribution temperature for space heating heat pumps should be kept as low as possible during the heating season.

Table 4 shows typical COP's for a water-to-water heat pump operating in various heat distribution systems. The temperature of the heat source is 5 °C, and the heat pump Carnot efficiency is 50%.

Table 4. Example of how the COP of a water-to-water heat pump varies with the distribution/return temperature.

Heat distribution system (supply/return temperature)	COP
Conventional radiators (60/50°C)	2.5
Floor heating (35/30°C)	4.0
Modern radiators (45/35°C)	3.5

2 Heat pumps for cooling

2.1 Air-conditioners classification

In this section, residential air-conditioning systems are classified according to three different criteria 2, 3:

- Thermal generation: air-conditioners are grouped as a function of the fluids that cross the condenser and the evaporator respectively.
- Distribution: this classification takes into account the fluid employed for transporting the generated cold to the room to be refrigerated.
- Cold transfer: air-conditioners are classified depending on the fluid that finally refrigerates the room.

2.1.1 Classification from the thermal generation point of view

This classification takes into account the fluids that go across the condenser and the evaporator respectively. They can be:

- Air/air systems: the fluid that crosses both the condenser and the evaporator is air; cold air is obtained as output
- Air/water systems: the fluids that cross the condenser and the evaporator are air and water respectively; as a result a cold water circuit is obtained (not considered in Directive 2002/31/EC).
- Water/air systems: the fluid that crosses the condenser is water and the fluid that crosses the evaporator is air; cold air is obtained as output.
- Water/water systems: the fluid that crosses both the condenser and the evaporator is water; as a result a cold water circuit is obtained (not considered in Directive 2002/31/EC).

2.1.2 Classification from the distribution point of view

Air-conditioning systems can also be classified according to the fluid that transports the generated cool to the room that is going to be refrigerated; for this purpose ducts or pipes are employed. This classification is mainly applicable to centralised systems. They can be:

- Air
- Water
- Refrigerant

2.1.3 Classification from the cold transfer point of view

This classification takes into account the way employed for transferring cold to the room. According to it the systems can be:

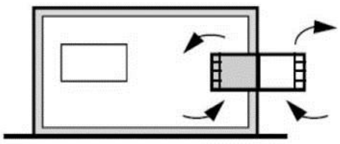
- All-refrigerant
- Refrigerant-air
- All-water
- Air-water
- All-air

All-refrigerant systems

In these systems room air is directly blown across special devices called DX coils in which the direct expansion of the refrigerant is performed.

Several types of equipment can be included in this category:

A) Single-packaged units: in this kind of equipment all components of the refrigeration cycle are included in a single package. There are two different modalities as a function of their mobility:
   - "Window" and "through-the-wall": in this case, one side of the mentioned package, which is fixed, is in contact with the outside air and the other provides direct cooling to the air inside. They can be installed in a window opening or in an opening in the exterior wall.



Window

Through-the- wall

Figure 4. Window and through-the-wall package air-conditioners

   - Single duct units: in contrast to the previous ones, these appliances are moveable. The unit is connected to the exterior through a duct in order to eliminate the hot air coming from the condenser. Due to this reason, they must be set close to a window or a dedicated hole must be made in the exterior wall.

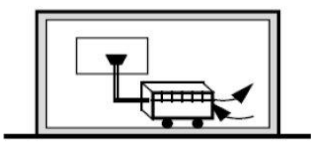


Figure 5. Single-duct air conditioners

An evolution of this type is the double-duct air conditioner. They are similar to the single-duct but a second hole at the condenser allows taking the condenser air from outside thus avoiding outside air infiltration inside the room to be cooled.

B) Non-ducted split-packaged units: this equipment comprises two packages, the interior and the exterior units that are connected by a pipe that transfers the refrigerant. The former includes the evaporator and a fan and the latter the compressor and the condenser. In this category, several types can be defined as a function of the mobility of the indoor and outdoor units.
   - Non-ducted fixed split-packaged units: both, indoor and outdoor units are fixed. The indoor unit can be wall mounted, console or ceiling suspended, cassette…

Figure 6. Non-ducted fixed split-packaged units

- Non-ducted split packaged units with mobile indoor unit: outdoor unit is fixed but indoor unit is mobile.

Figure 7. Non-ducted split-packaged units with mobile indoor unit

- Non-ducted split packaged units with mobile indoor and outdoor units: both, indoor and outdoor units are mobile.

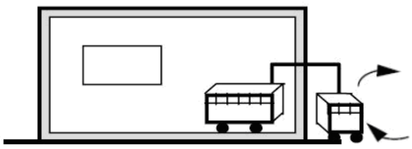


Figure 8. Non-ducted split packaged units with mobile indoor and outdoor units

C) Multi-split packaged units: they are similar to split-packaged units but in this case there are several indoor units (up to 4) connected to one exterior one. The control can be centralized or independent for each indoor unit.

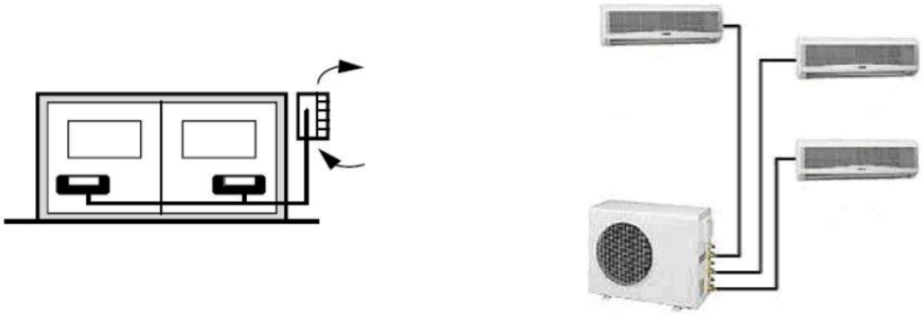


Figure 9. **Figure 2-1: Multi-split packaged units**

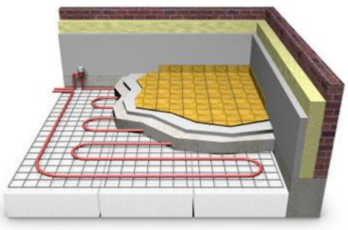
Refrigerant-air systems

These systems are similar to the previous ones with the addition of a primary air circuit. This air, which is cooled in a central chiller, supplies the ventilation requirements to the different rooms of the house. One example of this type of system is the ducted split packaged unit. This system is installed usually in houses or commercial buildings such as offices. It consists of an exterior unit that includes the compressor and the condenser and an interior unit that includes the evaporator and a fan. It is a centralised system in which the interior package is installed in the suspended ceiling. From this unit a network of ducts conduces the cold air to the rooms of the house or the building where it is delivered through grilles.

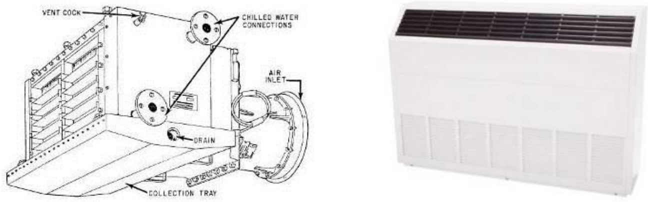
Figure 10. **Ducted split-packaged units**

All-water systems

These systems circulate cold water produced in a single chiller plant within the house. They include cool ceilings, radiant floor systems and fan-coils. The cold transfer is mainly performed by radiation in cool ceilings and radiant floors and by convection in fan-coils. In the last case, a fan blows room air over a coil containing the water, cooling it as a result. This centralised system has been usually employed in the tertiary sector although it has started to be employed in dwellings.



Radiant floor system



Fan-coil

Figure 11. All-water systems

Air-water systems

These systems are very similar to the previous ones. A chiller is used to produce cold water which is pumped around the building. The cold transfer from water to room air is performed in fan-coils. However, they also include a primary air circuit that performs ventilation functions.

All-air systems

All-air systems transfer cooled air produced in a central plant via ducting, distributing air through a series of grilles or diffusers to the room or rooms of the house.

There exist two different modalities of this centralised system: constant or variable flow. In the first one, the regulation of the cold that goes to each room is performed by modifying the temperature of the driven air. In the second one, the temperature of the driven air is constant but the flow is variable.

2.2 Energy consumption

Air-conditioning systems do not have a pre-determined consumption profile. In contrast, the electrical consumption of air-conditioning systems is related to the thermal demand of the room to be refrigerated which in its turn depends on many variables

- Characteristics of the building: geometry, internal loads (lighting, computers …), construction materials, openings, orientation, …
- Weather conditions: outdoor temperature, humidity, solar radiation, wind speed, wind direction, cloudiness conditions, atmospheric pressure…
- Comfort set-points
- Sizing of the air-conditioner (cooling capacity)
- Energy efficiency of the air-conditioner

In addition, the consumption profile depends on the type of technology employed for regulating the air-conditioning system, that is, for adapting the cooling capacity to the required thermal load. There exist two main ways for achieving this objective in residential air-conditioners:

- ON/OFF cycling: it consists of switching on and off the motor inside the compressor according to the thermal load demand. For this purpose a thermostat with a set-point and a dead band is employed. If for example it is supposed that the temperature setting is 23 ºC and that the dead band is 2 ºC, the compressor will be connected when indoor temperature reaches 24 ºC and disconnected when indoor temperature reaches 22 ºC.

- Inverter: it is a new technology in which the rotation speed of the compressor is electronically controlled. In this way, it is possible to maintain an almost fixed temperature without having to connect and disconnect cyclically the compressor.

Figure 12 shows a graphical representation of the temperature profiles obtained with the two technologies and the rotation speed of the compressor as well.

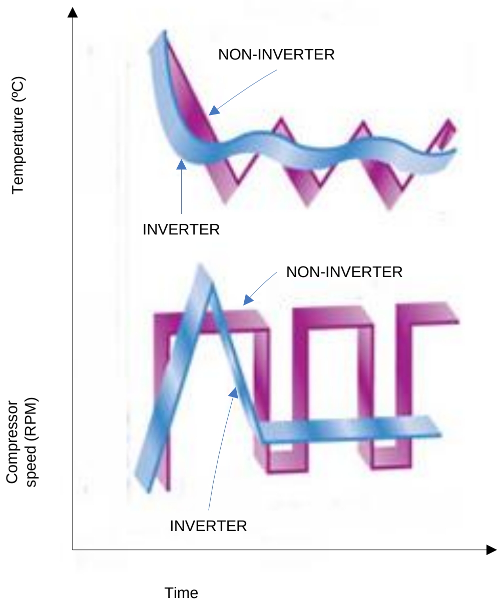


Figure 12. Temperature and compressor speed profiles for air-conditioners with and without inverter control

It can be observed that inverter power control is capable of reaching the temperate set-point more rapidly than the non-inverter one. Besides, this technology allows a more accurate temperature control and therefore the obtained comfort is better. The appliances equipped with this control technology are more efficient and have lower energy consumptions.

For non-inverter air-conditioners, the cycles in which the compressor operates at its maximum capacity and the cycles in which it is switched off are alternated. The duration of these cycles depend on the difference between the actual and the desired indoor temperatures. It can be observed that the length of the first cycle is higher than the one of the remaining cycles because the initial temperature is far from the set point one. Once the temperature set-point has been reached, the duration of the remaining cycles will vary as a function of the thermal load demand.

2.2.1 Air-conditioning system disconnection

It consists of completely interrupting the operation of the air-conditioning system for a given time interval. However, when the control action is released the payback effect is produced, whose value will depend on the duration of the control period as well as the thermal characteristics of the house.

This action can have a high impact on the living comfort in case it lasts a long time. Consequently it might represent cause of rejection by end-users from the comfort point of view; in this connection, the control has to be such that thermal stress is avoided, whichever the control is.

Air-conditioning and space and water heating system disconnection has been the basis of many direct load control initiatives.Technical implementation of these control actions could be performed in a short-term because the required technology already exists in the market.

2.2.2 Temperature set-point modification

This control action consists of modifying the temperature setting of the thermostat during the control period. In this way energy savings can be obtained while living comfort is possibly altered.

These control actions in a non-inverter air-conditioner cause an increment on the length of the off cycles of the compressor, and then a reduction of energy consumption. In an inverter air-conditioner, the rotation speed of the compressor motor is reduced thus decreasing the energy consumption.

Technical implementation of these control actions would be also possible in the short-term because most air-conditioners sold nowadays are equipped with a digital thermostat that would allow a remote control of the temperature setting without a significant investment.

2.2.3 Compressor capacity limitation

These control actions are only applicable to air-conditioning systems equipped with an inverter power control. In these cases it is possible to limit the operation regime of the compressor ensuring in this way that its electrical consumption is below a specific level.

It represents a feasible solution from the comfort point of view because end-users would not notice important variations on the living comfort. The only difference would be on the time required by the air-conditioning system to reach the temperature set-point that would be slightly higher.

The drawback of this option is its technical feasibility. Implementation of these control actions would require important changes on the electronic parts of the air-conditioning systems that allow the capacity limitation of the compressor. These changes should be carried out by manufacturers. In addition to this, the communication infrastructure that allows the reception of external signals containing information related to the capacity limitation would be required.

Consequently, this control option could represent a good alternative for being implemented in the long-term because important changes on the air-conditioning systems are required.

2.2.4 Standby control

Most modern air-conditioning systems include a standby mode. Although in this status the appliance is not operational, it allows its reactivation through remote control or a timer. The consumption of the air-conditioner in this mode can range from 0.3 to 25 W. Consequently, the total amount of energy demanded can be very high if it remains in this status for a long time. Other kind of control actions could be oriented to reduce this consumption by modifying the status of the air-conditioner from the stand-by to the off mode.

2.3 Load usage characteristics

The analysis of usage patterns of air-conditioning systems is essential for determining the energy consumption of these devices and the energy savings that can be obtained through the application of the control actions.

The main factors than influence its use in the residential sector are [3]:

- Climate zone: it is obvious that zones with hot climates present higher consumptions than zones with moderate or low temperature climates.
- Age of the building: new buildings are usually better equipped and therefore it is more probable for them to have an air-conditioning system installed. Nowadays, this trend is changing and the age of the building mainly determines the type of system installed. New

buildings are more likely to have a centralized air-conditioning system while old buildings are more probable to have a portable or a split one.

- Economic level: air-conditioners, in contrast to space-heaters, have been always considered a luxury appliance. Therefore families with higher incomes are more likely to own an air-conditioning system.
- Size of the habitat: the air-conditioning penetration is higher in cities than in small towns.

The utilisation of the air-conditioning system is mainly done in summer months. According to the study carried out in [2], the average use of air conditioners in dwellings in Spain and Italy is 5.2 hours/day and 3.2 months/year. As a result, the air-conditioning system is employed during almost 500 hours per year.

The actual load profile (in a summer day) in a specific installation depends on many factors, including the consumer habits. On the other hand, from the grid point of view, a whole group of air-conditioning equipments shows a load profile in which the different individual conditions of use are averaged. Reference [4] provides the average consumption profile of an air-conditioning system installed in single-family houses in Spain during a typical summer weekday in 1996 ('average' stands for the average over the whole sample of the power supplied to all the air–conditioning systems in the sample)

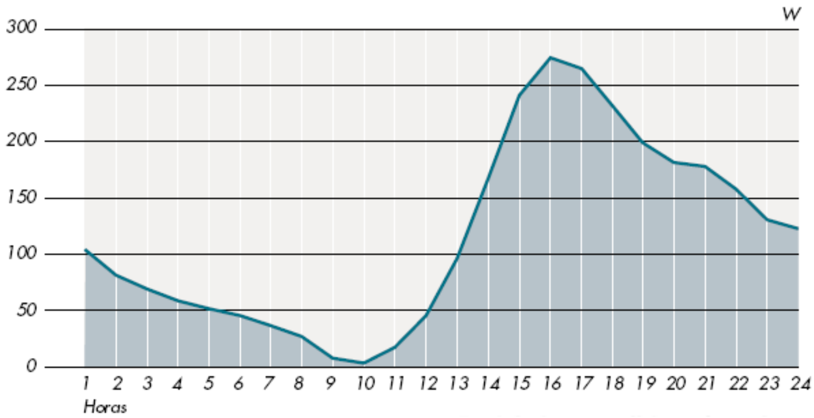


Figure 13. Average load curve of residential air-conditioning systems in Spain, 1996. Abscissa shows the load in % of average load

It can be seen that the maximum average consumptions occur during the time period that goes from 14:00. to 22:00; it is due to the combined effect of outdoor temperature, actual occupancy and request for operation, thermal inertia of building. Peak average demand of the day takes place at 16:00 taking a value of 275 % .

Similar results are presented in the reference [5], reported in Figure 14, which refers to a few (13) air-conditioning installations monitored in Italy and Greece during year 2000. There, a sustained consumption starts at 14:00 and lasts until 1:00 in the night.

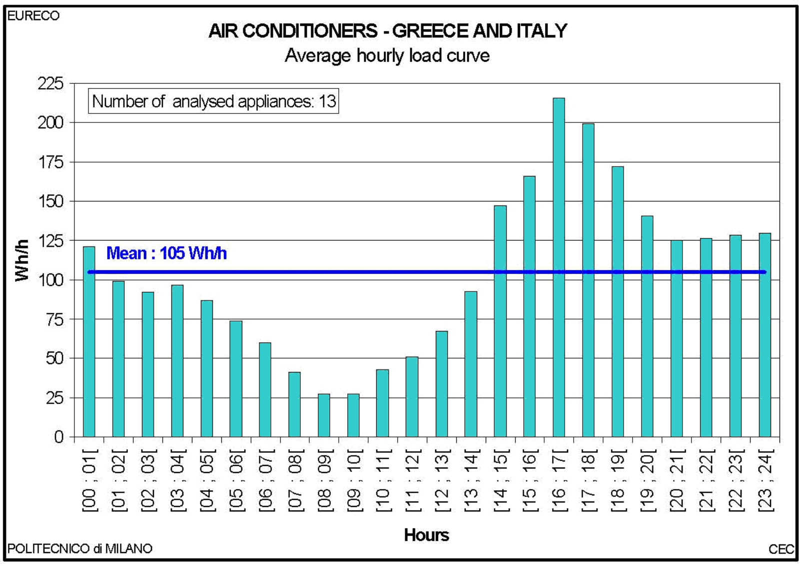


Figure 14. Average load curve of residential air-conditioning systems in Greece and Italy, 2000

Regarding comfort settings, in [4] was estimated that the average temperature set-point for domestic air-conditioners in Spain in the year 1996 was around 22 ºC.

3 Control characteristics

Air-conditioning and space heating systems can be controlled to reduce their daily energy consumption and to modify their load curve. They are appropriate equipment to achieve important reductions on the total energy demanded by the dwellings, as well as significant variations of the load shape. The loss of living comfort resulting from the control actions can still be kept limited.

Air-conditioning systems similarly to the space heating systems consume energy continuously along the day in order to maintain the indoor temperature close to the temperature set-point. Cold or heat demand of the house is related to outdoor temperature, with a delay between the peak of the outdoor temperature and the peak of the cold or heat demand, due to the building thermal inertia (for a constant indoor temperature setting). Usually, the peak of cold or heat demand occurs in periods when system demand peaks and energy price is high.

It is important to take into account that thermostatically controlled appliances, such as air-conditioners and space-heating systems tend to restore the temperature set-point once the control action has been released. As a result, they present a peak in its consumption just after the control period that can be very important if the actual indoor temperature is far from the ideal level. Consequently it will be necessary to take into account this issue, which is called “payback”, when the operation of these appliances is planned.

In addition, a scheduled operation can result in an increased electrical consumption also in hours preceding a high-price period with respect to the consumption of un-scheduled operation.

Next, a description of the control actions that could be potentially applied to residential air-conditioning systems is presented. These are described on the basis of air-conditioning/cooling systems, but similar actions can be applied also space heating. Usually, electrically heated houses or those heated by heat pumps are well-insulated, and therefore the thermal inertia of houses is high. This results in fairly slow loss of comfort: typically loss of heating for 1–3 hours decrease indoor temperature less than 2 ^{o}C.

3.1 Loss of comfort

Disconnecting air-conditioning systems for a period of time or raising the temperature set-point has the effect of (not dramatically) increasing the percentage of predicted dissatisfied people. In other words, a higher temperature set-point will not be seen as a loss of comfort by all people. Moreover, the loss of comfort can be accepted, based (as said) on economical and environmental concerns. The maximum acceptable temperature limit may even be 2–3 °C over the best comfort temperature when higher consumption reductions are required. Different thermal comfort models have been developed for estimating the relationship between temperature deviations and the share of dissatisfied people. For example Lenzuni and Del Gaudio [6] propose the discomfort levels as function of air temperature and humidity shown in Figure 15.

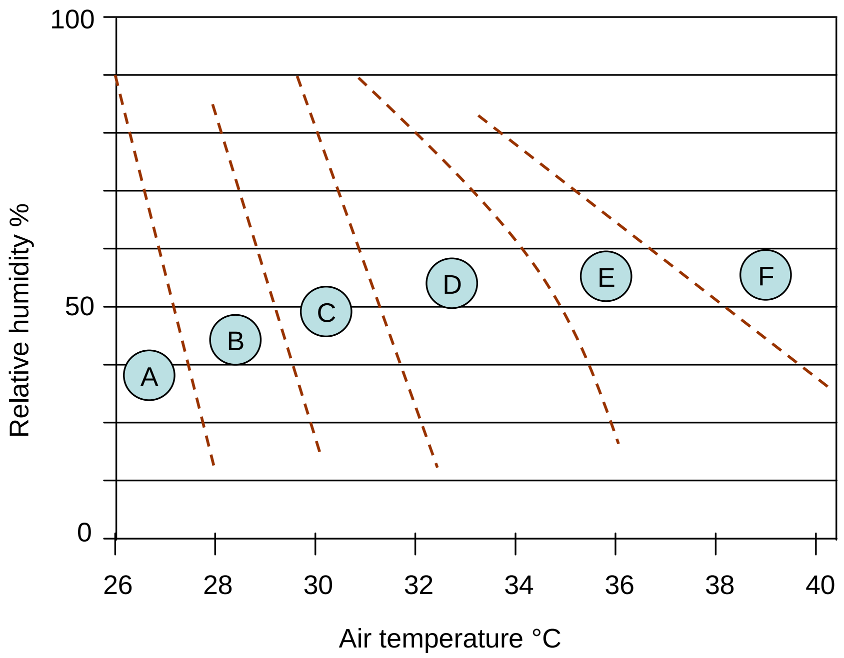


Figure 15. **Proposed discomfort zones in warm thermal environment, when activity level is low (corresponds to light work). Zone A manifests very low, B low, C intermediate, D high, E very high and F extreme discomfort.**

3.2 Ambient air heat pumps and system peaks

In some countries like in Finland, time-of-use tariff-based controlled electric heating is being replaced by non-responsive heat pumps. Nordic countries have their system peak demand during extremely cold weather when the days are short and solar radiation very small. During extremely cold weather houses having air source heat pumps in addition to other electric heating system consume daily as much or slightly more than electrically heated houses without heat pumps. This can be clearly seen from the hourly smart metering data now available to research. (At the same time solar power generation is very low and wind speeds are usually but not always low.) Thus non-controllable ambient air source heat pumps increase the system peak and make it necessary either to operate power plants with extremely short running time or deploy new sources of DR.

Ambient air source heat pumps are a cost efficient way to reduce end use energy consumption. Therefore they are increasingly applied as an additional heating form. Making all types of heat pumps as controllable DR resources is a potential solution to the problem.

4 Summary

4.1 Heat pumps and demand response

In principle heat pumps are suitable for demand response for several reasons:

- the penetration rates of different types of heat pumps for heating and cooling are high and increasing in most countries
- demand response needs during the system peaks fits well with the high use of heat pumps either for cooling in summer peak or heating in winter peak situations, similarly local peaks at network level can be decreased; on the other hand, in very low temperatures the COPs of ambient heat pumps are low and in very low temperatures (typically below - 20 to - 25 C^{o}) they have to be stopped and additional heating systems are in use (electricity or gas)
- from the customer's comfort point of view heat pumps can be controlled similar way as electric heating and other air-conditioning systems: due to the natural (building mass) and artificial heat storages the heating/hot water production and cooling can be switched off for certain time periods
- from the technical point of view the total switching-off the heat pumps or the thermostat set-point adjustments are possible in short term because heat pumps usually have remote control capabilities

However, some obstacles exist for the use of heat pumps for demand response like

- because technical requirements and solutions such as open interoperable interfaces and functionalities are still missing, there are not much experience from the use of heat pumps for demand response; therefore it may take long time before mature technical solutions are available
- in generally, lack of standardization in the field of Home Area Networks (HAN) means that available market solutions are incompatible, which a major cost barrier for home energy management based demand response; this is valid also heat pump based demand response
- after the control period of heat pumps their load will be high and this "pay-back" has to be taken into account in the control strategy
- starting current of heat pumps after switch-off or blackouts can be high and problematic to the networks; this has to be taken into account in the control strategy

4.2 Summary on situation in participating countries

The Table 5 shows roughly the penetration of heat pumps at the moment and in 2020 and/or 2030 in participating countries.

Table 5. Some estimations for the penetration of heat pumps (base-line scenarios)

	2010		2020		2030	
	number	total electric power (MW)	number	total electric power (MW)	number	total electric power (MW)
Austria	175 000	350	250000	508	343000	696
Finland	390 000	> 2000	1 000 000			
France	950 000		2 000 000			

Netherlands	?		1 500 000			
Spain	6.3 % of houses in 2008	share of summer peak 2.24 %	9 300 000			

The shares of different types of heat pumps are different in different countries:

- In Finland roughly 20 % were ground source based in 2010, but the air/air heat pumps have been very popular during the recent years
- In France the share of geothermal (ground source) is recently about 40 %
- In Spain in practice all heat pumps are air-based

The penetration of heat pumps are partly related to the energy policies, regulations and incentives related to heat pumps: in many countries heat pumps are seen as a way to increase energy efficiency and to reduce CO2-releases:

- In Finland there is financial support (max 20 %) for the renovation investments as well as income tax reduction for labor costs
- In France an income-tax credit permits to deduce from one's tax return a percentage of the investments made in different sustainable development installations. For geothermal heat pump, the tax credit was of 40% in 2010, and is of 36% in 2011. For air/water heat pump, the tax credit was of 40% in 2009, 25% in 2010, and is of 22% in 2011. The government also allows "eco"-loans at 0% interest for ecological installations. In the case of heat pumps, construction work such as drilling for geothermal heat pump for example can benefit from this loan. Renovation work can also benefit from the loan but only if there is a substantial energy saving with the new equipment. Also the VAT is reduced to 5.5% instead of 19.6% for heat pumps installations.
- In the Netherlands applying heat pump systems in homes and utility buildings is taken up in the design time energy performance index (EPC), to which newly built homes in the Netherlands have to comply. This makes it easy to compare heat pumps to other measures to conserve energy. Heat pumps in the Netherlands in existing homes are also subsidized on a per investment basis. For home owners the amount of money is approximately 5000 euro for water/water heat pumps and 2000 euro for air/water heat pumps. Allocated budgets change in time depending on the policy.
- In Spain there are trend to increase the share of geothermal heat pumps. At the moment this market is still very small in Spain. However Spanish regions are subsiding up to 20% of the total cost of geothermal heat pumps.

5 References

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Appendix 1 Present situation of heat pumps in Austria

A1.1. Number of heat pump installations

The current Situation shows that the majority of HP installed are below 20kW thermal power. Approximately factor 10 less the next power class of 20 to 80kW and factor 100 less the above 80kW power class (Table A1 1).

Table A1 1. Number of annual installed HP per power class in Austria [1]

HP power classification	2008	2009	2010	2011
< 20kW	11,563	11,083	10,540	11,528
20kW-80kW	1,443	991	871	876
> 80 kW	127	85	61	35
Total	13,133	12,159	11,472	12,439

A1.2. Electric Energy Demand Scenarios for 2030

From the data in Table A1 2 the number of installed HP and the total potential of DR per HP power class can be estimated (Table A1 3), assuming that the different power classes have a similar distributed share of the total number of installed HP.

Table A1 2. Mean and total thermal and electrical power of installed HP in Austria [1]

	Use water HP	Heating HP	Air condition HP	Sum
Thermal Power (mean) [kWth / HP a]	2,75	10,8	2,67	
Thermal Power (total) [MWth]	224	862	9	1.096
Electrical power (mean / HP) [kWel/ HP a]	1.1	3	1.07	
Electrical power (total) [MWel]	90	240	4	333

Table A1 3. Status quo for electrical power consumption of HP in Austria and scenarios according to [2].

HP power classification	Percentage on the total share [%]	2009 [MWel] Status quo	2020 [MWel] Baseline scenario	2020 [MWel] Accelerated scenario	2030 [MWel] Base scenario	2030 [MWel] Accelerated scenario
Installed HP		164.000	250.000	233.000	343.000	455.000
< 20kW	90%	300	457	426	627	831
20kW-80kW	9%	30	46	43	63	83
> 80 kW	1%	3	5	5	7	9
Total	100%	333	508	473	696	924

The share on existing building types provided in [2] makes the share of HP classes plausible. For instance small residential building (single and double family households) have over 90% share on building space. The status quo of the “electrical energy demand”, heating and use water heat pumps together are taken from [1].

A1.3. Practical potential of DR for HPs:

In this estimation it is assumed, that the relative share of power classes stay the same; in future scenarios the behavior of scaling will be the same between those classes

Realistic reduction of DR potentials: Concurrency factor (full load hours) imply that the full potential will not be available.

Following estimation has been made according to the full load hour from [1]: A full load hour of 1540h from total 8760h leads to approximately 35-40% availability in the heating period of six month, if it is assumed, that the HP for heating are mainly operating in the cold seasons.

Starting with the “first” 92MW (9MW+83MW in 2030) of the medium and big sized HP, approximately 2000 HPs must be integrated into DR measures. These numbers result if the total electric power per class is divided by the power class mean value. The practical DR potential would be up to 36,8MW (assuming 40% availability) of estimated 92 MW from the accelerated scenario during winter time. Prerequisites are thermal energy storage or thermal capacity enabling the possibility for a demand shift.

Hybrid between cooling and heating HP (reversible HP) could enable more potential especially for winter and summer peaks. Technology trends have this direction.

A1.4. Impact on the electrical power system

Standard transformer power rates are between 0,6 to 1MW, therefore the average share on the distribution grid’s load would be between 5% and 15%, when a HP of power class 20kW-80kW and >80kW is connected. According to the absolute number of HPs per power class installed (Table A1 3) in 2020 a number between 50-100 and in 2030 at least 100-200 distribution grids might be affected. A shift-able load of 15% by avoiding peak loads would already have a positive effect on the asset’s lifetime or would delay the reinforcement by increasing the safety margin of the transformer. Load flow simulations are needed to analyse these effects in detail. Gradual load control would also improve the facilitation and is seen as important to support possible services for DR.

References

[1] Innovative Energietechnologien in Österreich Marktentwicklung 2010, Berichte aus Energie- und Umweltforschung 26/2011, Bundesministerium für Verkehr, Innovation und Technologie, 2011

[2] Haas, R.; et. al.; Wärme und Kälte aus Erneuerbaren 2030; TU-Vienna, EEG, für den Dachverband Energie-Klima und WKO, Oktober 2007

Appendix 2 Present situation of heat pumps in Finland

A2.1. Background

In following sections, country-specific description from Finland is provided. For the background information, number and floor area of different types of buildings in Finland are presented in the Table A2 1.

Table A2 1. Building stock in Finland.

	Number of buildings	m2	% of total m2
Detached houses	1 082 511	148 147 806	35 %
Attached houses	75 109	32 132 585	8 %
Apartment houses	55 925	88 591 973	21 %
Shop buildings	41 419	25 135 863	6 %
Office buildings	10 732	18 250 844	4 %
Traffic buildings	54 134	11 340 432	3 %
Institutional buildings	7 835	9 858 061	2 %
Buildings for assembly	13 418	8 538 715	2 %
Educational buildings	8 885	17 241 611	4 %
Industrial buildings	39 581	44 289 520	10 %
Warehouses	25 964	16 928 080	4 %
Other buildings	5 675	1 840 896	0 %
All buildings	**1 421 188**	**422 296 386**	**100 %**

Furthermore, the statistical information about the heating methods of the buildings is presented in Table A2 2.

Table A2 2. Heating methods of the building stock in Finland.

Amount of the buildings	All buildings	Detached houses	Attached houses	Apartment houses	Shop buildings	Office buildings
In total	**1 421 188**	**1 082 511**	**75 109**	**55 925**	**41 419**	**10 732**
District heating	158 605	52 498	32 571	42 470	6 536	4 422
Oil	322 530	258 097	17 272	9 545	7 529	2 761
Electricity	540 986	456 581	23 942	2 291	18 328	2 611
Coal	7 037	6 604	36	94	55	16
Wood	276 674	262 334	650	1 102	4 165	207
Ground source heating	16 011	15 432	82	17	115	14
Others	99 345	30 965	556	406	4 691	701

Amount of the buildings	Traffic buildings	Institutional buildings	Buildings for assembly	Educational buildings	Industrial buildings	Warehouses	Other buildings
In total	**54 134**	**7 835**	**13 418**	**8 885**	**39 581**	**25 964**	**5 675**
District heating	1 957	3 933	2 369	3 377	5 865	1 819	788
Oil	5 278	2 268	2 615	3 342	10 723	2 222	878
Electricity	14 328	1 158	4 572	1 032	10 882	3 959	1 302
Coal	39	8	15	14	123	15	18
Wood	1 434	172	1 114	784	3 320	580	812
Ground source heating	121	29	22	12	109	46	12
Others	30 977	267	2 711	324	8 559	17 323	1 865

Evens et al. (2010) have estimated that approximately 30 % of the electric heating is direct electric heating, 62 % is partial storage, and 8 % is full storage electric heating.

In addition, in Figure A2 1, distribution of the heating methods by the end energy use in Finland is illustrated. Figure A2 2, again, will provide information about the share of the energy demand of the heating by building types.

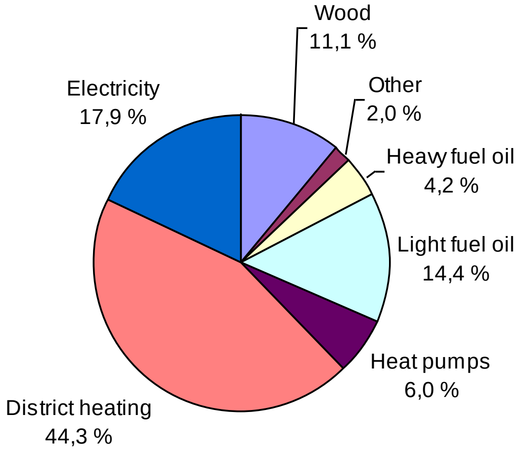


Figure A2 1. The share of the heating methods by end energy use.

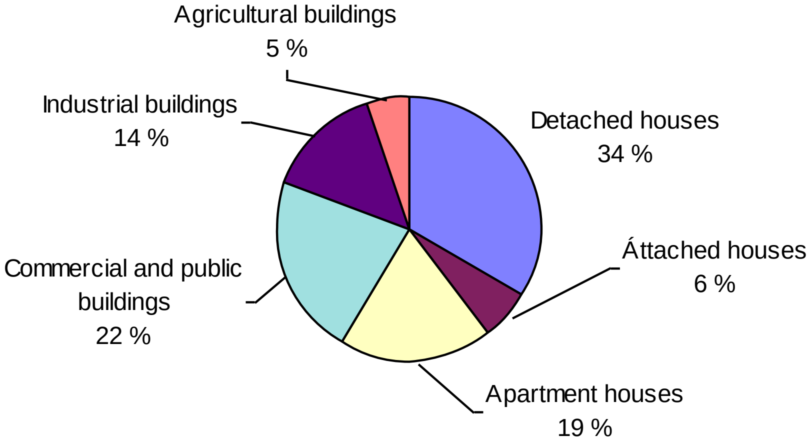


Figure A2 2. Distribution of the total heating energy demand by the building types.

A2.2. Technologies and their penetrations

Due to the climate conditions in Finland, heat pumps are mostly used as heating purposes. There is a lack of the statistics concerning the cooling energy demand in Finland, but roughly it has been estimated that the annual demand of the cooling energy of a building is less than 10 % of the heat demand of the same building. Furthermore, cooling systems are rare even in the new residential buildings in Finland, although there is almost always cooling in the new service buildings. However, installed heat pumps typically have also cooling function, thus it is likely that they are used also for cooling purposes, particularly if summers will be warmer in the future.

Ground source heat pumps are typically used as primary heating method, while air-source heat pumps are supplementary heating system. Ground source heat pumps are typically dimensioned for 50-70 % of the peak demand, which means that they produce 85-98 % of annual heat demand. Rest of the heat demand, during the coldest days of winter, as well as final heating of the tap water, is based on the electric heating. Heat distribution in ground source heat pumps are typically based on water circulation (floor heating or radiators). Seasonal performance factor (SPF) for ground source heat pumps in Finland is estimated typically to be 2.6–3.6. However, empirical studies have revealed a bit smaller heating season SPF, i.e. 2.4 (c.f. ENETE 2010). In Table A2 3, penetration level for ground source heat pumps in Finland during the years 1997-2007 is presented.

Table A2 3. Ground source heat pumps in Finland during the years 1997-2007

Year	Amount	Capacity [MW]	Generated heat [GWh]	Consumed electricity [GWh]	Utilized Primary energy [GWh]
1997	14 731	314,70	1 131,90	390,30	741,60
1998	15 434	329,70	1 216,10	419,30	796,70
1999	16 339	350,10	1 237,40	426,70	810,70
2000	17 539	375,80	1 174,20	404,30	769,30
2001	19 016	406,80	1 441,00	480,30	960,70
2002	20 495	437,80	1 567,90	522,60	1 045,20
2003	22 695	484,90	1 710,20	570,10	1 140,10
2004	25 600	548,20	1 962,00	654,00	1 308,00
2005	29 106	624,30	2 104,30	701,40	1 402,90
2006	33 612	721,90	2 502,10	834,00	1 668,10
2007	38 906	831,00	2 815,00	983,00	1 877,00

Air-source heat pumps are supplementary heating method in Finland, and heat distribution is typically based on the air heating (air-to-air heat pumps). Primary heating method in the building, where air source heat pump is installed, is typically electricity (it is estimated to be primary heating method in 80 % of those buildings). Other typical primary heating methods are oil and wood. Typical SPF for air-source heat pumps in Finland is 1.8-2.2. Typically air-source heat pumps can produce 30-40 % of the annual heat demand of a detached house. Outside air heat pumps are the most rapidly increasing heat pump types in Finland. In Table A2 4, the penetration of the outside air source heat pumps in Finland during 1997-2007 is illustrated.

Table A2 4. Air source heat pumps in Finland during the years 1997-2007

Year	Amount	Capacity [MW]	Generated heat [GWh]	Consumed electricity [GWh]	Utilized Primary energy [GWh]
1997	958	2,54	20,23	10,40	9,83
1998	1 662	4,41	35,20	18,11	17,09
1999	2 214	5,87	45,23	23,26	21,96
2000	3 014	7,99	53,90	27,73	26,17
2001	3 968	10,52	82,29	42,31	39,98
2002	5 872	15,57	123,57	63,53	60,05
2003	10 876	28,83	230,13	118,25	111,89
2004	18 876	50,03	403,08	207,06	196,02
2005	35 880	95,10	730,28	375,05	355,23
2006	65 880	174,60	1 356,28	696,84	659,44
2007	102 880	247,00	1 865,00	958,00	906,00

Furthermore, the penetration of the exhaust-air heat pumps in Finland during 1997-2007 is presented in Table A2 5.

Table A2 5. Exhaust air source heat pumps in Finland during the years 1997-2007

Year	Amount	Capacity [MW]	Generated heat [GWh]	Consumed electricity [GWh]	Utilized Primary energy [GWh]
1997	3 477	58,78	28,0	15,4	12,6
1998	3 578	59,93	29,6	16,3	13,3
1999	3 735	63,72	29,4	16,1	13,3
2000	4 035	70,15	28,0	15,4	12,6
2001	4 474	80,20	35,3	19,4	15,9
2002	5 114	93,47	40,8	22,4	18,4
2003	6 418	122,39	50,7	27,9	22,8
2004	8 018	157,61	59,4	32,8	26,6
2005	9 822	196,3	69,9	38,8	31,1
2006	11 875	239,8	87,2	48,0	39,2
2007	14 372	282,0	100,0	55,0	45,0

It is forecasted that the total amount of the heat pumps in Finland will be one million in year 2020, while currently it is about half million. The annual installed amount of the new heat pumps will develop as illustrated in the Table A2 6, while the total amount of heat pumps is developing as presented in Table A2 7.

Table A2 6. The amount of the annually installed heat pumps; statistics from years 2009 and 2010 and penetration scenario to year 2020 (Finnish heat pump association).

Type	2009	2010	2011	2015	2020
Ground source	6 137	8 091	11 000	15 000	20 000
Exhaust air	1 819	1 988	2 000	3 000	4 000
Air-to-water	1 819	1 150	3 000	5 000	6 000
Air-to-Air	57 977	53 821	60 000	50 000	40 000
Total amount of annually installed heat pumps	67 752	65 050	76 000	73 000	70 000

Table A2 7. The total amount of the heat pumps in Finland; statistics from years 2009 and 2010 and penetration scenario to year 2020 (Finnish heat pump association).

	2009	2010	2011	2015	2020
Total amount of heat pumps	340 000	390 000	465 000	750 000	1 000 000

A2.3. Policies related to heat pumps

There is a financial support for increasing the renewable energy usage of the residential buildings (detached, attached, and apartment houses). The support can be used for replacing the oil- or electricity based heating system by renewable energy sources, such as

- Ground source heat pump
- Air-to-water heat pump
- Wood-based heating (for instance heating by wood pellets)

The amount of the financial support is in maximum 20 % of the costs of the renovation, including devices and materials. In addition, there is a means-tested financial support for increasing the energy efficiency of the detached houses. The maximum amount of this support is 25 % of the costs of the renovation. However, this benefit is only for low-income people and there are strict limits for the incomes of the applicant.

Furthermore, there is a deduction of income taxes for households that purchase services. This deduction is for the labor costs of the services, and in many cases it is used for renovation of the houses, and hence can be used also for instance for the labor costs in the installing of the heat pumps.

A2.4. Load characteristics

Evens et al. (2010) have analyzed the load curves of the different heating methods in Finland during typical winter day. The results are presented in the Figure A2 3 and Figure A2 4. Electrical heating with storage is typically used during night-time tariff in two-time tariff system. Hence, it is mostly switched on between 10 pm and 7 am.

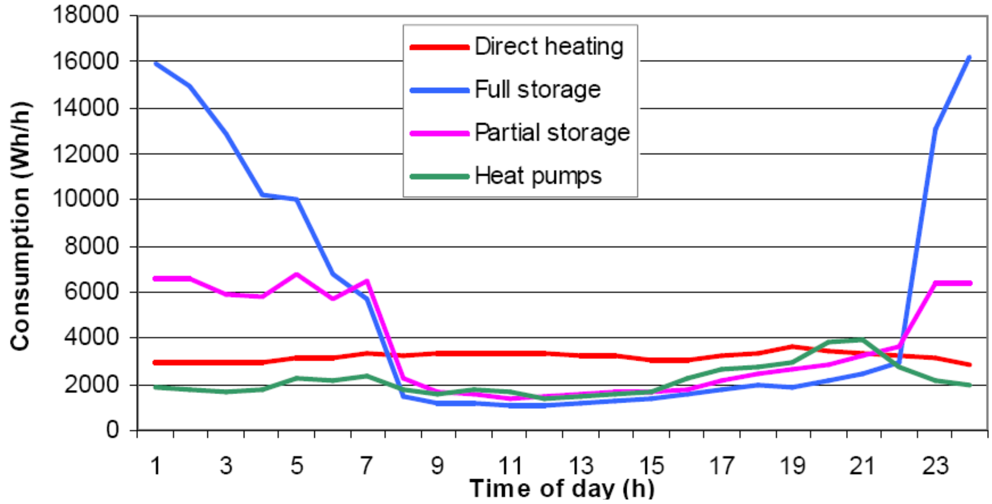


Figure A2 3. Load curves for different heating types during a typically January weekday in Finland (Evens et al. 2010)

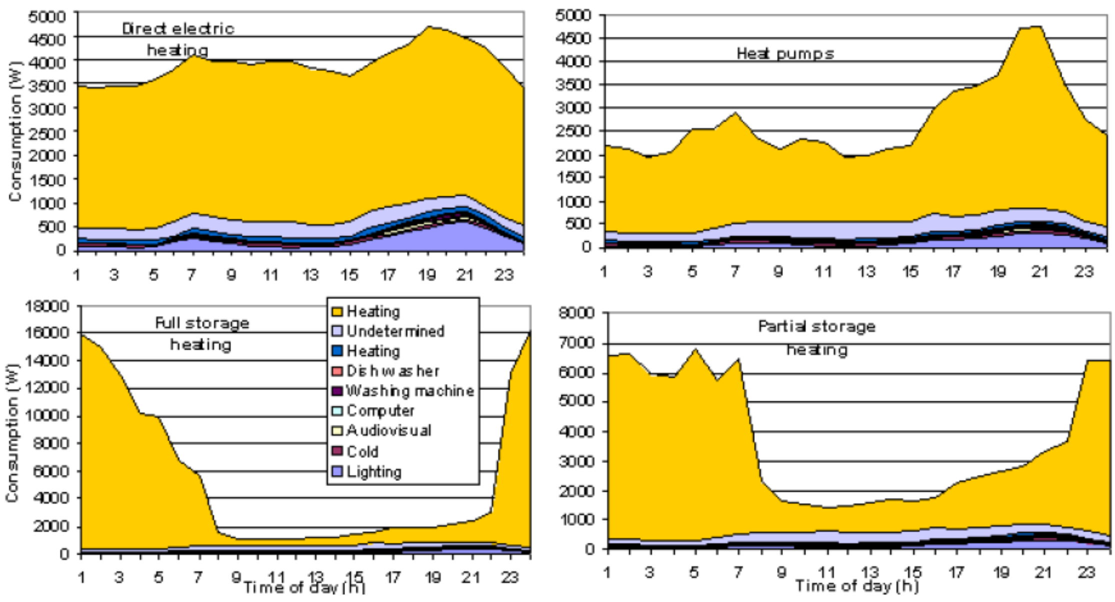
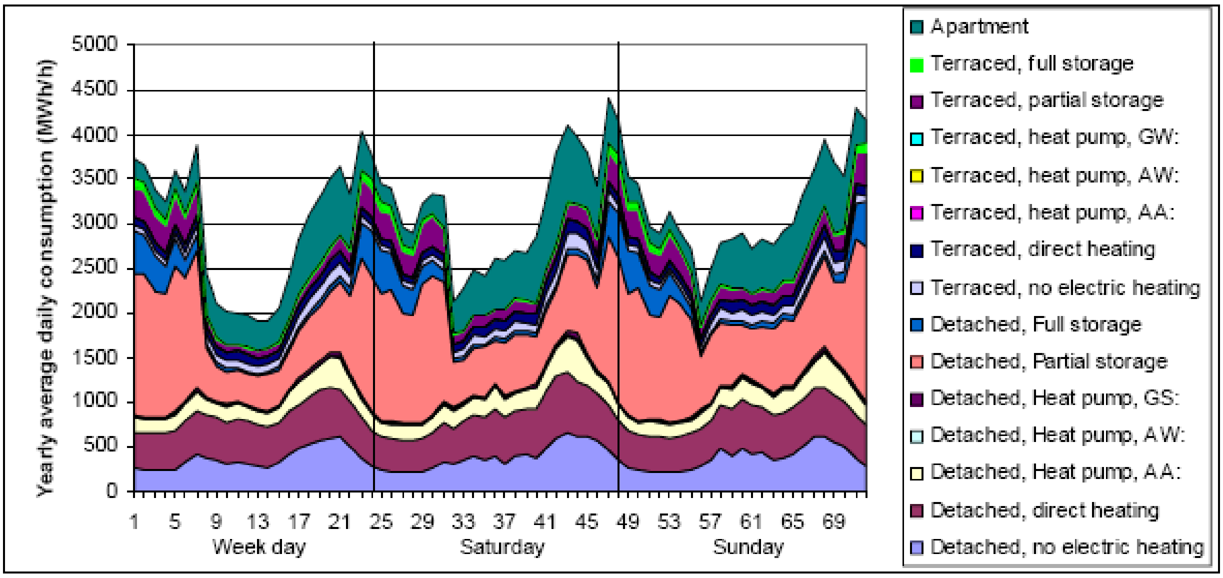


Figure A2 4. Load curves of detached house with different types of the heating (Evens et al. 2010)

Based on the load curves and statistics about the residential sector, Evens et al. (2010) have formed aggregated load curves for residential sector for typical winter days (weekday, Saturday, Sunday), presented in Figure A2 5.



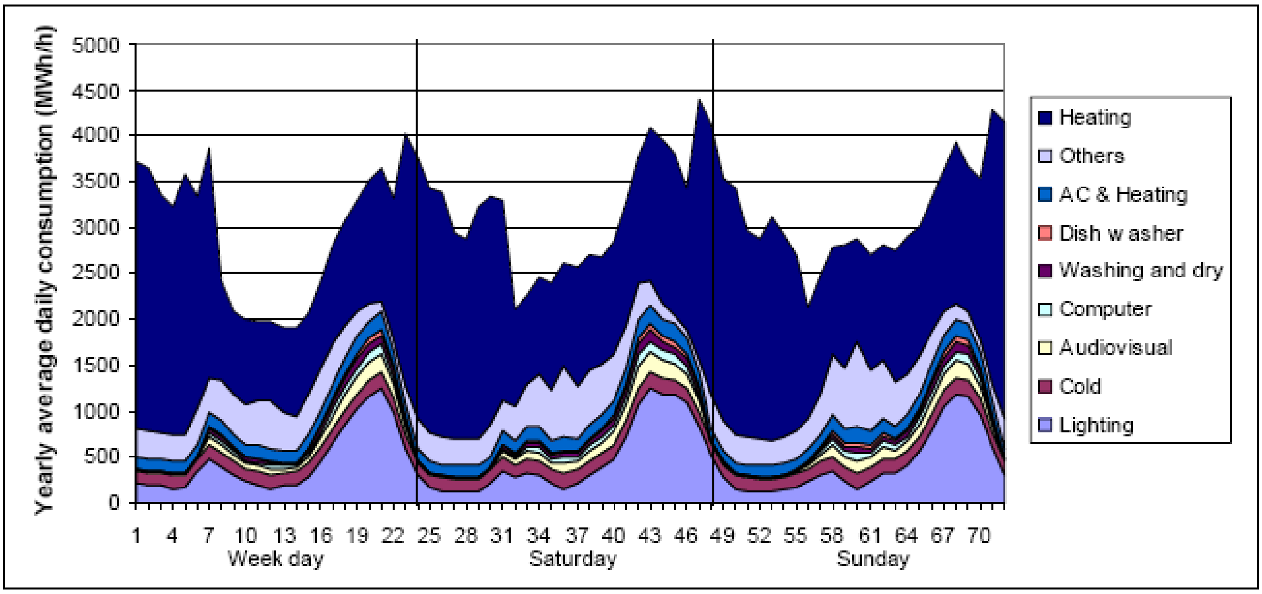


Figure A2 5. Aggregated winter load curve for residential sector in Finland (Evens et al. 2010)

In ENETE-project, there have been analyses of the hourly metered consumption data, combined with the questionnaire sent to the customers. Based on those analyses, for instance the energy saving potential of the heat pumps, as well as temperature correlations of the heating loads has been studied. In the Figure A2 6, the daily power consumption in two households as the function of the outside temperature is presented. Households are otherwise similar, but one is with ground source heat pump (left one in the figure) and another with direct electric heating.

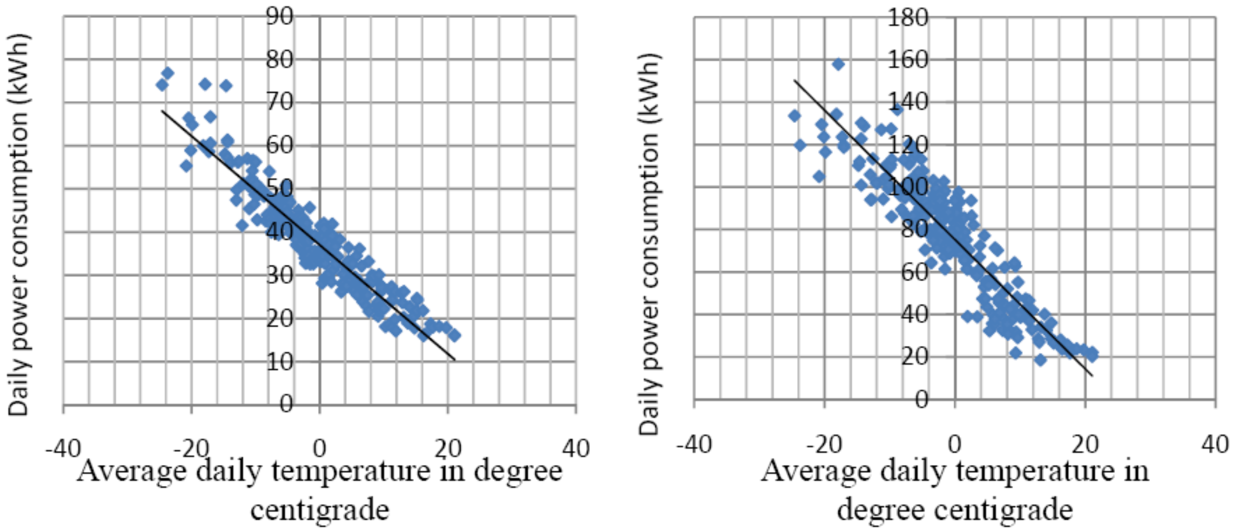


Figure A2 6. Average daily electricity consumption of two similar households, one with ground source heat pump (left) and another with direct electric heating (right). (ENETE 2010)

Based on above presented figure, the correlations between the temperature and electricity demand, as well as saving potential and SPF of the ground source heat pump are calculated. Results were 2.4 SPF and 58 % saving potential for ground source heat pump, compared with direct electric heating.

A2.5. Possible use for DSM

Evens et al. (2010) have analyzed load flexibility in the Finnish residential sector during typical winter day. Loads are categorized in the four categories:

- Easily manageable loads, such as heating and white goods
- Hardly manageable loads, such as cold appliances and computers
- Fixed loads: Lighting and audiovisual
- Undetermined loads, which includes undetermined end-use

Results of the analysis are presented in the Figure A2 7.

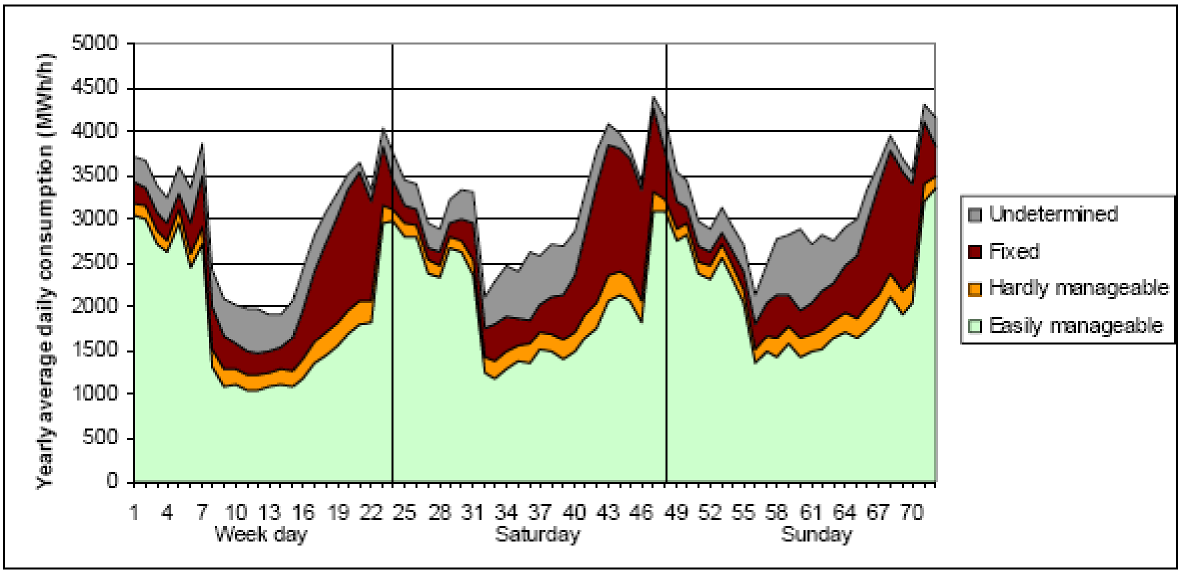


Figure A2 7. Estimated flexibility potential in the residential sector during an average winter week (Evens et al. 2010).

Easily manageable loads consist mainly from electric heating. Storage electric heating is already controlled by two-time tariff system, and there are considerations for more sophisticated control systems, based for instance the spot-prices of the electricity. However, while storing electric heating systems have already installed control systems, situation is not the same for the heat pumps. Hence, in order to control heat pumps, the development for the practical load management application to the customer end and modifications in the customer installations are needed, which obviously is quite burdensome task.

In addition to above mentioned, Rautiainen et al. (2009) have studied the possibility to use frequency dependent electric heating to manage disturbances in power system. Basic idea would be to switch heating on and off based on not only the temperature, but also the frequency, and maximum allowed temperature deviation from the normal situation (T_{max}), as illustrated in Figure A2 8.

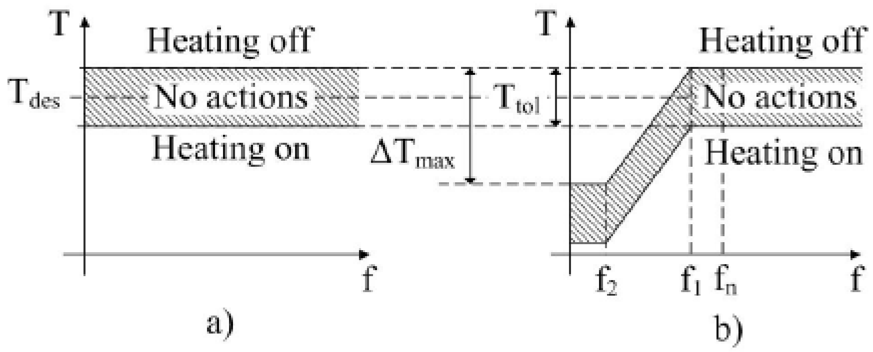


Figure A2 8. a) conventional heating thermostat, b) frequency based electrical heating control. (Rautiainen et al. 2009)

Although the principle was developed for electrical space heating, it could be used also with other controllable loads, such as heat pumps or charging of the electric vehicles.

A2.6. Research projects and case studies

Following research projects, related to this topic, are ongoing or have been finished lately

- ENETE – Promoting Energy Efficiency by Energy Companies
    - Project was carried out during 2008-2010, and was finished in August 2010
    - Research institutes: Aalto-University (TKK), Lappeenranta University of Technology, University of Eastern Finland, and VTT
    - Financed by TEKES (Finnish funding agency for technology and innovations) and private companies
    - Major tasks of the project were:
        - Demand control and management
        - Energy monitoring services to the electrical customers
        - Assessment of the spatial impact of the energy saving measures
        - Energy conservation impacts on health
        - Energy saving and energy business
    - There have been analyzed, for instance, demand side management potential and technology, impacts of the energy efficiency actions, such as heat pumps, on the electricity distribution
    - List of the publications will be in the final report (some of them listed in the references section)
    - Final report will be available later in 2010
- INCA – interactive customer gateway for electricity distribution management, electricity markets, and services for energy efficiency
    - Project was carried out during 2008-2010, and was finished in August 2010
    - Research institutes: Tampere University of Technology, Lappeenranta University of Technology, and VTT
    - Financed by TEKES (Finnish funding agency for technology and innovations) and private companies
    - Major tasks of the project were:
        - The overall concept; functions, exploiting processes and business models
        - Determination and demonstration of functions and technological solutions of network interface
        - Functions of advanced automatic meter reading (AMR)
        - Network connection of distributed generation as a part of interactive customer interface
        - Network interface of plug-in hybrid cars and effects on network infrastructure and electricity market
        - Technological solutions and business models for market and price oriented demand response
        - Effects of interactive customer interface on overall system-wide energy efficiency and survey of possibilities to develop energy efficiency services

        - Exploiting data of interactive customer interface in enhancing customer load modelling for network calculations, in network asset management and in active distribution management
    - List of the publications will be in the final report (some of them listed in the references section)
    - Final report will be available later in 2010
- SGEM – Smart Grids and Energy Markets
    - Five years research program (2009-2014), first funding period 9/2009-2/2011
    - Financed by TEKES (Finnish funding agency for technology and innovations) and private companies
    - All the major research institutes and private companies related to the field of the electricity distribution take part on the research program
    - Research themes include visions for smart grids towards 2035, active resources (demand response, EVs, DG), management and operation of the grid, and development of the electricity markets
    - Some of the publications listed in the reference section

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A2.7. References of the national part

Evens, C., Kärkkäinen, S., and Pihala, H. 2010. *Distributed resources at customers' premises*. Research report VTT. 2010.

Final report of the ENETE project (Promoting Energy Efficiency by Energy Companies). August 2010. Aalto University, VTT, University of Eastern Finland, Lappeenranta University of Technology

Belonogova, N., Lassila, J., Partanen, J. *Effects of demand response on the end-customer distribution fee*. CIRED Workshop, June 2010, Lyon, France

Belonogova, N., Lassila, J., Partanen, J. *Effects of demand response on the distribution company business*. NORDAC 2010, September 2010, Aalborg, Denmark

Rautiainen A., Repo S., Järventausta P., *Using frequency dependent electric space heating loads to manage frequency disturbances in power systems*. Proceedings of the PowerTech 2009, Romania, June 2009

Tuunanen, Jussi. "*Lämpöpumppujen vaikutukset sähköverkkoliiketoiminnan kannalta" (The effects of the heat pumps from the perspective of the electricity network business)*. Master's thesis. Lappeenranta University of Technology. 2009 (In Finnish)

Tuunanen, J., Honkapuro, S. & Partanen, J. "*Energy efficiency from the Perspective of Electricity Distribution Business*". The proceedings of NORDAC 2010, 6-7 September 2010, Aalborg, Denmark

Merkebu Zenebe Degefa, *Energy Efficiency Analysis of Residential Electric End Uses: Based on Statistical Survey and Hourly Metered Data*. Masters Thesis, Aalto University, 2010.

Merkebu Zenebe, Anssi Ahola, Matti Lehtonen, *Energy efficiency analysis of residential electric end uses*. NORDAC 2010 Conference, Aalborg, 6.7.9.2010.

Finnish Heat Pump Association (www.sulpu.fi)

Statistics Finland (www.stat.fi)

Appendix 3 Present situation of heat pumps in France

Heat pumps are devices which collect the heat from a source in order to restore it where it is needed. There are various types of heat pumps depending of the source where the heat is collected, the principal ones being geothermal heat pumps and air source heat pumps. These devices are interesting for their low electricity consumption compared to other classic heating technologies.

A3.1. Technological and commercial offer in France

Heat pumps are technologically and commercially very well developed on the French market.

Principle

The heat pump principle is to use a fluid running in a closed loop circuit successively collecting heat from a cold source (**3** in Figure A3 1 below) and restoring it to a hot source (**1** in Figure A3 1 below). The hot source is always a building to heat but the cold source can be either ground, water, or air.

The phenomenon of making colder a cold source in order to make hotter a hot source is of course not natural. In order to work, the fluid in the heat pump needs to be in turns expanded (**2** in Figure A3 1 below) then compressed (**4** in Figure A3 1 below). The expansion occurs before going through the cold source so that the fluid can vaporizes (in **3**) to collect the heat of the cold source. The compression occurs before going through the hot source so that the fluid can liquefies (in **1**) to release the heat to the hot source. External energy (most of the time electrical) is therefore needed for the compression stage. However this consumption is much less than what would need a classic heating device for the same heating power.

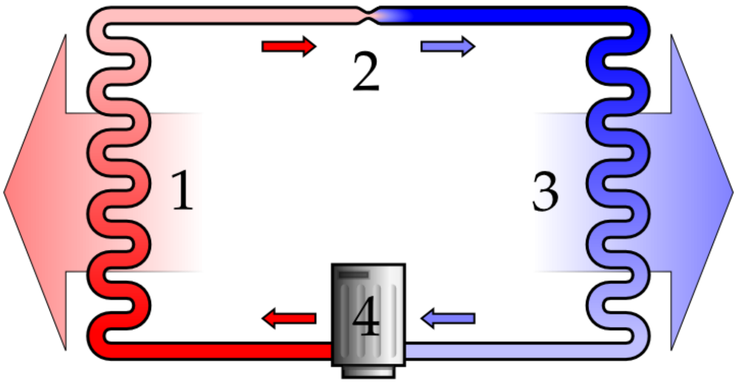

Figure A3 1. Principle of a heat pump cycle

Coefficient of performance – COP

The COP is a coefficient determining the performance of heat pumps. It is defined as the ratio of the useful heat over the work input. A classic electric heater has a ration of 1. Heat pumps usually have a COP between 2 and 4, but it can be much higher in certain types of applications (low output temperature for example) and technologies.

Technological offer

As previously said, there are various heat pumps types with different characteristics such as from what the heat is extracted, the type of compression method and the types of fluid circuits.

- Types of fluid circuits

- Direct expansion circuit: The same fluid is used for the heat collector, the pump and the heat emitter.
- Indirect expansion circuit: Two different fluid circuits are used, one for the heat collector and the pump and one for the heat emission side.
- Intermediate fluid circuit: Three different fluid circuits are used, one for the heat collector, one for the pump itself, and one for the heat emitter.

- Types of heat pump
  - Air heat pump: these heat pumps collect heat from the ambient air, either from outside or from an exhaust

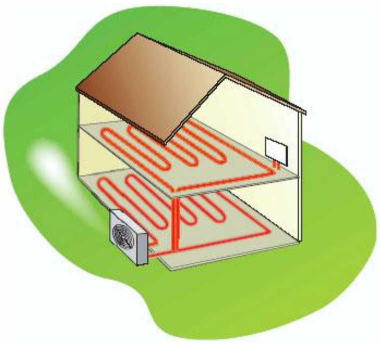

Figure A3 2. Air heat pump (here with floor heating system)

  - Geothermal heat pump: these heat pumps collect heat directly from the ground. Heat collectors can either be horizontal or vertical, depending of the type of heat exchange

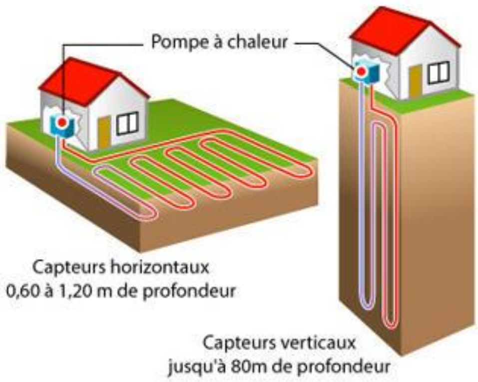

Figure A3 3. Geothermal heat pump with horizontal and vertical collectors

The table below summarizes the type of fluid circuits that are used depending of the type of heat exchange and the type of heat pump.

Type of fluid circuits	Air Heat Pump		Geothermal Heat Pump	
	heat from outside	recycled heat from inside	horizontal collectors	vertical collectors
air / water	indirect expansion			
air / air	direct expansion			
ground / ground			direct expansion	
ground / water			indirect expansion	
glycoled water / water			intermediate fluid	

Figure A3 4. Type of fluid circuits depending of the type of heat exchange and technology

Geothermal heat pumps globally have a very goof COP and are very effective during cold weather. Indeed they collect heat from the ground at depths where the temperature is almost constant all year round. This technology is often used alone as it can usually provide all the heating needs of the building/house where it is installed.

Air heat pumps generally have a lower COP than geothermal heat pump. And by very cold weather (-10°C/-20°C) their performances become bad and the heat pump can stop functioning. They are therefore often used with an additional heating system which works as backup during high heating needs.

Both of these technologies contribute in increasing the electricity peak demand that occurs for heating needs (daily, seasonally, but also as well at local network level than as national network level), especially if they are started up at the same time as when the peak demand occurs because of the starting of the compressors.

Commercial offer

There is a great diversity of the commercial offer of heat pumps in France since this technology is now well established on the market.

Certita is a company which delivers the “NF Heat Pump” label (French Norm). Up to the 9^{th} of November 2011 their website gathered a list of 1702 different heat pump products manufactured by 66 different brands covering all the different technologies described above.

“NF Heat Pump” is a voluntary label which needs to be asked by manufacturers. This label guarantees the compliance of the products regarding the different norms (French, European or international) and regarding minimum performances fixed by the *Certification Rules of the mark “NF Heat Pump”*.[1]

A3.2. The current state of Heat Pumps installations

In French Energetic Assessment[2] reports, published each year, the total number of heat pumps installed in the residential sector in France in 2008 was 350 000 (not counting air/air type), and was estimated to be around 550 000 at the end of 2010, plus 400 000 air/air type heat pumps.

[1] http://www.certita.org/files/Certification-rules-NF.pdf

[2] Bilan Energétique de la France pour 2010 – published in 2011 – MEDDTL

The French Organization for Heat Pump (AFPAC) publishes[3] numbers that are in the same range and that come from statistics of sales produced by the different manufacturers of heat pumps. They give a total number of heat pumps (still without counting the air/air heat pumps) in 2010 of 600 000. However the sales in 2009 dropped by 20% and the sales of 2010 by 35%.

In a report on buildings, energy, and environment[4], the ADEME counts 27.5 millions of main homes. The penetration rate of heat pumps in the residential sector is therefore about 3.4% (950 000 heat pumps for 27.5 millions possible installations).

From an energetic point of view, these 600 000 heat pump units produced 1649 kTep in 2010 (according to the 2010 French Energetic Assessment, published by the Department of Ecology, Sustainable Development, Transport and Housing).

Impact on the electrical network

Most heat pumps simply use an electric compressor. They are therefore a heating device using electric energy which contributes to the electric peak demand which occurs when heating needs are high.

Two characteristics of this device increase this peak demand contribution:

- The starting current needed when starting the compressor can be relatively high and induce strong constraints on the network, especially if they all start in the same time lapse
- When the weather is particularly cold, and that the COP of the heat pump (air heat pump only, not the geothermal one) is at its lowest, the electric consumption is increased even more. The contribution to the electric peak demand is consequently also increased, at the worst moment.

A3.3. Deployment perspectives

Heat pumps are already well deployed in France. The heat pump market is now well established. This is due to the early emergence of this technology which occurred after the 1979 energy crisis, when fuel oil prices went high. But it is only since 1997 that the market, helped by a quality control of products and new regulations, slowly started to grow.

A3.3.1 Current Regulations

The French government has set up different measures to help users to invest in heat pumps.

Sustainable development income-tax credit[5]

An income-tax credit on sustainable development installations was set up as a result of the Environmental Grenelle Agreements. This measure permits to deduce from one's tax return a percentage of the investments made in different sustainable development installations. For geothermal heat pump, the tax credit was of 40% in 2010, and is of 36% in 2011. For air/water heat pump, the tax credit was of 40% in 2009, 25% in 2010, and is of 22% in 2011. Air-air heat pumps are often used as a cooling equipment, heating being secondary, they are therefore not subsidized by the government.

The tax credit was reduced in 2011 by the government for economical reasons.

[3] La climatisation – Les pompes à chaleur – Les chiffres du marché français de janvier à décembre 2010, PAC & Clim'info and AFPAC

[4] Bâtiment – Energie et Environnement – 2010, ADEME Collection chiffres clés

[5] Article 200 quater du code des impôts Modifié par Décret n°2011-645 du 9 juin 2011 - art. 1

“Eco”-loan at 0% interest

The government also allows “eco”-loans at 0% interest for ecological installations. There are of course some specific criteria to fulfil in order to benefit from this eco-loan. In the case of heat pumps, construction work such as drilling for geothermal heat pump for example can benefit from this loan. Renovation work can also benefit from the loan but only if there is a substantial energy saving with the new equipment.

VAT of 5.5%

The VAT is reduced to 5.5% instead of 19.6% for heat pumps installations.

Norms

There are also norms controlling the installations of heat pumps. Their power is limited in accordance to their type of connection to the grid and type of engine starting process. Below is a list of the different norms and their specification:

- NF-C15-100: current limitation for low voltage grid connection (45A for a single phase connection, 60A for a three-phase connection)
- EN 61000-3-3: terms on voltage fluctuation
- EN 61000-3-2: terms on harmonic’s power

A3.3.2 Scenarios and forecasts

In August 2010, a National Plan in Favour of Renewable Energies[6] was delivered to the European Commission. This plan uses the scenario considered by the Program of Investments into Heat Production[7] delivered by the government to the French Parliament in 2009.

The program of investments agrees on a goal of 1200 kTep of heat production until 2012 and 1600 kTep until 2020, considering that in 2010 the heat production target was of 886 kTep.

In the 2010 French Energetic Assessment[8] (published in 2011), the numbers given for 2010, 1 336 kTep, are 151% higher than the objective, 886 kTep.

The scenario considered by the Program of Investments in Heat Production is for a total of 2 millions of housing equipped with a heat pump unit. This scenario also predicts a share of 20% of heat pump being geothermal, the rest being air/water heat pump.

A3.4. Conclusion

Heat pumps have come to a stage where the proposed products (air heat pump, geothermal heat pump) are mature, but where the penetration rate at a national level is still low. In 2010, there are about 950 000 heat pumps installed in France, of which 400 000 air/air type heat pumps. Indeed, compared to the 27.5 millions housing which could possibly possess a heat pump installation, the penetration rate obtained is approximately 3.4%.

There is a strong normative supervision of heat pumps installations but it is mainly concerning the start-up current. The fact that heat pumps mainly consume electricity at the precise moment of the peak demand (due to classic electric heating devices) is not supervised by regulations of any kind. It

[6] Plan National en faveur des Energies Renouvelables – Août 2010 – MEDDTL

[7] Programmation Pluriannuelle des investissements de production de chaleur - MEDDTL

[8] Bilan Energétique pour 2010 – published in 2011 – MEDDTL

should be kept in mind if a major development of heat pumps occurs. However the number of installations per year has decreased of 20% in 2009 and 35% in 2010.

Appendix 4 Present situation of heat pumps in the Netherlands

A4.1. Heat Pump Technology

The Netherlands has one of the largest fossil gas field reserves in the world and there is a large drive to integrate upcoming biogas production facilities in the gas grid. The gas grid net transmits 8 times as much energy compared to the electricity grid. Heating and hot tap water preparation systems in the Netherlands, therefore, use natural gas as a fuel. In contrast, heat pump technology is in the process of becoming widely spread in the Netherlands, because it allows, if installed and configured properly, efficient electrification of heating. On the central production level, electricity can be de-carbonized by using renewable energy resources or carbon dioxide can be captured more easily. Therefore it provides for a future proof heating system solution for well insulated buildings with low heat demands.

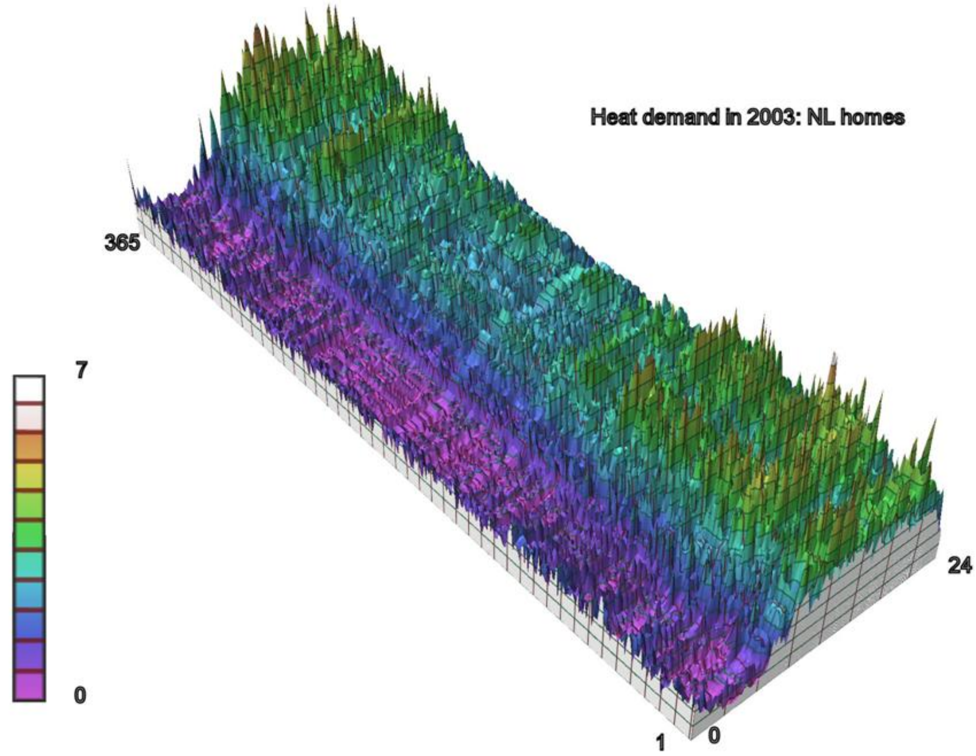

Figure A4 1. Heat demand as measured in Dutch homes (MJ/h)

In Figure A4 1 the measured heat demand for heating and tap water production of Dutch homes over a representative year is depicted. In dimensioning heat pump technology in the Dutch climate regime, it is difficult to cover the whole load-duration curve of a whole year. Especially for the peak heat demand periods, the required additional investment to cover all peaks is disproportionally high and temperature levels that can be reached are too low to prevent effective legionella contamination. Another problem with some heat pump systems is their decreasing efficiency and defrosting problems if they have to pump the heat to temperatures below a certain limit. Therefore, additional peak heat production capacity is co-installed in most cases. This capacity typically consists of small, high-efficiency, gas boilers or wire-heated resistance elements. So, most heat pumps are of a hybrid nature being either serial or parallel.

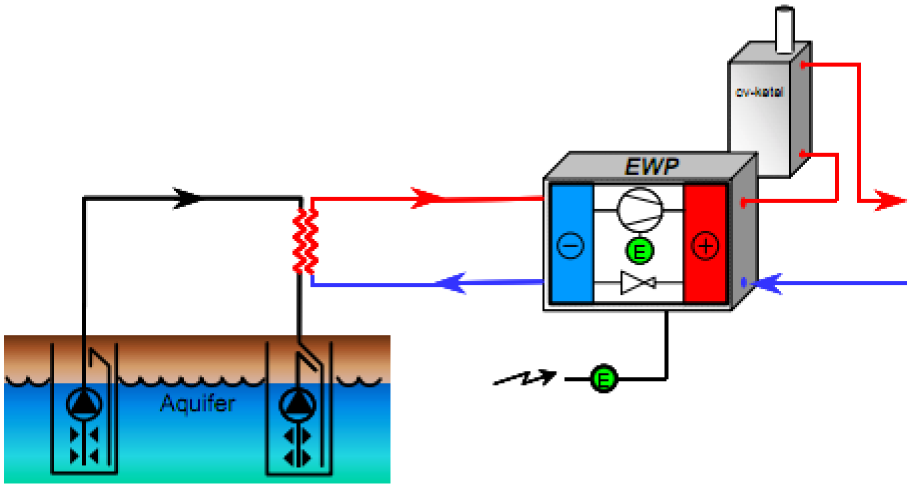

Figure A4 2. Example of hybrid system

In the last few years, also hybrid systems relying on air-water heat exchange have been developing especially in the residential sector as a successor of the high-efficiency gas fired heaters. Examples of these have now found their place on the market. Some of systems also are connected to the air inlets and outlets of homes and take part in the heating as well in the ventilation of homes. These types of systems are also used combined with insulation packages in renovation of homes. In bivalent systems a discrimination has to be made between parallel and serial systems. Recently also the ultra-high efficiency heater has been brought to the market as a third alternative. This system is based on the Organic Rankine Cycle physical principle, that aids in recovering extra energy from the primary power generation process.

A4.2. Heat/cold storage sources

A4.2.1 Aquifers as heat storage

In the Netherlands, there is a large installed base of heat pumps, based on aquifer storage of heat, especially in utility buildings (penetration in the Netherlands 30-40 percent for new projects). The opportunities of these types of heat storage depend on the absence of long term local subsurface flows of water in geological strata at a certain suitable depth. In the Netherlands, generally, the possibilities at most locations are good (see Figure A4 3; the blue-striped areas are less suited, the red dots represent example projects). The challenges in operating these devices is maintaining the heat/cold balance during a year to guarantee operation at the optimal COP and to comply to municipality license conditions and in configuring in relation to the other heat/cold generating devices and the realized user comfort. The latter provides for a major challenge due to the slow reaction of well-insulated buildings in reaction to control actions of the building management system and balancing with other heat producing devices (e.g. computers and printers). Aquifers allow comfort control by delivering cooling capacity in summer and heating capacity in winter. Due to their good insulation and their design to be heated passively, some office buildings currently have their switching point between heating and cooling at a temperature as low as 13 degree centigrade. In residential context, aquifer systems are used for apartment houses. When applied, the pay-back time of systems in the order of 5-10 years.

For individual homes the initial cost of aquifer based types of heat pumps in most cases are prohibitive. Furthermore, it is a storage technology, which hardly can be used in renovation of existing homes.

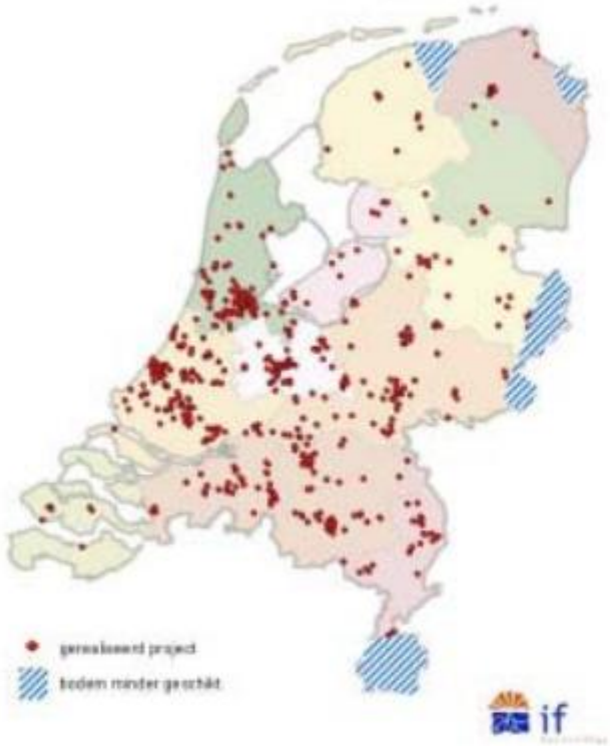

Figure A4 3. Aquifer possibilities in the Netherlands; the striped areas are less suitable

A4.2.2 Hot water tanks as heat storage

The heat capacity of a water tank containing 95 degrees Celsius hot water at an ambient temperature of 21 degrees is 87.2 Wh/kg as compared to electricity storage densities for Li-ion batteries of 140 Wh/kg. Thus, comparing to electricity storage batteries, hot water tanks provide a cheaper means of energy storage. In Dutch households there has not been a significant spread of electric boilers with storage tanks. Currently there is renewed interest into these types of devices due to their connection to power grid operation (see Figure A4 4). These device allow uncoupling of heat demand and electricity demand in such a way, that loads can be shifted to low price areas. The operation mechanism and market portfolio support possibilities are similar to the horticultural sector, apart from having an electricity price profile following heat demand opposed to an anti-cyclic setting with the highest heat demand during the night.

Figure A4 4. A storage tank along a micro-CHP

A4.2.3 Homes as heat storage

Buildings have, due to their mass, inherent heat storage capabilities. Once very well isolated, heat generation and delivery can be decoupled in time. Indeed, because most systems are used with low capacity heat generators, the latency may be very high. This poses problems to control and feedback to users. Systems are not tuned to follow a varying temperature profile but try to follow a more or less straight line.

A4.3. Heat pump projects in the Netherlands

In the utility building sector heat pumps have found their way in installation system design and configuration. Their use has been awarded in the design performance specification index. Their penetration has reached a 30-40 % level. In Figure A4 3 the locations of projects have been indicated by red dots.

In the residential sector, heat pumps are also attributed a substantial contribution to the Energy Performance Conformance index, that Dutch newly built homes have to comply. Therefore there is experience with several large projects. It appears, that utilizing heat pumps in projects generally requires a lot of attention and tuning from the installer. If not properly configured, heat pumps are shown not to reach their design efficiency. Design time operational requirements and actual performance and most importantly electricity consumption figures show a much higher spread than comparable more traditional heating systems. The major reason for this is in the electric resistance wired peak heater, that is activated to a larger extent by user thermostat settings in time. This particularly holds for bivalent heat pumps, in which the optimal strategies have to be found for both heating systems in the context of the building thermal behavior and the user temperature profile. Apart from the electricity bills in some occasions, users generally are satisfied, although comfort complaints occur sometimes. Usage of heat pumps for cooling adds to their economic application also in this sector.

A4.4. Policy perspectives for heat pumps

As already mentioned applying heat pump systems in homes and utility buildings is taken up in the design time energy performance index (EPC), to which newly built homes in the Netherlands have to comply. This makes it easy to compare heat pumps to other measures to conserve energy. The advantage of heat pumps for project developers is, that they shift the operational costs to the home owners.

Heat pumps in the Netherlands in existing homes are subsidized on a per investment basis. For home owners the amount of money is approximately 5000 euro for water/water heat pumps and 2000 euro for air/water heat pumps. Allocated budgets change in time depending on the policy.

A4.5. Demand response perspective of heat pumps

A4.5.1 Commercial perspective

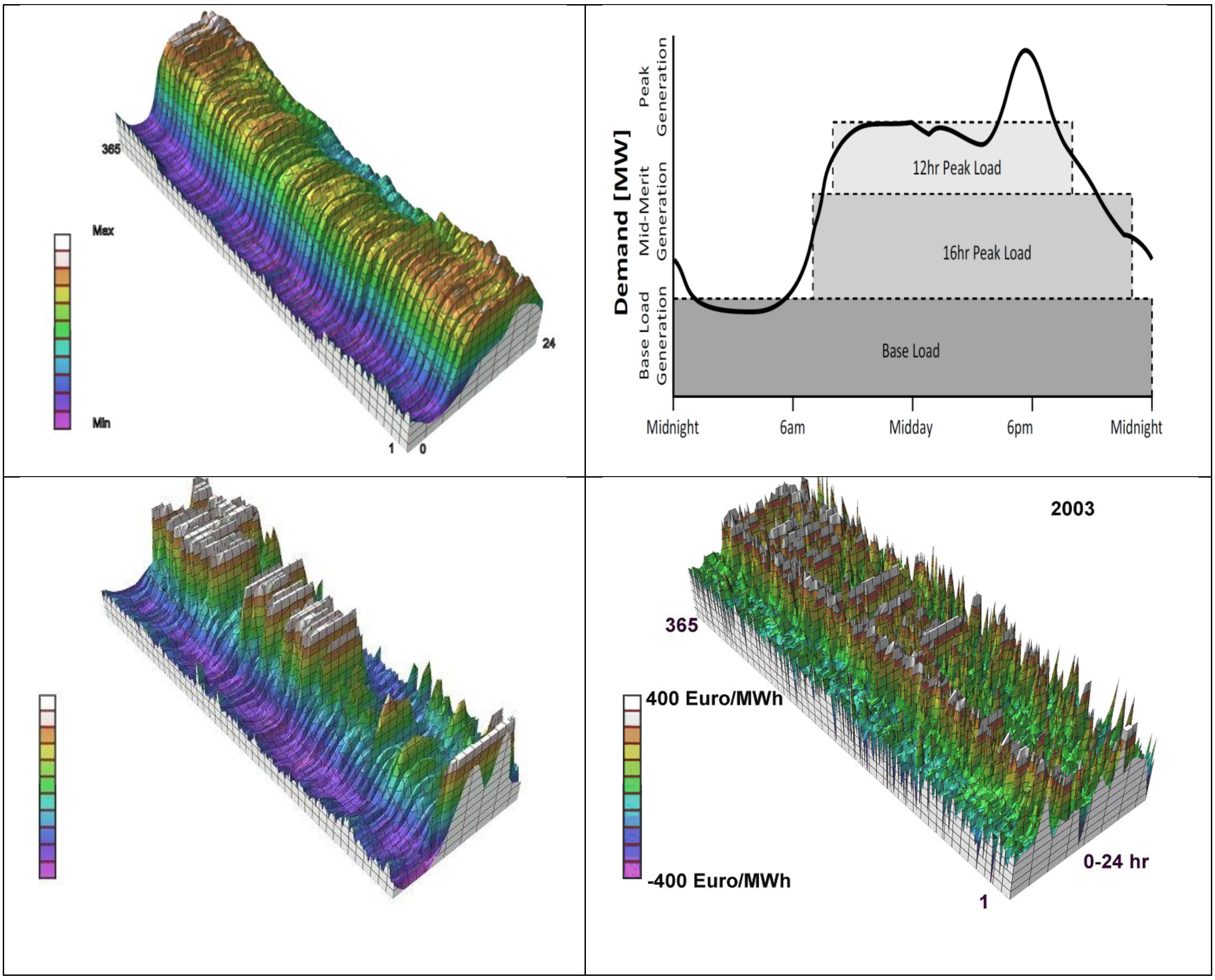

Figure A4 5. Figure 2 Year profiles of total load, merit order, Amsterdam Power eXchange and imbalance market prices

Figure A4 5 shows the load profile of the Dutch system. The plot shows the per-hour development (0-24) and per-day development (1-365) in one plot. The system is characterized by a relatively high base load, 16 hr time span and 12 hr timespan block load and peak load, which is served by large combined cycle gas turbines. Figure A4 5 further shows the price development of electricity prices in Euro/MWh on the APX market and the imbalance market. It can be seen, that there is a large price volatility during the day but also during the year. For heat pumps, there is a significant demand response advantage, by shifting the time electricity is consumed. The 1-hour timeslot resolution of the APX, but also the 15 minute timeslot of the imbalance market can be used. As can be seen in the right part of the plot, imbalance prices are peaking during 8:30 due to portfolio owners not able to ramp-up their large generators, that typically have a 30-45 min startup-time. Once being present in substantial; amounts in a portfolio, response loads can be used to compensate and thus can be used to make rectangular blocks to trade on the APX. Apart from being able to passively balance by influencing their operational strategy, also active balancing can take place at the prices at the imbalance market. On the reverse side, increased consumption by heat pumps at high peak periods might lead to a new customer profile segment for heat pump owners with higher tariffs.

A4.5.2 Distribution system operator perspective

One of the challenges of the near future for a more renewable Dutch electricity infrastructure is the embedding of high concentrations ('hotspots') of heat pumps in newly built domestic residences. In the Dutch situation demand of electricity occurs simultaneously with demand of heat, high electricity peak loads in the low voltage network are expected. In 'flameless' residential areas in the Netherlands, gas infrastructure investment costs are not done. These areas have problems in operating their distribution assets to prevent overloading in case there is an extra cold winter day. The power of the heat pump is typically 2.2 kW and the power of the electric resistance heating, which is available as a backup for cold days, is 6 kW. The peak power exceeds the design connection power of 1.1 kVA, which is a characteristic value for a Dutch household at the distribution level. Another problem is the blackstart of the grid in case of an outage in a prolonged cold period. All heat pumps will come in at the same time with full power requirements giving too large transformer loads for a prolonged period, possibly leading to new blackouts.

A4.6. Heat pump introduction scenarios in the Netherlands

Heat pumps have been attributed a large role in leading to more renewable and sustainable heating systems in the Netherlands. However the increased requirements in producing peak heating capacity for tap water (comfort requirements have risen from CW/3 to CW/6) and in cold weather situations coupled with the cost for the technology have hindered massive introduction of systems. Hybrid systems are now most close to the market. These entail electricity or gas based heat pumps for the base load and gas fired high-efficiency boilers as add-ons to generate tap water. The most recent projection is from 2009. The scenario is for hybrid air-water heat pumps.

2011-2015	340.000	182.000
2016-2020	1.000.000	535.000
2021-2030	2.980.000	1.479.400

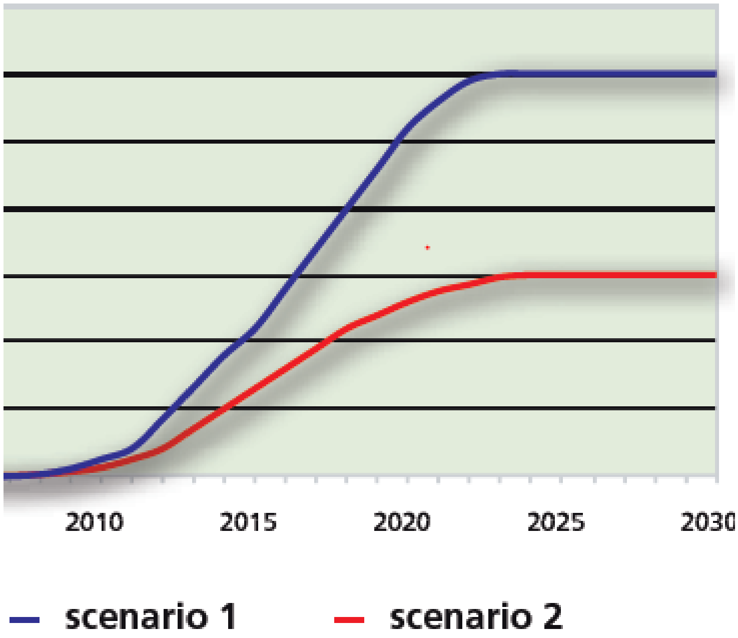

Figure A4 6. Penetration of heat pumps in target years for two scenario's

Figure A4 6 shows the penetration of electric and hybrid heat pumps in two scenario's. In the first, 75 percent penetration in the replacement market for traditional high-efficiency heating systems is assumed. The second is less ambitious and leads to a penetration of 40 % in the replacement market.

	CO_2-reductiepotentieel [Mton]	Energiebesparingpotentieel [$PJ_{primair}$]
2020	0,7 – 1,3	10,9 – 21,0
2030	1,6 – 3,4	27,9 – 64,0

Figure A4 7. Carbon dioxide reduction potential and energy saving potential in the Dutch situation

In Figure A4 7 the associated resulting carbon dioxide reduction and savings potential are given for the two scenario's. The chance of success for these scenario's depends on the growth to a renewable electricity society and of the fossil fuel costs.

A4.7. Research and demonstration projects in the Netherlands

As mentioned earlier, rollouts of heat pumps in the utility and residential building sector have taken place during the last decade. In the field of using demand response and storage, very limited project experience exists.

A project currently in operation in Hoogkerk is the 'PowerMatchingCity' field test[http://www.powermatchingcity.nl/UserPortal/?Length=0], executed as one of the field tests in the EU-FP6 Integral-project[http://www.integral-eu.com/index.php?id=1]. In this project, micro-CHPs and hybrid heat pumps, each with ample heat storage, are operated in 25 households equipped with 'smart' in home gateways, that coordinate filling/emptying buffers and operation of the comfort devices to achieve a number of goals. The project is one of the rollouts of the PowerMatcher software package[http://www.powermatcher.net/in-a-nutshell/], in which coordination takes place using software agents. The project also includes an extensive data collection infrastructure and user portal. The goals implemented in use cases include short lead time commercial optimization and distribution optimization, besides wind imbalance compensation and valorization of renewables.

Simulation studies have been done on the 'black-start' problem in the SmartProofs project[http://www.smartproofs.nl/wat-doen-we], that will be followed by a real field test in a 'hotspot' heat pump area. In **Virhe. Viitteen lähdettä ei löytynyt.** the results of intelligent control a restart with 100 heat pump loads after a blackout can be seen.

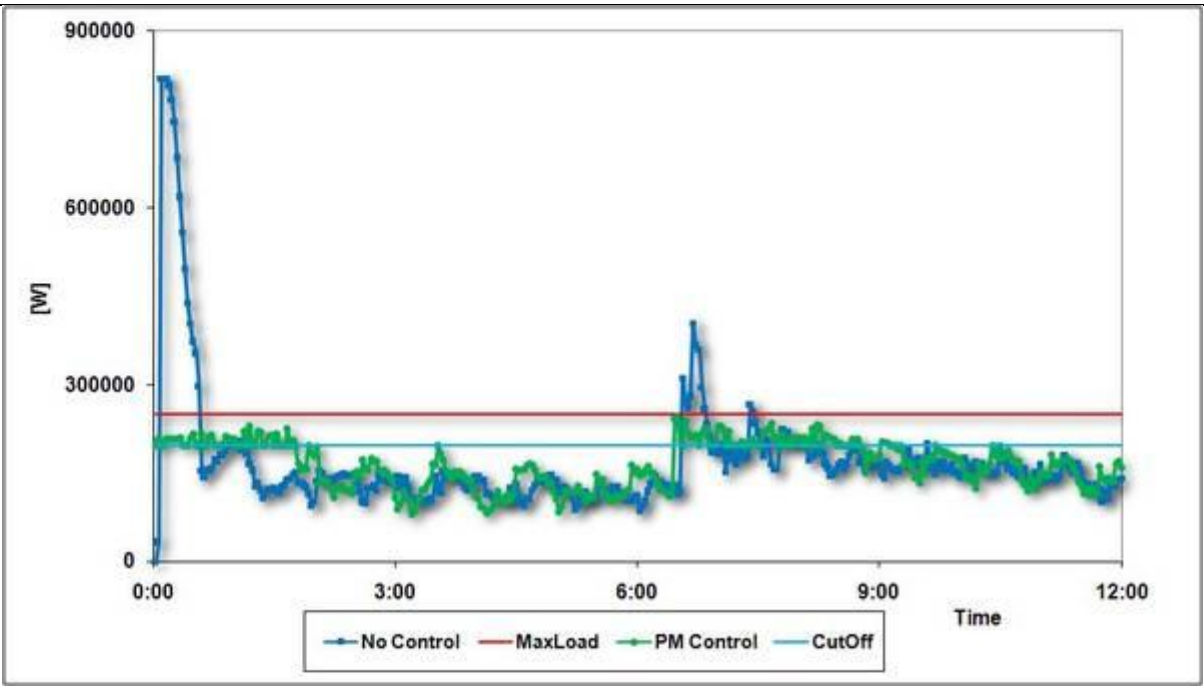

Figure A4 8. Load on a transformer station with heat pumps with and without coordination

In the Netherlands a taskforce SmartGrids has reported to the government recently. A dozen new projects with 500 residential customers on average will be tendered, in which also clusters of heat pumps will participate.

Appendix 5 Present situation of heat pumps in Spain

A5.1. Current Spanish heat pump market

According to the Spanish National Institute of Statistics, in 2008 6,3% of houses in Spain have a heat pump installed.

	Heat pumps (% of total households)
TOTAL NACIONAL	6,3
Andalucía	3,8
Aragón	2,7
Asturias (Principado de)	.
Balears (Illes)	13,2
Canarias	0,5
Cantabria	1,2
Castilla y León	0,4
Castilla -La Mancha	2
Cataluña	7,1
Comunitat Valenciana	20,8
Extremadura	14,4
Galicia	1,3
Madrid (Comunidad de)	2,3
Murcia (Región de)	28,1
Navarra (Comunidad Foral de)	0,9
País Vasco	0,8
Rioja (La)	1,4
Ceuta y Melilla	4,6

Figure A5.1. Heat pump installed in Spain in 2008

Regarding the impact in the consumption of a household, REE studies shows that in a working day in the winter it counts for 0,68% of the peak demand of the total peninsular system. On the other hand it counts 2,24% of the peninsular peak demand during a working day in summer.

Regarding its impact in the daily load shape of residential sector, next figures shows the different uses of electricity and its weight in a working day in winter and summer.

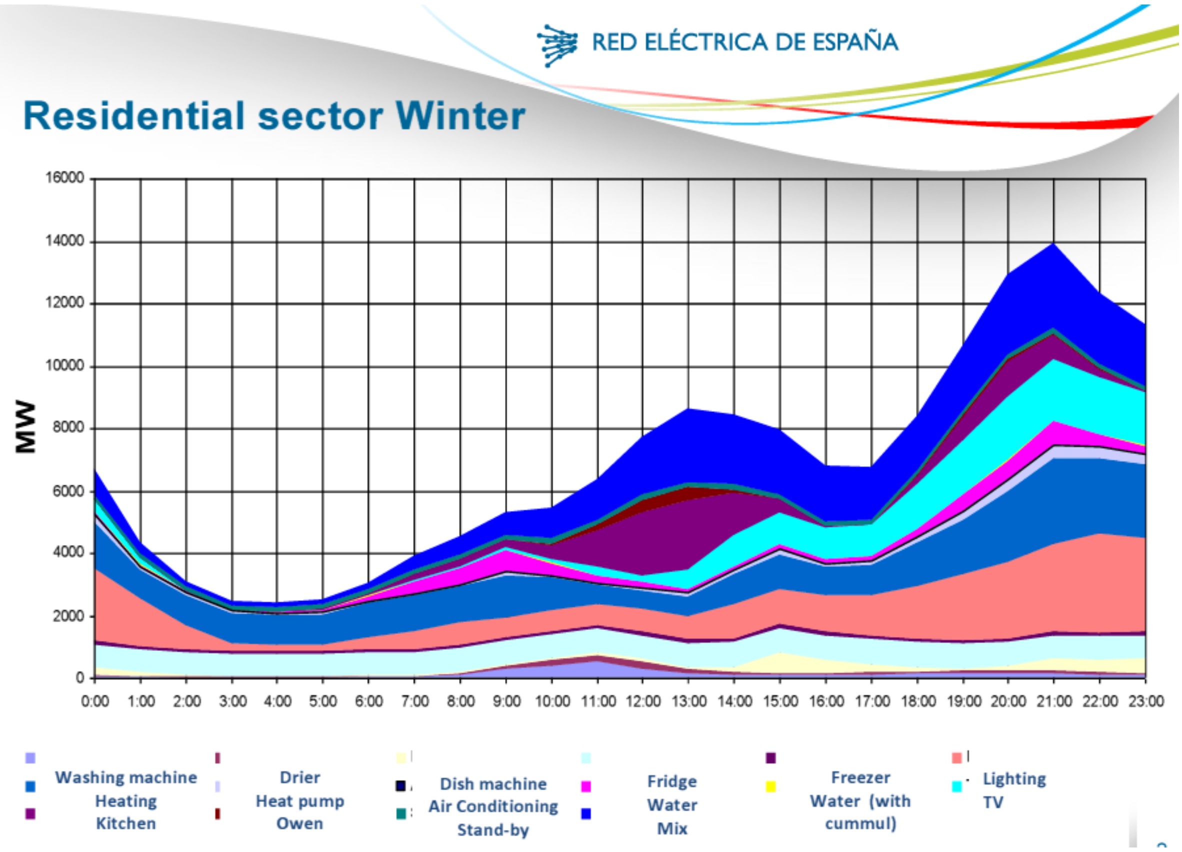

Figure A5.2. **Daily load in residential sector in winter working day of 2008**

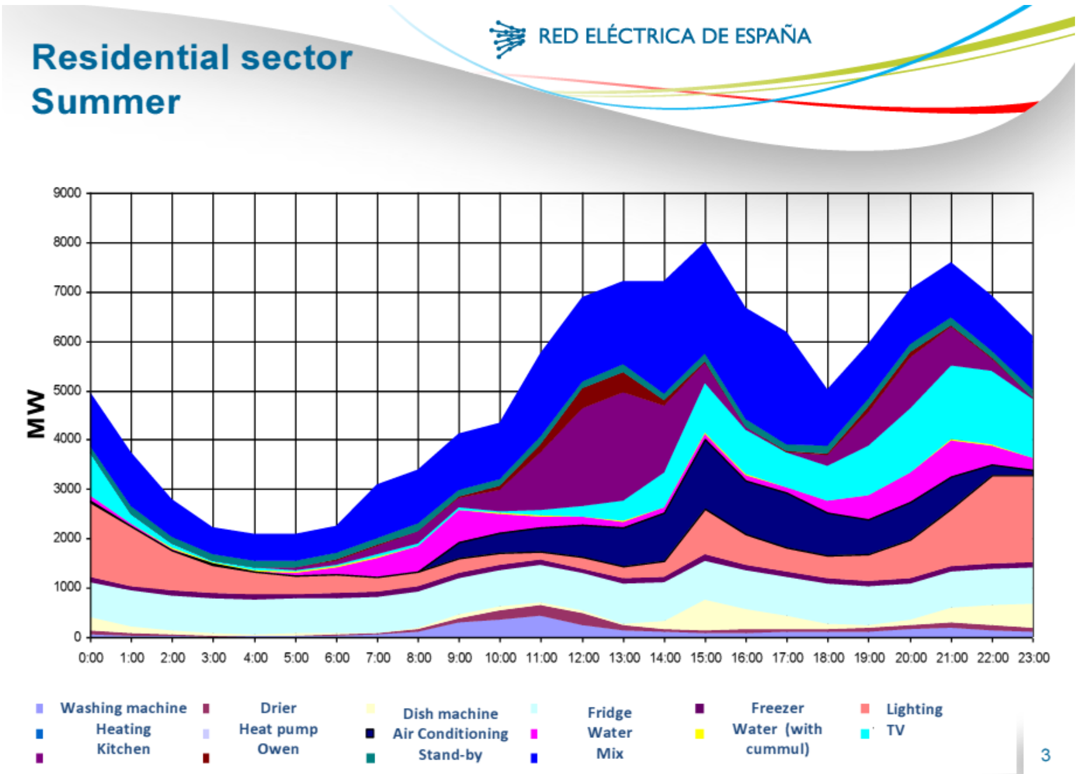

Figure A5.3. **Daily load in residential sector in summer working day of 2008**

Internal REE studies forecast that, taking into account the efficient scenario for 2020 it could imply 9,3 M of heat pumps in Spain.

Regarding heat pumps there is an important trend identified in Spain: the geothermal heat pump which are being favored by Spanish regulation and policies (instead, the heat pumps without geothermal do not have any incentive in Spain).

This market is still very small in Spain (Figure A5.4) however Spanish regions are subsiding up to 20% of the total cost of geothermal heat pumps.

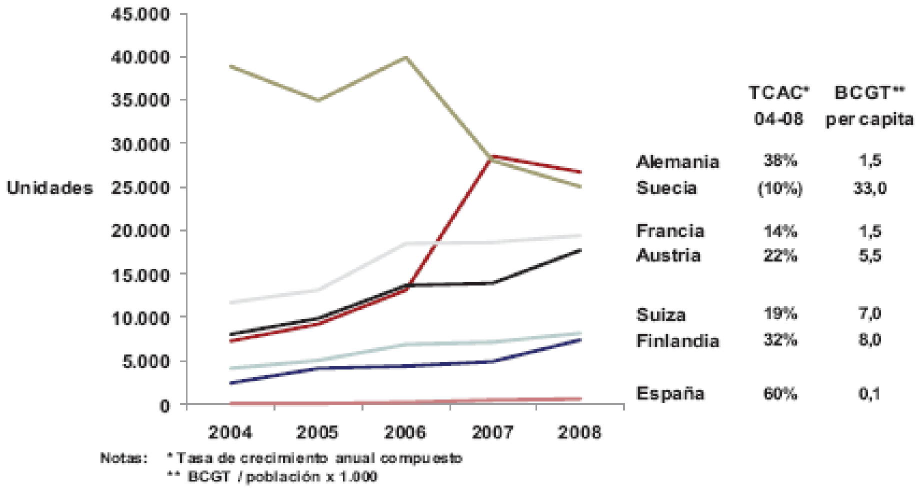

Figura 1. *Evolución de los mercados en Europa por número de unidades instaladas al año. Fuente: EH-PA, EGEC, FSW, PAC e investigación de eclareon.*

Figure A5.4. Evolution of the geothermal heat pump market in some European market

In fact, currently the number of geothermal heat pumps is estimated in only 3000 however in the short term is estimated to grow in 2000 new unities per year and in the medium term it can rise up to 10.000 unities per year.

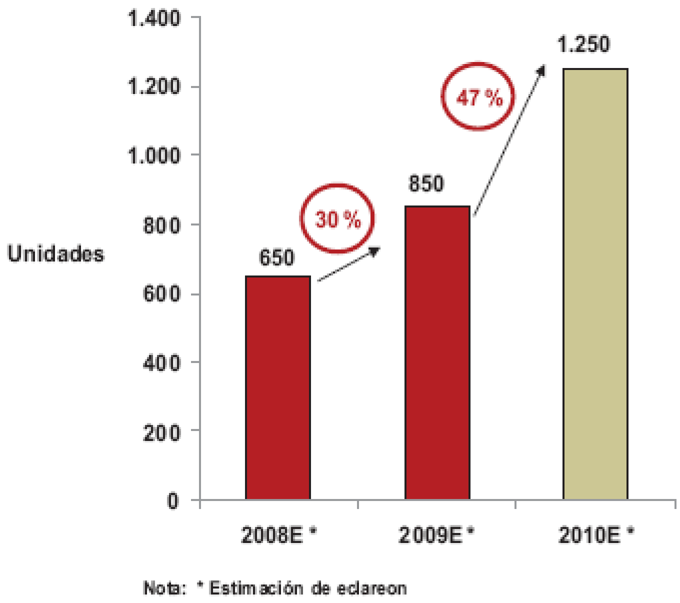

Figura 3. *Número de BCGT instaladas en España. Fuente: Investigación de eclareon.*

Figure A5.5. Annual installation of geothermal heat pumps in Spain

Source: "Análisis de la bomba de calor geotérmica en el panorama energético español", Perez. D, Aceves. C. II Congreso de energía Geotérmica en la edificación y en la industria.

Appendix 6 Overview of the IEA Demand-Side Management Programme

IEA Demand Side Management Programme

The Demand-Side Management (DSM) Programme is one of more than 40 co-operative energy technology programmes within the framework of the International Energy Agency (IEA).The Demand-Side Management (DSM) Programme, which was initiated in 1993, deals with a variety of strategies to reduce energy demand. The following 16 member countries and the European Commission have been working to identify and promote opportunities for DSM:

Austria	Netherlands
Belgium	Norway
Canada	New Zealand
Finland	Spain
France	Sweden
India	Switzerland
Italy	United Kingdom
Republic of Korea	United States

Sponsors: RAP

Programme Vision during the period 2008 - 2012: Demand side activities should be active elements and the first choice in all energy policy decisions designed to create more reliable and more sustainable energy systems

Programme Mission: Deliver to its stakeholders, materials that are readily applicable for them in crafting and implementing policies and measures. The Programme should also deliver technology and applications that either facilitate operations of energy systems or facilitate necessary market transformations

The Programme's work is organized into two clusters:

- The load shape cluster, and
- The load level cluster.

The 'load shape" cluster will include Tasks that seek to impact the shape of the load curve over very short (minutes-hours-day) to longer (days-week-season) time periods. Work within this cluster primarily increases the reliability of systems. The "load level" will include Tasks that seek to shift the load curve to lower demand levels or shift between loads from one energy system to another. Work within this cluster primarily targets the reduction of emissions.

A total of 24 projects or "Tasks" have been initiated since the beginning of the DSM Programme. The overall program is monitored by an Executive Committee consisting of representatives from each contracting party to the Implementing Agreement. The leadership and management of the individual Tasks are the responsibility of Operating Agents. These Tasks and their respective Operating Agents are:

Task 1 International Database on Demand-Side Management & Evaluation Guidebook on the Impact of DSM and EE for Kyoto's GHG Targets - *Completed*
Harry Vreuls, NOVEM, the Netherlands

Task 2 Communications Technologies for Demand-Side Management - *Completed*
Richard Formby, EA Technology, United Kingdom

Task 3 Cooperative Procurement of Innovative Technologies for Demand-Side Management – *Completed*
Dr. Hans Westling, Promandat AB, Sweden

Task 4 Development of Improved Methods for Integrating Demand-Side Management into Resource Planning - *Completed*
Grayson Heffner, EPRI, United States

Task 5 Techniques for Implementation of Demand-Side Management Technology in the Marketplace - *Completed*
Juan Comas, FECSA, Spain

Task 6 DSM and Energy Efficiency in Changing Electricity Business Environments – *Completed*
David Crossley, Energy Futures, Australia Pty. Ltd., Australia

Task 7 International Collaboration on Market Transformation - *Completed*
Verney Ryan, BRE, United Kingdom

Task 8 Demand-Side Bidding in a Competitive Electricity Market - *Completed*
Linda Hull, EA Technology Ltd, United Kingdom

Task 9 The Role of Municipalities in a Liberalised System - *Completed*
Martin Cahn, Energie Cites, France

Task 10 Performance Contracting - *Completed*
Dr. Hans Westling, Promandat AB, Sweden

Task 11 Time of Use Pricing and Energy Use for Demand Management Delivery- *Completed*
Richard Formby, EA Technology Ltd, United Kingdom

Task 12 Energy Standards
To be determined

Task 13 Demand Response Resources - *Completed*
Ross Malme, RETX, United States

Task 14 White Certificates – *Completed*
Antonio Capozza, CESI, Italy

Task 15 Network-Driven DSM - *Completed*
David Crossley, Energy Futures Australia Pty. Ltd, Australia

Task 16 Competitive Energy Services
Jan W. Bleyl, Graz Energy Agency, Austria
Seppo Silvonen/Pertti Koski, Motiva, Finland

Task 17 Integration of Demand Side Management, Distributed Generation, Renewable Energy Sources and Energy Storages
Seppo Kärkkäinen, Elektraflex Oy, Finland

Task 18 Demand Side Management and Climate Change - *Completed*
David Crossley, Energy Futures Australia Pty. Ltd, Australia

Task 19 Micro Demand Response and Energy Saving - *Completed*
Barry Watson, EA Technology Ltd, United Kingdom

Task 20 Branding of Energy Efficiency
Balawant Joshi, ABPS Infrastructure Private Limited, India

Task 21 Standardisation of Energy Savings Calculations
Harry Vreuls, SenterNovem, Netherlands

Task 22 Energy Efficiency Portfolio Standards
Balawant Joshi, ABPS Infrastructure Private Limited, India

Task 23 The Role of Customers in Delivering Effective Smart Grids
Linda Hull. EA Technology Ltd, United Kingdom

Task 24 Closing the loop - Behaviour change in DSM, from theory to policies and practice
Sea Rotmann, SEA, New Zealand and Ruth Mourik DuneWorks, Netherlands

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Also, visit the IEA DSM website: http://www.ieadsm.org