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Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 45

Hybrid Heat Pumps

Final Report

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Preface
This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) which is an Implementing agreement within the International Energy Agency, IEA.

The IEA
The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)
The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the Heat Pumping Technologies Programme. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP collaborative tasks or “Annexes” in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex. The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

The Heat Pump Centre
A central role within the HPT TCP is played by the Heat Pump Centre (HPC). Consistent with the overall objective of the HPT TCP the HPC seeks to advance and disseminate knowledge about heat pumps, and promote their use wherever appropriate. Activities of the HPC include the production of a quarterly newsletter and the webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
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Hybrid Heat Pumps

HPT Annex 45 Final Report

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Management summary

This document contains the final report from the Annex 45 Working Group from the Technology Collaboration Program on Heat Pumping Technologies (TCP HPT).

The goal of this annex was to develop knowledge on the technical development and the market opportunities for hybrid heat pumps.

Note: This report is intended as a first comparative overview of the opportunities for hybrid heat pumps in the participating countries. It may not accurately reflect the opinions of all participants on all topics.

A hybrid heat pump is the combination of a heat pump with a traditional fossil-fueled heater (boiler or furnace). By combining two heating technologies within a single control strategy, it is possible to flexibly choose the use of the heat pump or boiler/furnace part of the heating installation. This flexibility allows to optimize heat production according to local considerations. For instance, regarding CO_2-production, running costs, primary energy, grid congestion or load balancing. Additionally, a hybrid heating system may have lower investment costs than an all-electric heat pump and will often fit within comparably tight spaces.[1]

Because a fossil-fueled heater is always available as a back-up, hybrid systems are an enabler for the use of heat pumps in retrofit situations.

In particular, hybrid heat pumps allow:

- Flexible fuel choice
- Fit for a range of house types and buildings --> big retrofit market
- Quick upscaling possible, possibly delivering rapid and significant savings on CO_2
- Decoupling renovations of buildings and heating system renewal
- Experience building with heat pumps in a 'safe' way, enabling a smoother transition to wider deployment of all electric heat pumps
- 100% renewable heating, when the boiler part is run on renewable fuel, such as hydrogen, syngas, biogas, etc.
- Far-reaching and proven smart grid applications, because of their capacity for fuel/electricity switching

For (large) commercial buildings, e.g. in industry, offices or health care, hybrid heating systems have been common practice for a long time already. The primary motivation for using hybrid systems in these buildings is typically the possibility to choose the output power of each component in such a way as to optimize the balance between investment and running costs. Hybrid systems for small-scale applications have only recently become commercially available in appreciable numbers.

Because the market development for hybrids is only starting to take off, this Annex has tried to discuss the general position of hybrids within the domestic heating sector, rather than focusing on implementation or performance details. Only a limited amount of original research has been conducted.

This final report should be considered as a first step towards defining the advantages and disadvantages of hybrid systems and their typical application areas and role in the transition towards carbon neutral heating for homes.

This final report summarizes the discussion from the working group over the past three years (2016 – 2018). During this time, the market for hybrid HPs has changed quite a bit in several of the participating

[1] Total system costs depend on the heating device (e.g. Boiler, HP, or both), but also on additional requirements for a DHW storage tank or possibly replacement of radiators by convectors or underfloor heating.

countries. A growing wave of interest in hybrid HPs as an intermediate step towards renewable heating can be noticed in France, the Netherlands and the UK. Where possible, this report tries to accurately describe the latest policy and market developments.

Key findings

Because hybrids can be applied in existing buildings, they provide a potential for significant CO_2-savings that can be tapped into immediately and on a large scale. This also allows for markets and users to get used to heat pumps, preparing for large-scale electrification of domestic heating within the next decades. In addition, it may allow to smoothly adapt/improve the electricity grid to welcome a higher share of HPs in buildings.

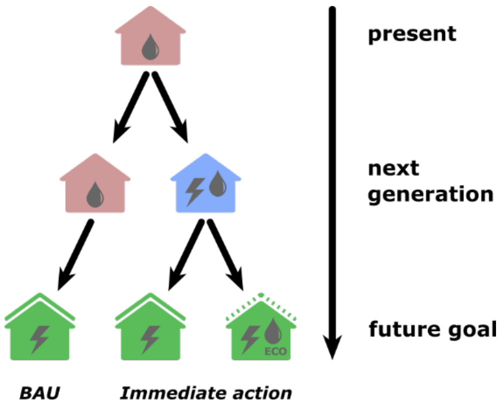


Figure 1 – Traditional (left) and hybrid (middle and right) route to renewable heating.

The figure illustrates a *Business as Usual* route to 100% renewable heating (left), versus a hybrid route to 100% renewable heating. Hybrid systems enable quick action, but the final energy system may still contain a significant proportion of hybrid heat pumps, where the boiler part uses non-fossil fuel for the remaining peak heating demand, hot water preparation, or grid flexibility.

Hybrid heat pumps provide flexibility beyond time-shifting electricity loads. Because it is possible to switch from electricity to gas or oil, the HP electricity demand can be completely decoupled from the heating demand at any time, providing a structural solution for local grid congestion.

The figure below shows this possibility:

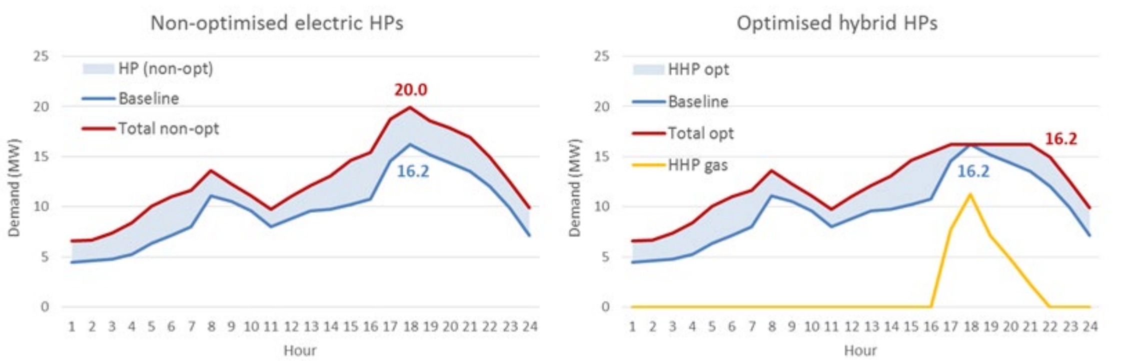


Figure 2 – Illustration of the possible effect of optimizing HP performance by adding a boiler. A non-optimised HP (left) may add electricity demand at peak hours. Optimizing the HP through the use of a gas boiler can completely remove the additional load at the peak. Source: Freedom Project / PassivSystems.

Basic control strategy is a key factor in determining the operating regime for hybrid heat pumps. Hybrid systems may be used to optimize heating for an individual house but can also be used to support grid load management, renewable production profile matching and other smart grid applications.

Energy prices form a major influence on market realization potential for hybrid heat pumps. Compared with standard boilers, hybrid systems may face strong competition on both investment and operation costs. Compared to all-electric systems, hybrids tend to be more favorable in both respects, albeit not universally so.

There is a wide variety of hybrid setups and use cases across participating countries. Each country has a couple of appropriate use cases, while no single use case is relevant for all countries. The list below gives an indication of the typical use cases for hybrid HPs that may be expected in the participating countries.

Situation	Problem/driver	Hybrid provides…	Applies to…
Collective heating / multi-family houses	Renewable energy with best business case.	Optimal balance between investment (€/$) and CO_2-savings.	NL, DE, IT
Houses with PV-installations	Maximize use of self-produced renewable electricity.	Hybrid systems can be optimized for hot water production during PV peak production.	DE, BE
Existing houses on gas grid or oil-fired boilers	CO_2-savings hard to achieve without renovation.	Immediate savings, without the need for building renovation. No "lock-in": future renovation will still provide extra savings on fossil fuels.	NL, BE, DE, CA, FR
Small houses	No space for hot water storage tank.	With hybrid, HP can provide at least baseload, boiler can still cover hot water.	NL, UK, BE
"Hard-to-treat" houses	Limited technical/architectural options for building-related measures. E.g. in monuments and old buildings.	Elegant way to provide at least a minimum amount of CO_2-saving, without necessitating (deep) renovation.	NL, UK, DE
Houses with LPG- or oil-fired boilers	Boiler fuel is expensive.	Immediate savings on fuel use.	BE, IT, DE, FR
Weak electricity grid or "end-of-the-line" grid connections.	Capacity of electricity grid too small for all-electric heat pump.	Maximal use of renewable energy with minimal peaks in grid load.	UK, CA, IT, FR
New built houses	Renewable targets / building regulation.	Desired amount of renewable energy or energy performance.	FR
Add HP to planned AC installation	Heating reference (furnace) is low-cost, AC installation needed	By choosing a reversible HP, with cooling as primary function, part of the heat demand can become low-CO_2 for a limited investment	CA
Enabler for large-scale grid management	Several grid-load issues: e.g. renewable production, electrical vehicles, mass-deployment of HPs, etc.	Electricity demand from hybrid systems can be switched off at will, providing plenty of smart grid potential.	Future development

Hybrid heat pumps may serve as a gateway to low-carbon heating.

Through the use of hybrids, it is possible to immediately realize a partial transition of the heating system towards 100% renewable, even if the building itself has not yet been renovated. Depending on the availability of renewable fuels (e.g. hydrogen, syngas, biogas), hybrid HPs may become a permanent part of the energy system.

Barriers to market growth

Hybrid heat pumps have a significant potential to accelerate the transition to low-carbon heating and facilitate the wide-spread introduction of all-electric heat pumps. To achieve this potential, a number of barriers must be removed.

Acknowledge hybrid HPs as a valuable option for transition to 100% renewable heating

Any successful policy regarding hybrid systems needs at least acknowledgement of their existence and possible usefulness in the energy transition. At the most basic level, it should be ensured that hybrid systems are covered – just like other renewable heating options – in

- Building regulations
- Incentives for renewable heating
- Product regulations such as ErP
- Testing standards
- Information campaigns

In some cases, hybrids may be the only option to realize at least a partly renewable heating source for domestic housing

In specific cases, it will be impossible to introduce low-temperature heating into houses. These houses may be heated using collective systems or district heating using specialized heat pumps, geothermal energy or fossil-free boilers. However, such projects may be prohibitively expensive. For these cases, hybrid systems (eventually combined with fossil-free fuel) may prove to be the only viable solution in the long run.

Hybrid HPs may serve as a transition technology, but also as a useful introduction for customers to gain experience with heat pump systems

Although hybrid systems provide their own set of advantages, both as a long-term solution and as a transition technology, an important spin-off for other types of HPs can be expected.
Because hybrid technology offers a *fail-safe* way to introduce HPs in existing homes, important experience can be gained for wider HP deployment. Consumers and installers alike will have the opportunity to develop best practices for HP applications. Because hybrid HPs have a wide application range, they may help to greatly speed up the market growth for <u>all types of heat pump systems</u>.

Make plans to stimulate the use of hybrid HPs and identify country-specific use-cases and market drivers

Typical use cases for hybrid systems differ greatly according to local circumstances (see section 3.5). Therefore, it is necessary to explore the application areas for hybrid HPs at a country level and develop appropriate stimulation measures and regulatory frameworks where necessary.

In particular, the role of hybrid HPs as an enabler and kick-starter in the transition to 100% renewable heating should be acknowledged. The potential for CO_2- and cost savings, targets for market growth and number of installed units should be made explicit.

1 Introduction and context

This document contains the final report from the Annex 45 Working Group from the Technology Collaboration Program on Heat Pumping Technologies (TCP HPT).

The goal of this annex was to develop knowledge on the technical development and the market opportunities for hybrid heat pumps.

A hybrid heat pump is the combination of a heat pump with a traditional fossil-fueled heater (boiler or furnace). By combining two heating technologies within a single control strategy, it is possible to flexibly choose the use of the heat pump or boiler/furnace part of the heating installation. This flexibility allows to optimize heat production according to local considerations. For instance, regarding CO_2-production, running costs, primary energy, grid congestion or load balancing. Additionally, a hybrid heating system may have lower investment costs than an all-electric heat pump and will often fit within comparably tight spaces.[2] Because a fossil-fueled heater is always available as a back-up, hybrid systems are an enabler for the use of heat pumps in retrofit situations.

In this report, we use the following definition for a hybrid heat pump (or 'hybrid' for short):

A hybrid heat pump is the combination of an electric heat pump and a fossil-fueled boiler or furnace under a single control strategy.

The scope of this annex is limited to domestic housing within the participating countries in annex 45.

Although heat pumps have been around on the market for several decades now, and boilers have been used in domestic heating for even longer, the combination of an HP and a boiler into a package under a single control strategy is relatively new on the market. The first truly commercial systems were – as far as we know – introduced in the Netherlands some two decades ago.

Note: This report generally uses the term 'boiler', to include both fossil-fueled boilers and furnaces.

The main components of a hybrid system, heat pump and boiler, are well known and have already been developed into mature market products. The novelty of the hybrid concept rather lies in the optimized and integrated control strategy that can be used to maximize performance of both components. According to the real-time circumstances, a choice can be made to use either the heat pump, or the boiler or even both components simultaneously.

For (large) commercial buildings, e.g. in industry, offices or health care, hybrid heating systems have been common practice for a long time already. The primary motivation for using hybrid systems in these buildings is typically the possibility to choose the output power of each component in such a way as to optimize the balance between investment and running costs. Hybrid systems for small-scale applications have only recently become commercially available in appreciable numbers.

In most cases, a full-capacity boiler (i.e. enough power to deliver space heating and domestic hot water even without the heat pump) will be used in conjunction with a smaller heat pump. Thus, hybrid packages are typically more expensive than a stand-alone condensing boiler and sometimes, depending on local circumstances, also more expensive than a stand-alone heat pump. Therefore, the market for hybrid systems in domestic houses has begun to emerge with the development of the energy transition only now.

[2] Total system costs depend on the heating device (e.g. Boiler, HP, or both), but also on additional requirements for a DHW storage tank or possibly replacement of radiators by convectors or underfloor heating.

Because the market development for hybrids is only starting to take off, this Annex has tried to discuss the general position of hybrids within the domestic heating sector, rather than focusing on implementation or performance details. This final report should be considered as a first step towards defining the advantages and disadvantages of hybrid systems and their typical application areas and role in the transition towards carbon neutral heating for homes.

The focus of the working group has been:

- Overview of the market opportunities for hybrid HPs;
- Overview of demonstration projects in the participating countries;
- Modelling and discussion on control strategies;
- The role of hybrid HPs in the transition towards 100% renewable/carbon neutral heating.

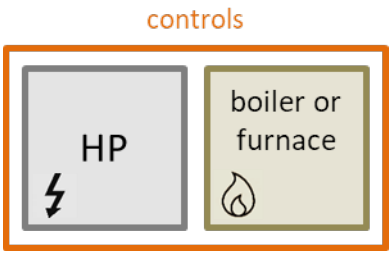
This final report summarizes the discussion from the working group over the past three years (2016 – 2018). During this time, the market for hybrid HPs has changed quite a bit in several of the participating countries. A growing wave of interest in hybrid HPs as an intermediate step towards renewable heating can be noticed in France, the Netherlands and the UK. In Germany and Canada, markedly less interest in hybrid HP solutions has been expressed from the policy domain. Where possible, this report tries to accurately describe the latest policy and market developments.

2 What is a hybrid heat pump?

2.1 General definition

The general definition for a hybrid heat pump used in this project is

A hybrid heat pump is the combination of an electric heat pump and a fossil-fueled boiler or furnace under a single optimized control strategy.



This definition is quite informal but has sufficed to guide the working group process.

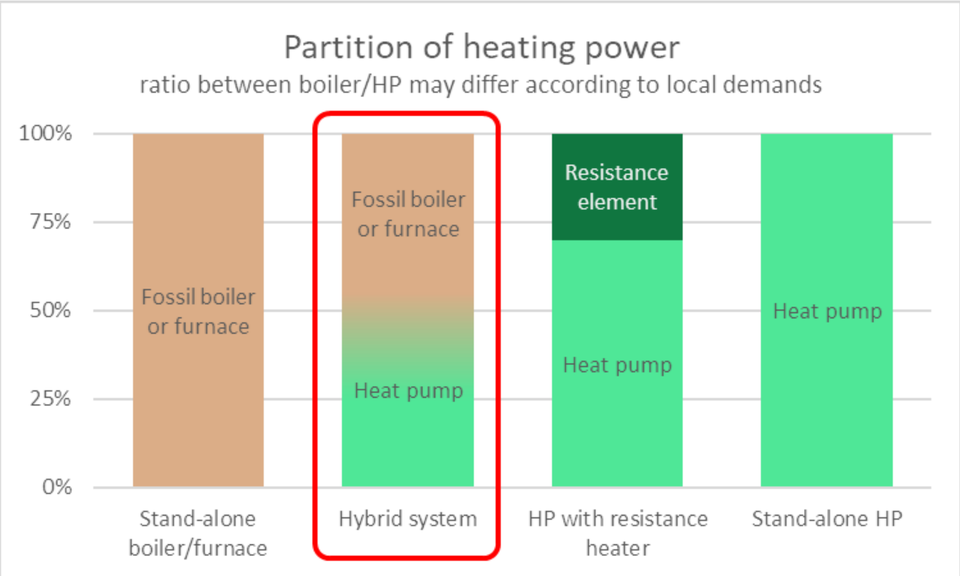


Figure 3 – Setup for a traditional boiler, hybrid HP, HP with electrical resistance (backup/peak) element, HP without additional heater (Left to right). The numbers are illustrations of possible setups, and not meant as recommendations for any specific use case.

Using this definition, a wide range of possible setups is still possible. However, a configuration consisting of an HP and an electrical resistance heater is explicitly *NOT* considered as a hybrid setup. The paragraphs below discuss some of the configuration aspects for hybrids.

2.2 System classification

2.2.1 Fossil heater type and fuel

For the purpose of supporting a heat pump within a hybrid system, it does not greatly matter which fossil heating system is used. This document generally uses the term 'boiler' to indicate both (condensing) boilers and furnaces, both gas-fired and oil-fired. Depending on the local circumstances, a suitable fossil heater will be used to complete the hybrid 'package'.

Within Europe, condensing boilers are typically used, whereas in Canada, furnaces form a major heating technology for homes. In the Netherlands and UK, gas-fired boilers are typically used.[3] In other countries (Belgium, France, Germany, Canada), a sizable installed base of oil-boilers exists, making oil-based hybrids a logical market choice.

These differences reflect the local historic heating trends. The success of hybrid systems and their added value in local markets will likely be determined by other factors, such as fuel/electricity prices and policy decisions for the domestic heating market.

2.2.2 Heat pump types

This document covers only electricity-driven HPs. Although hybrids containing gas heat pumps are perfectly possible, it does not seem a sensible approach to actually build such a system, simply because the main advantages of hybrids depend on the ability of the system to switch between the HP (electricity) and the boiler (gas/oil). Many heat pumps in hybrid configurations would not contain any electrical resistance backup heating themselves. Such an option is not necessary, considering the fact that backup or supplementary is already provided for by the boiler part.

The source of the heat pump can also be chosen to accommodate local needs. Most of the hybrids tend to use air-water heat pumps.[4] But especially in the Netherlands, there is a quite big market for heat pumps using ventilation exhaust air as a source. Ground-source water-water heat pumps could in theory be used in hybrid configurations, but the drilling costs are generally prohibitive in practice. When a ground-source heat pump is installed, it is often more cost-effective to implement an all-electric heating solution.

2.2.3 Space heating or domestic hot water

A hybrid package should be able to cover the household demand for space heating and hot water. The heat pump part of the package can cover only space heating or cover both space heating and hot water demand.

To produce domestic hot water (DHW) by a heat pump, the use of a hot water storage tank is necessary. The question whether the HP part of the hybrid system delivers DHW thus depends on the local possibilities. Especially in the Netherlands and the UK, combi boilers are typically used, where the fossil boiler provides instantaneous hot water. In addition, space constraints may limit the options for placing storage tanks. In those markets, hybrids tend to be of the *space heating only* type.

Solutions where the heat pump component is only used to produce hot water do exists. In practice, these systems are ‘reverse hybrids’, where the heat pump is not the primary household heating device, but rather functions as a limited addition to an otherwise fossil-fired heating system. This option will not be further discussed in the report, mainly because a developed market for these systems already exists.

2.2.4 Package setup

If the proper controls are used, it is possible to combine boilers and heat pumps from different manufacturers within a hybrid system. We distinguish two possible package setups:

1. **Add-on**
   In this setup, the heat pump is used as an additional system next to a boiler. Boiler and heat pump don’t need to be from the same manufacturer, but they can be, of course. This enables retrofitting existing boilers as hybrid systems. There is no need to physically integrate heat pump and boiler. The two components can be installed in separate rooms. As long as the components are governed by a single control system, hybrid operation can be optimally ensured. This explicitly means that a

[3] Natural gas in the UK is comparatively cheap, and oil/LPG-heated houses currently provide the biggest market opportunity.

[4] The market for hybrids is still very small in most countries, so precise statistics are not known. However, hybrid systems using a ground-source HP are hardly commercially available, whereas outside air hybrids can be commercially obtained in many different sizes and brands.

new set of controls must be set up. For instance, by allowing the HP controls to also decide the boiler operating window in a *master/slave* configuration.

2 **Integrated**
Integrated systems are boiler/HP combinations that are sold as one integrated package. Such a package consists of boiler, heat pump, controls, etc. that are specifically designed to operate together as a unit. This unit may be delivered as a single physical 'box' or consist of loose components that allow some freedom of installation geometry.

Note: In France, the regulatory definition of a hybrid heat pump necessarily implies an integrated system setup.

2.3 Dimensioning of the heat pump component

The heating capacity of the heat pump component is an important determinant for the investment cost and operation strategy. Assuming that the boiler component always has sufficient capacity, the size of the HP component can be chosen to fit some optimum criteria (e.g. investment cost, regulations, etc.).

The coverage ratio for space heating by the heat pump component depends on the relative capacity of the HP part compared to the total heat demand. The chart below gives a typical example chart and is derived from the load-duration curve of an example house in the Netherlands. Depending on the climate conditions, the exact shape of the graph may differ between countries. However, the behavior will be similar.

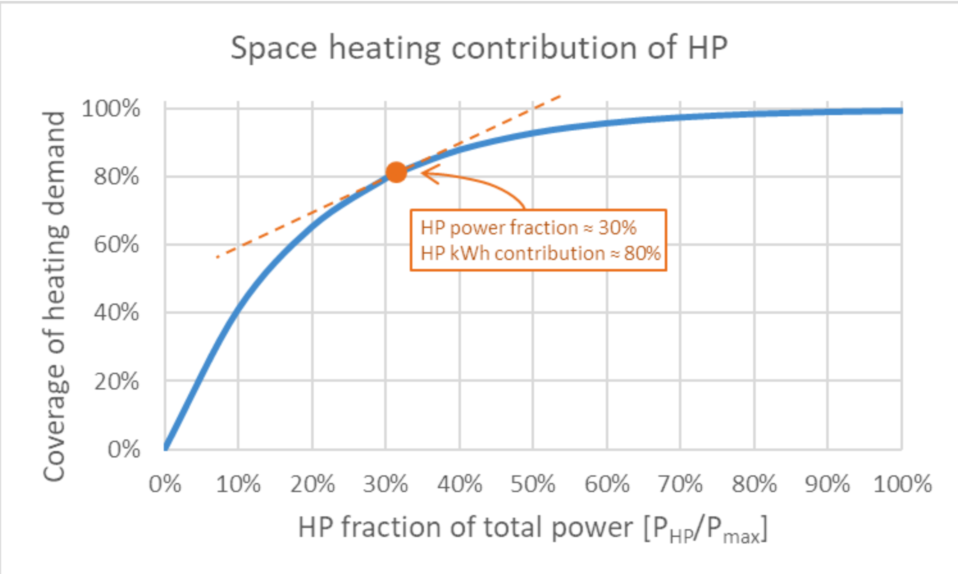


Figure 4 – Coverage ratio for space heating in relation to fraction of HP power to total heating power demand. This curve reflects the Dutch situation and has been calculated from climate data for the Netherlands. It may be considered representative for countries in the 'average' climate zone of Europe. Source: own calculation by BDH.

For a very small heat pump component, the coverage ratio rapidly rises. Put in other words, a given increase in HP capacity leads to a *larger* increase in coverage ratio. For large coverage ratios, this is reversed: a given increase in HP capacity leads to a *smaller* increase in coverage. This is because the maximum heating power is only used for a short time each year under extreme conditions, while a certain baseload of power demand will be needed throughout the heating season.

An HP capacity of around 30% to 50% of the maximal heating power demand strikes the middle ground between those behaviors and is often advised as an optimal compromise between HP investment costs and HP contribution to the heating demand. However, this number depends on climate zone, operating strategy, etc. The graph above is valid for the Dutch situation, but in France, for instance, 80% space heating coverage is typically reached at an HP power fraction of 40% to 50%. From the chart, it is clear that a large HP component is not at all necessary to achieve a sizeable contribution to the total heating demand.

The table below gives some insight into the consequences of this freedom of choice.

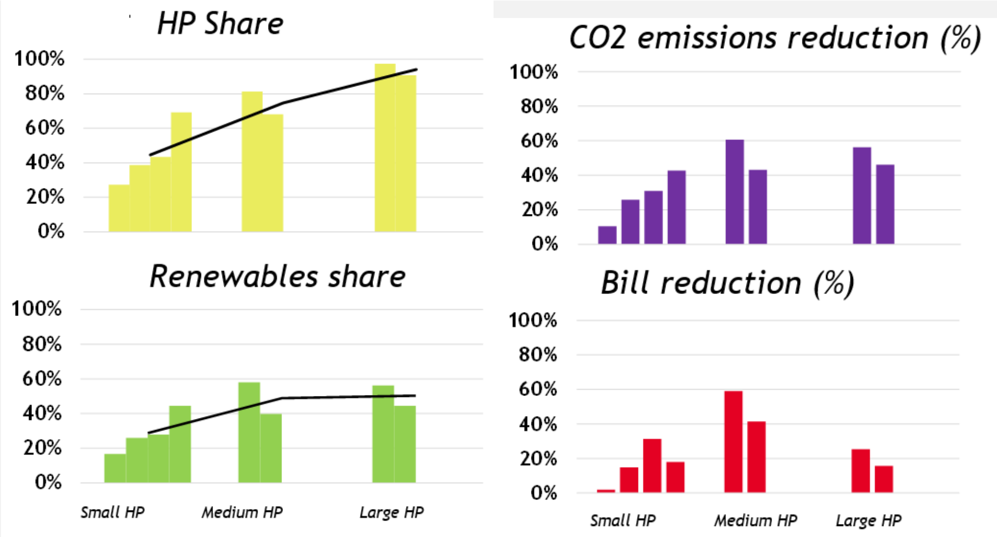
Size of HP in terms of P_{HP} / P_{max}	Description	Advantages	Disadvantages
<25%	Small HP component	Small, cheap system. Easy way to achieve at least a minimal contribution of renewable heating.	Limited benefit from HP.
30% - 50%	Average HP component	Relatively small and cheap system. Serious contribution to renewable heat production.	HP benefits could be larger.
55% - 70%	Large HP component	Almost full demand coverage by HP component. No DHW storage needed, if combi boiler is used.	Relatively expensive HP component.
>75%	Almost all-electric	Full demand coverage by HP. No DHW storage needed, if combi boiler is used. Flexible switching between fossil/electricity possible as grid service.	May be more expensive than using all-electric HP.

In practice, the choice of HP component power is limited by market availability of system sizes. Within the available options, the final choice is further shaped by practical considerations such as budget, placement options, building & heating regulations, installer's preference, etc. This implies, in turn, that the typical HP sizing will differ across countries, reflecting the local market situation.

Example – dimensioning the HP component of a hybrid installation

For the French situation, Electricité de France has explicitly tested the influence of HP dimensioning on performance. The figures below summarize the findings from 8 different installations. A 'medium' size installation corresponds to 6-9 kW thermal power of the heat pump component.

Interestingly, a larger heat pump does not significantly improve the share of renewable heating, or the emission reduction. This is because the space heating contribution is already maximally utilized when a medium-sized heat pump is used. A larger heat pump could theoretically deliver more power, and thus improve the renewable heating share. However, power demand is especially large for low temperatures. At these conditions, the HP is not switched off because the power is too small, but rather because performance drops. Therefore, a larger heat pump cannot deliver its full power to contribute to the heating demand at low outside temperatures.



In effect, then, it can be seen that a larger HP component does not improve performance, but does lead to higher costs.

Although this example is specific for the French situation, it is nonetheless a typical illustration for the dimensioning *sweet spot* of hybrid heat pumps.

2.4 Commercial availability of systems

The last couple of years have seen an enormous increase in the availability of hybrid systems, especially in Europe. Most of the conceivable configurations can now be commercially obtained. Although the participants in this Annex have started to compile a complete list of commercially available systems, such a compilation has become unfeasible due to the rapid growth in the number of available systems. There are, however, some configurations that could be considered to be ‘standard solutions’. The paragraphs below give some examples. For the layout of these diagrams, standard heat pump layout setup charts from Fraunhofer ISE have been used.

2.4.1 General layout of a hybrid heat pump package

The sketch below describes a general hybrid package, demonstrating the most important parts of the system.

The **heat pump** is the central component around which the hybrid system should be designed. Any type of heat pump is suitable, although air-water heat pumps tend to be used in most of the cases.

Domestic hot water may or may not be delivered by the heat pump. If the heat pump does provide DHW, a **DHW storage tank** must be present as well.

A **boiler or furnace** has a dual role: a) provide heating when boiler operation is momentary a better option than HP operation and b) provide additional heating when the HP alone cannot deliver enough power. The boiler generally provides these functions both for DHW and for space heating. A **storage tank for space heating** could be included into the system to optimize the running time of the HP.

The **heat transfer** system is not limited to strict low-temperature operation (e.g. underfloor heating). Even for transmission systems that are not strictly set up for ‘low-temperature heating’, the system temperature will be relatively low during most of the heating season. During these times, the HP can achieve good performance. Only under very cold conditions, the boiler component will outperform the HP regarding primary energy, CO_2 or running costs. This means that HP retrofit is possible if the transfer system is suitable for (relatively) low-temperature heating during a significant portion of the heating season.

The hybrid system itself can be either sold as an **integrated system** or as **separate components**. In the latter case, the HP does not need to be of the same manufacturer as the boiler and in fact could be installed as add-on to an existing boiler that was installed at an earlier time.

In principle, any boiler and HP could be combined into a hybrid package solution. System **controls** should ensure optimal operation of both HP and boiler. The question as to what 'optimal operation' means will strongly depend on local demands and goals. Control strategy is discussed in Section 2.5 and in more detail in Chapter 4. Naturally, realizing a reliable and well-performing control strategy is easier when both the HP and the boiler are from the same manufacturer.

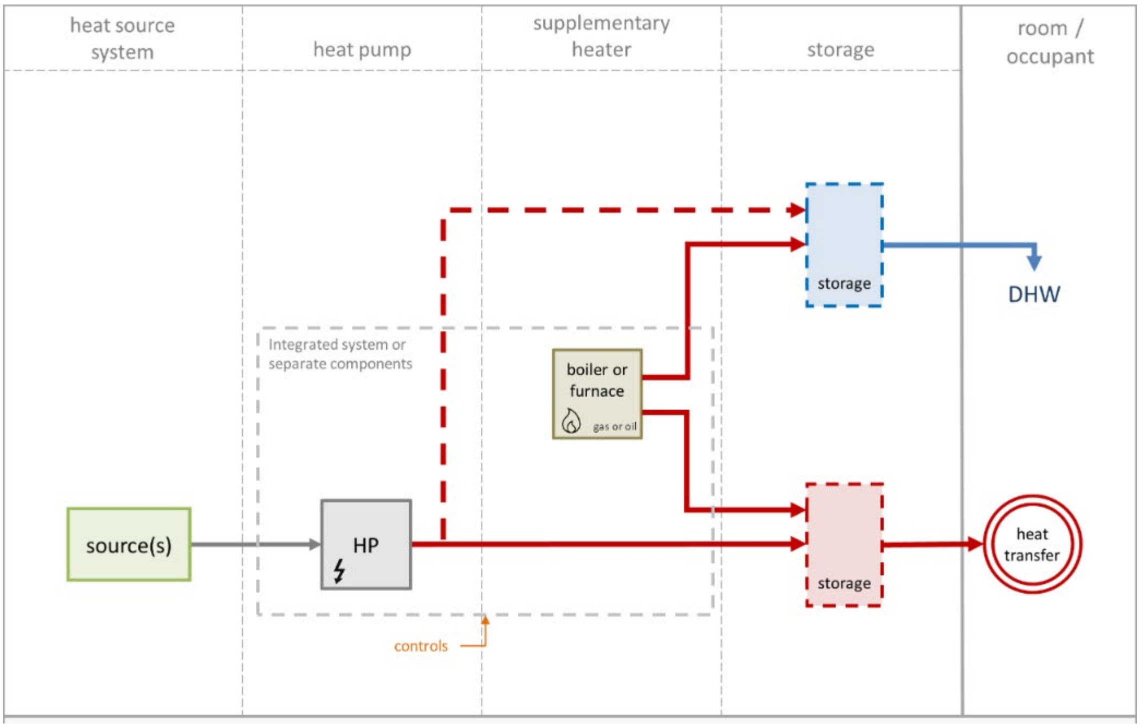


Figure 5 – General layout for a hybrid heat pump system (dashed components optional)

Example 1: integrated package solution

With perhaps the exception of the Dutch market, integrated hybrid packages are by far the most common available solution. Because the HP and boiler have been designed to work together, there is minimal risk of problems involving placement or controls. Also, it is logical to use an *air-source* HP. Under low temperature conditions, a ground-source HP should easily outperform both an air-source HP as well as a boiler/furnace in terms of COP. Thus, if a borehole is drilled to start with, it would make sense to set up the system to be HP-only.

For the most common hybrid packages, there is thus only a limited number of configurations. The most important distinguishing characteristic is whether or not a storage for hot water production is present. If no storage is used, hot water will be produced by the boiler (shown in the illustration below). If a storage tank *is* present, it is only natural to use the HP to deliver (part of) the hot water demand. Both configurations can be used and are often encountered in commercial applications and field trials. The storage tank issue is basically determined by the typical local preferences. In the Netherlands and the UK, for instance, the vast majority of systems are installed *without* storage tank, simply because combi-boilers are widespread and hot water storage tanks are seldom used in those countries.

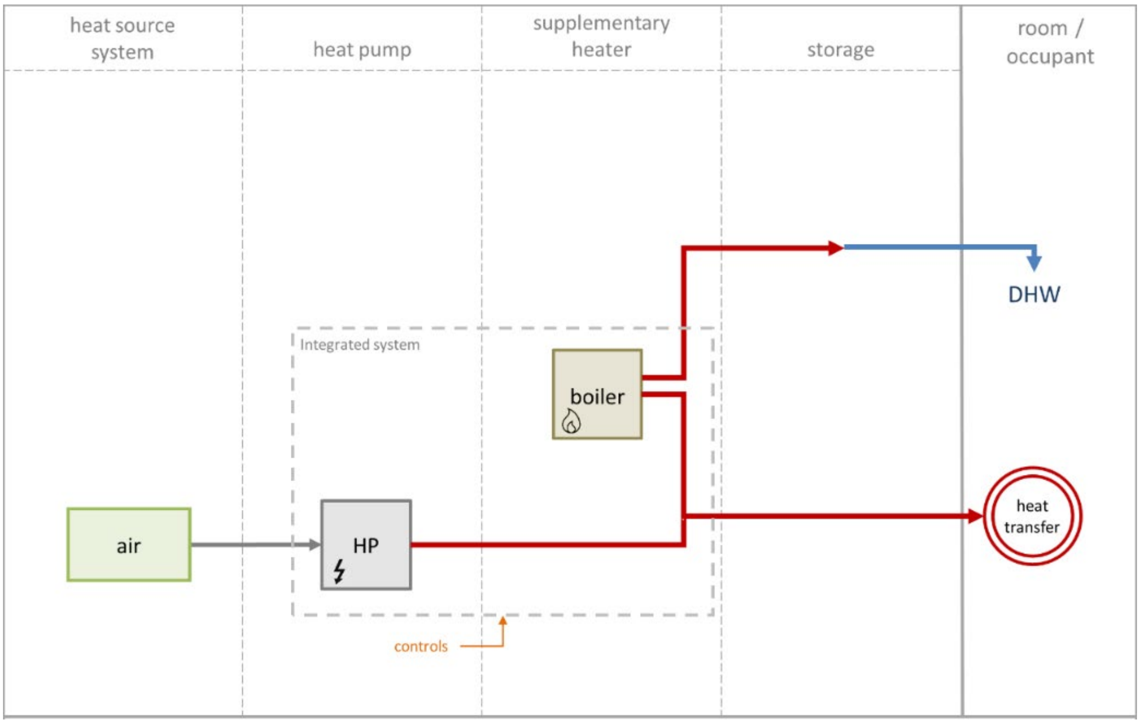


Figure 6 – Air HP with boiler as integrated package solution

Example 2: add-on solution with ventilation exhaust source

Add-on systems are very prevalent in the Netherlands, although virtually non-existent in other countries. The Dutch situation is quite exceptional: high-quality condensing boilers have become the market standard for the last 25 years, covering the heat demand in well over 90% of all houses. In addition, the majority of all boilers uses the *open therm* protocol for communication with the thermostat. Within this homogeneous installed boiler base, it is straightforward to develop control structures for add-on hybrids with very little operational risks. An advantage of this approach is that the retrofit market can be accessed easily by providing customers with the option to enhance their existing boiler by adding a (small) HP. This opportunity has been seized by several commercial HP manufacturers.

Most of the Dutch hybrid installations consist of outside-air source HPs. However, a rapidly developing market for *ventilation-source* add-on HPs exist (figure below). These HPs use the (warm) exhaust air from the mechanical ventilation fan. Mechanical ventilation systems have been required by building regulations in all houses build after 1975 and consequently, a large part of the Dutch building stock features a central ventilation fan, often placed in the direct vicinity of the boiler.

Although the exhaust air provides a high-temperature source for the HP (around 20 °C), the capacity of this source is naturally limited by the demand for fresh air within the living spaces. The HPs used are typically quite small, delivering around 1.5 kW of heat. Still, this is enough to provide around 1/3 of the heat demand of the average Dutch house. For these systems, the add-on hybrid provides a significant improvement in terms of CO_2 and running costs for a very low initial investment. However, it should be noted that an outside air HP would provide far better CO_2 performance on a yearly basis simply because it can deliver a higher heating capacity.

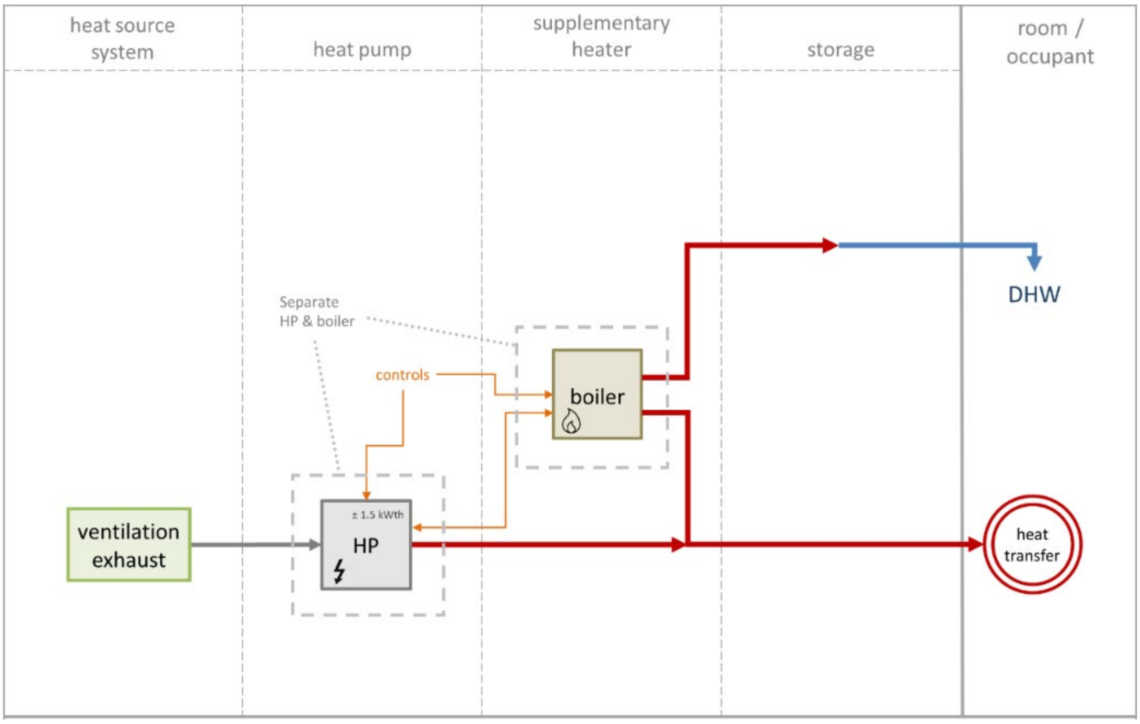


Figure 7 – Ventilation HP as add-on to the boiler

2.5 Control strategies

The control strategy of a hybrid system determines when the HP will provide heat and when the boiler will provide heat. This choice will be a *dynamic* one. At each point in time, HP and boiler performance can be compared and the 'best' option will be taken. Which of the two options is the 'best' one of course depends on the local conditions and the performance metric. Examples of possible performance metrics are:

- CO_2-emission
- Price (running costs)
- Primary energy

Apart from these three 'fundamental' efficiency metrics, operation may also be determined by external or internal signals:

- External preference signal (e.g. congestion tariff from grid operator)
- Internal optimization (e.g. avoid switching the HP or boiler on/off too often)
- Forced shutdown of HP (e.g. operating outside temperature too low, heat demand temperature too high)

These performance metrics are not mutually exclusive. Several of them could be optimized simultaneously.

The performance metrics can use fixed parameters (e.g. a set price or CO_2-emission for electricity and fossil fuel). Using fixed set points effectively translates into a *cut-off* outside temperature where performance of HP and boiler are equal. Below this temperature, the HP will be switched off.

Aside from the *optimal* cross-over temperature, some manufacturers have developed hybrid systems with HPs having no active defrost control. So, the HP is either stopped at quite high outdoor temperature (around 4°C) to avoid frosting or the HP is allowed to frost but will stop for "natural/passive" defrosting with the help of the boiler.

Real-time inputs can also be used as a decision basis. In this way, hybrids can be fully integrated into smart grids. In the present market, simple operating procedures based on fixed set points are used on a commercial basis. In research projects and field trials, hybrid systems have been very successful.[5] Because hybrids always have a fueled backup boiler available, a considerable freedom in shaping the electricity uptake profile is provided. Using real-time input also allows for precise performance optimization considering actual electricity production efficiency, CO_2-emission and cost instead of average values.

In the Freedom project (Wales, UK), dynamic real-time hybrid controls have been used to great success. Chapter 7 discusses this project in some detail.

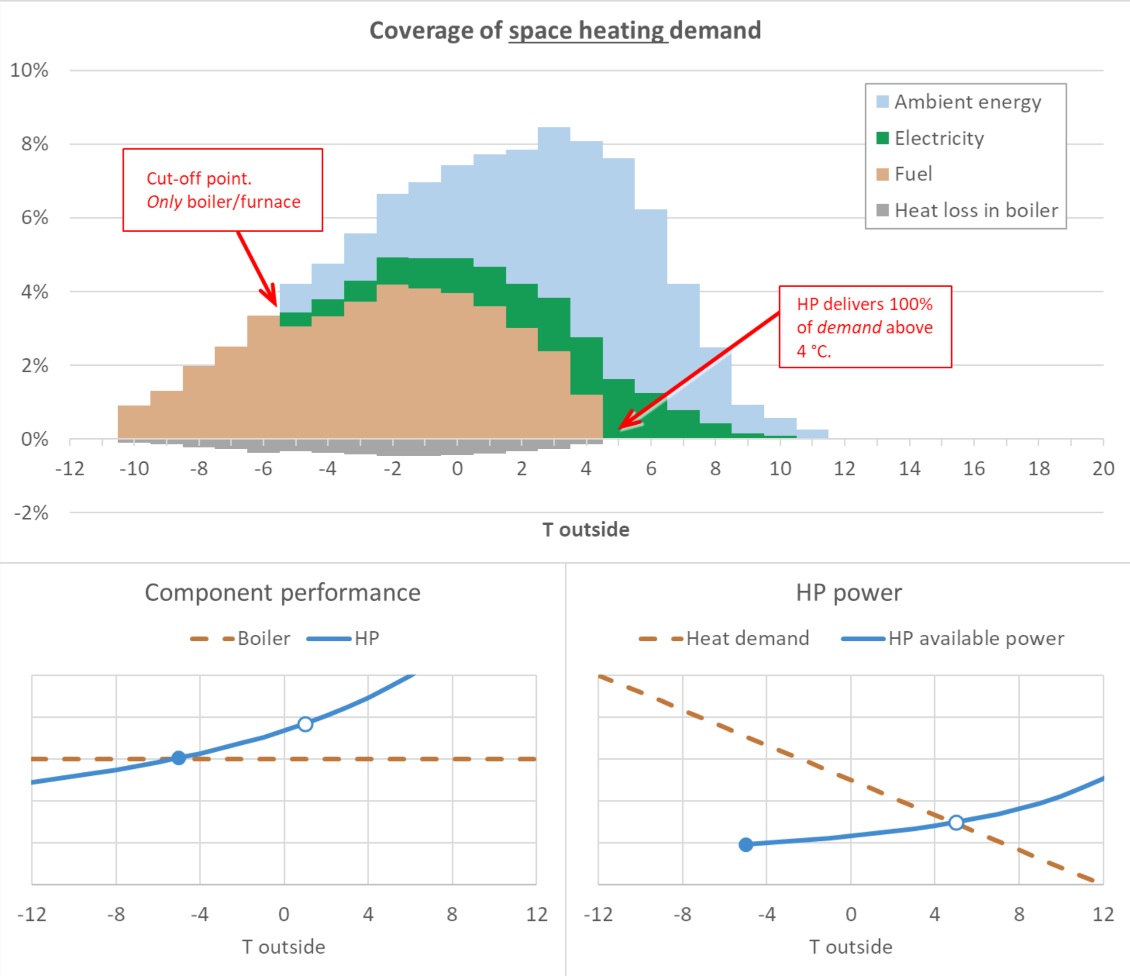


Figure 8 – Switching between HP and boiler operation in relation to outside temperature.
This example is based on an outside air HP in conjunction with a gas-fired boiler. The top panel shows the coverage of the space heating demand.
The bottom-left panel shows the 'performance' of the boiler & HP component. Performance can be measured in many different ways: e.g. running costs, CO_2, primary energy, grid congestion, etc. The y-axis thus only indicates the relative value of some arbitrary 'performance metric'. If HP performance is better --> the HP will be used. If boiler performance is better --> the boiler will be used for heating.
The bottom-right panel shows available HP power versus power demand, also in relative units. Whereas the heating demand will be higher for low outside temperatures, the available HP power will decrease with lower temperatures. In this example, the two lines cross at 5 degrees. This indicates the cross-over point: at 5 degrees or higher, no additional heating power from the boiler is needed.

[5] Large natural gas savings were found in the Netherlands, and hybrid systems were found to be excellently suited for smart grid applications in the UK. In Germany, small-scale tests with hybrid systems have not yet lead to a clear understanding of the way the HP and boiler interact in field trial setups.

The figure above gives an illustration of the space heating coverage using a hybrid system in a fixed control strategy. The horizontal axis gives the daily outside temperature, and the y-axis gives the fraction of space heat that is needed at that temperature. In this example, the bulk of the heat demand from the house lies between -3 and +7 °C. The colors indicate which system delivers the heat. Above 4°C, only the HP is active. Electrical energy[6] combined with ambient energy together provide the required heating. Below 4 °C, the boiler is used as well, first contributing a small portion to the heating demand. At that point, the HP performance is still fine, but HP power alone is not sufficient anymore. As the outside temperature further drops, the boiler contribution increases. At -5 °C, the *cut-off* point, the HP is no longer used, and the boiler provides the complete heat demand.

The bottom panels provide an indication of HP performance (*cut-off* shown as the cross-over between HP and boiler performance) and HP power (additional boiler output needed at 4 °C). Since only the relative values of HP/boiler performance and HP/demand power are relevant, there are no unit on the y-axes.

In the figure, the cut-off point is determined by component performance. The metric that determines this performance will depend on the situation, running cost, primary energy use, grid congestion status, or any other metric adapted to the local needs. Of course, these parameters are determined directly by the efficiencies of the HP and the boiler, combined with the external circumstances.

2.5.1 Implementation of the control strategy

The control strategy can be implemented as a fixed or flexible switching between HP and boiler operation.

Fixed strategy

A fixed implementation would for instance work to achieve

- Optimal running cost
- Minimum CO_2 emissions
- Best primary energy performance

Basically, the controls would set a certain value for the cut-off point. Depending on the real-time developments, either the boiler, the HP or both components will be operated.

In practice, consumer prices, primary energy and CO_2-emissions can be considered as fixed values for given fuels (oil, gas) or electricity. Also, the heating demand and the heating temperature that is needed are mainly determined by the outside temperature. Therefore, it is possible to simply use a specific value for the outside temperature as the cut-off point for HP operation. While this approach will not give the theoretically best performance (it ignores factors like wind-chill, solar irradiation, internal heat contribution from occupants, etc.), it is very easy to set up.

There is one big risk in using a completely fixed strategy: over time, values for the underlying parameters will change (e.g. lower CO_2-emissions for electricity production, higher costs for a particular fuel, changes in tax regimes, etc.).

For fixed control strategies, it should regularly be checked if settings are still OK or if changes are needed. This task generally cannot be carried out by the occupants themselves. So, to ensure good system performance, customers should be helped in this process, for instance by providing them with an intuitive and easy-to-use app that helps them to optimize the system settings.

> Note: In France, checking and updating operation settings is already an explicit requirement for boiler maintenance. This requirement will possibly also be implemented for HPs.

[6] The electrical energy that is used to operate the HP is released into the system as heat, so it contributes to the heat delivery.

Flexible strategy

A flexible strategy[7] is needed when the hybrid system should respond to dynamic parameters, such as

- Grid congestion
- Peak demand (i.e. peak shaving or demand response)
- Accommodating renewable electricity production
- Variable pricing or CO_2-emission factors

A dynamic strategy can also be used to optimize CO_2-emissions, running cost or primary energy use. Presently, there is no incentive for individual homeowners or tenants to do so, because these parameters are effectively fixed for them. Grid operators or energy suppliers, however, must cope with a continuously changing power production and demand. Being able to dynamically operate hybrid HPs is a powerful tool for those parties.

When implementing a flexible strategy to cope with these types of optimization goals, a smart interface must be provided and the complete toolbox of smart grid applications is available for optimization on the local, district, or energy system level.

There is an important difference between smart hybrids and smart all-electric HPs. In an all-electric system, heating demand may be shifted in time, for instance by using a thermal storage. However, at a different point in time (earlier or later), the necessary heating must still be provided by the HP. So, to decrease the electricity demand at one specific time, the electricity demand is bound to increase at another time.

In a hybrid setup, it is possible to switch from electricity to gas/oil at the desired moment. At this time, the electricity demand is decreased, and actually replaced by a fossil fuel demand. There will be no need to increase the electricity earlier or later in time to 'fill in the demand gap'.

2.6 Testing standards

Hybrid heat pumps are explicitly covered in the European testing norm for heat pumps: EN-14825:2018 (published December 2018). Testing methods are very similar for both all-electric and hybrid systems. To calculate the seasonal performance of a hybrid heat pump, it is necessary to specify the two cross-over points:

$T_{hp,off}$ specifies the cut-off point below which the HP is not used,
$T_{fb,off}$ specifies the 'bivalent point' above which the fossil boiler is not used.

For testing purposes each hybrid HP has to be assigned values for those temperatures. Although this makes fair and balanced testing possible, there are two possible issues where care should be taken when operating hybrid systems:

1. Flexible operating strategies are not evaluated in the testing standards. If flexible strategies are implemented, the performance of the hybrid system may be worse than calculated from the standard.
2. By choosing the two setpoints, the manufacturer of the system decides on a 'typical' setting for the heat pump parameters. In practice, however, the optimal setpoints will be strongly dependent on the local climate conditions. Care should be taken to determine the correct settings at installation time. Neglecting to do so, may have a potentially significant negative effect on the performance of the system (i.e. the HP may be switched off at times when it would be favorable to be running, or the HP may be switched on although running the fossil boiler would be a better option).

[7] It should be noted that off-the-shelf hybrids do not yet provide flexible operation functionality, just as off-the-shelf all-electric HPs are generally not yet suitable for complete smart grid integration.

3 Key findings

Hybrid HPs provide a combination between an electricity-driven HP component and a fossil-fuel-driven boiler component. These components may either be integrated into a single ‘package’ solution or can be separately installed. Whatever the physical configuration may be, the components will operate within a single control strategy. Depending on the chosen control strategy, hybrid HPs may be able to serve several different purposes. This versatility in physical configuration as well as control strategies is the central defining characteristic of hybrid HPs. It is thus logical to expect many differing market opportunities for hybrid HPs, depending on the local circumstances in any given market.

During the working group meetings, many such market opportunities were evaluated, investigated and modelled. The paragraphs below give an overview of the main conclusions from these discussions.

3.1 Hybrid HPs may enable quick and successful application of HP technology in existing buildings without the immediate need for renovation

Because hybrid HPs always have a fuel-fired boiler available as a back-up heater, hybrids are generally quite suitable for application in existing buildings. Depending on the chosen control strategy, the HP component will provide space heating and/or DHW for as long as this is favorable regarding CO_2-emissions, running cost, primary energy use, grid loads, etc. When needed, the boiler component can immediately take over the heating demand at any time, providing versatility and a very high level of supply security and comfort.

In existing buildings, a high heating temperature may be needed to provide the house with enough heat in mid-winter. During less cold months however, the capacity of the heat transfer system will generally be large enough to allow for a significantly lower heating temperature. During those months, running a HP will often be technically feasible and even favorable compared to a boiler.

Even without the need for a building renovation, it is thus possible to apply HP technology in existing buildings to some extent. Depending on the building characteristics and market situation, the HP contribution may range from marginal to almost 100% of the heating demand.

Because hybrids can be applied in existing buildings, they provide a potential for significant CO_2-savings that can be tapped into <u>immediately</u> and on a <u>large scale</u>. This also allows for markets and users to get used to heat pumps, preparing for large-scale electrification of domestic heating within the next decades. In addition, it may allow to smoothly adapt/improve the electricity grid to welcome a higher share of HPs in buildings.

Typically, the HP component in a hybrid system will have considerably smaller power output than a stand-alone HP solution would have. After all, there is no need for the HP component to meet the mid-winter peak demand. <u>Therefore, hybrid systems could provide a more cost-effective option for CO_2-savings than the application of stand-alone heat pumps, especially in existing buildings.</u>

It may be argued that renovating houses to bring them to 100% renewable heating right away is a better option than using a hybrid system as ‘stepping stone’. In fact, for each individual house, this may be a valid goal. At the same time, the lifespan of a heating installation is about 15 years, while renovating all buildings in a country will take much longer than that. In that sense, every society is <u>forced</u> to adopt intermediary solutions on the road towards 100% renewable heating.

Depending on the technology development, several routes are possible for houses that are not (yet) fit for extensive renovation, as illustrated in the figure below:

Left to right:

- Business As Usual --> replace existing boiler with a new boiler. Deployment of renewable heating will be postponed until insulation measures have been finished.
- Hybrid HP as intermediary step --> directly replace boiler with hybrid system. When insulation/renovation is possible, an all-electric HP can be installed.
- Hybrid HP and fossil-free fuel --> directly replace boiler with hybrid system. When fossil-free fuel becomes available, 100% renewable heating can be achieved with a hybrid HP. Renovation of the house in due time is strongly recommended, but not strictly necessary.

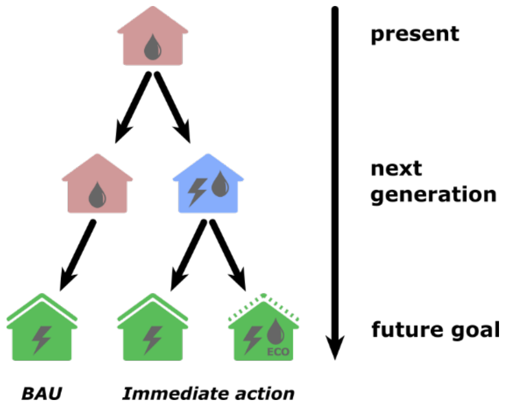


Figure 9 – Traditional (left) and hybrid (middle and right) route to renewable heating.

In some cases, the option of combining a hybrid HP with fossil-free fuel may provide some additional benefits. For instance:

- Lower cost of installation;
- No low-temperature heat transfer system necessary;
- Space constrains prohibit the use of DHW storage tanks;
- The electricity grid is not able to handle the simultaneous peak load of massive HP deployment.

3.2 Basic control strategy is a key factor determining the operating regime for hybrid HPs

When using a hybrid HP, it is possible to make a *dynamic* choice between employing the HP or the boiler component. There are basically four possibilities to make this choice:

1. Use price information to determine the most cost-effective component;
2. Use CO_2-levels for electricity / fuel to determine the optimal component;
3. Use primary energy use numbers to determine the component with least primary fuel consumption;
4. Take (real time) advice on the operating regime from external smart grid signals, such as electricity grid load status, amount of local renewable electricity production, etc.

Note that these possibilities are not mutually exclusive.

> In other words, hybrid systems may be used to optimize heating for an individual house but can also be used to support grid load management, renewable production profile matching and other smart grid applications.

The Freedom Project in Wales (**https://www.westernpower.co.uk/projects/freedom**) was carried out to investigate the possibility to use hybrid systems for smart grid uses. The two illustrations on the next page shows a sample of system behavior in two houses over a 24-hour period. From these figures, the versatility of hybrid systems is clearly visible.

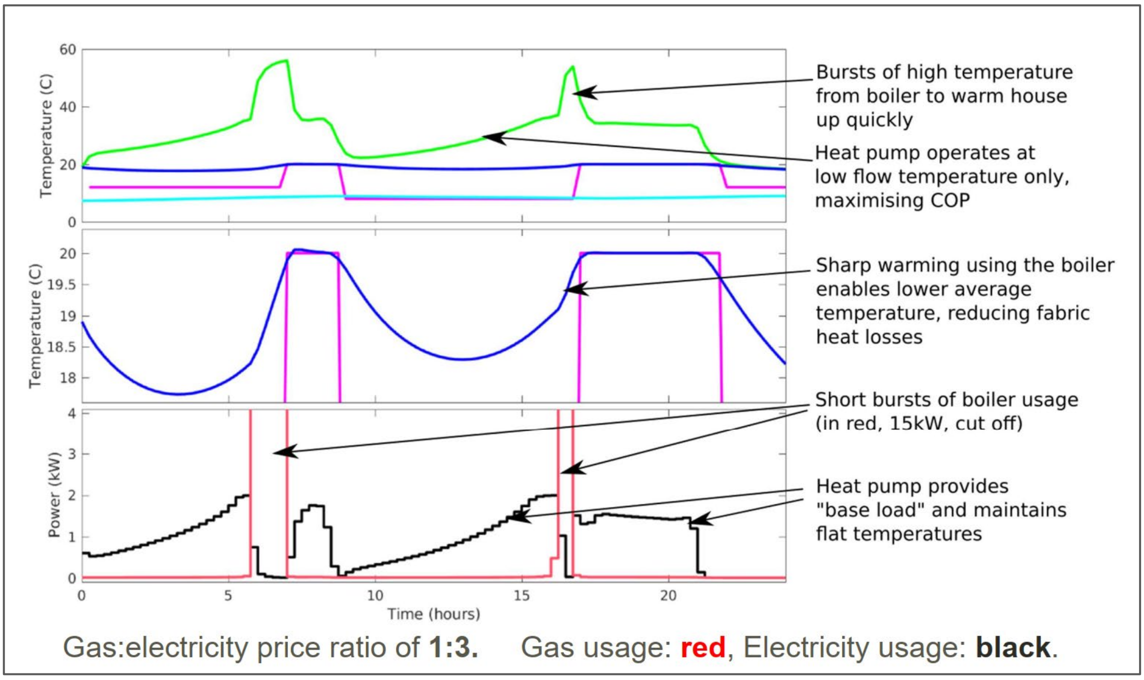


Figure 10 - Hybrid system used for optimal heating, in the absence of grid constraint signals.
The top panel shows HP and boiler temperature. [green: heating transfer temperature; dark blue: room temperature; magenta: room setpoint temperature; light blue: external temperature]
The middle panel shows the room temperature. [color coding as above]
The lower panel shows energy input. [red: gas demand; black: electricity demand]
Source: Freedom Project / Passiv Systems / W&W utilities.

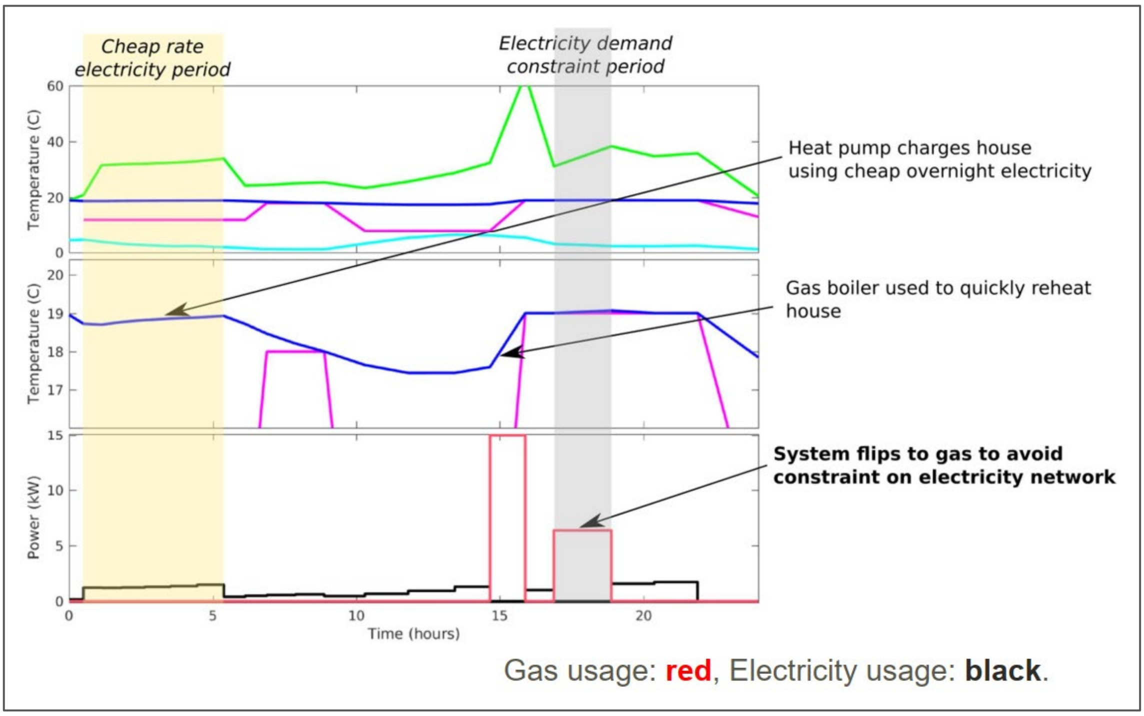


Figure 11 – Hybrid system used for optimal interaction with grid and optimal use of tariff structure. The top panel shows HP and boiler temperature. The middle panel shows the room temperature. The lower panel shows energy input. [Color same codes as above]
Source: Freedom Projects / Passiv Systems / W&W utilities.

3.3 Hybrid HPs provide flexibility beyond time-shifting electricity loads

Typical HP smart grid flexibility is based on the principle of time-shifting electricity demand. This can be achieved in several ways, for instance

- Changing the temporal pattern of the heat demand;
- Using thermal storage (the building itself may serve this purpose);
- Using electrical storage.

These approaches have the common characteristic that eventually, the full heating demand must be delivered by the heat pump. It is impossible to completely 'shield' the electricity grid from a specific demand peak. Sooner or later, the energy demand must be satisfied.

For hybrid HPs, the situation is different. Because it is possible to switch from electricity to gas or oil, the HP electricity demand can be completely decoupled from the heating demand at any time, providing a structural solution for local grid congestion.

The figure below illustrates this possibility.

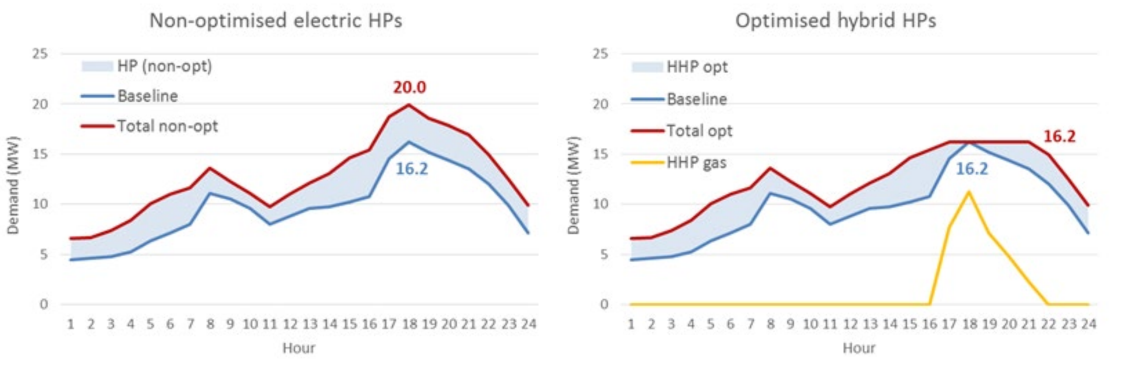


Figure 12 – Illustration of the possible effect of optimizing HP performance by adding a boiler. A non-optimised HP (left) may add electricity demand at peak hours. Optimizing the HP through the use of a gas boiler can completely remove the additional load at the peak. Source: Freedom Project / PassivSystems.

Field Trial Example

In the Freedom Project (**https://www.westernpower.co.uk/projects/freedom**), load capping was achieved by using the fossil boiler to reduce HP electricity demand to any specified hard load cap. The top slide shows the situation without smart controls: the total electricity demand (blue line) exceeds the load cap (red line) at several moments in time. The bottom slide shows the same situation with smart controls applied: the total demand never crosses the load cap. Where necessary, the gas-fired boiler temporarily delivers extra heat to cut down the HP electricity usage.

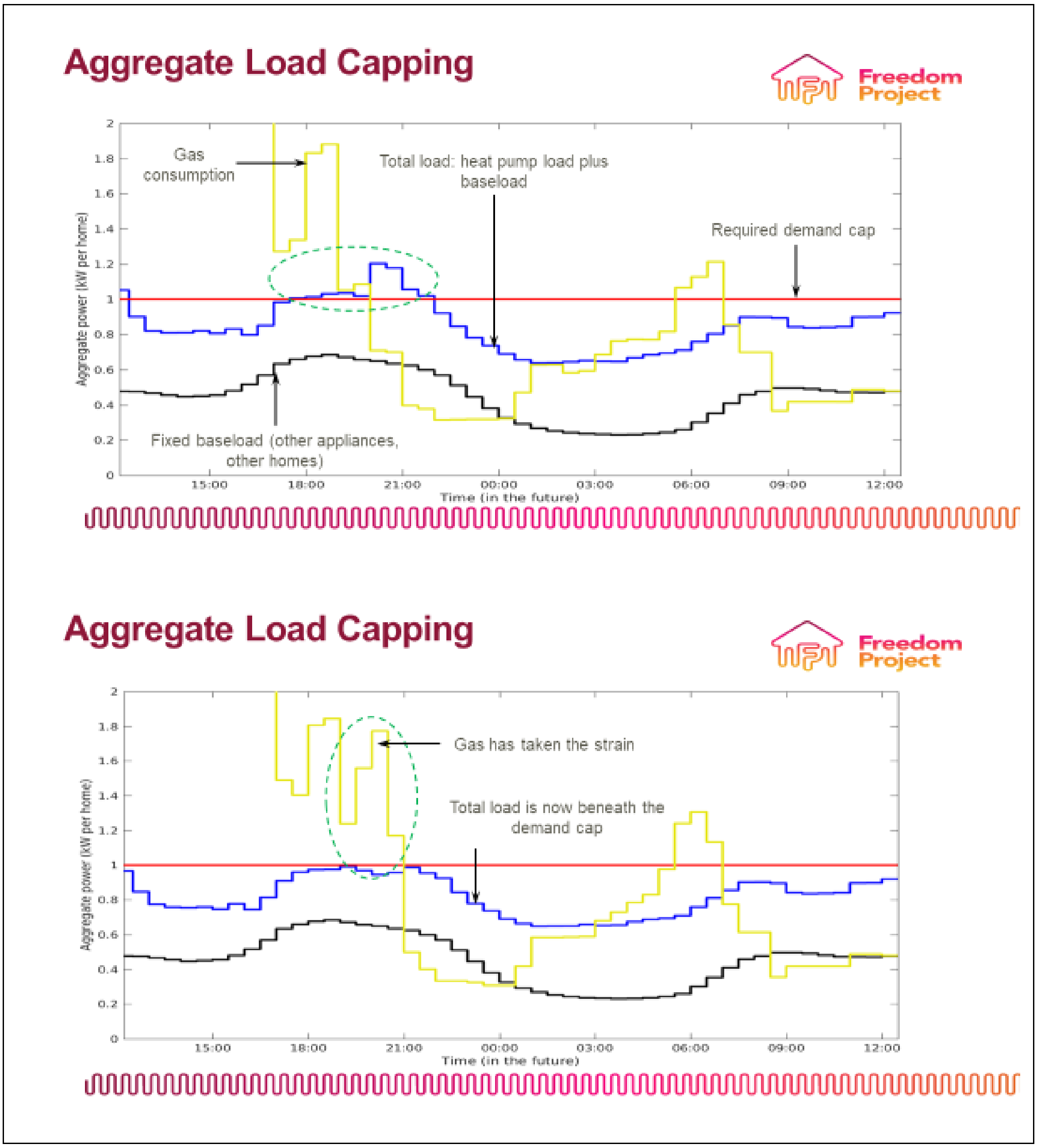


Figure 13 – Effectivity of load capping as demonstrated in the Freedom Project. Source: Passiv Systems / W&W utilities.

3.4 Energy prices form a major influence on market realization potential for hybrid heat pumps

Energy prices form the natural comparison base for different heating options. Based on average consumer prices for electricity and gas/oil, an indicative comparison can be made.

Use cases for hybrid systems differ strongly across countries and regions. This section deliberately provides a simplified analysis to demonstrate the effect of price differences alone.

For the charts below, the following input has been used:

Case	Electricity	Fuel	SPF Heat Pump	SPF hybrid HP	SPH boiler
NL, gas	€ 0.22	€ 0.08	3.00	3.50	85%
BE, gas	€ 0.28	€ 0.05	3.00	3.50	85%
DE, gas	€ 0.22	€ 0.06	3.00	3.50	85%
FR, gas	€ 0.17	€ 0.06	3.00	3.50	85%
UK, gas	€ 0.18	€ 0.05	3.00	3.50	85%
FR, oil	€ 0.17	€ 0.07	3.00	3.50	80%
CA, oil, Montreal	€ 0.05	€ 0.06	3.00	3.50	80%
CA, oil, Toronto	€ 0.12	€ 0.07	3.00	3.50	80%
DE, oil	€ 0.22	€ 0.04	3.00	3.50	80%
CA, gas, Montreal	€ 0.05	€ 0.01	3.00	3.50	85%
CA, gas, Toronto	€ 0.12	€ 0.04	3.00	3.50	85%

All hybrid cases: HP covers 80% of heat demand.

Figure 14 – Reference figures for comparing boiler, HP and hybrid HP. Note: the efficiencies for boiler, HP and hybrid HP have deliberately chosen to be equal for all countries, to show the pure price effect in the comparison. Naturally, efficiencies will differ across climate zones, and moreover, will depend strongly on the particular use case.
The SPF of a hybrid system is typically higher than for an all-electric HP. This is because the all-electric HP has to deliver heating at low outside temperatures (with relatively low COP). Hybrids will not operate the HP part under those conditions and hence, the total SPF will be better than for the all-electric HP.

These numbers should be thought of as an indication of the possible values. Large fluctuations may occur, depending on house type, insulation quality, climate conditions, etc. SPF values for HP performance have been chosen conservatively. It should be possible to achieve much better values with a consistent high-quality system setup and a well-insulated house. However, hybrid systems are likely to be used extensively for heating of existing houses, where full control over installation and insulation quality is often impossible.

Using the number from the table above, a comparison of the running cost between boiler (or furnace), hybrid HP and all-electric HP can be made. This comparison is shown below for natural gas and oil boilers in two separate charts.

Comparison with gas-fired boiler

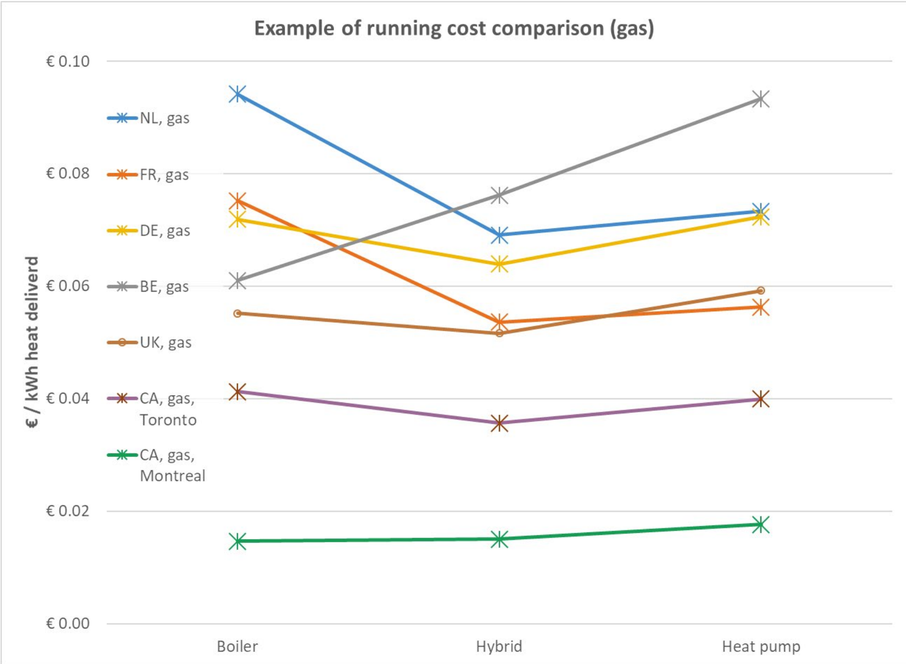


Figure 15 – Comparing gas-fired boiler, Hybrid HP and all-electric HP for selected countries.

Compared to gas-fired fossil boilers, (hybrid) HPs have generally lower operating costs. The difference between hybrid and all-electric HPs is, however, small. The difference arises because the switch from HP operation to boiler operation occurs at low temperatures, when HP performance starts to decline. As a result of this, the HP part of a hybrid system typically has a higher SPF than an all-electric HP.

From a pure cost perspective then, a hybrid system will often outperform all-electric systems, because the investment for a hybrid installation is lower in many cases.[8]

Belgium is an exception from this trend. It has a relatively high electricity price, which implies that HPs are only cheaper than boilers starting at a very good seasonal performance factor. Both hybrid and all-electric systems can be expected to have higher running cost than condensing boilers in Belgium.

For Germany, the special HP tariff is used for comparison. This tariff is not always available for each household. If the normal electricity tariff for Germany would be used, the situation would be comparable to Belgium, with boilers outperforming (hybrid) HPs in terms of running costs.

Apart from the relative position of the three alternatives considered here, the absolute value of the savings is also important. In Canada, for instance, (hybrid) HPs have lower running cost than a gas furnace. Still, the energy prices in Canada are too low to act as a real customer incentive for switching over to renewable heating options.

Given this analysis, it should come as no surprise that the Netherlands and France are presently the two participant countries with the largest installed hybrid HP base.

[8] Germany seems to be a notable exception. The comparison also differs from situation to situation: e.g. new-built houses or retrofit and other house and market parameters.

Comparison with oil-fired boiler

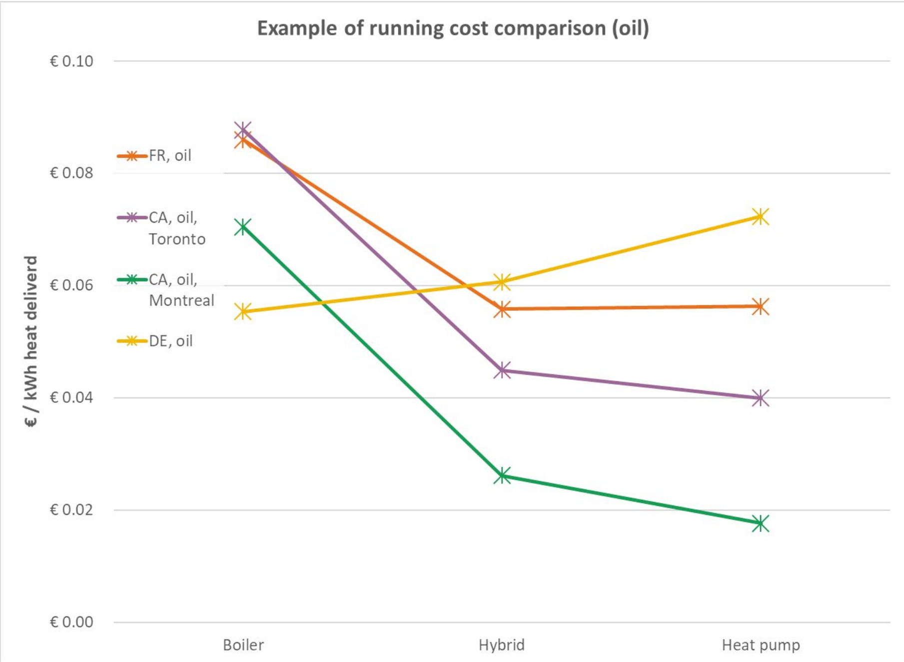


Figure 16 – Comparing oil-fired boiler, hybrid HP and all-electric HP for selected countries.

For oil-fired boilers/furnaces, the general picture is similar as for the gas-comparison. Heat pumps in Germany face stiff competition from condensing boilers. In France and Canada, heat pumps can be expected to deliver notable operating cost savings.

For Canada, despite the small savings for gas-fueled boilers, oil-boiler savings are comparable with France in absolute terms. This means that especially for oil-fired furnaces, (hybrid) HPs may become an attractive alternative heating option.

3.5 There is a wide variety of hybrid setups and use cases across participating countries

Hybrid heat pumps provide a wide and versatile range of possible operating strategies. This is reflected by the typical use cases for the participant countries. Within the working group, ten different use cases have been identified.

Each country has a couple of appropriate use cases, while no single use case is relevant for all countries. The list below gives an indication of the typical use cases for hybrid HPs that may be expected in the participating countries.[9]

Situation	Problem/driver	Hybrid provides...	Applies to...
Collective heating / multi-family houses	Renewable energy with best business case.	Optimal balance between investment (€/$) and CO_2-savings.	NL, DE, IT
Houses with PV-installations	Maximize use of self-produced renewable electricity.	Hybrid systems can be optimized for hot water production during PV peak production.	DE, BE

[9] Italy has not participated in this annex, but information on the use cases for Italy has nonetheless been discussed within the working group. It is included in the table for completeness.

Situation	Problem/driver	Hybrid provides…	Applies to…
Existing houses on gas grid or oil-fired boilers	CO_2-savings hard to achieve without renovation.	Immediate savings, without the need for building renovation. No “lock-in”: future renovation will still provide extra savings on fossil fuels.	NL, BE, DE, CA, FR
Small houses	No space for hot water storage tank.	With hybrid, HP can provide at least baseload, boiler can still cover hot water.	NL, UK, BE
“Hard-to-treat” houses	Limited technical/architectural options for building-related measures. E.g. in monuments and old buildings.	Elegant way to provide at least a minimum amount of CO_2-saving, without necessitating (deep) renovation.	NL, UK, DE
Houses with LPG- or oil-fired boilers	Boiler fuel is expensive.	Immediate savings on fuel use.	BE, IT, DE, FR
Weak electricity grid or “end-of-the-line” grid connections.	Capacity of electricity grid too small for all-electric heat pump.	Maximal use of renewable energy with minimal peaks in grid load.	UK, CA, IT, FR
New built houses	Renewable targets / building regulation	Desired amount of renewable energy or energy performance	FR
Add HP to planned AC installation	Heating reference (furnace) is low-cost, AC installation needed	By choosing a reversible HP, with cooling as primary function, part of the heat demand can become low-CO_2 for a limited investment	CA
Enabler for large-scale grid management	Several grid-load issues: e.g. renewable production, electrical vehicles, mass-deployment of HPs, etc.	Electricity demand from hybrid systems can be switched off at will, providing plenty of smart grid potential.	Future development

Because the typical use cases and the solutions that hybrid HPs offer are so different across countries, it may be necessary to devise specific policies for hybrid HP support for each country or even for each region.

3.6 Hybrid HPs may serve as a gateway towards low-carbon heating

Hybrid HPs provide a significant opportunity to save fossil fuels. Still, a major upgrade of the building stock is needed in most countries. Even if hybrid systems are rolled-out on a large scale, continuous attention to this upgrade is necessary. Eventually, domestic hot water and space heating will probably be delivered by a mixture of HPs, district heating and green fuels.

Through the use of hybrids, it is possible to immediately realize a partial transition of the heating system towards 100% renewable, even if the building itself has not yet been renovated. Depending on the availability of renewable fuels (e.g. hydrogen, syngas, biogas), hybrid HPs may become a permanent part of the energy system.

It is important that hybrids are indeed used to accelerate the transition. There should be a real and significant contribution to less primary energy, less CO_2-emissions and higher flexibility.

- Hybrid systems as alternative for stand-alone boilers -> generally an appropriate solution.
- Hybrid systems as ‘minimally sufficient’ renewable heating -> generally <u>not</u> an appropriate solution.

After the ‘first generation’ hybrids, a transition towards stand-alone electrical HPs should be feasible.

For some house types, hybrids may essentially be the only way to provide renewable heating. E.g. old monumental buildings, tight space constraints, etc. However, renewable fuel (power2gas, biofuel, gasification, etc.) for the boiler is then needed to achieve 100% renewable heating. Since the available ‘renewable fuel budget’ will probably be very tight, this route should not be taken for granted, but this really will depend on the chosen strategy for production and distribution of renewable fuel. Especially in the UK, hybrids are expected to play a significant and lasting role in the energy system to provide heat to houses and flexibility to the grid.

The charts below give a graphical representation of the argumentation above:

'BAU' scenario -> switch to 100% renewable heating when houses are renovated

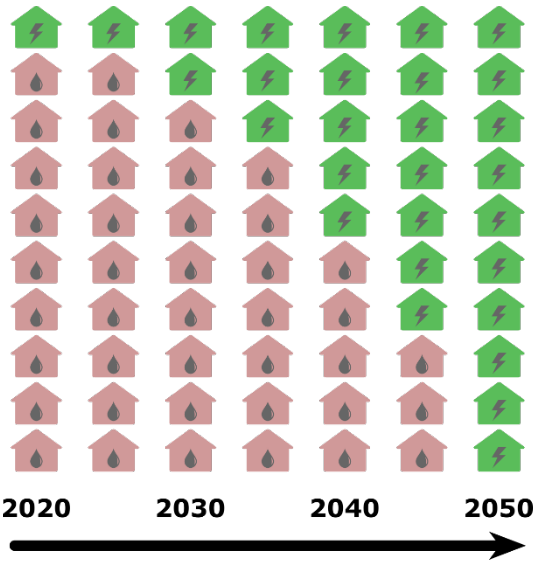


Figure 17 – Switching to all-electric heating without using hybrid HPs.

In this scenario, houses are only converted to 100% renewable heating when sufficient insulation measures have been taken. Although a part of the building population may be fit for renewable heating already, converting all houses will take at least several decades in most countries.

Hybrid HPs as intermediate solution

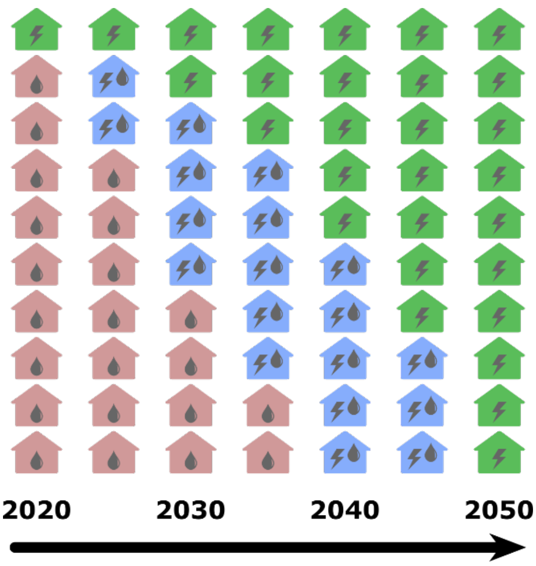


Figure 18 – Switching to all-electric heating using hybrid HPs as intermediate steps.

In this scenario, hybrid systems are used to achieve CO_2-savings for as much houses as possible, even in those houses where100% renewable heating is not (yet) possible. The end goal is still to switch over to 100% renewable heating without using boilers.

Hybrid HPs combined with fossil-free fuel

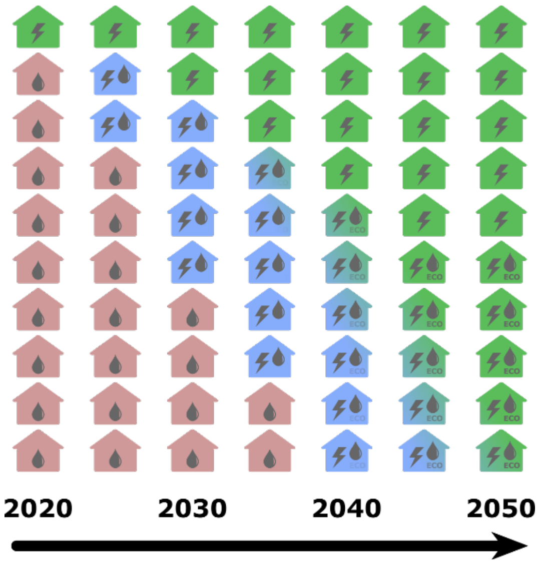


Figure 19 – Switching to a 'hybrid energy system'. Hybrid HPs are used as intermediate solution towards a mixed final situation where both all-electric heating and hybrid HPs with renewable fuel are used.

As a last option (the 'UK-scenario'), hybrid systems may be combined with fossil-free fuels, such as hydrogen from renewable power-to-gas plants or biogas. In this way, a first and rapid move towards less CO_2-emissions is made by switching to hybrid systems. Insulation and electrification of the heating production will take place, but simultaneously, hybrid HPs may become 100% renewable by switching to fossil-free fuel for the boiler part. The final situation will contain a mix of houses with all-electric HPs and renewable hybrids HPs.

4 Hybrid HP market in participating countries

Specific market data for hybrid HPs is not yet available on a large scale. The graphs below give an impression of general heat pump sales within the EU. This impression immediately shows the large impact of local pressures and conditions. Although the EU form quite a homogeneous market in many respects, the use of heat pumps and other sources of renewable heating shows significant variation across EU member states. Heating traditions, climatic conditions, tax policies, grid quality, building regulations are just a few of the factors that influence the HP market.

Similarly, it is to be expected that the development of the market for hybrid systems will greatly differ on a country by country, or even provincial, level. The overview of the local situation for hybrids in the next section illustrates some of the differences between the countries participating in this Annex.

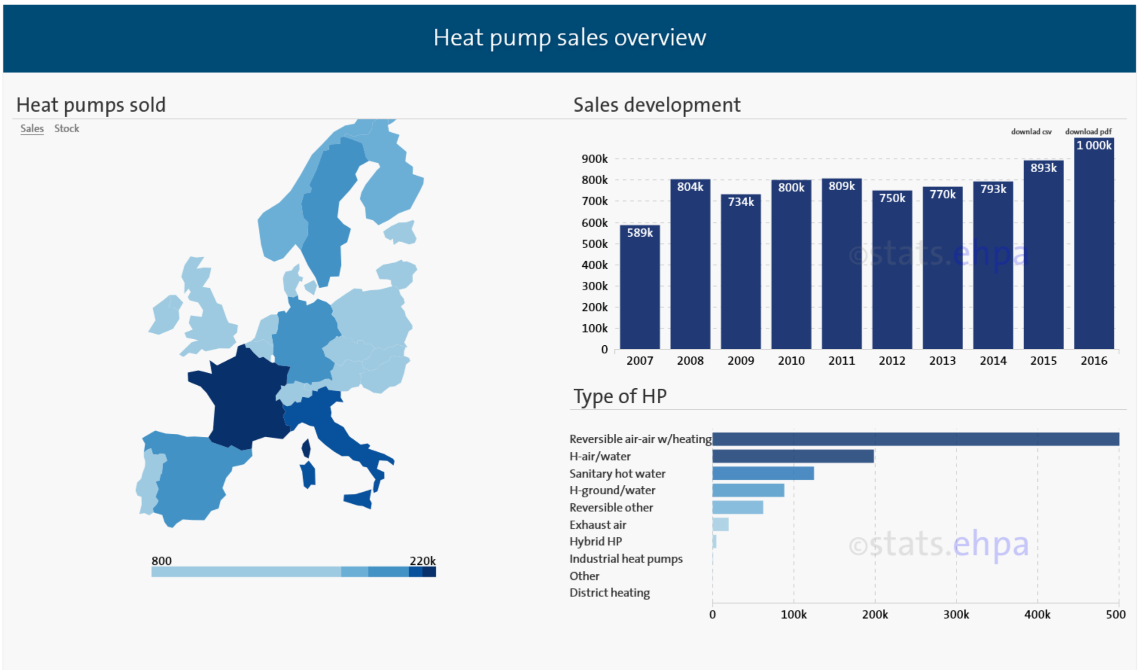


Figure 20 – Sales overview of heat pumps in Europe during 2016, including yearly development and type of HP. Data compiled by the European Heat Pump Association.

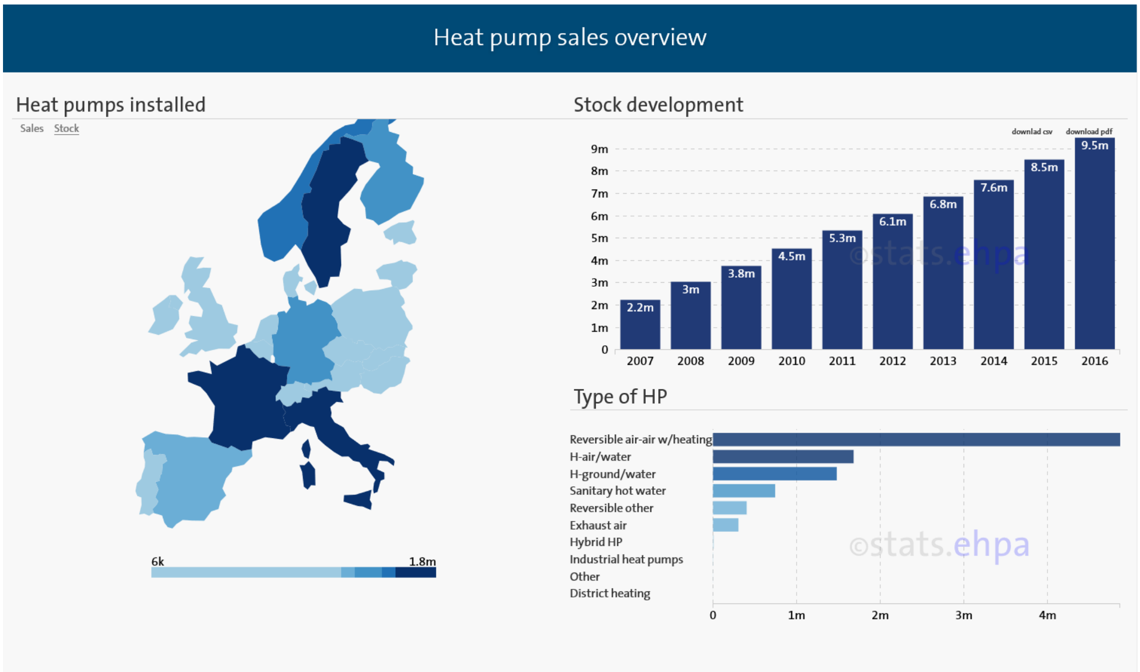


Figure 21 – Overview of installed heat pumps in Europe during 2016, including yearly development and type of HP. Data compiled by the European Heat Pump Association.

Yearly heat pump sales per country (EU, 2016). Hybrid HP data is only (unreliably) available for Belgium and Italy. In the chart below, figures for hybrids cannot be discerned.

The general HP trend shows a steady increase in the number of units sold. At present, 1 million systems are sold yearly, and total installed base in the EU amounts to 10 million units. France and Italy are decidedly up front in heat pump sales, especially as compared to countries of similar population (e.g. Germany, Spain, Poland). In relative numbers (units per capita), the Nordic countries are moving fastest

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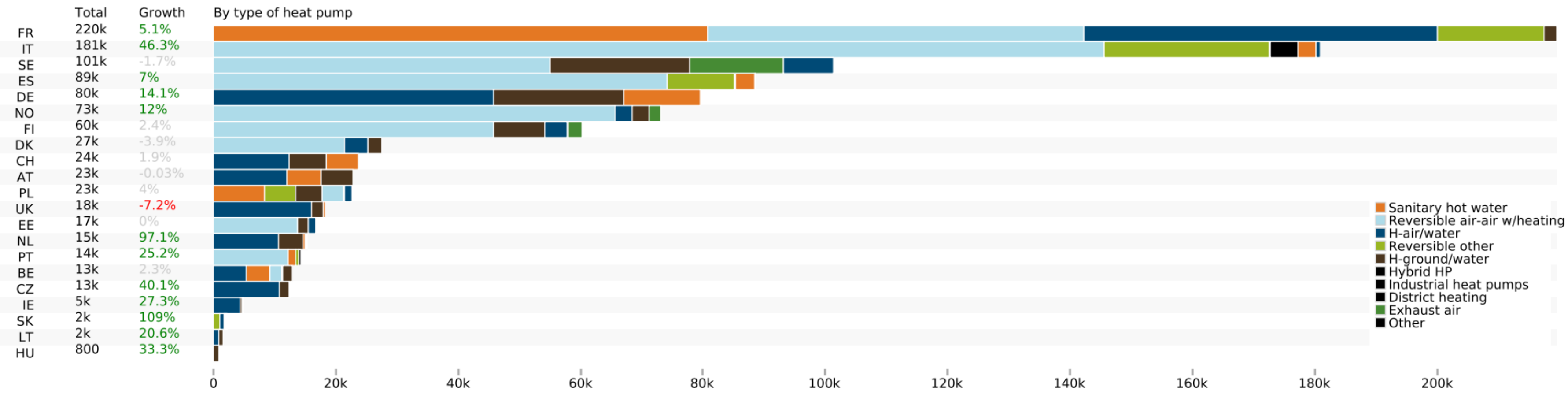


Figure 22 – Sales of heat pumps in European countries, divided by type of heat pump.

4.1 Overview of local situation per country

4.1.1 Canada

Hybrid heat pumps are still hardly used in Canada. Although hybrids may contribute to CO_2-saving, energy tariffs are very low. HPs generally are not very attractive to consumers from an economic point of view. The role of (hybrid) HP could be substantial, nonetheless. In 2013, residential and commercial energy use accounted for about 2,440 PJ or 27% of the total secondary energy use in Canada. For approximately 20% of the total secondary energy use in Canada, hybrid systems could have an impact, producing a significant reduction in fossil fuel use and reducing GHG emissions.

The effects of substituting fossil fuel furnaces or boilers for (hybrid) HPs will strongly vary between the provinces and territories. GHG intensity of electricity production ranges from several grams of CO_2 per kWh (mostly East-Canada, mainly hydropower) up to almost 800 g CO_2 / kWh (North and Mid-Canada, dominated by coal plants).

Even though it is difficult to make a business case for hybrid HPs, there often is a need for cooling during hot summer periods. Therefore, it might be a viable approach to stimulate the use of reversible heat pumps. These HPs would primarily be sized and installed to meet cooling demand. However, by using a reversible heat pump, part of the heating demand can be covered by HP at a very limited additional investment.

At this time, there are no Canadian Performance Standards for Hybrid Heating Systems. The Canadian Standards Association (CSA) Technical Committee for Energy Efficiency and Related Performance of Fuel-burning Appliances & Equipment, will address this issue shortly.

4.1.2 France

There are two main factors that impact the hybrid HP market in France:

1. Due to increased renewable electricity production, the electricity production profile will be impacted. The net capacity (i.e. difference between total demand and renewable production) will fluctuate on a daily basis, as well as on a seasonal basis. There will be sizeable swings in the net production demand, and timing of maximum and minimum production will vary according to weather conditions. Furthermore, the objective is to reduce the use of fossil-fired electricity plants in winter and to address electricity demand only with nuclear and renewables plants.
   Flexible appliances, that may be switched off when needed, can play a role in this transition. Especially in the heating season, when electricity demand is significantly higher than in the summer, hybrid HPs may be of value.
2. The pressure to lower CO_2-emissions will force energy reduction and CO_2-reduction in new houses as well as in old houses. In both sectors, hybrid systems may play a role, especially in those houses that are not (yet) fit for all-electric HPs.

For new houses there is an obligation to produce a part of the heating demand using renewable heating installations. This obligation pushes hybrid systems and accomplishes a significant contribution to the growth of renewable heating. However, the HP part of the hybrid systems in new houses is typically chosen as small as will possibly fit the regulations. Larger savings could be achieved if house owners would install hybrid systems with a somewhat larger HP component. Around half of the newly built houses are already equipped with all-electric HPs.

For existing houses, renewable heating poses a serious challenge. 60% of all houses has been built before 1975, when the first thermal regulations were put into place. Less than 15% has an energy label of C or better. Still, hybrid HPs may offer a firm base to achieve a first step in renewable heating in existing houses. Typically, a HP size of 5 – 10 kW would be optimal, with a boiler size of 20 – 25 kW.

The total heat pump stock in France is around 2 million. The HP sales have been driven by new houses during the last decade, but a new market impulse is expected from the use of hybrids in existing houses.

An extensive market study by EdF has compared different heating options for oil-heated French houses in many different situations (Monte Carlo simulation). The results indicated that both from a CO_2 and from an economic perspective, hybrid systems may be the best option in the majority of the cases. An extensive discussion of this research can be found in chapter 7.

4.1.3 Germany

In Germany, there is no real incentive to use hybrid HPs to obtain CO_2-emission reduction. The German combination of building stock, design temperature and CO_2-emission factors for electricity and fossil fuel leads to optimal cross-over points below -9 °C for retrofitted older buildings and -3°C even for un-retrofitted existing building.

When looking at the costs as optimization goal the results are very different. Whereas in new buildings the switching temperature accounts for -6°C, in the older buildings switching temperatures of 1°C and 5°C are calculated (for the electricity price of 21.7 Eurocent per kWh and 6.1 Eurocent per kWh for natural gas). These values consider the special heat pump electricity tariff. Considering the standard household tariff (29,9 €ct/kWh) the switching temperatures would even increase up to 2°C, 8 and 10°C. Thus, according to running costs a hybrid heat pump is an appropriate heating system; especially in older buildings but also (with high electricity prices) in new buildings.

These results indicate a major problem: the divergence between ecological and economical goals. Whereas in terms of ecological reasons the hybrid system is rarely useful compared to the single heat pump, the system operator would choose it because of economic advantages.

Hybrid heat pumps might still be useful for practical reasons, for instance, to provide DHW at the appropriate hygiene standards. Another reason for applying the hybrid system is the flexibly which it offers within the whole energy supply system. According to the current wind and photovoltaic power situation it can choose between using the heat pump or the boiler.

Regarding the building stock, over 90% is built before 2002. It can be assumed that the majority of these buildings have not been refurbished in order to provide space heating on a low heating temperature around 35°C. Accordingly, in Germany exists a very large potential application field for hybrid heat pump applications.
The main drivers for installing hybrid heat pumps in Germany are:

- Economic reasons (increasing with space heating temperatures)
- Utilization limits of heat pumps in terms of supply temperature
- Flexibility due to fuel switch.

Considering these results, the circumstances for hybrid heat pump systems seem to be appropriate for wider application. But it also has to be stated, that these circumstances have existed for some years now, without a significant influence on the expansion of this technology. Thus, the further development of hybrid heat pump systems is difficult to predict.

4.1.4 Netherlands

Hybrid heat pumps have been quite successful in the Netherlands for some years now. Starting over a decade ago, when the first hybrid heat pumps became commercially available. Since 2016, a subsidy scheme for renewable heating options for houses has been opened. This subsidy is also applicable to hybrid heat pumps. This has served as a great incentive for hybrid heat pump installments in the Netherlands.

The majority of hybrid heat pumps are installed in existing houses, often to be combined with existing condensing boilers. All-electric heat pumps are almost exclusively installed in new houses. Taken together, heat pumps are now slowly growing to nearly 10% market share (new installations) of all domestic heating systems.

As a solution for existing houses, hybrids are quite popular because:

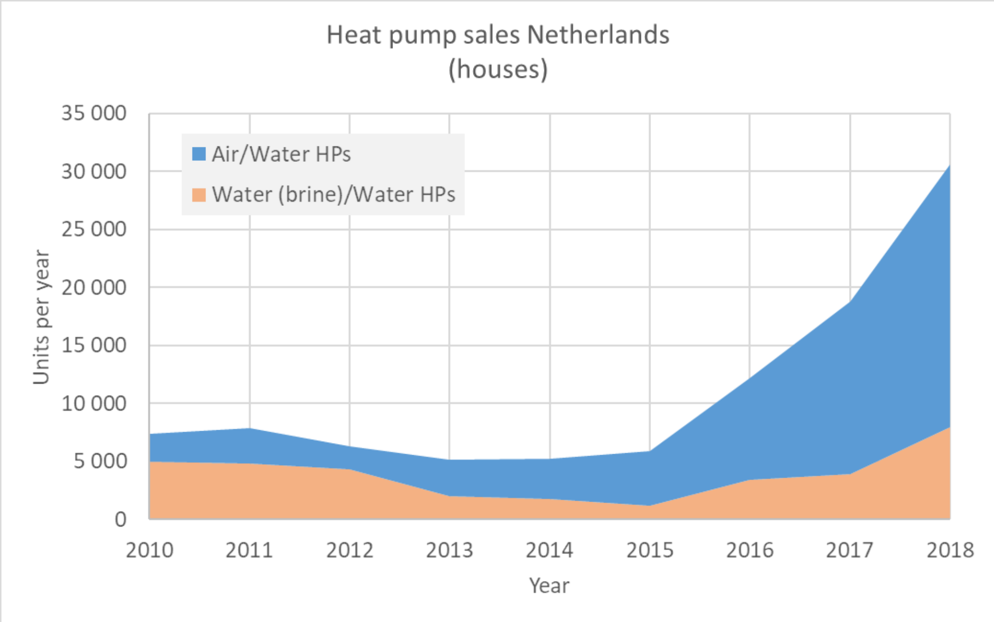
- Condensing *combi* boilers are used in over 90% of all houses now. DHW storage tanks are therefore seldom installed. Placement of DHW storage is considered undesired and often difficult in terms of available space in the house. Hybrid systems provide a way of using renewable heating, without the need to include a storage tank.
- For existing houses, realizing low-temperature heating transfer systems is difficult. A hybrid HP is a '*kick starter'* for renewable heating in existing houses, by monetizing on the ability to use a HP at least at the beginning and end of the heating season, when temperatures are moderate and existing radiators still deliver enough energy to the house with low temperatures.
- The investment in a hybrid HP is much lower than for an all-electric HP.
  Life-cycle cost for a hybrid system is typically in the same order as for a condensing boiler. Increasing energy taxes on natural gas tend to skew the business case to become *better* for hybrids and *worse* for condensing boilers.
- Large-scale performance data on HPs is hardly available and there is still little trust in HP systems. Hybrids – having a fossil boiler as fallback option – can bridge the confidence gap towards completely renewable heating.

Up to now, the Netherlands are not up to speed to reach their EU climate goals for 2020 and further. In the first half of 2019, the Dutch government will present their Klimaatakkoord (climate agreement). This agreement has been reached during negotiations between government and representations of many different sectors involved in the energy transition (industry and consumer organizations, NGOs, scientists, etc.). This agreement will present concrete measures to accelerate CO_2-emission reduction, renewable production and energy savings. The build environment, and in particular houses, form one of the central focus points for these measures. It is to be expected that insulation measures, renewable heating and renewable energy production will all be stimulated or imposed for house owners. Many renewable technology sectors will profit from this. Hybrid HPs are already gaining popularity, and this trend will probably continue for the next couple of years.

Example – successful market development through government support scheme and building regulations

Starting in 2016, a subsidy scheme for renewable heating appliances for houses was introduced in the Netherlands. This has led to a marked increase in the number of installed HPs per year. The graph below gives an overview of the number of installed HPs *in houses* for 2010 – 2018 (2018 estimate). After several years of constant sales, the market size has grown fivefold compared to the 2010-2015 level.

The bulk of the HP sales are of the air/water type. These systems are becoming more popular for new houses, but most of the systems are estimated to be installed in existing houses. There is no official statistic available for hybrid HPs, but a conservative estimate based on the graph below is 10.000 – 15.000 hybrid installations per year.



Source: Dutch central bureau of statistics (CBS)

New building permits are only given for houses without a natural gas connection for heating. Starting within the coming years, this will give another significant boost to the Dutch HP market.

The baseline sales for condensing boilers are approximately 400.000 units per year. If the present growth continues, and there is no reason to doubt it will, HPs will have a market share in the domestic heating market of more than 10% starting from 2019.

4.1.5 UK

The characteristics of the UK building stock create one of the main challenges with regards to the use of heat pumps:

- The high average age of the building stock means there is comparatively low thermal quality of the building envelopes.
- There is an increasing trend towards removing storage tanks from UK homes because of lack of space, and the dominance of combi gas boilers.

The availability of relatively low-cost gas and gas boilers creates a strong challenge for heat pumps – limiting the potential heat pump market size. The heating system stock in the UK is dominated by gas, which heats 85% of all dwellings. Even with the introduction of the domestic Renewable Heat Incentive in Spring 2014 it is expected that heat pumps will only pay back in off-gas grid buildings (i.e. replacing oil or electric heating). In 2020 heat pumps will likely reach a very low penetration of the building stock.

The characteristics of UK buildings, combined with the current high proportion of gas use for domestic heating, provide a potential opportunity for hybrid heat pumps utilising gas boilers.

The total HP market has been relatively stable at approximately 20.000 units sold per year since 2011. An estimated 10% - 15% of these units are hybrid HPs. However, from a technical perspective there is significant room for growth of the number of hybrid systems. Currently heat pumps are still a niche product for energy-aware customers. To achieve a break-through, it would be necessary to increase consumer trust in the quality and viability of using (hybrid) HPs for heating. Currently, there are clear disadvantages to using heat pumps (i.e. higher cost), combined with a (perceived) risk of dissatisfying performance. Hybrids may be able to bridge the gap between fossil boilers and all-electric HPs, but presently, consumer familiarity with hybrid systems is low.

4.2 Market potential and emission reduction

The market for hybrid systems is still in its fledgling stage. Therefore, it is difficult to predict the possible market share or contribution to CO_2-emission reduction. Furthermore, the conditions and expectations for domestic heating systems differ widely across countries.

Still, hybrid heat pumps feature a couple of characteristics that make them relatively suitable for application in houses, as compared to other renewable heating options.

- Small size possible (i.e. no storage tank for DHW if a combi boiler/furnace is present)
- Relatively low added investment costs, especially if cooling and heating demand are both present.
- High supply security by means of back-up boiler
- Flexible operation possible
- High-quality insulation or low-temperature heat transfer not necessary (although still advisable)

Because of these favorable characteristics, hybrid systems may become a ‘kick starter’ for renewable heating in the domestic sector. The majority of all existing houses may perhaps potentially be fitted with hybrids. Depending on the reference case, CO_2-savings may amount from 10% to 50% as compared to traditional heating. Taken together, this implies that hybrid HPs may contribute around 10% to 15% emission reduction for heating in houses, while also serving as a first step to completely renewable heating.

5 Overview of field trials

5.1 France

12 field tests have been realized in France, 5 with oil hybrid heat pumps, 7 with gas or propane hybrid heat pumps. The location of these field tests is visible on the map.
The main information about some of these sites are given in tables below.
Depending on the sites, the field tests lasted two or three years.

Data site	Le Perray en Yvelines	Waldighoffen	Marseille	Puiseaux	Veneux les sablons	Samois sur Seine
						
Occupants	2	4	2	3	1	2+2
construction	1985	1996	1975	1995	1900 + 1980	1989
Heated Surface (m²)	90	116	180	96	110	150
Replaced system				Gas boiler 24kW	Gas boiler 23kW	Oil boiler 20 – 40 kW
Emitters	Steel radiators	Heating floor + radiators	Steel radiators	Steel radiators	Steel radiators	Steel radiators
Initial consumption (kWh)	17000	21000		12000	29000	20000
Hybrid HP	**Gas**	**Propane**	**Propane**	**Gas**	**Gas**	**Oil**

Instal.	20/10/2013	10/ 2013	01/10/2011	27/12/2012	21/02/2013	08/02/2013
Type	Split / Low Temp.	Split / Condensing	One-piece Ext. / Condensing	One-piece Int. / Condensing	One-piece Ext. / Condensing	Split / Low Temp.
Power(kW)	HP 10 Boiler 25	HP 4,4 Boiler 30	HP 5 Boiler 30	HP 2 Boiler 24	HP 3 Boiler 27	HP 13 Boiler 25
COP 7/35	4,04	5,04	4	3,4	4	3,86
HP on	Text adjustable: -25/ +35	COP> (elec cost / gas cost) or Text>-3°C & COP>2,58	COP> (elec cost / gas cost) or COP > 2,58	Text>3°C & COP>2,58	COP(elec cost / gas cost) or COP > 2,58	Text adjustable: -25 / +35
DHW	HP+ Boiler	Boiler	Only heating	HP+ Boiler	Boiler	HP+ Boiler

The table below presents the main results for these field tests, highlighting three different sizings for heat pumps: small (< 5kW), medium (5-9kW) and large (>10kW).

	Results on heating season (2015 - 2016)											
	Low Power HHP		Medium Power HHP						High Power HHP			
Site	Gap (05)	Puiseaux (45)*	Veneux les Sablons (77)	Waldighoffen (68)	Marseille (13)	Faremoutiers (77)*	Jausiers (04)	Marolles sur Seine (77)*	Le Perray en Yvelines (78)	Melesse (35)	Blennes (77)*	Samois sur Seine (77)
Product												
Combustible	Gas	Gas	Gas	Gas	Propane	Oil	Propane	Oil	Gas	Oil	Oil	Oil
HP Power (kW)	3	2	5	5	5	6	8	8	10	14	11	13
Heating need (kWh)	5575	6675	14701	15411	8087	-	15658	2402	10037	22993	24639	10428
DHW need (kWh)	1231,7	1119	942	-	-	-	-	347	364	1352	103	1806
HP COP (Heating+DHW)	**1,7**	**3,1**	**2,7**	**3,6**	**3**	-	**2,6**	**3,1**	**2**	**2,5**	**2,9**	**2,5**
Heating HP coverage rate (%)	**18**	**37**	**72**	**85**	**39**	-	**67**	**87**	**97**	**97**	**74**	**96**
DHW HP coverage rate (%)	5	7	-	-	-	-	-	53	17	60	54	30
Bill gain(%)	**5**	**22**	**32**	**36**	**41**	-	**50**	**47**	**18**	**54**	**45**	**37**
CO2 reduction (%)	14	42	45	66	45	-	55	75	58	77	70	67
Primary energy efficiency [%]	88	104	99	129	105		87	110	80	97	107	93
Old system efficiency (%)	88	75	75	95	75	65	75	65	75	65	65	65

* Shorter or different period than the other sites

The results are very dependent on the installation quality, overall sizing and conditions but show a great and favorable impact of the retrofitting of a boiler by a hybrid heat pump in most of cases. As the French electricity is produced with a very low CO_2 emission, the main impact of boiler replacing is on the CO_2 emissions reduction.

5.2 Germany

Smart WP im Bestand	
Location, date	Several locations in Germany, 2014 – 2019
Parties involved	Fraunhofer ISE, AIT, Bosch Thermotechnik, Glen Dimplex, Elektrizitätswerk Mittelbaden, Heliotherm Wärmepumpentechnik, Lechwerke, Stadtwerke Stuttgart, Stiebel Eltron, Vaillant, Viessmann, Max Weishaupt
Setup	100 HPs, regular and hybrid systems. Detailed measurements on performance and suitability for smart grid applications.
Results	Final results not yet available
Status	In progress
References	**https://wp-monitoring.ise.fraunhofer.de/wp-smart-im-bestand/german/index/index.html**

5.3 Netherlands

"Innovatief 390" – 40 hybrid heat pumps at housing corporation	
Location, date	Eindhoven (Netherlands), 2017
Parties involved	Housing corporation "Woonbedrijf" and installer (Feenstra)
Setup	The main goal was to compare different types of hybrids in the same houses. 40 hybrids of 4 types were tested (4 x 10 houses). The houses involved were built in 1990. Hybrid types used: 1x Ventilation heat pump (Inventum) 3x Outside air heat pump (AWB, Nefit, Daikin)
Results	**Savings on natural gas use for heating** * 62%, 78% and 83% for the three types of outside air systems * 52% for the ventilation heat pump The outside air systems perform very satisfactorily. A significant natural gas savings was achieved. For the ventilation heat pump, the 52% decrease also indicates god performance, given the much smaller output power of the ventilation HP. **Practical experience** * Lessons learned regarding size, weight, ease of installation of different systems. * Experience with tenant communication. **Economic results** Over 90% of all installations had a payback time of less than 18 years (NL situation of 2017). This means that the savings from the system compensate the added investment within the installation replacement time.
Status	Finished
References	No public report available

"050 Hybride" – 50 hybrid heat pumps for customers of local energy supplier	
Location, date	Groningen (Netherlands), 2016 – 2020
Parties involved	Grunneger Power (Local energy supplier, coordination), GasTerra (Gas trading office), GasUnie (Transmission grid operator for gas), Shell, Huisman Warmtetechniek (Installer), BeNext (Data collection), Patrimonium (Housing corporation), City of Groningen, BDH (Data analysis)

"050 Hybride" – 50 hybrid heat pumps for customers of local energy supplier	
Setup	Approximately 50 houses will receive a hybrid heat pump at a reduced price. Systems will be monitored for performance. Goal is to get real-life data from a collection of different houses and use cases.
Results	No yet available
Status	Delayed. Installation almost done (Q1 2018), first results expected late 2019.
References	**https://grunnegerpower.nl/projecten/050-hybride/**

"Installatiemonitor" – large scale monitoring of HP smart meter data	
Location, date	Netherlands, starting 2019
Parties involved	BDH (coordination, analysis), RVO (NL government), DSOs and TSOs
Setup	Focus on monitoring data from a large set of houses with heat pumps. To get a large data set on practical performance numbers, this project only uses measurement data from smart energy meters (electricity & gas totals for the house). This means that individual details on the heat pump performance can't be directly measured. Statistical analysis will make detailed analysis nonetheless feasible. Both all-electric and hybrid systems will be part of the field trials.
Results	Not yet available
Status	Ongoing
References	No public report available.

5.4 UK

Freedom Project	
Location, date	Bridgend, heating season 2017/2018
Parties involved	Wales & West Utilities, Western Power Distribution, Passiv Systems, City University of London, Imperial College London, Delta EE
Setup	75 houses provided with hybrid system + advanced smart controls. Elaborate testing of savings (money, CO_2) and flexibility potential.
Results	Hybrid systems can provide significant savings, even when facing electricity grid constraints
Status	Finished
References	https://www.westernpower.co.uk/projects/freedom

6 Comparing fixed hybrid HP running strategies

In order to assess the most important influences for the appropriate operation of hybrid systems and to compare the different conditions (and to derive useful fields of application) in the Annex 45 partner countries a simple Excel-Tool was developed by Fraunhofer ISE. As a bivalent (hybrid) heating system, the Hybrid-Tool addresses systems that consist of an electrically driven compression-heat pump and a gas or oil-fired boiler. Moreover, the heating system has a joint regulation which controls the appropriate use of both heat generators. Thereby, a bivalent alternative operation is taken as a basis. I.e. above a certain switching temperature the heat pump is used, and below this temperature the fossil heat generator is used. The heating system is only used for room heating (no DHW heating).

> Note: this chapter discusses fixed operating strategies. If grid constraints and real-time changes in optimization parameters are taken into account, hybrid performance may differ. In particular, the optimization criteria in this chapter are strictly limited to the local situation within a house. Through smart grid integration, large-scale optimization of the energy system is possible.

Figure 23 shows the results page of the tool which also represents the input mask. The results are given in the form of a matrix of application (vertical) and optimization goal (horizontal). The areas of application include three buildings with different energy standards: New building, renovated and un-refurbished old buildings. In the calculation, these are included with different heating circuit temperatures. Thus, they directly influence the efficiency of the heat pump. The objectives of the operational optimization are considered as low as possible primary energy demand, $CO_{2\text{-eq}}$ emissions and consumption costs. Other (modifiable) constraints are

- efficiency of the heat pump (by entering a COP value, a pre-defined mean COP curve is adapted by means of parallel shifting)
- heat source air or ground by entering the COP in the according field
- efficiency of the boiler
- outdoor temperature-dependent heating temperature by entering the angle of the heating curve per building type
- final energy-related primary energy and $CO_{2\text{-eq}}$ factors as well as consumption costs for electricity and fossil fuel by selecting a country
- choice between gas and oil (when choosing a country)
- climate zone according to DIN EN 14825 (cold, average, warm)

The switching temperature (blue circle) and the heating demand covered by the heat pump (green) and the boiler (blue) stay in focus of the tool.

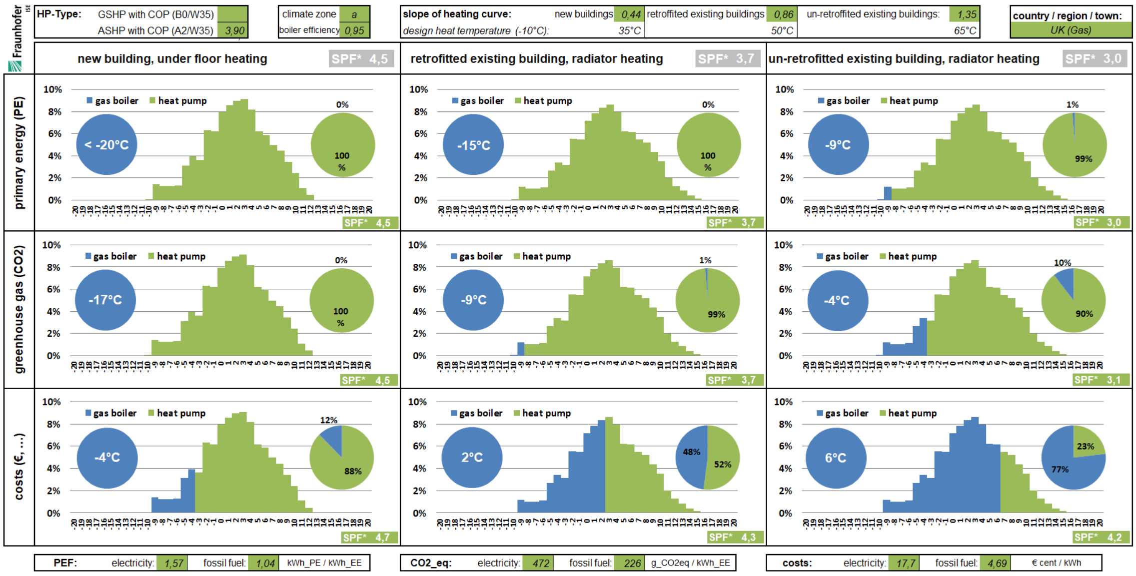


Figure 23: Input and output values to determine appropriate application areas with the Hybrid-Tool

The calculation is carried out according to a bin method, i.e. for each outdoor temperature bin it is determined whether the heat pump or the fossil heat generator is advantageous in relation to the respective optimization target. The efficiency values of both heat generators are used to convert the final energy-related to the useful energy-related parameters. Therefore, no absolute energy quantities are required. The efficiency of the boiler is assumed to be constant for all outside temperature bins. The COP of the heat pump is calculated individually for each temperature whereas the source and sink temperatures are used as variables. For an air source heat pump, the temperature of the outdoor air is taken into account and for a ground source heat pump an equation considering the dependencies of brine and outdoor air temperature is considered (based on field measurement data). With regard to sink temperatures, the heating circuit temperature is used as a function of the outside air temperature. The slope of this linear heating curve can be entered for each building type.

Figure 23 shows as an example the results for the UK. An average climate and the combination of an air source heat pump (COP A2/W35: 3.90) with a gas boiler (eff.: 95%) are assumed. Considering the ecological optimization goals only in un-retrofitted buildings and regarding $CO_{2\text{-}eq}$ emissions, a hybrid heat pump would be an appropriate solution. The gas boiler would run with outside air temperatures of -4°C and lower where 12% of the space heating demand would be covered. However, the hybrid heat pump would rather be applied in terms of economical optimization. In new buildings the switching temperature is calculated to -4°C and in the existing buildings to 2°C and 6°C. Worth mentioning is the strong impact of the switching temperature on the energy share covered by the heat generators close the temperature bins with peak heat demands. For example, increasing the switching temperature only from 2°C to 6°C equals a decrease of the energy share covered by the heat pump from 52% to 23%.

To compare the different conditions in the Annex 45 partner countries Figure 24 shows the results in terms of switching temperatures and heating energy share covered by the heat pump. For all European countries the average climate zone is assumed, whereas some regions in these countries are also defined as cold (Germany) and warm (UK, France). For Canada the cold climate zone is assumed. The colors highlight the HP´s energy share separately for the European countries and for Quebec in Canada. It has to be mentioned, that the Canadian states are characterized by very different economic and ecologic parameters for the final energy sources electricity and gas. Furthermore, a special HP tariff is additionally assumed for Germany as the gap to the household tariff is significant. All assumptions applied in the Hybrid-Tool are summarized in Figure 25.

State	Climate zone	Primary Energy						$CO_{2\text{-eq}}$ Emissions						Consumptions Costs					
		T [°C]	%HP	T [°C]	%HP	T [°C]	%HP	T [°C]	%HP	T [°C]	%HP	T [°C]	%HP	T [°C]	%HP	T [°C]	%HP	T [°C]	%HP
Belgium	average	-15	100	-7	97	-2	81	< -20	100	< -20	100	< -20	100	5	23	10	5	12	1
Netherlands	average	< -20	100	-14	100	-9	99	-16	100	-8	98	-3	86	-12	100	-4	90	1	60
UK	average	< -20	100	-15	100	-9	99	-17	100	-9	99	-4	90	-4	88	2	52	6	23
France	average	-14	100	-6	96	-1	75	< -20	100	< -20	100	< -20	100	-12	100	-5	93	0	68
Germany (HH-tariff)	average	< -20	100	-14	100	-9	99	-17	100	-9	99	-3	86	2	46	8	13	10	5
Germany (HP-tariff)	average	< -20	100	-14	100	-9	99	-17	100	-9	99	-3	86	-6	95	1	60	5	29
Canada / Quebec	cold	< -20	100	-15	95	-10	88	< -20	100	< -20	100	< -20	100	-3	57	3	19	7	8

Figure 24: Switching temperatures and heating share covered by the heat pump for a hybrid system (gas boiler + HP) in different countries regarding different optimization goals and fields of application calculated with the Hybrid-Tool

When comparing the optimizations goals for primary energy and $CO_{2\text{-eq}}$ emissions only a rare application field for hybrid systems appears. In new and retrofitted existing buildings the lowest heating energy shares for heat pumps account for 96% in France and for 95% in Quebec. The results for un-retrofitted buildings are slightly different. Significant energy shares of more than 10% for the gas boiler are calculated for France (25%, PE), Belgium (19%, PE) and Quebec (12%, PE) as well as for the Netherlands (14%, $CO_{2\text{-eq}}$) and Germany (14%, $CO_{2\text{-eq}}$). Thus, based on this calculation method with static values for primary energy and $CO_{2\text{-eq}}$, the significant advantage of hybrid heat pumps emerges rather from economic than ecologic optimization for all considered countries. Within the cost section the results differ a lot. From building type to building type the influence of lower HP´s efficiency associated with lower heating energy shares for the heat pump as part of a hybrid system are well comprehensible. Comparing all countries, the smallest HP´s energy shares are calculated for France and the Netherlands. This is due to the smallest ratios of 2.6 (France) and 2.8 (Netherlands) between electricity and gas price. The largest price ratios can be found in Belgium (5.4) and Germany for the usual household tariff (4.9). Corresponding to these price ratios the HP´s energy share accounts to maximum values of 46% in Germany and 23% in Belgium but only in new buildings. The very low HP´s energy shares in existing buildings would rather suggest the application of a single boiler with its very negative consequences in terms of ecological values. As also shown in the figure the special heat pump tariff in Germany would be an appropriate countermeasure to this imbalance. The results for Quebec are similar to the ones for Germany with household tariff but in terms of absolute costs on a much lower level (Figure 25).

State	Primary Energy Factor [kWh_PE/kWh_FE]		$CO_{2\text{-}eq}$ Factor [g/kWh_FE]		Price [€ct/kWh_FE]	
	Electricity	Gas	Electricity	Gas	Electricity	Gas
Belgium	2,65	1,12	235	226	28,00	5,19
Netherlands	1,58	1,03	495	222	22,00	8,00
UK	1,57	1,04	472	226	17,70	4,69
France	2,84	1,15	124	248	16,90	6,39
Germany (HH-tarif)	1,75	1,13	515	243	29,90	6,11
Germany (HP-tarif)	1,75	1,13	515	243	21,70	6,11
Canada/Quebec	1,50	1,00	50	237	5,00	1,25

PE: primary energy; FE: final energy

Figure 25: Assumptions for the different countries applied in the Hybrid-Tool

The results above show a major problem which counts for every country: the divergence between ecological and economical goals. Whereas in terms of ecological reasons the hybrid system is rarely useful compared to the single heat pump the hybrid system would be chosen due to economic advantages. In this context the following limitations of this calculation are important to note. The mentioned preferences of using the single heat pump instead of hybrid heat pump systems are only valid for heat pumps which are able to cover the necessary heating temperatures for space heating and domestic hot water (DHW). Especially in multi-family-buildings the requirements for hygienic DHW preparation are high and a challenge for standard heat pumps. Thus, hybrid heat pumps might still be useful for practical reasons. Another essential reason for applying the hybrid system is the offered flexibly within the whole energy supply system.

7 The Freedom Project – smart flexibility from hybrid systems

This chapter gives an overview of the objectives and main results of the Freedom Project, carried out by Wales & West Utilities and Western Power Distribution. The contents for this chapter have been taken from several project reports that were kindly made available by Passiv Systems.

7.1 Background and objectives

The Freedom Project is a joint Western Power Distribution and Wales & West Utilities £5m innovation initiative in the Bridgend 'living heat laboratory' in South Wales. It has investigated the network, consumer and broader energy system implications of high-volume deployments of hybrid heating systems (HHS). The technology, which combines a conventional gas boiler and an air source heat pump (ASHP) with PassivSystems optimised smart controls, can be used as fully flexible loads capable of providing significant energy system value. Hybrid heating systems could be a major component of residential heating decarbonisation if the value can be levered.

As an industry first, Distribution Network Operator (DNO), Western Power Distribution (WPD) and Gas Distribution Network (GDN), Wales & West Utilities formed a partnership and accessed their respective Network Innovation Allowances (NIA) and invested in PassivSystems to deliver the Freedom Project.

PHASE 1 of the project produced forensic models from which hypotheses of system performance, detailed market assessments and consumer research were derived. In addition, it delivered a four-home pilot installation project to assess the selected hardware, installation contractors and project customer engagement.

PHASE 2 ran over the 2017-2018 heating season and utilised 75 trial homes installed with hybrid heating systems in a mixture of private (including off-gas grid) and social housing. The performance was measured under a number of different operating scenarios. The gas boiler was generally a new highly efficient combination boiler (providing instantaneous hot water), but the trial also encompassed three system boilers with a hot water tank configuration, and a heat pump retrofitted to an existing boiler configuration.

Over the course of the Freedom Project main field trial, a number of interventions were planned where the control strategy of the heat pump was adapted to explore various scenarios and meet the research objectives of the project:

- Different fuel cost ratios (i.e. lower electricity price relative to gas) to explore future price scenarios.
- Fixed patterns of time-varying electricity tariffs and restricted-consumption periods as a simple proxy of the smart grid.
- 'Impulse' experiments to look at the effects of highly simultaneous fuel switching on both electricity and gas networks.
- Forecast average and marginal electricity carbon intensity.
- Aggregated demand management to simulate avoiding the capacity limit of an electricity subnetwork.

The wide range of HHS systems and operation modes means that matching technology and customer profiles could be important. The experiments with optimised controls in this trial explore how a range of these factors across different customer types.

The results from the trial and simulations demonstrate the potential benefits that large uptakes of HHS could have in the UK housing stock. Under current market conditions, uptake modelling by Delta-ee shows that uptakes of HHS are likely to be modest (less than 10% penetration) by 2050 if the flexibility benefits are not valued. Increasing the uptake requires major values to be accessible to customers from optimisation of the energy system.

Current market drivers are not sufficiently strong or focused on cross-vector operation to stimulate the market for HHS. Changes in energy policy combined with new business models could help drive the market to larger scales of deployment.

7.2 Results

7.2.1 Load management

The trial results demonstrate that optimised control of HHS can help manage and limit additional loads on the electricity distribution networks. Conventional air source heat pumps could increase loads by approx. 2 – 2.5 kW per house in a typical winter, rising to 5 kW in extreme winter events. This would require major reinforcement. The trial demonstrates that HHS can be operated to minimise or prevent any additional peak loads on the electricity networks.

7.2.2 Energy costs

The trial examines a number of different future energy price scenarios and tariff structures which drive the control system and determine when the heat pump or boiler operate. Time of use tariffs demonstrated the ability of a relatively simple mechanism to control loads and mitigate any additional peak impacts on the electricity networks.

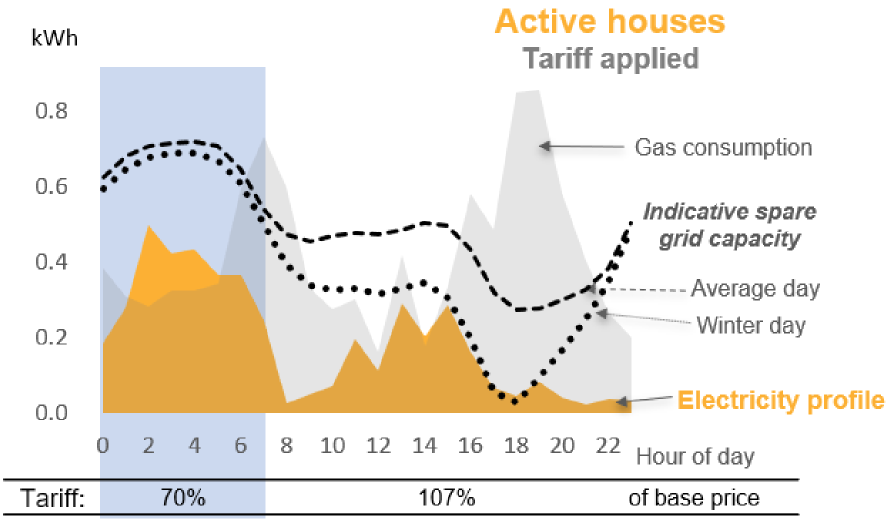


Figure 26 – Indication of the relation between grid capacity, price set point and gas/electricity use. Source: Freedom Project / Delta EE.

7.2.3 Network constraints

Aggregation of the control systems with overall network capacity constraints applied demonstrated the ability of the control system to maintain use of the heat pumps for heat delivery, but with shifting of operation outside the peak periods.

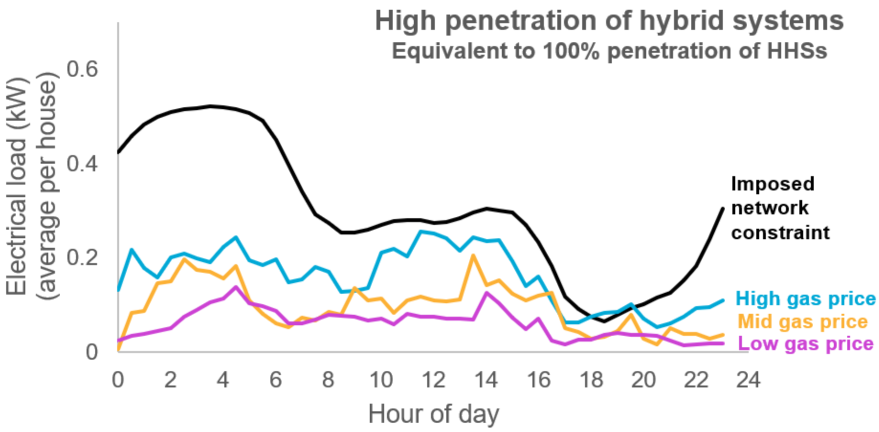


Figure 27 – Effect of network constraints: regardless of gas price, network constrains will be met. Source: Freedom Project / Delta EE.

7.2.4 Consumer benefits

With 100% penetration of air source heat pumps, customers would pay around £50 per year for network upgrades, HHS could reduce this to less than £5 per year if all these systems were controlled to minimise impact on the distribution networks by using gas boilers at peak demand times.

The project found that at today's prices, it is rarely cost-effective on a running cost basis to operate the heat pump; and even in the scenario that gas prices increase by 50%, it is only worthwhile for the heat pump to take 40–50% of the heat load. A 5kW heat pump capacity was sufficient to deliver this heat load – and having a bigger unit could compromise efficiency. Off-gas-grid homes on much more expensive LPG (Calor gas), where the heat pump could offer the householder significant running cost savings and took 78% of the heat load.

Lifecycle costs to households are higher for a hybrid system than for a gas boiler but lower than a conventional ASHP. The energy bill portion (gas and electricity) of the average lifecycle costs are very similar between the hybrid system and the gas boiler comparison. However, the lifecycle cost is much lower for gas boilers due to the capital cost making up the largest proportion of annualised cost to customer for hybrid system and ASHP.

Current consumer gas and electricity prices are hugely unrepresentative of their relative carbon emissions, and 'green taxes' have significantly increased electricity prices, having the perverse effect of pushing consumers away from using electricity generated from renewable sources for low carbon heating. The exception is off-gas-grid homes where there is a large and immediate opportunity.

7.2.5 Energy system benefits

The flexibility provided by having two heat sources from different energy suppliers, combined with the thermal storage inherent in buildings allows a number of different system values to be obtained. The future value of these revenue streams is very uncertain and will depend on how the market evolves and the competition in the market for flexibility services.

Energy system analysis on the basis of the field trial results identifies around £150 in additional value which may be obtained by each HHS system which includes the benefits of reduced electricity distribution reinforcements over conventional air source heat pumps.

The revenue from flexibility services is shown to make a significant contribution to hybrid systems being economically viable, and the additional network costs of the hybrid system are shown to be much lower than for the HP.

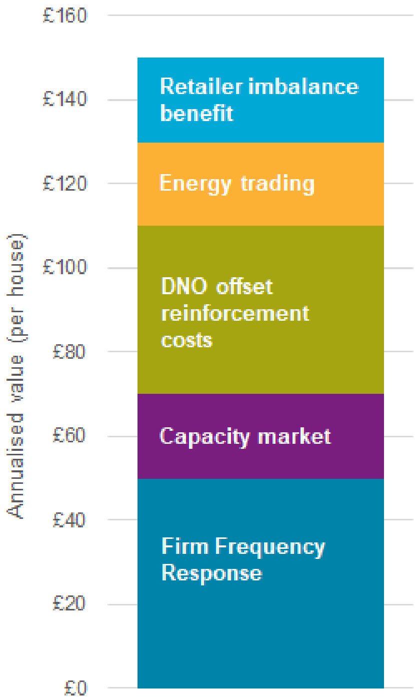


Figure 28 – Value of flexible hybrid HPs for different stakeholders. Source: Freedom Project / Delta EE.

7.2.6 Policy

Current policies, such as RHI, have no requirement for smart controls for hybrid heating systems (or, indeed, for any heat pumps). Project learning has shown that this is a shortfall, as inflexible electric heating is a risk to national infrastructure, compromises carbon reductions and does not give best value to end consumers (conventional hybrid heating controls are quite poor and revenue opportunities are lost).

8 Best heating options compared across building stock for France

The model used in this Annex has been developed by EDF R&D to study the potential of HHP at the scale of a building stock. First, this model has been used to study the installation of HHP on the old oil-fired building stock in France. Three million old houses are oil-fired in France and their energy consumptions are very high (≈17MWh/yr average heating need), and oil is very expensive compared to gas in France (see country report). These reasons make oil-fired houses an interesting target for energy efficiency and renewable energy introduction.

The model is based on a building stock description through houses typologies, insulation levels, and climatic areas. Based on surveys, oil-fired houses in France can be described by 4 houses typologies, 5 insulations levels and 4 climatic areas.

8.1 Model description

8.1.1 Houses typology

Four typologies have been chosen for this study:

- a 60m² mid-terrace house with two floors
- a 100m² detached house
- a 180m² detached house with two floors
- a 220m² detached house with two floors

8.1.2 Insulation levels

In France, houses insulation levels are constrained by thermal regulations since 1974. But most of old oil-fired houses have been built before any thermal regulation but have been retrofitted since. Insulation levels that have been considered are:

- Before RT 74 (1974 thermal regulation)
- Before RT 74 + insulated attic
- Before RT 74 + insulated attic + new windows
- Before RT 74 + insulated attic + new windows + walls insulation
- After RT 74

The building stock is described by associating a representativeness to each case (=a typology and an insulation level) in every climatic area.

8.1.3 Detailed thermal models

A detailed Dymola Modelica model is developed for every study case previously described. Every house is separated in several thermal zones with its own radiator. Emitters are considered well sized in this part of the study. Five heating behaviours have been tested, based on a survey on heating habits. In this detailed model, the energy system is generic and its efficiency is not considered. These models are used to get for every climatic data and every user behaviour the power and temperature level needed to heat the house. The output of this step are 400 yearly studies mixing:

- 4 houses typologies
- 4 climatic areas
- 5 insulation levels
- 5 heating behaviours

From this step, all calculus and modelling are made with Matlab.

8.1.4 Systems and emitters

First emitters sizing is added by correcting the temperature level needed. Two cases are added to the previous one, one “oversized emitters” case, in which temperature needed is lowered and one “undersized emitters” case, in which temperature needed is increased. Then, systems are modelled:

Energy systems are modelled to meet the thermal needs of the building. Different families of systems are represented:

- Boiler only (gas or oil)
- Medium and High Temperature (MT & HT) heat pumps (55 and 65 ° C) (+ electric booster)
- Very High Temperature HP (80 ° C) (without booster)
- MT & HT HHP (55 and 60 ° C) (with gas or oil boiler)

Apart from the boiler alone, which is defined by an average annual efficiency, each system is defined by:

- Design power
- Nominal performance (COP)
- Maximum operating water temperature (HP part only)

Then the performance is obtained by polynomials giving the power supplied and consumed by the heat pump according to the evaporator and condenser temperatures. Crossing systems efficiency with water temperature and heating need scenario allow to calculate the performance of the system.

8.1.5 Electricity tariffs

Another factor that has to be taken into account for the economic study, is the initial electric subscription level for every house and electricity price scenario. In France, different subscription levels exist and different energy costs are associated. We particularly studied the “Base” scenario, which is constant all over the year, and the “Heures pleines/Heures creuses” scenario which is variable. Generally, 8 hours are cheaper every day, late in the evening and in the early morning. For subscription level (power subscribed), a survey gives the ratio of electricity subscription for all typologies. This initial state is important to quantify the extra cost of installing a heat pump in substitution of a fossil boiler.

8.1.6 Fossil fuel tariffs

In France, gas and oil tariffs are constant all over the year. Regarding the gas, the price is depending on the subscription level, which is sized according to the yearly need. For both fossil fuel and electricity, an increase rate is considered to take into account the energy price inflation over the simulation period.

8.2 Modelling of the building stock

The general principle of this study is the drawing of a certain number of cases according to their representativeness in the building stock. For each draw, all energy systems are tested over 15 years and their profitability is evaluated over these 15 years.

First, an insulation scenario is chosen randomly. There is a certain probability that the level of insulation will increase over the 15 years considered. The year this increase is made, is randomly drawn. The probabilities are chosen such as the heating need of the building stock will decrease by a certain ratio over 15 years. For old oil-fired building stock, we consider a 15% heating need reduction.

Weather is chosen and will be the same for the 15 years of the simulation, only the energy price inflation will have an impact on the cost. A basic electrical subscription (kVA level) is chosen randomly but the probability of appearance is such that the representativeness of subscription levels for each dwelling is respected for an important number of draws.

From this stage, the study for each system over 15 years is launched. For each system, the first year, a heating behavior is chosen according to the energy bill. All the calculations are carried out for the considered system (energy produced, energy consumed, invoice...). These calculations are based on the maps introduced previously.

For the following years, the energy inflation rate is taken into account. The insulation level is adapted if necessary, according to the previously defined scenario. If the insulation level does not change from one year to another, the heating behavior remains the same. Otherwise, the procedure is the same as for the first year.

Then, calculations are made to classify systems, for example according to their consumption of primary energy, or according to their full cost. Calculations made include:

- Energy produced and consumed by each system and for each source
- Primary energy consumption
- CO_2 emissions
- Renewable energy ratio
- Return on Investment (ROI)
- Full cost including investment and running cost

8.3 Results on old oil-fired building stock

First, when the study was launched in 2012, on the market, the heat pump part of oil HHP is mainly high power (> 10kW). This sizing generates high investment costs, avoiding the massive diffusion of this technology. Moreover, these important powers are not synonymous with good performance. Indeed, at low outdoor temperatures, the high power does not ensure that the operation is optimal because existing houses often need high water temperature. Then, the HP quickly reaches its operating limits in water temperature and therefore HP is stopped, and the boiler is turned on.

In addition, other product families also have difficulty covering the entire building stock. For reasons of investment cost, VHT (80 ° C) heat pumps have significant return on investment. The ROI is also increased by a low average annual COP due to a 100% thermodynamic operation during the coldest days. An HT HP (65 ° C) can cover a large part of the needs without using its electrical booster but on cold days, performance is degraded. These days, it would be more interesting to heat with a boiler. The over-investment linked to the boiler of a Hybrid HP, lower than 2000 €, is amortized over 15 years.

8.3.1 Specification of a new oil Hybrid HP

Through parametric studies, EDF has defined the specifications for a range of Hybrid Next Generation, more adapted to the oil-heated building stock. The selected range is restricted to two products of 6 and 9kW. The associated temperature level is 63°C maximum in water temperature. The particularity of these products is the use of an injection compressor, allowing to reach high temperature level with interesting performances. The cost objective is about 10000 and 11500 € incl. taxes for the 6 and 9kW solutions fully installed. Results on the building stock are shown on the figure below.

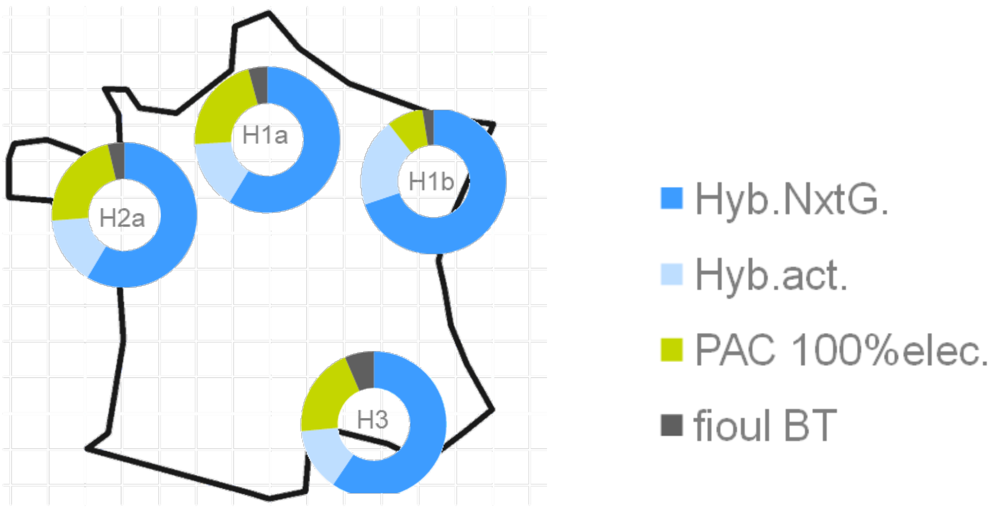


Figure 29 – Schematic picture of potential for hybrid next generation heat pumps throguhout France.

In 60% of the cases, this optimized hybrid system is economically the best replacement solution for an old oil boiler (full cost over 15 years investment + operation). The study carried out and the associated specifications were presented to many manufacturers, present or not on the oil hybrid market. The first effects have already been observed since the minimum power ranges offered by manufacturers have been reduced.

9 Barriers to market growth

Hybrids take up a market position between fossil-fueled boilers/furnaces and all-electric HPs. There are many valid reasons to advocate hybrid solutions at least as a partial step towards completely renewable heating for houses. At the same time, hybrid systems are no *silver bullet* solution to achieve renewable heating.

Policy goals for the use of hybrids strongly differ across participant countries in this Annex. Hybrids are typically seen as a transition solution, with perhaps a small percentage of houses retaining hybrid heating systems in the long run. Specifically in the UK, hybrids are expected to play a major and lasting role in the energy system.

To stimulate a realistic role for hybrid systems within the energy transition and the future energy system, some support will be necessary. We have identified four main potential barriers for further market development of hybrid HPs.

The typical uses cases for hybrid HPs are very different depending on the local circumstances. It is therefore not very helpful to define very specific policy recommendations. The list below gives some examples of good practices to maximize the positive impact from hybrid HP systems.

Acknowledge hybrid HPs as a valuable option for transition to 100% renewable heating

Any successful policy regarding hybrid systems needs at least acknowledgement of their existence and possible usefulness in the energy transition. At the most basic level, it should be ensured that hybrid systems are covered – just like other renewable heating options – in

- Building regulations
- Incentives for renewable heating
- Product regulations such as ErP
- Testing standards
- Information campaigns

In some cases, hybrids may be the only option to realize at least a partly renewable heating source for domestic housing

In specific cases, it will be impossible to introduce low-temperature heating into houses. These houses may be heated using collective systems or district heating using specialized heat pumps, geothermal energy or fossil-free boilers. However, such projects may be prohibitively expensive. For these cases, hybrid systems (eventually combined with fossil-free fuel) may prove to be the only viable solution in the long run.

Hybrid HPs may serve as a transition technology, but also as a useful introduction for customers to gain experience with heat pump systems

Although hybrid systems provide their own set of advantages, both as a long-term solution and as a transition technology, an important spin-off for other types of HPs can be expected.
Because hybrid technology offers a *fail-safe* way to introduce HPs in existing homes, important experience can be gained for wider HP deployment. Consumers and installers alike will have the opportunity to develop best practices for HP applications. Because hybrid HPs have a wide application range, they may help to greatly speed up the market growth for <u>all types of heat pump systems</u>.

Make plans to stimulate the use of hybrid HPs and identify country-specific use-cases and market drivers

Typical use cases for hybrid systems differ greatly according to local circumstances (see section 3.5). Therefore, it is necessary to explore the application areas for hybrid HPs at a country level and develop appropriate stimulation measures and regulatory frameworks where necessary.

In particular, the role of hybrid HPs as an enabler and kick-starter in the transition to 100% renewable heating should be acknowledged. The potential for CO_2- and cost savings, targets for market growth and number of installed units should be made explicit.

A Expert meeting 5 October 2017

In 2017 an expert meeting has been organized by the Annex participants. The goal of the meeting was to gather and discuss expert opinions on developments in the hybrid HP market and the possible role for hybrids in the energy transition. The sections below give an overview of the discussion topics. The identification of these topics alone has been a clear signal from the expert community as to which areas that need policy discussion, support and decisions.

> This appendix presents the results as written down by the discussion table leaders and has been included for reference. No editing was done.

A.1 Business models/economics and costs

Economics will play an important role in the roll out of hybrid heat pumps. Explanation is needed to the end-user that in a situation with low upfront investment with increasing volatile variable energy costs, we face considerable higher upfront costs, with much lower and less volatile energy costs. Inspiration can be found in the use of hybrid powered cars, which require also more understanding about the changing economics for the potential buyer.

Resuming one can conclude that without thorough explanation to the end-user, (hybrid) heat pumps will not ‘fly’ in big numbers. Proper, reliable communication is paramount.

Some perspectives from the participants at the table:

- Early adaptors go for drives as ‘green, comfort and futureproof’, and to far lesser extent for economic considerations. The mass market will be less ideologically influenced and look strictly at the numbers.

- The ratio between natural gas and electricity is quite unpredictable and might spam the process unforeseen, and more or less uncontrollable. Energy tax or CO_2 tax will be essential elements in the near future.
- Avoiding the obstacle of upfront investment might give heating as a service (Without any form of heating grid) finally a serious opportunity.

A.2 How to convince the customer?

The exact answer to this question wasn't found this morning. We had an open dialog about barriers and solutions. The biggest problem at the customer side is that they don't see a problem yet. Should a customer feel guilty when he takes a shower? (or should he take a shower when he is filthy?) The biggest barriers in the transition to a gasless house are:

- Not known with technologies or options
- No urgent yet
- Happy with gas stove
- Big and ugly outside units
- Afraid of change
- Outside units look like air-conditioning units with a negative image
- High investment
- ….

In our dialog, we agreed that the barriers are more important to reduce than focusing on solutions or technologies. Information and communication are key in this process. There are multiple directions to get customers thinking about buying a heat pump. At the moment that his gas boiler is in malfunction, subsidies, urgent caused by earthquakes and mister Putin etc. Customers prefer to make small steps for example first solar PV after that LED lights and later maybe a hybrid heat pump. The risk of taking these little steps is the law of the inhibitory advantage. (wet van de remmende voorsprong) For example, a customer has an energy bill of €200/month after placing solar PV, LED and a hybrid heat pump his monthly bill is €35/month. That last step to go all electric will probably not be made caused by a higher monthly energy bill. When a customer would make the switch to all electric in the first place, he would be happy with an energy bill of €80/month for example.

A.3 The role of green gas

There are way more renewable gasses than only green gas. There is bio-methane, syngas, synthesis gas, hydrogen and so on. Question was: why hybrid heat pumps when there are so many different gasses to decarbonise the current system? The answer to that is those gasses are still quite hard to produce in large numbers, so you need hybrid heat pumps to reduce the demand for gas in the residential areas if you want to reduce the emissions of CO_2 fast enough.

Also: in the future gas will be primarily used as a safety net for when there is no other sustainable source available, like, for example, in cold winters without wind- and solar power.

A.4 Hybrid heat pumps vs. other heating technologies

Every technique has its own use in the decarbonisation of our planet. Because of that, there is no need to 'hate' on each other, as all options strive for the same goal. For the transition it is crucial to acknowledge that it's hybrid heat pumps <u>and</u> other technologies, instead of versus.

A.5 Is the hybrid heat pump a final solution or a transition solution?

This subject seems for the participants at the table very relevant, because it also shines a light on the (longer) future perspective of the technology. And its relevance is clear if people ask themselves, why not go to an all-electric solution now, instead of a transition solution.

Resume of the discussion:
Hybrid heat pumps do have serious potential for being an end solution, provided there is an adequate availability of non-fossil gas available for the domestic building stock.

Some perspectives came across during the lively discussions:

- Even in the max scenario there will be not enough renewable electricity for total electrification of the heating demand (For ease of reference domestic hot water is included in this term) within the next decades;
- Availability and allocation of non-fossile gas might not be a subject for market forces, but for governmental policy;
- The public perception of 'clean electricity' versus 'dirty gas' can be an obstacle for factbased choices;
- Hybrid heat pumps can help avoiding the formidable cost involved with huge back-up power plants which are a requirement in a 100% all-electric scenario (Which for years on will be at least natural gas fired, since nuclear is no option in most countries);
- Final solution or in-between varies per country, influenced by amongst others the type of energy structure, energy tax regime, power generation type and population density

General remark:
The discussion took place based on the knowledge and paradigma of each participant at this very moment. The statement was made that turning the Energy Agreement of Paris into legislation will change the playing field even more. Where the resume of this table will not change, even perhaps becomes more valid.

A.6 Who decides and who benefits?

The first part of the discussion was about getting to know each other and hear about the common interest between supplier, grid operator, energy company and government.

How can you upscale the market for hybrid heat pumps? What are the assumptions?
Do you need a gas grid for housing market?

Yes, if you can build up a gas framework as backup for sustainable energy supply.
No, when the grid operator has to pay for (re)developing the gas grid.

Second part of the discussion was about who has the strongest lobby to the government:

Gas, district heating?
What about insulation market and the heat pump association?

Is a new business model for the Dutch government instead of gas income possible?

Tax incentives
E mobility tax incentives are leading. In our case a tremendous investment in infrastructure is needed, or is it fixed by smart grids and demand control?

At the end there was a small survey about the question: who decides.

most on the table recognize: the end user, guided by economic considerations

France put the government first
And UK suggested that research may help to change the government strategies & incentives.

A.7 The value of flexibility

There are two main source of value creation: balancing the "copper plate" and helping to manage congestion in the transmission or distribution grids.

Unfortunately, this value is currently difficult to turn into cash flow:

- Copper plate is difficult as hourly prices are often not reflected in consumer prices, and if they are, they represent a very small part of the price compared to taxes and other fees and tariffs
- Congestion management is – at the distribution level – mostly not allowed for residential consumers and almost never rewarded with cash payment.

Even if these barriers have been removed, it is still necessary for the business case to work to combine the income from these two different sources.

A.8 What can go wrong applying hybrid HPs

Critical points:

- Bad sizing and
- Bad implementation
  To be solved by:
  - Experienced installers: Education/Q-certificate/guidelines
- Large dimensions – much space needed
- Investment costs
- Control system does not work, especially critical when not integrated in one package of HP and gas boiler (add-on HP)

Stimulating options:

- Monitoring system -> more awareness of the user
- Switching point (T-bivalent) optimized by minimal CO_2-emission or by minimal energy costs

Special issues in France:

- Hybrid HP not successful until now – will change because:
  - Permission to use Energy Saving Certificates is granted to hybrid HP
  - Tax credits for oil fired boilers is no longer valid
- Overall implementation of all-electric systems causes no problem with the grid

Special issues in the Netherlands:

- Change the message – not necessarily follow the trias energetica (Chael Kruip)
- Dimensions too large for small apartments
- Low awareness of the possibility of applying hybrid HP

Other issues:

- Inflammable refrigerants

Opportunities:
District Heating (DH) as a threat -> DH as an opportunity: switching to LT district heating + applying booster-HP; booster HP can be used at building level (collective heating systems) and/or in individual DHW-systems.

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