Technology Collaboration Programme

by iea

Technology Collaboration Program on Heat Pumping Technologies (TCP-HPT)

HPT-Annex 46

Domestic Hot Water Heat Pumps

Annex 46

Market Overview

of

Sanitary Hot Water Systems

Compiled and edited by Onno Kleefkens M.Sc.

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Heat Pump Centre
c/o RISE – Research Institutes of Sweden
Box 857, SE-501 15 Borås
Sweden
Phone: +46 10 16 53 42

Website

https://heatpumpingtechnologies.org

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Production

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Preface

This project was carried out within the International Energy Agency Technology Collaboration Program on Heat Pumping Technologies (HPT TCP).

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 Program. 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 Program of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

Disclaimer

The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programs or TCPs. The TCPs are organized under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

The Technology Collaboration Program on Heat Pumping Technologies (HPT TCP)

The Technology Collaboration Program on Heat Pumping Technologies (HPT TCP) forms the legal basis for a Program of research, development, demonstration and promotion of heat pumping technologies. Signatories of the TCP, called participating countries, are either governments or organizations designated by their respective governments to conduct. The Program is governed by an Executive Committee (ExCo), which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

Annexes

The core of the TCP are the "Annexes". Annexes are collaborative tasks conducted on a cost-sharing and/or task-sharing basis by experts from the participating countries. Annexes have specific topics and work plans and operate for a specified period, usually a number of years. The objectives range from information exchange to the development and implementation of heat pumping technologies. An Annex is in general coordinated by an expert from one country, acting as the Operating Agent (manager). This report presents the results of one Annex.

Triennial Heat Pump Conference

The IEA Heat Pump Conference is one of the three major products of the Technology Collaboration Program on Heat Pumping Technologies. The Executive Committee supervises the overall organization and its quality and selects from a tender procedure the host country to organize the Conference and establishes an International Organization Committee (IOC) to support the host country and the ExCo.

The Heat Pump Centre

The Heat Pump Centre (HPC) offers information services to support all those who can play a part in the implementation of heat pumping technologies. Activities of the HPC include the publication of the quarterly Heat Pumping Technologies Magazine and an additional newsletter three times per year, the HPT TCP website, the organization of workshops, an inquiry service and a promotion Program.
The HPC also publishes results from the Annexes under the TCP-HPT.

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

Heat Pump Centre
c/o RISE - Research Institutes of Sweden Box 857, SE-501 15 BORÅS, Sweden
Phone: +46 10 16 55 12

Disclaimer

The information and analysis contained within this summary document is developed to broadly inform on worldwide developments. Whilst the information analysed was supplied by representatives of National Governments, a number of assumptions, simplifications and transformations have been made in order to present information that is easily understood. Therefore, information should only be used as guidance.

The market of domestic hot water heat pumps (DHWHP) is developing fast and at the moment of publication some information can already be overtaken by new developments. There are some websites listed at the reference pages of the report.

In compiling, editing and writing this report I would like to thank Kashif Nawaz (Oakridge National Laboratories, USA), Cordin Arpagaus (NTB Interstaatliche Hochschule für Technik Buchs, Switzerland), Justin Tamasauskas (CanmetÉNERGIE/CanmetENERGY, Canada), the Japanese National Team under Kyioshi Saito (Waseda University, Japan) and Neil Hewitt (Ulster University, UK).

Disclaimer

The views expressed in this report do not necessarily reflect those of the individual project participants.

Summary

The Annex's available resources had laid restrictions on the overall ambition of the Annex. Some of the topics which should or could be tackled were where possible handled under national governance, where often no budget was available as the goals did not fit into a running national program. Starting from the overall idea that the focus for the Annex on Heat Pump Water Heaters would concentrate on the mono-bloc air source heat pump water heater as the preferred solution in most cases, the market reality of sanitary hot water generated with heat pumping technologies showed a greater complexity than assumed at the start of the Annex.

Water heating for domestic appliances and other sanitary functions appear in single units for an individual end user and in collective units in larger systems/buildings. When speaking about Heat Pump Water Heaters generally we are speaking about the mono-bloc air source heat pump, defined as a single unit with heat pump (with compressor, expansion valve, evaporator and condenser), with a storage tank integrated often under the heat pump underneath. Mono-bloc systems will remain the preferred solution in most cases. However there is a great number of alternatives on water heating with heat pumps, other than the mono-bloc. There is a great number of alternatives for sanitary hot water with heat pumps in domestic applications, other than the mono-bloc, for single family houses and multifamily buildings, and in heat pumps for sanitary hot water systems for hotels, hospitals, sporting facilities, etc. have a large number of technologies with regional differences in demand and usage, thus showing a greater complexity than space heating/cooling systems.

In essence however these hot water systems consist of a heat generator, an insulated storage system/tank and a system distributing the hot water to draw off points or heat exchangers in a smaller system at a required temperature, more than often dictated by legislative requirements.

Throughout the developed world, the heating of water for domestic use is one of the largest consumers of energy in the household sector (10 to 20% energy share).

The actual energy consumed is impacted by consumer usage patterns and ambient environmental conditions. Such complexity creates a number of challenges for policy makers seeking to understand and effectively manage water heating energy consumption (source IEA 4E). Mandating the installation of high efficiency water heaters is the main policy tool used to ensure that high efficiency water heaters are installed regardless of any short-term inconvenience issues. Mandated measures can be:

- prohibiting inefficient water heaters from sale by setting clear efficiency standards;
- prohibiting low efficiency water heaters from being installed;
- requiring certain high efficiency technologies, such as solar water heaters, to be installed.

Applying heat pumping technology as one of the possible heat generators is still having a relatively small market with a much larger potential. The heat pump water heater (HPWH) market is characterized by the presence of several well-diversified international, regional, and local vendors and is highly fragmented. The regional and local vendors provide customized products at comparative prices and pose a stiff competition to the international players. However, they find it increasingly difficult to compete with the global vendors in terms of quality, features, and services. The level of competition among the market players will intensify in the coming years due to the increase in product extensions and technological innovations. The international players will also acquire regional or local players.

There is a clear segmentation in the residential market where:

- HPWH are installed in single family buildings, these are mainly monobloc air source heat pumps with large storage tanks and applied in the top-end of the market

- In Japanese market, HPWH for single family buildings are mainly split type called ECO-Cute.
- HPWH are installed in multifamily buildings, which are often high-temperature heat pumps in collective systems

However, there is a great variety of alternatives.

Contents

1. Introduction

The heat pump markets are currently growing at a steady pace. Energy prices and environmental concern have set the focus on energy conservation and use of renewable energy sources. Heat pump markets and policy in many countries have focused mainly on residential heat pumps for space heating.

While the residential market may be satisfied with standardised products and installations for space heating, this is not the case for Domestic Hot Water. Within a growing market in many of the IEA-countries for Domestic Hot Water Heat Pumps, there is still a large potential for energy optimisation and conservation and reduction of CO2-emissions, which are overlooked in policy papers and do not get market attention. Hot water systems in its appearance in domestic applications and sanitary systems for hotels, hospitals, sporting facilities, etc. have a large number of technologies with regional differences in demand and usage, thus showing a greater complexity than space heating/cooling systems. In essence however these hot water systems consist of a heat generator, an insulated storage system/tank and a system distributing the hot water to draw off points or heat exchangers in a smaller system at a required temperature, more than often dictated by legislative requirements.

In this hot water system the heat pump is one of the possible heat generators, still having a relatively small market but having a large potential.

In industrial countries, buildings account for some 40 % of the final energy consumption. A vast majority of this is the energy used for central heating. Nevertheless, as the numbers of modern constructions increase, whose building shells are very well insulated, the focus is shifting to the energy demands of hot water consumption, which is a steadily growing proportion in the energy footprint of a building. However, since central heating and the supply of hot water are traditionally linked systems in buildings, it remains unclear what the energy demand for warm water actually is, how this is influenced by usage of the building, and how it can be met with energy efficiency.

Domestic Hot Water Heat Pumps (DHW HPs) are heat pumps designed for the production of hot water only, traditionally used for bath/shower and kitchen. These types of heat pumps have been a growth engine for the European heat pump market in the last 2 years, growing to the tune of 30% per year against a trend of slight decline in the wider heat pump market. A doubling in the market size for DHW HPs is foreseen by 2017, particularly driven by the electric water heater replacement market and oil boiler upgrade market. That is not only the case for Europe; it is also seen as a market trend in the US, Japan and China, with great potential in Canada [9]. In combination with solar-photovoltaics, DHW HPs are overtaking and out phasing the market for solar thermal systems in Germany. However, for low energy housing, solar thermal systems can be excellently combined with DHW HPs. France will continue to be the biggest market with a growth rate in 2014 of 50%, but opportunities are growing in several other markets including Germany, Sweden, Poland, Benelux, Italy and Spain – if the right products and customer propositions emerge.

The largest potential for DHW Heat Pumps is in applications for:

- Replacement of direct electrical heating of DHW in existing buildings, individual domestic buildings, terraced houses in private ownership. This is an interesting market for Sweden and US.
- Replacement of collective DHW systems in apartment blocks and multifamily buildings by individual DHW generators in collective ownership as rented flats. This is an interesting market in large parts of Europe.
- In combination with air conditioning systems where the condenser heat is used for water heating with markets in Japan, US, Italy, Spain, China, Korea, etc.
- In combination with solar thermal systems, DHW HPs are of interest in nearly Zero Energy Buildings and in existing buildings

In the domestic space heating and cooling market the combination with DHW in one combi heat pump is a state of the art application in Europe. In these cases it is not a question of an individual DHW HP but of a combi heat pump with a storage tank.

Due to a strict governmental policy on energy performance for new domestic buildings, the inherently better insulation, and higher comfort demands for domestic hot water (DHW) by the end user, DHW is dominating the overall energy use of the house.

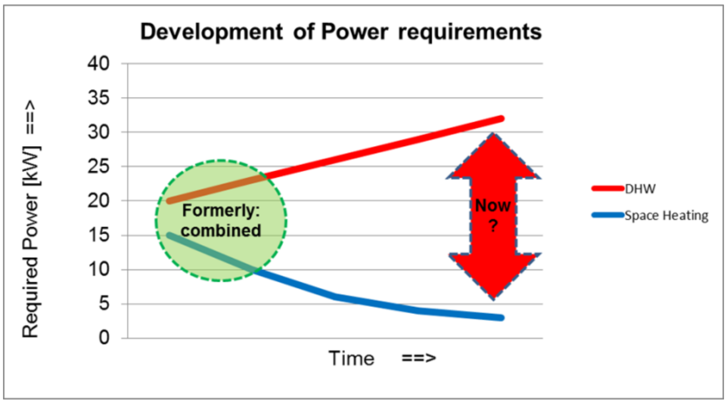


Figure 1.1: Trends in direct capacity demands of DHW and space heating

Although the overall potential is smaller than for existing buildings, the concepts need an integral approach to optimize the overall system. These types of new buildings and designs, which fit into smart-grids where the storage capacity of the DHW-tank gives added value, is a new market. This work is laid out under Annex 42 ‘Heat Pumps in Smart Grids’.

In choosing the right DHW system a high performing and efficient generator is the basis. However, the overall system efficiency depends on more than the efficiency of the generator alone. While the end user may only be interested in the efficiency of the apparatus, energy policy is concerned with the complete chain from primary (fossil) energy to the end user, and overall efficiencies have to be compared; the benefits of a highly efficient generation device can be nullified by poor system integration and large storage or distribution losses. This is a crucial point in the development of an energy neutral society within a smart energy infrastructure.

New ways to heat hot water independently from central heating are domestic hot water heat pumps (DHWHP), competing with other heat generators.

Market readiness means the ability of the market to adapt to a new technology. This factor influences backwards on legislation as no country would close down its own market due to lack of service competences for new technologies. Education plays a significant role in making markets ready for introduction of new technology. As an example, however, not directly connected with refrigerants, an on site monitoring of heat pumps in the Danish market showed that a surprisingly high number of heat pumps yielded a far too low COP. The reason was to be found in installation and setting of the heat pumps where installers did not understand the relationships between the temperatures and COP. The same scenario could be valid for CO_2 systems where energy efficiency depends heavily upon system settings. Not meeting expectations is poison for a new technology - a second chance will often not be given. Education and Training are today recognized as some of the most important factors for introducing low GWP refrigerants in the markets

2. Markets

In Europe the sales of air to water heat pumps is the fastest growing segment at a growth rate of 21.5% over 2007 to 2010, reaching 1.3 million units in 2010 from an estimated 730 thousand units in 2007. Further, volume sales of air to water heat pumps were likely to surpass the other heat pump categories by registering a 2014 to 2020 compounded annual growth rate of 13.6% in some regions. The significant change of the market is the continued boom of sanitary hot water or cylinder-integrated air-to-water (ATW) heat pumps, whose sales continue to boom in France, registering the highest growth of around 34% compared to 2011, with an estimated sales of over 36,000 units in 2012. The recent 2018 report by the European Heat Pump Association shows that after one year of reduced growth in 2017, the dynamics of hot water heat pumps have picked up speed again with an overall growth of 13.4% [10].

Outside Europe, sales of cylinder-integrated electric storage heat pump water heater (HPWH) units have expanded in the United States to reach an average of almost 70,000 units annually in 2017-2018, almost 2% of the total annual electric storage water heater sales[1].

Especially air-to-water heat pumps are mostly used for generating hot water in China. The Chinese market rose to RMB 4.8 billion (US$ 780 million) in 2012, growing by 10.5% over that of previous year. Recent years, DHW HP based heating is increasing. In 2012, more than 15 heat pump companies launched their air-to-water heat pumps for space heating.

However, these growth rates, the worldwide market for heat pump water heaters is still small compared to the other types of water heating equipment sold. Even with the big success recently of the ECO-Cute in the Japanese market, the market share in 2014 was 12.3% of the overall hot water heating market. In Japan, hot water heating is not so common. The majority of hot water use is for bathtubs.

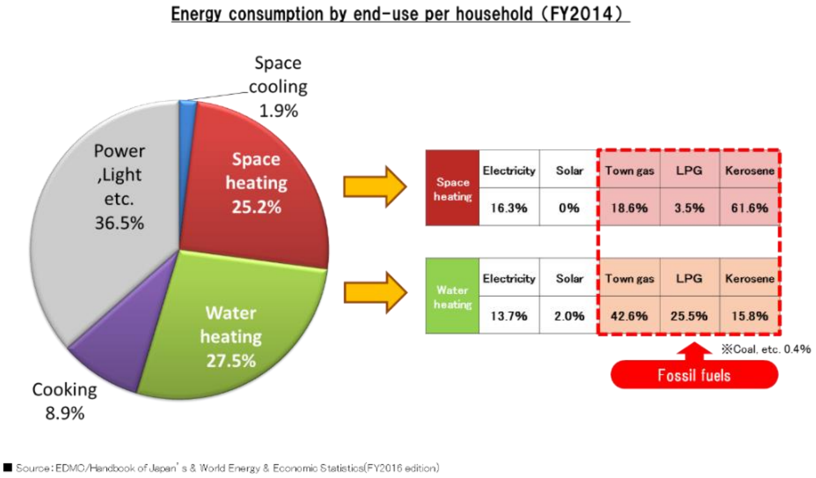
[1] https://www.energystar.gov/index.cfm?c=partners.unit_shipment_data

2.1 Asia

In Asia, the four major markets are Japan, South Korea, China and India. The market trends and figures given here are from the two country reports by the participants and from sources in the network of experts from the 12th IEA Heat Pump Conference.

2.1.1 Japan [04]

In Japan, the Eco Cute hot water heat pump using CO2 as a refrigerant has been a run-away success over the past decade. The substantial shipment growth was the result of support by the "Introduction Subsidy Scheme" initiated by the Japanese Government in 2002 to subsidize a part of the cost for introduction of heat pump water heaters. This scheme is, however, not currently implemented. The support scheme serves as a best-practice policy example for other national markets



If energy consumption is segmented by application, water heating accounts in the residential sector for 27.5%, of the overall energy use. This is almost the same as for space heating and air-conditioning (Fig2.1). In commercial buildings, 12.6% of the energy use is for water heating and 26.2% for space heating and air-conditioning.

Fig 2.1 – Energy consumption per household (2014)

For both cases of household and business use, approximately 90% of the energy source for water heating is fossil fuel.

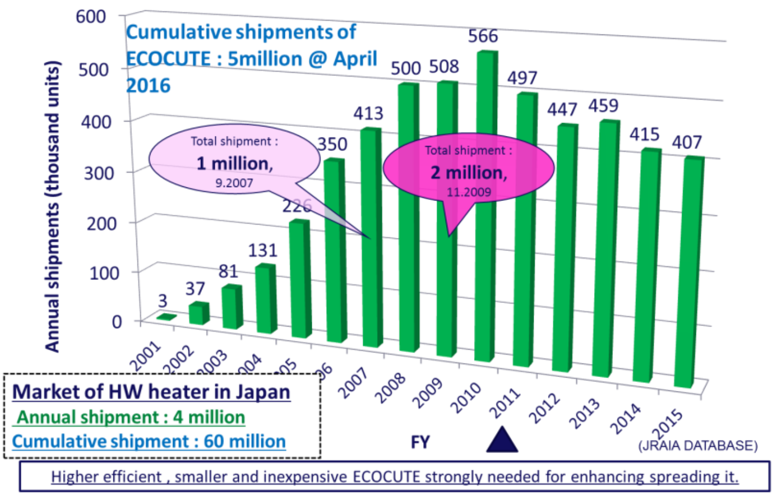


Fig 2.2: Transition of Shipment Volume of EcoCute (Source: Statistics of the Japan Refrigeration and Air Conditioning Industry Association)

According to the statistics, the shipments of ECO Cute HPWH's for residential use started around 2001. By the end of February 2015, an impressive 4.7 million units were expected to be installed in Japan alone with annual sales at 400,000-500,000 units per year, reaching a market share of 98% of all new residential heat pump water heaters in the country. By 2020, the Japanese government aims to reach 10 million Eco Cute units. The annual shipment volume declined and has been hovering at the 400,000-unit-level since 2012 due to the impact of the Great East Japan Earthquake.

There are three types of gas water heaters such as "only hot water supply", "hot water supply and bathtub reheating", and " hot water supply, bathtub reheating and room heating". The market sizes are 1 million, 1.1 million, and 0.35 million respectively, of which high-efficiency water heaters (Latent heat recovery type water heater) are 80,000, 40,000 and 250,000. The market sizes of oil water heaters, electric water heaters and HPWH are 400,000, 100,000 and 450,000, respectively.

Compared to the market size before the release of ECO-cute, the gas water heater has kept their market. There were 750,000 oil water heaters and 250,000 electric water heaters. Oil water heaters decreased by 350,000 units, and electric water heaters decreased by 150,000 units. These decreases are replaced by ECO-Cute.

Domestic heating is mainly air heating such as air conditioners and oil heaters, and the water heater type is only used in a limited area. This is because users usually stop heating completely when they are absent and start operation when returning home, and although hot water dash function and other improvements can be seen, it is not well accepted by the market.

In the residential market there is the need for downsizing, noise reduction, and cold weather specifications as well as higher efficiency and lower price.

2.1.2 South Korea [08]

As a newcomer, South Korea also makes various efforts to expand the heat pump market. Although the heat pump market continues to expand recently, domestic market is still staying in the poor level. In domestic heating space market, residential gas or oil boilers have accounted for 60% traditionally, however the market of heaters using heat pump water heater is growing recently and it makes up a 140 million US$ market in 2012. Recently KEPCO has launched a new program to promote heat pump water heater with a thermal storage for mid-night electric tariff program in order to replace the existing resistance electric heater, which can be expected to trigger a new market.

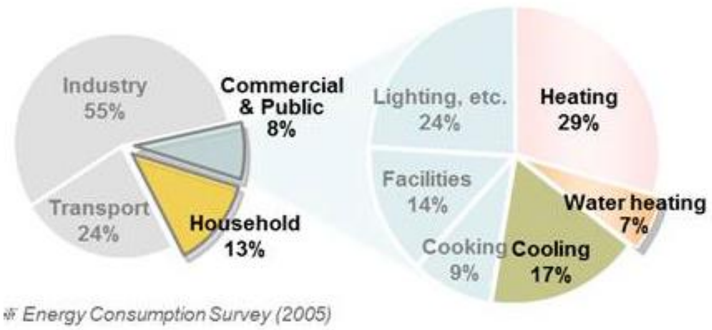


Fig 2.3: Energy use in Korea

Korea has a unique “Ondol (Korean floor heating system, http://en.wikipedia.org/wiki/Ondol)” culture such that almost 100% of households choose under floor heating systems that circulates hot water coming from gas or oil boilers through the floor. This system also provides hot water supply for sanitary use. Thus the vast majority of sanitary hot water is provided through gas- or oil-fired combi-boilers. A room air conditioner for cooling and a gas boiler for heating is typical heating system in Korea households. Korea is the 2nd largest gas boiler production country after UK. The South Korea heating system stock is dominated by gas and oil boilers, which account for 57% and 26% of the energy consumption in 20085. In recent years, condensing gas boilers have replaced oil boilers due to aggressive advertising and recognition of their greater energy efficiency.

At present, around 15.7 million South Korean households are connected to the gas grid, with 12.2 million households – that is, almost all – using gas-fired heating appliances. The government is in the process of expanding the gas grid further. The South Korea heating system stock is dominated by gas and oil boilers, which account for 57% and 26% of the energy consumption in 20081. In recent years, condensing gas boilers have replaced oil boilers due to aggressive advertising and recognition of their greater energy efficiency.

2.1.3 China [23]

In 2015, ASHP water heaters only achieved a growth of some 6.5% over 2014, a marked drop from the growth rate of more than 20% in 2014 and 2013. Regarding the proportion of household machines and commercial machines for domestic sales, household machines for domestic sales saw a further increased proportion and their quantity of sales reached 1.232 million units, up 11.4% from 2013.

In terms of market structure of ASHP water heaters, household appliance brands performed very well in 2015, of which traditional players like Midea, Haier, A.O.Smith, etc. shared close to 50% of the total market. Moreover, household appliance brands had a higher growth rate over dedicated brands, so the latter face an increasingly intensified survival pressure. Although household appliance brands aggressively seize the market due to their higher concentration, dedicated brands are not to be outdone, which have also been making steady progress following dedicated brand leaders like New Energy, Outes and Phnix. The substantial quantity helped dedicated brands secure about half of the entire market as well.

Of the whole hot water market, ASHP water heaters accounted for about 3% of domestic water heater market (in units) in 2015, showing a huge potential growth room. However, due to higher product worth, their sales accounted for about 10% in terms of worth.

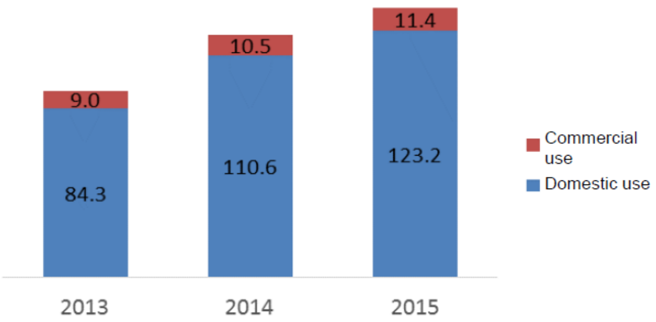


Fig 2.4 2013-2015 Domestic Sales of China's ASHP Water Heaters (in 10,000 units)

Household ASHP water heaters were still dominated by 150litres and 200litres products in 2015, their combined sale volume accounting for more than 85% of the total and their growth rate being higher than other capacities. Unpopular models dropped somewhat in sale volume in 2015 as a result of increased market competition. Mass production is the inevitable way for the development of household products, and it calls for reduction of product costs and gain more market acceptance. Currently, the industry prefers using 150L and 200L as the main models of household machine products, and efforts are also made to build various systems around large-scale development of the two mainstay products. Therefore, the continued growth of the two products in 2015 was in line with the development trend of the industry, driving up product concentration further.

Year	China AHPWH Domestic sales (billion CNY)		
2013	4.98	Household	843,000 Units
		Commercial	90,000 Units
2014	6.32	Household	1,106,000 Units
		Commercial	105,000 Units
2015	7.15	Household	1,232,000 Units
		Commercial	114,000 Units

**Data source, China Heat Pump Alliance.*

From 2015 onwards domestic heat pump water heaters using CO_2 refrigerant also started to enter the market.

Table 2.1 DHWHP ales in China [25]

A great breakthrough in policies for air source heat pump hot water system in 2015 was that the departments of housing and urban-rural development at provincial and city level began to approve including air source heat pump hot water systems into renewable energy sources, and specified its accounting method through a series of regulations. As an example in 2015, the Department of Housing and Urban-rural Development of Zhejiang Province further specified that “It is preferable to use renewable energy systems such as solar thermal system, air source heat pump hot water system, etc.” in the Design Standard for Energy Efficiency of Residential Buildings, in the “renewable energy design” section of which, “It is suitable to use air source heat pump hot water systems within Zhejiang province, particularly in the south of Zhejiang like Wenzhou, Taizhou and Lishui” was also specified.

2.2 North America

For North America the trends and developments in the United States and Canada are reported upon. Reports for Annex 42 are used as well as presentations from the 12th IEA heat Pump Conference.

2.2.1 United States [06]

Figure 2.3 from the EIA’s Commercial Building Energy Consumption Survey, shows that 55% of commercial buildings heat water with electricity while 42% heat with natural gas (trend reversed from residential buildings). Similar to the residential market, fuel oil only has a notable market share in the northeast where 14% of commercial buildings use oil for water heating. District heat and propane both have small single-digit market shares as fuel sources for water heating in all regions. Only 1% of buildings use district heat for water heating, but 9% of fuel consumption nationwide for water heating of commercial buildings is from district heat.

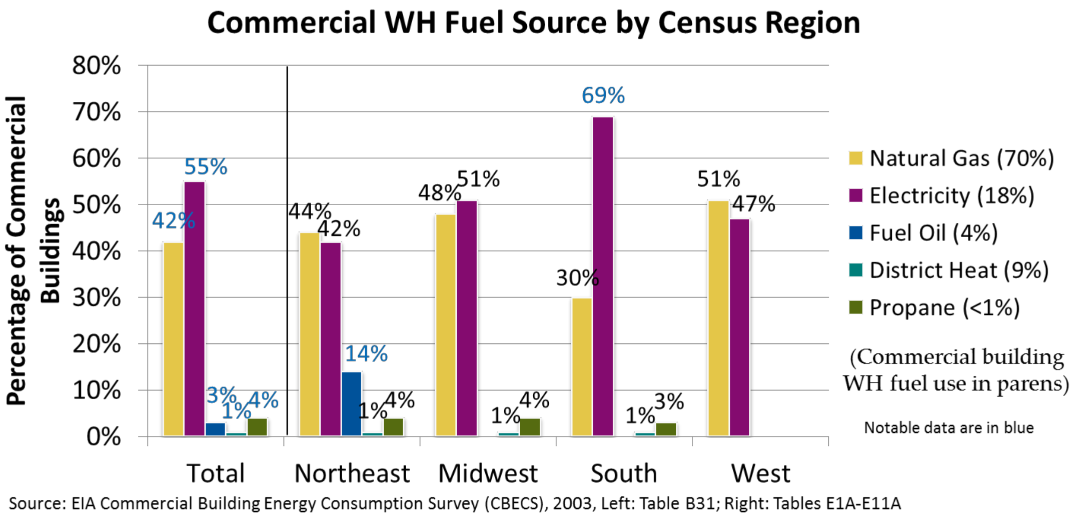


Figure 2.5 Commercial Water Heating Energy Consumption by Fuel and Region

As with residential applications, tankless water heaters are gaining some traction, particularly in small commercial buildings, such as restaurants. One or more tankless water heaters can be installed close to the load to provide an efficient overall solution. In large commercial buildings, such as offices, tankless point-of-use water heaters may be utilized for distributed system architectures where a single unit may serve a single restroom. However, tankless units are commonly used for large central systems in large buildings (small commercial buildings, such as restaurants, may utilize a bank of multiple tankless units in parallel to serve their load) Condensing technology is available on natural gas and propane/LPG water heaters in both storage and tankless configurations.

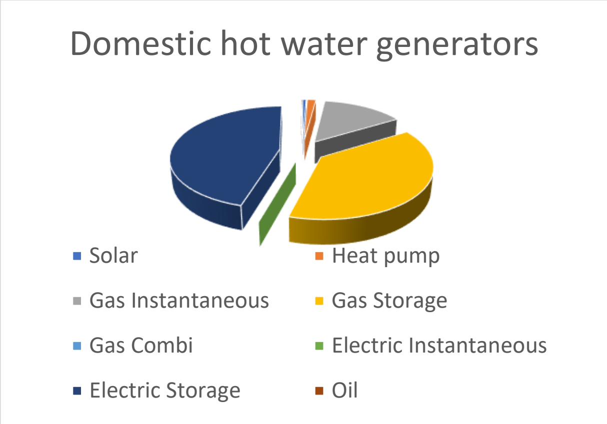


Fig 2.6 Types of Domestic Hot water heating in USA

Though solar and other renewable thermal water heating technologies (e.g., ground-source heat pumps, biomass) maintain a small market share (<1%), they have had increased attention from efficiency advocates. The federal government's 30% residential renewable energy tax credit, which includes solar water heating, along with many state and utility incentive programs have boosted awareness and grown the industry. Increased attention at the state and regional level on renewable thermal technologies continues to spur the industry. Improvements in integrating solar hot water systems with solar space conditioning and thermal storage will boost the interest in this technology.

Multiple manufacturers have begun selling HPWH's in recent years, making them widely available as a high-efficiency alternative to traditional electric resistance water heaters. Before establishment of the ENERGY STAR HPWH rating in 2009, HPWH's were not readily available in the US Market. ENERGY STAR-specified electric waters heaters must meet or exceed either an Energy Factor (EF, the standard efficiency measure prior to 2015) or a Uniform Energy Factor (UEF, the current standard efficiency metric) of 2.0, achievable only with HPWHs. The UEF of currently available ENERGY STAR qualified models ranges from 2.3 to 3.7 (over 20 different models available).

Heat pumps (particularly ASHPs) have gained significant market share over the past two decades, and projected shipments in the AEO 2014ER support this continued positive trend. Figure 2.7 shows that between 2011 and 2040, electric heat pumps (mostly air-source) are forecasted to rise in market share from 12% to 16%. Natural gas heat pumps are expected to maintain a lower percentage with less than 0.5% of the total market.

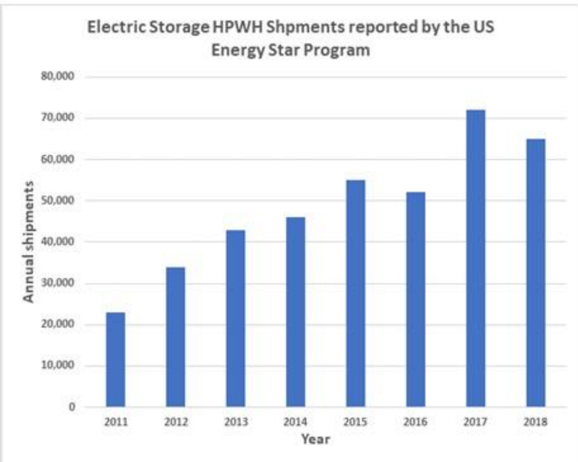


Fig 2.7 HPWH shipments in the U.S., 2011-2018[2]

HPWH's have also gained traction in recent years due to their ability to deliver significantly more heat for the same amount of electricity, when compared to conventional electric storage water heaters. Numerous reputable water heating manufacturers have released their own models, and by 2017-2018, HPWH shipments totalled about 70,000 on average with an estimated market penetration of almost 2%.

[2] https://www.energystar.gov/index.cfm?c=partners.unit_shipment_data)

2.2.2 Canada [01]

Energy is used in all five sectors of the economy: residential, commercial/institutional, industrial, transportation, and agriculture. In 2013, these sectors used a total of 8,924 PJ of energy, which makes Canada one of the highest per capita consumers of energy in the world. The industrial sector accounted for the largest share of energy, followed by transportation, residential, commercial/ institutional, and agriculture. Total GHG emissions associated with the energy use of the five sectors was 487 Mt in 2013.

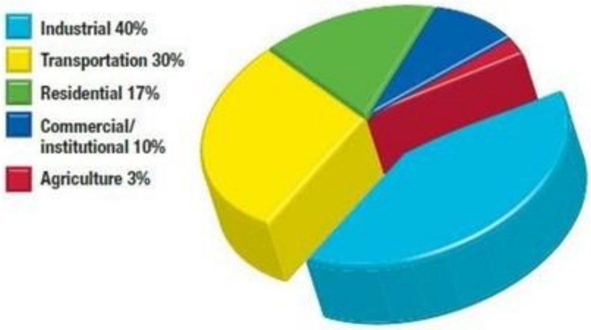


Fig 2.8 Secondary energy use by sector, Canada, 2013

Natural gas, electricity, wood, heating oil and propane were the sources of energy being used. Within a household, these forms of energy were used for a variety of activities. Because of Canada's cold climate, 63 % of Canada's residential energy use was for space heating in 2013. Water heating accounted for 19% in 2013, its share in energy use is likely to rise in the future, as improved building insulation levels and highly efficient mechanical systems reduce the energy required for space heating and cooling.

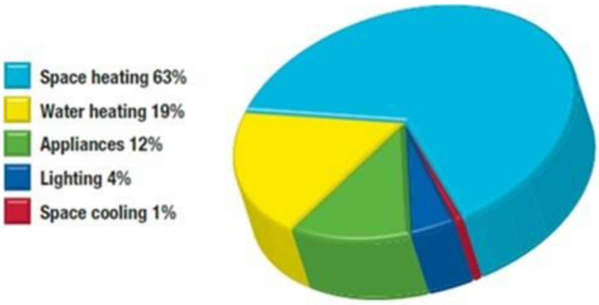


Fig 2.9 Distribution of residential energy use, Canada, 2013

In Canada, most hot water systems use three primary sources of energy: oil, natural gas and electricity. Solar domestic hot water systems are also used but to a much lesser extent. Energy sources tend to be distributed regionally depending on accessibility and cost; for example, oil is predominantly used in the North, electricity is predominant in Quebec, Manitoba and Atlantic Canada, and natural gas is the main energy source for water heating in Ontario, Saskatchewan, Alberta and British Columbia.

Applying heat pump technologies to DHW production offers the potential to efficiently address a major energy end use while at the same time opening a significant new market for heat pump manufacturers. Despite strong energy savings potential, the integration of HPWH's into buildings is far from straightforward. The simplest HPWH and by far the most common HPWH available in Canada is the ambient air-source unit, which removes heat from surrounding air. This system uses the indoor air as a thermal source, cooling the space while providing hot water and is a very good solution in warmer climates, since they provide hot water and cooling simultaneously. Nevertheless, in heating-dominated regions such as Canada, it is not as good, for it increases heating loads and overall building energy use. As such, this system requires a careful whole-building analysis to ensure that it improves overall energy efficiency.

Ducted HPWH and split system HPWH remove heat from outside air and work well in heating-dominated climates because they do not cool the ambient air. Some ducted units can even be converted between the two modes of operation (ducted and ductless) for optimum operation in either summer or winter. Nevertheless, additional ducting and or piping makes retrofit installations a challenge. Also, in Canada, these HPWH must be able to work at temperatures as low as -25 C.

Exhaust air units extract heat from a continuously exhausted air stream and are also a good fit for cold climate. However, the heat recovery ventilator can freeze up, reducing performance.

The majority of Canadian dwellings use a standard tank to meet their hot water heating needs. The predominant fuel source varies depending on the region: Electric hot water heaters dominate in the Maritimes and Quebec, natural gas fired systems are more common in Ontario and the Prairies, while British Columbia is evenly split between electricity and natural gas. Canada wide, 52% of residential hot water heaters are heated using natural gas and 44% through electricity. Oil and propane make up the remaining 4%. Of the households that know the age of their hot water heater, 48% are 5 years old or less, 38% are between 6 to 10 years old, 9% between the age of 11 and 15 years and the remaining 5% are older than 15 years. With a recommended replacement age of 13 years it can be expected that over the next 7 years over 50% of Canadian households will be replacing their hot water heater. Thus, with increased interest in introducing HPWHs into the Canadian market, it is important to evaluate the anticipated impact these systems can have and identify improvements to better adapt HPWHs in the Canadian climate.

2.3 Europe

In 2015 it was reported that HPWH's had in the last 2-3 years been the only sector of the European heat pump market to have grown significantly. Against a backdrop of the recent economic crises, a sluggish building sector, and a stagnating heat pump market, HPWH's have been doing extremely well. The market has more than quadrupled over the last five years, to over 60,000units/year across Europe. It was expected that the growth of HPWH's would to continue over the next five years (albeit at a slightly slower rate than we have seen so far), with the market at least doubling in size by 2017. Some estimates by important market players are even more optimistic, expecting the market to more than triple over the same period. However, it is reported that after the strong growth especially of the French market for HPWH's a spectacular growth of the market in this sector is not expected for the coming years.

In Europe the customer target group for standalone HPWH's is clearly defined. The upper middle class and above, and homeowners with a net monthly household income sufficient to afford the more expensive HPWH's, living in a sizable house with sufficient space to install a Monobloc Heat Pump with a large storage tank. Their greatest concern is safety, especially with heating appliances. The desire for comfort – for an ample supply of hot water – is second to this. The future market for HPWH's needs to reach out for cheaper and smaller products.

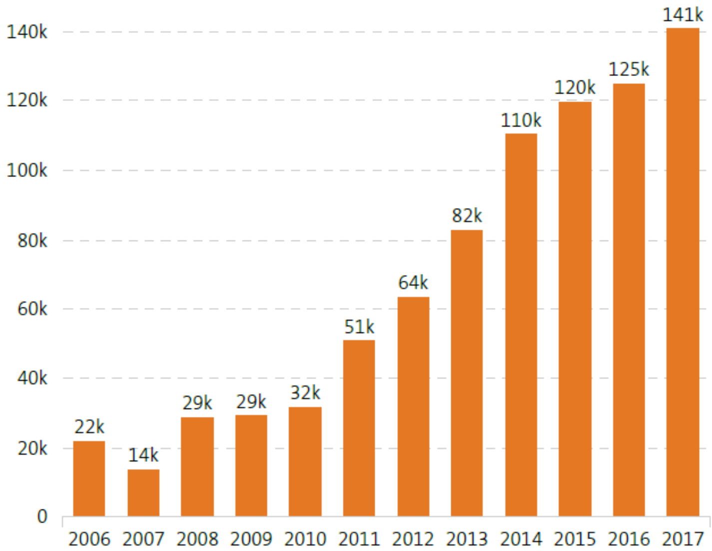


Fig 2.10 Especially in Europe we have seen a spectacular growth of sales for DHW HP's in the period from 2011 – 2014. Development of sanitary hot water heat pump sales, 2006-2017. Total accumulated sales: 828 398 units [10]

Given the very low market share versus hot water boilers of 1.6% and hence the enormous untapped potential, it is expected to be just a little dip in a continuing rally for this segment2. The markets in Switzerland and France point in the right direction, with their market shares of 11.8% and 5.3%, respectively.

The largest part of the DHW HP market today – and one of the key opportunities for future market growth – is the replacement of direct electric storage water heaters in existing buildings. With more than 3 million of these systems installed per year in France, Germany and the UK alone, and an installed base well in excess of 10 million in these markets, the opportunity is massive. Taking only a small share of this large potential would significantly boost the DHW HP sales figures across Europe.

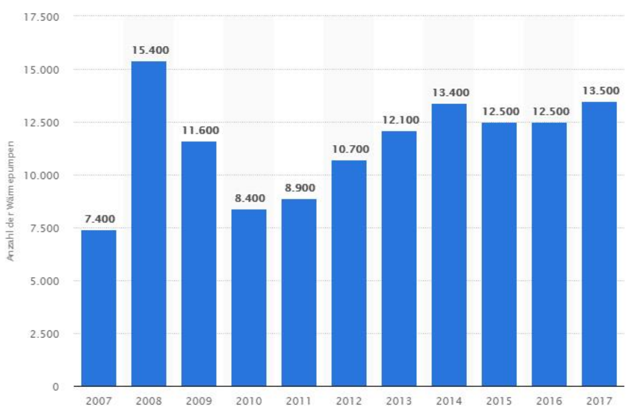


Fig 2.11 Development of the German market for DHW Heat Pumps

2.3.1 Switzerland [05]

Hot water supply is beside space heating the second most important energy portion in Swiss private households. The share of the final energy consumption on providing hot water accounts for 14.9% (31.7 PJ of totally 212.5 PJ in 2014) compared to 65.0% for space heating. The energy consumption for hot water is still dominated by the installed base of heating systems running on oil (36.6%), electricity (24.7%) and gas (22.4%). The share of renewable energy such as wood, solar and ambient heat accounts for 10.8%. Just 2.1% of the heating systems is based on heat pump technology. In 2014, nearly 35% of the Swiss population received their hot water from electricity-based heating systems, including electrical resistance systems (26.7% of the population), heat pumps (7.9%), and solar thermal heating systems (5.2%).

The average hot water consumption per person at 60°C varies between central systems and individual systems. In central systems, it is about 45 to 50 litres per person per day, for individual systems about 35 litres. Field measurements in multiple family houses reveal average hot water consumptions of 36 to 44 litres per day and person. For ten households monitored over a period of one year the mean value was 33.6 litres per day and person, which is close to the 35 litres per day and person described in the standard SIA 385/2.

The building stock accounts for about 1.7 million buildings in 2014, of which 57% are single and 26% multiple family houses. The trend towards single-family houses is unbroken. Overall, 70% of all buildings constructed since 2000 are single-family houses. The average living space per person increased gradually from 38 m2 in 1990 to 45 m2 in 2014. With the high-quality building standards of MINERGIE and strong insulation, the energy demand for space heating is continually being reduced and hot water became the largest portion in those buildings. Therefore, it is important to develop highly efficient heating systems for domestic hot water.

Like in other countries, the hot water consumption profiles in Swiss single-family households show a great variety depending upon the human behaviour and vary greatly from 8 to 65 litres per day and person. The central systems in multiple family houses do not experience this much fluctuation since there is an averaging effect of the individual human behaviours on the cumulated profile. There is a trend to install water saving armatures to limit the water consumption, which is contrasted by the trend towards more comfort and wellness, which increases the water consumption. Intelligent real-time display for the shower are available which promote a more conscious handling of hot water and leads to energy savings. The environmental awareness is foreseen to increase in the Swiss population and the use of heat pumps in particular has become part of the solution to our global environment.

The most popular systems for domestic hot water using heat pumps in single-family households are heat pumps generating space heating and hot water simultaneously, followed by combined solar thermal and heat pump systems, and DHW heat pumps (heat pump boilers). Heat pumps for DHW are applied in about 8% in single and 5% in multiple family houses. The sales numbers of DHW heat pumps have increased from 364 units in 2009 to 4’919 units in 2015. DHW heat pumps are of great importance in the retrofitting market as they are cost-competitive and cut energy consumption significantly. Measurements in the field and at the heat pump test centre (WPZ) show that heat pump boilers are about 3x as efficient as equivalent electric water heaters. The energy efficiency of DHW heat pumps has steadily improved. In 2012, two out of three DHW heat pumps achieved a COP of 2.60 (A15/W10-55), in 2014 about 90%.

The website www.topten.ch provides data of commercially available DHW heat pumps (heat pump boilers) in Switzerland from 31 suppliers and 78 models. The typical storage tank volumes are between 80 and 500 litres. Particularly suitable is the installation in rooms with waste heat from a technical, workshop or laundry room. Such a system can also be combined with photovoltaics for the electrical supply of the DHW heat pump. In practice, the heat pump boiler is delivered as a plug-in system and it is a simple substitute for an electrically heated boiler. DHW heat pumps are also available as a split system with outside air as energy. Split systems are gaining importance in single-family houses as such systems can be used both for space heating and water heating.

In multiple family houses, the hot water is generated centralized (central heat pump with storage tank and recirculation loop or trace heating) or decentralized. In centralized hot water heat pumps with storage tank, the water is heated in one large boiler and from there distributed to the different extraction points in each building. Due to long tubing runs, this installation often results in large heat losses. These losses need to be compensated by a heat tracing method. Using a recirculation loop for this purpose, the hot water circulates continuously from the top of the storage tank through the entire network and reaches every residential connection before it is fed into the storage in a separate circulation line. Alternatively, self-regulating electrical heating cables can be installed on all hot water pipes to keep the stagnant water warm. In large building complexes a combination of space heating and hot water system is often applied using a heating network with decentralized hot water storage tanks. Here, a central heat pump provides the heat for space heating and domestic hot water. Efficiencies of these systems are lower compared to recirculating loops or heating cables.

Typical heat sources in multiple family houses are ground heat, ground water or sewage water. More and more often, return water from the heating system is used in decentralized DHW heat pumps as heat source. In new multiple family houses, the heat distribution through the hot water pipe network is about half-half divided between recirculation loops and heating cable. However, there is a trend towards recirculation loop systems due to the unfavourable rating of electrical heating in MINERGIE buildings. Legionella prevention is typically done by at least one daily charge to 60°C for one hour.

2.3.2 France [03]

After the strong growth of the French market for DHW HP's a spectacular growth of HPWHs market in this sector is not expected for the coming years. The positive effect of the thermal regulation RT2012 has been sensible in 2013-2015 and now the penetration rate of HPWHs in new built individual houses is stabilized and even slowly decreases, due to double service heat pumps or combination systems including photovoltaic panels. The evolution of HPWHs market in this sector mainly depends on the rebound of the new built sector, which is quite uncertain for the moment (see figure below, evolution of new built sales over 12 months compared to the previous 12 months).

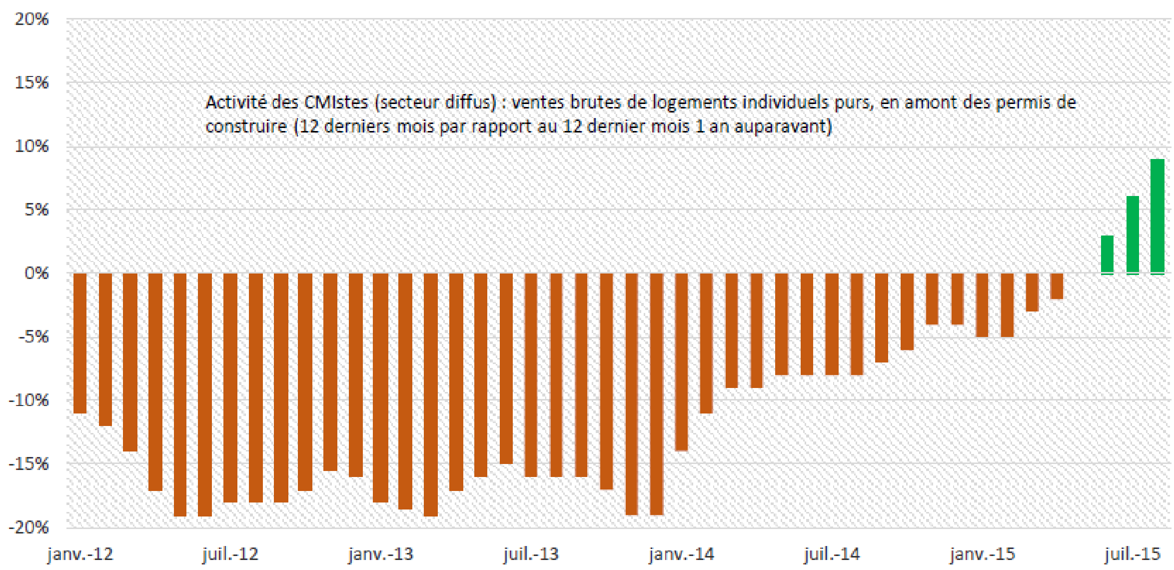


Fig 2.12 Evolution of new built sales over 12 months compared to the previous 12 months

Some studies forecast that in 2020, about 35% of new built individual houses will be equipped with a heat pump water heater, i.e. about 60000 to 65000 units sold per year (vs 50000/year in 2015). This figure is based on a estimation of 180 000 new built individual houses in 2020 (vs 135 000 in 2015).

In existing buildings, the main growth potential remains in the retrofit of electrical water heaters and other traditional water heaters. As seen previously, the stock of electrical water heaters represents almost 16 million units and about 1.3 million units are replaced every year.

Currently, the effect of retrofitting the electrical water heaters by HPWHs is negligible. This retrofit will develop under several conditions that lead to an improvement of the HPWHs return on investment:

- Decrease of capital costs of HPWHs
- Continuation of the tax credit "CITE" for HPWHs or global revision of the margins taken by each actor of the professional channel
- Increase of energy prices, in particular electricity

2.1.3 United Kingdom [02]

Domestic Hot Water (DHW) accounts for 14% of heat used in the UK home. This compares with 63% in space heating but is much more challenging to a major reduction than is space heating due to its relationships to hygiene and health. In the UK, domestic hot water accounts for 80 TWh delivered energy per year. With the move towards a low-carbon future, it can be expected that a combination of improved building insulation and the application of heat pumps or other technologies to space heating will drastically reduce carbon emissions. However, present heat pump systems are unable to supply instantaneous hot water; a combination boiler ('combi') can deliver 20-30 kW or more for this purpose and heat pumps sized to meet typical house space heating demand are rated around the 10 kW level. A larger heat pump would be uneconomic and would have an unacceptable capacity to meet normal requirements. Thus, the only way that present conventional heat pump systems can provide hot water is to charge a conventional DHW tank. This would not be an issue except that new build houses tend to be designed without space for domestic hot water tanks and opt for instantaneous hot water via a combi gas boiler. Also, there is a strong trend when replacing gas boilers to choose combi boilers and discard the storage tank to provide more space within the home. At present, almost two-thirds of the 23 million gas boilers in UK homes are 'combi' boilers with no large hot water tank. It should be noted that combi condensing boilers do not deliver DHW with laboratory test efficiency due to start up transients, hot water left in pipe runs etc.

It is estimated that at the end of 2012 there were approximately 90,000 heat pumps installed in the UK. At an average capacity of 10.5 kWth per heat pump, the total installed (thermal) heat pump capacity in the UK was around 9 MWth. Based on an SPF of 2.5 in the current UK heat pump park during the heating season, the electrical demand of the installed heat pump base during the heating season was ~3.6 MWel.

Using the projected uptake of heat pumps from the impact assessment of the Domestic Renewable Heat Incentive, we assume that the installed base of heat pumps in the UK will reach approximately 515-530,000 units in 2020. Applying the same assumptions as above, this means an installed UK heat pump capacity in 2020 of ~5.5 GWth or ~2.2 GWel. Heat pumps (without smart capabilities) could thus account for more than 5% of the average cold spell peak demand in the UK electricity network by 2020 (see chapter 2.2 for more information on peak demand projections).

Growth of UK HP market 2005-2010: Induced by rising fossil fuel prices and the availability of grants for installations in the social housing sector.

Slightly negative growth of the UK HP market 2011-2012: Due to the gloomy economic conditions, a removal of grants in the social housing sector, adverse trends in the energy prices, some negative press about heat pumps after the rush in the early years of the market development and the repeated delay of the Renewable Heat Incentive for domestic installations, which has led potential customers to postpone investment decisions or to opt for conventional alternatives.

The heat pump market in the UK is today dominated by air-to-water heat pumps, underpinned by a small base of ground source installations. It is expected that the introduction of the domestic RHI will revive the market from 2014 onwards and fuel a significant growth over the coming years. From 2014 onwards we could also see a stronger uptake of hybrid (and bivalent) solutions in the on-gas sector, mainly driven by the RHI and the introduction of more competitive products from some of the major market players in the UK.

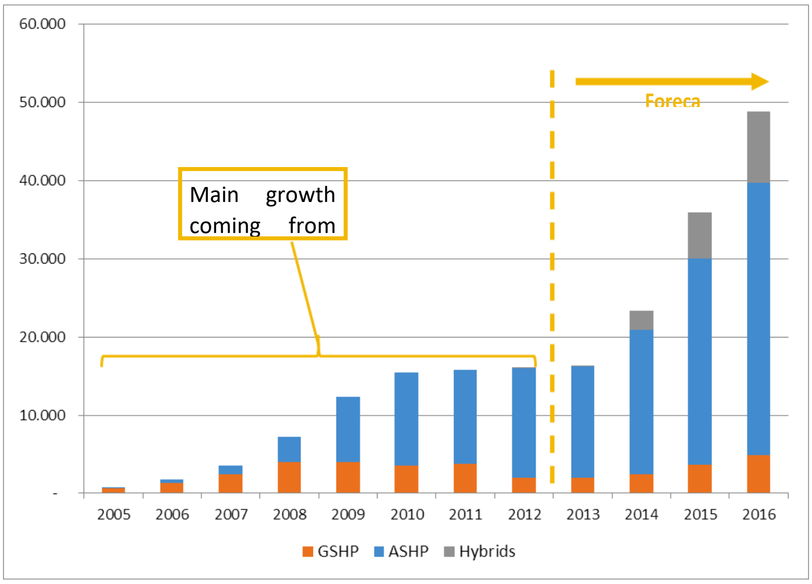


Fig 2.13 Historic and future trends in the UK heat pump market. Sources: Delta-ee Microgen Insight Service; Delta-ee Heat Pump Research Service.

The average size of new build UK homes is one of the smallest in Europe (see for example the 2011 study by the Royal Institute of British Architects9 or the 2001 study the French Office of National Statistics, INSEE10). Further, unlike homes in e.g. Germany, UK homes rarely have basements and heating systems are typically installed within the living space. There is therefore an increasing preference to not use hot water storage tanks. This lack of storage space could significantly reduce the flexibility potential from heat pumps in UK homes – especially when combined with the low thermal inertia of the building stock. With an average of only 85m² per home in the building stock and the average new build home being only 75m² in size, there is a trend towards removing hot water storage tanks in the UK in order to maximise useable space in the property. Only 51% of households in the UK were estimated to have a hot water tank in 2011, a reduction of 7% since 2008 – and a downward trend which is expected to continue. This trend reflects the increasing use of combination boilers (without tanks) which in 2010 made up more than 73% of the total gas boiler market.

2.3.4 Netherlands [07]

After a drop in sales due to the economic crisis and the lack of new domestic building developments, the market is recovering fast with growth rates not seen before. The main application of heat pumps is in newly built residences which as a consequence of the Dutch Energy Policy requirements has to develop towards energy zero. A number of large building developers have successfully adapted their production process towards industrialisation of the process, more than often incorporating heat pumping technologies in direct collaboration with one of the heat pump manufactures. These type of collaboration is also getting foothold in the renovation market with plug & play concepts. Heat pumps are in those cases double-function heat pumps, ground as well as air source heat pumps, with space and hot water heating. Compared to other European markets the storage capacity for hot water, of up to 150 litres, is traditionally relatively small.

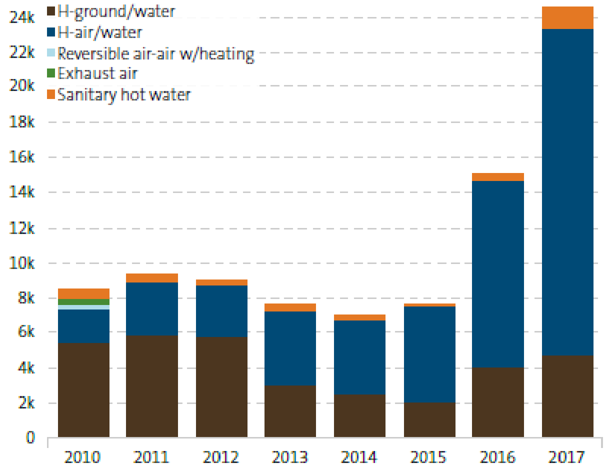


Fig 2.14 Heat pump sales development by type of heat pump ("H-" indicates primary heating function) [10]

Heat Pump Type	2012	2013	2014	2015	2016	2017	Growth
H - Air to water	2,954	4,277	4,210	5,458	10,662	18,032	74.8%
H - Ground to Water	5,786	3,054	2,510	2,086	4,041	4,738	17.2%
DHW HP	270	297	231	88	375	1,165	211.0%
Exhaust Air	0	0	0	0	0	7	
	9,010	7,628	6,951	7,632	15,078	23,942	62.8%

Table 2.2 Heat pump sales in Netherlands [10]

Standalone Heat Pump Water Heaters are a small part of the market, showing a remarkable growth in 2017 of 211%, to an amount of 1165 units.

This growth can be explained by the growth of awareness that individual solutions for hot water in collective systems can be a solution to reduce the system losses. Booster heat pumps and air source heat pumps are applied by Esco's in a number of Multifamily buildings.

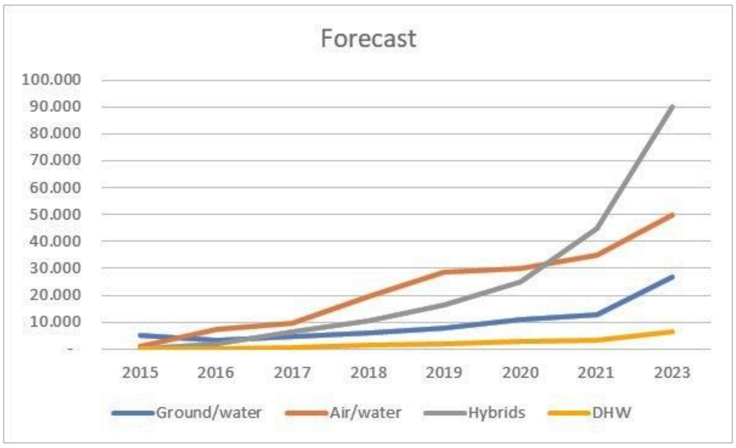


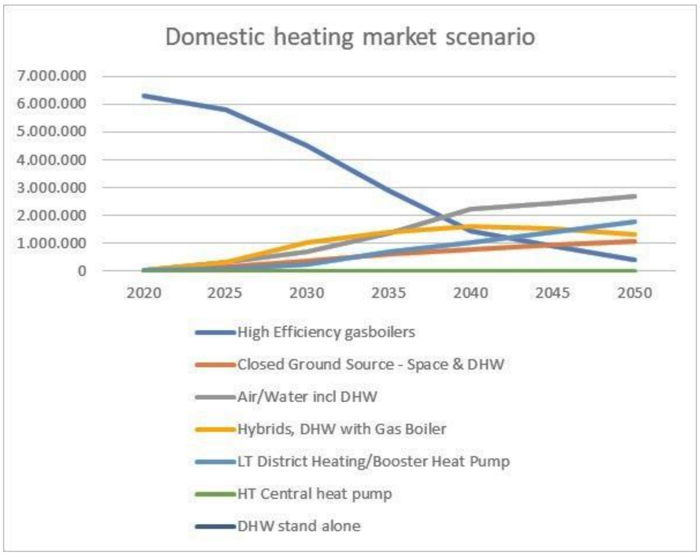
Fig. 2.15 Short term forecast of heat pump market in Netherlands [07].

With the momentary market developments it can be expected that on the short term this growth will continue up to 6.000 – 7.000 in 2023. The larger part of the market will be hybrid heat pumps where the gasboiler produces hot water and air/ground source double function heat pumps.

In the longer term policy will be effective on the market. Long term government policy (horizon: 2030) for the building sector focuses on:

1. No gas grids in newly built housing estates and districts.
2. Renovation of 200.000 domestic apartments/houses per year.

3. Introduction of low temperature district heating in densely populated areas with a high heating demand/profile.



In this scenario the gas boiler, which in 2020 is the dominant heating technology, with over 95% of the sales in domestic heating systems, will disappear from the market in a development towards electrification of the energy infra structure. Domestic Hot Water Heat Pumps will as expected mainly be applied in Multi-Family buildings.

Fig. 2.16 Long term forecast of heat pump market in Netherlands [07].

3. Policy

Throughout the developed world, the heating of water for domestic use is one of the largest consumers of energy in the household sector. However, water heaters vary in their type and mode of operation, the source of energy used and, potentially more than any other domestic appliance, the actual energy consumed is impacted by consumer usage patterns and ambient environmental conditions. Such complexity creates a number of challenges for policy makers seeking to understand and effectively manage water heating energy consumption. The specific mix of water heater types used varies considerably between countries as a result of culture, historic practice, existing infrastructure and energy source availability. Not surprisingly, the specific policy frameworks developed and deployed by policy makers vary significantly depending on these local conditions. In almost all policy there seems to be no direct specific support for optimisation of domestic hot water with heat pumping technologies.

However, in the majority of countries, at least some product types have mandatory and/or voluntary product performance standards in place. In practice, almost all regulatory regimes deploy a hybrid approach. For example, until regulatory transition currently underway, the USA specified a generic set of hot water service requirements for almost all water heaters, but applied differing minimum performance standards for each water heater type delivering that service. Even where 'pure' technology neutral standards are deployed, the specific service requirements selected often favour one or more particular product type(s). However, it is interesting to note that some of the best performing products across international markets have resulted from alternate policy interventions. For example:

- In Japan, the Eco Cute hot water heat pump using CO2 as a refrigerant has been a run-away success over the past decade. The rapid increase started in 2001 when the country implemented an effective and multifaceted support scheme that still serves as a best-practice policy example for other national markets.
- Korea has a high proportion of the best performing instantaneous water heaters despite the Korean minimum performance standard not being particularly challenging. This may be a spin-off from the aggressive advertising promoting condensing boiler systems spilling over into a consumer demand for condensing instantaneous water heaters, which are then easily identifiable via the Korean energy label.
- The North American ENERGY STAR programme is encouraging premium performance products across all water heater types.

Within a certain product type, i.e. heat pump water heater, electric storage water heater, instantaneous gas water heater or solar water heater there is a potential to make the products more efficient. Often the products are already available in the market. Further savings on household water heating systems can be achieved simply by eliminating the worst performing products from the market with no apparent loss of service to the consumer. Labels, certificates, test procedures focus on that aspect of the market. However, inherent in that approach is also the choice between types of water heater. The extreme example is a switch from the worst performing gas storage water heater to the best heat pump model would reduce annual energy consumption by almost 7 MWh per water heater.

Traditionally however policy makers are reluctant to make choices. Recently in 2019 the Dutch Government made clear in their transition policy that new houses and new housing quarters cannot be connected to the gas grid anymore. Thus leaving heat pumps and district heating as choices for space and water heating. On a larger scale, the technology neutral labelling of the water heaters in the EU clearly has such technology switching as a long-term goal. Further, the transition in regulatory requirements currently under way in the USA appears to be moving towards technology neutrality based on primary energy. For water heaters above 208 litres in the USA, it appears the likely impact will be to drive electrically heated water heaters to heat pump technology, and gas storage water heaters to condensing efficiencies. Not only is this likely to yield significant energy savings in the US market, it is also likely to stimulate the introduction of a large number of higher efficiency gas storage and electric heat pump products into the broader market. (source: 4E Benchmarking Document Domestic Water Heaters).

Indirectly the Building Regulations in many countries, if the calculation models are optimal (see Task 2 report), can stimulate end users in a switch toward a more efficient generator for hot water.

3.1 Policy in participating countries

In line with the above, the policies in the different countries in their overall approach have a general nominator focusing on energy conservation, renewables and energy security to reduce the greenhouse gases and pollution in line with the Paris agreements. As a basis, there are a number of legislative requirements described in directives, focusing on:

- Creating a challenge for individual technologies, through test procedures, standards and energy performance labelling, like European ECO label, TOP Runner in Japan, China Energy Label (CEL), Energy Star and Energy Guide labels in North America
- Creating a challenge for competing technologies, by setting energy targets for systems in buildings or by simply setting restrictions on certain types of technologies

3.1.1 Europe

In Europe the basis for the European Countries in the EU are:

- **Energy Efficiency Directive** (EED) establishes a set of measures to help the EU reach its 20% energy efficiency target by 2020. Under the Directive, all EU countries are required to use energy more efficiently at all stages of the energy chain from its production to its final consumption. This means that European households and industries need to become much more energy efficient. EU countries were required to transpose the Directive's provisions into their national laws by 5 June 2014.

  According to the Energy Efficiency Communication of July 2014, the EU is expected to achieve energy savings of 18–19% by 2020 – missing the 20% target by 1–2%. The fact that the target is non-binding is often blamed for this. President Juncker described in the Political Guidelines for the new EC that he would like to significantly enhance energy efficiency beyond the 2020 objective. A review of the EED is foreseen for 2016.

- **Energy Performance of Buildings Directive**. Annually, buildings are responsible for 40% of energy consumption and 36% of CO2 emissions in the EU. Currently, about 35% of the EU's buildings are over 50 years old. By improving the energy efficiency of buildings, total EU energy consumption could be reduced by 5– 6% and CO2 emissions could be lowered by about 5%. The Energy Performance of Buildings Directive (EPBD) (2010/31/EU) aims for high efficiency requirements for new buildings and deep renovations. It obliges the Member States that all new buildings in 2020 should be nearly Zero Energy Buildings (nZEBs). All new public buildings must be nearly zero-energy by 2018. The EPBD acknowledges heat pump applications in line with the RES Directive, and also explicitly mentions their reversible characteristic.
- **European ErP Directive** 2009/125/EC (Energy-related Products Directive), also known as the Ecodesign Directive (EU, 2013a), the EU adopted new requirements for the ecological design and labelling of energy-related products. Boilers and combined heaters (including heat pumps) and hot water heaters (including domestic hot water heat pumps) are affected. As of September 2015, all manufacturers are obliged to comply with the minimum requirements contained in the Ecodesign Directive. New equipment placed on the European market must meet these requirements.

3.1.2 Switzerland [05]

The Swiss federal government and the cantons want to significantly cut the energy consumption of the Swiss buildings with the building program and reduce CO_2 emissions (Das Gebäudeprogramm 2016; Prognos AG 2015). The Federal Act on the Reduction of CO_2 Emissions (CO_2 Act) of 23 December 2011 (Art. 34, Abs. 1) states that 1/3 of the CO_2 tax on fuels, but a maximum of 300 million CHF per year, are used for measures to reduce CO_2 emissions in buildings (Das Gebäudeprogramm 2015). Within this framework of the "Gebäudeprogamm" (Das Gebäudeprogramm 2016, 2015) the Confederation gives the cantons financial grants to:

- Part A: energy-related renovations of the building envelope of existing heated buildings, i.e. better insulated roofs, walls, floors, ceilings and windows. This is uniform throughout Switzerland; the Confederation allocates a maximum of 133 million CHF per year for energetic building renovation of roofs, walls, floors, ceilings and windows. The improved insulation of the building envelope lowers the heating costs and helps to reduce CO_2 emissions.
- Part B: promotion of the use of renewable energies, complete renovations of the heating system, the use of optimized building technology, and the use of waste heat. The cantons paid around CHF 79 million CHF subsidies in 2015 to house owners for the implemented measures in the fields of renewable energies, building technology and waste heat use (Das Gebäudeprogramm 2015). This replaces fossil fuels, which also reduces CO_2 emissions. In most cantons, the conversion to heating systems operated with renewable energy sources, such as heat pumps, solar or wood systems, is financially supported by the "Gebäudeprogramm".

The Swiss Federal Confederation, cantons, cities and municipalities, as well as campaigns from regional energy suppliers and private institutions are supporting the promotion of renewable energies and increasing energy efficiency. Today, many funding programs are offered at various levels in Switzerland. The webpage "Energiefranken" provides a list of the different types of funding programs of energy promotion in Switzerland. The programs are subdivided into several areas. After entering the postcode of the building location a list of all energy promotion programs are shown. The search includes funding programs for the cantons, cities and municipalities as well as campaigns from regional energy supply companies.

In the category of "buildings and living" there are specific funding programs related to hot water. For hot water, the cantons can grant subsidies for the following systems:

- solar thermal systems
- heat pump storage water heaters
- combined heat supply system (> 70 kW heat capacity, "Wärmeverbünde")

3.1.3 France [03]

French utility EDF Energy has taken a proactive approach to the market by actively selling heat pumps. As such the company has taken the strategic decision to go beyond facilitating and incentivising the introduction of the technology and is investing heavily in awareness raising and promotion to establish a position in the market.

This involves:

- Selling and installing product via installation partners.
- Building relationships with key manufacturers.
- Positioning themselves as 'green energy experts'.

Their promotional positioning has enabled them to leverage an existing trusted brand to continue to promote their gas alternative by offering hybrid solutions to new and existing customers.

Several factors indicate increasing customer pull for DHW HPs to replace direct electric water heaters over the next five years, driven by an increasingly attractive customer proposition:

- DHW HPs are already a relatively low upfront cost way of reducing energy bills – they can be installed for a price in the range of €2-3,000 - a fraction of the cost of space heating heat pumps or other renewables.
- Rising electricity prices, as well as improving HP efficiencies, will further increase the running cost savings to be achieved by DHW HPs over a direct electric water heater.

The entry into force of the Ecodesign requirements for water heaters will see manufacturers of direct electric water heaters having to significantly increase the insulation of their systems, which will otherwise be banned from the market. This will result in rising upfront costs for direct electric water heaters, making payback periods of DHW HPs against direct electric systems even shorter than they are today.

The introduction of the energy label for water heaters in 2015 is for the first time going to give customers comparable information on the efficiency of their water heaters, clearly showing the advantages of DHW HPs.

3.1.4 Netherlands [09]

By 2030, the Netherlands aims to reduce its greenhouse gas emissions by 49% compared to 1990 levels. More than 100 Dutch parties (mixture of government, businesses, NGO's) have jointly worked on a cohesive set of proposals which are laid down in the National Climate Agreement. For the built environment sector, it means roughly 1.5 million existing homes and 1 million utility buildings will have to be made more sustainable by 2030. With the present phasing- out natural gas policy a big role is foreseen for heat pumping technologies. A large number of commitments have been set or are being announced to make all of this possible.

The main goal of the National Climate Agreement of the Netherlands is to achieve a 49% reduction in national greenhouse gas emissions by 2030 compared to 1990 levels. The consultations on how to achieve this target took place within five sector platforms (Built environment, Mobility, Industry, Agriculture and land use and Electricity) and issues that affect multiple sectors (innovation, labour, finance, and spatial planning). Each sector platform was assigned a sector-specific target regarding the reduction in Mton would have to be realised by 2030 (48,7 Mton in total).

In order to achieve the emissions reduction target for 2030 of 3.4 Mt worth of cuts in the built environment, the main focus is to increase the pace of sustainability efforts to over 50,000 existing homes per year by 2021, and by 2030 this should accelerate to 200,000 homes per year. A structured approach has been chosen, tackling one district at a time. The municipalities play a crucial role in this regard by drawing up a transition vision for heat in consultation with stakeholders and end-users by the end of 2021, in which they will establish the time-table for a step-by-step approach to phasing out natural gas. The potential alternative energy infrastructures (all-electric, heat, green or eventually hydrogen gas in future) will be set out for districts planned for transition ahead of 2030, and municipal authorities will provide insight into the social costs and benefits and the integral costs for the end-users.

The preferred solutions may vary from one district to another. If the area has been densely developed, contains many high-rise buildings or has homes that were built before 1995, then a district heating grid could be the most suitable solution. If the area contains new homes set out in a spacious district, then an all-electric solution may be better. For many districts, the natural gas network will remain in place beyond 2030 and may even be used for green gas. Insulating and burning less gas, sustainable or otherwise, with a boiler in combination with hybrid heat pump might offer a sensible temporary solution. However, the condition of the homes is not the only relevant factor; the wishes of the residents in the district other than energy supply equally determine the pace and the outcome. Housing associations also play an important role to make their homes more sustainable, and to connect them to a different heating supply than natural gas in the years to come, under the condition that the monthly costs for rent and energy bills do not rise, including first-time movers.

The built environment sector platform has proposed a phased and pragmatic approach that, on the one hand, will seek to achieve a good head-start and, on the other, will develop the conditions and requirements for the scale-up and roll- out of measures for the future. With regard to homes, an approach of incentivisation and district-oriented management has been opted for. At an individual level, building owners can also be offered incentives to make their properties more sustainable. This approach will be successful if the sustainability efforts can be recouped through tenants' lower energy bills. Numerous innovations and significant cost savings will be required in order to fund these investments and make them affordable by means of energy savings and cost reduction. To this end, Test Beds for Natural Gas-free Districts (*Proeftuinen Aardgasvrije Wijken*) and an innovation programme have been launched, which will allow us to learn and experiment systematically, and to move forward with cost-effective up-scaling and implementation beyond the current government's term of office.

The development of heating devices that do not use gas (or do so to a lower extent) is in full swing. A Mission-driven Innovation programme (MMIP) focuses on technical and socio-economic innovation for the rapid growth of sustainable heating systems. The objective is to improve existing types of devices and systems (available <5 years), the development of new concepts (available >5 years) and corresponding services. Further, the Program is intended to promote user interest and enthusiasm regarding scope, comfort (noise, thermal), integration capacity and affordability (housing costs). The innovations will primarily be focused on applicability in existing inhabited situations, a lower overall cost price at systems level, and acceleration towards natural gas-free solutions. Providing access to new sustainable heating and cooling sources and thermal storage is required to meet the sharply growing demand for sustainable heat.

A large number of commitments are required to make this possible. The following mix of pricing and subsidy instruments has already been set or is being announced:

- 100 million euros/year – ISDE subsidy scheme (small-scale heat pumps);
- 100 million euros/year discount – Landlord charge;
- 50 million euros/year from 2020 to 2023 – Energy Investment Allowance for landlords;
- 50 to 80 million euros/year - Non-revolving heat fund for private property owners
- >40 million euros - Multi-year Mission-driven Innovation Programme (built environment)
- Changes will be made to the energy tax to provide a stronger incentive to improve sustainability, by ensuring that investments in sustainability are recouped within a shorter time period. The government has opted for the budget-neutral version, which will see the energy tax rate for the first bracket for natural gas increase by 4 cents per m3 in 2020 and +1 cent per m3 in the following six years. Households benefit more from this change than businesses.
- 300.000 euro - Green deal education installers heat pumps (education centers).
- and 100 million euros/year up to 2021 and 70 million euros/year from 2020, the neighbourhood approach and the renovation accelerator, respectively.

3.1.5 Japan [04]

The "Introduction Subsidy Scheme" initiated by the Japanese Government in 2002 to subsidize a part of the cost for introduction of heat pump water heaters is a best-practice policy example resulting in recent years that approximately 400,000 to 500,000 units are being shipped every year. This scheme is, however, not currently implemented. The government's role in raising awareness among market players has been especially instrumental in rapid market adoption. Through energy savings awards, financial support measures for R&D and awareness-raising campaigns, as well as green purchasing laws and consumer subsidy schemes, Japan is now close to its initial target of 5.2 million Eco Cute units by 2010.

Japanese utilities were instrumental in bringing the Eco-Cute CO2 heat pump to market. R&D funding was key to driving the initial technology development, along with attractive heat pump tariffs. As power consumption increased as the Japanese economy grew, it was an issue for power companies to level their power load to reduce daytime peak power. Late-night electricity was much cheaper than daytime electricity rates. Eco-Cute has become more popular because it uses late-night electricity and has a significant cost advantage over gas water heaters. However, since the cost of electricity has risen since the earthquake in 2011 and the late-night electricity rate has doubled, the cost merit has declined..

In addition, the strategy had a number of other features which contributed to its success:

- A long-term perspective was taken by all stakeholders across the sector.
- Electric utilities and manufacturers implemented a compelling marketing and promotion programme.
- All manufacturers used the shared Eco-Cute branding.

3.1.6 South Korea [08]

South Korea government announced 2nd National Energy Master Plan on January 2014. The major targets are:

- A renewables target of 5.2% in the primary energy supply by 2020 and 11% by 2035. The major increasing sources are PV and Wind energy.
- Distributed power plants (Microgrid with Renewables, Regional energy) will supply above 15% of total electricity generation by 2035.
- Demand reduction of 13% in the total energy demand and 15% in the electricity demand by 2035. To achieve targets, demand side management using a ICT (Information Communication Technology)-based smart grid including ESS (Energy Storage System) will be conducted. In addition, tax and tariff system will be changed.
- Reduction of carbon dioxide emission by 30% below business-as-usual (BAU) levels by 2020.

Renewables Portfolio Standard (RPS): A Renewable Portfolio Standard (RPS) was introduced in 2012 and replaces FIT(Feed-in Tariffs for new and renewables electricity1). The RPS forces power producers to supply a certain amount of their total power generation portfolio from new and renewable sources. The standards apply to generators with more than 500 MW of capacity. [2]

Renewables Heat Obligation (RHO) (plan): The South Korea government prepares RHO to promote heat energy from renewables such as solar thermal, geothermal and biomass. The RHO forces new buildings have a certain ratio of heat supply of their total heat energy consumption from new and renewable sources. Government expects RHO will be started in 2016.

Even though Korean heat pump market is comparatively small, recently government is struggling to deal with climate change and energy problem by expanding the heat pump market as one of products for a dynamic force for new growth in accordance with promoting green energy industry. In the future, the heat pump market will grow through boiler replacement demands and it is expected to have great market potential for industrial use as well as for residential use. Government endeavours to support for technology development and to systemize certification of performance, standard, quality and test regarding devices and system of heat pumps by selecting the heat pump as one of 15 green energy sectors of the green energy strategic roadmap. If this effort comes to fruition, it can achieve a very large effect nationally as the major means corresponding to convention on climate change and promote to be an internationally competitive industry by fostering export-intensive industry.

Until now, technology development for high efficient and eco-friendly heat pumps has progressed largely and R&D for compressor technology, improvement of a product structure and a heat exchanger, microprocessor control method and solution is proceeding actively. Especially, amid the anticipation of investment on and development for high-technology for heat pump water heaters, systematic production and R&D technology infra of the Industry-University-Institute are getting larger recently. In green energy strategic roadmap 2011 by government, heat pump sector is selected as "The domestic market expansion and achievement of international competitiveness through the development of new concept heat pumps". The goal is to increase localization rate and technology level, which have showed 90% and 85% respectively until last year, up to 100% both of them by 2030, and on the basis of that to raise 8% global market share to 20% in 2030. Government acknowledges that the heat pump reducing CO2 emission significantly as a single technology is an energy technology to replace existing primary heat source system, and recognizes necessity for technology development as a main means to respond to convention on climate change.

For promoting the heat pump industry, roadmap divides R&D program into commercialization and original technology development. 'Refrigerating, Air Conditioning and Freezing' unified in a heat pump system and middle capacity air to water (ATW) heat pump system are focused on commercialization. Firstly, the project is to promote domestic market and to carve out international market by developing 'Refrigerating, Air Conditioning and Freezing' unified in a heat pump system with high marketing opportunities based on VRF heat pump technology. This strategy is like killing three birds with one stone in that it encourages a product family ensuring for export strategy based on domestic supply, improves energy efficiency and reduces CO2 emission in the aspect of market and technology.

Due to these advantages a lot of investment and research is in progress. In addition, that is growing fast in Europe, Japan and other developed countries. Depending on the structure of the market, and standards about heat pump water heater for energy-efficient performance standardization is set by the local and national.

In Korea, heat pump water heater market began to be formed and exports are already being made in some big companies such as LG, Samsung and Autech Carrier.

3.1.7 China [24]

The National Development and Reform Commission (NDRC) is generally leading national energy saving and environment protection affairs in China. In order to facilitate energy saving product market growth, NDRC started the "Energy saving production market subsidy scheme" in 2012. The Air Source Domestic Hot Water Heat Pump was included in the scheme from June 1, 2013 to May 31, 2014. DHWHP buyers who were eligible could receive subsidies from 300 to 600 CNY (around 10% of the total retail price) depending on the rated heating capacity and COP.

	Rated heating capacity（W）	Subsidy (CNY)
3.4≤COP<4.0	≤4500	300
	>4500	350
COP≥4.0	≤4500	500
	>4500	550

Table 3.1 Subsidy in China on Air Source Heat Pump Water Heaters

Air Pollution Control is an important mover in Chinese policies. Coal fired boilers for space heating are a key reason for air pollution, especially in the north of China. In the Air Pollution Prevention and Control Action Plan introduced by the State Council in September 2013, heat pump application is recommended as an energy saving and clean energy space heating product to replace coal fired boilers.

The Beijing-Tianjin-Hebei (BTH) region and surrounding areas will continue to intensify efforts to cut coal fired boilers over the next five years. Most of the areas without a district heating supply facility are located in suburbs of cities or rural areas and where it is unlikely that the gas distribution network will reach in the next few years. There will be a big electricity driven heating product market. In 2015, Beijing municipal government gives a subsidy of up to 24,000 to 28,000 RMB per household to families who use clean energy products, like heat pumps, to replace coal fired boilers. The policy is expected to last for 3 to 5 years.

In 2016, the targeted installation is more than 150,000 units in Beijing, comparing with 5,500 units in 2015. There is around 30 times increase. Tianjin, Shandong, and Hebei provinces will follow Beijing in 2017 to support the air source heat pump installation. CHPA estimated the market will increase by more than 200% in 2017.

Since 2009 geo-thermal has been defined as renewable energy in Chinese renewable legislation. Being a renewable energy product, a subsidy from central and local government is available for GSHP. For example, in 2009, the GSHP application in rural areas could receive a subsidy of 60 CNY per M2 from central government. In Beijing, GSHP could receive a 50 CNY subsidy per M2 from local government. However, most of these government subsidies were stopped in 2012.

Aerothermal and ASHP so far haven't been incorporated in the renewable energy product list in Chinese national legislation and regulations. However, several provincial governments already recognize it as renewable energy, for example, Zhejiang province, through local legislation, aerothermal has been approved as renewable energy since 2013. In 2015 and 2016, Fujian, Guangxi, Hebei, Shandong and Beijing also published local regulations to accepted ASHP as a renewable energy product. The national level policy is under evaluation.

3.1.8 USA [06]

A confluence of regulatory and economic factors is rapidly pushing heat pump water heaters (HPWHs) into the mainstream residential marketplace. The primary regulatory catalyst is a new federal water-heating standard that mandates energy factors (EFs) around 2 for all new electric storage water heaters with capacities higher than 55 gal (DOE 2010). The regulation specifies the minimum EF as a function of rated storage volume, EF = 2.057-0.00113V, which corresponds to an EF range of 1.92 to 1.99 for rated tank volumes between 55 gal and 119 gal, respectively

This regulation is a major driver of change in residential water-heating technologies, because it effectively requires HPWHs in applications that have large hot water loads and where electricity is used for water heating. In addition, for energy-conscious consumers who want to decrease energy use, HPWHs are currently the only ENERGY STAR®-qualified electric water-heating products on the market (EPA 2012).

In addition to a changing regulatory environment in the residential electric resistance water heater (ERWH) market, financial factors are also pushing HPWHs into the mainstream. Inflation of residential retail electricity prices significantly outpaced general inflation, as measured by the consumer price index, between 2002 and 2009. The average residential retail price of electricity increased 36% between 2002 and 2009 (EIA 2012b), while the increase in the consumer price index was 19% over the same period (BLS 2012).

While electricity prices have since stabilized due to a slowdown in economic growth and declining natural gas prices (EIA 2012a), the relative increase in electricity prices over the past decade has played an important role in HPWH development. Furthermore, even though HPWHs have higher first costs than traditional ERWHs, many utility companies are offering sizable rebates for HPWH installations in the hopes of making these units more attractive in the residential marketplace.

Because all new HPWHs have a listed EF of 2 or higher—compared to 0.9–0.95 for ERWHs—if all ERWHs were replaced with HPWHs and these water heaters performed at their rated efficiencies, American consumers could save $7.8 billion annually (average of $182/household) in water heater operating costs and cut annual residential source energy consumption for water heating by 0.70 quads. HPWHs are not appropriate in all circumstances, however, and they may increase space-conditioning loads in some cases, so these figures represent the upper limit of potential savings based on EF ratings associated with the move from ERWHs to HPWHs.

3.1.9 Canada [01]

The current policy framework with regards to high efficiency water heating in Canada is quite limited. While voluntary labelling programs such as ENERGYSTAR are used in Canada, there is no current legislation or policies mandating the use of systems with EF>1. Despite this current context, the future for high efficiency water heating systems looks decidedly more promising.

The Canadian Federal Government has outlined its commitment to achieving its international emission reduction targets through its Pan-Canadian Framework on Clear Growth and Climate Change [1]. At the Energy and Mines Ministers Conference 2018, Natural Resources Canada's Office of Energy Efficiency (OEE) published its roadmap document Paving the Road to 2030 and Beyond: Market transformation road map for energy efficient equipment in the building sector [2]. This document supports the objectives of the Pan Canadian Framework by defining key short, mid, and long term aspirational goals for space heating, water heating, and fenestration sections. Under the water-heating portion of the Roadmap, three aspirational goals have been defined in order to move the market towards more energy efficient systems.

Short Term (By 2025):

- All market-available fuel-burning water heaters in Canada meet an energy performance of 90%

Medium Term (By 2030):

- All market available electric water heaters in Canada have an EF>1
- Residential gas HPs with an EF>1.4 can be manufactured and installed cost effectively

Long Term (By 2035):

- All market-available water heating technologies in Canada have an EF>1

Achieving these objectives, especially given the challenging climate and economic conditions faced by HPs in Canada, will require both significant R&D and deployment initiatives from government, research organizations, and industry. In support of these objectives, a variety of R&D priorities has been defined, including:

i. Developing higher efficiency and lower cost HPWH systems for the Canadian climate
ii. Identifying ideal HPWH systems by region
iii. Supporting the grid flexibility offered by HPWHs via new control algorithms
iv. Lab and field testing of both market available and advanced water heating technologies

While R&D targets are important for improving efficiencies and developing requisite scientific knowledge, policy initiatives are also required to direct the market towards better performing systems. To this end, a series of initiatives have also been defined, including:

i. Developing Canada-specific performance ratings and qualified product lists for HPWHs (both electric, and, in future, gas)
ii. Developing incentive programs for high efficiency water heaters
iii. Supporting the development and harmonization of codes and standards for water heat technologies

iv. Improving industry awareness through labelling programs, marketing, and targeted training and information sessions

In addition to these objectives, it is likely that other policies may also need to be updated, especially with regards to refrigerants. Many low-GWP alternatives to conventional HFCs have some level of flammability, limiting their application under current codes and guidelines. Further work will likely be required to facilitate their increased use, especially for hydrocarbon refrigerants such as propane that have been proposed and used in HPWH technologies.

This comprehensive proposed approach will likely have a significant impact in the coming years in developing and enhancing the market share of HPWH systems well adapted to the Canadian context.

[1] Govt. of Canada, 2016. Pan Canadian Framework on Clear Growth and Climate Change. Environment and Climate Change Canada, Gatineau, QC, CA.

[2] Natural Resources Canada, 2018. Paving the Road to 2030 and Beyond: Market transformation road map for energy efficient equipment in the building sector. Office of Energy Efficiency (OEE), Ottawa, ON, CA.

3.2 Discussion

In getting the right policy it a fine line of supporting the interests of commercial market players selling or installing heat pump technologies, against the sometimes large economic interests of companies selling competing and often traditional technologies. Straightforward policy support for DHW HPs is therefore very rare and not consistent across Europe, North America and Asia. The example of Japan cannot simply be copied by other countries.

Yet it can be of governmental interest to support DHW HPs as these can contribute to meeting policy targets as DHW HPs can

- Make a significant contribution to meeting energy efficiency and CO2 targets, through increasing the efficiency of the existing domestic heat sector – particularly displacing gas, electric and oil.
- Be a lower cost option to meet targets than many competing technologies – the upfront cost is relatively low and running cost savings generally high, so the economic proposition is good even without incentives in many markets
- Make a contribution to renewables targets if they are counted as renewable[3]
- Offer demand side flexibility which is easier to control than space heating (hot water is an easier load to manage than space heating)
- Be a way to manage the grid impact of escalating PV installations

Yet it is expected that mandating the installation of high efficiency water heaters is the main policy tool to ensure that high efficiency water heaters are installed regardless of any short-term inconvenience issues. Mandated measures can take the form of:

- prohibiting inefficient water heaters from sale,
- prohibiting low efficiency water heaters from being installed, or
- requiring certain high efficiency technologies, such as solar water heaters, to be installed.

[3] Often DHW HPs are not counted as renewable when the heat source is air from an internal space

Awareness of DHW HPs is growing in several markets, but in general, awareness is low amongst end-users (as is the case with space heating heat pumps) while on the other hand technology is broadly available. This means presenting and disseminating a simple, easily understood and compelling message to consumers. Central to this is giving consumers the confidence to embrace the technology, and create pull in the marketplace to assist in transitioning heat pumps from a niche product to one having mass market appeal. Awareness can be raised by:

- Product promotions and programmes.
- Information dissemination.
- Roadshows, information seminars, press and PR activities.
- Involvement of trusted actors and brands.
- On-going field trials, and tests with published results.

There is a role for all industry stakeholders in these activities as well as the other actors in the value chain: building and construction companies, energy companies, housing corporations, energy service companies, installers, knowledge and training institutes, research institutes and universities, branch organizations, financiers, etc.. The structure of an innovation system consists of five elements: Actors, Interactions, Institutions, Technology and Infrastructure.

- *Actors*
- Value chain: heat pump manufacturers, installers, wholesalers, construction companies, customers, etc. Indirectly: knowledge and training institutes, governments, branch organizations, financiers etc.
- *Interactions*
- Within the value chain (s), in research projects, at symposia, in joint pilot projects, during training courses or meetings of sector associations etc.
- *Institutions*
- Written rules: standards, minimum requirements in legislation and regulations, goals and strategies. Unwritten rules: culture in the sector or standards / values at customers.
- *Technology*
- Heat pumps exist in all shapes and sizes: stand alone or in combination with a high efficiency boiler, various external energy sources, large or small capacity etc.
- *Infrastructure*
- An infrastructure is needed that facilitates the release of financial resources and the training of sufficiently trained personnel. Knowledge must also be recorded somewhere (eg in databases), physical space in the home is needed and there must be sufficient production capacity.
- It keeps heat pumps highly profiled for all the right reasons amongst policy makers as a solution of choice in meeting their energy savings and emission reduction targets.
- It attracts participation and active engagement in the market by reputable actors.
- It builds confidence amongst customers and positions heat pumps as a reliable, cost effective, energy efficient and environmentally friendly heating alternative.

Successful marketing and promotion builds confidence and positions heat pumps favourably compared with alternative technologies. Based upon figures given by the IEA 4E Benchmark document on water heaters [11] there are large potential savings available from moving between types of water heater. On a delivered energy basis, and at the reference conditions used, water heater types providing similar levels of service have annual energy consumptions of:

- Air sourced heat pumps: 1.1 – 2.0 MWh;
- Direct electrically heated storage: 4.4 - 5 MWh;
- Gas instantaneous: 6.2 - 6.5 MWh;
- Gas storage: 6.0 - 7.7 MWh.

These figures are clear and convincing.

DHW HPs will look strong relative to competing technologies under Ecodesign and Ecolabelling in Europe, TOP Runner program in Japan and the ENERGY STAR in USA/Canada, which should support market growth – however this will not create immediate opportunities as there should/must be added value for the market players in the value chain to participate. In the market study [12] the business opportunities for the supply side are listed, which is a further basis for R&D as discussed under Task 4 of the Annex.

The attractiveness of hot water heat pumps in the European market is mainly caused by three factors [10]:

- The combination of a hot water heat pump with a fossil fuel boiler is often sufficient to fulfil the requirements of legislation, either in terms of the use of renewables, in terms of energy efficiency or both. Their use also has a saving effect on the primary energy required by the building, making it easier to achieve the requirements of ever stricter building codes. As a single measure, their installation increases the efficiency of the whole system without the need for larger renovation works, it also helps installers to get acquainted with the technology.
- The use of a hot water heat pump in combination with a photovoltaic and/or PVT-system provides a long-term cost efficient solution for hot water production in times of increasing electricity prices and decreasing feed-in tariffs. It ensures nearly emission-free sanitary hot water production all year round. The electricity that is not used for the building itself can still be sold, making 100% system utilisation possible. In a systems perspective, the heat pump system serves as a thermal battery that stores electricity converted into heat for later use. Its potential storage capacity provides a cost efficient option to balance fluctuating electricity supplies from wind and PV in smart grids. The storage potential is deemed to be far greater than that of pumped hydro storage and electric cars combined.
- For manufacturers new to the heat pump market, starting their engagement with sanitary hot water units is comparatively easy and in consequence, many new players start by entering the market in this segment and extend product coverage and production later. The parallel decline of solar thermal collector sales adds to this, as manufacturers from that sector seek new areas of activity where there existing competence can be deployed.

In the end it is the end-user, either private or collective through housing corporation, but also the building constructor and its engineers having to comply with the Energy Efficiency demands of a building, that decide on the choice of water heating technology to be applied in a new building or a renovation project. The renovation project can be a simple replacement of an old heater or system.

Costs and economy of the choice compared to the alternatives dominate the choice as well as awareness of DHW HPs and its alternatives. The strength of the customer proposition for DHW HPs is a function of:

- Market specific energy price ratios
- DHW HP efficiency
- Competing technology efficiency
- Upfront cost for DHW HP
- Marginal upfront cost relative to competing technologies
- Payback times

4. Technology and systems

Water heating for domestic appliances and other sanitary functions appear in single units for an individual end user and in collective units in larger systems/buildings. When speaking about Heat Pump Water Heaters generally we are speaking about the mono-bloc air source heat pump, defined as a single unit with heat pump (with compressor, expansion valve, evaporator and condenser), with a storage tank integrated often under the heat pump underneath. Mono-bloc systems will remain the preferred solution in most cases. However there is a great number of alternatives on water heating with heat pumps, other than the mono-bloc, where the greater flexibility in installation offered by separate systems will drive growth of non-integrated systems in some markets (e.g. where attic installation is common).

The choice of the right storage tank in relation to the heat pump makes a decisive contribution to the efficiency of the entire system. There are some ideas on preferred systems. Influential factors are:

- Heat exchanger (i.e. condenser and choice of refrigerant);
- Stratification in the storage tank;
- Less heat losses of the storage tank;
- Less heat losses in the hot water distribution system, especially in collective systems but also in individual systems;
- Choice of heat source, internal or external air source or ground source;
- Operational control and thermostat setting;
- Storage size, often over-sized;
- (Possible) auxiliary heaters;

Generally the cost effectiveness of the product is often a decisive argument for the end-user, but in some cases not so much.

Unfortunately, the standby losses of heat pump water heaters are often higher than traditional Electric Storage Water Heaters. Causes are mainly the additional piping, wraparound condensing unit, inadequate insulation and over-sizing of the storage tank. This mainly to blame on the inadequate design of the monobloc unit. It can be largely improved and it is a challenge for designers and developers. Installation of HPWHs in confined spaces also reduced efficiency by approximately 16%, which is consistent with other studies.

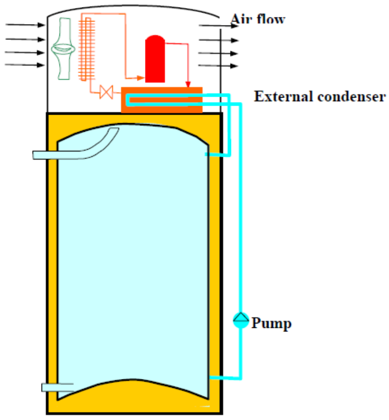
4.1 Condenser configuration

There is a trend within the Annex to work on wrap around heat exchangers as the prevailing technology available in a number of countries like France and North America. However spiral in tank heat exchangers are dominant in a number of other countries in Europe (i.e. Germany, Denmark, Sweden, Netherlands). Especially in the development of solar hot water storage tanks a number of models have been developed for these type of heat exchangers, with a focus on stratification and thermocline dynamics. Moreover the external plate heat exchangers are growing in popularity for small domestic systems.

Of great importance in the choice of condenser are:

- The choice of refrigerant.
- Overall efficiency
- Building of stable thermocline in the storage tank
- Costs of the end product
- Flexibility of the end product

The configuration of the condenser has great impact on a stable thermal stratification within the tank. Thermal stratification in the storage tank is also influenced by various parameters such as insulation thickness, flow rate at inlet and outlet, tank inlet and outlet geometry [20]



Gas Cooler as external condenser

The external condenser (gas cooler) can be tube-in-tube heat exchanger or brazed plate heat exchanger placed on top of a mono-bloc HPWH or placed adjacent to the storage tank in a split unit installation. This can also be used as retrofit for existing electric storage water heaters!

Fig 4.1 - External condenser

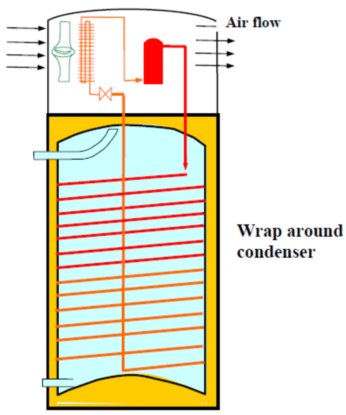
Advantages:

- High thermal efficiency as heat is exchanged in two counter flows;
- Small refrigerant charge possible. Andersson et. al. [14] have shown that by using a plate heat exchanger the refrigerant charge could be minimized without losing performance and capacity;
- Split units makes it possible to be flexible in storage sizes;
- Split units can be easy to install in small spaces;
- Flexible in choice of heat source;
- Full internal tank volume reserved for water storage;
- Retrofit of existing ESWH's;

Disadvantages:

- Stratification dependent on flow rate. Higher stratification favours better Unified Energy Factor and COP, a relatively lower circulation rate is recommended. However, if the flow rate is too low, it can adversely impact the performance as the water will be over-heated at the exit of gas-cooler which deteriorates the cycle performance as shown by Nawaz [15];
- Double wall HX required to mitigate possibility of water-refrigerant HX;

Equipping the storage tank with an external plate exchanger also allows: the system's overall size to be reduced to the minimum, maintenance to be simplified, and the combination of the power of the water heater and the performance of the heat exchanger to be optimised. This configuration becomes more and preferred by manufacturers.



Wrapped Tank Condenser

The refrigerant is flowing through a wrapped-tank condenser which is fixed around the storage tank. In many countries this is the prevailing technology for plug &play mono-bloc systems.

Fig 4.2 Wrapped tank condenser

Advantages

- Cheap integrated production costs, which is highly questionable for traditional manufacturers of storage water heaters, especially in Europe;

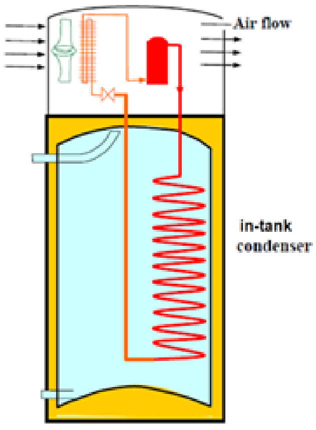
- No corrosion;
- No contact with water

Disadvantages:

- Only available as mono-bloc HPWH;
- Relatively high refrigerant charge;
- No flexible tank sizes;
- Leaking of refrigerant to outside of storage tank;
- Very poor stratification;

Charging/discharging of the wrapped coil water tank of the heat pump water heater is an important process which directly impacts the performance of the system. The thermal stratification in the tank maintained during the standby period is significantly affected by the charge/discharge process. As cold recovery water enters the tank and the supply hot water is discharged from the tank, the water circulation disturbs the thermal stratification and enhances the mixing thus reducing the tank water temperature and the overall effective draw-off volume.

In tank condenser



The in-tank condenser is the traditional heat exchanger for many European manufacturers as their background is a manufacturer of water heaters, specifically storage water heaters and solar water heaters, like Stiebel Eltron, Inventum, Dimplex, Gorenje, Ariston, ITHO-Daalderop, NIBE.

Although in Figure 4.3 illustrated as a condenser on the top of the storage tank the condenser in the majority of the Heat Pump Water Heaters is positioned at the bottom of the tank. In some cases it is thus possible to mount the condenser on the 'service hole' at the bottom of the storage tank. Thus the electric storage water heaters can be retrofitted. These were the first design in 1982/83 by the editor of this report working for Inventum in Netherlands.

Fig 4.3 – In-tank condenser

Advantages:

- Good stratification possible with minimum load of heat exchanger and optimal control;
- Split unit possible, although main suppliers still produce mono-bloc HPWH's;

Disadvantages:

- Potential leakage of refrigerant to water tank, thus a double coil HX required (only with toxic refrigerants);
- Potential corrosion of HX if different materials are used like copper and steel;
- Small loss of internal volume due to HX, this eliminated by the far better stratification, giving a higher first hour performance.

Auxiliary Heat Source

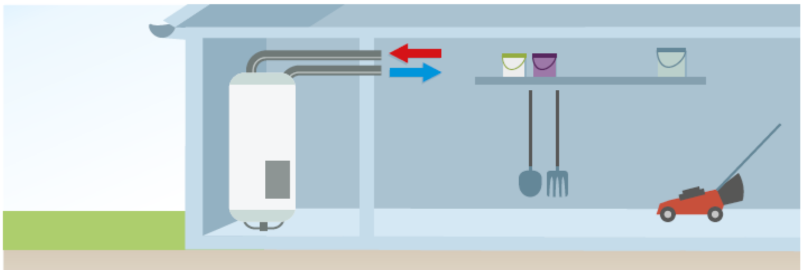
HPWHs often have an auxiliary heat source, usually an electric resistance element, which can supplement the vapour compression cycle during the initial heating of water from cold, during periods of high hot water demand or when the vapour compression cycle is unable to operate effectively (e.g. under frost or very low external temperature conditions). Such DHW HPs are sometimes called 'hybrid' models.

4.2 Sources

The main sources for HPWH's for a single family house are inside air and outside air. In the case of a double function heat pump in single family houses ground source HPs are also used. For multifamily buildings the sources can be air as well as ground sources.

External and internal air source both offer efficiency benefits dependent on the home. Regarding efficiency, there are pros and cons of systems extracting heat from both external and internal air: The temperature of external air is more variable than internal air, and can drop lower – which means efficiencies of the HP will be more variable. With internal air systems (particularly non-ducted systems), heat is extracted from inside the building, which can result in increased space heating demand and increased heat loss from the water tank – with overall efficiency losses. Internal air systems which are ducted can give efficiency benefits by utilising waste heat from e.g. showers and kitchens, to heat other rooms.

Indoor air source, not ducted



HPWHs using the air inside are a very common, often installed in unheated but aerated rooms like cellars and garages. In more temperate areas of North America, these units can also be installed in occupied spaces and provide the additional benefit of cooling the space. The minimum size of the room of installation is 20m³. The cold air can be expelled from the building to the outside via a duct, resolving some of the disadvantages but also eliminating some of the advantages.

Advantages

- Ease of installation, as no installer intervention on the refrigerant cycle needed. Almost a Plug & Play concept;
- Room where system is installed is cooled and can be used as storage room;
- Can use waste heat from other appliances in the room;
- Dehumidifies the room;
- Relatively high source temperature, with minimal temperature fluctuations over year (compared to systems using outdoor air).

As these types of HPWH's are almost always installed in larger garage boxes or cellars the advantages are rather marginal in mild climates. However in hot and humid climates it can be an important asset.

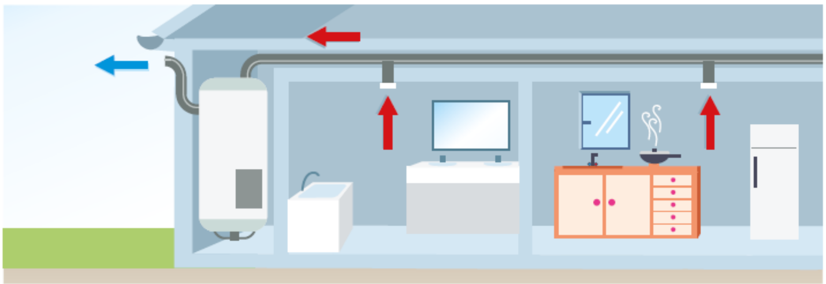
Disadvantages

- Room is cooled down (especially of effect in mild and cold climates):
  - insufficient insulation between heated and unheated area can lead to increased space heating demand;

- cooling down the room of installation leads to increased thermal store losses and decreasing efficiency of the heat pump;

- Installation outside the thermal envelope of the building leads to increased thermal store losses;
- Unlikely to be treated as a renewable energy source under building regulations in many states could be a major barrier – though should count towards efficiency requirements.

Indoor air source, ducted



DHW heat pumps using the air inside the building via ducts are less common than systems which are not ducted.

Principle: The system is ideally installed inside the thermal envelope of the building, warm air is extracted from other room inside the building. The cold air is usually expelled from the building to the outside.

Advantages

- Can be used in order to ventilate rooms with high humidity and auxiliary heat production (e.g. bathrooms & kitchens);
- Uses waste heat from appliances like showers, hobs, ovens, washing machines, tumble dryers, dish washers, fridges, freezers, etc.);
- Very high source temperature (20°C+) good efficiencies;
- Installation inside the thermal envelope reduces storage losses.

Disadvantages

- Draws calories from inside the thermal envelope of the building, not only when this is wanted/needed – e.g. when the shower or the oven is on, but also when it is not wanted/needed ? increases the space heating demand;
- Complexity and cost of installation – the system is more complex to install than a system which is not ducted, leading to higher labour and material costs as well as an increased interruption for the customer (only in retrofit);
- Unlikely to be treated as a renewable energy source under building regulations in many states could be a major barrier – though should count towards efficiency requirements.

Outdoor air source, ducted

DHW heat pumps using the air outside the building are usually very similar to systems using indoor air as heat source. The main difference, if any, is usually a defrost cycle for the evaporator.

Principle: This type of system is usually installed inside the thermal envelope of the building. Ventilation ducts draw air into the unit from outside, and expel air from the unit to the outside.

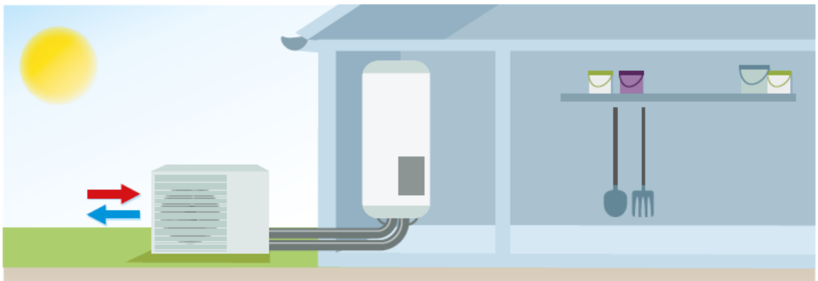
Advantages

- Relatively easy to install (especially if plumbing pre-existent), no installer intervention on the refrigerant cycle needed;
- Installation inside the thermal envelope of the building reduces thermal store losses;
- Ducting the airflow decreases the noise levels inside the building.

Disadvantages

- Exposure to colder outside air temperatures → decreases efficiency of the heat pump; increases need for use of backup heater (in cold regions, if used throughout the year);
- Intervention on the building envelope → higher labour and material costs;
- Likely to necessitate different system design decisions (e.g. refrigerant selection) in comparison to systems using indoor air for use in cold climates, with potentially higher first costs;
- Many current market systems have limited ability to operate with colder source air temperatures, limiting the number of products that can be used in this configuration.

Outdoor air source, split



DHW heat pumps using external air as the heat source via a split installation currently only have a small market share - mainly because very few companies have this type of system on offer but also due to the higher complexity of the installation (installation requiring a refrigerant trained installer). It is a growing part of the market however, as more and more manufacturers offer these systems 'installer ready' where the complete heat pump unit is outside with an external condenser and only connected to the storage tank with water pipes.

Principle: The thermal store of this type of system is usually installed inside the thermal envelope of the building. The thermal store includes the condenser and is connected to the external part of the system via piping containing the refrigerant.

Advantages

- Major noise sources (compressor & fan) are outside the building → decreased noise emissions inside the building;
- Installation of the thermal store inside the thermal envelope reduces storage losses;
- Possible installation of the thermal store closer to the extraction points allows to minimise distribution losses;
- Flexibility of installation / physical fit benefits because part of the system can be outside.

Disadvantages

- Exposure to colder outside air temperatures → decreases efficiency of the heat pump; increases need for use of backup heater (in cold regions, if used throughout the year);
- Complexity of installation – the system is more complex to install than most monobloc systems and requires a refrigerant trained installer → higher labour and material costs;
- Likely to necessitate different system design decisions (e.g. refrigerant selection) in comparison to systems using indoor air, with potentially higher first costs.

4.3 Monobloc or split system and tank sizes

Monobloc systems still dominate the market, but the need for lower cost products and requirements for simple and easy installation will drive the growth of split systems (many from China, & European manufacturers will launch splits developed themselves or OEMs).

There will be a place in the market for both internal air and external air systems. The greater availability of splits could grow the share of external air systems. There will also be a niche for alternative novel heat source systems

Some advantages for splits in terms of physical fit [12]:

- The advantages of splits are predominantly in physical fit: Part of the system is placed outside, and the internal unit is often wall-hung, taking up less space in the home. Because the fan is outside, there is reduced noise inside the home. However, the placing of the outside units of split systems may face regulatory restrictions in some markets / regions;
- Monoblocs can be placed outside in some cases, with associated physical fit & noise reduction benefits - but this is not common in Europe (outside installation of monoblocs is popular in other markets such as Australia);
- There are no significant differences in 'ease of installation' between monoblocs and splits if the installers are appropriately trained. However, splits require refrigerant handling qualifications which could be a challenge in some markets;
- There is not sufficient evidence to differentiate monobloc and split configurations in terms of efficiency or upfront cost (although many split systems available on the European market are manufactured in China, and the prices and efficiencies for such products can be lower than the equivalent European products).

Separating the tank makes installation more flexible:

- An un-integrated system which allows separation of the HP module from the hot water tank has one key benefit – it allows greater flexibility during the installation process. For example, if installing in an attic, the HP module and the tank can be transported to the attic separately, and assembled later – avoiding having to move a single larger, heavier unit;
- An un-integrated system does not provide other clear benefits in terms of costs, physical fit or efficiency.

Larger tanks will continue to dominate in markets with sufficient space, driven by the potential for integration with PV and smart applications. There is strong potential for products with smaller tanks in several countries, but the market is currently limited by the availability of small enough products.

A smaller tank is lower cost & opens market opportunities in space-restricted homes

- A DHW HP with a smaller tank has the advantages that it takes up less physical space and is cheaper (a system with an 80L tank could cost in the range €1,500, while a system with a 200L tank is likely to cost in excess of €2,500). It can also access a large share of the European electric water heater replacement market;
- A smaller tank may have some disadvantages in terms of efficiency: In larger properties, a smaller hot water storage tank means that the heat pump needs to cycle on and off more often to top up the tank – causing efficiency losses;
- However, there are also efficiency benefits from a smaller tank - if it is emptied of hot water more often this helps to maintain a bigger temperature gap between flow and return, which can significantly

increase performance. This advantage has to be balanced with having sufficient capacity (kW) to heat up the tank fast enough.

4.4 Heat Pumps for systems in Multi Family Buildings

Heating systems in Multi family can be individual systems where space heating/cooling and hot water are generated individually in each apartment/dwelling or it can be collective systems, where the space heating and hot water are generated in a central boiler room and distributed in circulation systems. Or a mix of individual and collective generation.

The low efficiency of DHW systems in Multi Family Buildings is well known by field practitioners. For many new residential building hot water delivery times and water waste have been getting steadily worse with newer buildings. The sources of inefficiency can be found in every one of the diverse phases entailed by DHW systems: from the design of the piping structure and the sizing of equipment to the selection of the applied control strategies. A better understanding of water deployment is desired in order to improve the whole system, both in the initial design phase and in the final control phase [20].

For multifamily buildings, mainly owned in the inner cities by housing corporations, the options of individual solutions are more complex. Collective systems maintained, optimized outside of the apartments in the building seems to be an interesting solution. Optimisation will have to be found outside of the front door of the apartment. Domestic hot water can be supplied centrally by a heat pump with a small heat exchanger in the apartment. A solution for potential legionella will have to be found. Another solution is to split space heating and domestic hot water and install a monobloc air source heat pump [13] or a booster heat pump [19] in the apartment. Major obstacle in that will be the lack of space for such a booster heat pump with storage tank in the apartment. District heating, fed with sustainable energy options at low temperatures, is another option. However this District Heating option can considered as the worst case scenario for energy optimisation od domestic hot water generation.

A study by the City of Vienna [18] clearly concludes that in terms of the sum of all system losses, decentralized solutions (hot water is produced where it is needed) are the best choice. However collective systems have their advantages mainly because these systems can be optimized and controlled centrally. A large number of the collective systems in housing blocks are circulation systems. The water which is circulated as energy bearer in the system, is not used as domestic hot water for shower, bath or consumption by the individual end user. The heat exchanger between the collective system and the individual end user system is for the domestic water use fed with cold water to be heated and used as domestic hot water. In principle thus the end user side can be regarded as an individual system with short pipe length and a content much smaller than 3 litres, as long as the cold water fed in for domestic use has a temperature lower than 20°C.

The current guidelines for legionella in collective systems seem contradictory to this, because they generally require thermal control of legionella in a distribution system in multi-family buildings. Thus for smaller collective systems, i.e. blocks of Multi Family buildings not connected to the district heating grid increasing the temperature of the distributed water to a level of 65 - 70°C is the standard solution. In the following paragraphs three solutions are described, being:

- Installing high temperature heat pumps in the circulation system for hot water distribution;
- Individual at the individual end user, based upon the volume limitation concept;
- Individual heat pump solutions.

Examples for new buildings and renovation are numerous.

4.4.1 High Temperature heat pump solutions

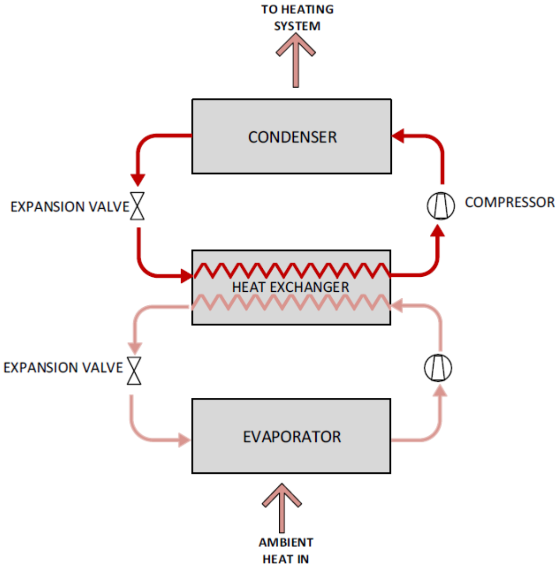
High temperature heat pumps are often the basis for collective systems. The recent developments in the market make these systems available, these are made possible by:

- Optimised design for specific refrigerants
- Cascade heat pumps
- Enhanced Vapour injection
- Sorption Technologies
- Gas engine driven heat pumps

However other solutions are being developed as still the internal temperature losses are considered too high.

Cascade heat pumps

A cascade system consists of two single-stage cycles (a low temperature and a high temperature cycle using different refrigerants) which are thermally connected by an intermediate heat exchanger, as shown in Figure 6. The low temperature cycle uses the refrigerant R-410a which is able to evaporate at a very low air temperature and condenses in the intermediate heat exchanger at a relatively low pressure and a temperature of about 45°C. This process transfers heat to the evaporator of the high temperature cycle which induces the evaporation of the second refrigerant R-134a. This refrigerant is then able to condense at a pressure that is not too high to affect performance.



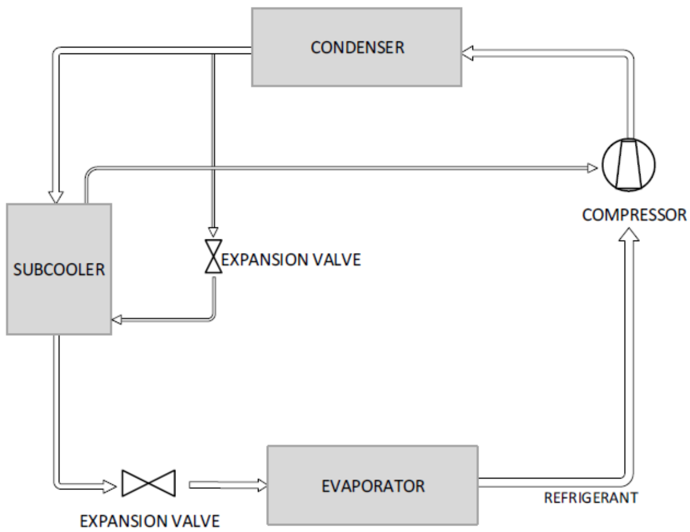
Cascade systems are capable of reaching temperatures of up to 80°C. Some systems are able to fluctuate between using both cycles together, and using just a single-stage cycle to optimise performance.

Performance optimization of a cascade multi-functional heat pump[4] in various operation modes.

Single-stage heat pumps are unreliable at low ambient temperature conditions and over high pressure ratios, resulting in deteriorated heating capacity and low COP. This makes them unpopular for use in the generation of hot water, especially above 65°C, for both domestic and industrial use. For purposes of reliability and maximum system performance, the cascade heat pump is preferred to single stage heat pumps. The cascade heat pump has higher heating capacity, higher hot water temperature and much stable water heating capacity than single stage heat pumps. They also have lower compressor discharge temperature, lower evaporating temperature, lower compression ratio and higher compressor volumetric efficiency than single stage refrigeration systems at the same cooling capacity. An informed knowledge of the design, operation and control of the cascade heat pump is therefore very important.

[4] A multi-functional heat pump delivers space heating and hot water, and some cases cooling.

Enhanced Vapor Injection



The EVI technique requires an additional loop to be added to the standard heat pump cycle. This loop enables a small proportion of the condensed refrigerant to be extracted and expanded through an expansion valve and into a counter flow heat exchanger which acts as a subcooler. The additional subcooling increases the evaporator capacity. The resulting superheated vapour is then injected into the compressor part way through the compression process as shown in Figure 7. The result is a significant gain in heating capacity due to the increased refrigerant mass flowing through the condenser for the same size of compressor. There is also an increase in power use, but the overall effect is to increase the COP. The cooling provided by the gas injection allows the operation of the compressor over a larger envelope compared to a conventional single stage cycle, providing higher output temperatures at low evaporating temperatures and reductions in compressor discharge temperatures

Gas fired Sorption heat pumps

The air-source gas-fired absorption heat pump (GAHP), uses an energy input (natural gas) to "pump heat" from the outdoors to an indoor conditioned environment. At the core of the GAHP is a group of heat exchangers, vessels, and a pump that comprise the "thermal compressor". The GAHPs that are currently commercially available are primarily models from the Italian manufacturer Robur, whose products and that of their few competitors are typically a) too large for residential applications and b) have equipment costs greater than $13,500 [Delta Energy & Environment, 2014].

Sorption products are gas driven heat pumps. In a sorption cycle the mechanical compressor found in a standard electric heat pump is replaced by a thermal compressor. A working pair of refrigerant and sorbent is used instead of the single refrigerant used in a conventional heat pump. For an absorption cycle, refrigerant vapour is drawn into a liquid sorbent, allowing them to combine chemically. The resulting solution is then pumped up to the condenser pressure and the refrigerant driven out of the sorbent in the generator by direct heating.

In an adsorption cycle the refrigerant vapour (usually water) is adsorbed by a solid sorbent (usually zeolite). The sorbent then has to be heated to release the refrigerant so adsorption in usually a batch process. In an absorption cycle the refrigerant and sorbent combine chemically whereas in an adsorption cycle they do not. The use of appropriate refrigerant/sorbent working pairs, and the fact that they can recover waste heat from gas burner providing direct heat, allows this technology to reach output temperatures above 60°C.

4.4.2 Individual Heat Pump Solutions for Collective systems

Xiaochen Yang et.al. [16] propose that since the insufficiently high temperatures and long-term stagnancy are the main risk factors for Legionella proliferation in collective hot water systems, alternative designs are needed that can eliminate those factors. The basic concepts behind such designs are temperature boosting and volume limitation. Temperature boosting can be achieved using local supplementary heating devices. It is clear that mostly in new systems the DHW and space heating systems are split in three, four and five pipe systems, where in the separate DHW distribution temperatures are raised to 70ºC.

Temperature control is still the most widely used method for preventing Legionella in hot water systems. In Denmark, for example, the standard regulates that the circulation pipe should be kept at 55ºC all the time, and it should be possible to heat the storage tank up to 60ºC on a regular basis. Some Scandinavian countries are currently planning to operate District Heating (DH) networks at lower temperatures (around 30– 70ºC) to reduce fossil fuel consumption and improve energy efficiency. The aim with Low Temperature DH is to reach supply temperatures that approach 50ºC. Considering heat losses, primarily in the heat exchanger, this means that the temperature of the water when it reaches the tap will be around 45ºC at the most. With the legislative demand in a majority of the countries that the temperature of the water should be a minimum of 50ºC when it reaches the tap, the feed temperature in the distribution system should be at least 10K higher.

The volume limitation concept by Linita Karlsson et.al. [17], in accordance with the German StandardW551, is that, if controlled properly, a system with a total volume (from hot water production to end use) of less than 3L can eliminate the risk of Legionella. The advantages of alternative design are numerous. With a central heat pump in the basement a decentralized substation can be used where the feed is 55ºC. Decentralized substations inhibit growth of Legionella by limiting the residence time in what might otherwise be favourable conditions. The idea is based on the German Standard W551 that in systems where the total volume between the point of distribution and the furthest tap does not exceed three litres there is no need for additional disinfection techniques (DVGW, 2004). These are so called small systems and are usually only found in single-family homes but the principle could be applied in apartment buildings as well. Each apartment would then have its own district heating central - a flat station – with an individual heat exchanger that would heat up water instantaneously when needed.

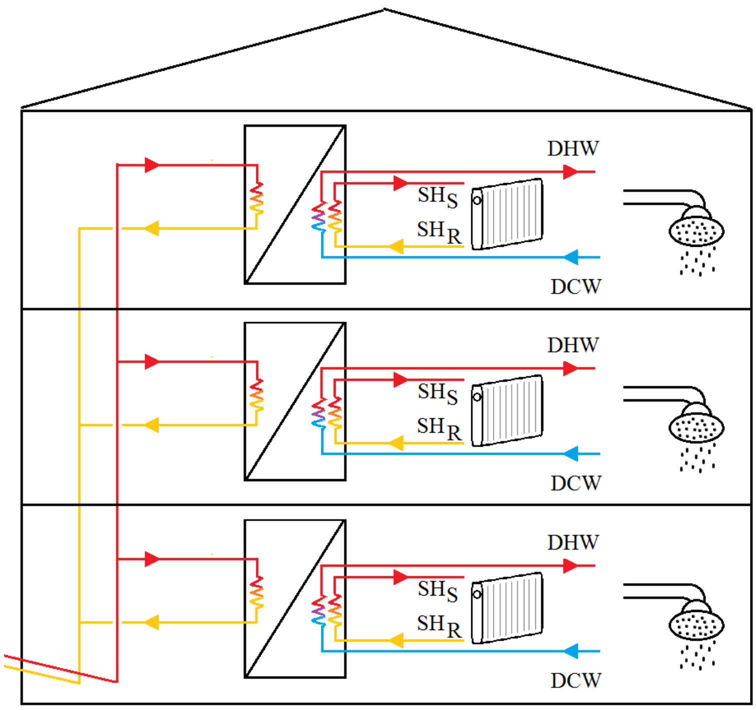


Fig 4.3 Process diagram of decentralized substations [17].

Decentralized substations has the potential to limit Legionella growth even with the lower supply temperatures from low temperature district heating. Yang, Li and Svendsen performed a study on a six story residential building in Denmark that concluded that an LTDH system with a supply temperature of 55°C could be operated with decentralized substations while still ensuring the water quality with regards to Legionella. Other advantages is that there is no need for water circulation which can significantly reduce the heat losses and that there is no addition of chemicals that may affect the water quality (Yang, Li & Svendsen, 2016b). The drawback is that it requires considerable investments and can be difficult to implement in existing buildings as the installation would require extensive renovations.

Boosting the temperature, the idea of an auxiliary heating device is to boost either the supply temperature or the DHW temperature to be able to meet the required temperatures. There are many types of heating devices but in this thesis only three will be investigated: electric heat tracing, micro heat pumps and electric heating elements.

- **Electric heat tracing**: One of the above mentioned heating techniques is to install electric cables on the DHW pipes (see figure 17 for a process diagram of the setup). The DHW can thus be heated to the required temperature even if the primary supply water temperature is too low. This also eliminates the need for circulation of hot water since the heating process is nearly instantaneous (Yang, Li & Svendsen, 2016c). Replacing the hot water circulation system with electric heat tracing can lead to large energy savings and economic benefits. To make electric heat tracing more efficient it is advised to introduce smart control where the heat load at varying times is considered.

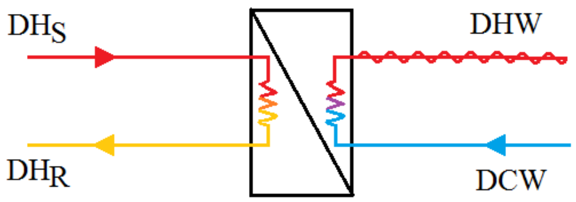


Fig 4.4 Process diagram of electric heat tracing [02]

- **Booster Heat Pumps [19]**: Another way to heat up the domestic hot water is to install a microbooster heat pump. The central LT heat pump feeds the floor heating in the houses, but at the same time the low temperature heat serves as a source for the booster heat pumps, which make hot water decentrally per apartment and store them in a tank. An advantage of this 'semi-central' system, the less complex distribution system, being a two-pipe system.

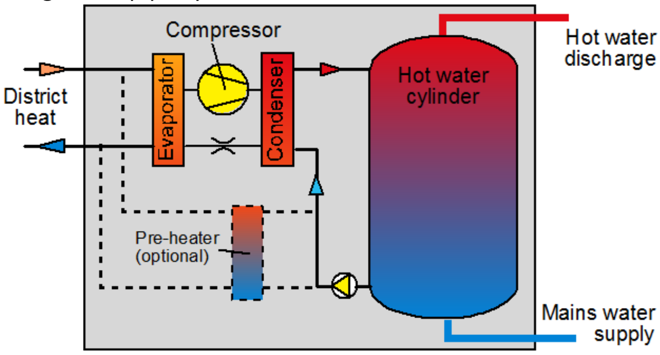


Figure 4.5 Basic layout of a booster heat pump.

- **Individual Domestic Hot Water Heat Pump**, which can be installed separately of the two pipe distribution system in the individual apartments. This seems to be a good solution for renovation of existing distribution systems to lower temperatures [13].
- Individual Double Function Heat Pump, which provides space heating and hot water individually per apartment. This is the preferred solution for large scale renovation project for a small but growing number of Dutch housing corporations [21].

- **Instantaneous electric heater**: The concept of an electric heater is to have an electric heater in addition to the heat exchanger. This provides instantaneous heating of either the supply stream, i.e. before the heat exchanger or directly of the DHW, i.e. after the heat exchanger.

There are several alternative technologies than thermal management that could theoretically be implemented. These can be divided into three categories: mechanical techniques, sterilization techniques and alternative system design. The implementation of the majority of them are hindered by the current legislation on temperature requirements. At present the only possible solutions are those that boost the DHW temperature, i.e. electric heat tracing, micro heat pump or electric heating element.

In collective systems, especially the larger district heating systems sterilization is an option to fight potential legionella infection. Sterilization techniques aim to kill bacteria and thus keep the colonization in check. This can be done either by adding a chemical to the water, that for example destabilizes the bacteria's cell wall, or by installation of ultraviolet lights or an advanced oxidation process. Five sterilization techniques can be observed in the market: chlorination, ultraviolet light, ozone, ionization and photocatalysis

4.6 Other Heat Pumping Technologies for Water Heating

New systems and combination of technologies appear on the market, whereas the fresh water system first developed for solar thermal systems now appear to be embraced by a number of European heat pump manufacturers as a solution to the challenge of legislation on legionella. Other solutions are the combination with solar thermal as has been studied in Annex 38, together with Task 44 for the TCP Solar Heating and Cooling. The approach in this Annex was to find a solution for solar heating with the support of heat pumps. When taking the heat pump as the basic heat generator and the solar thermal system as support, other more effective/efficient and cheaper solutions can be developed and applied. The combination with solar photovoltaic is offering however a larger potential as already been published in a number of papers and discussed at a special workshop at the 12th IEA Heat Pump Conference 2017 in Rotterdam.

The conclusions of the workshop were :

- The heat pump market is hindered by the increasing E-price;
- Electricity market and pricing is volatile and may develop in a flat rate system;
- There is synergy between Solar and Heat pumps. (without heat pumps solar thermal probably has no future);
- The market is more interested in the PV-HP combination and the combination with solar thermal;
- The business case for Solar Heat Pumps very much depends on the (national) conditions, pricing, regulation;
- Solar & HP is a win-win, provided that costs decrease!

4.6.1 Fresh water systems:

In contrast to conventional DHW cylinders, the drinking water is not used for storing thermal energy but instead is only heated when required, by means of a powerful plate heat exchanger. The energy for this DHW heating is drawn from a heating water buffer cylinder, which can be heated by a wide range of systems – by solar thermal systems, or by solid fuel boilers, conventional oil/gas boilers, heat pumps or other systems.

As a penalty of higher temperatures it may difficult to achieve high COPs, so where possible lower heating temperatures are preferred, even if the system can reach a higher temperature. Fresh Water systems having become popular for solar thermal systems are getting a market for DHW Heat Pumps. For avoiding Legionnaires disease a fresh water system seems to be a good choice.

Freshwater modules are used for convenient and hygienic DHW heating according to the instantaneous water heater principle.

Another advantage of a fresh water station is that hot water is heated in the flow. Stagnant warm drinking water, which is a potential source of Legionella, is avoided. In private households, therefore, one can do without preventive measures against Legionella and provide hot water with only 45 ° C. This low temperature is completely sufficient for comfort, which approximates the solar thermal. Thanks to the low temperature in the buffer tank, the solar collectors can harvest more energy from the sun than at buffer temperatures of 75 ° C and more, which are necessary for legionella prevention. Similarly, heat pumps work more efficiently when they need to provide low temperatures.

Fresh water systems come in 2 types:

- An additional heat exchanger is placed externally on the tank
- An additional fresh water coil is passed through the tank

Clean, fresh water is then passed through the heat exchangers. The clean water and stored water never mix. The Legionella bacteria stay in the tank.

Benefits of this system include:

- 100% health risk removed;
- Lower running costs;
- Regulating flow rates and temperatures.

Some European manufacturers of fresh water systems include: Viessmann, IDM Energie System, Ochsner and Heliotherm.

4.6.2 DHW Heat Pumps & Solar Photo Voltaic

Integration with Solar Photo Voltaic could be a game-changer for DHW HPs in number of markets. With the levelized cost of electricity generation from photovoltaic installations reaching grid parity in more and more European countries it becomes attractive to increase the amount of PV electricity which is consumed directly by the owner of the PV system (e.g. in Germany, Italy and Spain). DHW HPs are one possible option to increase this self-consumption. Compared to the demand profile of space heating HPs a DHW unit has the advantage that the heat demand is relatively stable throughout the year, thus corresponding better with the production profile of a PV system

Since the introduction of an incentive for the self-consumption of PV electricity in Germany in 2009 several HP players have emerged on the market for integrated solar PV + DHW HP offerings – initially mainly in Germany but now with offerings expanding into other markets. The systems use data provided by the inverter of the PV system in order to control the DHW HP. They typically react to an increase of PV production by increasing the target temperature in the storage tank, thus storing PV energy as heat for later use.

Increased interest in this type of system was noted at ISH2013, with both Stiebel Eltron and Vaillant signing cooperation agreements with SMA, the large German inverter manufacturer. Further, several DHW HP manufacturers are working on advanced controls which will enable intelligent integration with PV.

New utility business models are emerging in the integration of HP + PV, where the utility captures the value from controlling the operating times of the HP according to energy prices and to maximise self-consumption incentives.

At the 12th IEA Heat Pump Conference a number of papers was presented on this topic as was the case at the ISES Solar World Congress, SWC 2017.

4.6.3 Solar Assisted Heat Pumps

A solar-assisted heat pump (SAHP) is a machine that represents the integration of a heat pump and thermal solar panels in a single integrated system. Typically these two technologies are used separately (or only placing them in parallel) to produce hot water. In this system the solar thermal panel performs the function of the low temperature heat source and the heat produced is used to feed the heat pump's evaporator. The goal of this system is to get high COP and then produce energy in a more efficient and less expensive way.

It is possible to use any type of solar thermal panel (sheet and tubes, roll-bond, heat pipe, thermal plates) or hybrid (mono/polycrystalline, thin film) in combination with the heat pump. The use of a hybrid panel is preferable because it allows covering a part of the electricity demand of the heat pump and reduce the power consumption and consequently the variable costs of the system.

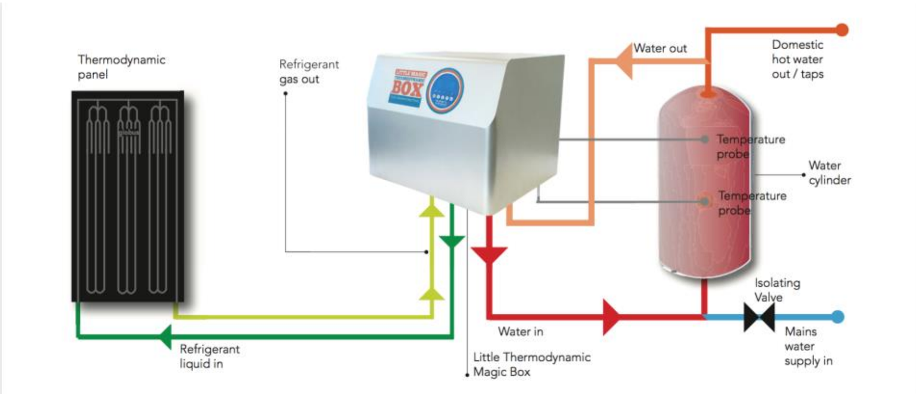


Fig 4.6 Plug & Play solar assister heat pump configuration

The heat pump on atmospheric sensors [22]

The combination of a low temperature solar thermal collector and a heat pump allows the production of domestic hot water in large quantities by combining the advantages of both technologies. The heat pump uses the solar collector installed on the roof to harvest solar and atmospheric energy.

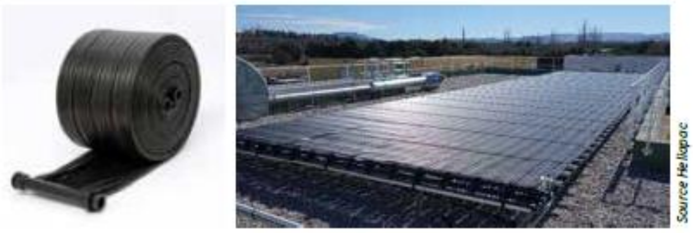


Fig 4.6 Solution of simple to be installed solar support system on roofs of Multifamily buildings

Principle of operation

The low temperature solar collector is generally installed on the roof of the building. It consists of one or more sheets of EPDM (elastomeric rubber resistant to UV and weathering) tubes. The solar collector circulates water and an antifreeze (Mono Propylene Glycol) sanitary quality. The connection between the solar collector and the technical room is made by a round-trip piping.

In the technical room, a heat pump draws energy from the solar circuit fluid and transfers them to domestic hot water at a higher temperature level. By recovering this heat energy, the heat pump cools the solar circuit. When it becomes colder than the outside temperature, the solar collector is able to recover not only solar energy but also energy taken from the atmosphere by convective exchange.

On some installations, a heat exchanger makes it possible to carry out a first preheating of the water (prior to that carried out through the heat pump) when the solar collector is exposed to a lot of sunshine.

Heat pumps are specially designed to work with a solar collector and at high temperatures (up to 65 ° C) to produce hot water.

The heat pump heats one or more storage tanks. A device of three-way motorized valves makes it possible to concentrate the recovered power on the distribution zone to work in priority on the next drawing. This device ensures an optimization of the performance of the heat pumps according to the needs. It guarantees a stability of the distribution temperature even in the event of a large tipping point. It also keeps the temperature distribution loop with the energy provided by the solar collector and the heat pump.

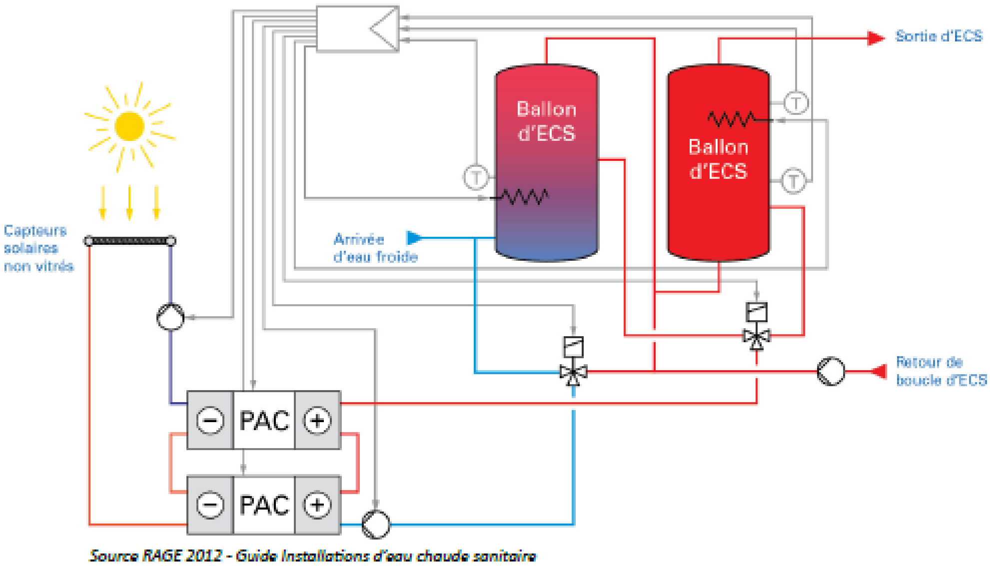


Fig 4.7 Configuration of collective solar assisted system for Multifamily buildings

For domestic hot water production at 55 °C, solar collector contributions represent, on average over the year, about 60% of the total need, the compressor consumption 30%, and the contributions of the back-up order of 10%.

These systems are often challenged by the higher material and installation costs associated with solar thermal vs. Solar PV technologies, which is one of the challenges to the R&D Strategy for future systems

4.7 Manufacturers

The overview of manufacturers is far from complete

4.7.1 Asia

The main countries manufacturing HPWH's are Japan, China and Korea:

Japan, with:

- Mitsubishi Electric Corporation
- Daikin Industries Ltd.
- Corona Corporation
- Toshiba Carrier Corporation
- Hitachi Global Life Solutions, Inc.
- Panasonic Corporation

South Korea, with LG, Samsung.

China with:

- Midea
- Haier
- A.O.Smith
- Gree
- Tongyi
- New Energy
- Outes
- Phnix

4.7.2 North America

A variety of economic and regulatory factors are pushing HPWHs back into the mainstream marketplace. Five major HPWH products are currently available in the water heater market. Key specifications for these HPWHs are shown in Table 4.7.1. These specifications include the two U.S. Department of Energy performance metrics: EF and FHR.14

Model	Capacity (gal)	EF	FHR (gal)	Electric Resistance Elements (kW)
GE GeoSpring	50	2.35	63	Upper: 4.5 Lower: 4.5
A.O. Smith Voltex	60/80	2.33	68/84	Upper: 4.5 Lower: 2
Stiebel Eltron Accelera 300	80	2.51	78.6	Upper: 1.7 Lower: None
Rheem EcoSense	40/50	2	56/67	Upper: 2 Lower: 2
AirGenerate AirTap Integrated	50/66	2.39/2.4	60/75	Upper: 4

Table 4.7.1 Key Specifications of Integrated HPWHs Currently Available in the U.S. Market [1-10][5]

The EF represents the efficiency of the electric heating elements and tank losses under a consistent, 24-hour test procedure. The FHR represents the amount of hot water that can be supplied by a fully heated storage water heater during an hour of operation. Storage tank volume is often used as a proxy for water-heating capacity, but FHR is the preferred metric. See Section 4.2 for more details about the EF and FHR test procedures.

The main US manufacturers are also profiling on the Canadian market, made easy by comparable demands on performance and test procedures

- A.O. Smith
- Rheem
- GE
- GWH water heaters
- John Wood
- Giant
- HTP
- MDV
- Midea
- Westinghouse
- Bradford White
- Richmond
- Ruud
- Vaughn
- Whirlpool

4.7.3 Europe

The larger part of heat pump manufacturers and specifically manufacturers of Heat Pump Water Heaters (HPWH) are not OEM's. Business focused on being an OEM supplier, and with partnerships in place with several major European players, they have a strong route to market. The future potential for this type of specialist OEM company is strong as an increasing number of European players aim to get quickly to market with a DHW HP, leap-frogging the product development stage.

Chinese OEM manufacturers open up market opportunities for many small European companies with various backgrounds, from installer companies to companies with a background in solar thermal or solid fuel boilers

There is a number of categories and types of manufacturers producing HPWH's:

- Companies producing heating boilers, the biggest in Europe being Bosch (with Nefit in Netherlands), Viessmann, Vaillant, BDR-Thermea. As these companies are well established with a strong brand and large installer networks, they are well positioned to upsell existing boilers with DHW HPs, or sell boiler + DHW HP as a boiler replacement package. They could capture a large share of the boiler upgrade/replacement market. These companies also have a large market share of larger collective heating systems.

[5] Any omission of a manufacturer or product is unintentional, and no endorsement of any commercial product or manufacturer is implied.

- Companies with a background of manufacturing water heaters, specifically storage water heaters, like Stiebel Eltron, AO-Smith, Inventum, Dimplex, Gorenje, Ariston, ITHO-Daalderop. Like the companies with heating storage systems they traditionally already have a strong market base.
- Heat Pump Manufacturers, traditionally focused on space heating, but a number of these manufacturers also manufacture HPWH's only. In a European market they have the disadvantage of a large market already covered by traditional heating systems.

A number of main market players dominate the European selling their products under a number of different Brands.

- Atlantic is biggest market player in terms of sales (~50% of the French market, which itself accounts for ~50% of the European market), with a long history and experience in DHW HPs.
- Ariston has the widest range of DHW HP types on the market, and one of the longest active players. One of the few to offer systems with smaller water tanks (<100L) – so uniquely positioned to capture a sector of the building stock which most competitors cannot yet tackle (multi-family homes / homes with space restrictions).
- Dimplex
- Stiebel Eltron
- Gorenje is a successful hot water heating & white goods manufacturer from Slovenia, with a strong brand, particularly in Eastern/south-eastern Europe. Gorenje is amongst the market leaders in Eastern/South-Eastern Europe for hot water heat pumps.
- BDR-Thermea
- Bosch
- Vaillant
- Viessmann
- Ochsner
- Groupe Muller (F)
- Vesttherm A/S
- METRO Therm

5. Scenario’s

The three major markets in the countries participating in the Annex, Asia, North America and Europe have different market conditions and thus scenario’s that are different.

5.1 North American Market Scenario

Heat pump water heaters (HPWHs) are finally entering the mainstream residential water heater market. Possible catalysts are increased consumer demand for more energy-efficient electric water heating and a new federal water-heating standard that effectively mandates the use of HPWHs for electric storage water heaters with nominal capacities higher than 55 gal. Compared to electric resistance water heaters (ERWHs), the energy and cost savings potential of HPWHs is tremendous. Converting all ERWHs to HPWHs could save American consumers $7.8 billion annually ($182 per household) in water heater operating costs and cut annual residential source energy consumption for water heating by 0.70 quads [1-10].

EHPs are popular in milder climates and where local electricity rates are competitive (namely the South and the Pacific Northwest). As EHP technology improves, this is beginning to be the case in cold climates too, where gas heating is well established. In total, this market and regulatory pressure create an opening for gas heating equipment with an AFUE greater than 100%, namely a gas heat pump. This is most compelling in the cold climate regions, where savings potential is greatest and where saturation of condensing-efficiency products is greatest.

While currently available Gas driven Absorption Heat Pump systems are prohibitive on a size and first-cost basis, their energy and cost saving potential is quite large. Assuming a baseline 78% AFUE furnace with 3% of input as parasitic electricity loads, the energy and operating cost savings for an EnergyStar rated electric ASHP (HSPF = 8.2) and a GAHP with an assumed seasonal AFUE of 140% with 6% of input as parasitic electricity loads are shown in Figures 1and 2 for several regions in the U.S. Annual residential heating loads are assumed for single-family housing [Huang, 1999], with locations ordered from largest to smallest left-to-right, nationwide source energy conversion factors are used, and local electricity-to-gas (E/G) price ratios are based on 2013 state-wide averages.

Significant source energy and therm savings are achieved by the GAHP in comparison to the electric ASHP, even in mild climates. Due to the current period of depressed natural gas prices, significant comparative operating cost savings are also achieved, even in the Pacific Northwest with an E/G of 2.27. Using the local gas rates, these therm savings would yield between $2,550 (Texas) to $10,730 (Massachusetts) in savings over a 15 year period assuming a 4% average annual utility rate increase. As a result, even the extreme savings case in Boston would have difficulty justifying the aforementioned equipment costs when the baseline furnace installation is $2,200 [Leslie, 2015]. Therefore, to realize these large energy savings for this major natural gas end use, a low-cost GAHP for cold climates is essential.

In Canada, future market growth is likely to be driven by key new aspirational goals set for space and water heating equipment (defined in the Office of Energy Efficiency’s Market Transformation Roadmap for Energy Efficient Equipment), which target efficiencies > 100% by 2030. This context represents a prime growth opportunity for HPWH makers to expand market share, and for Canadian building owners to reduce energy use and related GHG emissions.

5.2 Market scenario for Asia

The Asian market can be split into three different markets:

- Japan
- South Korea
- China

Japan

The Japanese market, although the annual shipment volume of ECO-Cute Heat Pump Water Heaters is at 400,000-500,000 units per year since 2012, is still enormous, as with this level of sales it is approximately 12% of the market. In the residential market there is the need for downsizing, noise reduction, and cold weather specifications as well as higher efficiency and lower price. With that goals for manufacturers to the ECO-Cute Heat Pump the market acceptance will grow.

China

The Guidebook for Including Aerothermal Energy in the Category of Renewable Energy Sources issued by the Center of Science and Technology of Construction, MOHURD, in November 2015 provided estimation of energy conversation potential for ASHP hot water and heating applications. The aggregated energy saving potential of ASHP water heaters in regions where the climate is hot in summer and cold in winter, in cold regions, in regions where it is hot in summer and warm in winter, and in mild regions is estimated at 16.2 million tons of standard coal per year; and in Northern China and the middle and lower reaches of the Yangtze River where ASHPs are used for heating, the aggregated energy saving potential is 40.97 million tons of standard coal per year.

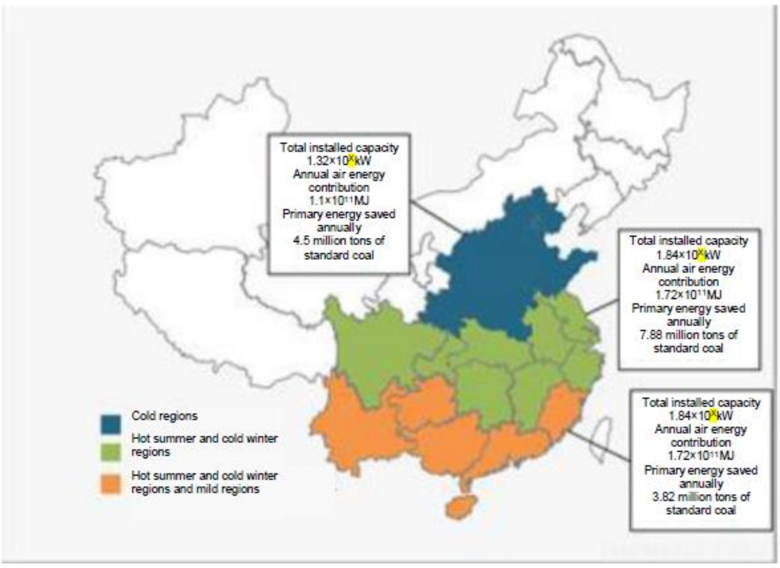


Fig 5.1 Energy saving potential of DHWHP's in China [23]

Korea

The Korea heat pump market is still not very well developed and in competition with the large district heating schemes. Yet especially in the large building stock of residential multi family buildings there is a large potential as companies like Samsung and LG have the right products for high temperature applications

5.3 European Market Scenario

Some European markets are growing especially for DHW HPs, others not. The European market with qualities not comparable to other worldwide markets is quite diversified. There is great difference in heating systems between the colder North and the warmer Mediterranean South. In the North space heating and hot water heating is more than often combined in one generator, often a gas boiler in UK and Netherlands, or in Scandinavian inner cities often supplied by District Heating. In the South split systems for the lesser needed space heating and hot water heating are more common, where often for hot water an electric storage water heater is installed. In larger single family houses the heating systems in Germany, France and Switzerland are often oil fired systems. Next to the difference between North and South there are due to the historical past great differences between the East and the West, where particularly Eastern Europe solid fuel heating systems are common (close to 2 million in Poland) as well as inner city District Heating systems, next to having coal fired and nuclear power plants with a relatively low grid efficiency.

There is in the top end of the market a strong and still growing existing market for larger systems (200-300L tanks), as these type of heat pumps are sold and installed in the top-end of the market of single family houses where installers chose to install often over sized systems. This is in a number of countries like Germany, Austria and Switzerland the main market for DHW HPs with many manufacturers and the greatest competition. In a number of countries, mainly Netherlands and Italy systems are much smaller and often installed at lower costs, as these have to be installed in smaller spaces where housing corportations and buolding contractors are the main clients. The best opportunities for DHW HPs in Europe in other parts of the markets are in:

- Installing in new build to meet building regulations, where especially the building regulations focus on Energy Zero, therewith hot water becoming the dominant heat demand in the system.
- Replacing electric water heaters in existing buildings, driven by customer need for energy cost savings. There are well over 10 million electric water heaters in Europe (annual installations in the order of 500k – 1.5 million per year in some of the biggest markets including France, Italy, Spain, and Germany)
- DHW HP replaces water tank to 'upgrade' existing oil boiler (or solid fuel system) to boost hot water efficiencies - especially in summer. There are well over 10 million oil boilers in Europe, and several million which are aging (>3 million in Germany alone thought to be installed before 1995). Customer driver to reduce annual running costs of electric water heaters, oil boilers and solid fuel systems in existing buildings.
- Retrofit of existing gas or oil boiler with a new boiler and a DHW HP or a double function heat pump, replacing direct electric water heaters – in both cases driven by customer need for energy cost savings
- Smart controls to enable integration with PV – and eventually smart grids. The combination of DHW HPs with other technologies – particularly fossil boilers and PV – widen the market opportunities and sales channels for DHW HPs, create attractive customer propositions, and can create new business opportunities for manufacturers and utilities. Benefiting from self-consumption incentives for PV and optimising heat storage to capture value from 'smart operation' in demand response
- Smaller systems designed for homes where space is at a premium e.g. compact wall-hung systems with <100L tanks; systems with detachable HP module
- Collective systems replacing the distribution systems for hot water with individual DHW HP's, either a booster type or a air/air DHW HP homes – driven by customer need for energy cost savings
- Low temperature distribution systems of the 4^{th} Generation District Heating.

There are in the market sufficient buildings where DHW HPs could fit without any challenges on the physical fit, with electric water heaters + >200L tank, or with basements/garages, which have enough space for existing DHW HP products. However there are millions of homes with space restrictions which could fit the smaller DHW HPs.

As a consequence of these market opportunities there is a number of technology challenges. Sales can boost if sufficient smaller products are available which are cheaper and easy to install or fit into existing systems and spaces:

- Split easy to install systems will have market opportunities, whereas the tank and heat pump can be plug & play integrated into the building structure
- Low costs and good performance required. Low upfront cost can be critical in large parts of the market. Performance does not need to be "Rolls Royce" – but sufficient to give running cost savings
- Smaller systems designed as multi-family home solution or single family house where space is at a premium e.g. compact wall-hung systems with <100L tanks; systems with detachable HP module.

There are important markets in:

- Italy, Finland, Sweden where 75% of homes are multi-family with collective space heating & individual electric water heaters with tanks of under 100L which could be replaced with compact DHW HPs,

- Belgium, Netherlands, UK where space is at a premium, often no basements, installation commonly in the attic)
- Spain is beginning to attract the interest of some of the biggest players (e.g. Atlantic, Ariston), but growth will depend on availability of small systems (90% of electric water heaters in Spain have <100L tanks), and the macro driver of Spanish recovery from the economic crisis.

But also in large parts of the 'forgotten' markets in Germany, Austria and Switzerland and in Eastern Europe.

The strength of the proposition for DHW HPs varies depending on energy price ratios and grid carbon levels in different markets, but in the analyses representing the UK, France, Germany & Poland, DHW HPs achieve running cost savings over oil in all cases – representing a strong opportunity. However, rapidly rising electricity prices in the past relative to oil in some markets could reduce the running cost savings - in Germany, the recent increase in electricity rates is making the proposition for HP more challenging. In most markets, DHW HPs give carbon savings over oil, but high grid carbon intensity as in Eastern Europe means on short term that carbon savings are poorer vs. oil. As carbon intensity reduces, the proposition will improve. In most markets DHW HPs will struggle to compete with gas on running cost or carbon savings, as with space heating heat pumps – with the possible exception of a market such as France, where electricity prices and carbon emissions per kWh are lower relative to gas than in other markets. Governmental policy on energy prices can influence the markets and choices will have to be made here, which can be difficult as it is a choice between options.

The Dutch Government has made a clear example by tax measures thus effectively for the individual end-user raising the gas tariffs and reducing the tariffs for electricity.

Government and Utilities:

The development of the market is dependent on the willingness of major parties in the value chain to support this. Important here is the relation between governments and energy companies/utilities.

DHW HPs offer utilities a number of business opportunities

- Selling DHW HPs to customers via partnership with manufacturer / OEM as part of a portfolio of offerings available under a wider energy services package – DHW HPs offer the customer energy cost savings at a low upfront cost relative to many other microgeneration / renewable systems.
- Business models to capture value from the use of DHW HPs for load management / PV-integration – hot water is arguably an easier load to control than space heating, so there are opportunities to control the operating times of DHW HPs to manage grid congestion. Where the DHW HPs is integrated with PV, the operating times can be controlled to maximise self-consumption of PV electricity at peak times. The value from self-consumption incentives can be captured by the end-user or by the utility (already an attractive proposition in Germany & increasing in other markets).

On their pursuit of a decarbonised grid European governments have, to varying degrees, supported sales of distributed energy generation systems, mostly in the form of Photovoltaics (PV). The vast majority of the PV systems have been installed in the last 5-6 years and will start becoming due for replacement around 2025. By that time, progress towards decarbonisation of electricity production is likely to push end user electricity prices to ever higher levels.

Governments and utilities will have a strong interest in maintaining the installed decentralised PV generation capacity, as this will account for fair share of the total electricity needs.

The expected push towards the replacement of installed Photovoltaics will represent an opportunity for heat pumps. Offered together with PV as a system they will become attractive to:

- End users – a low cost option for provision of heat and domestic hot water,
- Utilities – a good tool to balance the smart grid demand/response system,
- Governments – a way to make progress with the decarbonisation of heat within existing dwellings.

As a long term replacement of fossil fuel boilers, heat pumps have the potential to save an increasing amount of CO2 emissions in the future but their uptake depends heavily on their competitiveness in terms of providing an operating cost advantage to the end user.

Which DHW HP products offers the best market opportunities?

- There is a gap in the market for small systems (with tank size of 80-100L) – a very small number of manufacturers offer such systems so competition is low, and the market potential in some markets is significant.
- External air systems will grow market share – they offer greater flexibility in installation/physical fit, reduce internal noise, and usually count as renewable (meaning they should qualify for incentives).
- Internal air systems are a good option in the right application, but the market is limited to homes with enough space, and they usually do not count as renewable. Noise inside the building can be an issue.
- Integration of DHW HPs with PV offers a strong market growth opportunity and alternative route to market for DHW HPs.

UK: Sales of DHW HPs today are very low with only a handful of products available in the UK. Despite the UK being the biggest heating market in Europe, the preference for gas combi boilers for DHW production and space heating limits the DHW HP opportunity. Over the next 5 years, sales of a few thousand per year could be possible, buoyed by the overall strong growth in the UK heat pump market expected to 2017.

France Rapid growth of past years likely to continue, if at a slightly slower rate, with regulation in new build placing DHW HPs at the forefront of new build DHW solutions. In retrofit, a vast stock of electric water heaters could be replaced, and cost-saving benefits will attract consumers. Further opportunities are to upgrade existing oil boilers – driven by cost saving requirements of customers, and upselling by boiler companies. Sales could well exceed 80,000 / year by 2017.However, a stock of >1 million oil boilers and 150,000 oil boiler replacements per year points to an opportunity for upgrading/upselling oil with DHW HPs.

Spain: Little growth has been seen so far, but a large market for electric water heaters (>600,000 installs per year and an installed stock of ~6 million) indicate a strong addressable market for DHW HPs. Spain is beginning to attract the interest of some of the biggest players (e.g. Atlantic, Ariston), but growth will depend on availability of small systems (90% of electric water heaters in Spain have <100L tanks.

7. Conclusions

Throughout the developed world, the heating of water for domestic use is one of the largest consumers of energy in the household sector. However, water heaters vary in their type and mode of operation, the source of energy used and, potentially more than any other domestic appliance, the actual energy consumed is impacted by consumer usage patterns and ambient environmental conditions. Such complexity creates a number of challenges for policy makers seeking to understand and effectively manage water heating energy consumption. The specific mix of water heater types used varies considerably between countries as a result of culture, historic practice, existing infrastructure and energy source availability. Not surprisingly, the specific policy frameworks developed and deployed by policy makers vary significantly depending on these local conditions. However, in the majority of countries, at least some product types have mandatory and/or voluntary product performance standards in place with these requirements tending to fall into two broad categories:

- Product specific: Typically individual aspects of product energy consumption are limited, e.g. minimum requirements are placed on the efficiency of the water heating process or the rate of heat loss during water storage;
- Technology neutral: Specific levels of water heating service are defined, with an associated maximum energy consumption assigned to that level of service irrespective of technology deployed.

In practice, almost all regulatory regimes deploy a hybrid of the two approaches. For example, until regulatory transition currently underway, the USA specified a generic set of hot water service requirements for almost all water heaters, but applied differing minimum performance standards for each water heater type delivering that service. Even where 'pure' technology neutral standards are deployed, the specific service requirements selected often favour one or more particular product type(s). However, it is interesting to note that some of the best performing products across international markets have resulted from alternate policy interventions. For example:

- In Japan, the Top Runner programme does set mandatory performance requirements but, rather than setting minimum requirements for individual products, future product performance targets are based on a category/application-specific weighted average value of shipments from manufacturers. This has led the Japanese heat pump water heater market to be being dominated by some of the best performing products in the world. Australia also has some very high performing heat pump models apparently drawn into the market by emissions-based white certificate schemes in some States.
- Korea has a high proportion of the best performing instantaneous water heaters despite the Korean minimum performance standard not being particularly challenging. This may be a spin-off from the aggressive advertising promoting condensing boiler systems spilling over into a consumer demand for condensing instantaneous water heaters which are then easily identifiable via the Korean energy label.
- The North American ENERGY STAR programme is encouraging premium performance products across all water heater types.

Given the range of policy deployed, and the specific local conditions, it is not surprising that not one country has the best performing products across all water heater types. However, for all countries, there is potential to make savings across almost all water heater types. The magnitude of the savings potential varies but in some cases it is very large. For example, savings of over 1 MWh per year per product are available to policy makers in Canada simply by moving the market towards the more efficient gas storage water heaters already available locally. Even for electric storage water heaters where manageable losses are limited, savings of 100 to 200 kWh/year per product are available to policy makers in most countries. Within the context of the total annual energy consumption of water heaters, such savings might appear insignificant. However, savings of this magnitude are often sought for other products (e.g. refrigerators) and could be achieved simply by eliminating the worst performing products from the market with no apparent loss of service to the consumer.

There are, however, much larger potential savings available from moving between types of water heater. On a delivered energy basis, and at the reference conditions used, water heater types providing similar levels of service have annual energy consumptions of:

- Air sourced heat pumps: 1.1 – 2.0 MWh;
- Direct electrically heated storage: 4.4 - 5 MWh;
- Gas instantaneous: 6.2 - 6.5 MWh;
- Gas storage: 6.0 - 7.7 MWh.

Hence, to take the most the most extreme example, a switch from the worst performing gas storage water heater to the best heat pump model would reduce annual energy consumption by almost 7 MWh per water heater. However, traditionally, policy makers have been reticent in pursuing policies that would drive switching of product type, even where technology neutral policy measures have been deployed. But recently, the technology neutral labelling of the water heaters in the EU clearly has such technology switching as a long term goal. Further, the transition in regulatory requirements currently under way in the USA appears to be moving towards technology neutrality based on primary energy. For water heaters above 208 litres in the USA, it appears the likely impact will be to drive electrically heated water heaters to heat pump technology, and gas storage water heaters to condensing efficiencies. Not only is this likely to yield significant energy savings in the US market, it is also likely to stimulate the introduction of a large number of higher efficiency gas storage and electric heat pump products into the broader market. If this is the case, such products (or similar derivatives) may become more widely available internationally and present policy makers elsewhere with more options for managing their own markets.

References

[01] –Sunyé, Roberto; Kegel, Martin; Tamasauskas, Justin; Task 1 Market Overview Canada; Canmet ENERGY; April 2018

[02] – Shah, Nikhilkumar N; Hewitt, Neil J.; Task 1 Market Overview United Kingdom; Ulster University - Belfast; August 2017

[03] – Radulescu, Mihai; Task 1 Market Overview France; EDF; 10th September 2016

[04] – Saito, Kiyoshi (editor); Task 1 Market Overview; Waseda University - Tokyo; 10th April 2017

[05] – Arpagaus, Cordin; Vetsch, Bernhard; Bertsch, Stefan; Task 1 Market Overview Switzerland; Interstaatliche Hochschule für Technik Buchs, NTB; November 14 2016

[06] – Kleefkens, Onno (editor); Task 1 Market Overview USA; Phetradico; April 2018

[07] – Kleefkens, Onno; Task 1 Market Overview Netherlands, Phetradico; April 2018

[08] – Seo, Jeonsik; Task 1 Market Overview Korea; KRAAC, Phetradico; April 2018

[09] – Bakker, Marion; Strategic outlook Climate Agreement the Netherlands; Netherlands Enterprise Agency; HPT Magazine VOL.37 NO 3/2019

[10] – Nowak, Thomas; Westring, Pascal; European Market and Statistics Report 2018; European Heat Pump Association, Vacaldata Ltd.; Brussels 2018.

[11] - IEA 4E Mapping and Benchmarking: Benchmarking Report for domestic gas and electric, storage, instantaneous and heat pump water heaters

[12] – Sugden, Lindsay; Bergman, Lukas; Technology Innovation: Domestic Hot Water Heat Pumps; Delta Energy & Environment Ltd; October 2013.

[13] – Heinonen, Janne; Heat Pump Application recovering Exhaust Air Energy in large Apartment Buildings, Enermix Ltd, 11th IEA Heat Pump Conference Montréal 2014

[14] - K. Andersson, E. Granryd and B. Palm, Water to water heat pump with minimum charge or propane, 13th IIR Gustav Lorentzen Conference on Natural Refrigerants, Valencia, Spain, 2018.

[15] - Kashif Nawaz, Bo Shen, Ahmed Elatar, Van Baxter, Omar Abdelaziz, Feasibility Analysis of a Commercial HPWH with CO2 Refrigerant, Building Equipment Group, Oak Ridge National Laboratory, Report for the US Department of Energy under contract DE-AC05-00OR22725, July 2017

[16] - Xiaochen Yang, Hongwei Li and Svend Svendsen; DTU; Alternative solutions for inhibiting Legionella in domestic hot water systems based on low-temperature district heating; Journal of Building Services Engineering Research & Technology 37(4)

[17] - Linita Karlsson; Klara Ottosson. Overcoming issues with Legionella in DHW in LTDH systems;; thesis at Lunds Tekniska Högskola; 2018 Lund

[18] - Manuela Farghadan et. al, Technologieleitfaden Warmwasser, Magistrat der Stadt Wien, Februar 2016

[19] - Micro Heat Pumps in Hybrid – Low Temperature District Heating Concepts, Krijn Braber, Charles Geelen (Infinitus), Onno Kleefkens (RVO), 11th IEA Heat Pump Conference, Montréal 2014

[20] - Félix Iglesias and Peter Palensky, Profile-Based Control for Central Domestic Hot Water Distribution, Austrian Institute of Technology (AIT), IEEE Transaction on Industrial Informatics, Vol. 10, No. 1, February 2014

[21] – Dutch Heat Pumping Technologies Journal Vol 1; Phetradico Communication and Publishing, May 2017, ISSN number – 2543-2028

[22] - La Pompe à Chaleur, Des solutions pour l'eau chaude sanitaire en habitat collectif, Dossier AFPAC - N°5, 2017

[23] - Fang Qing, Song Zhongkui, Gao Yifeng; Development Report of China Air Energy (Air Source Heat Pump Heating) Industry; 2016

[24] - Hengyi Zhao, et.al.; Strategic outlook of Heat pump development in China; China Heat Pump Alliance; 12th IEA Heat Pump Conference 2017.

Heat Pump Centre
c/o RISE - Research Institutes of Sweden PO Box 857
SE-501 15 BORÅS
Sweden
Tel: +46 10 516 53 42
E-mail: hpc@heatpumpcentre.org

www.heatpumpingtechnologies.org

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