HPT-Annex 46
Domestic Hot Water Heat Pumps

Annex 46

Task 1 Market Overview

Country Report United Kingdom

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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
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Disclaimer

The information and analysis contained within this document is developed to broadly inform on developments in the United Kingdom. Whilst the information analysed was supplied by representatives from various companies and sources 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.

Dr Nikhilkumar N Shah & Prof Neil J Hewitt - Ulster University

Heat pump benefits

	2017	Potential*
Sales	22k	966k
Stock	183k	13.3m
Renewable energy produced	2.8 TWh	202 TWh
CO2 emissions saved	0.71 Mt	51.6 Mt
Final energy saved	3.6 TWh	259 TWh
Full time jobs provided	1 274 Jobs	92 609 Job

* The potential is calculated based on the method presented in chapter 4.6.

Key facts

Capital	London	
GDP per capita	31 500 €	rank

Housing

Dwelling stock by category		
Total	27 469 425	% of tot
Single	6 336 100	23.1%
Two	8 268 240	30.1%
Multi	12 579 140	45.8%
Non residential	285 945	1%
Average energy consumption per m²	260 kWh/m²	
Space heating	162 kWh/m²	62.5%
Water heating	41.2 kWh/m²	15.9%
Other	56.4 kWh/m²	21.7%
Growth of new building permits	6.3%	

Renewable energy

Share of renewable energy of total consumption	-
EU 2020 target for the share of renewable energy	15%
National emission factor of electricity	441 g/kWh

Energy consumption

Dwellings by energy source used for space heating		
Gas	20 949 520	82.1%
Oil	2 087 720	8.2%
Biomass	91 480	0.36%
District heating	229 550	0.9%
Electricity	1 894 610	7.4%
Coal	264 090	1%
Final energy prices (euro cents per kWh of thermal energy)		
Electricity	0.18 €/kWh	
Gas	0.06 €/kWh	
Heating oil	0.08 €/kWh	
District heating	-	
Pellets	0.06 €/kWh	

Market overview
Source Nowak, Thomas; Westring, Pascal; European Market and Statistics Report 2018; European Heat Pump Association, Vacaldata Ltd.; Brussels 2018)

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Summary

- Domestic sector has second highest energy consumption (41.3 Mtoe) i.e. 29% in UK final energy use where 82% of that domestic energy is used for space heating (70%) and hot water production (12%)
- Domestic hot production is dominated by natural gas (76%), electricity (8%) and oil (4%) and 91% of housing stock is served by central heating systems that require significant and persistent policy drive to diversify the gas use to other technologies
- More than 50% of the UK housing stock was built before 1964 which translates to high heating cost, less insulation/thermal mass and more than 50% housing stock are other than apartments and terraced types, which would have some space around property for efficient heating system (e.g. heat pump) installation
- Housing stock ownership plays important role in upgrading hot water system where 65% of dwellings are owner occupied
- Hot water consumption is highly influenced by occupancy and personal preference. In UK, there are 27.1 million households, with 28% being occupied by 1 person, 35% are occupied 2 people, 16% are occupied by 3 people and 21% are occupied by 4 or more people
- Average households use around 387 litres of water per day and up to 132 litres per person translating to 16.8 MJ/day. The average delivery temperature is around 51.9°C with water heating time around 2.6 hour/day
- DHWHP's are available in the UK market with capacity of 1 to 4.5 kW and storage volume of 150 to 300 litres and efficiency (COP) in a range of 2.5 to 3.5 with possible cost between £1200 to £2000.
- There is potential for DHWHP in 4.3 million dwellings which use fuel other than gas or in off-gas network area. Overall potential of 15 million can be achieved in existing properties which already have hot water storage tanks.
- In order to promote DHWHP's, strict building regulations, government incentives for two to three-decades, awareness, installer training, manufacturer and utilities company involvement along with dedicated research cluster/funding on domestic hot water will help to improve and develop innovative-compact-smart product which can adopt in smart grid concept

1 Overview on the UK Energy Policy and Domestic Energy Consumption

1.1 UK Energy Policy

Over the past several years, UK energy policy was focused on energy efficiency and increasing share of renewable sources as the UK has committed to cut its greenhouse gas emissions by at least 80% of 1990 level by 2050 under the Climate Change Act (2008). Under EU Directive 2009/28/EC, the UK's National Renewable Action Plan (NREAP) outlies pathways to meet 15% of its energy consumption from renewable sources by 2020. This could be achieved by mix of 12% of heat related energy consumption met by renewable sources; 31% of electricity demand met by electricity generated from renewable energy sources; 10% of transport energy demand met by renewable energy sources. In 2016, UK achieved 8.9% of final energy from renewable sources from a mix 24.6% of electricity, 6.2% of heating/cooling and 4.5% of transport energy from renewable sources[1]. However, transport and domestic sector contributed 40% and 29% respectively in final energy consumption (141 MToe) in 2016. Figure 1 shows final energy consumption by sector for 2016.

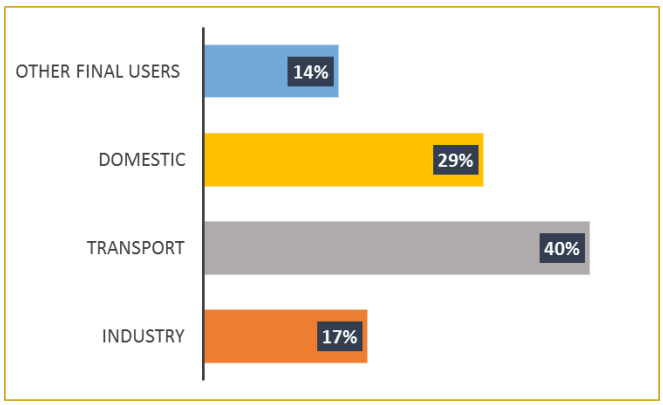

Figure 1 Final energy consumption by sector (2016) (Source: DBEIS, Energy consumption in the UK (ECUK) 2017: Data tables: Table 1.01)

This provides challenges and potentially changing drivers of UK energy policy post EU BREXIT referendum results of UK leaving the EU. New policy is more focused towards electrification of transport sector along with increasing share of renewable in electricity generation, smart/flexible appliances/tool for domestic sector and thermal/electrical energy storage technologies. However, decarbonising heat remains the one of the important policy tool in order to meet emission reduction target as 76% of energy consumption was related to heat in overall energy consumption excluding transport[2].

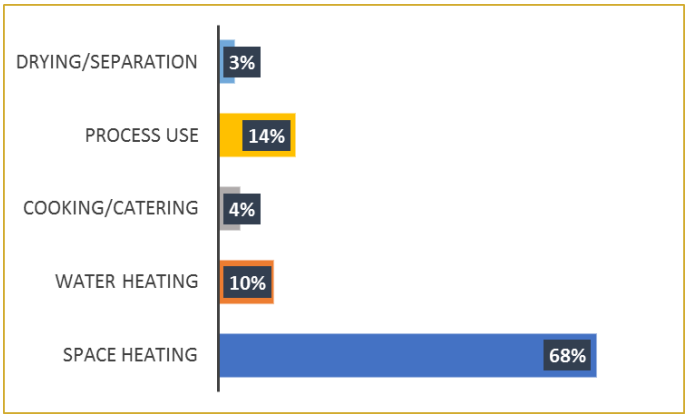

Figure 2 shows overall energy consumption for heat by end uses. It is evident that 78% of energy related to heat is used for space heating and water heating and it is prominent energy consuming sector apart from process use in Industry.

Figure 2 Overall energy consumption for heat by end use (2016) (Source: DBEIS, Energy consumption in the UK (ECUK) 2017: Data tables: Table 1.04)

In general, in order to achieve carbon emission reduction targets in various sectors, the UK renewables policy framework relies on three main components:

[1] BEIS (2017) UK Energy in Brief 2017, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/631146/UK_Energy_in_Brief_2017.pdf

[2] BEIS (2017), Energy consumption in the UK, https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

- Financial support for renewables;
- Removing barriers (administrative, policy uncertainty, etc.);
- Supporting and developing emerging technologies;

There are several financial mechanisms and programmes to promote renewable energy share and to improve energy efficiency. Such mechanism involves feed-in tariff, renewable heat incentive for domestic and non-domestic sector, feed-in-tariffs (FIT), renewable obligations (RO), renewable energy guarantee of origin (REGO), energy company obligation (ECO) and other social programme (i.e. warm home discount, boiler replacement grant, government electricity rebate etc.)[3]. However, these programmes are constantly changing and some of them are closed or replaced with other schemes.

1.2 Domestic Energy Consumption

UK domestic sector consumed 41 MToe energy to meet domestic energy demand in 2016 which was 29% in final energy use. Domestic energy is mainly used for space heating and hot water production. Figure 3 shows domestic energy consumption by end use where space heating and water heating contribution was 82% in domestic energy consumption[2]. UK domestic sector is highly dependent on fossil fuel to meet heating demand. Natural gas dominates to meet space heating and DHW energy demand.

Figure 4 shows domestic energy consumption by fuel type for space heating and DHW for 2016. Natural gas followed by electricity is the main fuel for both space heating and hot water production. However, use of bioenergy and waste (others) is also picking up.

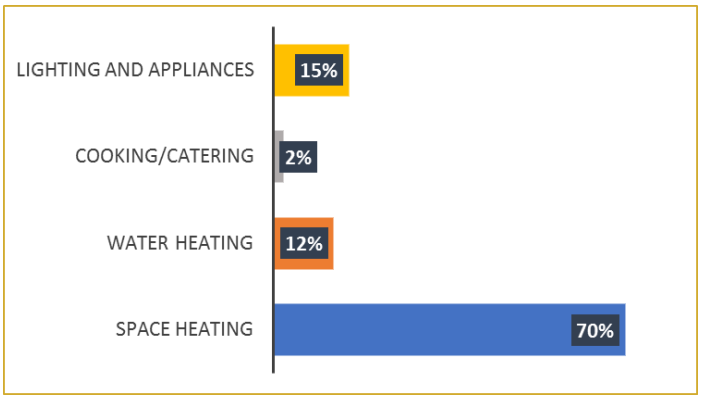

Figure 3 Domestic energy consumption by end use (2016) (Source: DBEIS, Energy consumption in the UK (ECUK) 2017: Data tables: Table 1.04)

[3] Ofgem (2017), https://www.ofgem.gov.uk/environmental-programmes

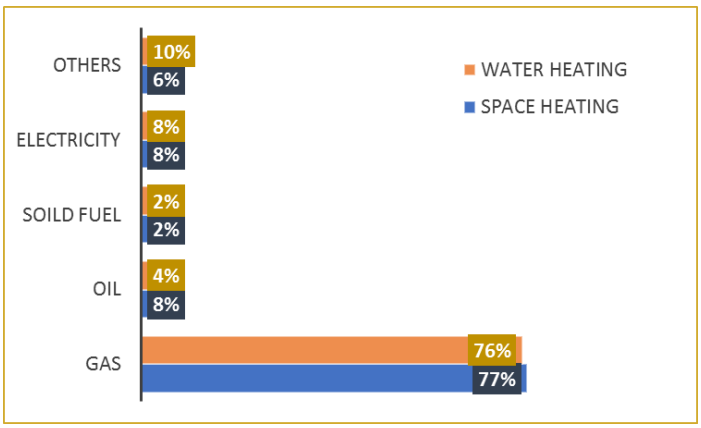

Figure 4 Domestic energy consumption by fuel type: Space heating & Water heating (2016) (Source: DBEIS, Energy consumption in the UK (ECUK) 2017: Data tables: Table 1.04)

2 Housing Stock, Household and Family

UK housing stock comprises range of houses similar to other European countries where their construction age and type influences selection and deployment of efficient/renewable heating and/or hot water system. However, it is important to know definition of dwellings, household and family in order to understand data presented here and to relate its potential and challenges for Domestic hot water heat pump. The Department for Communities and Local Government with part of National and Official Statistics have presented definition of Dwellings, Household and Family as followings[4] [5]:

- *Dwelling:* A dwelling is defined (in accordance with the Census definition) as a self-contained unit of accommodation. Self-containment is where all the rooms (including kitchen, bathroom and toilet) in a household's accommodation are behind a single door which only that household can use. Non-self-contained household spaces at the same address should be included together as a single dwelling. Therefore, a dwelling can consist of one self-contained household space or two or more non-self-contained household spaces at the same address.
- Ancillary dwellings: (e.g. 'granny annexes') are included provided they are self-contained, pay separate council tax from the main residence, do not share access with the main residence (e.g. a shared hallway) and there are no conditional restrictions on occupancy.
- Non-permanent (or 'temporary') dwellings are included if they are the occupant's main residence and council tax is payable on them as a main residence. These include caravans, mobile homes, converted railway carriages and houseboats. Permanent Gypsy and Traveller `
- *Households:* One person or a group of people who have the accommodation as their only or main residence AND (for a group) either share at least one meal a day, or share the living accommodation, that is, a living room or sitting room. The occupant(s) of a bedsit who do not share a sitting or living room with anyone else comprise a single household.
- *Family*: A family is a married, civil partnered or cohabiting couple with or without children, or a lone parent, with at least one child, who live at the same address. Children may be dependent or non-dependent (*1. Households where there is one family and one individual for example a married couple with their daughter and a lodger or a married couple with one elderly parent are classified as a one family household: couple 2. One family household: couple and one family household: lone parent, can contain dependent and nondependent children)

Based on this definition, UK housing stock, ownership, families' and heating/hot water system statistics have been presented in following section which provides important background information for restricted market share and potential of DHWHP.

[4] DCLG (2016), Dwelling stock estimates: 2015, England https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/519475/Dwelling_Stock_Estimates_2015_England.pdf

[5] ONS (2016), Families and households in the UK:2016, https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/bulletins/familiesandhouseholds/2016

2.1 Housing Stock

In 2014, the UK housing stock contained 28.1 million dwellings[6] from 27.42 million in 2011. However, UK wide detailed housing data is only available up to 2011 from UK housing energy fact file report published in 2014 which has been used to get good understanding of dwelling types, age and ownership[7]. Figure 5 represents age of UK housing stock where more than 50% dwellings have been built before 1964. This emphasis on more energy requirement for heating due to less insulation or thermal mass. The housing stock distribution by type shows that more than 50% houses are terraced and semi-detached type followed by flat, detached and bungalows (Figure 6). Apart from apartment and terraced (total 48%) type dwelling, space requirement would not be much issue for installation of renewable technology such as heat pump. However, space saving would be more important densely populated city such as London. Ownership of housing stock plays important role in energy efficiency measures and selection of new heating technologies.

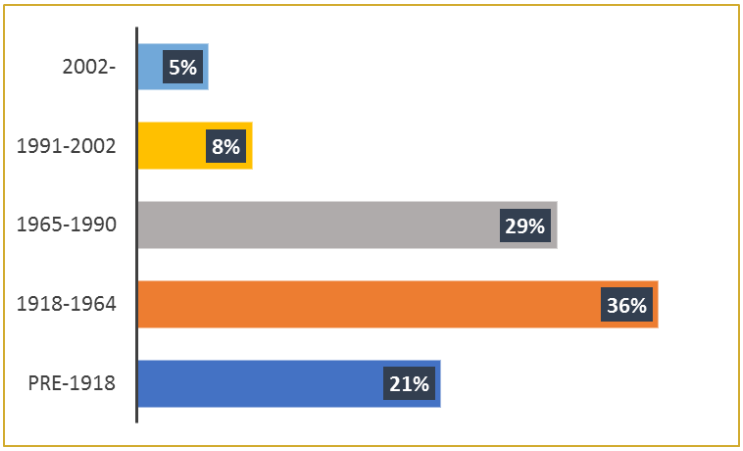

Figure 7 shows UK housing stock distribution by tenure type where 65% of housing stock is owner occupied followed by private rented (18%), social landlord (9%) and local authority owned (8%). This reflects low uptake of efficient technologies (e.g. heat pump) due to high capital cost and lack of awareness, a prime concern for owner occupied housing stock while upgrading or selecting new technology.

Figure 5 UK housing stock by age (2011) (Source: DECC, United Kingdom housing energy fact file:2013: tables: Table 4d Housing stock- age bands)

[6] DCLG (2017), Live tables on dwelling stock (including vacant), Table 101: by tenure, United Kingdom (historical series), https://www.gov.uk/government/statistical-data-sets/live-tables-on-dwelling-stock-including-vacants#history

[7] DECC (2014), United Kingdom housing energy fact file:2013, https://www.gov.uk/government/statistics/united-kingdom-housing-energy-fact-file-2013

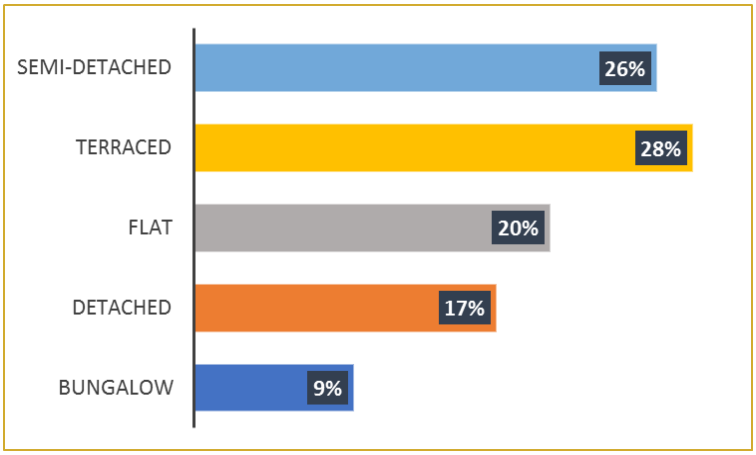

Figure 6 UK housing stock by type (2011) (Source: DECC, United Kingdom housing energy fact file:2013: tables: Table 4c Housing stock- type)

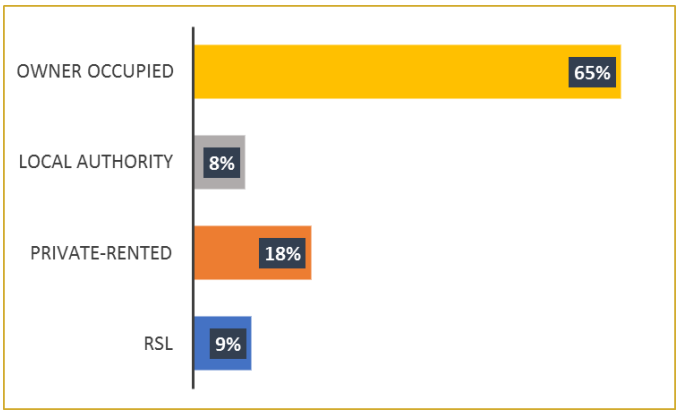

Figure 7 UK housing stock by tenure (2011) (Source: DECC, United Kingdom housing energy fact file:2013: tables: Table 4e Housing stock- tenure)

2.2 Household and Family

Domestic energy demand, mainly for hot water depends on number of occupants in a family, personal choice and weather. Hence, it is important to understand type of families and household which highly influences heating size and selection. In the UK, Office for National Statistic (ONS) published report on families and household in 2016. According to this report, there were 18.9 million families (27.1 million household) in the UK where almost 7.7 million people live alone in the UK and majority of them were women[8]. Detailed distribution based on families and household was also presented in ONS report. Figure 8 shows household distribution based on household size. UK household contained most likely 2 people (35%), 16% household contained 3 people and 21% household contained 4 or more people whereas household type showed that 57% household contained one family couple. These detailed statistics helps to estimate occupancy level, hot water demand and DHWHP potential based on family/household sizes in different housing stock across the UK.

[8] ONS (2016), Families and households in the UK: 2016, https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/bulletins/familiesandhouseholds/2016

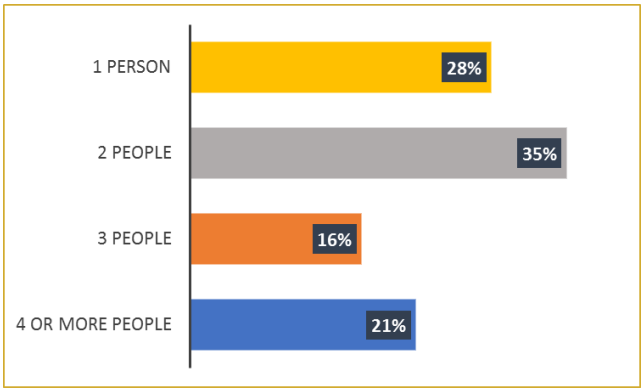

Figure 8 Percentage of household by household size in 2016 (Source: ONS, Families and households in the UK: 2016)

3 Domestic Hot Water System and Hot Water Consumption

Most of the UK dwellings have central heating system to meet their space heating and hot water demand. According to UK housing fact file report (2013), 91% UK dwellings had central heating system in 2011 which translate to about 25 million homes[7]. Central heated dwellings mostly used gas (93%) and oil (4%) to meet heating demand whereas non-centrally heated dwellings (2.43 million) used mostly electricity (92 %) followed by gas (6%), solid fuels (2%). Hence, it shows clear potential for energy efficient heating and hot water technology in weak gas network area or dwellings without central heating system.

Central heating uses mostly oil and gas boiler for space heating and hot water demand. There were about 22.8 million boilers (gas & oil) where nearly 60% boilers were combi type. As name suggest, combi boiler combines central heating with domestic hot water heating in one box where boiler instantly heat waters as it flows through the unit and usually retain little water (except in heat exchanger coil)[7]. However, there are still 40% dwelling equipped with boiler that uses standard /condensing boiler which has separate hot water tank to meet hot water demand (about 11 million dwellings), a huge potential for DHWHP as an efficient retrofit technology to replace existing hot water tank without need of additional space.

3.1.1 Hot water system

In the UK, hot water system is combined with space heating and such type of (central) heating system which is highly reliant on natural gas. There are many different type of hot and cold-water supply services within the building which may varies based on building size and complexity. However, Health and Safety Executive (HSE) has provided good overview of main type of hot and cold-water system in the UK. There is various possible combination of such kind system but broadly it can be divided as[9]:

- Smaller hot and cold-water system
- Gravity-fed cold-water system
- Pressurised system

Smaller hot water systems use mains cold water to water heaters with outlets at point of use. Figure 9 shows non-storage type water heater which includes combination boiler type which uses gas as fuel (and provide space heating too) and instantaneous water heater which uses electricity for water heating in electrical heating coil. Such type of systems is mostly used in small building s and office and do not have water storage tank with flow limitations decided by the system heating capacity.

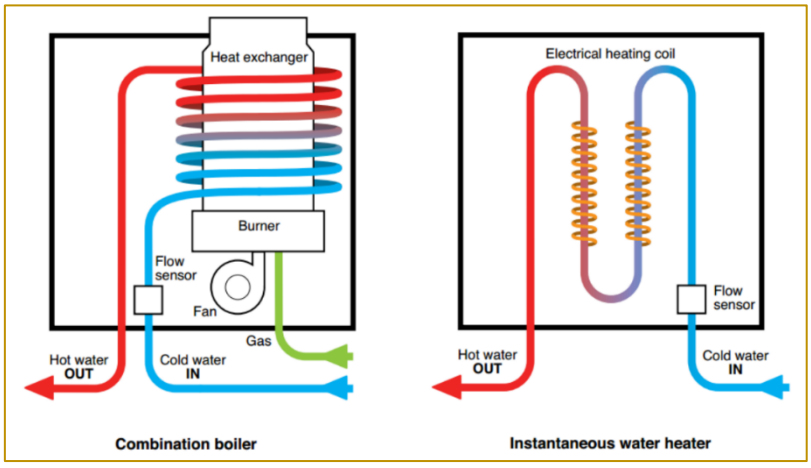

Figure 9 Non-storage type water heaters using gas (left)) and electricity (right) (Source: HSE (2014), Legionnaires' disease Part 2)

[9] HSE (2014), Legionnaires' disease, Part 2: The control of legionella bacteria in hot and cold-water system, http://www.hse.gov.uk/pubns/priced/hsg274part2.pdf

Figure 10 shows another small hot water system which stores small volume of water (not more than 15 litres) and maintains water temperature based on set points. Such system requires recovery times after stored volume of hot water is used. For larger storage volume, combination water system is also used which hold cold water (10-200 litres) on top and hot water (15-200 litres) on bottom and hot water is heated by immersion heater whereas top cylinder feeds bottom cylinder via external cold feed pipe and hot cylinder has expansion pipe in cold cylinder too. However, such system requires careful risk assessments due to cross contamination and cold/hot water temperature limits to store and at a supply points.

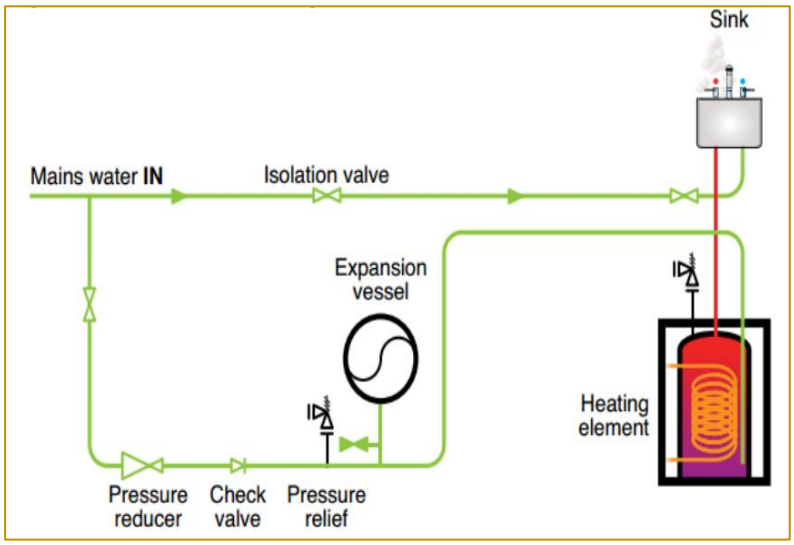

Figure 10 Low storage volume point of use water heater (Source: HSE (2014), Legionnaires' disease Part 2)

Most domestic dwellings and small buildings uses gravity-fed system to distribute hot and cold-water system. Figure 11 shows example of gravity-fed cold and hot water system. Cold water from mains supply water to cold water tank which maintains stable pressures and provides water to calorifiers (hot-water cylinder) where it is heated and drawn via pipes that branch to sinks, washbasins, baths showers etc. In a case of pressurised system, cold water tank is removed and it uses mains pressures and directly connected to a calorifier, water heater or heat exchanger. Such system requires expansion valve and other safety measures. The same kind of arrangement used on central-heating system that provided space heating via radiators directly from gas/oil boiler (or other heat source) for space heating in addition to hot water supply system mentioned here. Most commercial building uses gravity fed re-circulation system where hot water is re-circulated via additional pump which enables quick hot water availability at any taps despite distance from calorifier and reduces the risk of localised temperature fluctuations.

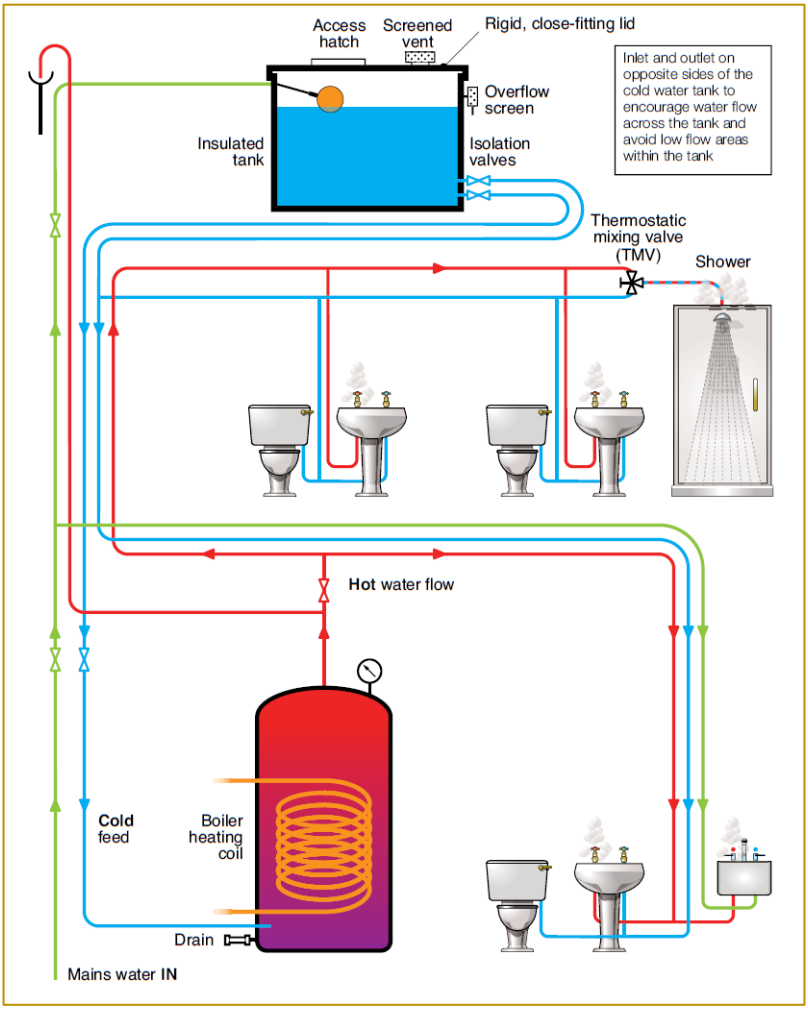

Figure 11 Gravity-fed hot and cold-water system (Source: HSE (2014))

Hot water produced using storage vessels uses different source of energy. Storage vessels are heated directly or indirectly using internal or external heat exchanger. Figure 12 shows different types of method used for hot water production with storage vessel. Direct-fired type water heater has shown to have a low incidence of colonisation by legionella. Indirect type water heater may use gas/oil boiler/ heat pump or other system as heat source. It may use shunt pump to avoid stratification and achieve uniform high temperature to avoid legionella formation. Solar heater type system can be used in conjunction with any other heating system as hybrid.

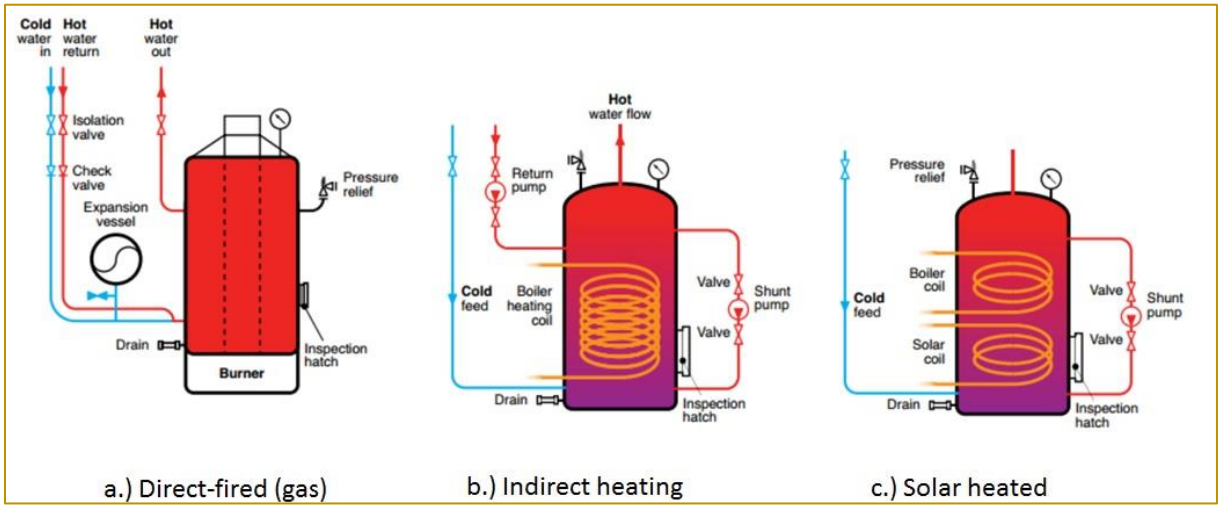

Figure 12 Hot water heaters: Calorifier and hot water cylinder (Source: HSE (2014), Legionnaires' disease Part 2)

3.2 Statistics on hot water use

Hot water usage varies from person to person based on human behaviour and occupancy in a dwelling. In the UK, energy consumption related to hot water production has fallen significantly since 1970 due to improved energy efficiency of appliances, insulation and heating system. There is a good estimate on hot/cold water use and energy consumption from Energy Saving Trust (EST) field trial and report on domestic water use. EST published two reports based on the water energy calculator which used self-declaration responses of energy use by householder and small-scale monitoring. This report provides good understanding on overall water including information on shower time, nos. of bath, heating system, occupancy, washing machine/dishwasher usage etc. Outcome based on self-declaration has been summarised as following[10]:

- Per person water usage: 142 litres/day
- Average household water consumption: 349 litres/day
- Each individual on average takes about 4.4 showers and 1.3 baths each week
- Hot water contribution: £228 in annual energy bill, 875 kg of CO_2 per household per annum
- Shower (25%) are biggest water users followed by toilets (22%), others (cold taps) (22%), washing machine (9%), bath (8%), bathroom (hot tap) (7%), hand wash dishes (4%), garden/car (1% each).
- Most people spend about seven and half minute in shower (approximately 8 litres/min) and 87%-person people do not exceed ten minutes on their daily shower.

However, the properties monitored in sample gave slightly different result but provided useful information for overall water usage. Table 1 shows summary of water usage data at point use from monitored properties sample.

[10] EST (2014), At home with water, http://www.energysavingtrust.org.uk/sites/default/files/reports/AtHomewithWater%287%29.pdf

Table 1 Summary of water usage values from sample[11]

	Mean values from sample monitoring/survey
Per household consumption (PHC)	387 litres/day
Per person	132 litres/day
Bath per household volume frequency Per bath volume	 51 litres 0.68 event 83.3 litres/event
Shower per household volume frequency per shower volume flow rate duration	 86 litres 1.75 event 50.5 litres/event 6.9 litres/minute 7.7 minute/event
Toilet per household volume frequency per flush volume	 74 litres 11.16 event 6.8 litres/flush
Taps per household volume frequency flow rate	 113 litres 75.30 event 3.1 litres/minute
Dishwasher per household volume frequency per cycle volume	 10 litres 0.70 event 14.5 litres/cycle
Washing machine per household volume frequency per cycle volume	 33 litres 0.65 event 50.4 litres/cycle

More detailed data related to hot water energy consumption has been derived from EST's field trial of approximately 120 dwellings[12]. This report provides sound basis for DHW energy consumption in the UK along with other work/reports/field trials. Figure 13 shows typical daily run off profile and associated energy for a single dwelling. There are two peaks; one in the morning and second in the evening.

[11] EST (2015), At home with water 2 technical report, http://www.energysavingtrust.org.uk/sites/default/files/reports/AHHW2%20final.pdf

[12] DECC (2011), Measurement of domestic hot water consumption in dwellings, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf

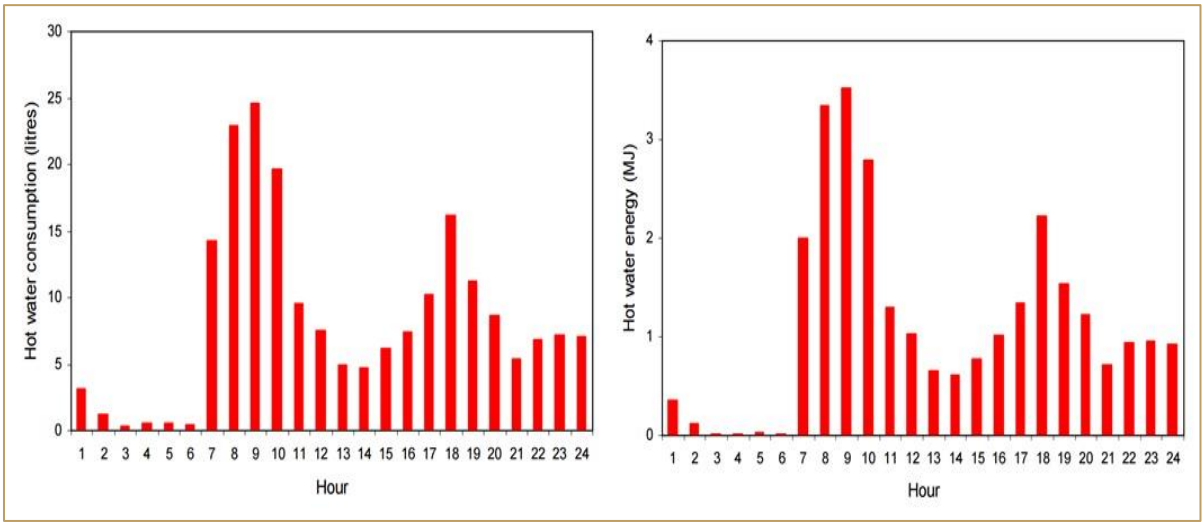

Figure 13 Typical daily run off profile of single dwelling (left) and energy content (right) (Source: DECC (2011), Measurement of domestic hot water consumption in dwellings)

Overall DHW consumption of all data set remains around 128 litters/day with energy content in a range of 16.8 MJ/day where regular boiler tends to deliver higher temperature compared to combi boiler. In additions, this field trial focused on several parameters such as cold-water inlet temperature, delivery temperature from combi and condensing boiler and energy content etc. Table 2 shows a summary of field trial data based on their mean value. This value has been adopted in a model to present energy content requirement based on number of occupants. In addition, KIWA carried out study on behalf of DECC on storage/buffer tank use for heat pump application. The report shows that overall efficiency for water generation remains around 81%. However, heat delivered at the tap shows efficiency of 38% or lower where DHW usage is lower[13]. Hence, it is important to reduce piping losses and installation near the point of use in order to improve efficiency at tap level. The information from research, field trials and survey provides very useful to design HPWH system according to local demand considering oversize factor, efficiency, reduced capital cost and potential application as an instantons water heater.

Table 2 Summary of measurement domestic hot water consumption in dwellings[12]

Mean values	***EST's field trial**
Household consumption	122 litres/day (± 18 litres/day)
Energy content	16.8 ± 2.2 MJ/day
Delivery temperature	51.9°C (±1.3°C)
Heating time	2.60 ± 0.35 hours/day (mainly 6 am to 10 am and 6 pm to 11 pm)
Run-off	28 ±4 run-offs/day
Cold water temperature	15.2 ±0.5°C
Energy cost	0.168 MJ/litres (to rise of 40°C)
BREDEM formula (litres/day)	38+25N (no of occupants)
Field trial (litres/day)	46+26N , 40+ 28N (N=<5)
Field trial energy consumption(MJ/day/person)	5+4N

[13] DECC (2013), Investigation of the integration between hot water cylinders buffer tanks and heat pumps, https://www.gov.uk/government/publications/investigation-of-the-interaction-between-hot-water-cylinders-buffer-tanks-and-heat-pumps

4 Regulations/Legislation/Standards

Within the UK framework of regulations, governing water-heating products exists a complex structure of requirements and stipulations put on industry from manufacturers of appliances to installers and specifiers. Certain standards relate to the product design and safety features, other aspects of these requirements relate to the product efficiencies and how products are selected for use against their overall contribution to industry.

4.1 Building regulations

In the UK, Building regulations exist to govern the construction and renovation of buildings across the UK. The scope of the regulations covers all aspects of the construction process from design, construction, materials, thermal insulation, health and safety, electrical supply, provision of services, energy efficiency, fire regulations, ventilation etc. Out of sixteen statutory guidance[14] form part of building regulations of which part G and Part L is mainly influences the domestic building, installation, emission and safety of heating system including hot and cold-water supply. The UK Energy policy translates into Building Regulations Part L. Contained within this document are requirements on target emissions that new buildings must adhere to. These targets relate directly to building energy consumption and CO_2 emissions. Target Emission Rates [TER] have declined steadily with new revisions of Building Regulations and this trend is likely to continue. TER decreasing over time has made HWHPs more attractive to building specifiers. However, it can be expected in the future with even more stringent regulations on building efficiency, not only will it be desirable to consider a HPWH during building specification but it will actually become essential to review this technology in a similar way that regulations have been changed in France leading to a promotion of the technology and rapid growth in the sector.

When considering the installation of a hot water heat pump, quite a significant set of these conditions must be considered. For example, Building Regulations G3 gives guidance on unvented water systems for the supply of domestic hot water. Compliance with G3 directly affects the design of a water cylinder in terms of safety valve requirements, thermostat settings and T&P discharge requirements. For appliance manufacturers this results in a more expensive product for UK specification and for installers this means more installation time and cost to cater for discharge piping. Above appliance level, Building Regulations requirements stipulate requirements for electrical installations and fixed wiring, design and installation of air ducting and how the product or appliance contributes to the energy consumption of the dwelling or building in general. In addition, domestic building service compliance guide provides good overview of different heating technologies and their efficiency requirement in England[15].

4.2 Water Regulations

UK Water regulations are responsible for governing water hygiene, protecting public health and safeguarding water supply promoting the efficient use of water across all premises in the UK. Some of the product aspect in terms of hot water (e.g. scalding) is covered in building regulations (i.e. Part G). The product design is also affected by ensuring compliance with water regulations, i.e. all materials are non-contaminating, back flow of water into the mains supply is prohibited and bacterial growth is prevented to protect human health. Legionella prevention as recommended by the Health & Safety Executive[16] states that water should be stored at or higher than 60°C inside a storage cylinder and distributed at 50°C or higher. For the manufacturer this means achieving these high temperatures is paramount however, this can be often realised by means of an electrical resistance heater. The end user will be affected by how the appliance meets the requirements to sanitise the cylinder in terms of running costs which are a factor of COP at high temperatures and heat up strategy, i.e.

[14] DCLG (2016), Approved documents, https://www.gov.uk/government/collections/approved-documents
[15] Domestic building service compliance guide, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/453968/domestic_building_services_compliance_guide.pdf
[16] HSE (2014), Legionella and Legionnaire's disease, http://www.hse.gov.uk/legionnaires/index.htm

temperature that electrical resistance element is activated if at all.

4.3 Standards and support mechanism

4.3.1 Standards

All products placed on the UK market must be CE marked likewise in all other European countries. This means the products are compliant with all relevant European and British standards associated with that product. Energy related product (ErP) compliance is listed under a requirement for CE marking however, it's also important to highlight in isolation due to the fact ErP compliance illustrates the product efficiency and energy performance rating of the product in a simulated mode of operation. For water heating ErP became relevant in September 2015. The directive affects showers, instantaneous water heaters, direct electric cylinders, indirect cylinders etc. Products are tested and provided with an Energy label and product Fiche.

In the UK, Microgeneration Certificate Scheme (MCS)[17] (BS EN ISO/IEC 17065:2012) brings products together which generates electricity and/or heat from renewable sources. MCS provides compliance, installation guidance and certification for products and installer in order to have efficient products in the market with high quality installation. MCS covers up to 45kW heat generating and up to 50 kW electricity generating technologies. MCS included ErP directive which affects any heating or hot water product equal or less than 400 kW. Eco design and Energy labelling are part of ErP directives. Eco design will set a minimum energy performance and environmental criteria for energy related products and Energy labelling will have product label efficiency between A+++ to G. In addition, energy label for complete installation will be provided too.

MCS covers building integrated PV products, biomass, heat pump Micro CHP, small and micro wind turbine, solar PV, solar thermal. In heat pump category it includes air-source heat pump, exhaust-air heat pump, gas absorption heat pump, ground/water heat pump, Solar assisted heat pump (DHW only). Followings are the heat pump standards that are used for heat pumps:

Heat pump test standards:

- EN 14511:2013 Parts 1 – 4 Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling;
- EN 12309-5:2014 Gas-fired absorption and adsorption heat pump appliances with a net heat input not exceeding 70 kW;
- EN 16147 "Heat pumps with electrically driven compressors. Testing and requirements for marking of domestic hot water units;
- EN 14825:2013 Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling. Testing and rating at part load conditions and calculation of seasonal performance.
- BS EN 12102:2013. Air conditioners, liquid chilling packages, heat pumps and dehumidifiers with electrically driven compressors for space heating and cooling. Measurement of airborne noise. Determination of the sound power level.
- Heat pumps with electrically driven compressors designed to provide domestic hot water only shall be tested using the standard EN 16147 and Annex A of MCS 007.
- Solar assisted heat pumps designed to provide domestic hot water only shall be tested using the standard EN 16147, Annex A and Annex B of MCS 007.

[17] MCS (2016), MCS standards, http://www.microgenerationcertification.org/mcs-standards/mcs-standards

4.3.2 Support mechanism

In the UK domestic Renewable Heat Incentive [RHI] is available to obtain government support when installing renewable heating systems. The funding mechanism is available for new homes or retro fit situations and is available for a 7-year period. The payments are made on a quarterly basic and it is essential that the generated heat is metered to obtain payment. The type of technologies covered are solar thermal, biomass, air source and ground source heat pumps. Table 3 shows tariff available in the UK for various renewable technologies. From a homeowner perspective the payments received can actually assist with financial supporting a project however an improved installer must be responsible for installing the system. For heat pump applications, homeowners are paid up to £0.1018 per kWh generated to heat homes under the scheme. For a typical UK new build with an average daily heating demand of 6 kWh this equals £223 per annum payment guaranteed for seven years. However, New build properties are not eligible unless building your own home whereas Northern Ireland has scrapped domestic RHI in February 2016. In addition, RHI training support Scheme (only available in England) is available to supports short training and apprentice in renewable heating technologies for plumbing and heating engineers.

Table 3 Renewable heat incentives tariff in the UK (Source: Ofgem (2017): Tariffs and payments: Domestic RHI)

Time frame	Biomass boiler and stoves (p/kWh)	Air source heat pumps (p/kWh)	Ground source heat pumps (p/kWh)	Solar thermal (p/kWh)
Application submitted up to 31/12/2017	6.54	10.18	19.86	20.06

5 UK heat pump market, brands/products and associations

5.1 Heat pump market

Heat pump market is growing due to its higher efficiency for heating/cooling/DHW; especially air-to-water (ATW) market share is higher due to lower installation cost compared to ground source heat pump. In 2016, heat pump stock was 163k units in the UK which saved 0.63 Mt CO_2[18]. UK heat pump market grew by 6% in 2015 compared to 2014 where the biggest growth was in sanitary hot water (SHWHP) sector by 155%. However, only 408 units of SHWHP were sold in 2015[19]. HPWH are very common and well understood in countries like USA and Japan. DHWHPs have started to gain popularity in the UK heating market. There are many reasons for this change in development of the technology and growth in the sector, however one of the main reasons is the benefits the technology provides for building energy efficiency compliance on new builds and reduced running costs for the retrofit market. Details about some of the main product manufacturers observed to be acting in the UK domestic hot water heat pump market has been presented in following section.

5.2 Products and brands

Domestic hot water heat pump (DHWHP) or hot water heat pump (HWHP) functions same way as conventional heat pump system used for space heating/cooling. It may use free energy from ambient air, ground, exhaust air or air from building to heat water in a storage tank. Figure 14 shows view of typical heat pump water system commonly used. Such system contains mainly hot water tank, condenser (immersed in tank), evaporator and compressor. In addition, there are various possible installation with HPWH based on available space, source of energy and use of system.

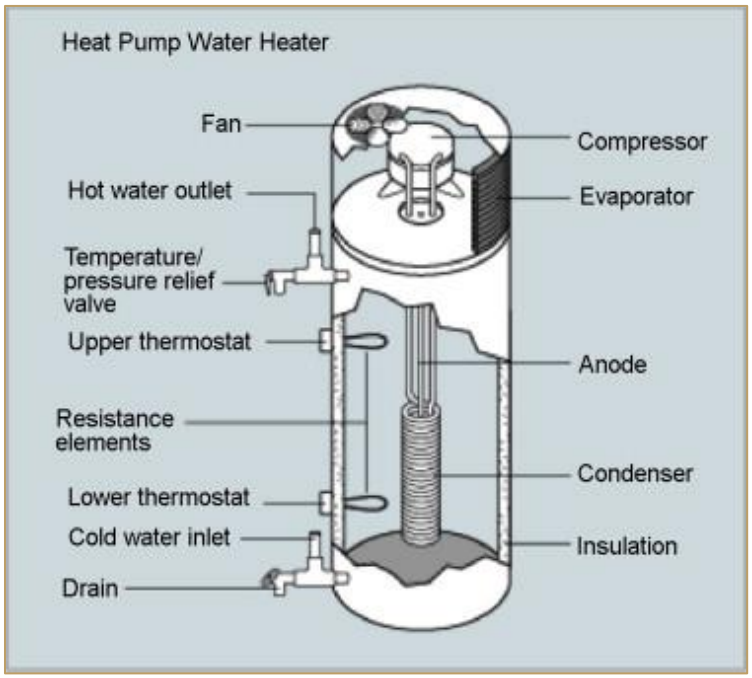

Figure 14 Cutaway view of heat pump water heater[20]

[18] EHPA (2017), stats ehpa, http://www.stats.ehpa.org/hp_sales/country_cards/
[19] EHP (2016), European heat pump market and statistics report 2016, The European heat pump associations (EHPA), Brussels
[20] Hepbasil and Kalinci (2009), "A review of heat pump water heating systems", Renewable and sustainable energy reviews, vol 13, page 1211-1229

There is various configuration of heat pump water heater based on heat source and available space/ducting. Such arrangements include ambient air, outdoor air, exhaust air, ground as source with single or split unit with possible combination of heat transfer fluid and integration of renewables technology such as solar. Figure 15 shows various possible configuration of HPWH based on source, unit and based on unit configuration air borne noise can be measured from ducting or unit as whole.

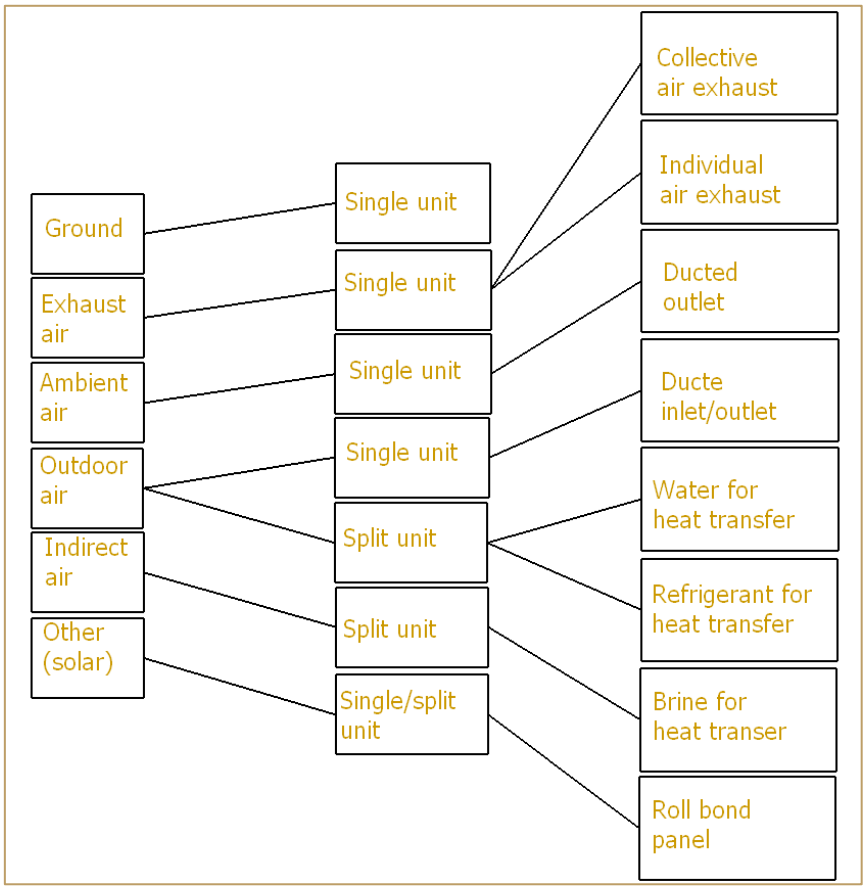

Figure 15 Possible arrangements of heat pump water heater

HPWH market is very strong in Japan which are mainly based on CO_2 and know an as ECO CUTE. ECO CUTE are available from 4.5 to 6 kW capacity which can provide water temperature up to 65°C. In the UK, there are several heat pump products available in in different sizes. However, the MCS certified products and installer ensures quality installation as per standards. For the purpose of this report, heat pump product under MCS search criteria has been considered since it provides standard installation and also eligible for Governments' incentive schemes. MCS has list of air-source heat pump (ASHP), ground-source heat pump (GSHP), exhaust air heat pump (EAHP) and solar-assisted heat pump (SAHP). ASHP criteria includes application for space heating, space heating/hot water, space heating/hot water -VHTHP and unspecified. However, there is not any separate category for certified DHWHP or HPWH product. There are total 558 MCS certified ASHP products from 32 companies available in UK market in a size of 5 to 16 kW.

Table 4 shows list of manufacture found from MCS product search for ASHP. Many of the manufacturer listed in ASHP also have products for ground-to-water or water-to-water source heat pump too. There are around 623 listed products under category of ground/water source heat pump. List of ground/water source heat pump manufacturer has been given in the table in addition to manufacturer mentioned for ASHP. However, this list is for reflection on UK heat pump market only and list is not inclusive.

Table 4 List of heat pump manufacturer/product as per MCS certified product criteria

List of ASHP manufacturer under MCS Product search	
Aermec S.P.A., ait-deutschland GmbH Atlantic, Air-Deutschland GmbH Bosch Thermoteknik AB (IVT Varmepumpar) CTC division- Enertech Limited, Daikin Europe N.V., Danfoss Varmepumpar AB Earth Save Products Limited, GDC Group Limited (Dimplex), Global Energy systems and Technology Ltd Glow-warm Grant Engineering (IRE) Ltd Heliotherm Wamepumpentechnik GmbH Hitachi Air Conditioning Products Europe S.A.U. Husky heat pumps IDM Energiesysteme GmbH KUFI INT, s.r.o	Lailey and Coates Ltd LG Electronics UK Mitsubishi Electric Europe UK, Mitsubishi Heavy Industries Air-Conditioning Europe, Ltd. NIBE Energy Systems Ltd Northern Gas Heating Ltd OCHSNER Warmepumpen Panasonic Marketing Europe GmbH PicoEnergy GmbH & Co. Samsung Electronics EHQ Stiebel Eltron UK Limited Thermal Earth Ltd Thermia heat pumps Vaillant Group UK Ltd Viessmann Ltd Waterkotte GmbH
Ground/water heat pump manufacturer list in addition to above mentioned manufacturer	
Bosch Thermotechnology Ltd (Worcester Bosch Group) Calorex Heat Pump Limited Climaveneta S.p.A. Ecoforest Geotermia, S.L. Kensa Engineering Ltd	Neura AG Refcool Manufacturing Ltd Suomen Lampopumpputekniikka OY Ltd Warmflow Engineering Co Ltd Water Furnace International Inc

In addition to ASHP and GSHP (and/or WSHP), SAHP and EAHP category has other listed manufacturer. However, there is not separate category for DHWHP or HPWH, but combination of external unit of air-source or water-source or ground-source with separate water cylinder can be used for production of hot water along with space heating application. There are only 5 listed products in hot water application across all category. Table 5 shows list of hot water heat pump product in UK market. This list has been prepared from internet search for hot water heat pump and MCS product search. However, this list is not inclusive and may have missed potential products. Overall estimated cost for DHWHP varies in a range of £1200 to £2000 with efficiency (COP) in a range of 2.5 to 3.5.

Table 5 List of hot water heat pump products in UK market

Ref	Product/Manufacturer	Type	Water storage capacity (l)	Heating Capacity (kW)
1	ESP Ecocent / Earth Save Product Ltd	Air-to-water (exhaust) (listed)	150 to 300	1 to 3.45
2	BMTB & LMTB IV/Magic thermodynamic Box Limited	Air-to-water (solar assited HP) (listed)	130/300	
3	Energie ECO/Energie EST Lda	Air-to-water (solar assited HP) (listed)	250	1.69 to 4.5
4	Thermboil / Energy Panel S.L.	Air-to-water (solar assited HP) (listed)	200	2
5	STIBEL ELTRON	Air-to-water	300	1.7

6	EDEL / Dimplex	Air-to-water	200/270	1.6
7	GionaUK	Air-to-water	200/250/300	2 to 2.8
8	NUOS/ Ariston	Air-to-water	200/250	2.78
9	Q-ton/ Mitsubishi heavy Industries Air-conditioning Europe Ltd	Air-to-water (listed)		30

5.3 Associations

In the UK, there are few association focusing on domestic heating and hot water field. The Energy and Utility Alliance (EUA) has six sub division, out of two division namely, Heating and Hot Water Industry Council (HHIC)[21] and Hot Water Association (HWA)[22] directly focuses on hot water and heating industry. Energy saving trust (EST)[23] is also very active in the field of energy efficiency, conservation and sustainability in domestic heating/hot water products guidance, field trial and ratings. Another associations named BEAMA[24] represents built environment electrical infrastructure products from transmission to distribution and services which covers electric heat pump, smart grid, smart meter etc. However, Heat Pump Association (HPA)[25] is the only association that solely focuses on heat pump related activity through collaboration between government, client, industry and public. In addition, there are several other association which focuses on heating side through different mode such as The Association of Plumbing & Heating Contractors (APHC), The Association of Decentralised Energy (ADE), Federation of Environmental Trade Association (FETA) (which covers HEVAC and HPA too).

[21] HHIC, http://www.centralheating.co.uk/
[22] HWA, https://www.hotwater.org.uk/
[23] EST, http://www.energysavingtrust.org.uk/
[24] BEAMA, http://www.beama.org.uk/
[25] HPA, http://www.heatpumps.org.uk/

6 Market drivers/potential and barriers

6.1 Market drivers/potential

Although the heat pump market in the UK is not strong as compared other European countries/Japan/USA but it is getting momentum due to local, national policy and regulations. Main market driver for domestic hot water heat pump includes:

1.) Electricity vs gas price: Cheap electricity
2.) Government incentives (e.g. RHI)
3.) Building regulation and standards
4.) Skilled designer, installer and people mind set
5.) Wide spread of smart grid concept, demand side management
6.) Support mechanism, payments, tariffs for consumer, possible ancillary services/payments and role of aggregator in long term.

Decarbonizing domestic sector is backed up by strict building regulations and electrification of heat along with developing market mechanism in smart grid concept with demand side management opportunity. Although per square foot space cost is important in city like London, high energy efficiency/low energy demand in new building paves the path for efficient DHWHP. However, this calls for innovative product design and efficiency drive to make it attractive for new building which requires less space (e.g. small storage volume).

In addition, 4.3 million of UK housing stock uses fuel other than gas (also off-gas grid) to meet their heating and hot water demand. About 2.9% of UK housing stock is without central heating (2.43 millions) which mostly uses electricity as a fuel whereas and 14% centrally heated housing stock (1.83 million) uses fuel other than gas. In addition, 40% of centrally heated housing stock uses standard/condensing boiler which has separate hot water tank to meet hot water demand this represents about 11 million dwellings[7]. Hence, the total potential for DHWHP could be around 15 million for existing housing stock in addition to new built properties. However, this uptake will not be possible without change in local policy, building regulations, support from government, awareness, skilled installation/training, local utility/manufacturer (of heat pump) company involvement to develop innovative-smart-compact DHWHP.

6.2 Barriers/challenges

There are many barriers to market for a heat pump water heater. The technology is beginning to grow in popularity in the UK market as certain drivers which are required begin to change and become available. For example, the UK energy policy has an influence on the type of technologies used for domestic heating and hot water. Likewise do government tariffs or incentives, specification of new technology by building designers and also customer awareness are all issues that need to be addressed to promote heat pump water heating technologies. Government incentives and available funds to homeowners do not reflect at present how valuable this technology can be to helping the country achieve energy savings and CO_2 reductions. A recommendation to improve the future deployment of hot water heat pumps to UK policy makers would be to make available a grant/funding mechanism to aid homeowners with capital investment costs.

In this scenario, some challenges faced by homeowners is actually finding a suitable installer who is registered to carry out the work. Qualified installers tend to charge more up front and it is often reported that the benefit of RHI is mitigated by the extra expense RHI installer's request. In other European countries where the technology is successfully specified and approved for government funding the annual sales of such products hugely exceed what UK sales volumes tend to illustrate.

6.2.1 Product Specification & Building Design

Building consultants and engineers hold a lot of responsibility for the specification of heating systems and hot water supply for buildings, commercial and domestic use. They have a specific objective to fulfil the energy needs of a dwelling with a robust solution and often is the case that they select solutions that offer familiarity, ease of selection and reliability. Consultants also are responsible for ensuring compliance with building regulations and energy efficiencies. Considering the importance of this type of role, manufacturer's engagement with consultants is paramount in determining the product selections made for new buildings. Providing CPD courses demonstrating how new technologies meet regulations and compliance is one method of engaging with consultants.

Some barriers to obstruct the progression and expansion of the use of heat pumps in general are the restrictions that are apparent at the building or dwelling. These restrictions often relate to lack of space, position, electrical supply/capacity, access to heat source for inclusion of the heat pump at retro fit situations. A combination of these issues is typically sufficient to persuade homeowners to upgrade their heating system to more modern versions of what they already have in place. For air source heat pump water heaters, the issue of air ducting the product intake and exhaust air to outside air results in issues for installers in that a reasonably restrictive building may be in place prohibiting the fitting of ducting through walls, roof spaces and facades etc. These points can be easily addressed by building designers and architects by locating the hot press or storage cupboard adjacent to an external wall to allow access directly to the outside of the building to easily fit air source heat pump intake and exhaust air vents.

6.2.2 Consumer Awareness & Installer Confidence

The customer may be considered to be the homeowner, landlord or installer in certain cases. These stakeholders often have a huge influence on what type of heating systems are fitted to a building, more so with retro fit but often with new builds where consultants are not required. They can often sway the decision a consultant makes should they have a greater awareness in certain areas. Little information is readily available to homeowners or landlords regarding available heating systems and technologies, these stakeholders are often not informed sufficiently to make decisions about available water heating systems and comparable installation and running costs. A recommendation would be to make publicly available a simple calculator that would allow the general public to compare installation and running costs for various water heating systems. This tool could take the existing system in place as a datum point and provide feedback to customers about product running costs and installations costs to allow for an informed decision to be made before opting for a conventional hot water heating system. Another recommendation worth noting would be regarding product advertising and raising customer awareness through advertising. The most effective route to target customers directly within the heating market tends to be via trade magazines, installer engagement sessions and through exhibitions such as home improvement or energy exhibitions that typically occur around the country on an ongoing basis.

In general heat pump technology is a sector that most typical UK installers tend to shy away from getting involved with at point of installation. Correct heat pump installation and commissioning is key for effective operation of the appliances achieving efficiencies stipulated by manufacturers. For hot water heat pumps, specifically air source units the installation process is reasonably straightforward. The challenge that manufacturers face is demonstration to the installer base that the products are simple to install and no more complex than a more conventional water heating system such as a combi boiler etc. In addition to installation, installers also need confidence that the heat pump water heater will operate, function and deliver sufficient hot water to meet the needs of the homeowner avoiding the need to return to the home for system upgrades, modifications or troubleshooting. It is critical that heat pump water heater manufacturers engage with the installer and customer base to provide training, demonstration and information dissemination events to promote the technology.

6.2.3 R & D Program

The UK government's expenditure on Science, engineering and technology (SET) was £11.4 billion in 2015[26] of which £10.2 billion was expenditure on research and development. The UK research councils (RCUK) distributes and manages such funds (£3.4 million) for R &D activities in seven discipline area. The RCUK has special programme on Energy which combines various research councils and is investing more than £625 million in research and skills to pioneer a low carbon future. Engineering and Physical Research Council (EPSRC) manages R&D funding for energy theme with current portfolio of 471 grants with worth of £485.05 million[27]. Under EPSRC energy theme, there are several projects under end use energy demands (energy efficiency), energy networks and energy storage which directly or indirect investigates low carbon technologies related to domestic sector. However, only one project found when searched for domestic hot water[28]. Hence, it is required to have dedicated funding and research and development programme that covers domestic hot water and all technologies development under one umbrella. This will help to bring experts from industries, council, association, academics, utilities to work on dedicated topic.

[26] ONS (2017), UK government expenditure on science, engineering and technology: 2015, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/ukgovernmentexpenditureonscienceengineeringandtechnology/2015

[27] EPSRC (2017), https://www.epsrc.ac.uk/research/ourportfolio/themes/energy/

[28] EPSRC (2017), GoW search, http://gow.epsrc.ac.uk/Search.aspx

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