Technology Collaboration Programme
by iea

Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 46

Domestic Hot Water Heat Pumps

Executive Summary

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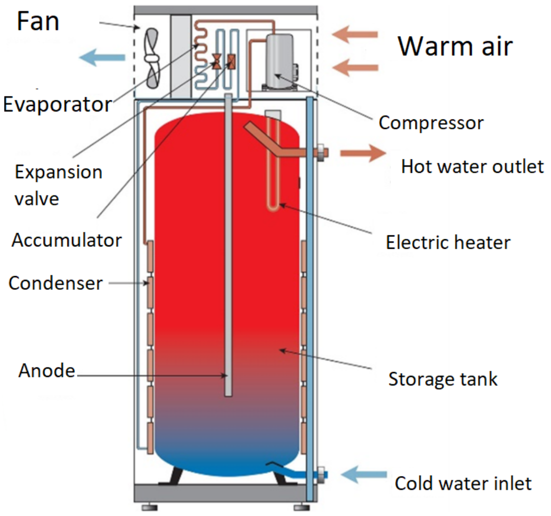
1 Executive summary

The share of Domestic Hot Water (DHW) production in the total heat consumption of the building has increased. In new low-energy single family as well as multifamily buildings and the temperature of DHW is higher than the temperature for space-heating. Thus DHW production has become a dominant factor in heating systems for new buildings. The same is the case for the 'deep' renovation of existing buildings.

The main objective for the Annex has been to provide deeper insight in the challenges to achieve the full potential in applying Heat Pump Water Heaters (HPWH) and to achieve the potential reduction of CO_2-emissions, using various concepts and systems for new as well as existing buildings in the renovation process. This is achieved by giving the right information on the boundary conditions:

- Reviewing available Heat Pump Water Heaters, mainly mono-bloc but also larger collective systems;
- Reviewing the different system concepts for single family as well as multifamily buildings;
- Developing and validating a model to enable an objective comparison of Heat Pump Water Heating technologies and systems;
- Data basing example projects;
- Creating a web based information platform to serve participating countries by publishing information on their market approach and training courses.
- Holding regular workshops.
- An overview of R&D on Heat Pump Water Heaters, along with the R&D still needed.



On Heat Pump Water Heaters (HPWH) we generally are speaking about 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 underneath the heat pump. These mono-bloc systems will remain the preferred solution in many cases for single family houses. However there is a great number of alternatives for Domestic Hot Water with heat pumps in domestic applications, other than the mono-bloc, for single family houses and multifamily buildings, for sanitary hot water systems for hotels, hospitals, sporting facilities, etc.. There is a large number of technologies available with regional differences in demand and usage, thus showing a greater complexity than space heating/cooling systems.

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 many cases, the market reality of hot water generated with heat pumping technologies proved to be more complex than assumed at the start of the Annex, more complex then space heating. The main work in the Annex has focused on the technology of the mono-bloc heat pump water heater, under the headings: policy, refrigerants, test procedures, technology modelling and R&D. Next to this the important boundary conditions have been studied, being legionella, system design, collective heating networks and calculation models for large applications, coming into touch with larger heat pumps.

In essence however hot water systems consist of a heat generator (i.e. a heat pump), 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). Due to a strict governmental policy on energy performance for new domestic buildings, the inherently better insulation, and higher comfort demands by the end user and the relatively high temperatures needed, due to legislation, for domestic hot water, the energy demand for generating this hot water will dominate the overall energy use of the house, becoming a challenge for policy makers. 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.

Market scenario

The Heat Pump Water Heater market is characterized by the presence of a diversified regional and highly fragmented supply side providing with their knowledge of the market customized products. This is posing a stiff competition to the international players. However, the local manufacturers find it increasingly difficult to compete these, while the international players also take over or collaborate more and more with regional or local players.

The best opportunities for HPWH are in:

- Installing in new single family and multifamily buildings to meet building regulation requirements;
- Retrofit of existing gas or oil boiler in single family buildings or terraced houses, with a new boiler and a heat pump water heater or a heat pump for both space and hot water heating;
- Replacement of direct electrical heating of hot water in existing buildings, individual domestic buildings, terraced houses, driven by customer need for energy cost savings;
- Retrofit of collective distribution systems for hot water in domestic multifamily buildings with individual heat pump water heaters, either a booster type or an air source HPWH;
- Homes where space is at a premium, with compact wall-hung systems with < 100L tanks or split HPWH;
- Ability for smart operation with PV integration and/or connection to smart grid;
- Low temperature distribution systems of the 4th Generation District Heating, with booster HPWHs.

The three major markets - North America, Asia and Europe - represented by the countries participating to the Annex have different market conditions and different usage scenarios

Policy

Applying heat pumping technology is one of the possible heat generators to reduce the energy usage and CO_2 emissions significantly. Although there are some noticeable successes in the market developments, heat pump water heaters are still having a relatively small market share with a much larger potential. Traditionally however policy makers are reluctant to make choices, thus except for Japan in the past with the Top Runner program, there seems to be no specific support for market development of heat pump water heaters. In general, mandating the installation of high efficiency water heaters is the main policy tool used to ensure that high efficiency water heaters are installed. 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.

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.

As a basis, there is 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 the ErP and EL regulations, 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

Finally 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.

Test procedures

Test procedures are the basis for quality labels, calculation models and therewith an important element in governmental policy instruments. However world-wide there is a disturbing landscape with a great number of test methods for heat pump water heaters in use in different regions of the world, with major differences between them. As a result, manufacturers have to undertake a different set of tests to be able to sell their products on the worldwide market. Harmonisation of test procedures is urgently needed.

The ISO Working Group 12 on Heat pump water heaters of ISO/TC 86/SC 6/WG 12 on HPWHs has developed a harmonisation framework, for drafting a test procedure now available as standard ISO 19967-1:2019.

The European standard EN 16147 and the ISO 19967-1 standards are very similar and are assessing the water heating energy efficiency of the heat pump water heaters based on the rating of a coefficient of performance (COP_{DHW}) over a 24h load profile. Several load profiles, each one consisting of a series of draw-offs characterised by the hot water outlet temperature and the amount of energy tapped, are described and allow to rate a large capacity range of heat pump water heaters. In addition, if the unit is provided with a smart control, i.e. self-learning of the hot water usage, the coefficient of performance can take benefit of this smart function. Other characteristics such as the standby power input and the volume of available water at 40°C within one single draw-off are also performance parameters of the heat pump water heater.

Legionella

Heat pumping technologies for single-family buildings as well as in collective systems for multi-family buildings, sports centres, hospitals, etc. are well fitted and capable to deliver the required temperatures according to general legislation dominant in the participating countries, to fight Legionella. If there is a problem, this cannot be caused by the heat pump itself. For single family buildings this is traditionally done with an additional electric resistance. But, as a consequence of the existing regulations for legionella and the need for heat pumps suitable for retrofit, especially in collective systems, refrigerants and solutions for DHW applications with higher than traditional (>60°C) heat supply temperature are in demand. Modifications to the refrigerant cycle such as cascading refrigerant cycles can be used to increase the output temperature further up to 80°C with other refrigerants, like CO_2 and in cascade R410A/R134a, but also gas driven heat pumps are in the market.

However based upon literature studies it is concluded that the domestic hot water temperatures can be below 60°C without increased risk of Legionella if the overall volume of domestic hot water in the distribution system is below three litres. This finding sets the rule for designing the domestic hot water systems supplied by low-temperature collective distribution systems in multifamily buildings, as well as for district heating systems.

- Legionella disease is a lung disease originated by inhaling vaporized water from showers and not caused by drinking water from the tap.
- The risks of Legionella infection exists in locations of stored (stagnant) hot water at relatively low temperatures and in collective systems. The bigger and more complicated a water distribution network

is, the greater the risk for the growth of Legionella bacteria. Systems in single-family houses with a water distribution system smaller than three litres are known not to be affected by legionella.

- Harmonization in legislation does not exist but is needed when the demands in legislation differ too much there will be no equal markets as the demands have consequences for the test procedures as well. Although legionella cycles are not included in test procedures because considered as "safety operation" and not "normal use ", the temperature demands affect the test procedures for heat pump water heaters.
- Increasing hot water storage temperatures to 60°C recommended for Legionella control decreases the energy efficiency, increasing CO_2 emissions. It is not suggested to take a slack attitude to the problem, but the broad-brush turn-up-the-thermostat approach, given the energy penalty involved, can be debated. Further study in this area is justified.

Refrigerants

For Heat Pump Water Heaters at this moment no alternative low GWP refrigerant fulfils all the ideal requirements at once.

For HPWHs not much focused research is available in which results show which refrigerant is the ‘best solution’. GWP can be a useful metric to compare different refrigerants. However, it may to overestimate the benefits of low GWP refrigerant to environment, as it does not take into account many other affecting factors, like the use of high efficiency components and system design, such as the optimal storage size, stratification and condenser design. Ensuring proper installation, optimised control and operation, under all common operating and climate conditions are factors not directly related to the technology itself and the choice of refrigerant. In the end, the overall energy use of the installation is an important factor in the calculation of the LCCP or TEWI factor.

The main policies worldwide focus on banning the use of refrigerants with a high GWP. However this does not necessarily result in lowering climate impact, expressed in term of LCCP value. Thus, LCCP evaluation can be necessary in order to account for the entire climate impact of a system when selecting an alternative refrigerant. Alternative refrigerants to the currently used refrigerants (R134a, R410A) are:

- Carbon dioxide (R744) and Propane (R290) are natural refrigerants, which can be used to reach higher output temperatures up to 80°C.
- R152a, R1234yf, R1234ze(E) and Ammonia are interesting alternatives for DHW HP, not yet broadly in use but already tested in R&D projects, while R32 is strongly promoted by a number of manufacturers.

In the choice of refrigerants the condenser configuration exchanging heat with the storage tank and the risks (like flammability) of the refrigerant play an important role. Oak Ridge National Laboratory (ORNL) has done a number of studies in this area and great leap forward with Propane has been achieved with research by Kungliga Tekniska Högskolan (KTH) among others.

Multi Family Buildings

Particularly, water heaters are one of the most complex product categories due to a large variety of product types, technologies, and fuels used for heating water. Simple solutions are available for single family houses, but for collective systems solutions can be more complex. The low efficiency of domestic hot water systems is well known by field practitioners. For many new residential multifamily buildings hot water delivery times and heat losses in distribution systems have been getting steadily worse.

On the subject of "best system design" with regard to energy-efficient hot water supply, a number of conclusions can be drawn:

- Based on the sum of all losses, decentralized solutions (hot water is generated where it is needed) are the best solution.

- In general, 2-pipe systems with home stations perform better in terms of distribution losses than 4-pipe systems, which is mainly due to shorter length of distribution pipes.
- In order to be able to integrate renewable energies in apartment blocks, central solutions can be preferred, with the exception of the combination of photovoltaics and ventilation heat pumps for apartment blocks with a low demand for space heating (such as in the French climatic zones H3 and H2c) and in Energy Zero of Passiv houses.
- Especially with heat pumps an efficient operation by separation of distribution system for hot water heating and space heating can be achieved. For this technology, the advantages of optimized generation (4-pipe system) must be contrasted with the advantages of lower losses (2-pipe system) and evaluated on a case-by-case basis.
- Due to the magnitude of the distribution losses (heat losses through the pipelines) in centralized solutions, it is strongly recommended to optimize all pipeline lengths as early as the planning phase and to insulate distribution lines beyond what is required and to consider the possibility of using inline systems.
- Losses in heat supply represent the second highest loss share for central options and can be reduced by intelligent technology selection and optimization (optimized design, coordination of hot water, heating and storage combinations and control engineering integration, ongoing monitoring).

Power supply (pumps) and storage losses play a minor role. Optimizations in existing (old) systems (pump replacement, additional insulation in storage), however, can certainly lead to significant savings.

System models for DHW production and distribution

Currently, the biggest challenge for every user of building and plant simulation is the large number of different simulation tools. Every simulation software has a main area of application and is optimized for this specific problem. Even software with a wide range of applications or specialized multi-physics software cannot calculate every problem in an accurate and efficient manner. If DHW is not included based on objectively verified values, it will not be possible to assess future systems that are predominantly dimensioned around tap water for their energy performance.

For policy purposes models (often commercially available) have been developed to calculate the energy performance of buildings required for building permits or commercial transactions. Climate, location and building specific components, often traditional for certain regions are the basis of these models, where it is expected that it will be difficult to make clear comparisons between those. Given the market of models already on the market, it does not make sense to develop an 'own' Annex 46 model.

Overall it is important to think in terms of complete system concepts. Even if the heat is produced with a high energy efficiency, high storage and/or distribution losses still remain unnecessary and eventually will cause a low overall system efficiency to the best generating apparatus. It is therefore important to consider the heat generators not only individually but to design a complete DHW concept with a critical view on performance, comfort and legionella prevention. If DHW is not included based on objectively verified values, it will not be possible to assess future systems that are predominantly dimensioned around tap water.

With new distribution systems in the market, especially in collective systems, adequate publicly available calculation models do not exist taking into account the latest innovations in domestic hot water technologies. More specifically a model should be developed that can be used for the different countries basically giving support to the existing formal legal calculation models. A proposal was done under Annex 46 but the required funding for the work was not available.

Technology modelling

Although the monobloc Heat Pump Water Heaters have reached an important level of maturity on the market, it seems that there is still room for improvement of their energy performance. Under this Task modelling on the technology has been executed and has been published upon by:

- EDF has presented a model for a monobloc Heat Pump Water Heater with a 'wrap-around' heat exchanger for the storage tank. The study done by Électricité de France (EDF) has resulted in new design for Heat Pump Water Heaters that achieves appr. 37 % average annual energy saving and appr. 30 % reduction of the electrical bill while ensuring a same level of comfort for the end-users.
- Oak Ridge National Laboratory, developed a heat pump design model with a special model for HPWH. Stratification in the storage tank is an important basis for the optimization of the system. Computational Fluid Dynamics (CFD) model using ANSYS 17.2 and an effective, hardware-based HPWH equipment design tool, a quasi-steady-state HPWH model was developed based on the DOE/ORNL Heat Pump Design Model (HPDM). The model is freely available.
- Waseda University, especially for CO_2 DHW HP's. One very complex model (confidential) and another simplified model were developed.
- Ulster University works with TRNSYS and did a number of studies on storage in relation to smart grids and validation of models on their test houses at the University.

In a survey more than 40 papers from other authors/institutes/universities, than the participants, were studied, with topics ranging from:

- Optimization of refrigerants and condensers;
- Stratification;
- Smart grids and storage;
- Combination with solar, often from the angle of solar thermal.

Understandingly the main modelling initiated for heat pumping technologies has a focus in very special heat pump related topics and challenges, such as refrigerants, heat exchangers etc., but also on the market challenges such as smaller, cheaper and more efficient and fit to market demands such as smart grids.

Worldwide there is a large number of models (some academic exercises!) available also for other condensers. Manufacturers do have often their own models.

- Heat Pump Water Heaters are not very energy efficient as in the process of heating and draw offs a lot of losses occur, thus reducing the optimal COP from 4.5 to 2.5.
- In a great number of institutes work is done fairly independent from each other with a different focus on the goals to be achieved. Some, like KTH in Sweden focus on reducing the refrigerant charge with flammable working fluids, others focus on the storage capacity in smart grid applications (Grid Flexibility). Important R&D focus is 'smaller and cheaper' as well as cold climate applications.
- The discussion in the Annex did not come to a clear conclusion whether we should have 'wrap-around', external plate, or internal spiral heat exchangers, although lab-test at ORNL clearly show the advantages of external plate heat exchangers.
- A few degrees temperature difference in the thermostat (hysteresis) gives a better COP. That idea can be used for optimisation of the control mechanisms.
- With an increasing number of heat pumps installed for space heating and cooling the optimisation is in the combination with water heating in double function application. The larger the heating capacity for space heating, the smaller the storage tank (even down to 50 litres)

In comparing DHW concepts and systems a market divide can be made between individual and collective systems and newly developed or built systems and infrastructures compared to existing systems in retrofit.

Research and Development

Although heat pump water heaters are by far the most efficient way to heat water heat pump water heaters in itself are not very energy efficient as in the process of heating and draw offs a lot of losses occur. In the residential market there is the need for downsizing, noise reduction, and cold weather specifications as well as higher efficiency and lower price.

In the participating countries some specific programs for R&D on heat pump water heaters are or have been running and some general R&D programs run in which amongst others heat pump water heater technologies are supported. During the Annex work it became clear that the great number of the main heat pump manufacturers/suppliers are not Original Equipment Manufacturers and get their components for manufacturing heat pumps from the world-wide market, compressor technologies, valves, evaporators and refrigerants. Therewith, R&D from non-OEM manufacturers will be mostly ‘application development’ focusing on the application boundaries of the existing and future markets and customer needs and preferences. This is an interesting market where innovation is of great importance to reach the market. Important topics for development, focusing on local market acceptance are:

- System technologies, especially occurring in collective systems, where smart system lay out and control mechanisms can reduce the temperatures, volume flows and heat losses, thus optimize the energy efficiency as well as economic performance. Booster Heat Pump Technology is one of those technologies that came forward out of the need to reduce distribution losses and are now the technology for the 4th Generation Low Temperature District Heating.
- Installer focused technologies, focusing on making installation of the technology more simple or fit for the local conditions. The traditional installer is not really capable (on a large scale needed for a market transition) to give consumer advice and install the best option. Often oversizing is the case to avoid complaints. Sizing fit for small spaces, Plug & Play concepts are the dominant topics. These technologies are often specific for local manufacturers with a strong home market.
- End-user focused technologies. Consumer adoption is critical to the success of the heat pump water heater technologies. Water heating is a challenging market because units are only replaced when they fail which is typically 10 to 15 years and energy efficiency is not always a priority. End-users are not aware of the advantages on the long term and will traditionally go for the cheapest solution.
- Water quality management technologies and technologies to reduce the usage of water without losing comfort. Having effect on the capacity of the heat pump and storage size this is not directly a topic researched by heat pump manufacturers.
- Smart technologies. Grid operators are interested in the storage capacity of DHW Heat Pumps, although the capacity is smaller than with direct resistance heating and alternative storage technologies are coming on the market and are being researched. Domestic Hot Water Heat Pumps can contribute to solutions for several energy system-related obstacles. Within the Annex 46 working group, we distinguish five main smart heat pump contributions:
  1. Keeping grid load under control while renewable energy production grows to restrict or even avoid grid capacity investments.
  2. Keeping grid load under control during extreme conditions (i.e. ‘coldest week’), again avoiding grid capacity investments.
  3. Increase self-consumption of renewable energy sources (achieving better grid balance and higher economic end user value).
  4. Selling flexibility to the grid, for the benefit of balance responsible parties, grid operators, traders, etc.
  5. Allowing for a higher share of heat pumps in the energy system without risking local overload problems.

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