Thermally driven heat pumps

HOW THEY WORK AND WHY THEY MATTER

association of the European Heating Industry

www.ehpa.org www.ehi.eu


Photo: Ariston Group

This report was written by members of the European Heat Pump Association (EHPA) and the European Heating Industry association (EHI)

For more information, please see www.ehpa.org and www.ehi.eu

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Thermally driven heat pumps (TDHP) are an innovative and promising segment of the heat pump market. They prove useful for several fields of application and contribute to the claim that heat pump technology can meet nearly all requirements in the marketplace for heating, cooling and domestic hot water. EHPA and EHI support heat pump technology in all possible applications (new and existing buildings, industrial processes, district heating and cooling etc.).

Technology overview

EHPA and EHI refer to a thermally driven heat pump as defined in the draft Ecodesign and Energy Labelling Regulation (EU) 813/2013 and 814/2013: "Thermally driven heat pump means a heat pump using heat or an engine to drive the sorption or compression cycle". There are three main type of thermally driven heat pumps; gas sorption heat pump (GAHP) and thermal compression heat pump (TCHP) are both covered by EN 12309 and gas engine heat pump (GEHP) is covered by EN 16905.

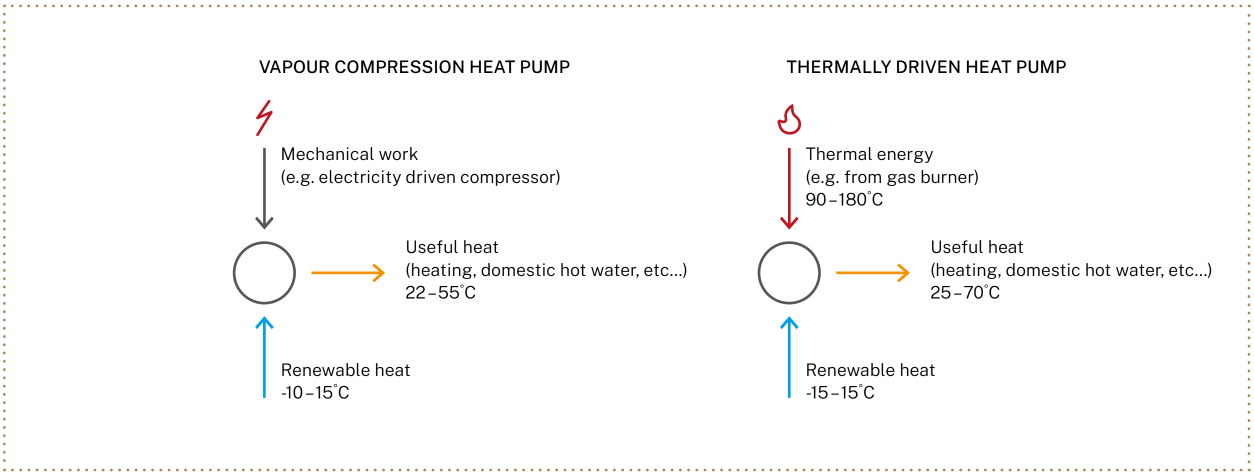

Figure 1
How a thermally driven heat pump works

A heat pump uses energy to "pump" renewable heat (e.g. ambient heat) from a low temperature level to a temperature level where it can be used to heat a house or produce domestic hot water. While a vapour compression heat pump uses electricity to drive the heat pump, a thermally driven heat pump uses heat to drive a "thermal" compressor. This heat can come from a gas burner that drives the thermodynamic cycle, for example (Figure 1).

Key performance factors of TDHP

The key performance indicators of thermally driven heat pumps are:

→ Contribution to EU energy and climate targets: CO_2-emissions reduction of 30 to 40% compared with traditional heating technologies), primary energy savings and efficient use of energy, diversification of energy sources. When using renewable gases in TDHP, CO_2 emissions can be further reduced.

→ Reduction in primary energy required compared to traditional heating technologies of up to 40%.

→ Good performance at low outdoor air temperatures (not only on ground source applications) and higher heating supply temperatures (also with radiators).

→ Application in areas with insufficient available load from the electric grid (extra load on the grid from TDHPs is negligible) and in areas with harsh climates (and available gas supply, also LPG).

→ Lower cost for drilling (ground source heat pump) due to the need for a smaller heat source and reduced need for back-up/bivalent systems due to stable output power.

→ Feed-in temperature up to 70°C: compatible with "retrofit applications" and DHW requirements.

→ Reversible heating & cooling possible.

→ Heat pump technologies offer more efficient use of energy than the traditional heating technologies and this no matter the energy use (renewable electricity, gaseous fuel, natural gas). Use of gaseous fuel, widely distributed in many European countries, which can be converted into green gas (bio-methane, hydrogen) in the next few years, further reducing CO_2 emissions. In fact, the introduction of fuels such as syngas, biogas, biomethane and hydrogen (so-called "green hydrogen" available through the electrolysis of water using renewable electricity) will make the gaseous fuel renewable. Syngas and biogas could be used in TDHP units through an upgrading process of Biogas to bio-methane.

The ability to provide high output temperatures allows TDHPs to be directly used with existing heating systems. "High temperature levels" means heating and DHW supply temperatures 55°C and higher. Sorption heat pumps currently market available and under development are specifically addressing the retrofit market in existing buildings with existing heating systems, which often still means supply temperatures at these levels. In the respective standards there are two heating maximum supply temperatures defined:

→ Low temperature supply 35°C
→ Intermediate temperature supply 45°C
→ Medium temperature supply 55°C
→ High temperature supply 65°C

These are the nominal (maximum) heating supply temperatures at the respective heating design outside temperature of the considered climatic zone (e.g. -12°C for average climate).

Due to their design for use with hydronic systems (very often based on radiators), TDHPs easily integrate with other heating technologies (solar energy systems, condensing boilers, or electrical heat pumps). TDHPs are receiving increased interest in the marketplace due to the previously mentioned advantages leading to high sales growth in all market segments and geographic areas that are currently addressed.

Gas sorption heat pump (GAHP)

There are two main types of sorption heat pumps: absorption and adsorption.

Absorption heat pump

The gas absorption heat pump incorporates in addition to the evaporator, condenser and expansion elements (typical components of a compression system), a thermal compression system (generator, absorber and solution pump) that replaces the mechanical compressor of a traditional compression system. The device is driven by heat, which can come from various energy vectors such as natural gas, bio-methane, hydrogen or waste heat (Figure 2).

Photo: Robur

41.3 kW aerothermal
gas absorption
heat pump

18.9 kW aerothermal
gas absorption
heat pump

During operation, the energy vector is converted into heat and this is supplied to the solution generator. Under the influence of the supplied energy, a natural refrigerant such as ammonia is evaporated from the rich solution (ammonia/water). The ammonia vapour at high pressure and temperature passes through the rectifier shelves. In the rectification process, a large part of the water vapor is removed from the ammonia vapors.

Then the purified ammonia vapors give up their heat in the condenser (heating up the water for central heating / hot water) and the now liquid refrigerant flows to the expansion element. This refrigerant state change, therefore, represents the first useful effect of the heat pump. After reducing the pressure, the cold liquid ammonia is fed to the evaporator, where it takes the heat from the lower source and evaporates, even at very low temperatures.

The refrigerant vapors are then directed to the absorber. In the absorber the ammonia vapours are absorbed by a poor (water-rich) solution. The ammonia is absorbed by water and thus a rich solution is formed that releases heat due to the exothermic nature of the absorption process. The hot rich solution is fed again to the heat exchanger (heating up the water for central heating / hot water) and this represents the second useful effect of the heat pump. This absorption process (that characterizes the entire thermo dynamic cycle) allows also to a vapor (ammonia) to be absorbed into a liquid (water), enabling the replacement of the typical refrigerant "gas compression" action, with a "liquid pumping" action, which is much less energy-consuming.

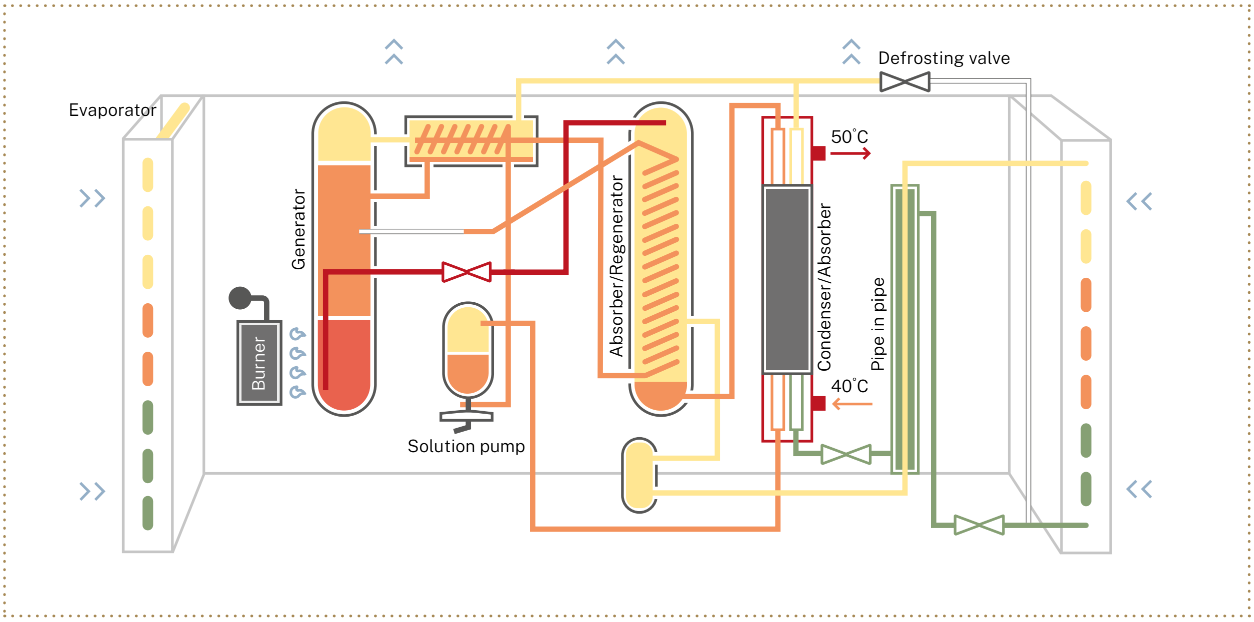

Figure 2
How an absorption heat pump works

🟥 Weak solution

🟧 Strong solution

🟨 Refrigerant vapour

🟩 Refrigerating fluid

🟥 Hot water

Next, the liquid refrigerant solution is then sucked up by the solution pump, which injects it at high pressure back again into the generator. This process makes it possible to capture renewable energy from the environment (at the evaporator) even at very low temperatures and to use a primary energy vector to activate the thermodynamic cycle.

It is important to observe that the absorption cycle performs particularly well with high thermal lifts (difference between the evaporator and condenser temperature) maintaining high efficiency and high output power. Therefore, absorption heat pumps are particularly useful to address the *hard-to-abate* sector of the space and water heating (existing buildings in average or cold regions).

The absorption system is characterised by stable operation and makes it possible to obtain a constant value of power supply in the whole range of temperatures of the lower source (the temperature of the lower source does not affect the change of temperatures of power supply from the device).

Absorption technology is mature and reliable. It has been used in refrigeration applications for decades. Its application to heating is merely a refrigeration cycle where the useful effect is the heat released by condenser and absorber instead of the cooling effect obtained at the evaporator.

Adsorption heat pumps

Adsorption heat pumps can, for example, use water or ammonia as a refrigerant. Transfer of ambient energy to the system is achieved by evaporating the refrigerant. The refrigerant (water or ammonia) vapor is adsorbed at the surface of a solid (e.g., zeolite or activated carbon). This process releases heat at a higher temperature level. Once the adsorbent is saturated, the refrigerant is expelled in a desorption phase using heat from a fuel burner (see Figure 3). Whereas absorption functions continuously, adsorption technology is a cyclic process (adsorption/desorption), which appears to be continuous due to the response time of the heating circuit and respective heat pump design (e.g. more than one adsorption module) and control.


Photo: Cooll

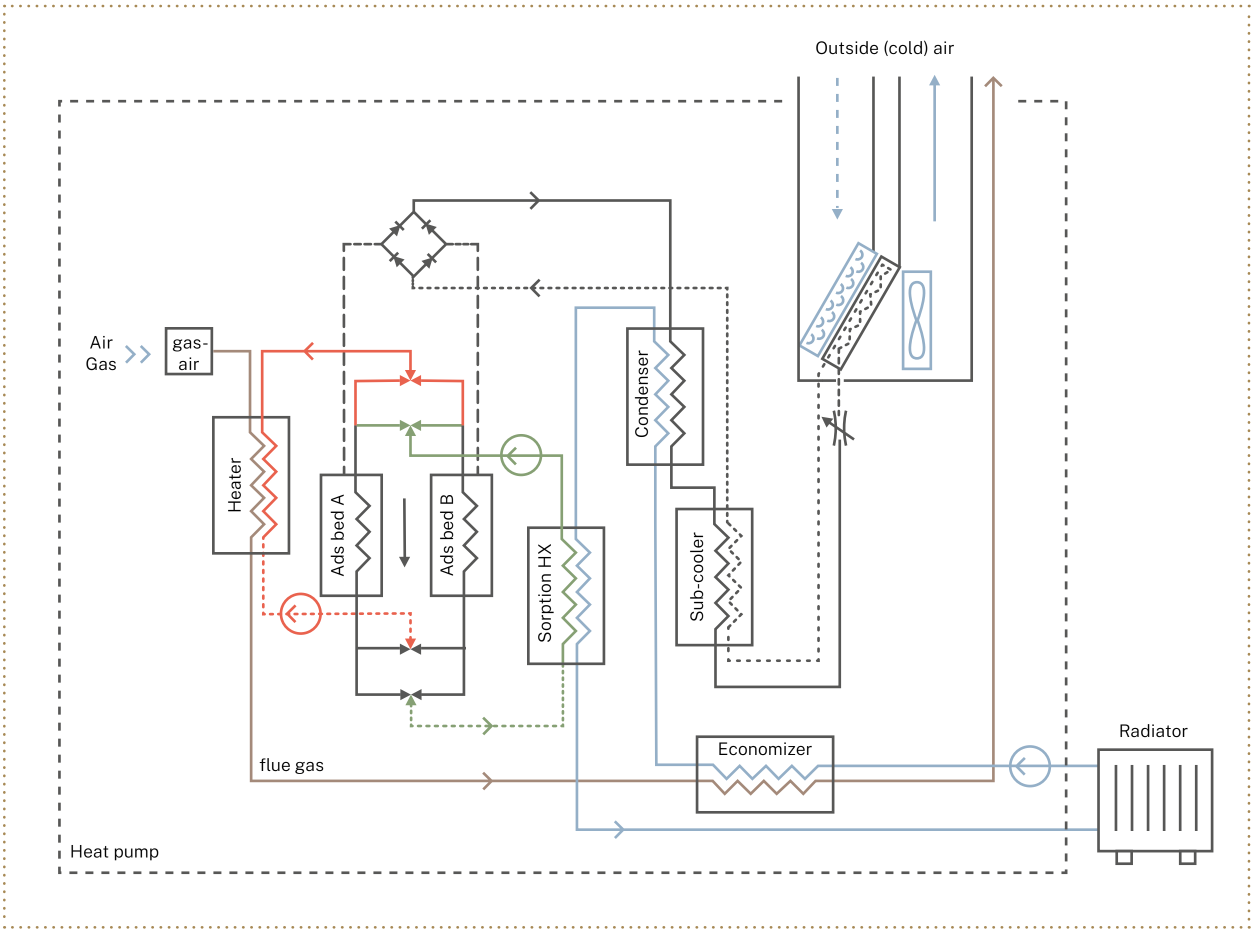

Figure 3
How an adsorption heat pump works

- Ammonia high pressure
- Ammonia low pressure
- Ammonia alternating pressure
- Process water hot
- Process water cold
- Central heating water

A gas burner keeps a heater containing process water on the right temperature (about 180°C, with the pressurized process water remaining in the liquid phase). This hot water heats in turns two elongated beds filled with adsorption material. This results in a thermal wave moving in about five minutes from one end to the other end of the beds, heating it to 180°C from one end to the other end.

The adsorption material contains adsorbed refrigerant, e.g., ammonia. By heating the bed with the thermal wave, the refrigerant gas desorbs at high pressure from the adsorption material and feeds the heat pump cycle. At the same time the second bed is being cooled by the process water (green circuit) employing a similar thermal wave, giving off the heat via the sorption heat exchanger to the central heating water, for instance at 50°C. By cooling the bed with the thermal wave, the low-pressure ammonia coming from the heat pump flows back into the array and adsorbs back on the adsorption material. Using the thermal wave, roughly half of the heat needed for heating the bed can be recovered from the cooling bed. This is key to obtain a good efficiency of this system.

Gas Absorption Heat Pump technology is the most widespread and mature technology within TDHP on the market, introduced over 20 years ago and currently available in different sizes and with different types of renewable energy supply (aerothermal, geothermal and hydrothermal).

Thermal compression heat pump (TCHP)

Sorption technologies are not all there is to thermally driven heat pumps. The technology of thermal compression, very close from the Stirling motor principle, will also soon reach commercial applications (Figure 4).

Photo: Boostheat

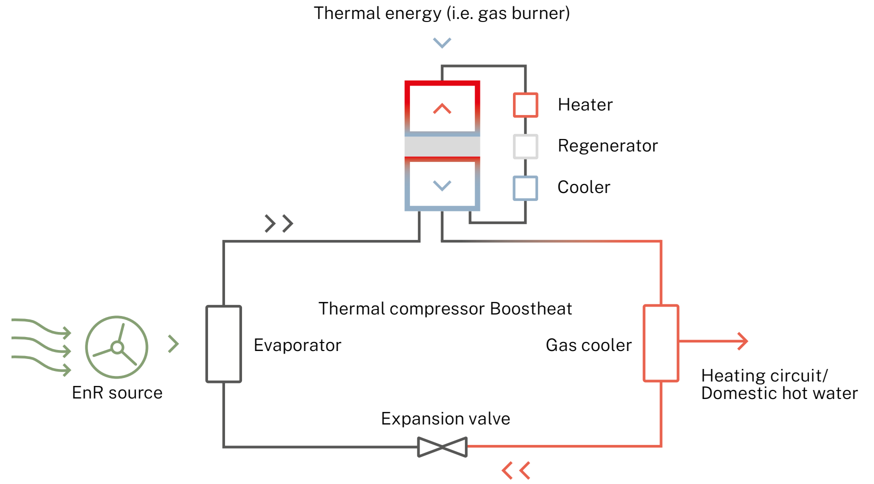

Figure 4
Heat pump cycle whose efficiency is provided by the self-compression of its own refrigerant using thermal power supplied by an external source

In a thermal compressor, heat is used to activate only the compression cycle without mechanical power transmission, and directly powers the heaters (upper chamber of the compressor). The thermal compressor drives the heat pump cycle at 700°C, dramatically increasing its efficiency. This is simply explained by the principle of the Carnot cycle: higher temperature difference translates into increased efficiency.

Unlike a volume compressor where power is transmitted by mechanical work, the thermal compressor does not have a working piston but a displacer piston without lubrication which improves system lifetime and contributes to ease of maintenance compared to a standard compressor. The thermal compressor is directly heated through the wall of the compressor chamber enclosing the refrigerant (R744) which increases in pressure due to the rising temperature. The direct high efficiency compression of CO_2 (R-744) works at pressure levels between 30 and 100 bars.

The current systems are developed with CO_2 refrigerant, yet the technology is refrigerant and heat source agnostic.

Gas engine heat pump (GEHP)

Gas Endothermic Heat Pumps are direct expansion systems with a compressor of a similar type to those in an Electric Heat Pump system.

A variable speed (rpm) gas engine is used as the driving source of a compressor instead of an electric motor. This gas engine compressor drive has 2 advantages:

1. Availability of waste heat from the gas engine that can be valorised.
2. No need of electrical consumption for motor power thanks to the gas engine.

Photo: Panasonic

The main components in a GEHP are an endothermic gas-fired engine (GE), one or more rotary or scroll compressors for a vapor compression heat pump (HP), a condenser, an expansion valve and an evaporator (Figure 5).

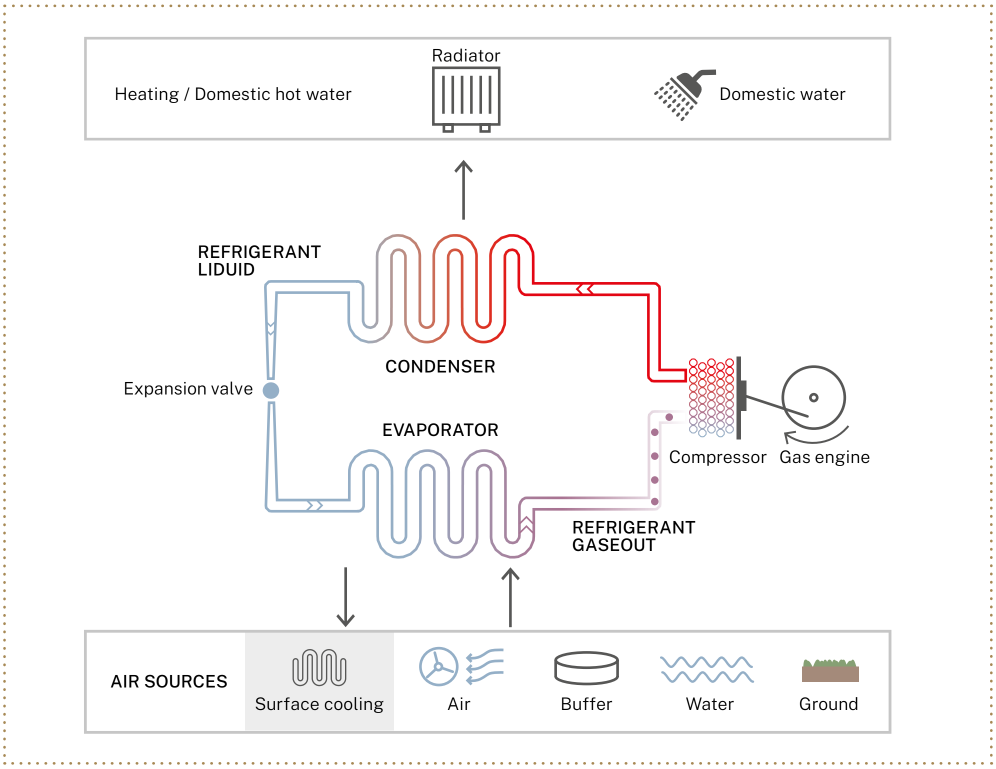

Figure 5
Gas endothermic heat pump (GEHP) – main components

The engine is commonly fuelled by natural gas (NG), methane, propane, or liquefied petroleum gas (LPG), and are liquid cooled.

Similar to electric-driven heat pumps (EHP), the GEHP can typically use with a 4-way reversing valve to satisfy heating and cooling demands. The GEHP can be an air-to-air, air-to-water, air-to-brine, water-to-water, water-to-brine, brine-to-water or brine-to brine heat pump.

The heating / cooling power of the GEHP condenser / evaporator can be regulated by acting on the compressor's speed, utilising the rotary speed of the engine.

One of the main characteristics of GEHP is the availability of the waste heat of the engine that may be recovered, providing additional thermal power. The heat is recovered from exhaust gases and the engine cylinder jackets. During heating and cooling operation, the waste heat available from the engine may be used to provide free domestic hot water respectively heating water at a higher temperature level (70°C).

In heating operating mode, the waste heat available from the engine may also be used to increase the lower temperature at the heat pump evaporator, thus reducing the influence of outdoor air temperature, increasing the thermal power output, and reducing the defrost cycle (Figure 6).

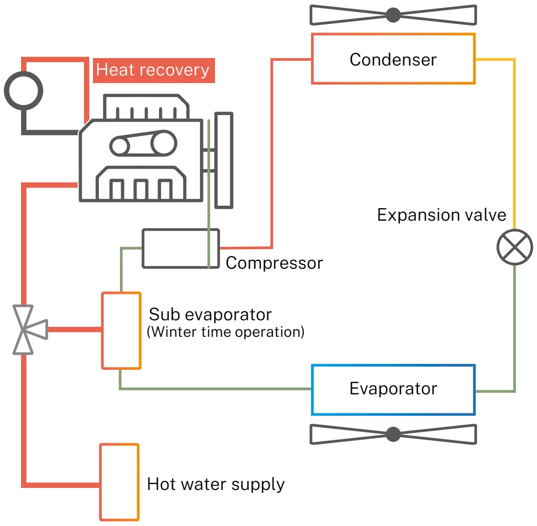

Figure 6
Engine heat recovery

Use of renewable energy and efficiency

Possible sources of ambient heat are air, water and ground as well as waste heat. Considering the primary energy, the performance is commonly declared as the gas utilisation efficiency (GUE) according to European Norm EN12309 or EN 16905. Additionally, a seasonal primary energy ratio is declared, that also takes into account the overall seasonal performance, the electrical consumption for pumps and control, and thus makes TDHP technology also directly comparable to other heating technologies.

A typical seasonal energy efficiency ratio for a TDHP used in average climate with high temperature emission systems (i.e. radiators) is greater than 1.1, and for low-temperature heating systems (e.g. floor heating) it is greater than 1.25, which is much higher than the respective values for traditional heating technologies. CO_2 emissions are therefore reduced by the same factor as result of the high efficiency in the energy conversion. Likewise, all energy conversion appliances, also in the case of TDHPs a clean (or cleaner) energy vector (bio-methane, hydrogen, power gas) will result in a correspondingly clean heating function.

Market development

The sale of high quality, reliable thermally driven heat pumps is increasing. In the light commercial, industrial, and residential market segments more than 30000 systems were in operation across Europe by the end of 2020.[1] Increased technology awareness and market availability are expected to create additional demand in several European markets. Whilst sales volumes vary widely across Europe, the technology is developing at a fast pace thanks to the easy applicability of these appliances to replace traditional gas boilers. In fact, they use the existing energy vector, with similar delivery temperatures, but with a significant reduction in fuel consumption.

Europe is the most active area in the development and construction of TDHP, both large (light commercial applications) and small-capacity systems (residential applications). Several major players (Robur, Bosch Thermotechnik, BDR Thermea Group, Aisin Tecnocasa, Panasonic, Yanmar) are already active in the market segment of TDHP solutions and new ones are going to enter in the near future.

Other European utilities are developing their own programs for accelerating the introduction of this technology and offer their customers an additional option to best suit their needs for comfort and reduction of environmental footprint.

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[1] Estimation made by a group of manufacturers

TDHPs will be among the solutions for the decarbonisation of the HVAC sector

EHPA's and EHI's role is to support the use of "heat pump technologies" for user comfort and their multiple benefits towards a climate neutral Europe in 2050. Heat pump technologies can be used to decarbonize buildings and industrial processes irrespective of the specific design/layout of a heat pump-based solution.

The decision of the kind and purpose of the heat pump technology is up to the needs and requirements of the user. The heat pump should provide the majority of the useful energy and can be supported by other solutions and energy carriers.

New buildings today can include high-performance thermal insulation. However, these buildings will only represent 10-25% of the buildings stock in 2050 and to achieve the ambitious climate goals that have been set out, the remaining buildings will also need to be decarbonised.

Buildings are different across Europe and so are heating needs, due to different climates, energy infrastructure, available renewable energy resources at local level, individual preferences, and economic resources. There is no one-size-fits-all solution.

Gas-fueled space and water heaters (i.e., condensing boilers, micro-cogeneration including fuel cells, gas fired heat pumps and hybrid heat pumps) today typically burn fossil fuels. This is due to the fact that there is not yet enough renewable gas available (e.g., green hydrogen, biomethane, green e-gas) that can be injected into the gas grid. This situation is similar to that of electricity two decades ago. Since then, the renewables share in electricity production has grown significantly, and the same is expected to happen for gas in the next decades. In its REPowerEU Communication, the European Commission presented its new ambition for the renewable gases and proposed an increased target for the EU product of biomethane and the EU's hydrogen strategy and domestic production by 2030. [2]

In response, gas-fueled space heaters are moving towards a 'green' gas readiness so that they are able to burn green gas, i.e., biomethane, e-methane, and green hydrogen in blended and pure form.

Gas-fueled space and water heaters on the market today are already capable of working with up to 100% bio-and e-methane and some condensing boilers can already accommodate a variable share of hydrogen of up to 30%. Industry is currently developing appliances that can work with 100% hydrogen.

In most parts of Europe, the gas grid can be adapted fairly quickly[3] to accommodate up to 20% hydrogen with very limited costs.[4] The gas grid can be used to store renewable energy when the supply of energy exceeds electricity demand. This will be needed to ensure security of supply.

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A108%3AFIN (2.1.2 and 2.1.3)

[3] MARCOGAZ, Overview of test results & regulatory limits for hydrogen admission into existing natural gas infrastructure & end use, October 2019. Link: https://www.marcogaz.org/publications-1/documents/

[4] French TSOs and DSOs, Final report, Technical and economic conditions for injecting hydrogen into natural gas networks, June 2019. Link: http://www.grtgaz.com/fileadmin/

In addition, on the gas infrastructure side, developments are ongoing in preparation for the transition from fossil fuel gas to biomethane, green e-methane, green hydrogen or blends.

The combined use of thermal energy in the form of gas and renewable energy from the air, ground and water allows high thermal efficiencies to be obtained for the production of heat. The change of technology, from boilers to TDHPs, enables a significant reduction of the consumption; for the same amount of energy supplied, it is possible to save up to 30% of gas and about the same amount of CO_2 emissions. Gas will therefore still be an essential energy vector, but this vector must be able to be used by technologies that are more efficient than those of today, i.e., condensing or even non-condensing boilers.

The use of TDHP is intended in particular to supply thermal energy at the same temperatures as those of the boilers for existing buildings, without generating uncomfortable conditions in the heated rooms. Furthermore, the production process of renewable gaseous fuels, such as biomethane and hydrogen, is greatly accelerated by various European countries, in order to start injecting an ever-increasing percentage of renewable gas into the gas networks, which will further reduce the CO_2 produced as well as the consumption of fossil fuels. The maturity of this technology, which has been on the market for about 20 years now, allows us to offer efficient appliances for every type of building and system, from small residential housing units to hospitality buildings, from school and public buildings to large commercial and industrial complexes.

Political support

EHPA and EHI aim at facilitating the roll out of heat pump technologies, either stand alone or in combination with other solutions and energy carriers, since they will be key for the decarbonisation of heating.

European countries have defined concrete targets to reduce carbon emissions in order to protect the climate. TDHP benefit from these requirements, as they use renewable energy, reduce primary energy demand and significantly reduce CO_2 emissions. They are especially suited to the renovation of existing buildings, where they can be employed without an impact on the electricity grid. In several European countries, TDHP technology is being promoted through financial incentives positively supporting consumer decisions towards adopting new technologies in the market. Such countries include – but are not limited to – Belgium, Germany, Italy, and the Netherlands.

Finally, in its REPowerEU Communication the European Commission proposed an ambitious target to wean off Europe of (Russian) gas. It includes a fast forward target of 10 million hydronic heat pumps to be installed by 2026 aiming at doubling the installation rate, and a total of 30 million newly installed hydronic units by 2030/31. The new ambition for the renewable gas together with these targets for the deployment of heat pump technologies will further increase the interest for TDHPs.


Photo: Panasonic

With special thanks to:

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heating & cooling solutions

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caring for the environment

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