Heat Pumps and their Role in Energy Transition

An IENE Study (M85)

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Contents

Definition of Heat Pumps - Introduction

Heat pumps are a modern and efficient technology that helps to reduce both energy consumption and carbon dioxide emissions.

Heat pumps are energy-efficient devices that operate on the principle of thermodynamics and use electricity to transfer heat from a lower temperature space (e.g. the environment) to a higher temperature space (e.g. the interior of a building).

This process made possible through the refrigeration cycle, which includes the following phases:

- evaporation,
- compression,
- liquefaction and
- expansion of the refrigerant.

Heat pumps offer:

- **Heating**: Heat pumps can be used to heat indoor spaces by transferring heat from the outdoor environment to the interior of the building.
- **Cooling**: in reverse mode, they can be used for cooling, transferring heat from the inside of the building to the outside environment.
- **Hot water**: Some heat pumps can also produce hot water for domestic use.

In recent years, heat pump manufacturers have been using R32, as refrigerant, due to its high efficiency, low GWP, reduced fluid quantity and compliance with environmental regulations. R32 is seen as a viable and cost-effective option for modern heat pumps.

However, modern refrigerant fluids have started to be used such as R260 (propane), R744 (CO_2), etc.

The penetration of heat pumps in the European Union is on the rise, with a significant increase in sales. This growth supported by European policies and national incentives, aiming at the Green Energy Transition and the achievement of the EU climate targets by 2050.

The penetration of heat pumps in the US is on the rise, with a significant increase in sales, although the future looks bleak due to the environmental policies of the Trump presidency.

In China, the promotion policy for heat pumps is high, particularly, due to, both their manufacturing in the country and the environmental policies in place in the country.

How Heat Pumps work

Figure 1 describes how the Heat Pump system draws heat from one source (outdoor environment) and transfers it to another source (heating or cooling space).

1. Basic elements of a heat pump

A heat pump consists of the following main elements:

- **Outdoor unit (Evaporator)**: Absorbs heat from the environment (air, ground or water).
- **Indoor unit (Condenser)**: Transfers the heat to the indoor space.
- **Compressor**: Increases the pressure and temperature of the refrigerant.
- **Expansion Valve**: Reduces the pressure and temperature of the refrigerant.
- **Refrigerant**: The fluid that transfers heat.

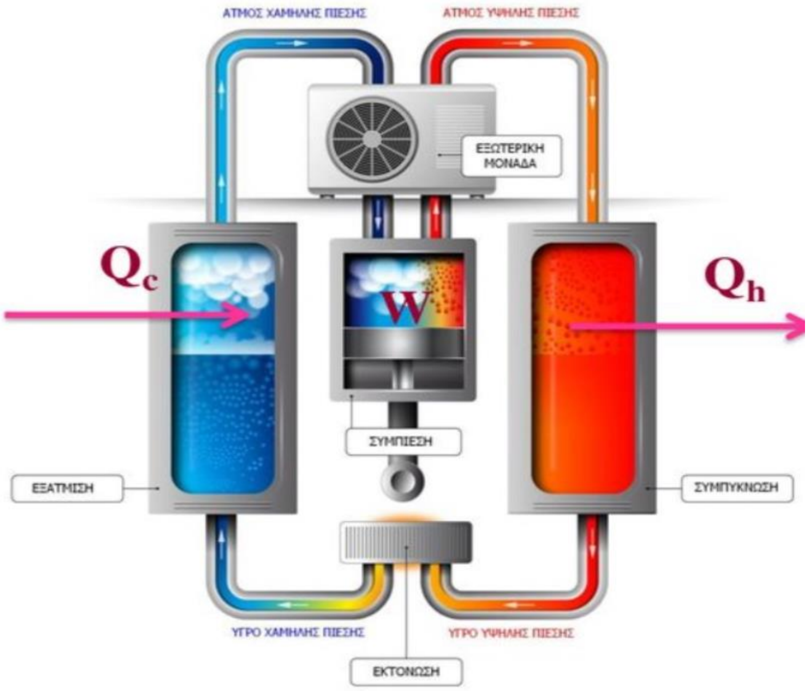


Figure 1: Main components of a heat pump

2. Functional diagram

The operating diagram of a heat pump is based on the Carnot thermodynamic cycle and includes four main phases:

Phase 1: Evaporation

The refrigerant (in liquid state) flows into the evaporator. The evaporator absorbs heat from the external source (e.g. air, ground or water). The refrigerant evaporates and turns into a gas.

Phase 2: Compression

The refrigerant gas flows into the compressor. The compressor increases the pressure and temperature of the gas. The gas becomes superheated.

Phase 3: Condensation

The superheated gas flows into the condenser (indoor unit). The condenser releases heat into the indoor space (for heating) or into the environment (for cooling). The gas cools and turns into a liquid.

Phase 4: Expansion

The liquid refrigerant flows through the expansion valve. The pressure and temperature of the refrigerant are drastically reduced. The refrigerant is returned to the evaporator to repeat the cycle.

3. Heating and cooling operation

In Heating: The heat pump transfers heat from the outside environment (e.g., air or ground) to the interior space.

In Cooling: The heat pump works in reverse, transferring heat from the indoor space to the outdoor environment.

4. Energy flow diagram.

The energy flow diagram of a heat pump is illustrated in Figure 2:

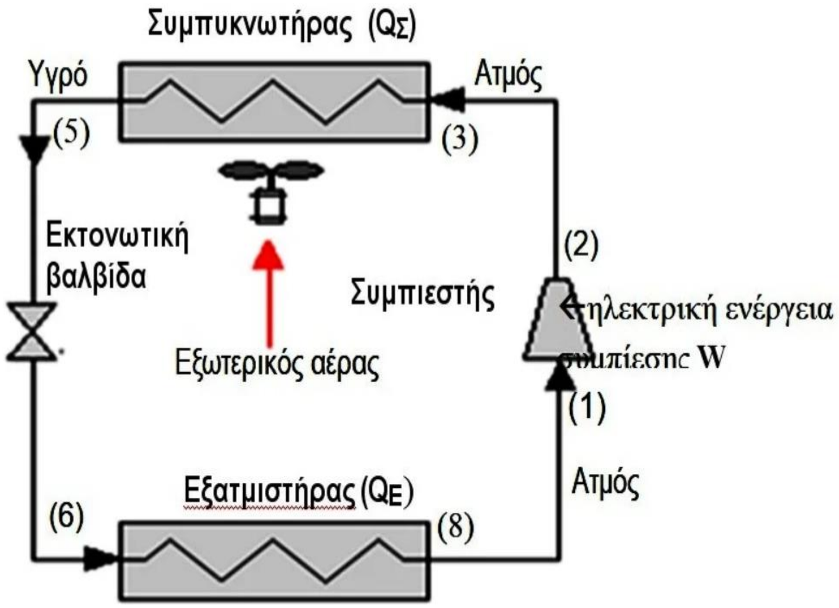


Figure 2: Heat flow diagram

5. Coefficient of Performance (COP)

The Coefficient of Performance (COP) of a heat pump is a dimensionless quantity that expresses the efficiency of the heat pump. It is defined as the ratio of the useful heat energy supplied (or removed) by the heat pump to the electricity consumed to operate it.

- COP is always greater than 1 for Heat Pumps, as they transfer more energy than they consume.
- The COP depends on the temperature conditions of operation (source and receiver temperature).
- For example, if a heat pump provides 4 kWh of thermal energy by consuming 1 kWh of electricity, then the COP is 4.

Mathematical Definition:

$$\mathrm{COP} = \frac{Q}{W}$$

Where:

- Q is the thermal energy transferred (Joule or kWh),
- *W* is the electricity consumed (Joule or kWh).

Application to Heat Pumps:

1. **For heating (COP_{therm})**:

$$\mathrm{COP}_{\theta\varepsilon\rho\mu.} = \frac{Q_{\theta\varepsilon\rho\mu.}}{W}$$

where:

Q_{therm}. is the heat supplied to the heating space.

For cooling ($COP_{cool.}$):

$$\mathrm{COP}_{\psi\upsilon\kappa.} = \frac{Q_{\psi\upsilon\kappa.}}{W}$$

where:

Q_{cool}. is the heat removed from the cooling space.

Types of heat pumps

General

The operating principle of all different types of heat pumps is the same. Depending on the choice of the source "pumping" energy and the energy medium, heat pumps can be divided into the following three main categories:

α. Air-to-Air heat pumps: The thermal energy output medium of this type of pump is usually water circulating in the heating network or in an exchanger in a heat exchanger with an integrated heat pump for Hot Water. They are ideal for residential buildings and operate both at high outdoor temperatures and at temperatures as low as -20°C.

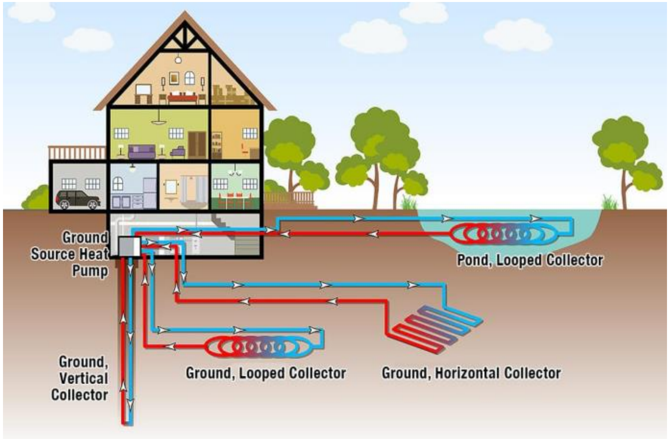
In air-to-water heat pumps there are two main sub-categories:

α1. Heat pumps that contain all their equipment in one device (classified as **monoblock** or **compact**) are built for outdoor installation, drawing energy directly from the environment. There are of course some models which have the possibility to be connected to air ducts, so that they can be installed indoors.

α2. Split unit heat pumps, which consist of two devices, the indoor and the outdoor unit. In this type of heat pump, the cooling assembly that draws energy from the environment is located in the outdoor unit, while the hydraulic assembly, which will be connected to the heating plumbing, is located in the indoor unit.

β. Air-to-air heat pumps that have air as both the source of energy pumping and the means of energy output, air (outdoor air - indoor air, respectively)

c. Water-to-water heat pumps (closed or open circuit geothermal pump): in this category the source of energy extraction comes from the ground with horizontal or vertical exchangers, which transfer the (thermal) energy of the subsoil to the pump. The thermal energy carrier is water, as in air-to-water thermal energy recovery.



Another distinction of heat pumps is:

α. Heat pumps with DC inverter technology, which adapt themselves to the heating or cooling requirements of the room continuously, resulting in particularly low consumption during operation.

β. On/Off heat pumps which deliver the maximum possible performance without adapting to the requirements of the heated space, as in the previous type of heat pump.

Description of heat pumps with wide application in buildings

1. Heat pumps of the monobloc type

Monobloc heat pumps are a type of heat pump that integrates all the basic elements of the system into one unit. This design approach offers several advantages, especially compared to split-unit heat pumps, which consist of two separate units (indoor and outdoor).

Monobloc heat pumps are a simple and efficient solution for heating and cooling, particularly suitable for applications where installation needs to be quick and economical. Despite limitations such as larger dimensions, monobloc heat pumps continue to gain popularity due to their simplicity and reliability.

A description of monobloc type heat pumps is given as:

1. The design features

- All the main components of the heat pump (compressor, evaporator, condenser, expansion valve) are located in a single unit, which is usually installed externally.
- The installation is simple, as no connection is required between the indoor and outdoor unit.
- Monobloc pumps are connected directly to the central heating system (e.g. water as a heat transfer medium).

2. Mode of operation

Monobloc heat pumps operate in the same way as other heat pumps, based on the Carnot thermodynamic cycle, discussed previously.

3. Advantages of monobloc heat pumps

- No indoor unit is required, which simplifies the installation process.
- The connection is made directly to the existing central heating system.
- Installation is faster and less expensive, as it does not require the installation and connection of two separate units.
- Since all the components are located in one unit, there is no need for refrigerant piping between the indoor and outdoor units, which reduces the risk of leaks.
- Heat pumps, of the monobloc type, are ideal for large installations, such as industrial or commercial, as they can be connected to existing heating systems.

4. Disadvantages of monobloc heat pumps

- The unit is larger in size compared to the outdoor units of the two-part pumps, which can cause problems in confined installation spaces.
- The performance of the heat pump can be affected by the quality and condition of the existing heating system (e.g. nozzles, piping).
- Monobloc heat pumps can have reduced performance at very low outdoor temperatures, although newer technologies are improving this issue.

5. Applications

Monobloc heat pumps are used in:

- **Residential**: For heating and hot water, especially in new installations or renovations.
- **Commercial buildings**: For heating and cooling large spaces.
- **Industrial facilities**: For heating and cooling in industrial processes.

2. Geothermal Heat Pump, GHP

Geothermal heat pump, GHP, is one of the most efficient and sustainable solutions for heating, cooling and hot water production, especially in residential buildings.

A description of GHP is given as:

Mode of operation

The geothermal heat pump uses ground heat as an energy source. It is based on the Carnot thermodynamic cycle and consists of (see Figure 3):

1. **Underground system (6)**: tubes placed below ground (horizontally or vertically) containing a cooling fluid that absorbs heat from the ground.
2. **Heat pump (1,2,3,4)**: Transfers heat from the ground to the water in the heating or cooling system.
3. **Distribution system (5)**: Usually underfloor heating or radiators (or FCUs) to distribute heat to the space.

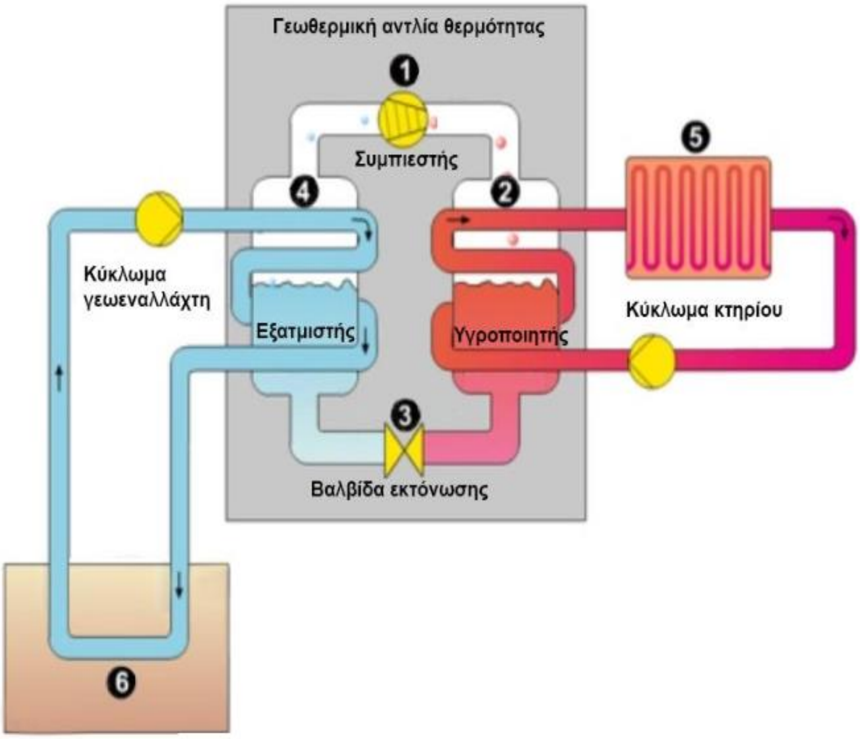


Figure 3: Parts of a GHP

Advantages of CHP

- The coefficient of performance (COP) is usually 3,5-5, i.e. it provides 3,5-5 times more energy than it consumes.
- Ground heat is free and available all year round.
- It does not use fossil fuels, which reduces the environmental impact.
- The soil has a constant temperature, which ensures stable performance even in extreme weather conditions.

Disadvantages

- Installation of the underground system is expensive (15,000-30,000 € depending on complexity).

- The installation of the underground system of the GHE requires a lot of space (horizontal or vertical).

3. Split unit heat pump

The split unit heat pump is a system consisting of two main parts: an outdoor unit and an indoor unit, connected by pipes for the circulation of the refrigerant. This type of heat pump is widely used for heating and cooling of enclosed spaces, such as homes, offices or commercial buildings.

A CHP split unit consists of:

1. The outdoor unit contains the basic components of the system:

- **Compressor:** Increases the pressure and temperature of the refrigerant.
- **Compressor:** Here the refrigerant removes or absorbs heat from the outdoor environment, depending on the function (heating or cooling).
- **Expansion Valve:** Adjusts the flow of the refrigerant and reduces its pressure.
- **Fan:** Helps to exchange heat between the refrigerant and the outside air.

2. Indoor Unit.

The indoor unit is installed inside the room and includes:

- **Heat Exchanger:** The refrigerant exchanges heat with the indoor air.
- **Fan:** Distributes the heated or cooled air in the space.
- **Air Filter:** Clean the air of particles and allergens.
- **Thermostat and Controls:** Allow for easy adjustment of temperature and system operation.

3. Controls: Allows you to control and control the temperature and humidity of the room.

The two units are connected by:

- **3:** Carry the refrigerant between the units.
- **Electrical connections:** To power and control the system.

The heat pump operates on the basis of the thermodynamic refrigeration cycle:

1. **In heating mode (See Figure 4):**
   - The refrigerant absorbs heat from the outside air, even at low temperatures.
   - The compressor increases the pressure and temperature of the refrigerant.
   - The refrigerant transfers the heat to the indoor exchanger, where the room air is heated.

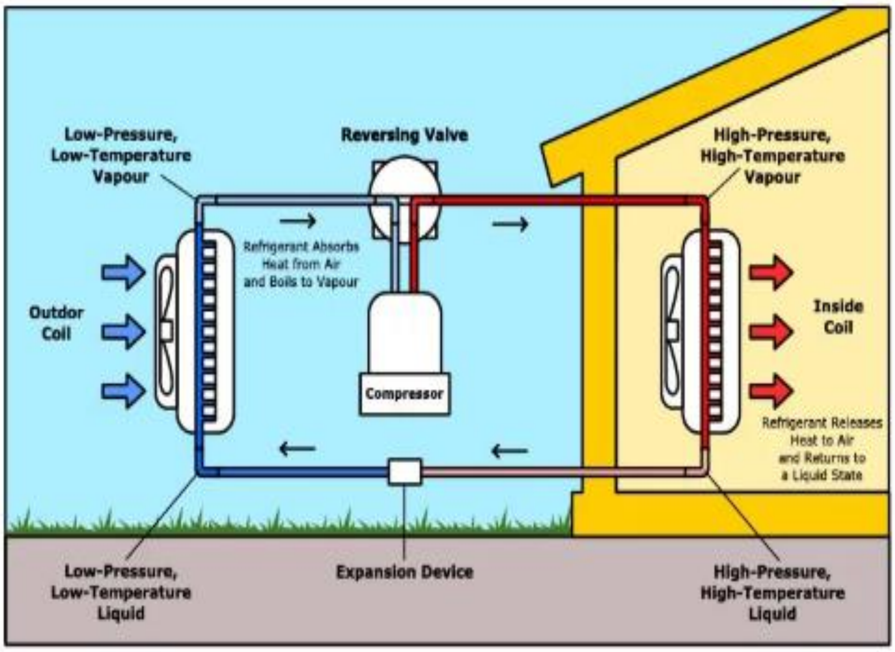


Figure 4: Split unit heat pump in a heating cycle

2. **In cooling mode (see Figure 5):**
    - The refrigerant absorbs heat from the indoor space.
    - The heat is dissipated to the external heat exchanger.
    - Cool air is returned to the indoor space.

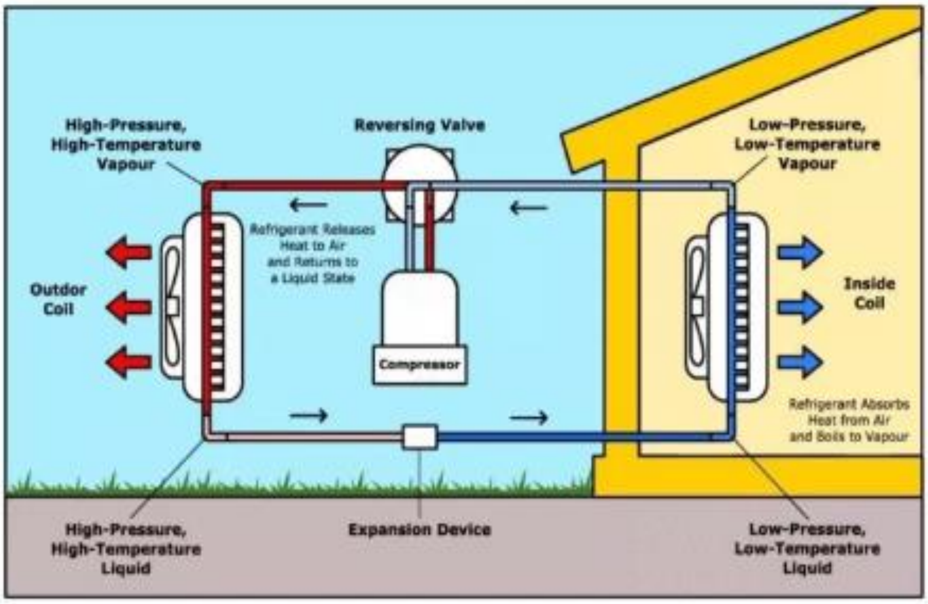


Figure 5: Split unit heat pump in cooling cycle.

The main advantages are:

- Heat pumps have a high COP, which makes them energy efficient.
- They can be used for both heating and cooling.
- Heat pump split units allow easy installation
- The indoor units are almost silent.

Comparison of a conventional heating system with a standard heat pump

A gas boiler burns natural gas to produce heat, which is transferred to the water in the heating system.

Advantages

- Installing a gas boiler has low initial costs
- Easy to install and maintain.

Disadvantages

- Natural gas has a high cost and its prices fluctuate.
- Burning natural gas contributes to climate change.
- It is not a sustainable environmental solution in the long term.

The typical air-to-water heat pump uses outside air as a heat source.

Advantages

- The installation has a moderate initial cost
- COP is typically 2.5-4, depending on weather conditions.

Disadvantages

- Efficiency decreases at very low temperatures (below -10°C).
- Compared to geothermal pump, energy consumption is higher.

Refrigerants used in heat pumps

Refrigerant fluids (refrigerants) are essential components of heat pumps, for transferring heat from one point to another in the thermodynamic cycle. Refrigerant fluids are selected on the basis of their thermodynamic properties, environmental impact and safety. The basic refrigerant fluids used in heat pumps, and their properties are:

1. Fluorochlorocarbons, HFCs are the most common refrigerant fluids in modern heat pumps. They do not contain chlorine, so do not damage the ozone layer, but have a high Global Warming Potential (GWP). Main examples are R-410A, widely used in residential and commercial heat pumps, has a high GWP but is efficient and safe, and R-32, which has a lower GWP than R-410A and is becoming increasingly popular due to its reduced environmental impact.

Increasingly, R32 is being preferred by air conditioning manufacturers as a refrigerant fluid because of its advantages over other refrigerants.

The reasons why R32 is widely used are:

(a) its lower GWP, (675), which is significantly lower than the GWP of R410A (2,088),

(b) high energy efficiency compared to R410A, which leads to reduced energy consumption and lower operating costs

(c) higher boiling temperature, which improves heat pump performance, especially in refrigeration applications,

d) has a higher energy density than R410A, which means that less refrigerant fluid is required for the same performance, leading to smaller system dimensions, reduced material costs, easier installation and maintenance.

R32 is non-toxic and has low flammability (class A2L according to safety standards). Although it is flammable at high concentrations, modern heat pumps are designed with safety measures to minimise the risks. R32 is cheaper to produce and acquire compared to HFOs, making it an economically viable option for manufacturers. Despite its many advantages, R32 has some disadvantages, such as flammability: although low flammability (A2L), it requires care during installation and maintenance, and higher operating pressure: In some conditions, R32 operates at higher pressures than R410A, which may require special equipment design.

2. Hydrofluorocarbons HFOs which are the new generation of refrigerant fluids with very low GWP and reduced environmental impact. They are used as an alternative to HFCs; with main examples being R-1234yf used mainly in automotive industry and having very low GWP and R-1234ze; with low GWP, suitable for commercial and industrial applications.

3. Natural refrigerant fluids that have very low GWP and are considered environmentally friendly. However, some of these may be flammable or toxic, requiring careful handling. Main examples are R-290 (Propane): Very low GWP and high energy efficiency, with use in small domestic CHPs; R-600a (Isobutane), used in refrigerators and small CHPs, with very low GWP; R-717 (Ammonia) for industrial applications due to its high efficiency, but is toxic and requires care; and R-744 (Carbon dioxide, CO_2) with very low GWP and use in commercial and industrial CHPs and requires high operating pressure.

4. Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons HCFCs which have been banned due to their damaging effect on the ozone layer and high GWP. The main example is R-22 (HCFC), widely used in the past but banned in many countries due to its harmful effect on the environment.

Criteria for selecting the appropriate refrigerant fluid include:

- **Global Warming Potential (GWP)**.
- **Performance**: the refrigerant fluid should have good thermodynamic performance.
- **Safety**: fluids with low toxicity and non-flammable are selected.
- **Regulations**: [1]The selection shall comply with international and national regulations (e.g. EU F-Gas Regulation).

Regarding the future of refrigerant fluids in heat pumps, this is directed towards the use of natural fluids and HFOs with very low GWP to reduce their environmental impact. At the same time, regulations, such as the EU F-Gas Regulation, are promoting the gradual replacement of high GWP fluids.

[1] https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/eu-rules/f-gas-legislation_en

Advantages - Disadvantages of using Heat Pumps

Heat pumps (HP) are one of the most energy efficient and sustainable technologies for heating and cooling. However, like all technologies, they have disadvantages.

At the same time, their prospects up to 2030 are very positive, as the market is expected to continue to grow. The following is an analysis of the disadvantages and prospects:

Advantages of heat pumps:

High efficiency: Heat pumps are much more efficient than traditional heating methods as they transfer heat instead of generating it.

Environmentally friendly: Since the energy they use comes from renewable sources, heat pumps have a lower environmental impact.

Multi-functionality: They can be used for both heating and cooling, offering a complete solution for air conditioning a space.

Disadvantages of heat pumps.

Initial installation costs: the initial cost of purchasing and installing a heat pump is higher compared to traditional heating systems (e.g. NG boilers).

However, this cost is recouped over time through reduced energy consumption.

Dependence on the outdoor temperature: The performance of heat pumps decreases at very low outdoor temperatures (typically below -10°C to -15°C). In such conditions, backup heating (e.g. electric or gas) may be required.

Space requirements: Air-to-air or air-to-water heat pumps require an outdoor unit, which may be aesthetically unpleasant or require installation space.

Geothermal heat pumps require extensive installations (e.g. underground pipes), which increases cost and complexity.

Flammable refrigerant fluids: Some refrigerant fluids (e.g. R32) are flammable (A2L class), which requires caution during installation and maintenance.

A232: Heat pumps are powered by electricity. In areas where the electricity grid is based on fossil fuels, their environmental impact is less positive than that of a grid powered by renewable energy.

Maintenance complexity: Heat pumps require proper maintenance to maintain their performance, which can increase operating costs.

Heat pumps reduce CO_2 emissions - NREL study.

A recent study (April 2024), published in the journal Joule[2], by the US NREL (National Renewable Energy Laboratory) modelled the entire housing stock of the 48 US states and found that switching from a conventional heating system to a heat pump reduces CO_2 emissions in each of the 48 states.

The NREL study uses six different scenarios for the future of the electric grid, from high carbonization (95% carbon-free EE by 2035) to low (only 50% carbon-free electricity by 2035, in the event that renewables end up costing more than their current prices predict). They found that depending on the scenario and efficiency level, heat pumps reduce annual household CO_2 emissions by 36% to 64% - or 2.5 to 4.4 Mt CO_2 equivalent per year per housing unit. Preventing 2.5 Mt of CO_2 emissions is equivalent to burning 1.27 tn of coal, while at the high end of the study, 4.4 Mt of CO_2 is almost equivalent to the emissions of a flight path from New York to Tokyo (~4.6 Mt). According to the study, CO_2 emission reductions tend to be higher in regions with colder winters when primarily oil-fired boilers are replaced by CHP, as observed in the case of Maine, in the NE US.

But heat pumps can produce emissions in the same way that typical air conditioning systems do: by leaking refrigerant fluid into the environment. Although in the process of being phased out, the typical R-410A refrigerant in HVAC systems is 2,088 times more potent a greenhouse gas than CO_2, so even small leaks have a disproportionately large impact.

The additional emissions from refrigerant leaks from heat pump refrigerant make little difference, given the high emissions that heat pumps avoid, according to the NREL study. Typical R-410A leakage rates increase emissions by an average of only 0.07 Mt CO_2 equivalent per year, reducing the total savings of 2.5 Mt by just 3%. NREL's study focused on air-to-air heat pumps, which, in cold temperatures, draw heat from the outside air and can be 3 to 4 times more efficient than fossil fuel boilers, while geothermal heat pumps can be more than 5 times more efficient. The bottom line is that if every American household that uses LP, oil or inefficient electric heating immediately switched to a heat pump for heating, U.S. CO_2 emissions would be reduced by 5% to 9%

[2] https://www.cell.com/joule/fulltext/S2542-4351(24)00049-7?_returnURL=https%3A%2F%2Flinkinghub.elsevier.com%2Fretrieve%2Fpii%2FS2542435124000497%3Fshowall%3Dtrue

Example of a GHG application in office building

An example application for the calculation of Heat Pump power in a 420 m2 office space built in 2000, with a northeast (NE) orientation in Athens, requires taking into account the following factors

1. Climatic data of Athens:
   - Winters are mild, with minimum temperatures rarely falling below 0°C.
   - Summers are hot, with temperatures that can reach 40°C.
2. Type of area: Office space has specific heating/cooling needs due to the presence of people, electrical appliances and lighting that generate heat.
3. Orientation: a north-eastern orientation means less sunlight and heat in winter, but can reduce the need for cooling in summer.
4. Thermal insulation: The quality of the building's insulation determines heat loss.
5. Number of people: assuming that the office space is used by around 50-70 people, this will affect the cooling needs due to the heat they generate.

Estimation of heat/cooling load:

Heating

For office space in Athens, the required heating capacity is usually between 40-50 W/m^2, due to the mild winters.

So, 420 m^2 × 45 W/m^2 = 18,900 W (18,9 kW).

Cooling

For cooling, we have to consider the heat generated by people and appliances. In office spaces, the heat generated by people and equipment can be significant.

- Heat from people: 60 people × 100 W/person = 6 000 W (6 kW).
- Heat from equipment and lighting: Approximately 10-15 W/m^2, i.e. 420 m^2 × 12 W/m^2 = 5 040 W (5,04 kW).
- Heat load from space cooling: 420 m^2 × 40 W/ m^2 = 16 800 W (16,8 kW).

Total cooling thermal load:

6 kW (people) + 5,04 kW (equipment) + 16,8 kW (space) = 27,84 kW.

Recommended heat pump capacity: heating capacity: 19 kW &
cooling capacity: 28 kW.

Policies for the penetration of HP: World market

1. Policy for the penetration of HP in the EU

The penetration of heat pumps in the European Union (EU) has increased significantly in recent years, mainly due to the shift towards energy efficient and sustainable heating and cooling solutions.

1. Main penetration figures

Sales growth: According to the EHPA the sales of HP in EU were increased by +34% in 2021 compared to 2020, comprising to 2,2 million units.

Total installed base: By 2021, the total installed base of heat pumps in the EU is estimated at 16.7 million units.

Countries with high penetration: The countries with the highest penetration of heat pumps are:

- **Norway**: Around 60% of new buildings use heat pumps.
- **Sweden**: About 50% of buildings have heat pumps installed.
- **Finland**: Around 40% of households use heat pumps.
- **Germany and France**: The two largest markets in the EU, with significant growth in sales.

Figure 1 shows annual sales of all types of CHP in 13 European countries, according to an EHPA study[3]

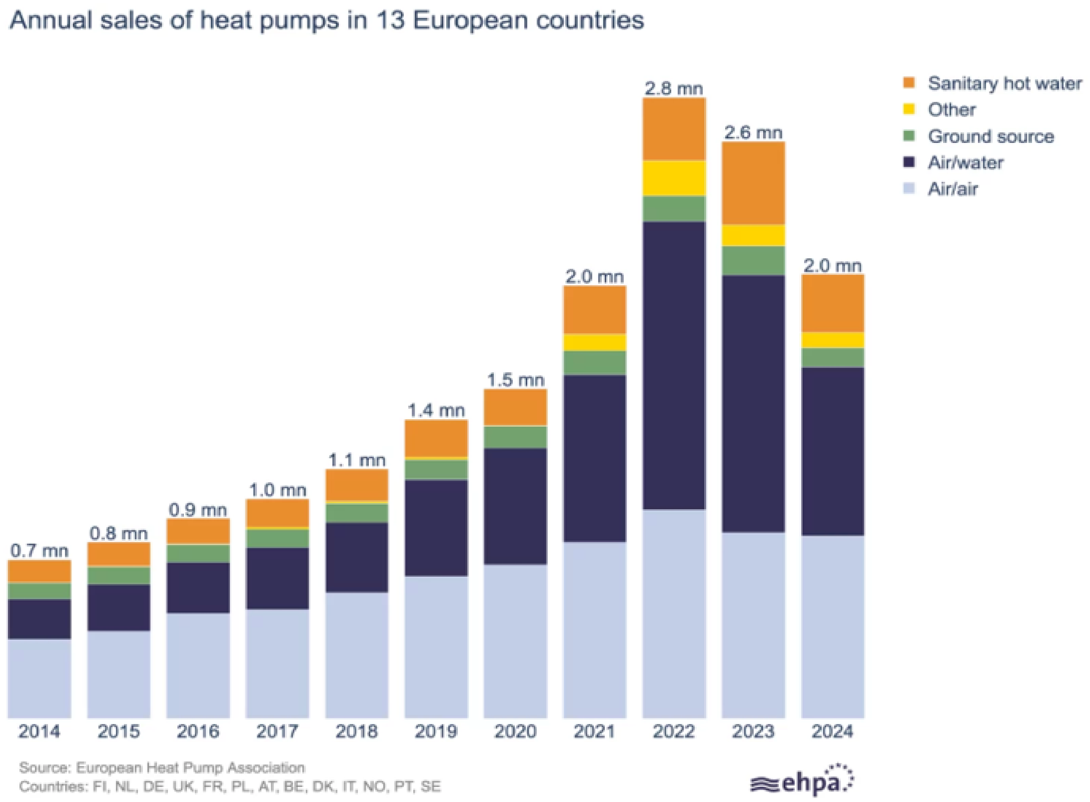


Figure 1: Annual sales of CHP from 2014 to 2024

[3] https://www.ehpa.org/

According to a study by the European Heat Pump Association-EHPA.[4] heat pump sales fell by 23% in 2024, as first data from 13 countries show, with 2 million heat pumps sold in 2024 in these countries, compared to 2.6 million in 2023. In 2023, sales in 21 European countries fell to 3.02 million, a decline of around 6.5% compared to 2022, reversing a decade-long trend. This consolidates the slowdown seen in annual sales (see Figure 1).

In total, there are around 24 million heat pumps installed in buildings in Europe (2024).

2. Incentives and policies

The development of the heat pump market is supported by European and national policies, such as:

- [5]**European Green Deal (European Green Deal):** Target for climate neutrality by 2050.
- **Energy Performance of Buildings Directive (EPBD**): Promotion of renewable energy sources for heating and cooling in buildings.
- **National incentives**: Many countries offer subsidies, tax breaks and other incentives for the installation of heat pumps.

3. Environmental impacts of the use of CHP in the EU

Heat pumps sold in the last twenty years have contributed to GHG emission savings of 41.07 Mt (see Figure 2). The breakdown of emission savings by country is similar to that of RES production, as both calculations are directly linked to the number of units installed and the relative reduction in demand for fossil energy.

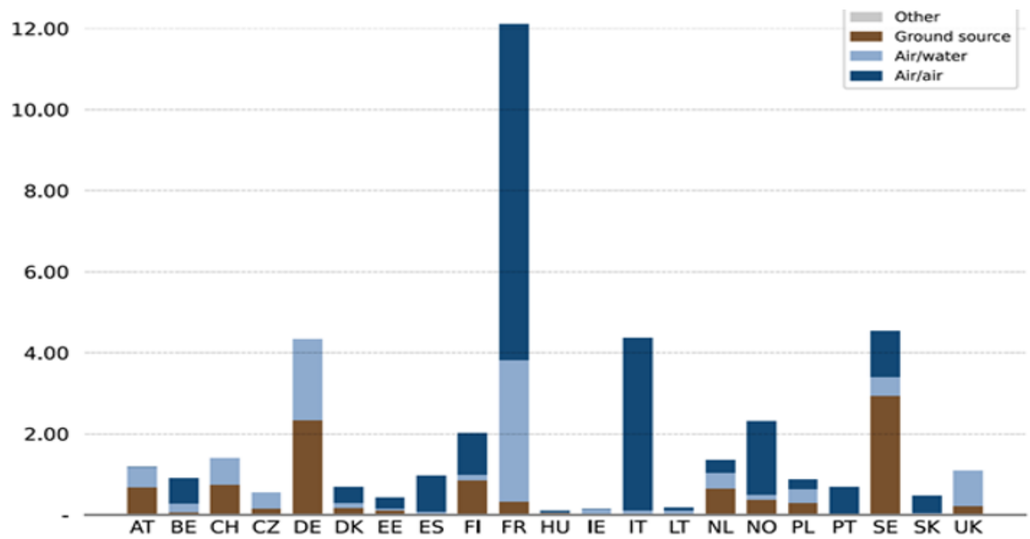


Figure 2: GHG emission savings based on 2020 sales, by country (in Mt)

4. Future projections

According to EHPA, the heat pump market in the EU is expected to grow at a rate of 15% per year until 2030. [6]The International Energy Agency (IEA-IEA) predicts that heat pumps will meet 50% of EU heating demand by 2050.

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[4] https://www.ehpa.org/market-data/

[5] *Fit for 55 package under the European Green Deal, consulted 25 October 2021,* ***https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/package-fit-for-55***

[6] https://www.iea.org/energy-system/buildings/heat-pumps

2. Policies for the penetration of HPs in US

The penetration of heat pumps in the US has increased significantly in recent years, mainly due to the shift towards energy efficient and sustainable heating and cooling solutions. According to the International Energy Agency (IEA), heat pump sales in the US increased by 15% in 2021 compared to 2020. By 2021, the total installed base of heat pumps in the US is estimated at 20 million units.

The states with the highest heat pump penetration are:

- California: High demand due to climate goals and incentives set by the state.
- Northeastern states (e.g. New York, Massachusetts): due to cold winters and energy efficiency incentives enacted by their states.

Policies to promote GHGs in the period 2017-2024

1. The 1th Trump Presidency

President Trump's climate policy during his presidency (2017-2021) was characterized by support for traditional energy sources, such as coal, NG, etc., and removed the US from international climate agreements such as the Paris Agreement. This policy has had a significant impact on the development of heat pumps and other renewable technologies in the US. Trump's energy and environmental policies affected the penetration of heat pumps and the main impacts of his energy and environmental policies were:

Reduction in support for renewables

The Trump administration withdrew the US from the Paris Agreement in 2017, signalling a reduction in commitment to fight climate change. This policy focused on boosting fossil fuel production, reducing the promotion of renewables.

Reducing federal incentives

The Trump administration reduced or eliminated many federal programs and incentives for energy efficiency in buildings and renewables that could support the adoption of heat pumps. At the same time, the Trump administration sought to repeal building energy efficiency regulations that encouraged the use of heat pumps.

Impact on the market

The lack of federal support and emphasis on fossil fuels reduced the growth of the heat pump market in the US during Trump's 1st term. However, many states (e.g. California, New York) continued to promote renewable energy and heat pumps through their own programs and incentives

Making it economically advantageous to use CHP

Heat pumps are energy efficient and can reduce heating and cooling costs for consumers. This cost advantage has continued to drive the market, even without federal support.

2. Biden Presidency (2021-2024)

With Biden's presidency in 2021, the U.S. returned to the Paris Agreement and implemented new incentives to encourage renewable energy, including heat pumps. The Inflation Reduction Act (IRA), passed in 2022, included significant incentives for the installation of heat pumps, which further boosted their market.

The Inflation Reduction Act of 2022 (IRA) is one of the most significant laws recently passed in the US, aiming to address economic, environmental and social issues. The main objective of IRA is to reduce the national debt, promoting renewable energy and energy efficiency, therefore, HPs.

Regarding Climate Crisis and Energy, the IRA proposes:

- **Strengthening renewable energy**: the law provides tax incentives for clean energy production, such as solar, wind and geothermal energy.
- **Reducing greenhouse gas emissions**: The goal is to reduce emissions by 40% by 2030.
- **Promote electromobility**: Electric vehicles are promoted through tax incentives for the purchase of electric cars.
- **Supporting energy efficiency**: Programmes to improve energy efficiency in buildings and industry.

The IRA believes that investments in clean energy and environmental programs will create hundreds of thousands of new jobs in the US by 2030.

3. The 2nd Trump Presidency (2025-2028)

Donald Trump returned to the US presidency for the 2025-2028 term, and is likely to resume policies that favour fossil fuels and reduce support for renewables, including heat pumps. However, the impact of his policies will depend on many factors, including state resistance, market trends and international pressure. The potential impact of Trump's policy is estimated as:

Decreasing federal support

The Trump administration may reduce or, again, eliminate federal incentives for heat pump installation, such as subsidies and tax credits.

Eliminate regulations

The Trump administration may repeal or weaken building energy efficiency regulations that encouraged the use of technologies such as heat pumps, something it did not achieve in his 1st Presidency.

Withdrawal from international agreements

It is likely that the Trump administration will again withdraw the US from the Paris Agreement or other international climate initiatives, reducing the pressure to adopt new technologies that promote energy conservation and Renewables.

Factors that may limit the impacts of these policies include:

- State resistance, since many states have their own policies to encourage RE and will continue to support RE regardless of federal policy.
- The market for heat pumps has grown significantly in recent years due to increasing demand for energy efficient solutions and falling costs of the technologies. These trends may continue even without federal support.
- The international community continues to promote the adoption of renewable energy sources. The European Union, China and other countries may put pressure on the U.S. to continue the Energy Transition policy.

- Many companies in the US have invested in renewable technologies, including heat pumps. These companies may lobby to maintain incentives and support.

3. Policy on the penetration of CCS in China

Key penetration figures

China is the largest heat pump market in the world. According to the IEA, heat pump sales in China grew by 13% in 2021.

By 2021, the total installed base of heat pumps in China is estimated at 100 million units.

The regions with the highest heat pump penetration are:

- **North China**: Due to cold winters and policies to reduce carbon pollution.
- **South China**: Increasing demand for cooling due to hot and humid summers.

Incentives and policies

China has targets to reduce carbon emissions and increase the use of renewable energy based on its "Green Transition" policy.

China has implemented policies to encourage the use of heat pumps, such as subsidies and tax incentives.

Future projections

The heat pump market in China is expected to continue to grow at a rate of 12% per annum until 2030.

Policies for DH penetration in Greece: The role of the "Exoikonomo" Programme

General

Greece has recognised the importance of heat pumps as a high energy efficiency technology for heating and cooling and DHW, contributing to the reduction of greenhouse gas emissions and the Energy Transition. Greece is aligned with European Directives such as the Energy Efficiency Directive-EED or the Energy Performance of Buildings Directive-EPBD, which promote the installation of high efficiency systems such as heat pumps. A key example is newly constructed buildings that are required to meet strict energy efficiency criteria (A+), and heat pumps are the preferred solution to achieve this. An important tool for the promotion of DH is the National Energy and Climate Plan (NECP) and its revisions, which includes targets for reducing energy consumption and increasing the use of RES, where heat pumps play an important role.

Through the NSRF and the " Exoikonomo " programme, citizens and businesses can receive financial support for the installation of heat pumps, which is presented below. There are also tax credits for investments in smart energy technologies, including heat pumps. Banks and financial institutions offer favorable lending terms for energy upgrades, including heat pumps. The Ministry of Energy and Climate Change organises awareness campaigns on the benefits of heat pumps, both at domestic and commercial level. There are platforms that provide information on available subsidy schemes and technical specifications of systems.

The " Exoikonomo " programme

The **"** Exoikonomo **"** programme is part of the broader objectives of the European Union and the Greek state for energy transition and green growth and is an initiative that aims to reduce energy consumption in households and businesses by upgrading the energy efficiency of buildings. The Exoikonomo programme was launched in 2019 as part of the national strategy for energy transition and the promotion of energy efficiency.[7]

Today, the **" Exoikonomo 2025**" Programme is part of the projects supported by the Recovery and Resilience Fund and aims to promote the national and EU energy policy for energy saving by improving the energy class of households, achieving primary energy savings of more than 30% for each dwelling through energy upgrading by at least 3 energy categories. The total investment financed by the resources of the Recovery and Resilience Fund will contribute to energy savings and energy renovation of at least 11,500 homes by 2025. The investment includes separate incentives to support families with a disabled family member/member, Thessalian victims, earthquake-affected people of Arkalochori and Samos, families with three dependent children and vulnerable households.

The total budget of the programme amounts to €1.5 billion, with funding from national and European funds.

The programme is divided into two phases:

- **" Exoikonomo 1"**: a budget of € 700 million.
- **" Exoikonomo 2"**: Budget €800 million.

In the first phase of the "Eco-Economy 1" programme, more than 150,000 applications were received, while the second phase - "Eco-Economy 2" - has also received a large number of applications, with estimates of more than 200,000 applications.

The objectives and actions of the "Eco-Economy" programme are:

- Upgrading insulation, replacing windows, installing solar panels, renewing heating/cooling systems, installing air conditioning.
- Reduction of the energy footprint of households and businesses. Exoikonomo
- Reducing CO_2 emissions and promoting green growth.

The programme provides subsidies ranging from 40% to 85% of the total cost, depending on the income of the household or business. The subsidies cover projects:

- In the building envelope (e.g. building insulation, new energy glazing, roof insulation, etc.)
- Installation of renewable energy systems (e.g. solar water heaters, PV, GHP, heat pumps).

Applications are submitted online via the platform.

Regarding heat pumps, they are one of the technologies encouraged through the programme as they offer high energy efficiency and reduced CO_2 emissions. The programme covers:

- Air-to-water heat pumps: Air-to-air heat pumps - air-to-air heat pumps - for heating, cooling and DHW production
- CHP: For heating and cooling using ground heat.
- Hybrid systems: Combining CHP with other technologies (e.g. solar panels).

[7] https://exoikonomo2025.gov.gr/

The advantages of the 'Save' programme for heat pumps are:

- The program offers subsidies of up to 40-50% of the total cost, depending on the technology and the building category. For energy-poor families, subsidies can reach up to 85%.
- The program offers loans at interest rates of up to 1% to cover the remaining costs. Repayment is made in long-term instalments, which facilitates financial management.
- Installing a heat pump reduces heating and cooling costs by up to 50-70%, depending on the technology and usage conditions.
- Energy upgrading increases the energy efficiency of the building, which also increases the value of the property.

Comparison of costs with and without the "Energy Efficiency" programme

Parameter	Without Programme	With "Exoikonomo" Programme
Installation costs	10.000 €	5.000 € (50% subsidy)
Loan	-	5.000 € (1% interest rate)
Monthly loan instalment	-	~50 € (10 years)
Annual operating costs	1.200 €	600 € (50% reduction)

Conclusions

Over the last decade, the global and European heat pump market has a 10% annual growth rate from 2011 to 2020, resulting in an expected installation of 1 million heat pumps per year in 2021. For the next decade, up to 2030, studies of HP manufacturers[8] estimate an acceleration of annual CHP installation reaching 4 million, representing an annual growth rate of 20%. This means that 1 in 3 heating systems installed will be HP, compared to 1 in 10 in 2020. The key driver for this growth is the introduction of strengthened legislation, governing new construction in many European countries, setting minimum standards for thermal insulation of homes, mandatory use of renewable energy sources, up to a ban on fossil fuel fired boilers, and the use of DH.

In parallel, a series of initiatives to promote HP in the heating and cooling market, based on the firm commitment of the European Green Deal to reduce CO_2 emissions to make the EU the first climate neutral continent by 2050, meaning decarbonising the heating and cooling sector, which contributes 40% of CO_2 emissions[9], will be key to achieving this target. However, the current rate of growth of HP markets across Europe is insufficient to decarbonise heating and cooling by 2050. Bold decisions are needed to address the problem of distorted price policies that favour the use of fossil fuels and fossil fuel technology. The latest figures show that 6.5% of global GDP or US$ 5.4 trillion is spent on fossil fuel subsidies. This is a huge challenge for the carbonisation of the heating and cooling industry, where the benefits of heat pumps have a central role in a sustainable European energy system.

[8] https://www.daikin.eu/en_us/product-group/air-to-water-heat-pump-high-temperature/daikin-altherma-3h-ht.html

[9] State of the Union, Renewable heating and cooling systems, 25/10/21, https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_1598

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