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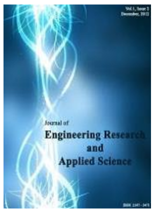

# Air Source Heat Pumps for Low-Carbon Energy Transition and Sustainable Building Air-Conditioning

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**Abstract**
Air-source heat pumps (AHPs) have recently been touted as a significant energy-saving technology and a potential path to decarbonizing space heating. However, recent studies suggest that in cold climates like Minnesota, all-electric AHP systems achieve these energy savings at higher initial and operating costs than natural gas-heated homes. This study examines dual-fuel (or hybrid) applications that combine AHPs and natural gas heating to reduce the high operating costs of all-electric AHP systems. Dual-fuel AHP products can replace central air conditioning and be integrated with existing natural gas heating systems. This configuration allows for the use of gas heat or AHPs for space heating, depending on economics and customer priorities. This product category can serve as an entry-level application for PACAs, familiarizing consumers and installers with PACA technology and enabling them to realize most of the savings of PACA systems while minimizing the barriers to all-electric PACA installations.

**Keywords:** *Air source heat pumps (PACA); low-carbon energy transition; air conditioning systems*

## 1. Introduction

Europe aims to become the first climate-neutral continent by 2050 and therefore targets an emissions reduction of at least 55% by 2030. As part of the EU Green Deal, the current practice of the carbon border tax has entered its final phase. Renewable heat pumps, a potential tool to achieve this goal, are a low-carbon heating technology and are compatible with the EU Green Deal. Regarding technological developments, this article first provides information on the R32 refrigerant with its low global warming potential and high energy efficiency, and describes R32-based heat pumps and the latest technological advances in these devices. Regarding application, research results are presented comparing the energy efficiency and CO2 emissions of an air-to-water heat pump using R32 as a refrigerant for heating with those of an air-to-water heat pump using R410A. Finally, suggestions are made for promoting the uptake of heat pump technology in Turkey [1-7].

In 2021, heat pumps met approximately 10% of global space heating demand, but the pace of installation is accelerating. In 2022, global heat pump sales increased by 11% year-on-year. In 2021, the increase was 13% compared to 2020, but 3 million units were sold in 2022 to contribute to European climate targets. In developed countries, commercial and residential buildings account for approximately 40% of national energy consumption and 25% of greenhouse gas emissions. This is the sector where savings must be prioritized. The thermal performance of buildings is therefore continuously improving thanks to thermal regulations. In addition, comfort requirements require ever more energy. As the demand for domestic hot water (DHW) continues to rise, cooling demands are also emerging or increasing to offset the internal heat gains caused by the proliferation of household appliances. A better-insulated thermal envelope also means that new buildings require less energy for heating and more for cooling. As a result, the heat demand of new buildings is more balanced between heating and cooling throughout the year [2, 3].

In winter, energy is used exclusively for heating and hot water production. Between winter and summer, some buildings may need to air condition south-facing rooms and simultaneously heat north-facing rooms. In summer, energy is needed for hot water production and simultaneous space cooling. One solution to this dual energy demand is the heat pump, which supplies heating power to the condenser and cooling power to

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the evaporator. This study presents a heat pump model capable of compensating for fluctuations in heating and cooling demand (simultaneous or not). This HPS (heat pump for simultaneous heating and cooling) heat pump can be installed in hotels with high hot water demand and in buildings with glass facades where simultaneous heating and cooling are often required.

## 2. What is a heat pump?

According to the laws of thermodynamics, heat transfer occurs spontaneously from bodies of higher temperature to bodies of lower temperature, but never spontaneously in the opposite direction. This is only possible in refrigeration systems that operate according to the cyclic process principle (e.g., a refrigerator). The most common refrigeration cycle is the vapor-compression cycle, which consists of four elements: the compressor, which uses a refrigerant as the working fluid, the condenser, the expansion valve/throttle valve, and the evaporator [1-7].

Although heat pumps and chillers operate on the same cycle, their functions differ. While a refrigerator extracts heat from a cold environment, a heat pump transfers it to a warm environment, thereby warming it. Heat from a low-temperature source is transferred from the outside to a warmer environment. The heat source can be air, water, or ground, while the warmer environment can be a house or other facility [1].

Based on the physical properties of energy transfer, a heat pump uses renewable energy and electricity to generate useful energy through a refrigeration cycle. The main components of a refrigeration system include the refrigerant and its piping, as well as the compressor, expansion valve, evaporator, and condenser. As shown in Figure 1, the refrigeration cycle generally consists of four stages [1].

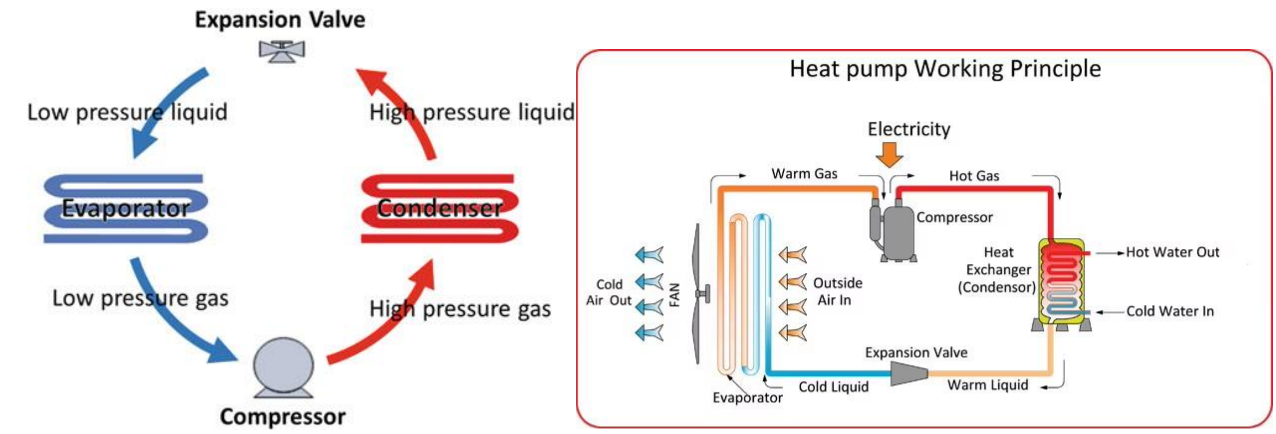

Figure 1. Four-stage refrigeration cycle (left) and operating principle of the heat pump (right).

The refrigeration cycle consists of four phases [1]:

- In the first stage, the refrigerant enters the compressor in gaseous form and is superheated after leaving the compressor.
- In the second stage, the superheated gas passes through the condenser to remove heat. The condenser removes the heat and condenses the gas into a liquid.
- In the next step, the liquid refrigerant passes through the expansion valve, creating a liquid-gas mixture with lower pressure and lower temperature.
- The cold liquid-gas mixture then passes through the evaporator to completely evaporate in the final step before returning to the compressor and the cycle begins again.

Heat pumps use different refrigerants. There is no universal rule for selecting the refrigerant. The criteria are based on aspects such as chemical stability, thermophysical properties, safety, and environmental factors:

- *Chemical stability:* The coolant must function stably in the cooling system.
- *Thermodynamic properties:* The freezing temperature must be significantly below normal operating conditions. The critical point and boiling point must be appropriate for the application. To keep operating costs low, appropriate operating pressures must be defined.
- *Safety factor:* The use of flammable and toxic refrigerants must be limited.
- *Environmental factor:* The coolant must decompose quickly and without releasing harmful substances into the atmosphere, and direct emissions (e.g. leaks) must be minimized.

A heat pump is generally defined as a machine that transfers heat from the natural environment to buildings. In a refrigeration system, the circulating refrigerant facilitates heat transfer from one area to another. The refrigeration cycle is based on the first and second laws of thermodynamics [6]. These two principles help explain how a heat pump works. According to ASHARE [7], the first law of thermodynamics is called the law of conservation of energy. For any system, whether open or closed, the energy balance is calculated as follows:

[Input energy] – [Output energy] = [Net increase in energy stored in the system]

The first law states that energy can neither be created nor destroyed, but it can change its form and location. When a heat pump operates, the cooling system absorbs heat from renewable energy sources to produce usable heat at a higher temperature for space heating and hot water. The cycle can produce cooler air or chilled water for space cooling and release the heat to the outside.

**3. Types of heat pumps**

With regard to the heat source, heat pumps can be divided into three types: air heat pump, water heat pump and ground source heat pump [1, 4].

**Air-source heat pumps:** Air is a free and easily accessible natural heat source. These pumps heat rooms via underfloor heating, fan coil units, or radiators. They are also easy to install and maintain. Air-source heat pumps are ideal for air conditioning and are widely used worldwide. Figure 2 shows an air-source heat pump for heating and cooling residential buildings.

Figure 2. Air source heat pump [4].

**Water-source heat pumps:** These heat pumps draw water from a well, lake, river, or municipal water supply and use it as a heat source. If rivers, lakes, oceans, or groundwater are located near the area to be heated or cooled, heat transfer pipes are installed there.

**Geothermal heat pumps:** Heat is exchanged with the ground via horizontally or vertically buried geothermal heat exchangers. The heat transfer medium, usually glycolated water, is transported through underground pipes.

**4. The advantages of heat pumps**

One of the main advantages of heat pumps is their energy efficiency [1]. Thanks to technological advances, an air-source heat pump generates five units of heating energy while consuming only one unit of electricity (e.g., COP = 5). Heat pumps are also cost-effective. Thanks to their low operating costs, maintenance, repair, and servicing costs are lower than with other systems. They are a cost-effective investment that pays for itself quickly. Heat pumps are also safe and pose no risk of explosion, fire, or poisoning, as no combustion processes take place [4].

Heat pumps are evolving technologically. For example, compressors and refrigerants are evolving daily. In combination with solar collectors, they can be used for both hot water and space heating. Heat pumps do not require fossil fuels and are therefore an important tool for reducing greenhouse gas emissions. Their use does not produce any waste such as gases, smoke, slag, or odors. $CO_2$ is only emitted in the power plant where the electricity is generated. They do not pollute the building environment. Furthermore, they can be designed for different uses and, thanks to compact outdoor units, can be integrated into the building envelope [4].

## 5. The latest developments in heat pump technology

Given recent developments and trends in the heat pump sector, we are observing a rise in hybrid heating systems, especially hybrid heat pumps. These systems combine the heat pump's indoor unit with a condensing combi boiler. The device's algorithm considers the outdoor temperature, current fuel prices, and other parameters. It then selects the most efficient and cost-effective option. If necessary, the user can then switch between the heat pump and the combi boiler to achieve the best efficiencies. By choosing this type of appliance, dependence on natural gas can be reduced instead of replacing the heating appliance [4]. Another important development concerns refrigerants. The refrigerant R32 is now used in many types of appliances, including split air conditioners and chillers [1].

The main characteristic of R32 refrigerant is its zero ozone depletion coefficient (ODP = 0). Its global warming potential (GWP) is only one-third that of R410A, the preferred refrigerant in current heat pumps and air conditioners. R32 also requires less volume than R410A. For example, using R32 instead of R410A in a 4 kW heat pump reduces the refrigerant charge by 30% and the efficiency by 6%. As this example shows, R32 enables more compact designs while increasing energy efficiency [4].

R32 was first used in air-to-water heat pumps in 2017/18. Thanks to R32, a hot water outlet temperature of 65°C and an energy efficiency rating of A+++ (operation down to -25°C) were achieved . Thanks to state-of-the-art technology, R32 consumes 30% less refrigerant than R410A in single-compressor systems, delivering hot water at 70°C with high performance and an energy efficiency rating of A+++ (COP over 5). The operating temperature range has been reduced to -28°C (outside temperature) [4]. These units, which deliver rapid payback while generating savings, can be easily monitored and controlled via mobile devices thanks to the online control function [4].

## 6. The contribution of the heat pump to air conditioning systems

In international markets, the cost of fossil fuels is rising daily due to wars, global issues, and political reasons. Issues such as the goal of phasing out fossil fuel use in the EU by 2050, the European Green Deal, and the limitation of $CO_2$ emissions have led to a rapid increase in electric air conditioning systems. With the emergence of concepts such as nearly zero-energy buildings and zero-energy houses, heat pump systems that integrate solar thermal and photovoltaic energy are becoming increasingly popular [1, 4, 7].

Today, a technological infrastructure is available that meets the heating, cooling, and hot water needs of a heat pump-powered building air conditioning system. Although these applications are primarily found in the European Union, they have only recently been introduced in our country. In urban planning, buildings can be designed according to an integrated concept that combines architecture, engineering, and urban planning. Systems that generate electricity while simultaneously providing air conditioning via a solar thermal heat pump can therefore shape the future of air conditioning in the short and medium term [1, 4, 7 ].

## 7. Conclusion

A heat pump is a highly efficient, economical, and environmentally friendly solution for heating and cooling your home year-round for optimal comfort. Thanks to their high efficiency, heat pumps are cost-effective to operate thanks to their electric operation. Their heating costs are lower than those of oil, propane, or electric heaters, sometimes significantly lower. Their costs are roughly the same as those of a gas heater; depending on the electricity and gas prices in your area, they may be slightly higher or lower. High-efficiency heat pumps also help reduce cooling costs: their efficiency is typically more than twice that of window air conditioners and significantly higher than that of conventional central air conditioners.

A heat pump stores heat energy. Believe it or not, anything warmer than space contains heat energy, and heat pumps can transfer this heat inside or outside your home. Even in sub-zero temperatures, the air stays warm. A heat pump efficiently extracts heat from the cold outside air, concentrates it, and transfers it into your home to maintain a comfortable indoor climate all winter long . According to the laws of physics, it takes far less energy to transport heat than to generate it. Some people believe that heat pumps simply don't work in sub-zero temperatures, but modern technology has significantly improved their performance. Many current models for cold climates produce sufficient heat down to outside temperatures of 5, -5, or even -15 °C.

Although the European heat pump market was expected to exceed one million units in 2022, ISKID5 data from 2021 showed that 11,000 heat pumps were sold in Turkey. In addition, according to TÜİK (Turkey), statistics According to Kurumu, over one million fossil fuel combi boilers have already been sold in Turkey. Compared to the European trend, the Turkish market is not yet fully developed. An analysis of the reasons for the insufficient development of the heat pump market leads to the following conclusions:

- Turkey imports 99% of its natural gas and distributes it to districts with 15,000 inhabitants via BOTAŞ by presidential decree [6]. Measures are being taken to transport natural gas to regions where there is a shortage of natural gas.
- The high costs of natural gas are borne by the state,
- Higher initial investment costs due to lack of necessary incentives for heat pumps.

Therefore, users are increasingly turning to natural gas combi boilers. Current developments and trends in the heat pump sector show that they are recognized worldwide as an indispensable tool for reducing the carbon footprint. The production and use of heat pumps are increasing rapidly thanks to European incentives to reduce fossil fuel consumption and thus emissions. In Turkey, production and distribution can be promoted through measures such as tax reductions (VAT), direct incentives for initial investments by end users, and low-interest bank loans for the development of modern heat pumps in the domestic market.

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