Small Diameter Copper Tubes Make Heat Pumps More Efficient

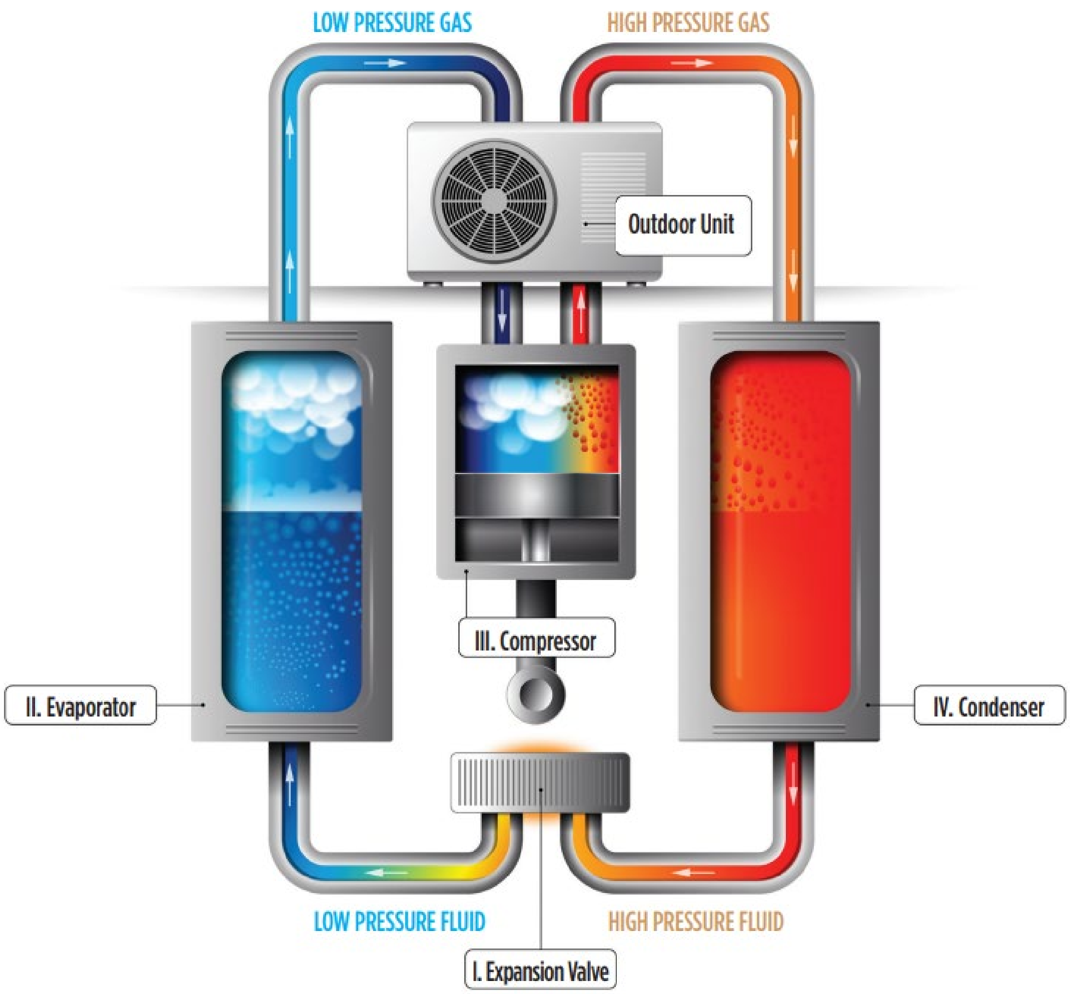


Figure 1 – VCC for heat pump. (Source: Adobe Stock)

Throughout history and modern times, humanity has accomplished heating mainly by burning fuels such as coal, oil, natural gas, and electrical resistance heating. Nonetheless, there is another method of heating: heat pumps.

According to the Second Law of Thermodynamics, isolated systems will always arrive at a state of thermodynamic equilibrium. In other words, temperature differences will even out. Through the vapor compression cycle (VCC), however, refrigerant can be heated or cooled further than the ambient (Fig. 1).

The VCC works as follows:

I. Cooled refrigerant passes through an expansion valve.
II. The refrigerant picks up heat as it expands through outdoor unit (ODU).
III. The compressor adds work energy as it compresses and condenses the refrigerant.
IV. Heat gained from Steps II and III is released through the indoor unit (IDU).

Then, the cycle repeats.

Depending on the outdoor and indoor ambient temperatures as well as the efficiencies of the coils, the heat output can be many times the work input. This advantage over electrical resistance heating is of great interest for energy efficiency. The ratio of heat output to work input is also called the coefficient of performance (COP).

Such a device is called a "heat pump." Air conditioners, refrigeration equipment, and any VCC appliance could be labeled a "heat pump." In this article, the term "heat pump" is restricted to refer to equipment and appliances that use the VCC for heating.

New Heat Pump Designs

The need for better heat pump designs is urgent for two reasons: First, heat pumps can replace equipment and appliances that burn hydrocarbons. This "electrification" or "decarbonization" allows heating to be accomplished with clean, renewable energies such as hydroelectric, geothermal, solar, and wind.

Second, thanks to the laws of thermodynamics, heating by the VCC is *much more efficient* than heating by combustion or electrical resistance. Heat pumps significantly increase the system efficiency by moving outdoor energy indoors. The kinetic energy from the compressor is added to the thermal energy absorbed from the outdoor ambient. The heating capacity (in Btu/h, or kilowatts) is typically many times the compressor power (in horsepower, or kilowatts).

Suffice it to say fossil fuels dominate the nations of the world. Weaning one and all from fossil fuel will depend in part upon imaginative new designs of heat pumps. New principles relating to the application of the VCC are emerging with the potential to revolutionize heating as much as cooling.

Several of these trends are as follows:

1. Ground source heat pumps (GSHPs)
2. Air source heat pumps (ASHPs)
3. Air-To-Water heat pumps (ATW HPs)
4. Low GWP refrigerants
5. Cold climate air source heat pumps (CC-ASHPs)

The intelligent application of new heat pump technology can substantially reduce carbon dioxide released into the atmosphere.

Let's take a closer look at these trends.

1. Ground Source Heat Pumps

In past decades, ground-source heat pumps (GSHPs) or water-source heat pumps generated much enthusiasm. The main selling point was that such heat pumps could work well even in cold climates. Typical temperatures at a depth of six to ten feet (that is, below the frost line) are steady at about 55 °F.

GSHPs remain popular in many locales. Closed loop systems circulate heat-carrier fluid through pipes installed in the ground. Open loop systems pump groundwater stored in aquifers and mines. Heat pumps are used to extract the low-grade heat from warm carrier fluid or groundwater and upgrade it to more useful temperatures (> 40 °C) required for the heating of buildings. The cooled carrier fluid or groundwater is then returned to the subsurface, and the cycle repeats.

GSHPs can be used for heating, cooling, or both, i.e., heating during winter and cooling during summer. The main disadvantage of GSHPs is the high cost or impracticality of installing underground heat exchangers.

2. Air Source Heat Pumps

Move over GSHPs and make room for Air Source Heat Pumps. ASHPs can be classified as Air-to-Air (ATA) heat pumps and Air-to-Water (ATW) heat pumps. The common denominator is that the evaporator captures heat from the ambient air.

ASHPs offer several advantages compared to GSHPs. The main advantage is lower cost. In the USA, where ducted furnaces and central AC are everywhere, air source heat pumps look like central air conditioners, but the roles of the outdoor unit (ODU) and an indoor unit (IDU) are reversed. Indeed, many brands of ASHPs are reversible. They can be used for cooling in the summer and heating in the winter, especially in lower latitudes with mild winters. ATA HPs in the heating mode use the ODU as an evaporator and the IDU as a condenser. Ducted systems are pervasive in legacy homes that previously used a gas furnace for heating.

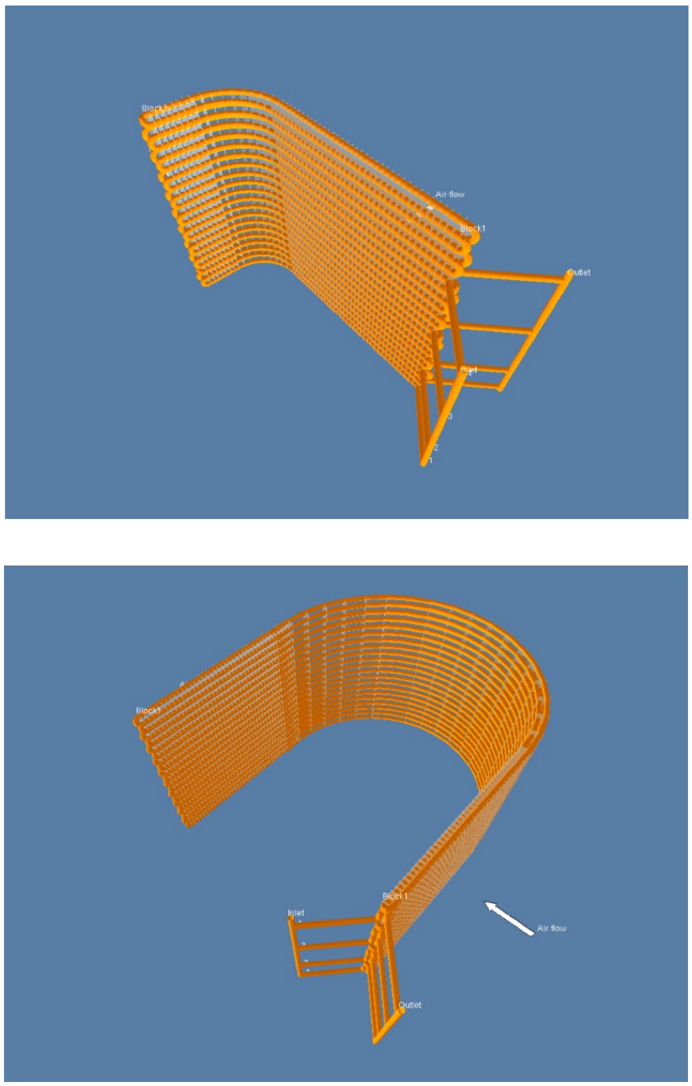
When the ODU serves as an evaporator, the copper tubing in round tube plate fin (RTPF) heat exchangers tends to be larger in diameter than the copper tubing in outdoor condensers. Copper tube diameters as large as 3/8 inches (9.52 mm) or 1/4 inches (6.35 mm) are not uncommon for this application. Microchannel heat exchangers are rarely used in outdoor evaporators because of drainage, freezing, and defrosting issues.

The IDU could be configured to allow heated air from the condenser to be directed through a system of ducts; alternatively, the IDU could be remote from the ODU. Refrigerant from the condenser could be routed through insulated copper pipes to wall units hung in various living spaces. Either of these configurations would be considered an ATA ASHP.

The trend now is toward ASHPs. Except for frigid climate zones, ASHPs can provide adequate heating through most heating days of the year, although COPs drop on cold winter days. Using the latest technology, the ASHPs save homeowners energy even in Northern climates.

Outdoor evaporators for heat pumps come in many shapes and sizes. In the United States, they are typically C-Type heat exchangers similar to the outdoor condensers commonly used in residential central air conditioning systems. Simple I-Type (flat slab) heat exchangers can also be evaporators in split systems. Figures 2a and 2b show 3D representations of C-shaped and L-shaped heat exchanger blocks with smaller diameter copper tubes for use in a heat pump as simulated with HXSim simulation software.

Figure 2 – HXSim Simulation Software allows for the design of heat exchangers for heat pumps using smaller diameter copper tubes. (a) L-shaped block. (b) C-Shaped block. Source: International Copper Association.



3. Heat Pump Water Heaters

A heat pump water heater (HPWH) could obtain heat from ground or air sources. Either of these heat pumps is more efficient than a fossil-fuel-burning boiler. Output can be used for space heating or domestic hot water (Fig. 3a and 3b).

(a) **(b)**

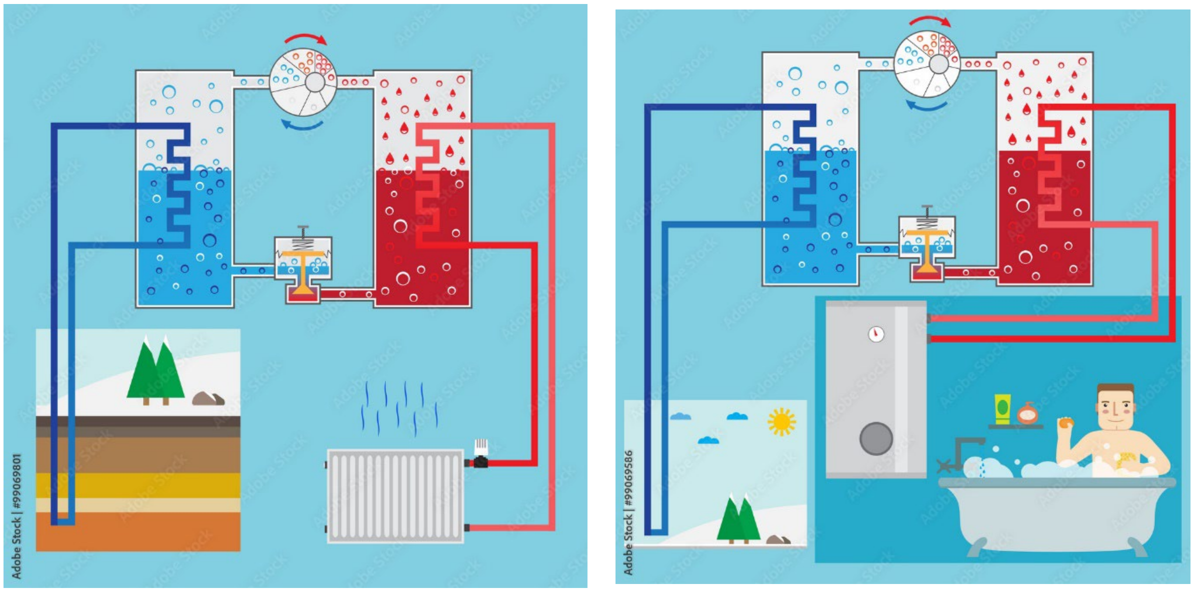


Figure 3 – Heat pumps can produce hot water: (a) Ground source heat pump (GSHP) for space heating. (b) Air source heat pumps (ASHP) for domestic hot water. (Source: Adobe Stock)

The heat from the compressed refrigerant is transferred to the water through a finless condenser coil or brazed plate heat exchanger. The hot water can then be pumped to radiators or baseboard heaters, or radiant heating can be accomplished by pumping hot water or a secondary fluid through a network of pipes built into floors or walls.

Heat pumps water heaters have received much attention from the U.S. Department of Energy (DOE) and the California Energy Commission (CEC), the EIA International Heat Pump Forum, the American Council for an Energy-Efficient Economy (ACEEE), and many other government agencies and non-governmental organizations (NGOs). The DOE is authorized to establish and amend energy conservation standards and test procedures for consumer water heaters [1].

Many OEMs exhibited HPWHs at recent trade shows. Residential appliances from A.O. Smith, Gree, Rheem, Rinnai, Stiebel Eltron, and others were notable. Bradford White Water Heaters provides the AeroTherm® Series Heat Pump Water Heater as described in a video on its website [2].

4. Low GWP Refrigerants for Heat Pumps

Heat pumps offer higher energy efficiencies than natural gas or electrical resistance heating. The high coefficients of performance (COPs) of heat pumps are the driving force behind their adoption. The COP of a heat pump is the ratio of useful heating or cooling divided by the work input. That said, there is one catch. Most of today's heat pumps contain HFCs or HFC-HFO blends. The advantages of high COP are offset by the HFCs' high Global Warming Potential (GWP).

Several industry leaders are advocating for the use of low-GWP *natural refrigerants* such as hydrocarbons (R290 and R600a) as well as carbon dioxide (R744) and ammonia (R717). While these have mainly been used in refrigeration equipment, there is a growing push to use them in other applications. In particular, higher charge limits have been approved by the International Electrotechnical Commission (IEC) safety standards for propane (R290) and other flammable refrigerants in household air conditioners, heat pumps, and dehumidifiers [3]. These increases are being put on the fast track, especially in light of the urgency to install more heat pumps in Europe to alleviate dependence on fossil fuels.

Yoram Shabtay of HTT described an ODU for an R290 Heat Pump Water Heater at the 2022 ATMOsphere America Summit [4]. While R290 is flammable, there is an option of placing components charged with R290 outdoors, where charge limit conditions could be relaxed. This approach unlocks new possibilities for developing heat pumps with low-GWP natural refrigerants. In the ATMO case study, the 14 kW evaporator is made with 5 mm diameter copper tubes. Heat exchanger designs were simulated using HXSim software (Fig. 4), and performance was verified on the actual units (Fig. 5).

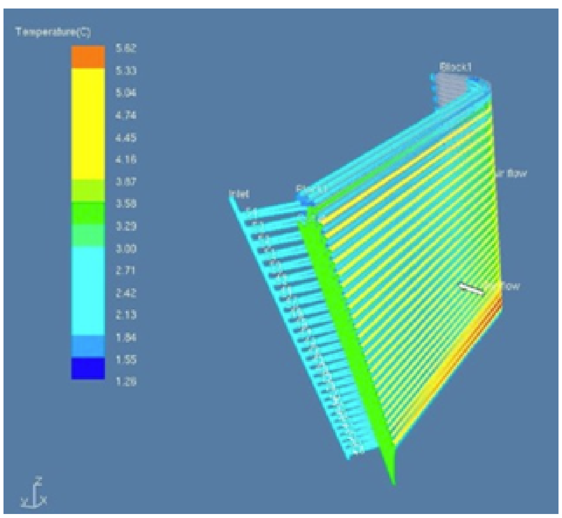


Figure 4 – HXSim simulation results can be printe dimensions. Here are simulation results for the e climate air source heat pump using R290 refrigerant.

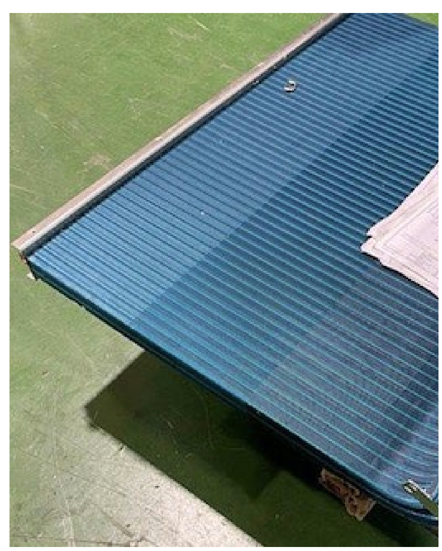


Figure 5 – The evaporator modeled in Figure 5 was built and tested confirming the accuracy of the simulation. This L-shaped evaporator is mare from 216 hairpin copper tubes with 5 mm outer diameter. There are four hairpin tubes in each of the 54 circuits.

5. Cold Climate Air Source Heat Pumps (CC-ASHPs)

The R290 heat pump application described in the last section is also suitable for operation in cold climates. Most major AC manufacturers now boast cold-climate air source heat pumps (CC-ASHPs). These heat pumps have features that make them attractive and practical even at higher latitudes. High COPs in cold climates could spur the adoption of heat pumps for space heating as energy costs increase (Fig. 6).

The Northeast Energy Efficiency Partnership (NEEP) is one of six Regional Energy Efficiency Organizations (REEOs) funded partly by the US Department of Energy to support state efficiency policies and programs. NEEP maintains a product listing of CC-ASHPs [5].

Consider that the ODU of a CC-ASHP is an evaporator. As the refrigerant expands, it reaches temperatures even colder than the outdoor temperatures since heat must be transferred from the environment to the refrigerant.

CC-ASHPS should incorporate a defrost cycle. Consequently, optimal operating cycles are under investigation. The idea is to briefly reverse the flow of the refrigerant to melt any ice buildup on the fins and tubes of the heat exchanger. The Copper Development Association sponsored research on this topic by Optimized Thermal Systems [6].

Remarkably, CC-ASHPs using low-GWP refrigerants are already available in the marketplace in the USA and Europe [4]. In many of these systems, smaller diameter copper tubes play a key role in squeezing the heat out of the cold ambient air at sub-freezing temperatures.

Figure 6 – Even at temperatures before freezing, today's cold climate air source heat pumps (CC-ASHPs) deliver heating more efficiently than burning fossil-fuels or electrical resistance heating.

Toward the Future

The magic of the VCC revolutionized our modern world. It ushered in the age of air conditioning, leading to significant demographic changes and creating industries dedicated to comfort. Simultaneously, refrigeration created a global cold chain, crossing national boundaries “from farm to fork” in ways never possible before.

Yet the story of the VCC has not yet been entirely written. The use of heat pumps for heating has barely begun, mainly because there has been no need. If necessity is the mother of invention, then innovations in heat pump designs can be assured in the next few years.

Many agree that rebates and tax incentives will be required to stimulate the broad adoption of heat pumps on the scale necessary to meet energy conservation goals. The “Inflation Reduction Act of 2022” includes numerous incentives for heat pumps and other energy-saving products. Details can be found in the final bill and numerous online reports [7].

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FIGURE CAPTIONS

Figure 1. Through the vapor compression cycle (VCC), however, refrigerant can be heated or cooled further than the ambient

Figure 2a: L-shaped heat exchanger. Simulation Software allows for the design of heat exchangers for heat pumps using smaller diameter copper tubes with various refrigerants.
Source: International Copper Association. www.microgroove.net/HXSim

Figure 2b: C-Shaped heat exchanger. Simulation Software allows for the design of heat exchangers for heat pumps using smaller diameter copper tubes with various refrigerants. L-shaped heat exchanger.
Source: International Copper Association. www.microgroove.net/HXSim

[OR COMBINED CAPTION: Figures 2a and 2b. 3D representations of C-shaped and L-shaped heat exchanger blocks with smaller diameter copper tubes for use in a heat pump as simulated with HXSim simulation software.]

Figure 3a / 3b: Heat pumps can produce hot water: (a) Ground source heat pump (GSHP) for space heating. (b) Air source heat pumps (ASHP) for domestic hot water.

[OR COMBINED CAPTION Figure 3a and 3b. Output can be used for space heating or domestic hot water.]

Figure 4. Heat exchanger designs were simulated using HXSim software.

Figure 5. Heat pump performance was verified on the actual units

Figure 6: Even at temperatures below freezing, today's cold climate air source heat pumps (CC-ASHPs) deliver heating more efficiently than either burning fossil fuels or electrical resistance heating.