Quantum Mechanics_ heat pump

Outdoor components of a residential air-source heat pump

A **heat pump** is a device that provides heat energy from a source of heat to a destination called a "heat sink". Heat pumps are designed to move thermal energyopposite to the direction of spontaneous heat flow by absorbing heat from a cold space and releasing it to a warmer one, and vice-versa. A heat pump uses some amount of external power to accomplish the work of transferring energy from the heat source to the heat sink.

While air conditioners and freezers are familiar examples of heat pumps, the term "heat pump" is more general and applies to many HVAC devices used for space heating or space cooling. When a heat pump is used for heating, it employs the same basic refrigeration-type cycle used by an air conditioner or a refrigerator, but in the opposite direction - releasing heat into the air-conditioned space rather than the surrounding environment. In this use, heat pumps generally draw heat from the cooler external air or from the ground.[1]

Overview

In heating, ventilation and air conditioning (HVAC) applications, the term *heat pump* usually refers to easily reversible vapor-compression refrigeration devices optimized for high efficiency in both directions of thermal energy transfer.

Heat spontaneously flows from warmer places to colder spaces. A heat pump can absorb heat from a cold space and release it to a warmer one, and vice-versa. "Heat" is not conserved in this process, which requires some amount of external high grade (low-entropy) energy, such as electricity.

Heat pumps are used to provide heating because less high-grade energy is required for their operation than appears in the released heat. Most of the energy for heating comes from the

external environment, and only a fraction comes from electricity (or some other high-grade energy source required to run a compressor). In electrically powered heat pumps, the heat transferred can be three or four times larger than the electrical power consumed, giving the system a coefficient of performance (COP) of 3 or 4, as opposed to a COP of 1 of a conventional electrical resistance heater, in which all heat is produced from input electrical energy.

Heat pumps use a refrigerant as an intermediate fluid to absorb heat where it vaporizes, in the evaporator, and then to release heat where the refrigerant condenses, in the condenser. The refrigerant flows through insulated pipes between the evaporator and the condenser, allowing for efficient thermal energy transfer at relatively long distances.

Reversible heat pumps

Reversible heat pumps work in either thermal direction to provide heating or cooling to the internal space. They employ a <u>reversing valve</u> to reverse the flow of refrigerant from the compressor through the condenser and evaporation coils.

- In **heating mode,** the outdoor coil is an evaporator, while the indoor is a condenser. The refrigerant flowing from the evaporator (outdoor coil) carries the thermal energy from outside air (or soil) indoors, after the fluid's temperature has been augmented by compressing it. The indoor coil then transfers thermal energy (including energy from the compression) to the indoor air, which is then moved around the inside of the building by an <u>air handler</u>. Alternatively, thermal energy is transferred to water, which is then used to heat the building via radiators or <u>underfloor heating</u>. The heated water may also be used for <u>domestic hot water</u> consumption. The refrigerant is then allowed to expand, cool, and absorb heat to reheat to the outdoor temperature in the outside evaporator, and the cycle repeats. This is a standard refrigeration cycle, save that the "cold" side of the refrigerator (the evaporator coil) is positioned so it is outdoors where the environment is colder.
- In **cooling mode** the cycle is similar, but the outdoor coil is now the condenser and the indoor coil (which reaches a lower temperature) is the evaporator. This is the familiar mode in which air conditioners operate.

Operating principles

Mechanical heat pumps exploit the physical properties of a volatile evaporating and <u>condensing</u> fluid known as a <u>refrigerant</u>. The heat pump compresses the refrigerant to make it hotter on the side to be warmed, and releases the pressure at the side where heat is absorbed.
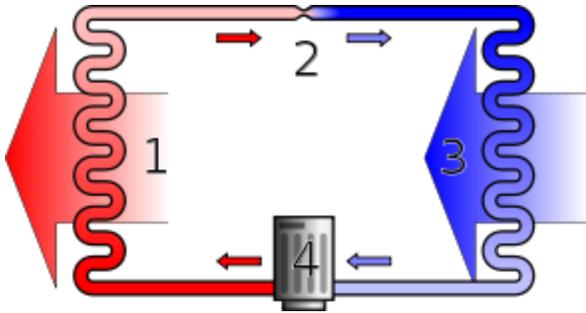
A simple stylized diagram of a heat pump's <u>vapor-compression refrigeration</u> cycle: 1) condenser, 2) expansion valve, 3) evaporator, 4) compressor.

The working fluid, in its gaseous state, is pressurized and circulated through the system by a <u>compressor</u>. On the discharge side of the compressor, now hot and highly pressurized vapor is cooled in a <u>heat exchanger</u>, called a <u>condenser</u>, until it condenses into a high pressure, moderate temperature liquid. The condensed refrigerant then passes through a pressure-lowering device also called a metering device. This may be an <u>expansion valve</u>, <u>capillary</u> tube, or possibly a work-extracting device such as a <u>turbine</u>. The low pressure liquid refrigerant then enters another heat exchanger, the evaporator, in which the fluid absorbs heat and boils. The refrigerant then returns to the compressor and the cycle is repeated.

It is essential that the refrigerant reaches a sufficiently high temperature, when compressed, to release heat through the "hot" heat exchanger (the condenser). Similarly, the fluid must reach a sufficiently low temperature when allowed to expand, or else heat cannot flow from the ambient cold region into the fluid in the cold heat exchanger (the evaporator). In particular, the pressure difference must be great enough for the fluid to condense at the hot side and still evaporate in the lower pressure region at the cold side. The greater the temperature difference, the greater the required pressure difference, and consequently the more energy needed to compress the fluid. Thus, as with all heat pumps, the <u>coefficient of performance</u> (amount of thermal energy moved per unit of input work required) decreases with increasing temperature difference.

<u>Insulation</u> is used to reduce the work and energy required to achieve a low enough temperature in the space to be cooled.

To operate in different temperature conditions, different refrigerants are available. Refrigerators, air conditioners, and some heating systems are common applications that use this technology.

Heat transport

Heat is typically transported through engineered heating or cooling systems by using a flowing gas or liquid. Air is sometimes used, but quickly becomes impractical under many

circumstances because it requires large ducts to transfer relatively small amounts of heat. In systems using refrigerant, this working fluid can also be used to transport heat a considerable distance, though this can become impractical because of increased risk of expensive refrigerant leakage. When large amounts of heat are to be transported, water is typically used, often supplemented with <u>antifreeze</u>, <u>corrosion inhibitors</u>, and other additives.

Heat sources/sinks

A common source or sink for heat in smaller installations is the outside air, as used by an air-source heat pump. A fan is needed to improve heat exchange efficiency.

Larger installations handling more heat, or in tight physical spaces, often use water-source heat pumps. The heat is sourced or rejected in water flow, which can carry much larger amounts of heat through a given pipe or duct cross-section than air flow can carry. The water may be heated at a remote location by <u>boilers,</u><u>solar energy</u>, or other means. Alternatively when needed, the water may be cooled by using a <u>cooling tower</u>, or discharged into a large body of water, such as a lake or stream.

<u>Geothermal heat pumps</u> or ground-source heat pumps use shallow underground heat exchangers as a heat source or sink, and water as the heat transport medium. This is possible because below ground level, the temperature is relatively constant across the seasons, and the earth can provide or absorb a large amount of heat. Ground source heat pumps work in the same way as air-source heat pumps, but exchange heat with the ground via water pumped through pipes in the ground. Ground source heat pumps are more simple and therefore more reliable than air source heat pumps as they do not need fan or defrosting systems and can be housed inside. Although a ground heat exchanger requires a higher initial capital cost, the annual running costs are lower, because well-designed ground source heat pump systems operate more efficiently.

Heat pump installations may be installed alongside an auxiliary conventional heat source such as electrical resistance heaters, or oil or gas combustion. The auxiliary source is installed to meet peak heating loads, or to provide a back-up system.

Applications

HVAC

In <u>HVAC</u> applications, a heat pump is typically a <u>vapor-compression refrigeration</u>device that includes a reversing valve and optimized heat exchangers so that the direction of *heat flow* (thermal energy movement) may be reversed. The reversing valve switches the direction of refrigerant through the cycle and therefore the heat pump may deliver either heating or cooling to a building. In cooler climates, the default setting of the reversing valve is heating. The

default setting in warmer climates is cooling. Because the two heat exchangers, the condenser and evaporator, must swap functions, they are optimized to perform adequately in both modes. Therefore, the efficiency of a reversible heat pump is typically slightly less than two separately optimized machines.

Plumbing

In plumbing applications, a heat pump is sometimes used to heat or preheat water for swimming pools or domestic water heaters; the heat energy removed from an air-conditioned space may be recovered for water heating.

Refrigerants

Until the 1990s, the refrigerants were often chlorofluorocarbons such as R-12 (dichlorodifluoromethane), one in a class of several refrigerants using the brand name Freon, a trademark of DuPont. Its manufacture was discontinued in 1995 because of the damage that CFCs cause to the ozone layer if released into the atmosphere.

One widely adopted replacement refrigerant is the hydrofluorocarbon (HFC) known as R-134a (1,1,1,2-tetrafluoroethane). Heat pumps using R-134a are not as efficient as those using R-12 that they replace (in automotive applications) and therefore, more energy is required to operate systems utilizing R-134a than those using R-12. Other substances such as liquid R-717 ammonia are widely used in large-scale systems, or occasionally the less corrosive but more flammable propane or butane, can also be used.

Since 2001, carbon dioxide, R-744, has increasingly been used, utilizing the transcritical cycle, although it requires much higher working pressures. In residential and commercial applications, the hydrochlorofluorocarbon (HCFC) R-22 is still widely used, however, HFC R-410A does not deplete the ozone layer and is being used more frequently. Hydrogen, helium, nitrogen, or plain air is used in the Stirling cycle, providing the maximum number of options in environmentally friendly gases.

More recent refrigerators use R600A which is isobutane, and does not deplete the ozone and is friendly to the environment.[*citation needed*]

Dimethyl ether (DME) is also gaining popularity as a refrigerant.[2]

Efficiency

When comparing the performance of heat pumps, it is best to avoid the word "efficiency", which has a very specific thermodynamic definition. The term coefficient of performance (COP) is used to describe the ratio of useful heat movement per work input. Most vapor-compression heat pumps use electrically powered motors for their work input. However, in many vehicle applications, mechanical energy from an internal combustion engine provides the needed work.

When used for heating a building on a mild day, for example 10 ℃, a typical air-source heat pump (ASHP) has a COP of 3 to 4, whereas an electrical resistanceheater has a COP of 1.0. That is, one joule of electrical energy will cause a resistance heater to produce only one joule of useful heat, while under ideal conditions, one joule of electrical energy can cause a heat pump to move much more than one joule of heat from a cooler place to a warmer place. Note that an air source heat pump is more efficient in hotter climates than cooler ones, so when the weather is much warmer the unit will perform with a higher COP (as it has less work to do). Conversely in extreme cold weather the COP approaches 1. Thus when there is a wide temperature differential between the hot and cold reservoirs, the COP is lower (worse).

On the other hand, ground-source heat pumps (GSHP) benefit from the moderated temperature underground, as the ground acts naturally as a store of thermal energy.[3] Their year-round COP is therefore normally in the range of 2.5 to 5.0.

When there is a high temperature differential on a cold day, (e.g., when an air-source heat pump is used to heat a house on a cold winter day of 0 ℃ (32 ℉)), it takes more work to move the same amount of heat to indoors than on a mild day. Ultimately, due to Carnot efficiency limits, the heat pump's performance will approach 1.0 as the outdoor-to-indoor temperature difference increases for colder climates (outside temperature gets colder). This typically occurs around −18 ℃ (0 ℉) outdoor temperature for air source heat pumps.

Also, as the heat pump takes heat out of the air, some moisture in the outdoor air may condense and possibly freeze on the outdoor heat exchanger. The system must periodically melt this ice. When it is extremely cold outside, it is simpler, and wears the machine less, to heat using an electric-resistance heater rather than to overload an air-source heat pump.

The design of the evaporator and condenser heat exchangers is also very important to the overall efficiency of the heat pump. The heat exchange surface areas and the corresponding temperature differential (between the refrigerant and the air stream) directly affect the operating pressures and hence the work the compressor has to do in order to provide the same heating or cooling effect. Generally, the larger the heat exchanger the lower the temperature differential and the more efficient the system becomes.

Heat exchangers are expensive, requiring drilling for some heat-pump types or large spaces to be efficient, and the heat pump industry generally competes on price rather than efficiency. Heat pumps are already at a price disadvantage when it comes to initial investment (not long-term savings) compared to conventional heating solutions like boilers, so the drive towards

more efficient heat pumps and air conditioners is often led by legislative measures on minimum efficiency standards.[4]

In cooling mode, a heat pump's operating performance is described in the US as its energy efficiency ratio (EER) or seasonal energy efficiency ratio (SEER), and both measures have units of BTU/(h·W) (1 BTU/(h·W) = 0.293 W/W). A larger EER number indicates better performance. The manufacturer's literature should provide both a COP to describe performance in heating mode, and an EER or SEER to describe performance in cooling mode. Actual performance varies, however, and depends on many factors such as installation, temperature differences, site elevation, and maintenance.

Heat pumps are more *effective* for heating than for cooling an interior space if the temperature differential is held equal. This is because the compressor's input energy is also converted to useful heat when in heating mode, and is discharged along with the transported heat via the condenser to the interior space. But for cooling, the condenser is normally outdoors, and the compressor's dissipated work (waste heat) must also be transported to outdoors using more input energy, rather than being put to a useful purpose. For the same reason, opening a food refrigerator or freezer actually heats up the room rather than cooling it because its refrigeration cycle rejects heat to the indoor air. This heat includes the compressor's dissipated work as well as the heat removed from the inside of the appliance.

The COP for a heat pump in a heating or cooling application, with steady-state operation, is:

$$COP_{\text{heating}} = \frac{\Delta Q_{\text{hot}}}{\Delta A} \leq \frac{T_{\text{hot}}}{T_{\text{hot}} - T_{\text{cool}}},$$

$$COP_{\text{cooling}} = \frac{\Delta Q_{\text{cool}}}{\Delta A} \leq \frac{T_{\text{cool}}}{T_{\text{hot}} - T_{\text{cool}}},$$

where

- ΔQ_{cool} is the amount of heat extracted from a cold reservoir at temperature T_{cool},
- ΔQ_{hot} is the amount of heat delivered to a hot reservoir at temperature T_{hot},
- ΔA is the compressor's dissipated work.
- All temperatures are absolute temperatures usually measured in kelvins or degrees Rankine.

Coefficient of performance (COP) and lift

The COP increases as the temperature difference, or "lift", decreases between heat source and destination. The COP can be maximized at design time by choosing a heating system requiring only a low final water temperature (e.g. underfloor heating), and by choosing a heat source with

a high average temperature (e.g. the ground). Domestic hot water (DHW) and conventional heating radiators require high water temperatures, reducing the COP that can be attained, and affecting the choice of heat pump technology.[citation needed]

Pump type and source	Typical use	35 °C (e.g. heated screed floor)	45 °C (e.g. heated screed floor)	55 °C (e.g. heated timber floor)	65 °C (e.g. radiator or DHW)	75 °C (e.g. radiator and DHW)	85 °C (e.g. radiator and DHW)
High-efficiency air source heat pump (ASHP), air at −20 °C[5]		2.2	2.0	-	-	-	-
Two-stage ASHP, air at −20 °C[6]	Low source temperature	2.4	2.2	1.9	-	-	-
High efficiency ASHP, air at 0 °C[5]	Low output temperature	3.8	2.8	2.2	2.0	-	-
Prototype transcritical CO2(R744) heat pump with tripartite gas cooler, source at 0 °C[7]	High output temperature	3.3	-	-	4.2	-	3.0
Ground source heat pump (GSHP), water at 0 °C[5]		5.0	3.7	2.9	2.4	-	-
GSHP, ground at 10 °C[5]	Low output temperature	7.2	5.0	3.7	2.9	2.4	-
Theoretical Carnot cycle limit, source −20 °C		5.6	4.9	4.4	4.0	3.7	3.4
Theoretical Carnot cycle limit, source 0 °C		8.8	7.1	6.0	5.2	4.6	4.2
Theoretical Lorentzen cycle limit (CO2 pump), return fluid 25 °C, source 0 °C[7]		10.1	8.8	7.9	7.1	6.5	6.1

Theoretical Carnot

cyclelimit, source 10 ℃	12.3	9.1	7.3	6.1	5.4	4.8

COP variation with output temperature

One observation is that while current "best practice" heat pumps (ground source system, operating between 0 ℃ and 35 ℃) have a typical COP around 4, no better than 5, the maximum achievable is 8.8 because of fundamental Carnot cyclelimits. This means that in the coming decades, the energy efficiency of top-end heat pumps could at least double. Cranking up efficiency requires the development of a better gas compressor, fitting HVAC machines with larger heat exchangers with slower gas flows, and solving internal lubrication problems resulting from slower gas flow. Depending on the working fluid, the expansion stage can be important also. Work done by the expanding fluid cools it and is available to replace some of the input power. (An evaporating liquid is cooled by free expansion through a small hole, but an ideal gas is not.)

Types

Compression v. absorption

The two main types of heat pumps are compression and absorption. Compression heat pumps operate on mechanical energy (typically driven by electricity), while absorption heat pumps may also run on heat as an energy source (from electricity or burnable fuels).[8] An absorption heat pump may be fueled by natural gas or LP gas, for example. While the Gas Utilization Efficiency in such a device, which is the ratio of the energy supplied to the energy consumed, may average only 1.5; that is better than a natural gas or LP gas furnace, which can only approach 1.

Heat sources and sinks

By definition, all heat sources for a heat pump must be colder in temperature than the space to be heated. Most commonly, heat pumps draw heat from the air (outside or inside air) or from the ground (groundwater or soil).[9]

The heat drawn from ground-sourced systems is in most cases stored solar heat, and it should not be confused with direct geothermal heating, though the latter will contribute in some small measure to all heat in the ground. True geothermal heat, when used for heating, requires a circulation pump but no heat pump, since for this technology the ground temperature is higher than that of the space that is to be heated, so the technology relies only upon simple heat convection.

Other heat sources for heat pumps include water; nearby streams and other natural water bodies have been used, and sometimes domestic waste water (viadrain water heat recovery)

which is often warmer than cold winter ambient temperatures (though still of lower temperature than the space to be heated).

A number of sources have been used for the heat source for heating private and communal buildings.[10]

Air (ASHP)

Main article: Air source heat pumps

- Air source heat pump (extracts heat from outside air)

    - Air-air heat pump (transfers heat to inside air)

    - Air-water heat pump (transfers heat to a heating circuit and a tank of domestic hot water)

Air-air heat pumps, that extract heat from outside air and transfer this heat to inside air, are the most common type of heat pumps and the cheapest. These are similar to air conditioners operating in reverse. Air-water heat pumps are otherwise similar to air-air heat pumps, but they transfer the extracted heat into a water heating circuit, floor heating being the most efficient, and they can also transfer heat into a domestic hot water tank for use in showers and hot water taps of the building. However, ground-water heat pumps are more efficient than air-water heat pumps, and therefore they are often the better choice for providing heat for the floor heating and domestic hot water systems.

Air source heat pumps are relatively easy and inexpensive to install and have therefore historically been the most widely used heat pump type. However, they suffer limitations due to their use of the outside air as a heat source. The higher temperature differential during periods of extreme cold leads to declining efficiency. In mild weather, COP may be around 4.0, while at temperatures below around 0°C (32°F) an air-source heat pump may still achieve a COP of 2.5. The average COP over seasonal variation is typically 2.5-2.8, with exceptional models able to exceed this in mild climates.

In areas where only fossil fuels are available (e.g. heating oil only; no natural gas pipes available) air source heat pumps could be used as an alternative, supplemental heat source to reduce a building's dependence on fossil fuel. Depending on fuel and electricity prices, using the heat pump for heating may be less expensive than using fossil fuel. A backup fossil-fuel, solar hot water or biomass heat source may still be required for the coldest days.[*citation needed*]

The heating output of low temperature optimized heat pumps (and hence their energy efficiency) still declines dramatically as the temperature drops, but the threshold at which the

decline starts is lower than conventional pumps, as shown in the following table (temperatures are approximate and may vary by manufacturer and model):

Air Source Heat Pump Type	Full heat output at or above this temperature	Heat output down to 60% of maximum at
Conventional	47 °F (8.3 °C)	32 °F (0 °C)
Low Temp Optimized	41 °F (5 °C)	17 °F (−8.3 °C)

Ground (GSHP)

Main article: Ground-source heat pump

- Ground source heat pump (extracts heat from the ground or similar sources)
    - Ground-air heat pump (transfers heat to inside air)
        - Soil-air heat pump (soil as a source of heat)
        - Rock-air heat pump (rock as a source of heat)
        - Water-air heat pump (body of water as a source of heat, can begroundwater, lake, riveretc.)
    - Ground-water heat pump (transfers heat to a heating circuit and a tank of domestic hot water)
        - Soil-water heat pump (ground as a source of heat)
        - Rock-water heat pump (rock as a source of heat)
        - Water-water heat pump (body of water as a source of heat)

Ground-source heat pumps, also called geothermal heat pumps, typically have higher efficiencies than air-source heat pumps. This is because they draw heat from the ground or groundwater which is at a relatively constant temperature all year round below a depth of about 30 feet (9 m).[11] This means that the temperature differential is lower, leading to higher efficiency. Well maintained ground-source heat pumps typically have COPs of 4.0[12] at the beginning of the heating season, with lower seasonal COPs of around 3.0 as heat is drawn from the ground. The tradeoff for this improved performance is that a ground-source heat pump is more expensive to install, due to the need for the drilling of boreholes for vertical placement of heat exchanger piping or the digging of trenches for horizontal placement of the piping that carries the heat exchange fluid (water with a little antifreeze).

When compared, groundwater heat pumps are generally more efficient than heat pumps using heat from the soil. Closed loop soil or ground heat exchangers tend to accumulate cold if the ground loop is undersized. This can be a significant problem if nearby ground water is stagnant

or the soil lacks thermal conductivity, and the overall system has been designed to be just big enough to handle a "typical worst case" cold spell, or is simply undersized for the load.[13] One way to fix cold accumulation in the ground heat exchanger loop, is to use ground water to cool the floors of the building on hot days, thereby transferring heat from the dwelling into the ground loop. There are several other methods for replenishing a low temperature ground loop; one way is to make large solar collectors, for instance by putting plastic pipes just under the roof, or by putting coils of black polyethylene pipes under glass on the roof, or by piping the tarmac of the parking lot.[14]

Exhaust air (EAHP)

Main article: Exhaust air heat pump

- Exhaust air heat pump (extracts heat from the exhaust air of a building, requires mechanical ventilation)

  - Exhaust air–air heat pump (transfers heat to intake air)

  - Exhaust air–water heat pump (transfers heat to a heating circuit and a tank of domestic hot water)

Water source heat pumps (WSHP)

- Uses flowing water as source or sink for heat

- Single-pass vs. recirculation

  - Single-pass — water source a body of water or a stream

  - Recirculation

    - When cooling, closed-loop heat transfer medium to central cooling tower or chiller (typically in a building or industrial setting)

    - When heating, closed-loop heat transfer medium from central boilers generating heat from combustion or other sources

Hybrid (HHP)

Hybrid (or twin source) heat pumps: when outdoor air is above 4 to 8 Celsius, (40-50 Fahrenheit, depending on ground water temperature) they use air; when air is colder, they use the ground source. These twin source systems can also store summer heat, by running ground source water through the air exchanger or through the building heater-exchanger, even when the heat pump itself is not running. This has dual advantage: it functions as a low running cost for air cooling, and (if ground water is relatively stagnant) it cranks up the temperature of the ground source, which improves the energy efficiency of the heat pump system by roughly 4% for each degree in temperature rise of the ground source.

Air/water–brine/water heat pump (hybrid heat pump)

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The air/water–brine/water heat pump is a hybrid heat pump, developed in Rostock, Germany, that uses only renewable energy sources. Unlike other hybrid systems, which usually combine both conventional and renewable energy sources, it combines air and geothermal heat in one compact device. The air/water–brine/water heat pump has two evaporators — an outside air evaporator and a brine evaporator — both connected to the heat pump cycle. This allows use of the most economical heating source for the current external conditions (for example, air temperature). The unit automatically selects the most efficient operating mode — air or geothermal heat, or both together. The process is controlled by a control unit, which processes the large amounts of data delivered by the complex heating system. The control unit comprises two controllers, one for the air heat cycle and one for the geothermal circulation, in one device. All components communicate over a common bus to ensure they interact to enhance the efficiency of the hybrid heating system. The German Patent and Trade Mark Office in Munich granted the air/water–brine/water heat pump a patent in 2008, under the title "Heat pump and method for controlling the source inlet temperature to the heat pump". This hybrid heat pump can be combined with a solar thermal system or with an ice–storage. It trades and is marketed under the name *ThermSelect*. In the United Kingdom, *ThermSelect* won the 2013 Commercial Heating Product of the Year award of the HVR Awards for Excellence, organised by *Heating and Ventilating Review*, an industry magazine.

Heat distribution

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Heat pumps are only highly efficient when they generate heat at a low temperature differential, ideally around or below 32 °C (90 °F). Normal steel plate radiators are not practical, because they would need to be four to six times their current size. Underfloor heating is one ideal solution. When wooden floors or carpets would spoil efficiency, wall heaters (plastic pipes covered with a thick layer of chalk) and piped ceilings can be used. These systems have the disadvantage that they are slow starters, and that they would require extensive renovation in existing buildings.

The alternative is a warm air system. Such a setup can either complement slower floor heating during warm up, or it can be a quick and economical way to implement a heat pump system into existing buildings. Oversizing the fans and ductwork can reduce the acoustic noise they produce. To efficiently distribute warm water or air from a heat pump, water pipes or air shafts must have significantly larger diameters than in conventional, hotter-source systems, and underfloor heaters should have much more pipes per square meter.[*citation needed*]

Solid state heat pumps

Magnetic

Main article: Magnetic refrigeration

In 1881, the German physicist Emil Warburg put a block of iron into a strong magnetic field and found that it increased very slightly in temperature. Some commercial ventures to implement this technology are underway, claiming to cut energy consumption by 40% compared to current domestic refrigerators.[15] The process works as follows: Powdered gadolinium is moved into a magnetic field, heating the material by 2 to 5 °C (4 to 9 °F). The heat is removed by a circulating fluid. The material is then moved out of the magnetic field, reducing its temperature below its starting temperature.[*citation needed*]

Thermoelectric

Main articles: Thermoelectric cooling and Thermoelectric materials

Solid state heat pumps using the thermoelectric effect have improved over time to the point where they are useful for certain refrigeration tasks. Thermoelectric (Peltier) heat pumps are generally only around 10–15% as efficient as the ideal refrigerator (Carnot cycle), compared with 40–60% achieved by conventional compression cycle systems (reverse Rankine systems using compression/expansion);[16] however, this area of technology is currently the subject of active research in materials science.

Thermoacoustic

Main article: Thermoacoustic hot air engine

Near-solid-state heat pumps using thermoacoustics are commonly used in cryogenic laboratories.[*citation needed*]

Historical development

This section requires expansion. *(June 2008)*

Milestones:

- 1748: William Cullen demonstrates artificial refrigeration.
- 1834: Jacob Perkins builds a practical refrigerator with diethyl ether.
- 1852: Lord Kelvin describes the theory underlying heat pump.
- 1855–1857: Peter von Rittinger develops and builds the first heat pump.[17]

- 1940: Robert C. Webber is credited as developing and building the first ground heat pump.[18]

See also

Energy portal

- EcoCute domestic heat pump water heater
- Züblin AG Energietübbing[19]
- Flash evaporation
- Geothermal heat pump
- heat exchanger
- Renewable heat
- Thermoelectric heat pumps that use the Peltier effect
- vapor-compression refrigeration
- Vortex tube
- IEA-ECBCS Annex 48 : Heat Pumping and Reversible Air Conditioning

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