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Heat Recovery Ventilation

Prepared By

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Heat recovery ventilation, also known as HRV, mechanical ventilation heat recovery, or MVHR, is an energy recovery ventilation system using equipment known as a heat recovery ventilator, heat exchanger, air exchanger, or air-to-air heat exchanger which employs a counter-flow heat exchanger (countercurrent heat exchange) between the inbound and outbound air flow.[١] HRV provides fresh air and improved climate control, while also saving energy by reducing heating (and cooling) requirements.

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Introduction

A Heat Recovery Ventilator (also known as HRV) consists of two separate air-handling systems – one collects and exhausts stale indoor air; the other draws in outdoor air and distributes it throughout the home. HRVs provide fresh air at a reduced cost, while also saving energy by reducing the heating (or cooling) requirements. Energy Recovery Ventilators (ERVs) are closely related, however ERVs also transfer some of the humidity (or moisture) of the exhaust air to the intake air.

Heat Recovery Ventilator (HRV)

An HRV is a mechanical ventilation device that helps make your home healthier, cleaner and more comfortable by continuously replacing stale indoor air with fresh outdoor air. HRVs are set apart from other mechanical ventilation devices by their ability to exchange heat between the supply and exhaust air streams, which in turn reduces the cost of heating or cooling the healthy fresh air that circulates through the home. HRVs are sometimes called air-to-air heat exchangers because they preheat or cool incoming air using exhaust air.

In recent years, more and more existing homes have undergone energy-efficiency improvements such as upgraded insulation, improved air sealing, the installation of energy-efficient windows, doors and heating systems, etc. As well, improved practices in new home construction have resulted in more energy-efficient and airtight conventional homes.

In many of these homes, air infiltration through doors, windows and other openings in the building shell is too random and does not always provide adequate ventilation. Even when there is an acceptable rate of air exchange, the fresh air may not be getting to the rooms where it is needed. As a result, mechanical ventilation is needed in many conventional homes in order to evenly distribute fresh air throughout the home and maintain a healthy living environment. An added benefit of mechanical ventilation systems is their capability to filter the incoming fresh outdoor air

Heat Recovery Ventilation

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Benefits

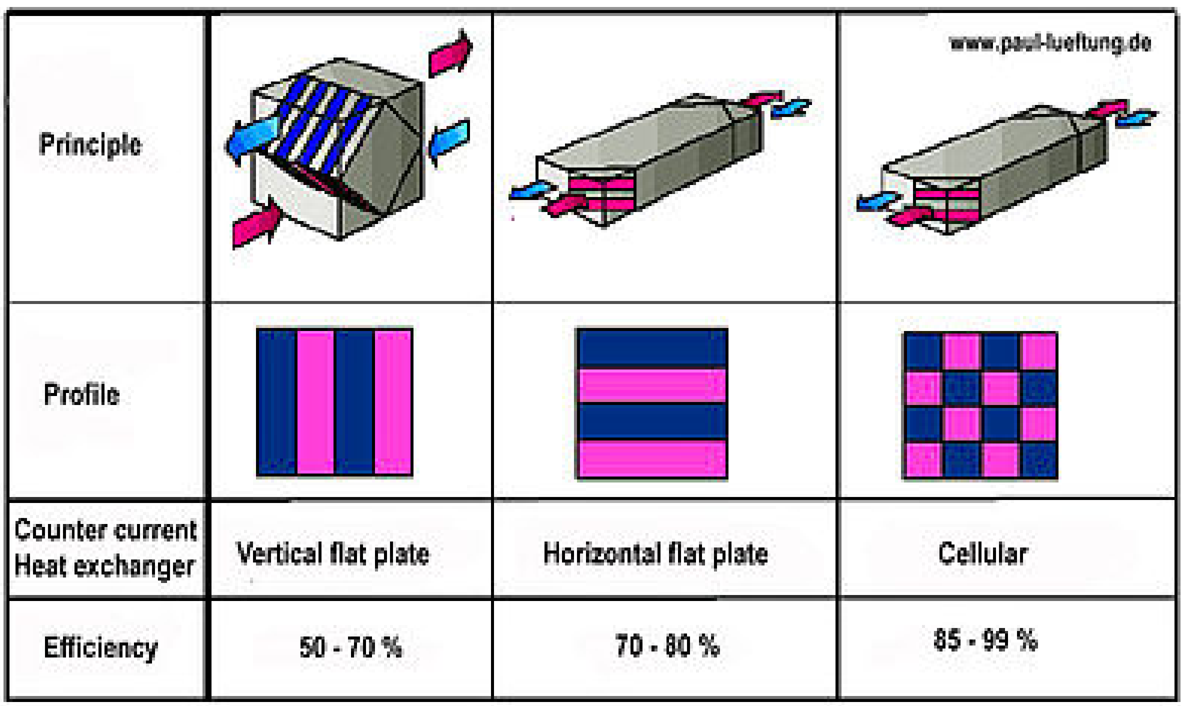
As building efficiency is improved with insulation and weatherstripping, buildings are intentionally made more airtight, and consequently less well ventilated. Since all buildings require a source of fresh air, the need for HRVs has become obvious. While opening a window does provide ventilation, the building's heat and humidity will then be lost in the winter and gained in the summer, both of which are undesirable for the indoor climate and for energy efficiency, since the building's HVAC systems must compensate. HRV

technology offers an optimal solution: fresh air, better climate control, and Energy efficiency - Sustainability.

Technology

Heat recovery ventilation-HRVs and ERVs can be stand-alone devices that operate independently, or they can be built-in, or added to existing HVAC systems. For a small building in which nearly every room has an exterior wall, then the HRV/ERV device can be small and provide ventilation for a single room. A larger building would require either many small units, or a large central unit. The only requirements for the building are an air supply, either directly from an exterior wall or ducted to one, and an energy supply for air circulation, such as wind energy or electricity for a fan. When used with 'central' HVAC systems, then the system would be of the 'forced-air' type.

Air to air heat exchanger



Principle			www.paul-lueftung.de
Profile			
Counter current Heat exchanger	Vertical flat plate	Horizontal flat plate	Cellular
Efficiency	50 - 70 %	70 - 80 %	85 - 99 %

Types of Recuperator air to air heat exchangers.

There are a number of types of heat exchanger that can be used in Heat recovery ventilation-HRV devices:

- cross flow heat exchanger up to ٦٠% efficient (passive)
- Recuperator, or cross plate heat exchanger, a countercurrent heat exchanger, as diagrammed to the right
- Thermal Wheel, or rotary heat exchanger (requires motor to turn wheel)
- Heat pipe
- thin multiple heat wires (Fine wire heat exchanger)

See also:

- Shell and tube heat exchanger
- Plate heat exchanger
- Plate fin heat exchanger
- Ground-coupled heat exchanger
- Dynamic scraped surface heat exchanger
- Waste Heat Recovery Unit
- Micro heat exchanger
- Moving bed heat exchanger

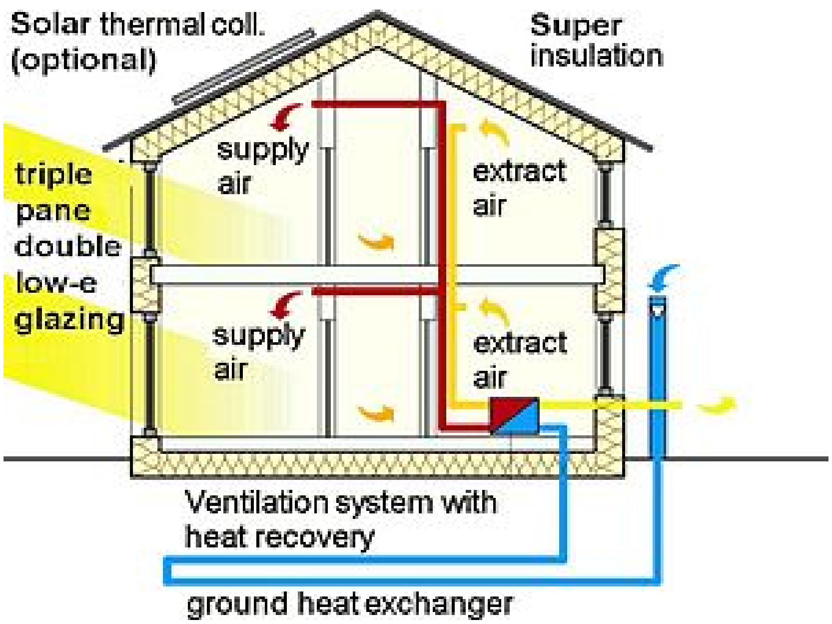
Incoming air

The air coming into the heat exchanger should be at least ٠°C. Otherwise humidity in the outgoing air may condense, freeze and block the heat exchanger.

A high enough incoming air temperature can also be achieved by

- recalculating some of the exhaust air (causing loss of air quality) when required,
- by using a very small (١ kW) heat pump to warm the inlet air above freezing before it enters the HRV. (The 'cold' side of this heat pump is situated in the warm air outlet.)
- Using a heating "battery" supplied by heat from a heat source eg hot water circuit from a wood fired boiler, etc.

Earth-to-air heat exchanger



Heat recovery ventilation, often with an earth-to-air heat exchanger, is essential to achieve German Passivhaus standards.

Main article: Ground-coupled heat exchanger

This can be done by an earth warming pipe ("ground-coupled heat exchanger"), usually about ٣٠ m to ٤٠ m long and ٢٠ cm in diameter, typically buried about ١.٥ m below ground level. In Germany and Austria this is a common configuration for earth to air heat exchangers.

In high humidity areas where internal condensation could lead to fungal / mould growth in the tube leading to contamination of the air, several measures exist to prevent this.

- **Ensuring the tube drains of water.**
- **Regular cleaning**
- **Tubes with an imbedded bactericide coating such as silver ions (non-toxic for humans)**
- **Air filters F٧ / EU٧ (>٠,٤ micrometres) to traps mould (of a size between ٢ & ٢٠ micrometres).**
- **UV air purification**
- **Use a earth to "water" heat exchanger, see below.**

The pipes may be either corrugated/slotted to enhance heat transfer and provide condensate drainage or smooth/solid to prevent gas/liquid transfer.

Air quality

This is highly site dependent.

Radon

One critical problem being located in soils with underlying rock strata which emit radon. In these situations the tube needs to be airtight from the surrounding soils, or an Air to Water heat exchanger be used.

Bacteria and fungi

Formal research indicates that Earth-Air Heat Exchangers reduce building ventilation air pollution. Rabindra (٢٠٠٤) states, “The Earth-Air Tunnel is found not to support the growth of bacteria and fungi; rather it is found to reduce the quantity of bacteria and fungi thus making the air safer for humans to inhale. It is therefore clear that the use of EAT (Earth-Air Tunnel) not only helps save the energy but also helps reduce the air pollution by reducing bacteria and fungi.”

Likewise, Flueckiger (١٩٩٩) in a study of twelve Earth-Air Heat Exchangers varying in design, pipe material, size and age, stated, “This study was performed because of concerns of potential microbial growth in the buried pipes of 'ground-coupled' air systems. The results however demonstrate, that no harmful growth occurs and that the airborne concentrations of viable spores and bacteria, with few exceptions, even decreases after passage through the pipe-system”, and further stated, “Based on these investigations the operation of ground-coupled earth-to-air heat exchangers is acceptable as long as regular controls are undertaken and if appropriate cleaning facilities are available”.

Earth-to-Water heat exchanger

An alternative to the earth to air heat exchanger is the earth to "water" heat exchanger. This is typically similar to a geothermal heat pump tubing embedded horizontally in the soil (or could be a vertical pipe/sonde) to a similar depth of the EAHX. It uses approximately double the length of pipe Ø ٣٥ mm ie around ٨٠ metres compared to an EAHX. A heat exchanger coil is placed before the air inlet of the HRV. Typically a brine liquid (heavily salted water) is used as the heat exchange fluid which is slightly more efficient and environmentally friendly than polypropylene heat transfer liquids.

In temperate climates in an energy efficient building, such as a passivhaus, this is more than sufficient for comfort cooling during summer without resorting to an airconditioning system. In more extreme hot climates a very small air to air micro-heat pump in reverse (an air conditioner) with the evaporator (giving heat) on the air inlet after the HRV heat exchanger and the condensor (taking heat) from the air outlet after the heat exchanger will suffice.

Seasonal bypassing

At certain times of the year it is more thermally efficient to bypass the Heat recovery ventilation-HRV heat exchanger or the earth to air heat exchanger (EAHX).

For example, during the winter, the earth at the depth of the earth to air heat exchanger is ordinarily much warmer than the air temperature. The air becomes warmed by the earth before reaching the air heat exchanger.

In the summer, the opposite is true. The air becomes cooled in the earth to air exchanger. But after passing through the EAHX, the air is warmed by the heat recovery ventilator using the warmth of the outgoing air. In this case, the HRV can have an internal bypass such that the inflowing air bypasses the heat exchanger maximising the cooling potential of the earth.

In autumn and spring there may be no thermal benefit from the EAHX—it may heat/cool the air too much and it will be better to use external air directly. In this case it is helpful to have a bypass such that the EAHX is disconnected and air taken directly from outside. A differential temperature sensor with a motorized valve can control the bypass function.

Energy recovery

Energy recovery includes any technique or method of minimizing the input of energy to an overall system by the exchange of energy from one sub-system of the overall system with another. The energy can be in any form in either subsystem, but most energy recovery systems exchange thermal energy in either sensible or latent form.

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Principle

A common utilization of this principle is in systems which have an *exhaust stream* or *waste stream* which is transferred from the system to its surroundings. Some of the energy in that flow of material (often gaseous or liquid) may be transferred to the *make-up* or *input* material flow. This *input* mass flow often comes from the system's surroundings, which, being at ambient conditions, are at a lower temperature than the *waste stream*. This temperature differential allows heat transfer and thus energy transfer, or in this case, recovery. Thermal energy is often recovered from liquid or gaseous waste streams to *fresh make-up* air and water intakes in buildings, such as for the HVAC systems, or process systems.

System approach

Energy consumption is a key part of most human activities. This consumption involves converting one energy system to another, for example: The conversion of mechanical energy to electrical energy, which can then power computers, light, motors etc. The input energy propels the work and is mostly converted to heat or follows the product in the process as output energy. Energy recovery systems harvest the output power and providing this as input power to the same or another process.

An energy recovery system will close this energy cycle to prevent the input power from being released back to nature and rather be used in other forms of desired work.

Examples of energy recovery

- **Heat recovery is implemented in heat sources like e.g. a steel mill. Heated cooling water from the process is sold for heating of homes, shops and offices in the surrounding area.**
- **Regenerative brake is used in electric cars, trains, heavy cranes etc where the energy consumed when elevating the potential is returned to the electric supplier when released.**
- **Active pressure reduction systems where the differentioal pressure in a preassurized fluid flow is recovered rather than converted to heat in a pressure reduction valve and released.**
- **Energy recovery ventilation**
- **Energy recycling**
- **Water heat recycling**
- **Heat recovery ventilation**
- **Heat recovery steam generator**

- **Heat Regenerative Cyclone Engine**
- **Hydrogen turbo expander-generator**
- **Thermal diode**
- **Thermal oxidizer**
- **Thermoelectric Modules**
- **Waste heat recovery units**

Environmental impact

There is a large potential for energy recovery in compact systems like large industries and utilities. Together with Energy conservation it should be possible to dramatically reduce the world energy consumption. The effect of this will then be:

- **Reduced number of coal fired power plants**
- **Reduced airborne particles, NOx and CO٢ - improved air quality**
- **Slowing or reducing climate change**
- **Lower fuel bills on transport**
- **Longer availability of crude oil**
- **Change of industries and economies not fully researched**

In ٢٠٠٨ Tom Casten, chairman of Recycled Energy Development, said that "*We think we could make about ١٩ to ٢٠ percent of U.S. electricity with heat that is currently thrown away by industry.*

A ٢٠٠٧ Department of Energy study found the potential for ١٣٥,٠٠٠ megawatts of combined heat and power (which uses energy recovery) in the U.S.,[٣] and a Lawrence Berkley National Laboratory study identified about ٦٤,٠٠٠ megawatts that could be obtained from industrial waste energy, not counting CHP.[٤] These studies suggest about ٢٠٠,٠٠٠ megawatts—or ٢٠% -- of total power capacity that could come from energy recycling in the U.S. Widespread use of energy recycling could therefore reduce global warming emissions by an estimated ٢٠ percent.[٥] Indeed, as of ٢٠٠٥, about ٤٢ percent of U.S. greenhouse gas pollution came from the production of electricity and ٢٧ percent from the production of heat.

It is, however, difficult to quantify the environmental impact of a global energy recovery implementation in some sectors. The main impediments are

- **Lack of efficient technologies for private homes. Heat recovery systems in private homes can have an efficiency as low as ٣٠% or less. It may be more realistic to use energy conservation like insulation or improved buildings. Many areas are more dependant on forced cooling and a system for extracting heat from dwellings to be used for other uses are not widely available.**
- **Ineffective infrastructure. Heat recovery in particular need a short distance from producer to consumer to be viable. A solution may be to move a large consumer to the vicinity of the producer. This may have other complications.**

- Transport sector not ready. With the transport sector using about ٢٠% of the energy supply, most of the energy is spent on overcoming gravity and friction. Electric cars seems with regenerative breaking seems to be the best candidate for energy recovery. Wind systems on ships are under development. Very little work on the airline industry is known in this field.

Heat exchanger

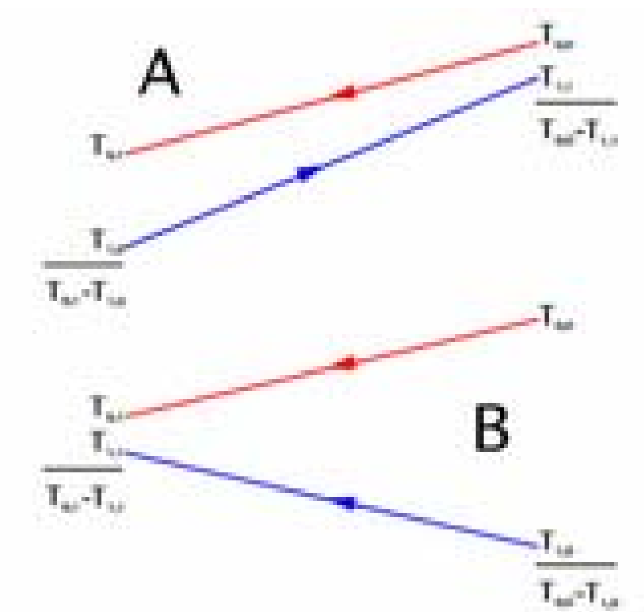
An interchangeable plate heat exchanger

Tubular heat exchanger.

A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall, so that they never mix, or they

may be in direct contact.[١] They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air.

Flow arrangement



Countercurrent (A) and parallel (B) flows

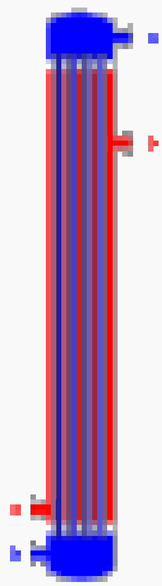
- 

Fig. ١: Shell and tube heat exchanger, single pass (١–١ parallel flow)

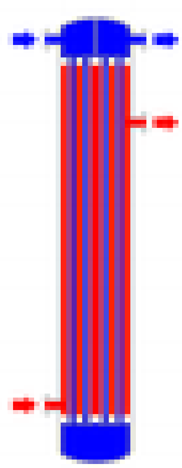
- 

Fig. ٢: Shell and tube heat exchanger, ٢-pass tube side (١–٢ crossflow)

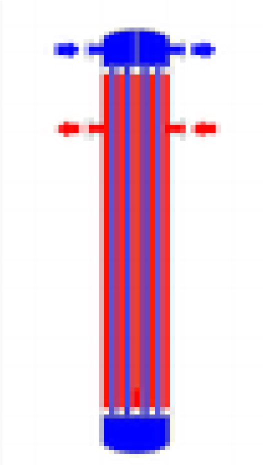


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Fig. ٣: Shell and tube heat exchanger, ٢-pass shell side, ٢-pass tube side (٢-٢ countercurrent)

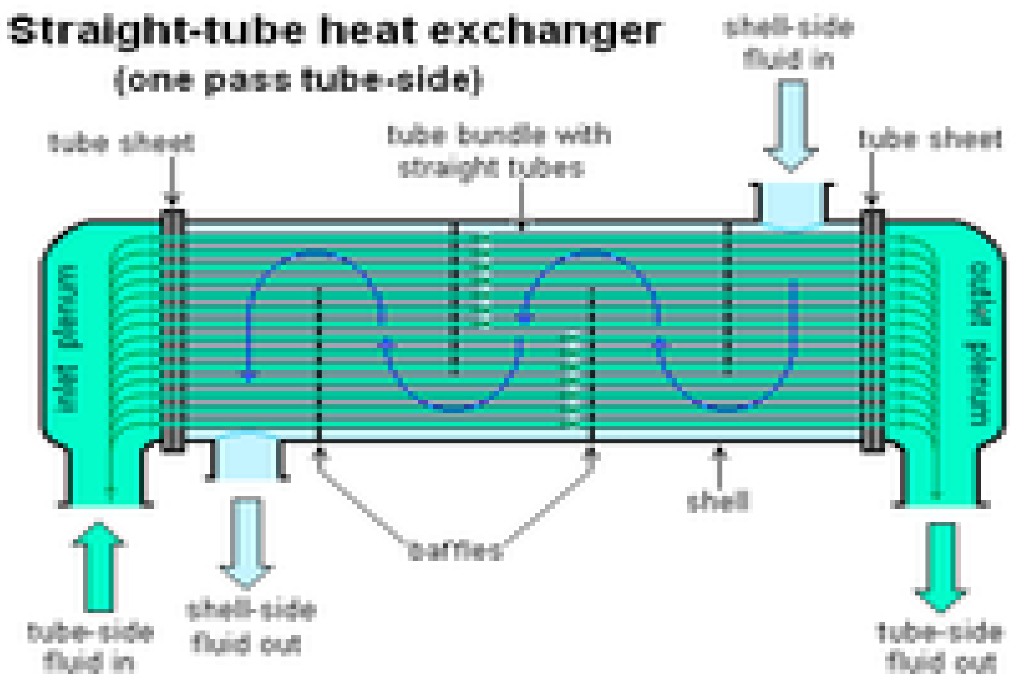
There are two primary classifications of heat exchangers according to their flow arrangement. In *parallel-flow* heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side. In *counter-flow* heat exchangers the fluids enter the exchanger from opposite ends. The counter current design is most efficient, in that it can transfer the most heat from the heat (transfer) medium. See countercurrent exchange. In a *cross-flow* heat exchanger, the fluids travel roughly perpendicular to one another through the exchanger.

For efficiency, heat exchangers are designed to maximize the surface area of the wall between the two fluids, while minimizing resistance to fluid flow through the exchanger. The exchanger's performance can also be affected by the addition of fins or corrugations in one or both directions, which increase surface area and may channel fluid flow or induce turbulence.

The driving temperature across the heat transfer surface varies with position, but an appropriate mean temperature can be defined. In most simple systems this is the "log mean temperature difference" (LMTD). Sometimes direct knowledge of the LMTD is not available and the NTU method is used.

Types of heat exchangers

Shell and tube heat exchanger



A Shell and Tube heat exchanger

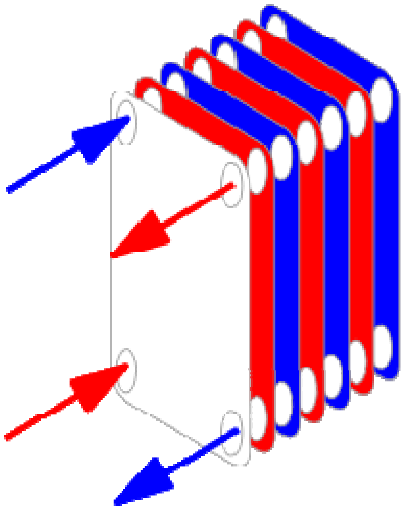
Main article: Shell and tube heat exchanger

Shell and tube heat exchangers consist of a series of tubes. One set of these tubes contains the fluid that must be either heated or cooled. The second fluid runs over the tubes that are being heated or cooled so that it can either provide the heat or absorb the heat required. A set of tubes is called the tube bundle and can be made up of several types of tubes: plain, longitudinally finned, etc. Shell and tube heat exchangers are typically used for high-pressure applications (with pressures greater than ٣٠ bar and temperatures greater than ٢٦٠ °C). This is because the shell and tube heat exchangers are robust due to their shape. There are several thermal design features that are to be taken into account when designing the tubes in the shell and tube heat exchangers. These include:

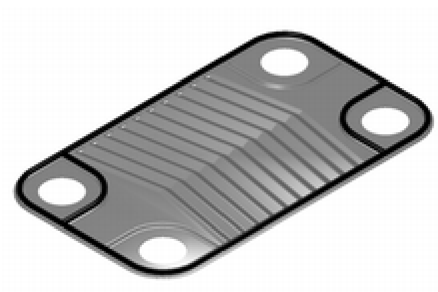
- **Tube diameter: Using a small tube diameter makes the heat exchanger both economical and compact. However, it is more likely for the heat exchanger to foul up faster and the small size makes mechanical cleaning of the fouling difficult. To prevail over the fouling and cleaning problems, larger tube diameters can be used. Thus to determine the tube diameter, the available space, cost and the fouling nature of the fluids must be considered.**
- **Tube thickness: The thickness of the wall of the tubes is usually determined to ensure:**
  - **There is enough room for corrosion**
  - **That flow-induced vibration has resistance**

- Axial strength
- Availability of spare parts
- Hoop strength (to withstand internal tube pressure)
- Buckling strength (to withstand overpressure in the shell)

- Tube length: heat exchangers are usually cheaper when they have a smaller shell diameter and a long tube length. Thus, typically there is an aim to make the heat exchanger as long as physically possible whilst not exceeding production capabilities. However, there are many limitations for this, including the space available at the site where it is going to be used and the need to ensure that there are tubes available in lengths that are twice the required length (so that the tubes can be withdrawn and replaced). Also, it has to be remembered that long, thin tubes are difficult to take out and replace.
- Tube pitch: when designing the tubes, it is practical to ensure that the tube pitch (i.e., the centre-centre distance of adjoining tubes) is not less than ١.٢٥ times the tubes' outside diameter. A larger tube pitch leads to a larger overall shell diameter which leads to a more expensive heat exchanger.
- Tube corrugation: this type of tubes, mainly used for the inner tubes, increases the turbulence of the fluids and the effect is very important in the heat transfer giving a better performance.
- Tube Layout: refers to how tubes are positioned within the shell. There are four main types of tube layout, which are, triangular (٣٠°), rotated triangular (٦٠°), square (٩٠°) and rotated square (٤٥°). The triangular patterns are employed to give greater heat transfer as they force the fluid to flow in a more turbulent fashion around the piping. Square patterns are employed where high fouling is experienced and cleaning is more regular.
- Baffle Design: baffles are used in shell and tube heat exchangers to direct fluid across the tube bundle. They run perpendicularly to the shell and hold the bundle, preventing the tubes from sagging over a long length. They can also prevent the tubes from vibrating. The most common type of baffle is the segmental baffle. The semicircular segmental baffles are oriented at ١٨٠ degrees to the adjacent baffles forcing the fluid to flow upward and downwards between the tube bundle. Baffle spacing is of large thermodynamic concern when designing shell and tube heat exchangers. Baffles must be spaced with consideration for the conversion of pressure drop and heat transfer. For thermo economic optimization it is suggested that the baffles be spaced no closer than ٢٠% of the shell's inner diameter. Having baffles spaced too closely causes a greater pressure drop because of flow redirection. Consequently having the baffles spaced too far apart means that there may be cooler spots in the corners between baffles. It is also important to ensure the baffles are spaced close enough that the tubes do not sag. The other main type of baffle is the disc and donut baffle which consists of two concentric baffles, the outer wider baffle looks like a donut, whilst the inner baffle is shaped as a disk. This type of baffle forces the fluid to pass around each side of the disk then through the donut baffle generating a different type of fluid flow.



Conceptual diagram of a plate and frame heat exchanger.



A single plate heat exchange

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An interchangeable plate heat exchanger applied to the system of a swimming pool

Plate heat exchanger

Main article: Plate heat exchanger

Another type of heat exchanger is the plate heat exchanger. One is composed of multiple, thin, slightly separated plates that have very large surface areas and fluid flow passages for heat transfer. This stacked-plate arrangement can be more effective, in a given space, than the shell and tube heat exchanger. Advances in gasket and brazing technology have made the plate-type heat exchanger increasingly practical. In HVAC applications, large heat exchangers of this type are called *plate-and-frame*; when used in open loops, these heat exchangers are normally of the gasket type to allow periodic disassembly, cleaning, and inspection. There are many types of permanently bonded plate heat exchangers, such as dip-brazed and vacuum-brazed plate varieties, and they are often specified for closed-loop applications such as refrigeration. Plate heat exchangers also differ in the types of plates that are used, and in the configurations of those plates. Some plates may be stamped with "chevron" or other patterns, where others may have machined fins and/or grooves.

Adiabatic wheel heat exchanger

A third type of heat exchanger uses an intermediate fluid or solid store to hold heat, which is then moved to the other side of the heat exchanger to be released. Two examples of this are adiabatic wheels, which consist of a large wheel with fine threads rotating through the hot and cold fluids, and fluid heat exchangers.

Plate fin heat exchanger

Main article: Plate fin heat exchanger

This type of heat exchanger uses "sandwiched" passages containing fins to increase the effectivity of the unit. The designs include crossflow and counterflow coupled with various fin configurations such as straight fins, offset fins and wavy fins.

Plate and fin heat exchangers are usually made of aluminium alloys which provide higher heat transfer efficiency. The material enables the system to operate at a lower temperature and reduce the weight of the equipment. Plate and fin heat exchangers are mostly used for low temperature services such as natural gas, helium and oxygen liquefaction plants, air separation plants and transport industries such as motor and aircraft engines.

Advantages of plate and fin heat exchangers:

- **High heat transfer efficiency especially in gas treatment**
- **Larger heat transfer area**
- **Approximately ٥ times lighter in weight than that of shell and tube heat exchanger.**
- **Able to withstand high pressure**

Disadvantages of plate and fin heat exchangers:

- **Might cause clogging as the pathways are very narrow**
- **Difficult to clean the pathways**
- **Aluminum alloys are susceptible to Mercury Liquid Embrittlement Failure**

Pillow plate heat exchanger

A pillow plate exchanger is commonly used in the dairy industry for cooling milk in large direct-expansion stainless steel bulk tanks. The pillow plate allows for cooling across nearly the entire surface area of the tank, without gaps that would occur between pipes welded to the exterior of the tank.

The pillow plate is constructed using a thin sheet of metal spot-welded to the surface of another thicker sheet of metal. The thin plate is welded in a regular pattern of dots or with a serpentine pattern of weld lines. After welding the enclosed space is pressurized with sufficient force to cause the thin metal to bulge out around the welds, providing a space for heat exchanger liquids to flow, and creating a characteristic appearance of a swelled pillow formed out of metal.

Fluid heat exchangers

This is a heat exchanger with a gas passing upwards through a shower of fluid (often water), and the fluid is then taken elsewhere before being cooled. This is commonly used for cooling gases whilst also removing certain impurities, thus solving two problems at

once. It is widely used in espresso machines as an energy-saving method of cooling super-heated water to be used in the extraction of espresso.

Waste heat recovery units

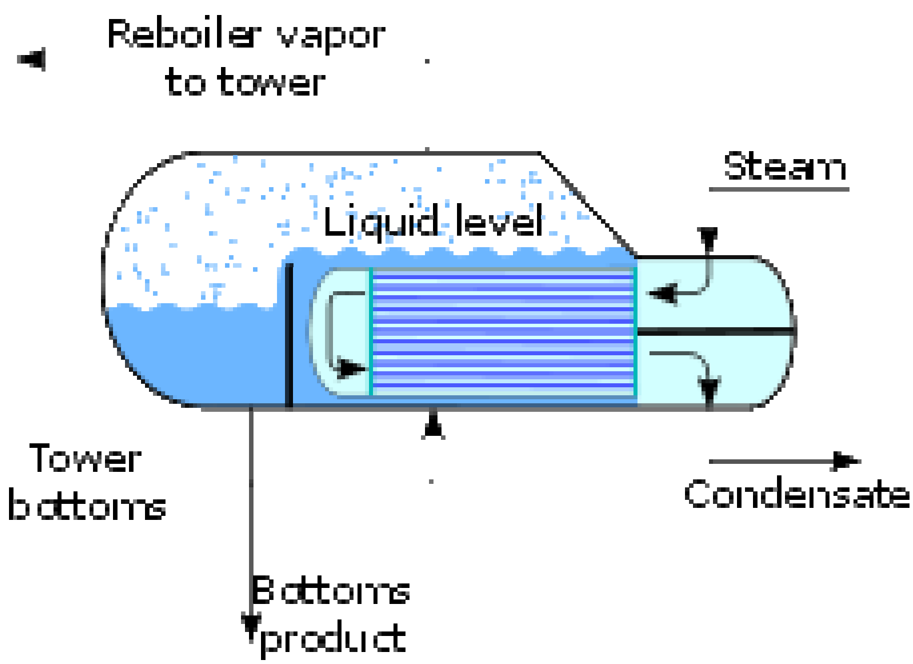
A Waste Heat Recovery Unit (WHRU) is a heat exchanger that recovers heat from a hot gas stream while transferring it to a working medium, typically water or oils. The hot gas stream can be the exhaust gas from a gas turbine or a diesel engine or a waste gas from industry or refinery.

Dynamic scraped surface heat exchanger

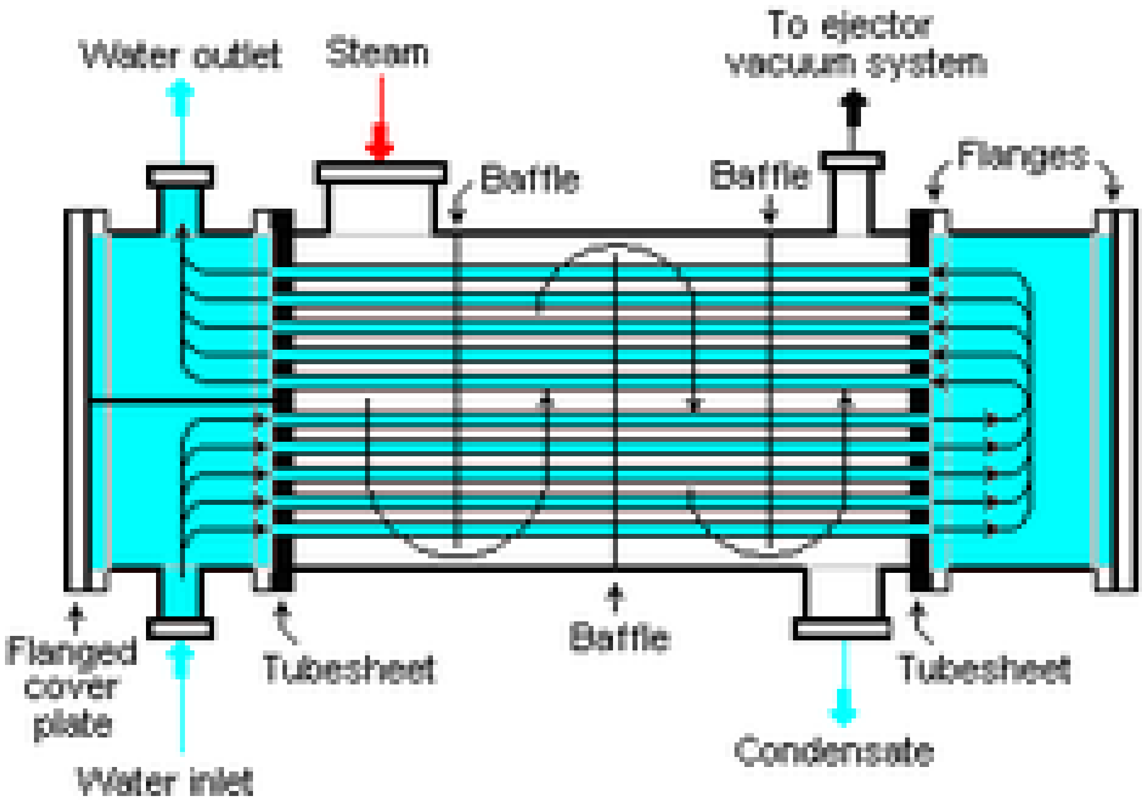
Another type of heat exchanger is called "(dynamic) scraped surface heat exchanger". This is mainly used for heating or cooling with high-viscosity products, crystallization processes, evaporation and high-fouling applications. Long running times are achieved due to the continuous scraping of the surface, thus avoiding fouling and achieving a sustainable heat transfer rate during the process.

The formula used for this will be Q=A*U*LMTD, whereby Q= amount of heat transferred; U= heat transfer coefficient; A=Heat Transfer Area; LMTD = Log mean temperature differential

Phase-change heat exchangers



Typical kettle reboiler used for industrial distillation towers



Typical water-cooled surface condenser

In addition to heating up or cooling down fluids in just a single phase, heat exchangers can be used either to heat a liquid to evaporate (or boil) it or used as condensers to cool a vapor and condense it to a liquid. In chemical plants and refineries, reboilers used to heat incoming feed for distillation towers are often heat exchangers.

Distillation set-ups typically use condensers to condense distillate vapors back into liquid.

Power plants which have steam-driven turbines commonly use heat exchangers to boil water into steam. Heat exchangers or similar units for producing steam from water are often called boilers or steam generators.

In the nuclear power plants called pressurized water reactors, special large heat exchangers which pass heat from the primary (reactor plant) system to the secondary (steam plant) system, producing steam from water in the process, are called steam generators. All fossil-fueled and nuclear power plants using steam-driven turbines have surface condensers to convert the exhaust steam from the turbines into condensate (water) for re-use.

To conserve energy and cooling capacity in chemical and other plants, regenerative heat exchangers can be used to transfer heat from one stream that needs to be cooled to another stream that needs to be heated, such as distillate cooling and reboiler feed pre-heating.

This term can also refer to heat exchangers that contain a material within their structure that has a change of phase. This is usually a solid to liquid phase due to the small volume difference between these states. This change of phase effectively acts as a buffer because it occurs at a constant temperature but still allows for the heat exchanger to accept additional heat. One example where this has been investigated is for use in high power aircraft electronics.

Direct contact heat exchangers

Direct contact heat exchangers involve heat transfer between hot and cold streams of two phases in the absence of a separating wall Thus such heat exchangers can be classified as:

- Gas – liquid
- Immiscible liquid – liquid
- Solid-liquid or solid – gas

Most direct contact heat exchangers fall under the Gas- Liquid category, where heat is transferred between a gas and liquid in the form of drops, films or sprays.

Such types of heat exchangers are used predominantly in air conditioning, humidification, water cooling and condensing plants.

Phases	Continuous phase	Driving force	Change of phase	Examples
Gas – Liquid	Gas	Gravity	No	Spray columns, packed columns
			Yes	Cooling towers, falling droplet evaporators
		Forced	No	Spray coolers/quenchers
		Liquid flow	Yes	Spray condensers/evaporation, jet condensers
	Liquid	Gravity	No	Bubble columns, perforated tray columns
			Yes	Bubble column condensers
		Forced	No	Gas spargers

Gas flow	Yes	Direct contact evaporators, submerged combustion

HVAC air coils

One of the widest uses of heat exchangers is for air conditioning of buildings and vehicles. This class of heat exchangers is commonly called *air coils*, or just *coils* due to their often-serpentine internal tubing. Liquid-to-air, or air-to-liquid HVAC coils are typically of modified crossflow arrangement. In vehicles, heat coils are often called heater cores.

On the liquid side of these heat exchangers, the common fluids are water, a water-glycol solution, steam, or a refrigerant. For *heating coils*, hot water and steam are the most common, and this heated fluid is supplied by boilers, for example. For *cooling coils*, chilled water and refrigerant are most common. Chilled water is supplied from a chiller that is potentially located very far away, but refrigerant must come from a nearby condensing unit. When a refrigerant is used, the cooling coil is the evaporator in the vapor-compression refrigeration cycle. HVAC coils that use this direct-expansion of refrigerants are commonly called *DX coils*.

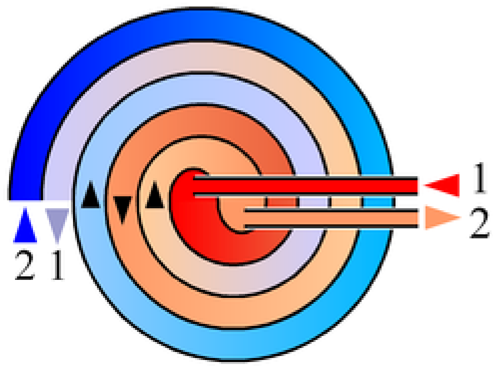
On the air side of HVAC coils a significant difference exists between those used for heating, and those for cooling. Due to psychrometrics, air that is cooled often has moisture condensing out of it, except with extremely dry air flows. Heating some air increases that airflow's capacity to hold water. So heating coils need not consider moisture condensation on their air-side, but cooling coils *must* be adequately designed and selected to handle their particular *latent* (moisture) as well as the *sensible* (cooling) loads. The water that is removed is called *condensate*.

For many climates, water or steam HVAC coils can be exposed to freezing conditions. Because water expands upon freezing, these somewhat expensive and difficult to replace thin-walled heat exchangers can easily be damaged or destroyed by just one freeze. As such, freeze protection of coils is a major concern of HVAC designers, installers, and operators.

The introduction of indentations placed within the heat exchange fins controlled condensation, allowing water molecules to remain in the cooled air. This invention allowed for refrigeration without icing of the cooling mechanism.[١١]

The heat exchangers in direct-combustion furnaces, typical in many residences, are not 'coils'. They are, instead, gas-to-air heat exchangers that are typically made of stamped steel sheet metal. The combustion products pass on one side of these heat exchangers, and air to be conditioned on the other. A *cracked heat exchanger* is therefore a dangerous situation requiring immediate attention because combustion products are then likely to enter the building.

Spiral heat exchangers



Schematic drawing of a spiral heat exchanger.

A spiral heat exchanger (SHE), may refer to a helical (coiled) tube configuration, more generally, the term refers to a pair of flat surfaces that are coiled to form the two channels in a counter-flow arrangement. Each of the two channels has one long curved path. A pair of fluid ports are connected tangentially to the outer arms of the spiral, and axial ports are common, but optional.

The main advantage of the SHE is its highly efficient use of space. This attribute is often leveraged and partially reallocated to gain other improvements in performance, according to well known tradeoffs in heat exchanger design. (A notable tradeoff is capital cost vs operating cost.) A compact SHE may be used to have a smaller footprint and thus lower all-around capital costs, or an over-sized SHE may be used to have less pressure drop, less pumping energy, higher thermal efficiency, and lower energy costs.

Construction

The distance between the sheets in the spiral channels are maintained by using spacer studs that were welded prior to rolling. Once the main spiral pack has been rolled, alternate top and bottom edges are welded and each end closed by a gasketed flat or conical cover bolted

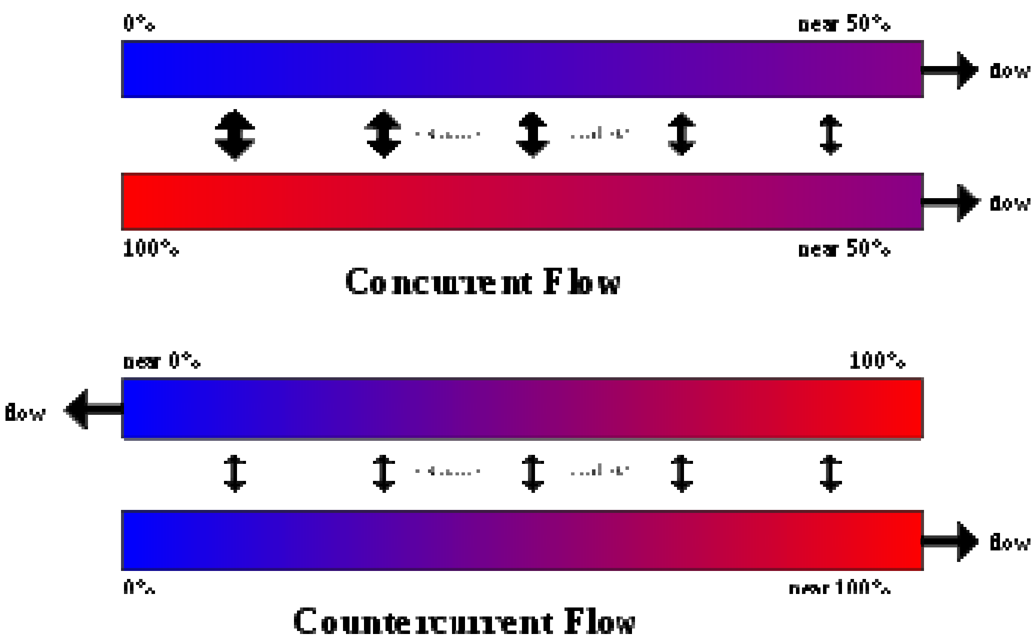
to the body. This ensures no mixing of the two fluids will occur. If a leakage happens, it will be from the periphery cover to the atmosphere, or to a passage containing the same fluid.

Self cleaning

SHEs are often used in the heating of fluids which contain solids and thus have a tendency to foul the inside of the heat exchanger. The low pressure drop gives the SHE its ability to handle fouling more easily. The SHE uses a "self cleaning" mechanism, whereby fouled surfaces cause a localized increase in fluid velocity, thus increasing the drag (or fluid friction) on the fouled surface, thus helping to dislodge the blockage and keep the heat exchanger clean. "The internal walls that make up the heat transfer surface are often rather thick, which makes the SHE very robust, and able to last a long time in demanding environments." They are also easily cleaned, opening out like an oven where any build up of foulant can be removed by pressure washing.

Self-Cleaning Water filters are used to keep the system clean and running without the need to shut down or replace cartridges and bags.

Flow Arrangements



Concurrent and countercurrent flow.

There are three main types of flows in a spiral heat exchanger:

١. **Counter-current Flow: Fluids flow in opposite directions. These are used for liquid-liquid, condensing and gas cooling applications. Units are usually mounted vertically when condensing vapor and mounted horizontally when handling high concentrations of solids.**
٢. **Spiral Flow/Cross Flow: One fluid is in spiral flow and the other in a cross flow. Spiral flow passages are welded at each side for this type of spiral heat exchanger. This type of flow is suitable for handling low density gases which passes through the cross flow, avoiding pressure loss. It can be used for liquid-liquid applications if one liquid has a considerably greater flow rate than the other.**
٣. **Distributed Vapor/Spiral flow: This design is a condenser, and is usually mounted vertically. It is designed to cater for the sub-cooling of both condensate and non-condensable. The coolant moves in a spiral and leaves via the top. Hot gases that enter leave as condensate via the bottom outlet.**

Applications

The SHE is good for applications such as pasteurization, digester heating, heat recovery, pre-heating (see: recuperator), and effluent cooling. For sludge treatment, SHEs are generally smaller than other types of heat exchangers.

Selection

Due to the many variables involved, selecting optimal heat exchangers is challenging. Hand calculations are possible, but much iteration is typically needed. As such, heat exchangers are most often selected via computer programs, either by system designers, who are typically engineers, or by equipment vendors.

In order to select an appropriate heat exchanger, the system designers (or equipment vendors) would firstly consider the design limitations for each heat exchanger type. Although cost is often the first criterion evaluated, there are several other important selection criteria which include:

- **High/ Low pressure limits**
- **Thermal Performance**
- **Temperature ranges**
- **Product Mix (liquid/liquid, particulates or high-solids liquid)**
- **Pressure Drops across the exchanger**
- **Fluid flow capacity**
- **Clean ability, maintenance and repair**
- **Materials required for construction**

- Ability and ease of future expansion

Choosing the right heat exchanger (HX) requires some knowledge of the different heat exchanger types, as well as the environment in which the unit must operate. Typically in the manufacturing industry, several differing types of heat exchangers are used for just the one process or system to derive the final product. For example, a kettle HX for pre-heating, a double pipe HX for the 'carrier' fluid and a plate and frame HX for final cooling. With sufficient knowledge of heat exchanger types and operating requirements, an appropriate selection can be made to optimise the process.

Monitoring and maintenance

Online monitoring of commercial heat exchangers is done by tracking the overall heat transfer coefficient. The overall heat transfer coefficient tends to decline over time due to fouling.

$$U=Q/A\Delta T_{lm}$$

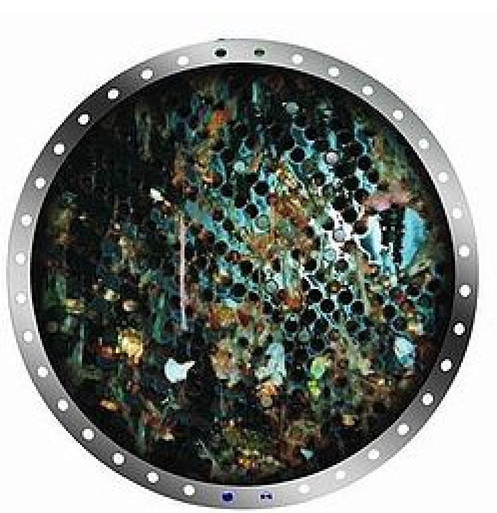
By periodically calculating the overall heat transfer coefficient from exchanger flow rates and temperatures, the owner of the heat exchanger can estimate when cleaning the heat exchanger will be economically attractive.

Integrity inspection of plate and tubular heat exchanger can be tested in situ by the conductivity or helium gas methods. These methods confirm the integrity of the plates or tubes to prevent any cross contamination and the condition of the gaskets.

Mechanical integrity monitoring of heat exchanger tubes may be conducted through Nondestructive methods such as eddy current testing.

Fouling

Main article: Fouling



A heat exchanger in a steam power station contaminated with macrofouling.

Fouling occurs when impurities deposit on the heat exchange surface. Deposition of these impurities can be caused by:

- **Low wall shear stress**
- **Low fluid velocities**
- **High fluid velocities**
- **Reaction product solid precipitation**
- **Precipitation of dissolved impurities due to elevated wall temperatures**

The rate of heat exchanger fouling is determined by the rate of particle deposition less re-entrainment/suppression. This model was originally proposed in ١٩٥٩ by Kern and Seaton.

Crude Oil Exchanger Fouling. In commercial crude oil refining, crude oil is heated from ٢١ °C to ٣٤٣ °C prior to entering the distillation column. A series of shell and tube heat exchangers is typically used to exchange heat between the crude oil and other oil streams, in order to get the crude to ٢٦٠ °C prior to heating in a furnace. Fouling occurs on the crude side of these exchangers due to asphalting insolubility. The nature of asphalting solubility in crude oil was successfully modeled by Wiehe and Kennedy. The precipitation of insoluble asphaltenes in crude preheat trains has been successfully modeled as a first order reaction by Ebert and Paschal who expanded on the work of Kern and Seaton.

Cooling Water Fouling. Cooling water systems are susceptible to fouling. Cooling water typically has high total dissolved solids content and suspended colloidal solids. Localized precipitation of dissolved solids occurs at the heat exchange surface due to wall temperatures higher than bulk fluid temperature. Low fluid velocities (less than ٣ ft/s) allow suspended solids to settle on the heat exchange surface. Cooling water is typically on the tube side of a shell and tube exchanger because it's easy to clean. To prevent fouling, designers typically ensure that cooling water velocity is greater than ٠.٩ m/s and bulk fluid temperature is maintained less than ٦٠ °C. Other approaches to control fouling control combine the "blind" application of biocides and anti-scale chemicals with periodic lab testing.

Maintenance

Plate heat exchangers need to be disassembled and cleaned periodically. Tubular heat exchangers can be cleaned by such methods as acid cleaning, sandblasting, high-pressure water jet, bullet cleaning, or drill rods.

In large-scale cooling water systems for heat exchangers, water treatment such as purification, addition of chemicals, and testing, is used to minimize fouling of the heat exchange equipment. Other water treatment is also used in steam systems for power plants, etc. to minimize fouling and corrosion of the heat exchange and other equipment.

A variety of companies have started using water borne oscillations technology to prevent biofouling. Without the use of chemicals, this type of technology has helped in providing a low-pressure drop in heat exchangers.

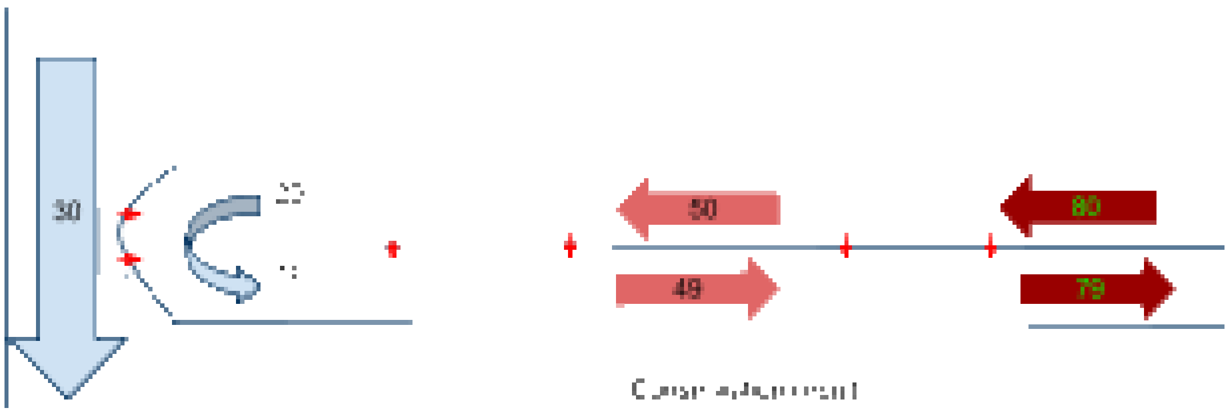
In nature

Humans

The human nasal passages serve as a heat exchanger, which warms air being inhaled and cools air being exhaled. You can demonstrate its effectiveness by putting your hand in front of your face and exhaling, first through your nose and then through your mouth. Air exhaled through your nose will be substantially cooler.

In species that have external testes (such as humans), the artery to the testis is surrounded by a mesh of veins called the pampiniform plexus. This cools the blood heading to the testis, while reheating the returning blood.

Birds, fish, marine mammals



Countercurrent exchange conservation circuit

"Countercurrent" heat exchangers occur naturally in the circulation system of fish, whales and other marine mammals. Arteries to the skin carrying warm blood are intertwined with veins from the skin carrying cold blood, causing the warm arterial blood to exchange heat with the cold venous blood. This reduces the overall heat loss in cold waters. Heat exchangers are also present in the tongue of baleen whales as large volumes of water flow through their mouths Wading birds use a similar system to limit heat losses from their body through their legs into the water.

In industry

Heat exchangers are widely used in industry both for cooling and heating large scale industrial processes. The type and size of heat exchanger used can be tailored to suit a process depending on the type of fluid, its phase, temperature, density, viscosity, pressures, chemical composition and various other thermodynamic properties.

In many industrial processes there is waste of energy or a heat stream that is being exhausted, heat exchangers can be used to recover this heat and put it to use by heating a different stream in the process. This practice saves a lot of money in industry as the heat supplied to other streams from the heat exchangers would otherwise come from an external source which is more expensive and more harmful to the environment.

Heat exchangers are used in many industries, some of which include:

- Waste water treatment
- Refrigeration systems
- Wine-brewery industry
- Petroleum industry.

In the waste water treatment industry, heat exchangers play a vital role in maintaining optimal temperatures within anaerobic digesters so as to promote the growth of microbes which remove pollutants from the waste water. The common types of heat exchangers used in this application are the double pipe heat exchanger as well as the plate and frame heat exchanger.

In aircraft

In commercial aircraft heat exchangers are used to take heat from the engine's oil system to heat cold fuel. This improves fuel efficiency, as well as reduces the possibility of water entrapped in the fuel freezing in components.

Early ٢٠٠٨, a Boeing ٧٧٧ flying as British Airways Flight ٣٨ crashed just short of the runway. In an early-٢٠٠٩ Boeing-update sent to aircraft operators, the problem was identified as specific to the Rolls-Royce engine oil-fuel flow heat exchangers. Other heat exchangers, or Boeing ٧٧٧ aircraft powered by GE or Pratt and Whitney engines, were not affected by the problem.

A model of a simple heat exchanger

A simple heat exchanger might be thought of as two straight pipes with fluid flow, which are thermally connected. Let the pipes be of equal length L, carrying fluids with heat capacity C_i (energy per unit mass per unit change in temperature) and let the mass flow rate of the fluids through the pipes be j_i (mass per unit time), where the subscript i applies to pipe ١ or pipe ٢.

The temperature profiles for the pipes are $T_١(x)$ and $T_٢(x)$ where x is the distance along the pipe. Assume a steady state, so that the temperature profiles are not functions of time. Assume also that the only transfer of heat from a small volume of fluid in one pipe is to the

fluid element in the other pipe at the same position. There will be no transfer of heat along a pipe due to temperature differences in that pipe. By Newton's law of cooling the rate of change in energy of a small volume of fluid is proportional to the difference in temperatures between it and the corresponding element in the other pipe:

$$\frac{du_1}{dt} = \gamma(T_2 - T_1)$$

$$\frac{du_2}{dt} = \gamma(T_1 - T_2)$$

Where $u_i(x)$ is the thermal energy per unit length and γ is the thermal connection constant per unit length between the two pipes. This change in internal energy results in a change in the temperature of the fluid element. The time rate of change for the fluid element being carried along by the flow is:

$$\frac{du_1}{dt} = J_1 \frac{dT_1}{dx}$$

$$\frac{du_2}{dt} = J_2 \frac{dT_2}{dx}$$

where $J_i = C_i j_i$ is the "thermal mass flow rate". The differential equations governing the heat exchanger may now be written as:

$$J_1 \frac{\partial T_1}{\partial x} = \gamma(T_2 - T_1)$$

$$J_2 \frac{\partial T_2}{\partial x} = \gamma(T_1 - T_2).$$

Note that, since the system is in a steady state, there are no partial derivatives of temperature with respect to time, and since there is no heat transfer along the pipe, there are no second derivatives in *x* as is found in the heat equation. These two coupled first-order differential equations may be solved to yield:

$$T_1 = A - \frac{Bk_1}{k}\, e^{-kx}$$

$$T_2 = A + \frac{Bk_2}{k}\, e^{-kx}$$

where $k_{١} = \gamma / J_{١}$, $k_{٢} = \gamma / J_{٢}$, $k = k_{١} + k_{٢}$ and A and B are two as yet undetermined constants of integration. Let $T_{١٠}$ and $T_{٢٠}$ be the temperatures at x=٠ and let $T_{١L}$ and $T_{٢L}$ be the temperatures at the end of the pipe at x=L. Define the average temperatures in each pipe as:

$$\overline{T}_1 = \frac{1}{L}\int_0^L T_1(x)dx$$

$$\overline{T}_2 = \frac{1}{L}\int_0^L T_2(x)dx.$$

Using the solutions above, these temperatures are:

$$T_{10} = A - \frac{Bk_1}{k} \qquad T_{20} = A + \frac{Bk_2}{k}$$

$$T_{1L} = A - \frac{Bk_1}{k}e^{-kL} \qquad T_{2L} = A + \frac{Bk_2}{k}e^{-kL}$$

$$\overline{T}_1 = A - \frac{Bk_1}{k^2L}(1 - e^{-kL}) \qquad \overline{T}_2 = A + \frac{Bk_2}{k^2L}(1 - e^{-kL}).$$

Choosing any two of the above temperatures will allow the constants of integration to be eliminated, and that will allow the other four temperatures to be found. The total energy transferred is found by integrating the expressions for the time rate of change of internal energy per unit length:

$$\frac{dU_1}{dt} = \int_0^L \frac{du_1}{dt}\,dx = J_1(T_{1L} - T_{10}) = \gamma L(\overline{T}_2 - \overline{T}_1)$$

$$\frac{dU_2}{dt} = \int_0^L \frac{du_2}{dt}\,dx = J_2(T_{2L} - T_{20}) = \gamma L(\overline{T}_1 - \overline{T}_2).$$

By the conservation of energy, the sum of the two energies is zero. The quantity $\overline{T}_2 - \overline{T}_1$ is known as the "log mean temperature difference" and is a measure

of the effectiveness of the heat exchanger in transferring heat energy.

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GOOD LUCK FOR ALLREADERS