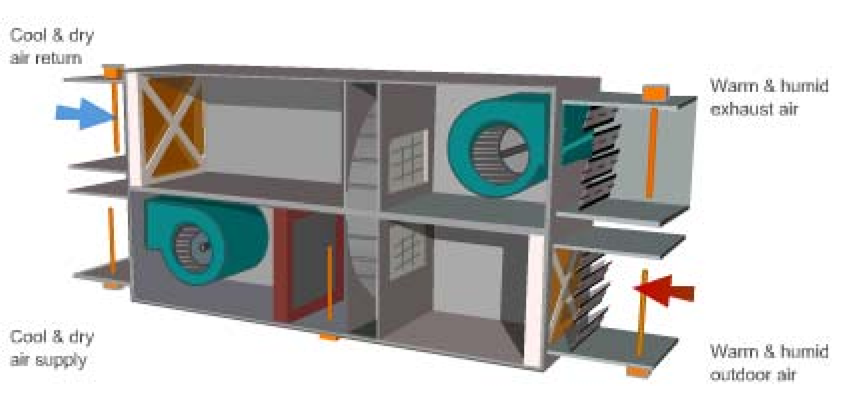

Heat Recovery System

Department of Mechanical Engineering
The University of Hong Kong

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- An Ideal Heat Recovery System
- Compliance with the Codes
- Rate of Energy Transfer and Energy Transfer
- Performance Rating
- Effectiveness
- Energy Recovery Calculation
- Procedure for determination of energy recovered

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- Fixed Plates Heat Exchangers
- Rotary air-to-air Heat Exchangers
- Heat Pipe Heat Exchangers
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- Heat Recovery Chiller Options
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Heat Recovery System

Process-to-Comfort

Comfort-to-Comfort

Process-to-Comfort

Definition

Waste heat captured from a process exhaust.

Process

Strip coating plants, can plants, pulp and paper plants,
Cogeneration
Exhaust air of boiler.

Overheat

Modulated during warm weather to prevent overheating makeup air.

The Heat

Recover **sensible heat** only (not transfer moisture between the airstreams).

Comfort-to-Comfort

Definition

Heat recovery device lowers the enthalpy of the building supply air during warm weather and raises it during cold weather

Approach

Transferring energy between the ventilation air supply and exhaust airstreams.

Product

Commercial and industrial energy recovery equipment

Residential and small-scaled commercial: Heat recovery ventilators [Small-scale packaged ventilators with built-in heat recovery components]

Sensible + Latent

Sensible heat devices (i.e., transferring sensible energy only) or total heat devices (i.e., transferring both sensible energy and moisture)

Heat Recovery Systems

Air-to-air

Energy recovery

Heat Recovery

Chiller

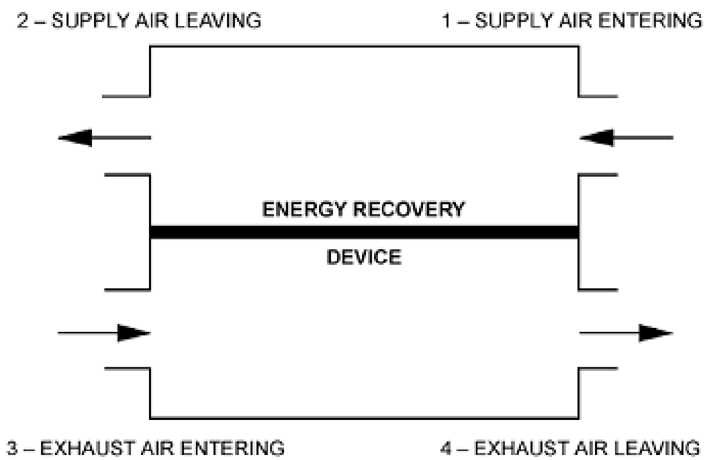
Ideal Air-to-Air Energy Exchange

Allows partial-pressure-driven moisture transfer between the streams

Totally blocks pollutants, biological contaminants & particulates between streams

Allows temperature-driven heat transfer between the airstreams

Air-to-air Energy Recovery



A heat exchanger for cooling outdoor ventilation air as air passes through it.

A heat and moisture heat exchanger →moisture from highly humid outdoor air to the less humid indoor air

Dehumidifying air to reduce its moisture content needs large amount of power.

The lowered humidity of the entering ventilation air →substantial savings of energy.

Compliance with Codes

ASHRAE Standard 90.1-2001

It sets **minimum** design requirements that encourage energy efficiency.

This standard requires the use of exhaust-air energy recovery when an individual fan system meets both of the following conditions:

- Design supply airflow equals or exceeds 2.4 m^3/s
- Minimum outdoor airflow > or = 70 % design supply airflow

Rate of Energy Transfer & Energy Transfer

Rate of energy transfer depends on:

Exchanger geometry (parallel flow/counterflow/cross-flow, number of passes, fins),

Thermal conductivity of the walls separating the streams,

Permeability of walls to gases passage.

Energy Transfer depends on :

Cross-stream dry-bulb temperature differences→ heat transfer.

Cross-stream mass transfer →Air, gases, and water vapor (may also in leakage)

Latent heat transfer as sensible heat → water vapor condenses into liquid

Performance Rating

ASHRAE Standard 84 **-** Method of Testing Air-to-Air Heat Exchangers

(1) Establishes a uniform method of testing for obtaining performance data.

(2) Specifies the data required, calculations to be used and reporting procedures for testing the performance

(3) Specifies the types of test equipment for performing such tests.

ARI Standard 1060 **-** Rating Air-to-Air Energy Recovery Ventilation Equipment

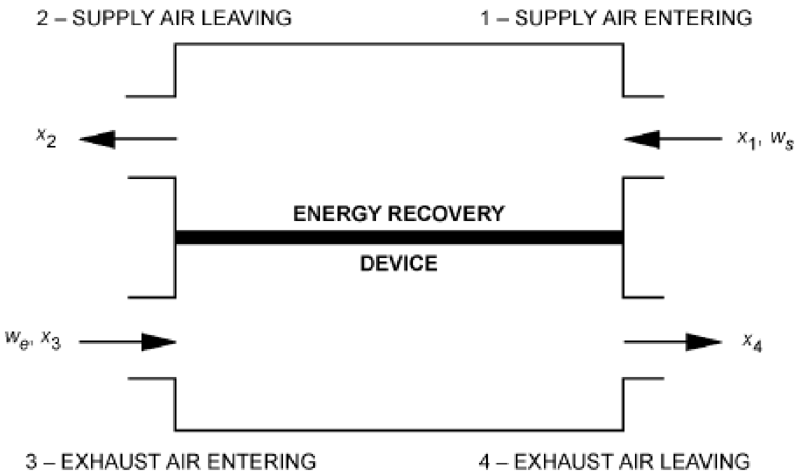
An industry-established standard for rating the performance of air-to-air heat/energy exchangers for use in energy recovery ventilation equipment.

Establishes definitions, requirements for marking and nameplate data, and conformance conditions intended for the industry.

Effectiveness

ASHRAE *Standard* 84 defines effectiveness as

$$\varepsilon = \frac{\text{Actual transfer (of moisture or energy)}}{\text{Maximum possible transfer between airstreams}}$$



ε = moisture (or water vapor mass), sensible, or total effectiveness
x = humidity ratio W, dry-bulb temperature t, or enthalpy h
w_s = supply air mass flow
w_e = exhaust air mass flow
w_{min} = the smaller of w_s and w_e

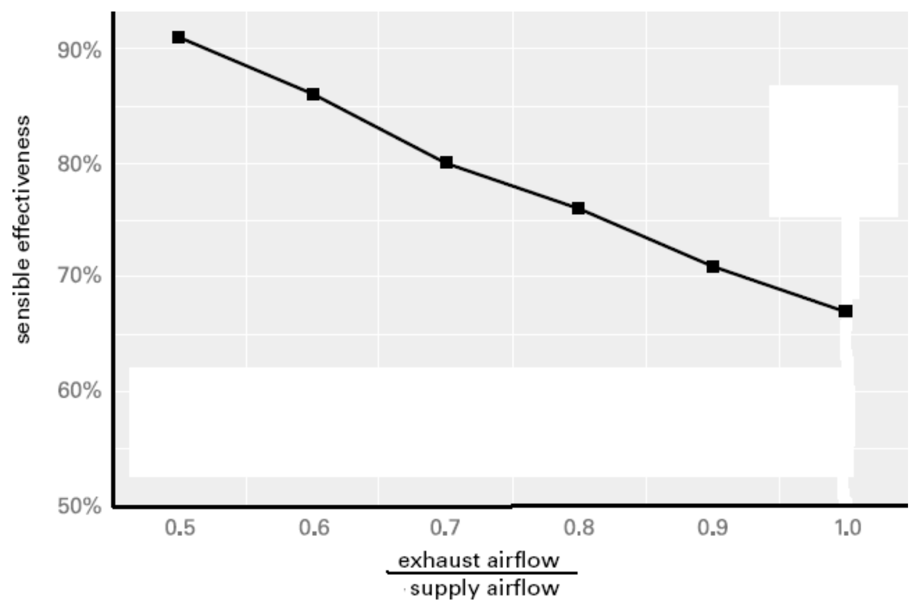
$$\varepsilon = \frac{w_s(x_2 - x_1)}{w_{min}(x_3 - x_1)} = \frac{w_e(x_3 - x_4)}{w_{min}(x_3 - x_1)}$$

The leaving supply air condition is

$$x_2 = x_1 + \varepsilon\left(\frac{w_{min}}{w_s}\right)(x_1 - x_3)$$

and the leaving exhaust air condition is:

$$x_4 = x_3 - \varepsilon\left(\frac{w_{min}}{w_e}\right)(x_1 - x_3)$$



Energy Recovery Calculation

$$q_{total} = Q\rho(h_{in} - h_{out})$$

$$q_{sensible} = Q\rho c_p(t_{in} - t_{out})$$

where

$q_{total} = q_{sensible} + q_{latent}$ = total energy transfer, kW

$q_{sensible}$ = sensible heat transfer, kW

Q = airflow rate, m^3/s

ρ = air density, kg/m^3

c_p = specific heat of air = 1.00 kJ/(kg·K)

t_{in} = dry-bulb temperature of air entering exchanger, °C

t_{out} = dry-bulb temperature of air leaving exchanger, °C

h_{in} = enthalpy of air entering heat exchanger, kJ/kg

h_{out} = enthalpy of air leaving heat exchanger, kJ/kg

Procedure for determination of energy recovered

Air-to-air energy recovery applications

Step 1. Calculate theoretical maximum moisture and energy transfer rates $w_{m,max}$ and q_{max}.

Step 2. Establish the moisture, sensible, and total effectivenesses ε_m, ε_s, and ε_t.

Step 3. Calculate actual moisture and energy (sensible and total) transfer.

$$w_m = \varepsilon_m w_{m,max}$$

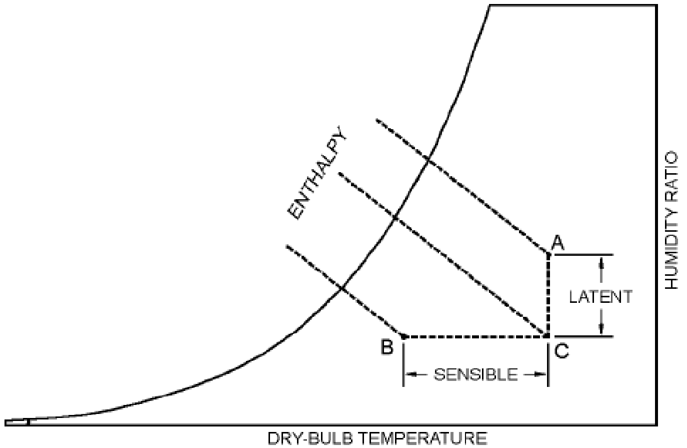
$$q_{actual} = \varepsilon q_{max}$$

where ε and q may be for sensible or total energy transfer.

Step 4. Calculate leaving air conditions for each airstream.

Step 5. Check the energy transfer balance between airstreams.

Step 6. Plot entering and leaving conditions on psychrometric chart.



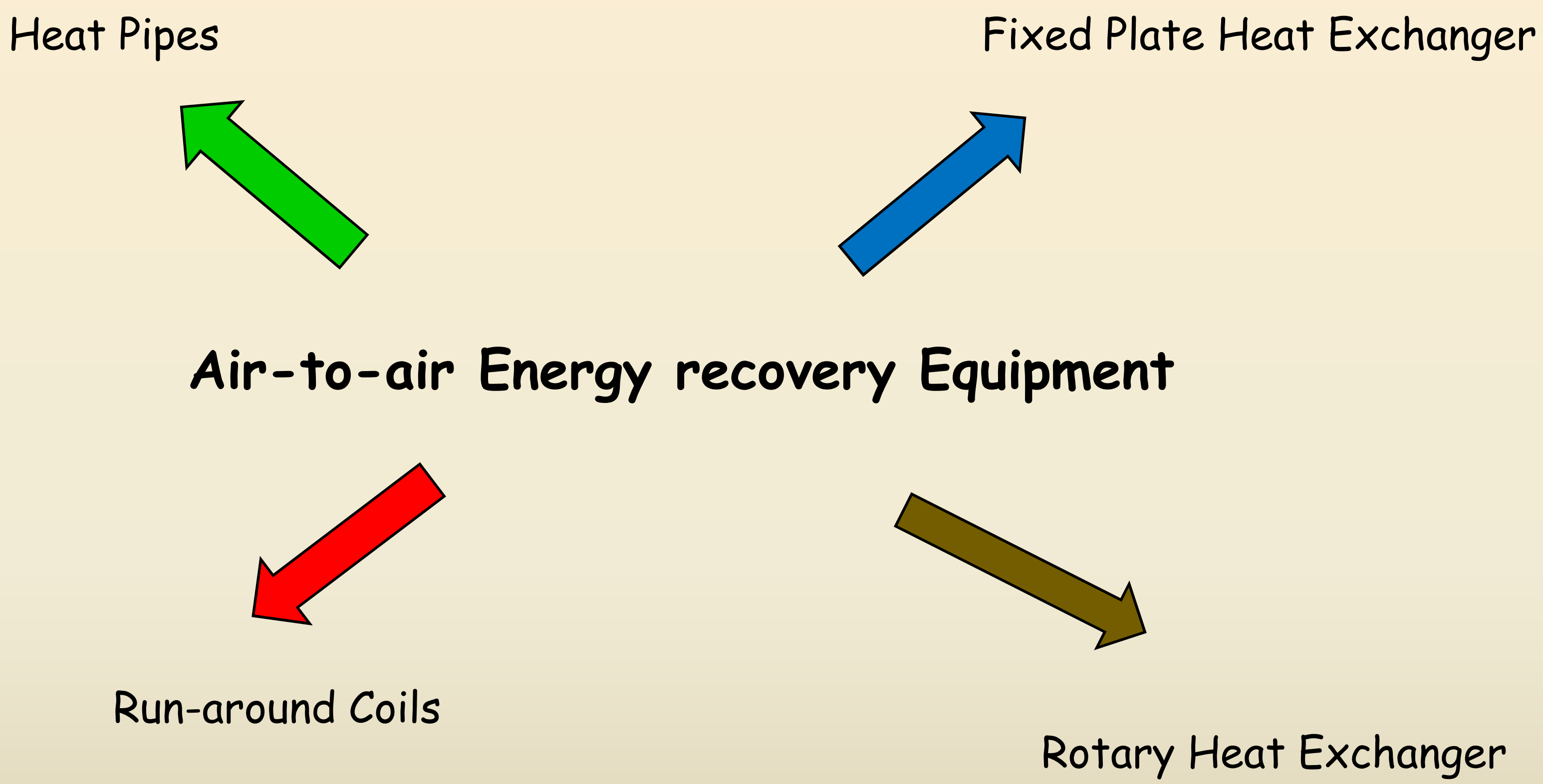
Maximum Sensible and Latent Heat from Process A-B

Sensible $q_{max} = \rho c_p Q_{min}(t_3 - t_1)$

Total $q_{max} = \rho Q_{min}(h_3 - h_1)$

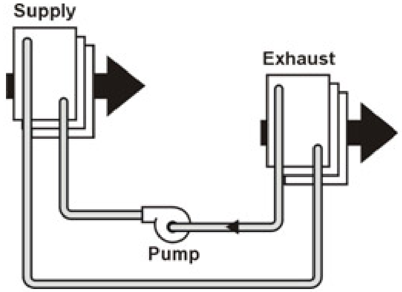
$$q_{total} = Q\rho(h_{in} - h_{out})$$

$$q_{sensible} = Q\rho c_p(t_{in} - t_{out})$$

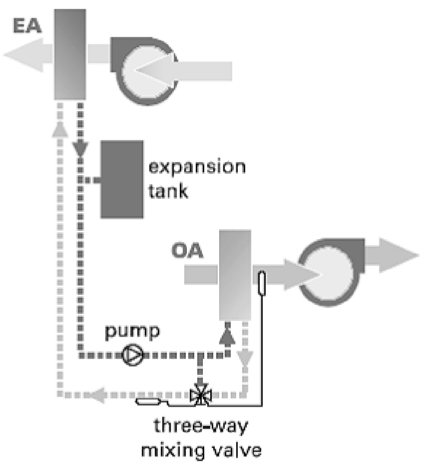

Heat Pipes
Fixed Plate Heat Exchanger
Air-to-air Energy recovery Equipment
Run-around Coils
Rotary Heat Exchanger

Common air-to-air energy-recovery technologies	
Sensible-Energy Recovery	Total-Energy Recovery
■ Coil loops	
■ Heat pipes	
■ Fixed-plate heat exchangers	
■ Rotary heat exchangers (also known as "sensible-energy wheels" or "heat wheels")	■ Rotary heat exchangers (also known as "total-energy wheels" or "enthalpy wheels")

RUN-AROUND COILS



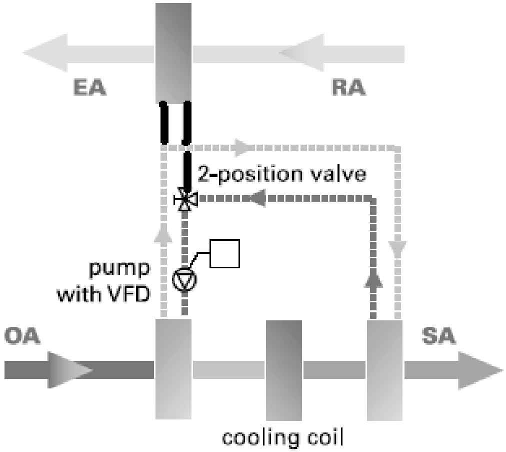
Run-around coil system



Coil loop

- The run-around coils are finned-tube copper coils placed in supply and exhaust airstreams. Also called a "coil loop"
- Two or more finned-tube coils that are piped together in a closed loop
- A small pump circulates the working fluid through the two coils
- Working fluid - a solution of inhibited glycol and water through the two coils
- An expansion tank in the system
- Modulating capacity (three-way mixing valve or a variable-speed drive on the pump)
- In summer, the exhaust air from the air-conditioned space cools the circulating fluid in the coil. The cooled fluid is then pre-cool outdoor air.
- In winter, heat is extracted from the exhaust air and then transferred to the make-up air.

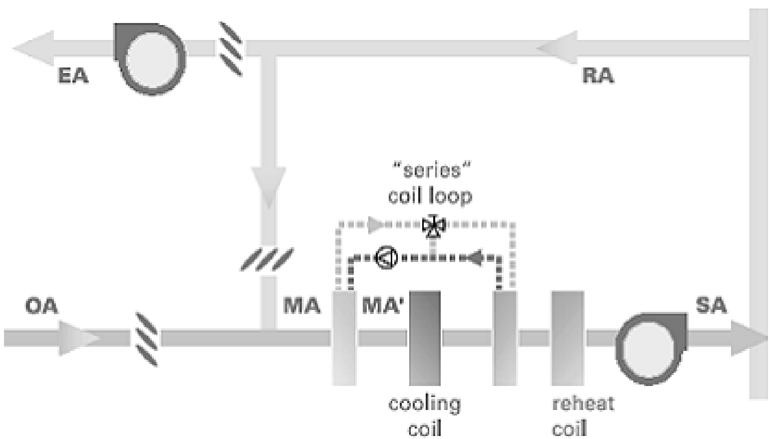
RUN-AROUND COILS



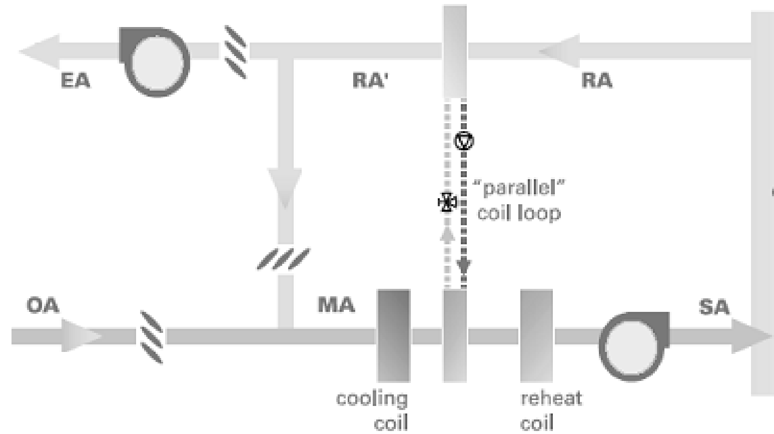
Coil loop with three coils

- The most flexible - transfer energy between air streams that are physically separated by some distance
- Recover energy from multiple exhaust-air streams (using multiple exhaust-side coils)
- Multiple coils - requires additional coils, more piping and glycol, and a larger pump.

RUN-AROUND COILS



"Series" transfer in a constant-volume, mixed-air system



"Parallel" recovery in a constant-volume, mixed-air system

RUN-AROUND COILS

Typical Performance

Coil-loop selections:

Sensible effectiveness of 45% to 65 %, balanced airflow

Airside static-pressure loss of 75-250 Pa per coil.

Varies number of rows, spacing and type of fins, face velocity, and fluid flow rate for a specific application.

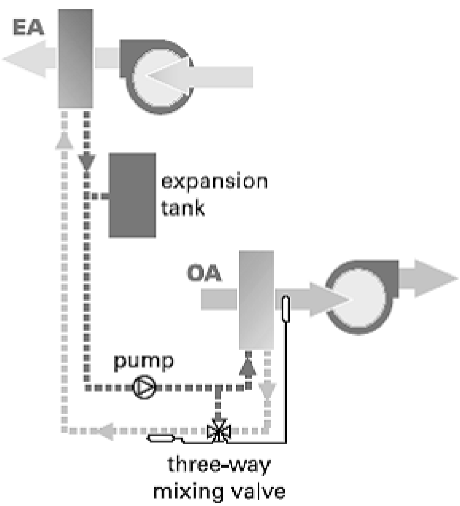
Adding more rows and fins to the coils:

→ increases the sensible effectiveness of the coil loop

→ the fan(s) to consume more energy

Net energy saved = Energy recovered - additional fan and pump energy.

RUN-AROUND COILS



Coil loop

Coils with fewer rows (four or six) and wider fin spacing (120 fins/ft)

→reduces the pressure drop

→maximize net energy savings (best payback)

Coils with more rows (8) and closely spaced fins (144 fins/ft)

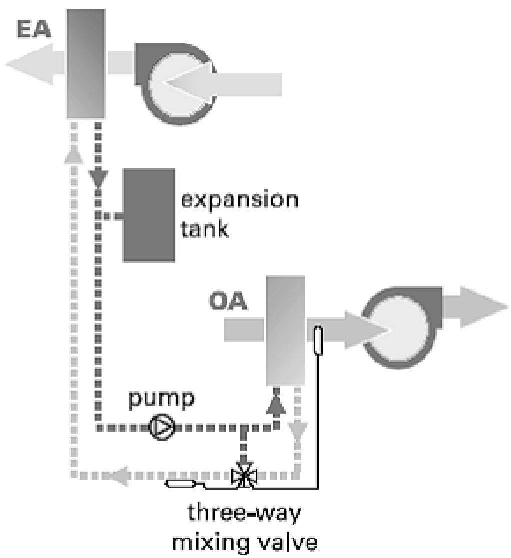
→ maximize effectiveness → max. heat recovered

Other Hints in design

For a coil loop that **reheats supply air** using series arrangement→ try to use two-row coils.

Minimizing the number of coil rows →reduce fan power.

RUN-AROUND COILS



Coil loop

Capacity Control

Three-way mixing valve or a variable-speed drive on the pump → prevent the coil loop from overheating the supply air.

A temperature sensor in the supply air stream, downstream of the supply-side coil, monitors the leaving-air temperature.

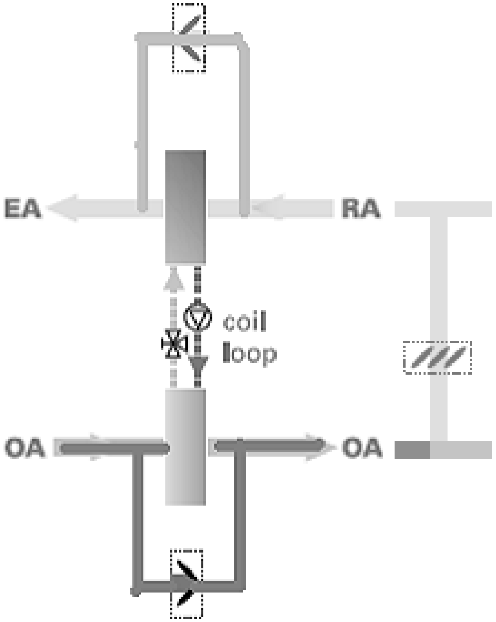
The mixing valve then appropriately modulates the fluid flow rate through the supply-side coil.

Reduce flows through the supply-side coil

→the loop adds less heat to the supply air stream/

→modulating the fluid flow rate through the entire coil loop (variable flow)

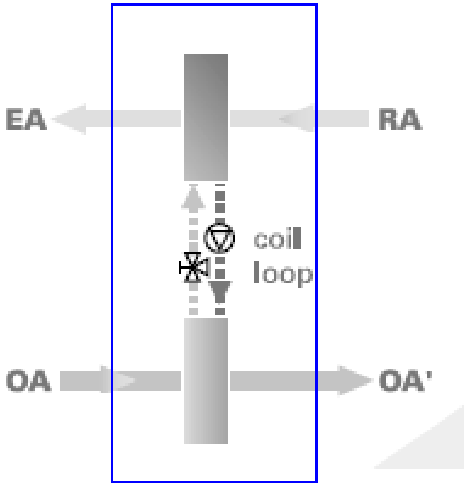
RUN-AROUND COILS



Outdoor-air preconditioning in a mixed-air system with airside economizer :

- Size the coil loop for *minimum* ventilation airflow, (not full economizer airflow).
- Use bypass dampers in both air streams to reduce fan energy consumption when the coil loop is inactive.
- Use bypass dampers not mixing valve or variable-speed drive for the pump for control capacity.

RUN-AROUND COILS



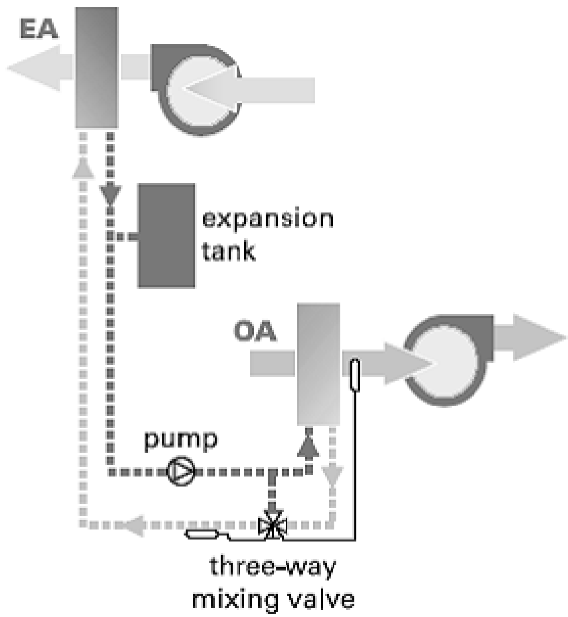
Cross-Leakage

No Cross-Leakage in principle as two air streams physically separated from each other (only working fluid to transfer heat)

Problem if the coils of the loop housing within a single air handler and its casing not leakage proof.

Pressure in exhaust side < the supply side to reduce the risk of cross-leakage .

RUN-AROUND COILS



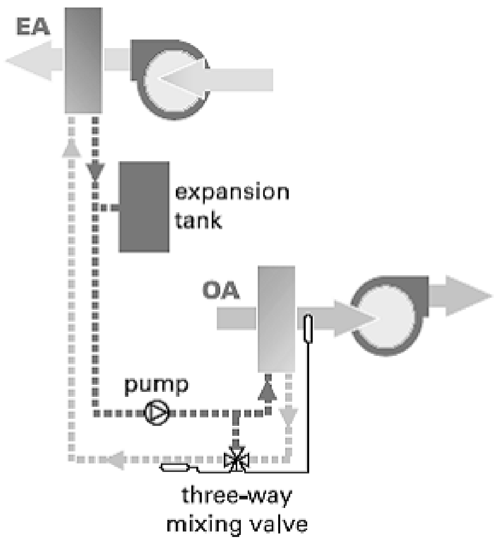
Coil loop

Considerations for recovering energy with coil loops

Advantages

- Transfers energy between air streams that are separated by distance, simplifying retrofits
- No cross-leakage between air streams
- Flexible design/application: Coils can be selected for the optimum amount of energy transfer, making them less expensive than other energy-recovery devices
- Easily turned off when energy recovery is not beneficial
- Easy to control
- Fits readily within the casing of a packaged air handler

RUN-AROUND COILS



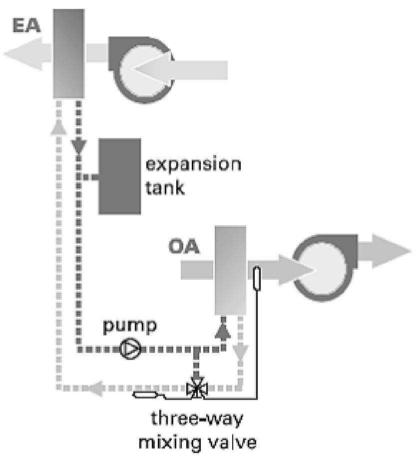
Coil loop

Considerations for recovering energy with coil loops

Disadvantages

- Transfers only sensible heat
- May require an expansion tank to accommodate expansion and contraction of heat-transfer fluid
- Requires design and field installation of piping, pump, expansion tank, and mixing valve (or variable-speed drive)
- Requires maintenance of the pump

RUN-AROUND COILS



Coil loop

Maintenance

Coil energy recovery loops require little maintenance.

The only moving parts are the circulation pump and the three-way control valve.

However, to ensure optimum operation,

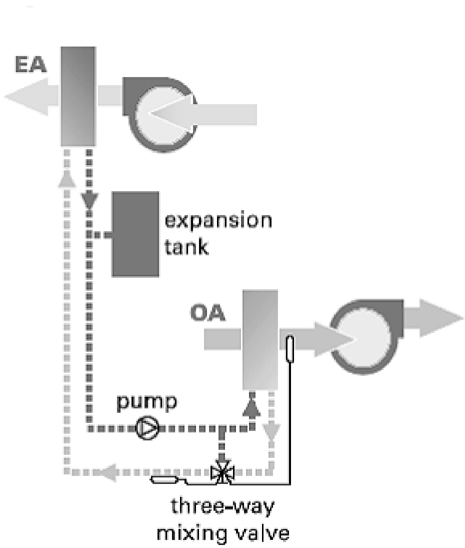
→the air should be filtered,

→the coil surface cleaned regularly,

→the pump and valve maintained,

→the transfer fluid refilled or replaced periodically.

RUN-AROUND COILS



Coil loop

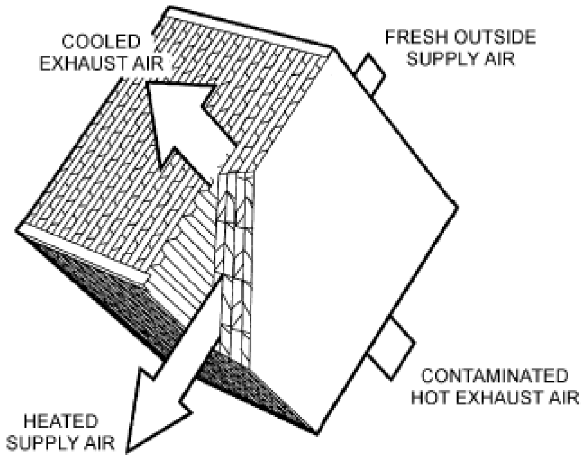
Thermal Transfer Fluids.

An inhibited ethylene glycol solution in water is commonly used when freeze protection is required.

An inhibited ethylene glycol break down to an acidic sludge at temperatures above 135°C.

A non aqueous synthetic heat transfer fluid for freeze protection and exhaust air temperatures exceed 135°C.

FIXED-PLATE EXCHANGERS



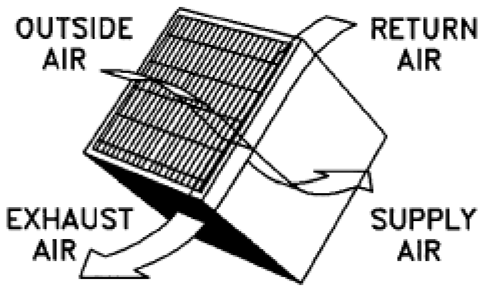
Fixed surface plate exchangers have no moving parts.

Alternate layers of plates, separated and sealed (I.e. the heat exchanger core), form the exhaust and supply airstream passages.

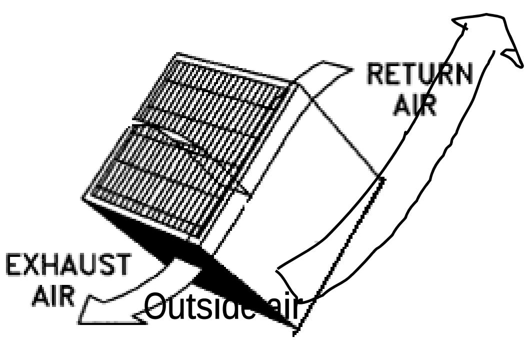
Plate spacing range from 2.5 to 12.5 mm

Heat is transferred directly from warm airstreams through separating plates into cool airstreams.

FIXED-PLATE EXCHANGERS



CROSSFLOW HEAT EXCHANGE



Counter flow Heat Exchanger

Design and construction restrictions → cross-flow heat transfer

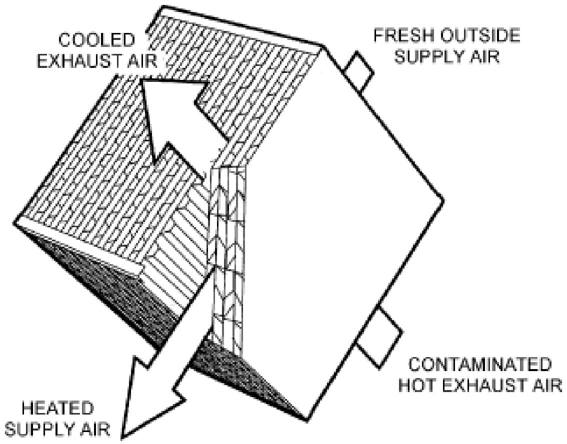
Counter flow patterns increase heat transfer effectiveness.

Latent heat of condensation = moisture condensed as the temperature of the warm (exhaust) air stream drops below its dew point

Latent heat of condensation and sensible heat are conducted through the separating plates into the cool (supply) air stream.

Moisture is not transferred.

FIXED-PLATE EXCHANGERS



Design Considerations

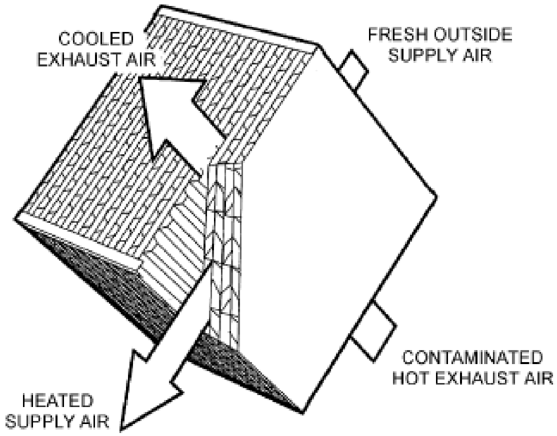
Plate exchangers are available in many configurations, materials, sizes, and flow patterns.

Many are modular, and modules can be arranged to handle almost any airflow, effectiveness, and pressure drop requirement.

Plates are formed with integral separators (e.g., ribs, dimples, ovals) or with external separators (e.g., supports, braces, corrugations).

Air stream separations are sealed by folding, multiple folding, gluing, cementing, welding, or etc.

FIXED-PLATE EXCHANGERS



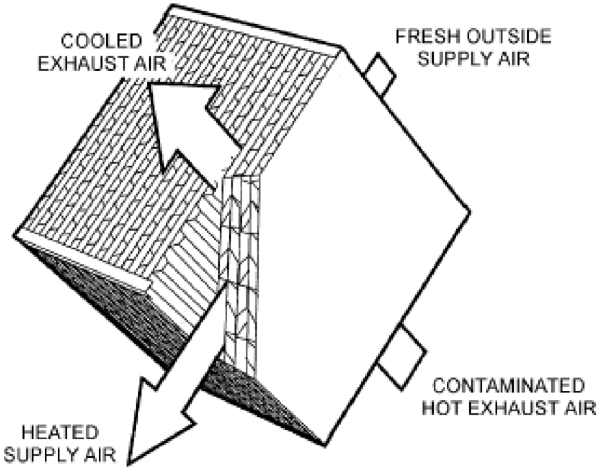
Design Considerations

Heat transfer resistance through the plates is small compared to the air stream boundary layer resistance on each side of the plates.

Aluminum is the most popular construction material for plates (its non-flammability and durability).

Polymer plate exchangers have properties that may improve heat transfer by breaking down the boundary layer and are popular because of their corrosion resistance and cost-effectiveness.

FIXED-PLATE EXCHANGERS



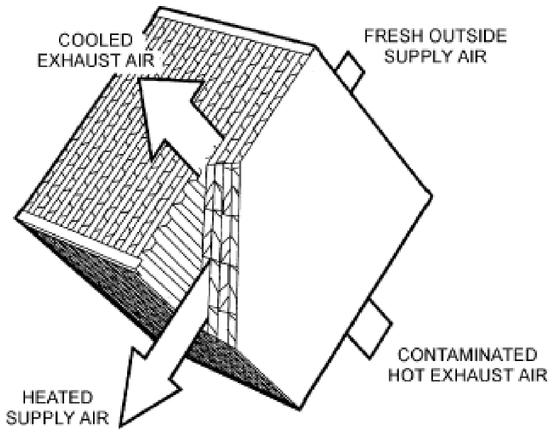
Design Considerations

Plate exchangers normally conduct sensible heat only

Water-vapor-permeable materials, such as treated paper and new microporous polymeric membranes, for transferring moisture

Plate exchangers in modular design to allow capacity each of range 0.01 to 5 m^3/s to form a one for 50 m^3/s

FIXED-PLATE EXCHANGERS



Performance

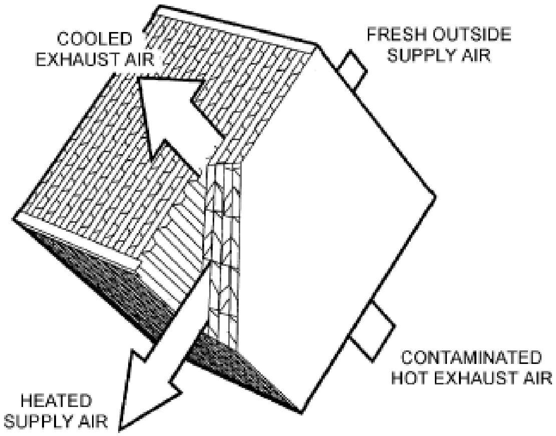
Fixed-plate heat exchangers can economically achieve high sensible heat recovery and high total energy effectiveness

A primary heat transfer surface area separating the airstreams

No additional secondary resistance (i.e., pumping liquid, or transporting a heat transfer medium) for cases of other exchangers

Simplicity and lack of moving parts → reliability, longevity, low auxiliary energy consumption, and safety performance.

FIXED-PLATE EXCHANGERS



Differential Pressure/Cross-Leakage

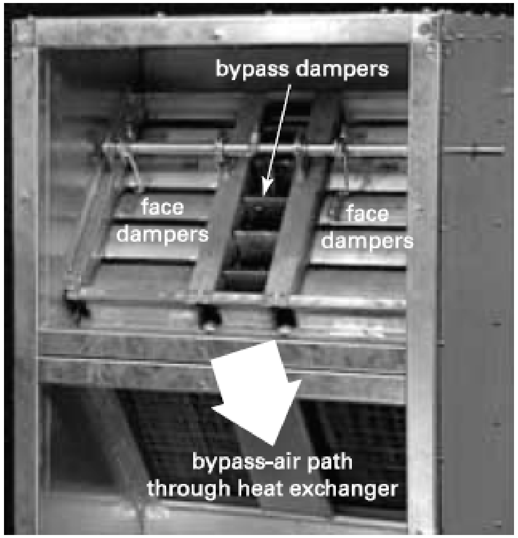
It is a static device built → little or no leakage occurs between airstreams

As velocity increases, the pressure difference between the two airstreams increases exponentially

High differential pressures may deform the separating plates or even damage the exchanger (for differential pressures > 1 kPa - rare)

High air velocities & high static pressures require special exchangers.

FIXED-PLATE EXCHANGERS



Face-and-bypass dampers

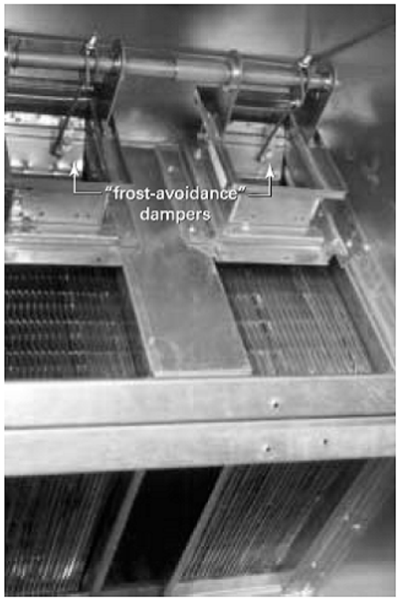
Capacity Control

Face-and-bypass dampers for control the capacity of a fixed-plate heat exchanger

Face dampers closed + Linked bypass dampers open to reduce airflow

Face-and-bypass dampers avoid overheating the supply air by reducing the amount of heat transfer that occurs in the heat exchanger.

FIXED-PLATE EXCHANGERS



"Frost-avoidance" damper

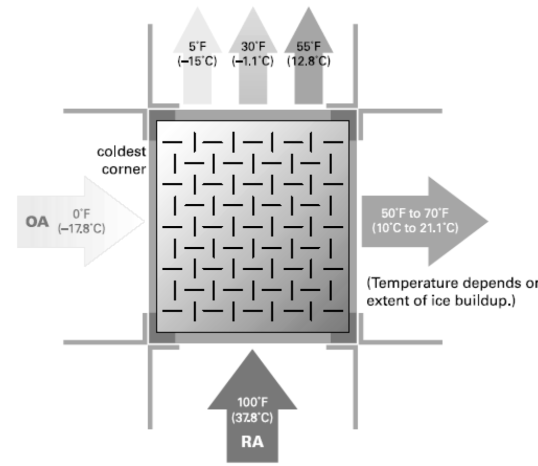
Frost Prevention

Frost is most likely to develop in the corner of the heat exchanger

Cold entering outdoor air recovers heat from the exhaust air on the leaving edge of the heat exchanger.

In this corner, exhaust air is in contact with the coldest surface of the heat exchanger, which approximates the entering outdoor-air condition.

This means that frost will form when the outdoor air drops below 0°C DB.



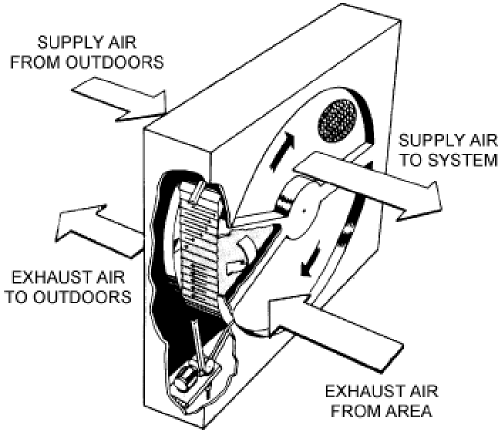
"Cold spot" in a fixed-plate heat exchanger

FIXED-PLATE EXCHANGERS

Advantages	Disadvantages
■ Relatively high sensible effectiveness	■ Transfers only sensible energy (heat)
■ Little cross-leakage between air streams	■ Requires adjacent air streams
■ Easy to clean	■ Relatively high frost threshold
	■ Heavy
	■ High first cost in large applications

Considerations for recovering energy with fixed-plate heat exchangers

ROTARY AIR-TO-AIR ENERGY EXCHANGERS



A **rotary enthalpy wheel**, has a revolving cylinder filled with an air-permeable medium having a large internal surface area.

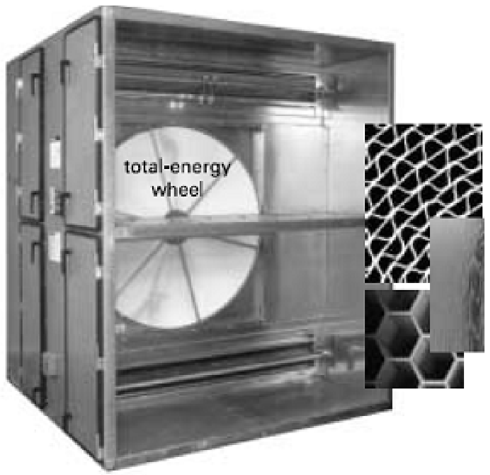
Adjacent supply and exhaust airstreams each flow through one-half the exchanger in a counterflow pattern.

Heat transfer media may be selected to recover sensible heat only or total heat (sensible heat plus latent heat).

Quite compact and with high transfer effectiveness.

A desiccant film coating on wheel surfaces absorbs moisture (wheel at more humid airstream). Moist desorbed from film → less humid airstream.

ROTARY AIR-TO-AIR ENERGY EXCHANGERS



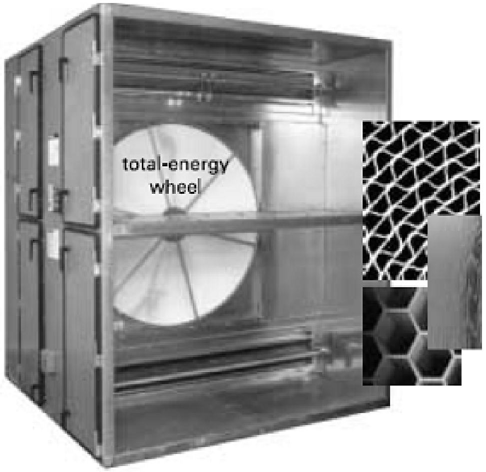
Sensible heat

The medium picks up and stores heat from the hot air stream and releases it to the cold on.

Latent heat

1. The medium condenses moisture from the airstream with the higher humidity ratio (medium temperature <dew point or by desiccants)
2. Releases the moisture through evaporation (and heat pickup) into the air stream with the lower humidity ratio.

ROTARY AIR-TO-AIR ENERGY EXCHANGERS



Construction

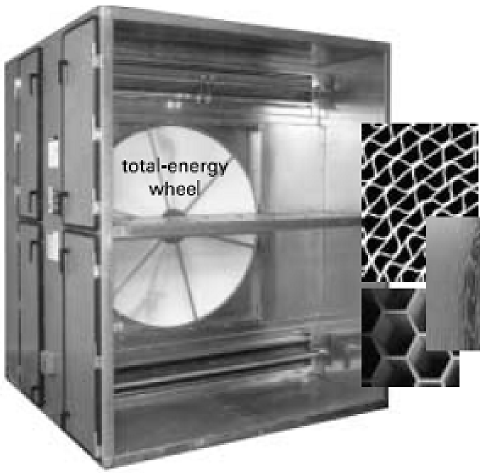
Air contaminants, dew point, exhaust air temperature, and supply air properties influence the choice of materials for the casing, rotor structure, and medium

Aluminum, steel, and polymers are the usual structural, casing, and rotor materials for normal comfort ventilating systems

Exchanger media are fabricated from metal or mineral materials

Random flow or directionally oriented flow through their structures.

ROTARY AIR-TO-AIR ENERGY EXCHANGERS



Random flow media

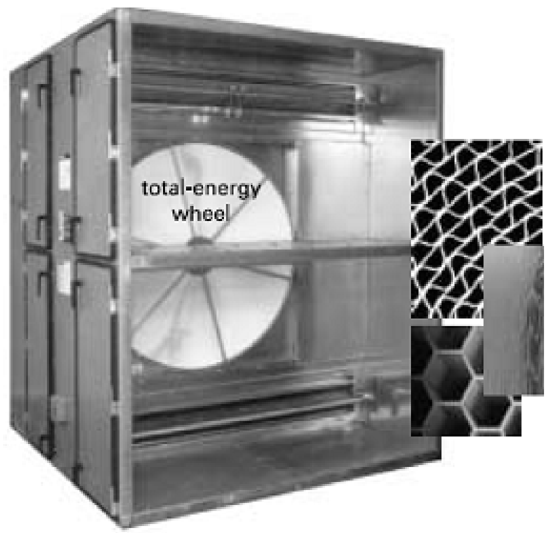
Knitting wire into an open woven cloth or corrugated mesh, which is layered to the desired configuration.

Aluminum mesh, commonly used for comfort ventilation systems, is packed in pie-shaped wheel segments.

These media should only be used with clean, filtered airstreams because they plug easily.

Random flow media also require a significantly larger face area than directionally oriented media for given values of airflow and pressure drop.

ROTARY AIR-TO-AIR ENERGY EXCHANGERS



Directionally oriented media

The most common consist of small (1.5 to 2 mm) air passages parallel to the direction of airflow.

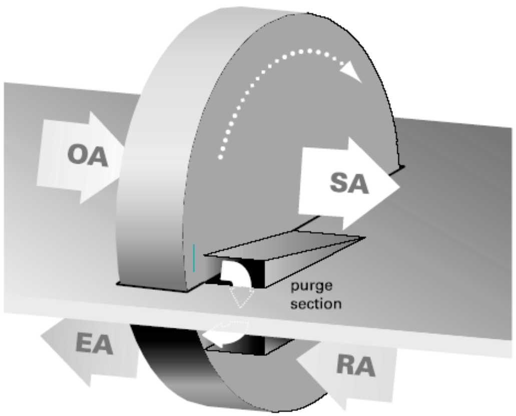
Air passages are triangular, hexagonal, or other.

Aluminum foil, paper, plastic, and synthetic materials are used for low and medium temperatures.

Media for sensible heat recovery are made of aluminum, copper and stainless steel.

Media for total heat recovery are fabricated from any of a number of materials and treated with a desiccant (typically silica gels, titanium silicate, synthetic polymers and etc).

ROTARY AIR-TO-AIR ENERGY EXCHANGERS



Cross-Contamination

Carryover

Air entrained within the volume of the rotation medium is carried into the other air stream.

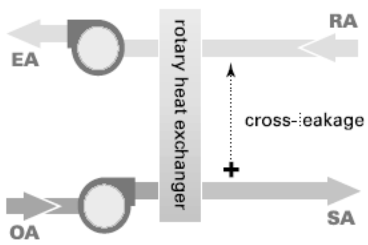
Leakage

Differential static pressure across two airstreams drives air from a higher to a lower static pressure region.

A **purge section** can be installed on the heat exchanger to reduce cross-contamination.

ROTARY AIR-TO-AIR ENERGY EXCHANGERS

Draw-through exhaust, blow-through supply

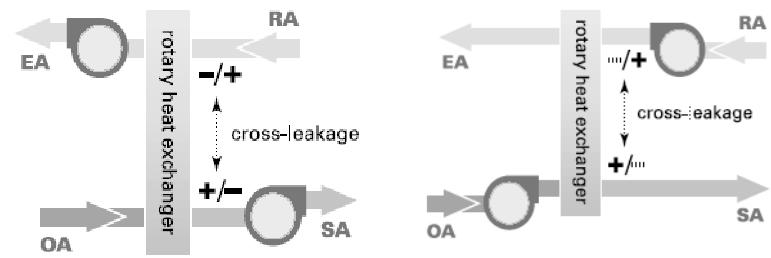


Creates a comparatively higher static pressure in the supply path

Air leaks from supply path to exhaust path

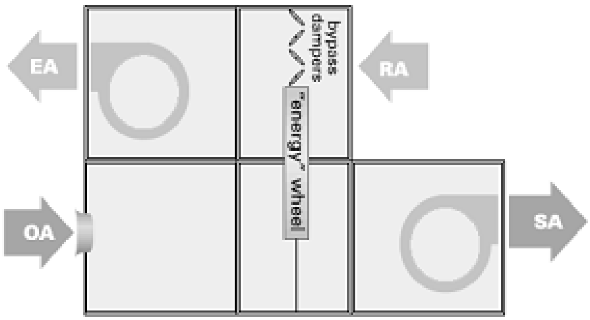
Draw-through exhaust, draw-through supply (left fig)

Blow-through exhaust, blow-through supply (right fig)



Direction of leakage depends on the static pressure difference between the supply and exhaust air streams

ROTARY AIR-TO-AIR ENERGY EXCHANGERS



Comparison - Exhaust Air Bypass preferred

Exhaust-air bypass →a more linear unloading characteristic than a VFD (stable control)

Exhaust-air bypass → wider range of capacity control.

Regulation of wheel energy recovery:

Supply air bypass control

An air bypass damper, controlled by a wheel supply air discharge temperature sensor, regulates the proportion of supply air bypassing exchanger.

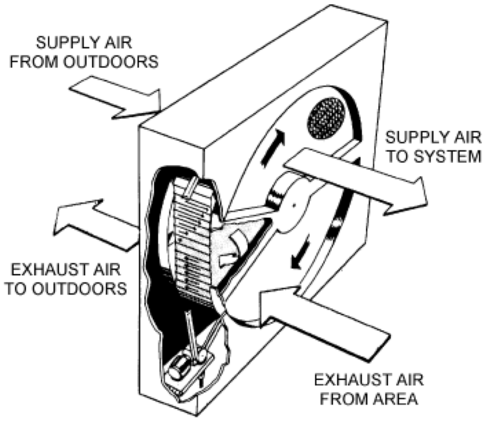
Varying wheel rotational speed** - **variable-speed drives

(1) A silicon controlled rectifier (SCR) with variable-speed dc motor,

(2) A constant speed ac motor with hysteresis coupling,

(3) An ac frequency inverter with an ac induction motor.

ROTARY AIR-TO-AIR ENERGY EXCHANGERS



Maintenance

Rotary enthalpy wheels require little maintenance.

The following maintenance procedures for best performance:

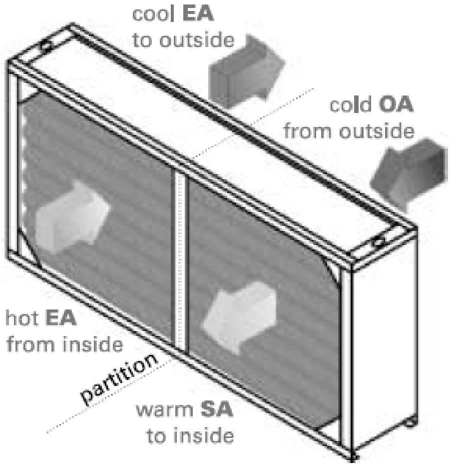
- Clean the medium when lint, dust, or other foreign materials build up.
- Media treated with a liquid desiccant for total heat recovery must not be wetted.
- Maintain drive motor (manufacturer's recommendations)
- Speed control motors (commutators and brushes)
- Belt or chain tension.
- Refer to the manufacturer's recommendations for spare and replacement parts.

ROTARY AIR-TO-AIR ENERGY EXCHANGERS

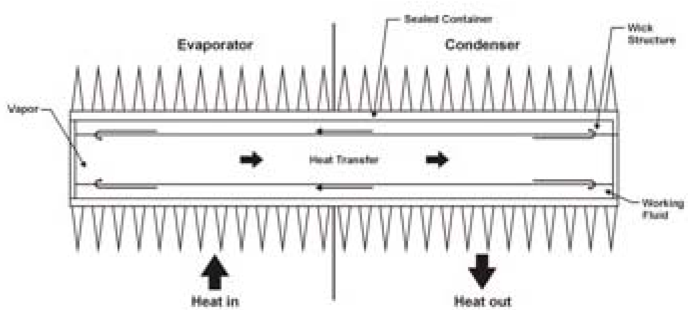
Advantages	Disadvantages
■ *Total*-energy wheels transfer both sensible heat and moisture (latent energy)	■ *Sensible*-energy wheels transfer only sensible heat
■ High effectiveness	■ May permit cross-leakage between air streams
■ Can be packaged inside an air handler	■ Belt, motor, and bearings require periodic maintenance
■ "Self-cleaning" with respect to dry particles	

Considerations for recovering energy with rotary heat exchangers

HEAT PIPE HEAT EXCHANGERS

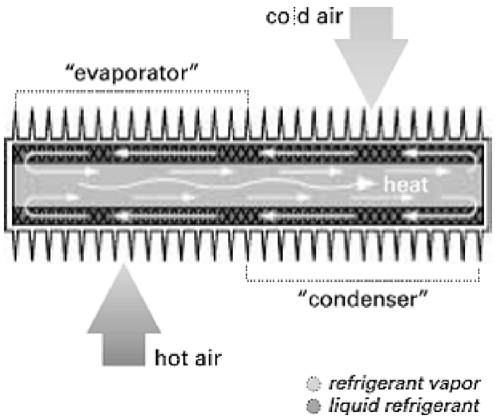


Heat-pipe assembly

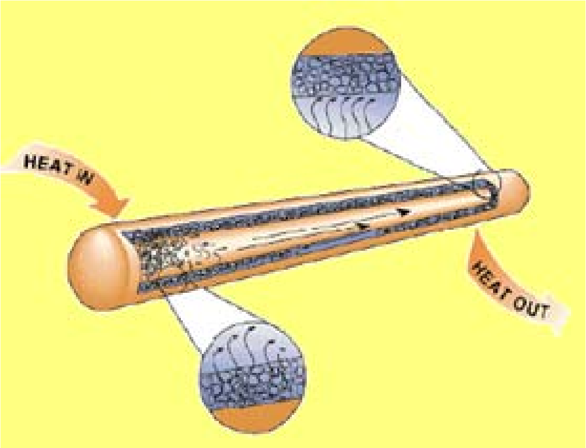


- A passive energy recovery device
- With appearance of an ordinary plate-finned water coil
- Tubes not interconnected
- Divided into evaporator and condenser by a partition plate.
- Sensible heat transfer devices
- Condensation on the fins allow latent heat transfer

HEAT PIPE HEAT EXCHANGERS

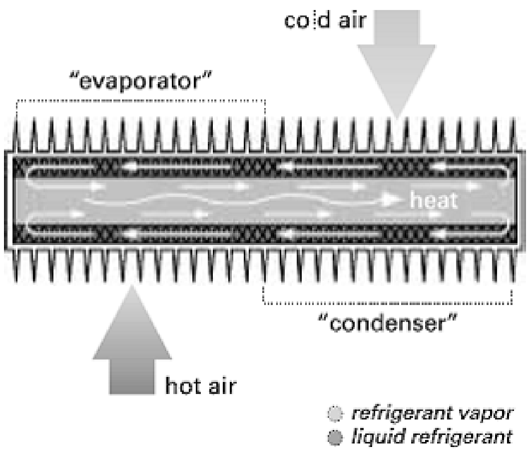


Cross section of heat-pipe tube



- Heat pipe tubes are fabricated with an integral capillary
- Wick structure, evacuated, filled with a suitable working fluid,
- Permanently sealed.
- The working fluid is normally a refrigerant.
- Fin designs include continuous corrugated plate fin, continuous plain fin, and spiral fins.
- Modifying fin design and tube spacing changes pressure drop at a given face velocity.

HEAT PIPE HEAT EXCHANGERS



Cross section of heat-pipe tube

Principle of Operation

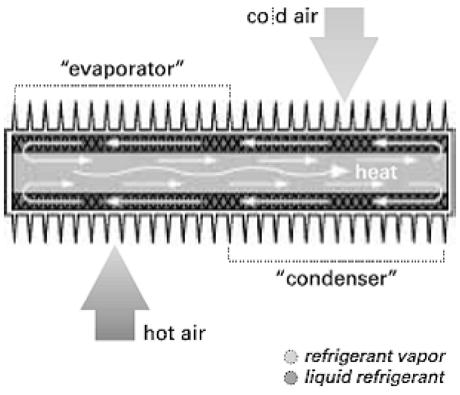
Hot air flowing over the evaporator end of the heat pipe vaporizes the working fluid.

A vapor pressure gradient drives the vapor to the condenser end of the heat pipe tube

Vapor condenses at condenser releasing the latent energy of vaporization.

The condensed fluid is wicked or flows back to the evaporator, where it is re-vaporized, thus completing the cycle.

HEAT PIPE HEAT EXCHANGERS



Cross section of heat-pipe tube

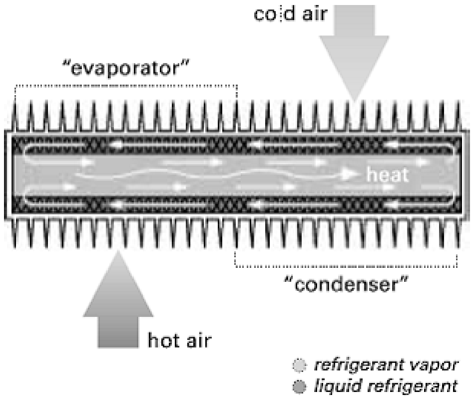
Energy transfer in heat pipes is isothermal.

A small temperature drop through the tube wall, wick, and fluid medium.

Heat transfer capacity that is affected by :

- Wick design,
- Tube diameter,
- Working fluid,
- Tube orientation relative to horizontal.

HEAT PIPE HEAT EXCHANGERS



Cross section of heat-pipe tube

Construction Materials

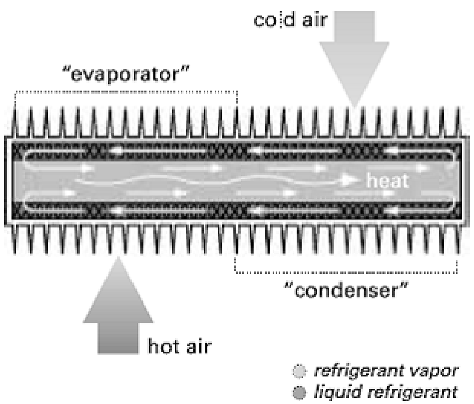
HVAC systems use copper or aluminum heat pipe tubes with aluminum fins.

Exhaust temperatures < 220°C : aluminum tubes and fins.

Protective coatings on finned tube for corrosive atmospheres(Coatings with negligible effect on thermal performance).

Steel tubes and fins for > 220°C with aluminized fins (prevent fin rusting).

HEAT PIPE HEAT EXCHANGERS



Cross section of heat-pipe tube

Operating Temperature Range

The working fluid :

→high latent heat of vaporization,

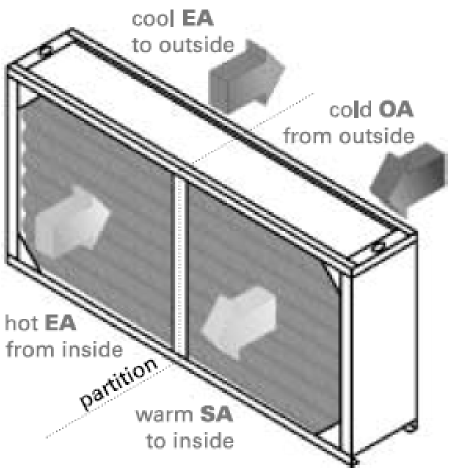
→high surface tension,

→a low liquid viscosity over operating range;

→ Thermally stable at operating temperatures.

→ No condensable gases from decomposition of thermal fluids → deteriorate performance.

HEAT PIPE HEAT EXCHANGERS



Heat-pipe assembly

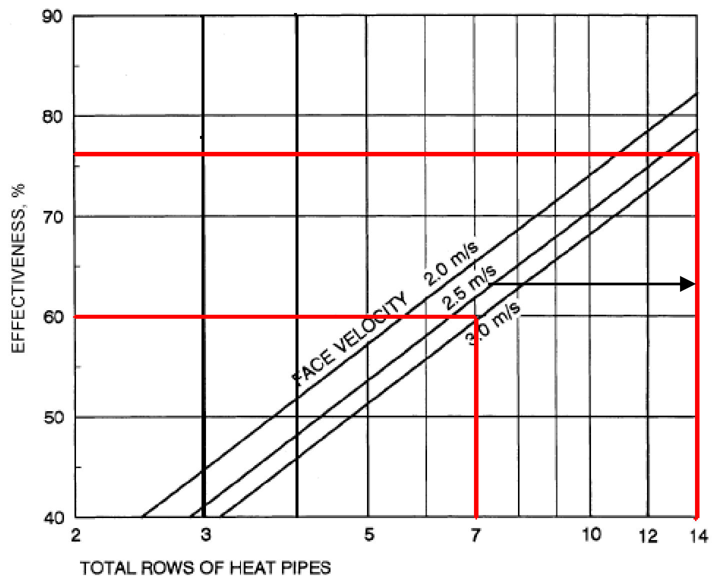
Cross-Contamination

Zero cross-contamination for pressure differentials between airstreams of up to 12 kPa.

A vented double-wall partition between the airstreams → additional protection against cross-contamination.

Exhaust duct attached to the partition space for exhaust of leakage at space between two ducts.

HEAT PIPE HEAT EXCHANGERS



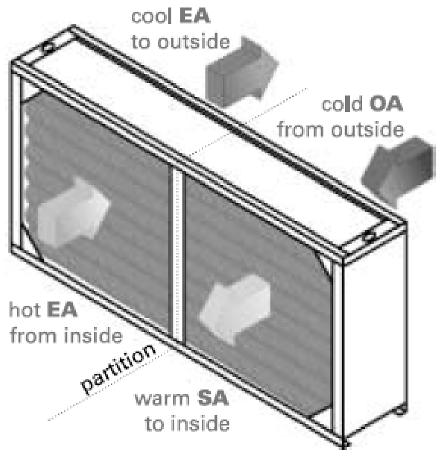
Performance
Heat pipe heat transfer capacity depends on design and orientation.

As number of rows increases, effectiveness increases at a decreasing rate.
Illustration example:
7 rows at 3 m/s at 60% effectiveness
14 rows at 3m/s at 76% effectiveness.

Heat transfer capacity increases roughly with the square of internal pipe diameter.
25 mm internal diameter heat pipe transfers roughly 2.5 times as much energy as a 16 mm inside diameter pipe.

Large diameters are for larger airflow applications.

HEAT PIPE HEAT EXCHANGERS



Heat-pipe assembly

***Heat transfer* capacity limit is virtually *independent of heat pipe length*, except for very short heat pipes.**

1 m long heat pipe has approximately the same capacity as a 2 m pipe.

2 m heat pipe has twice the external heat transfer surface area of the 1m pipe capacity limit would reach sooner.

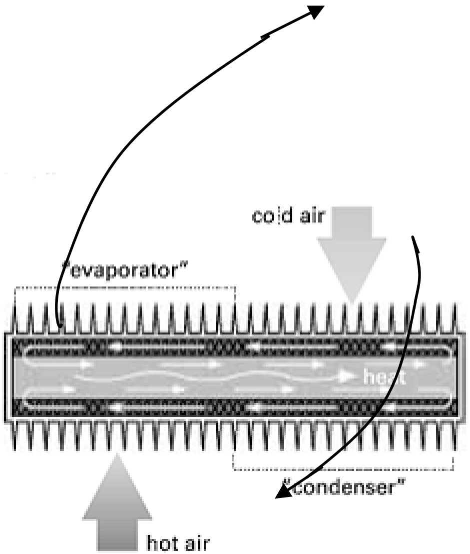
***Dirtiness* of the two airstreams →affects fin design and spacing**

Fin spacing of 1.8 to 2.3 mm for typical HVAC applications

Wider fin spacing for dirty exhaust side

Pressure drop constraints prevents deterioration of performance due to dirt buildup on the exhaust side surface

HEAT PIPE HEAT EXCHANGERS



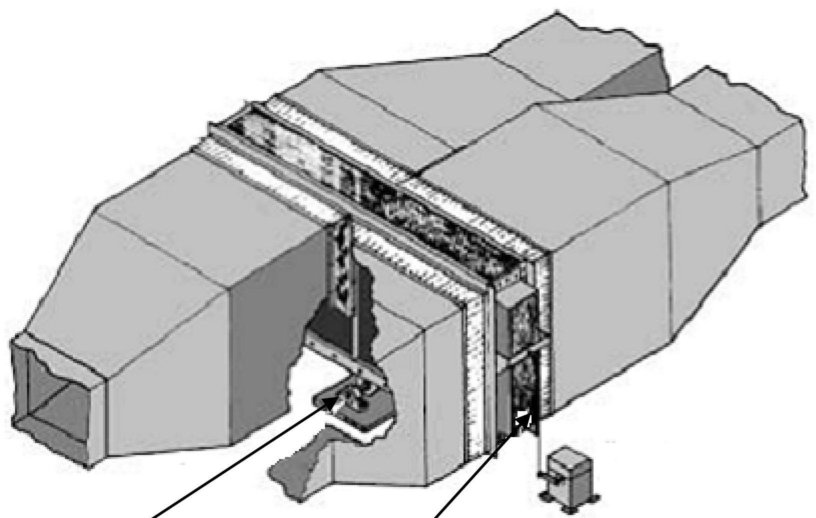
Controls

Changing the slope (tilt) of a heat pipe controls the amount of heat it transfers.

Operating the heat pipe on a slope with the hot end below (or above) the horizontal **improves** (or retards) the condensate flow back to the evaporator end of the heat pipe.

This feature for regulating the **effectiveness** of the heat pipe heat exchanger.

HEAT PIPE HEAT EXCHANGERS



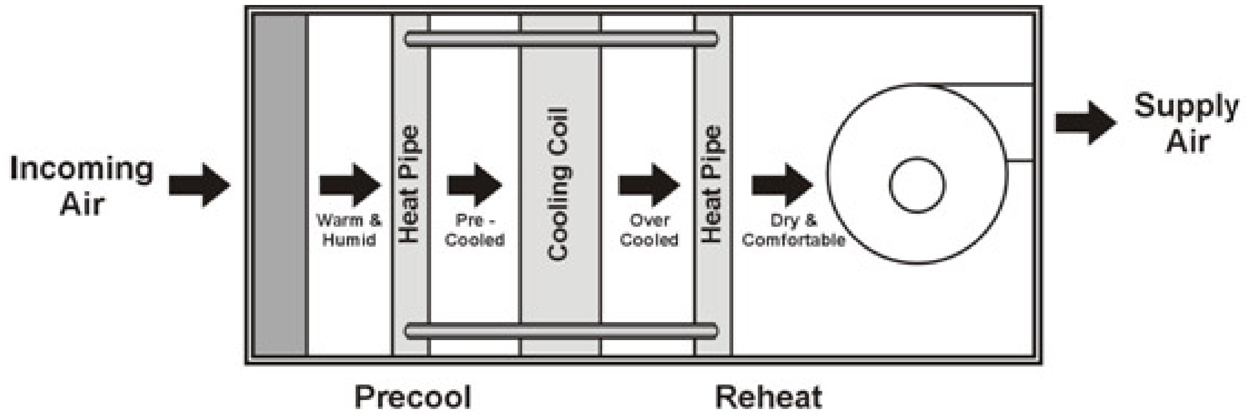
In practice, tilt control is effected by pivoting the exchanger about the center of its base.

HEAT PIPE HEAT EXCHANGERS

Advantages	Disadvantages
■ Little cross-leakage between air streams	■ Contains refrigerant
■ Relatively low maintenance	■ Transfers only sensible energy (heat)
■ Can be packaged inside an air handler	■ Requires external face-and-bypass dampers to prevent unwanted heat transfer

Considerations for recovering energy with heat pipes

HEAT PIPE HEAT EXCHANGERS



Application of heat pipe in HVAC

Heat pipe contributes to the HVAC by pre-cooling and reheating the air.

The pre-cool section of the heat pipe is located in the incoming air stream.

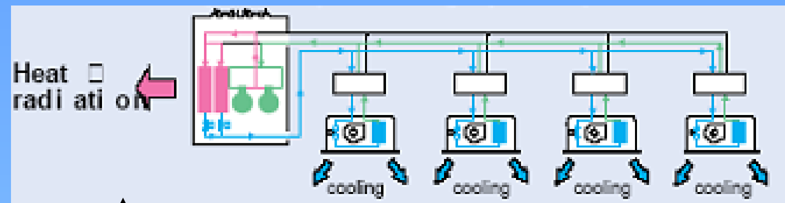
When warm air passes over the heat pipes, the refrigerant vaporizes, carrying heat to the second section of heat pipes, placed down stream.

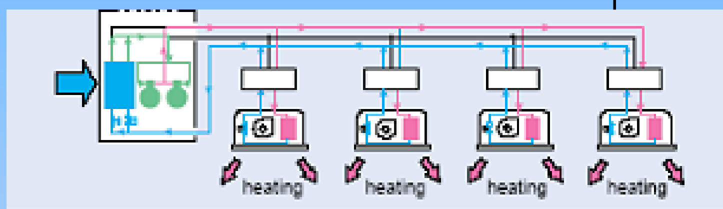
The "overcooled" air is then reheated to a comfortable temperature by the reheat heat pipe section, using the heat transferred from the pre-cool heat pipe.

This entire process of pre-cool and reheat is accomplished with no additional energy use.

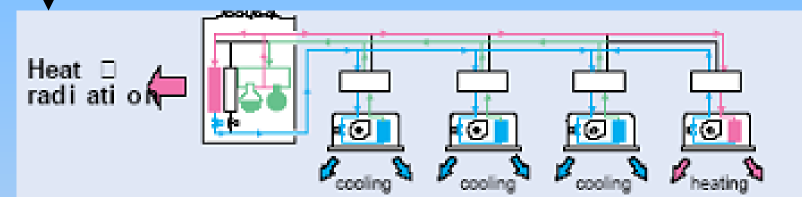
VRV System

Heat radiation operation (all cooling operation)

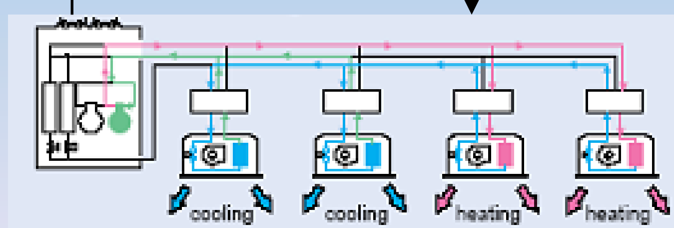




Heat absorption operation (all heating operation)



Heat recovery operation (cooling & heating operation)



Heat absorption tendency heat recovery operation (mainly heating, part cooling operation)

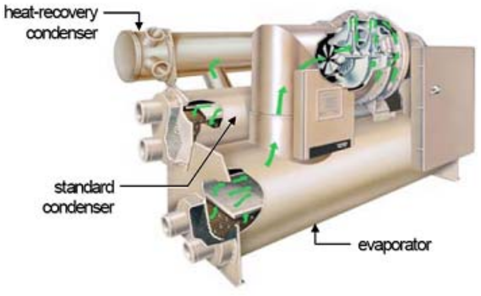
Heat Recovery from Water Cooled Chiller

Heat recovery is the process of capturing the heat that is normally rejected from the chiller condenser.

Recovered heat from chiller for space heating, domestic water heating, or another process requirement.

Heat recovery chiller should be considered with simultaneous heating and cooling requirements.

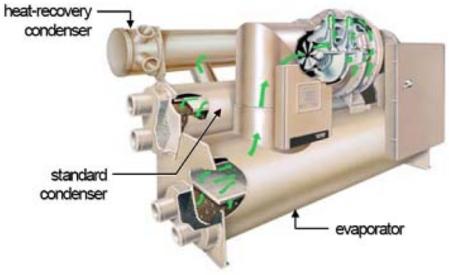
Heat recovery chiller could also be considered for in facilities where the heat can be stored and used at a later time



Heat-Recovery Chiller

Heat Recovery from Water Cooled Chiller

Heat recovery can be applied to any type of water chiller.



Heat-Recovery Chiller

***Chiller with standard Condenser*:**

Operating at higher condensing temperatures and recovering heat from the water leaving the condenser.

***Separate condenser* :**

Double-bundle water-cooled centrifugal chiller.

***Desuperheater*:**

Used in smaller chillers.

A desuperheater is a device between compressor and condenser to recover heat from the hot refrigerant vapor.

Heat Recovery from Water Cooled Chiller

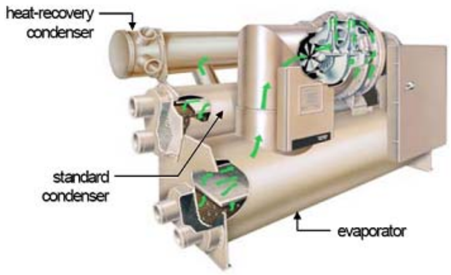
Heat recovery in water-cooled centrifugal chillers - Double-Bundle heat-recovery chiller

The **dual-condenser or double-bundle** heat-recovery chiller contains a second, full-size condenser connecting to a separate hot-water loop.

Heat recovery chiller rejecting more heat and hence higher leaving-hot-water temperatures than an auxiliary condenser.

Varying the temperature or flow of water through the standard condenser→ control amount of heat rejected.

Chiller efficiency is degraded slightly in order to reach the higher condensing temperatures.

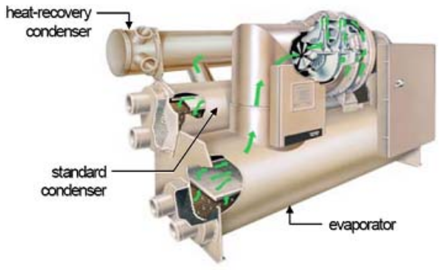


Heat-Recovery Chiller

Heat Recovery from Water Cooled Chiller

Heat recovery in water-cooled centrifugal chillers - Auxiliary-Condenser

An ***auxiliary-condenser*** heat-recovery chiller makes use of a second, but smaller, condenser bundle.



Heat-Recovery Chiller

It rejects less heat than dual-condenser chiller.

Leaving hot-water temperatures are also lower → for preheating water at upstream of the primary heating equipment or water heater.

It improves chiller efficiency because of the extra heat-transfer surface for condensing.

Heat recovery in water-cooled centrifugal chillers

Water Source heat pump chiller

A water source heat pump chiller is a standard chiller requiring no extra shells.

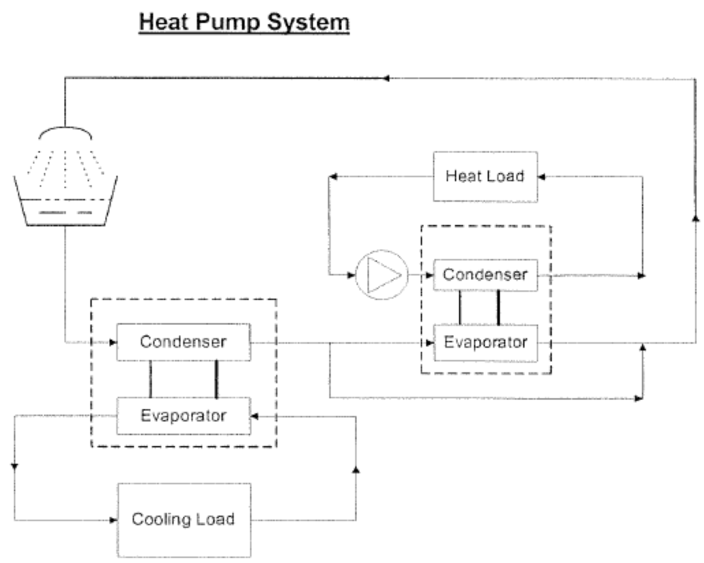
The useful heat produced in condenser.

The evaporator is connected to the upstream of other chillers.

It only removes enough heat from the chilled water loop to handle the heating load served by the condenser water loop.

This application is useful in a multiple-chiller system where there is a base or year-round heating or process load, or where the quantity of heat required is significantly less than the cooling load.

The heating efficiency of a heat-pump chiller is the highest of any heat-producing device.



Heat-Recovery Chiller Options

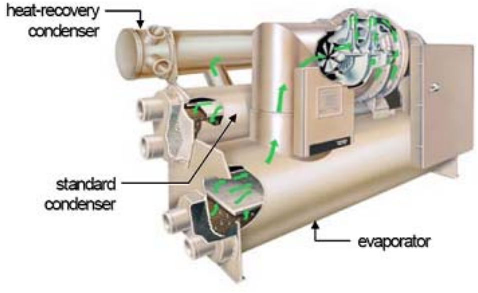
heat-recovery (dual) condenser	auxiliary condenser	heat pump
Second, full-size condenser	Second, smaller-size condenser	No extra condenser
Large heating loads	Preheating loads	Large base-heating loads or continuous operation
High hot-water temperatures	Moderate hot-water temperatures	High hot-water temperatures
Controlled	Uncontrolled	Controlled
Degrades chiller efficiency	Improves chiller efficiency	Good heating efficiency

Heat Recovery Chiller Efficiency

There is usually an efficiency penalty associated with the use of heat recovery with a chiller.

The cost of this efficiency penalty, however, is typically much less than the energy saved by recovering the "free" heat.

The energy consumption of a heat-recovery chiller > a cooling-only chiller (higher pressure differential at which the compressor must operate).



Heat-Recovery Chiller

Comparison of Chiller with Heat Recovery Option

Heat-Recovery Chiller Efficiency

chiller type	cooling mode	heat-recovery mode
cooling-only centrifugal chiller	0.57 kW/ton [6.2 COP]	not applicable
heat-recovery centrifugal chiller	0.60 kW/ton [5.9 COP]	0.69 kW/ton [5.1 COP]

The energy consumption of a centrifugal chiller operating in heat-recovery mode (producing 40.6°C condenser water is 5.1 COP).

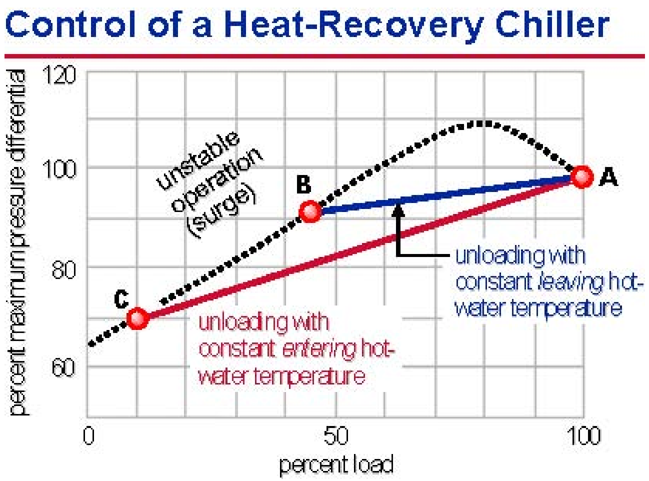
The efficiency of the same chiller operating in the cooling-only mode (no heat being recovered and producing 35°C condenser water is 5.9 COP.

A comparable cooling-only chiller of the same capacity and operating at the same cooling-only conditions consumes 6.2 COP.

The heat-recovery chiller uses 4 % more energy in the cooling-only mode than the chiller designed and optimized for cooling-only operation.

To perform **a** **life-cycle cost** analysis to determine whether heat recovery is a viable option.

Control heat-recovery capacity



Control based on the temperature of the water **leaving** the heat-recovery condenser causes the condenser-to-evaporator pressure differential to remain relatively high at all loads (line **A** - **B**).

High pressure differentials at low cooling loads increases the risk of a centrifugal compressor operating in its unstable region (surge).

Control heat-recovery capacity based on the temperature of the hot water **entering** the heat-recovery condenser is preferred.

The condenser-to-evaporator pressure differential is allowed to decrease as the chiller unloads (line ***A*** - **C**)→ keeping the centrifugal chiller from surging (more stable operation).

Question and Answer