

Heat recovery technologies for energy efficient buildings in hot and humid climate

濕熱氣候下節能建築的熱回收技術

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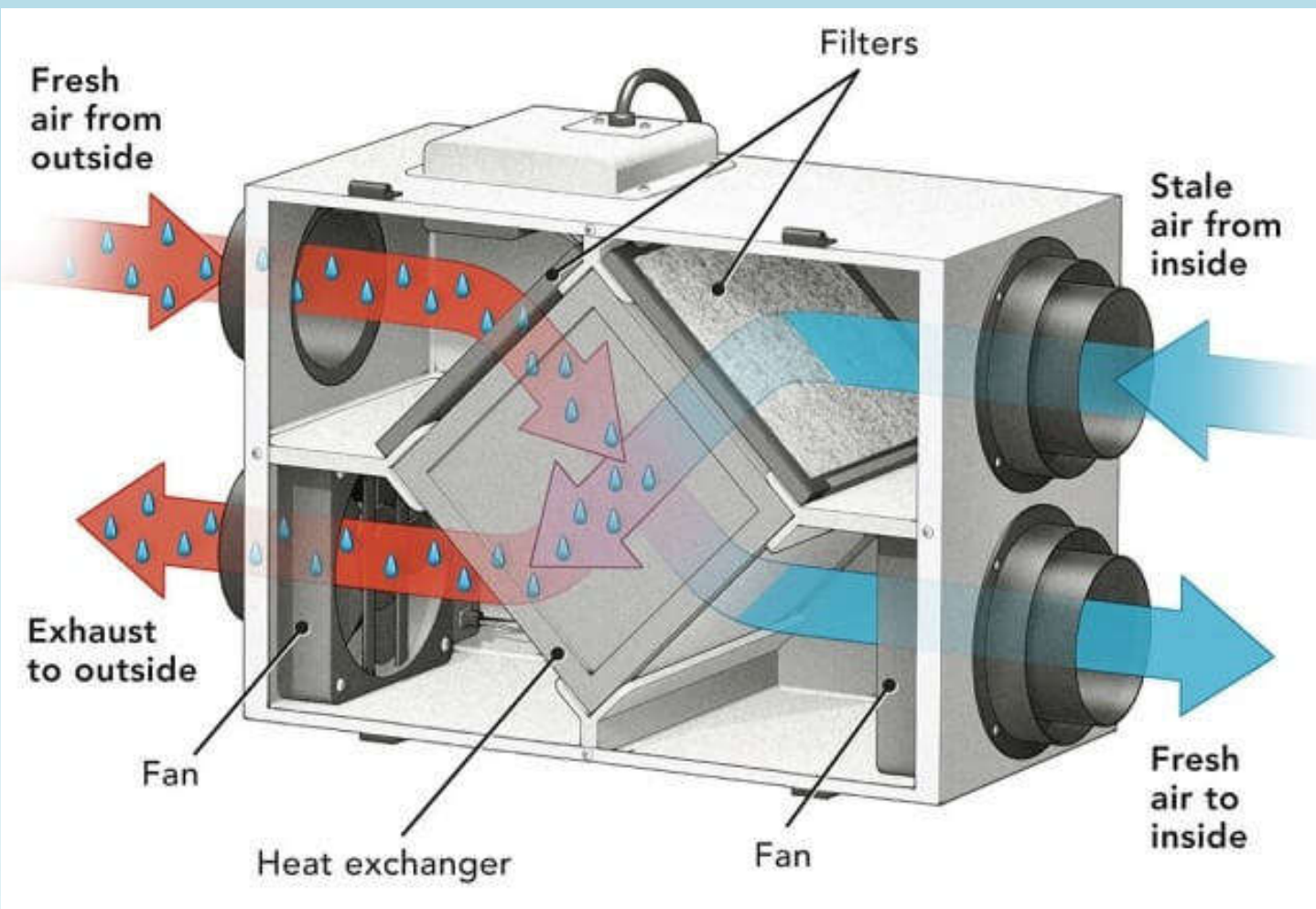
- Basic principles
- Air-to-air energy recovery
- Applied heat pumps
- Heat recovery chillers
- Wastewater heat recovery
- Conclusions



Basic principles

熱 回 收 技 術

- **Heat recovery** is the process of collecting and re-using heat that is generated from any process where the heat would otherwise be lost
- Can help reduce the energy consumption of the process or the heat can be used elsewhere, reducing running costs and carbon emissions
- It can be used in most buildings since the majority use energy is HVAC (heating, ventilation & air-conditioning) or some may house industrial processes that generate heat



An example of heat recovery ventilation system

(Source:

<https://energywiseireland.ie/hrv-overview/>)

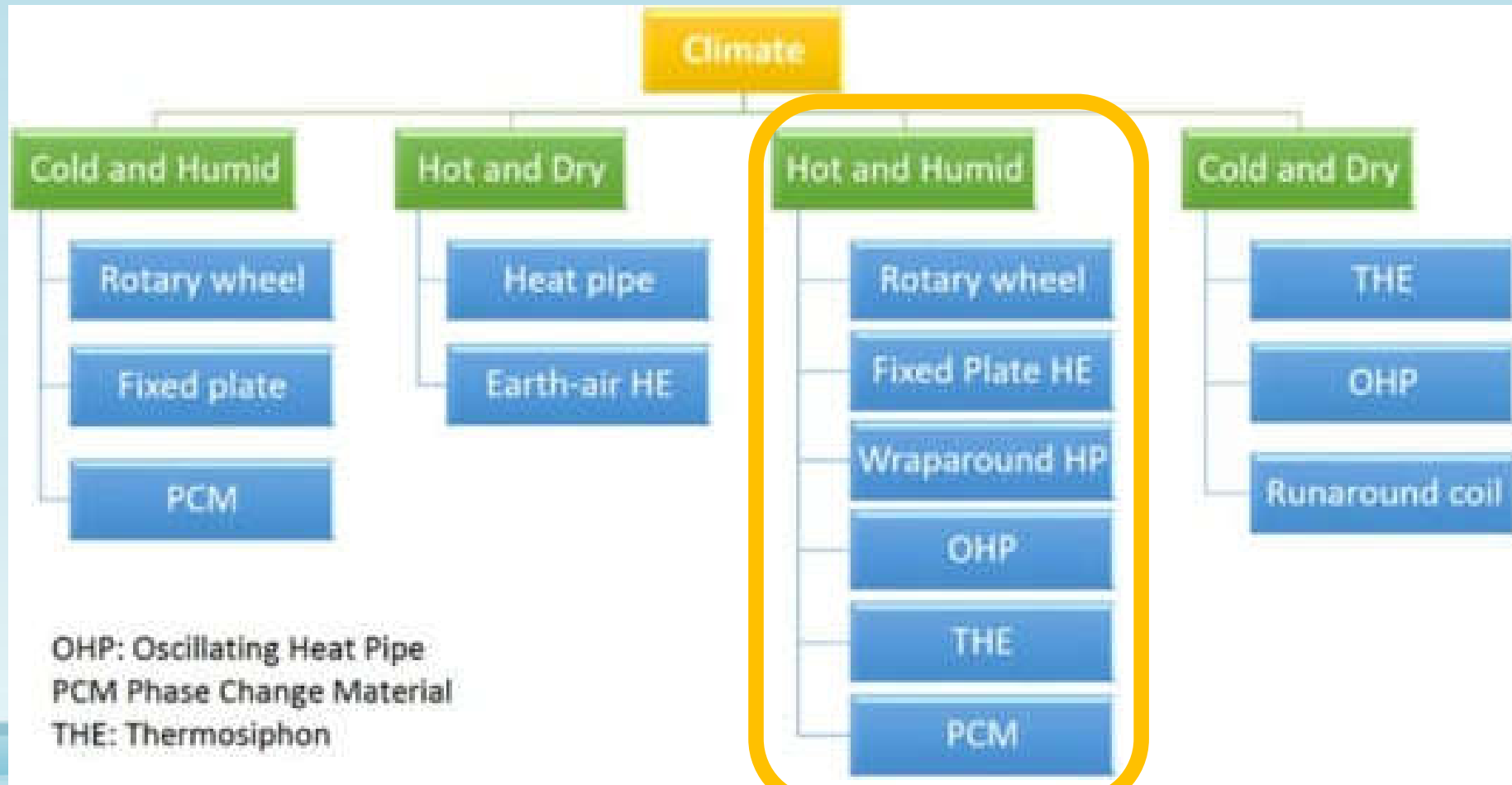


Basic principles

熱回收技術

- Sources of waste heat that might provide opportunities for heat recovery include:
 - Ventilation systems (air side)
 - Refrigeration units and chiller units (water side)
 - Boilers (e.g. flue economiser)
 - Power generation plant
 - Plant cooling systems
 - Hot liquid effluents and high-temperature exhaust gases
- Typical heat recovery equipment: heat exchangers, recuperators and regenerators

Heat recovery devices according to the climate





Basic principles

熱回收技術

- Heat sources and sinks:
 - Air (outdoor ambient air, exhaust from ventilation)
 - Water (well, surface, tap, condensing, waste)
 - Ground (ground-coupled, direct expansion)
 - Solar energy (direct or indirect heated water/air)
 - Industrial process (process heat or exhaust)
- Use the waste heat to support domestic water heating, terminal reheat, outdoor air heat, dehumidification, space or process heating

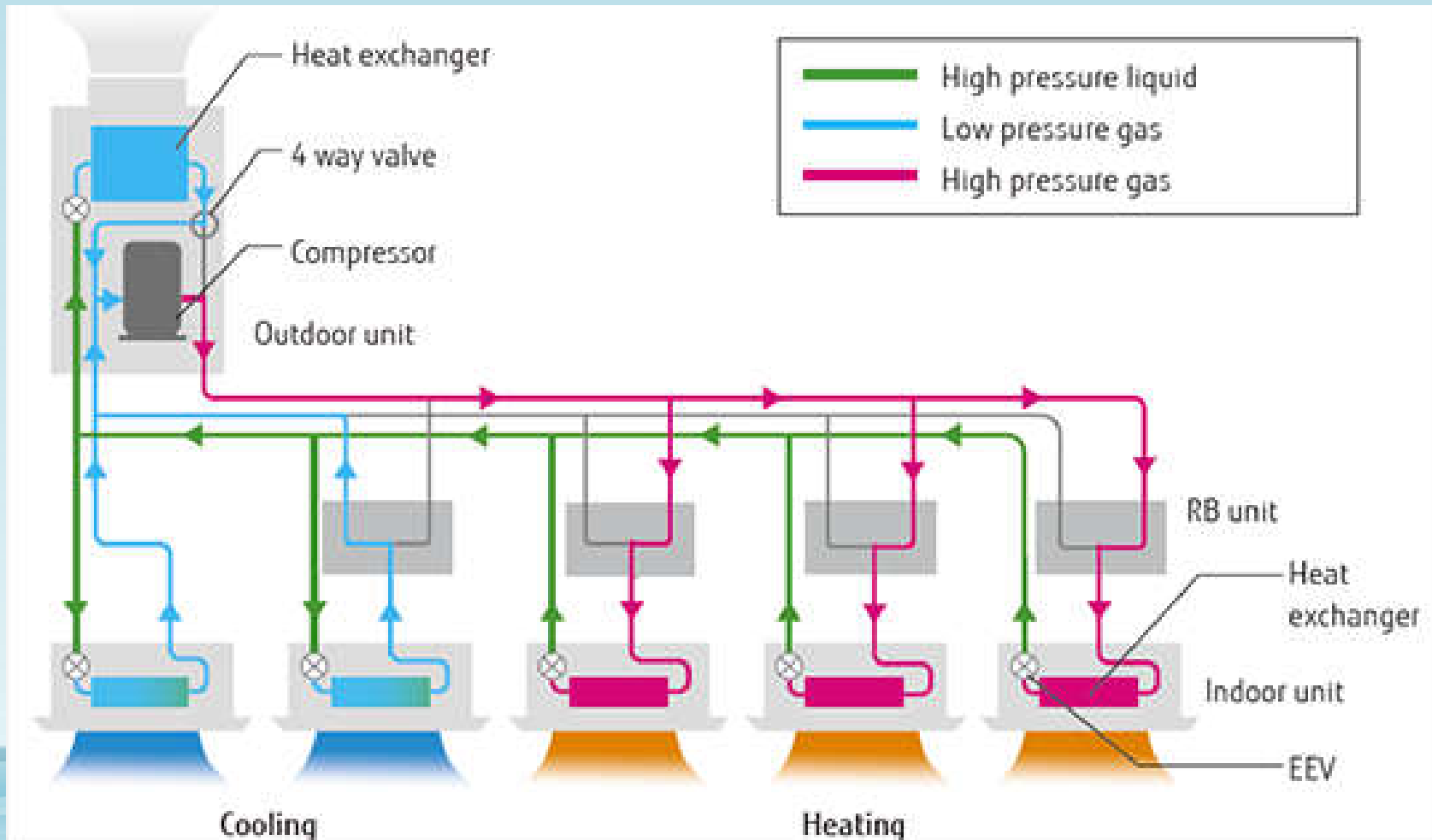


Basic principles

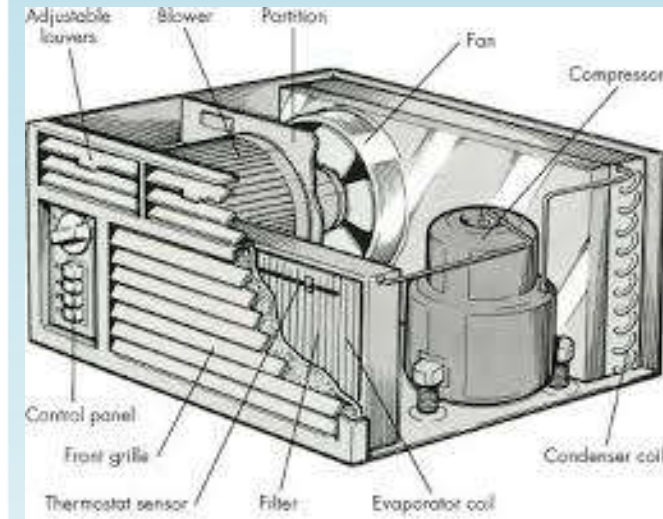
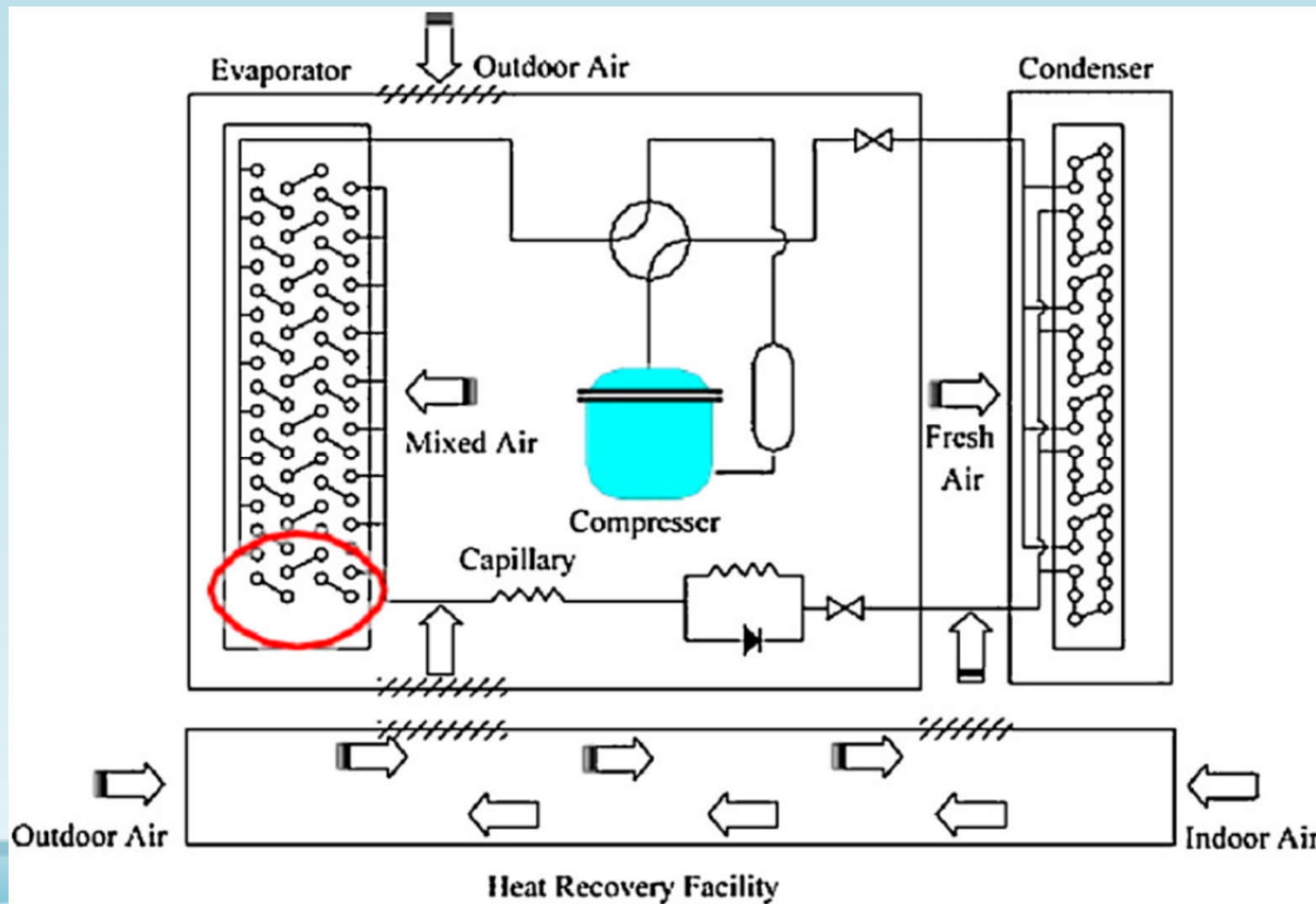
熱回收技術

- Heat recovery systems for HVAC and buildings:
 - Air-to-air energy recovery
 - Variable refrigerant flow (VRF) systems that enable recovery of energy between cooling and heating
 - Reverse cycle water-to-air heat pumps on a common water loop that allows recovery of energy between units rejecting heat and those requiring heat
 - Heat recovery/reclaim chillers that simultaneously provide heating and cooling (with single or double bundle/condenser)
 - Wastewater heat recovery (WWHR)

Variable refrigerant flow (VRF) system with heat recovery for simultaneous cooling & heating



Window-type air conditioner with heat recovery facility

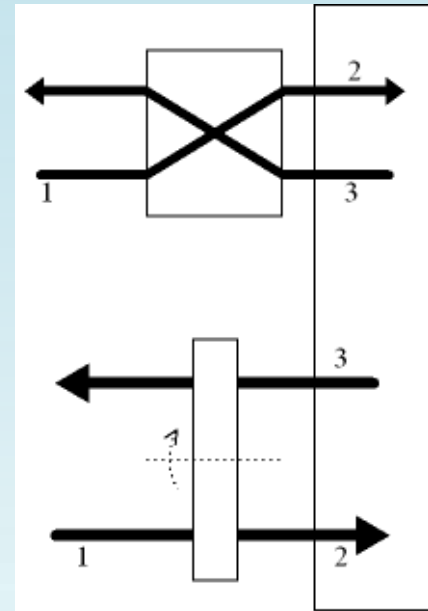


(Source: Mardiana-Idayu A. & Riffat S. B., 2012. Review on heat recovery technologies for building applications, *Renewable & Sustainable Energy Reviews*, 16 (2) 1241-1255. <https://doi.org/10.1016/j.rser.2011.09.026>)

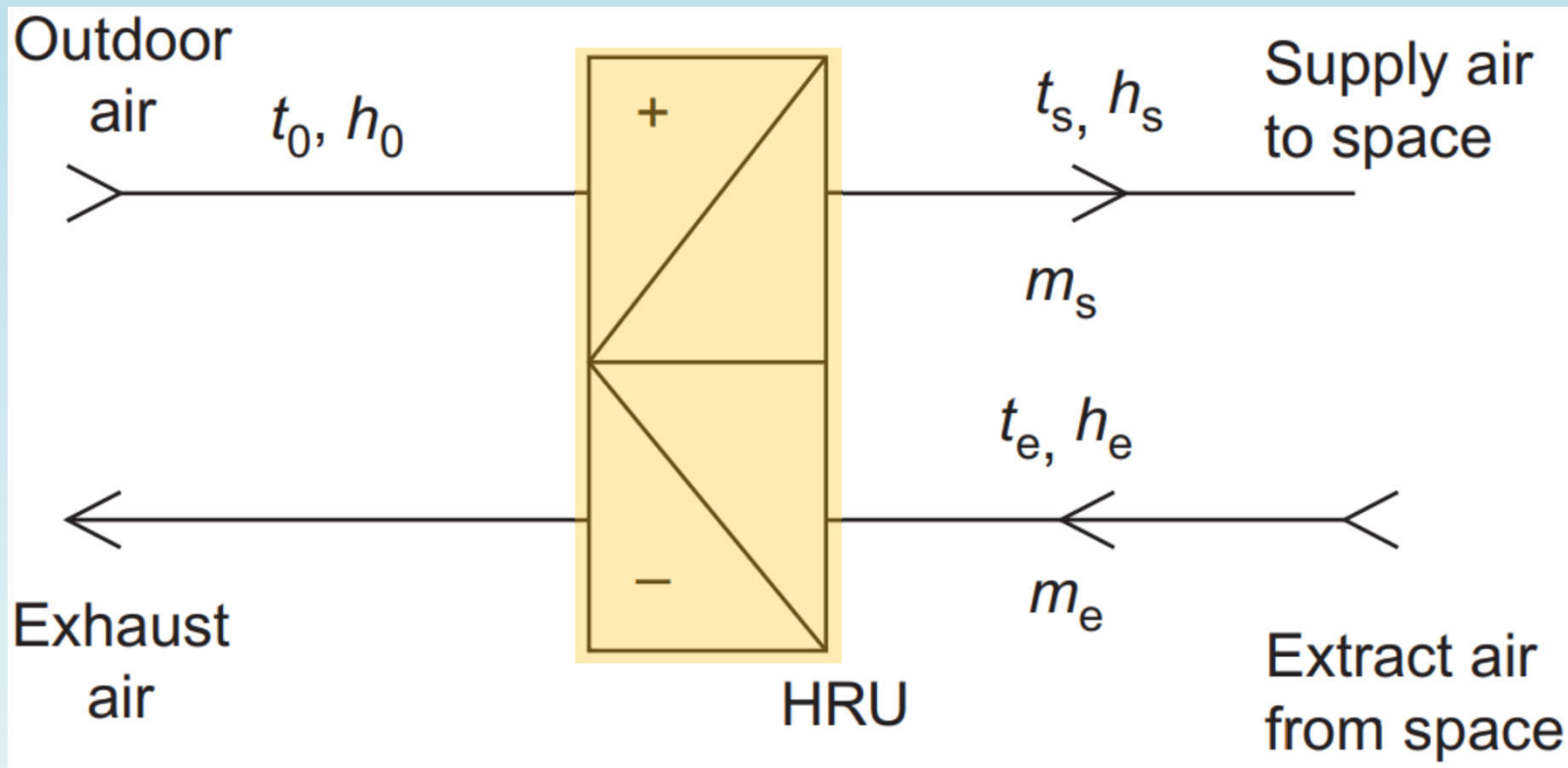
Air-to-air energy recovery



- Recover **heat and/or moisture** between two air streams
- Important for maintaining acceptable indoor air quality (IAQ) while reducing energy costs
- Energy can be recovered either in its sensible (temperature only) or latent (moisture) form, or combination of both
 - Sensible only: **Heat Recovery Ventilator (HRV)**
 - Energy/enthalpy: **Energy Recovery Ventilator (ERV)**



Schematic of an air-to-air heat recovery unit (HRU)



Symbols:

t = temperature ($^{\circ}\text{C}$)

h = enthalpy (kJ/kg)

m = air mass flow rate (kg/s)

Subscripts:

0 = outdoor air

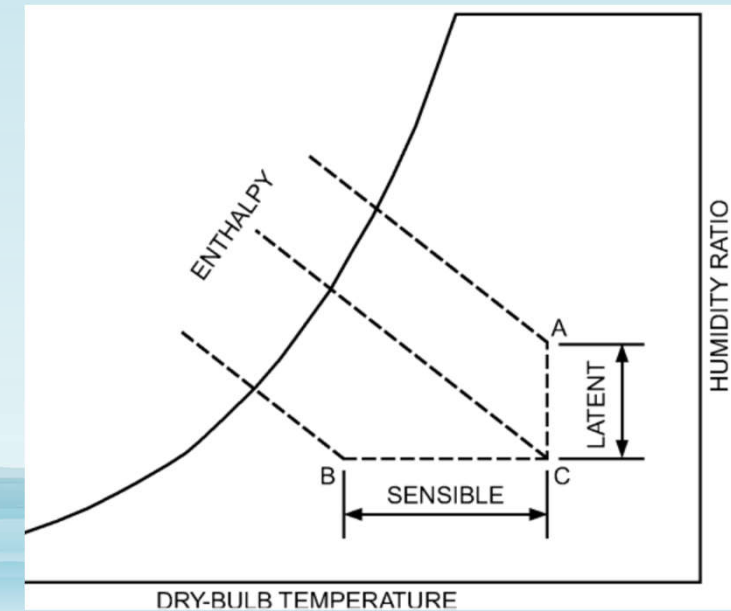
s = supply air

e = exhaust air

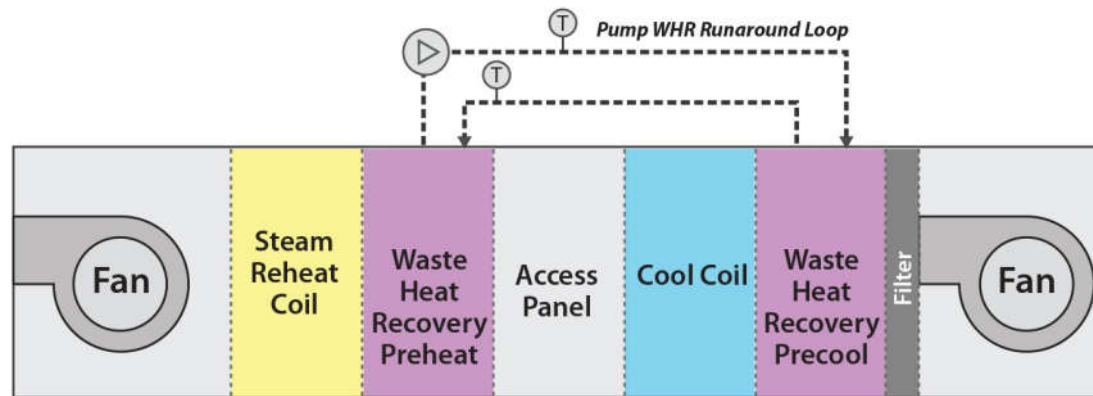
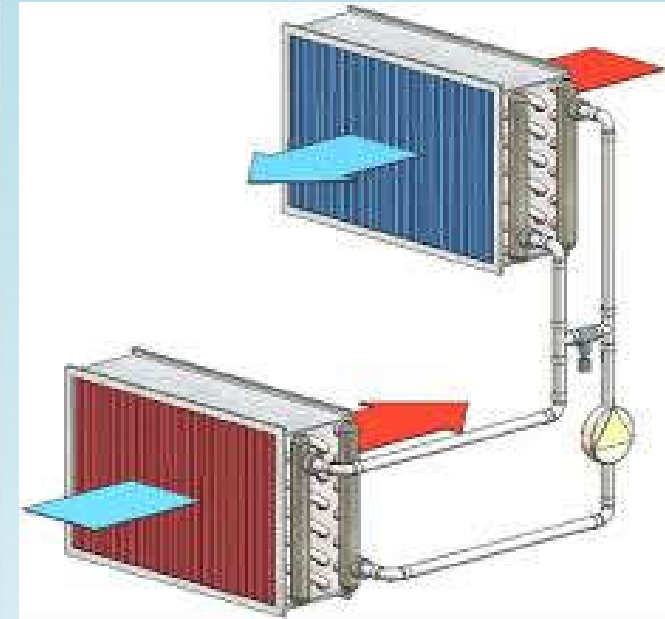
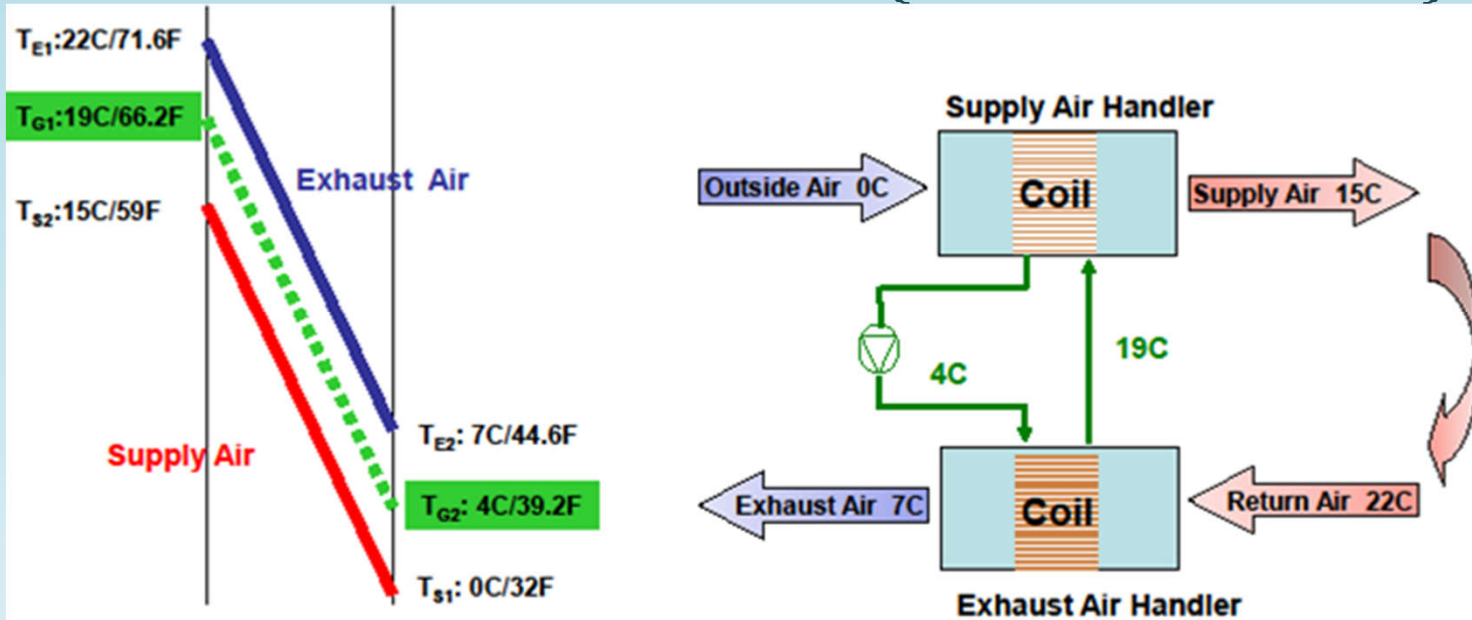
Air-to-air energy recovery



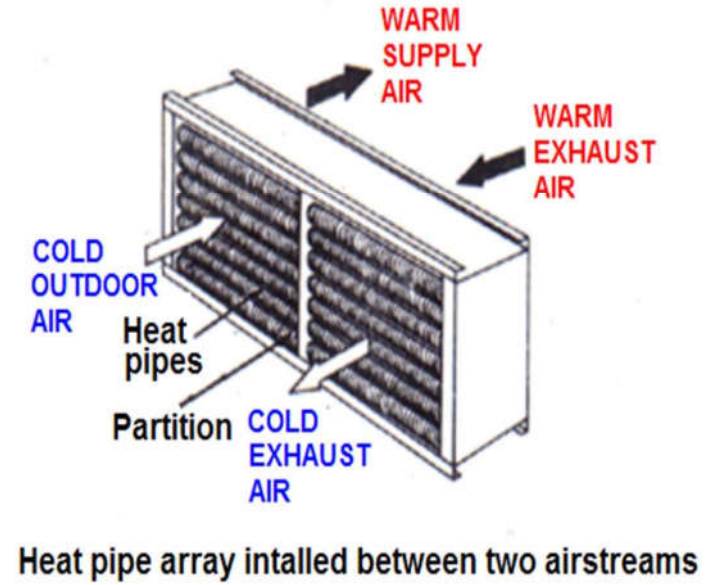
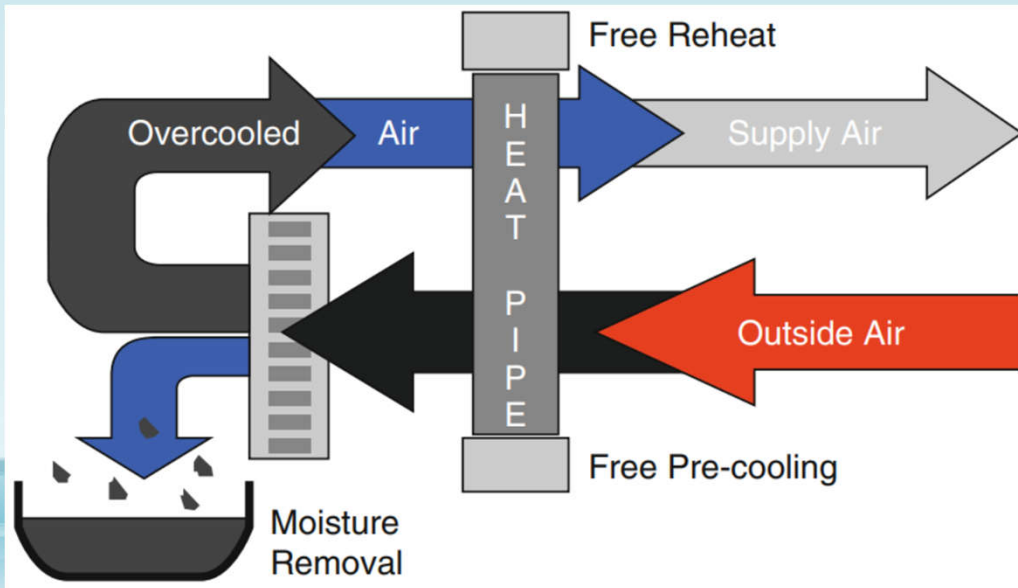
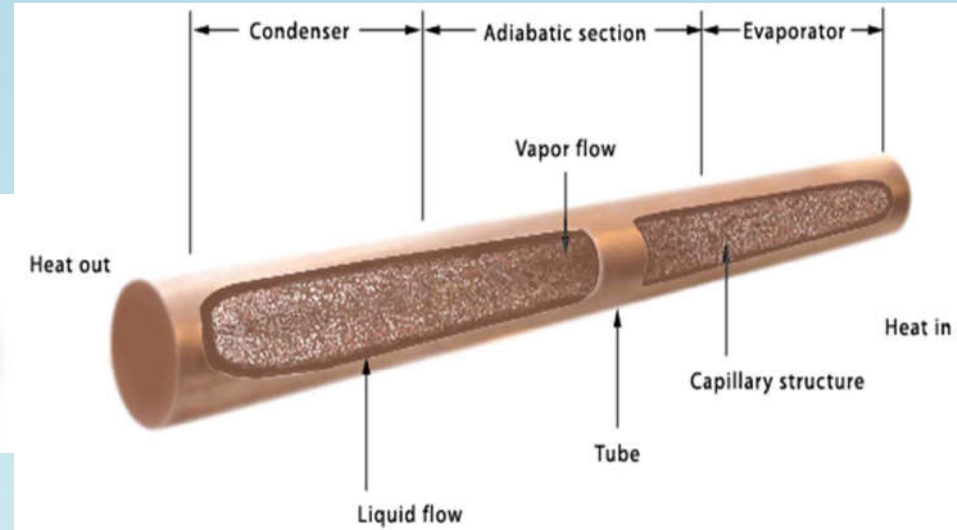
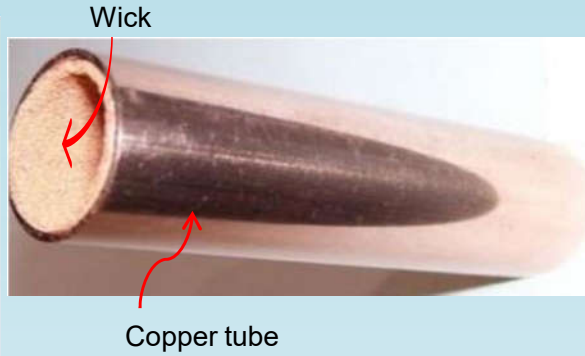
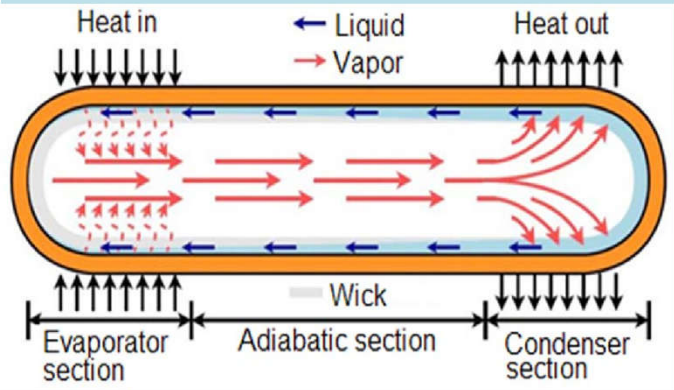
- In winter, exhaust air to heat the outdoor air
- In summer, exhaust air to absorb the heat and humidity from the outdoor air
- Examples of air-to-air energy recovery devices:
 - Run-around coil
 - Heat pipe
 - Two-phase thermosiphon heat exchanger
 - Plate heat exchanger
 - Energy transfer wheel



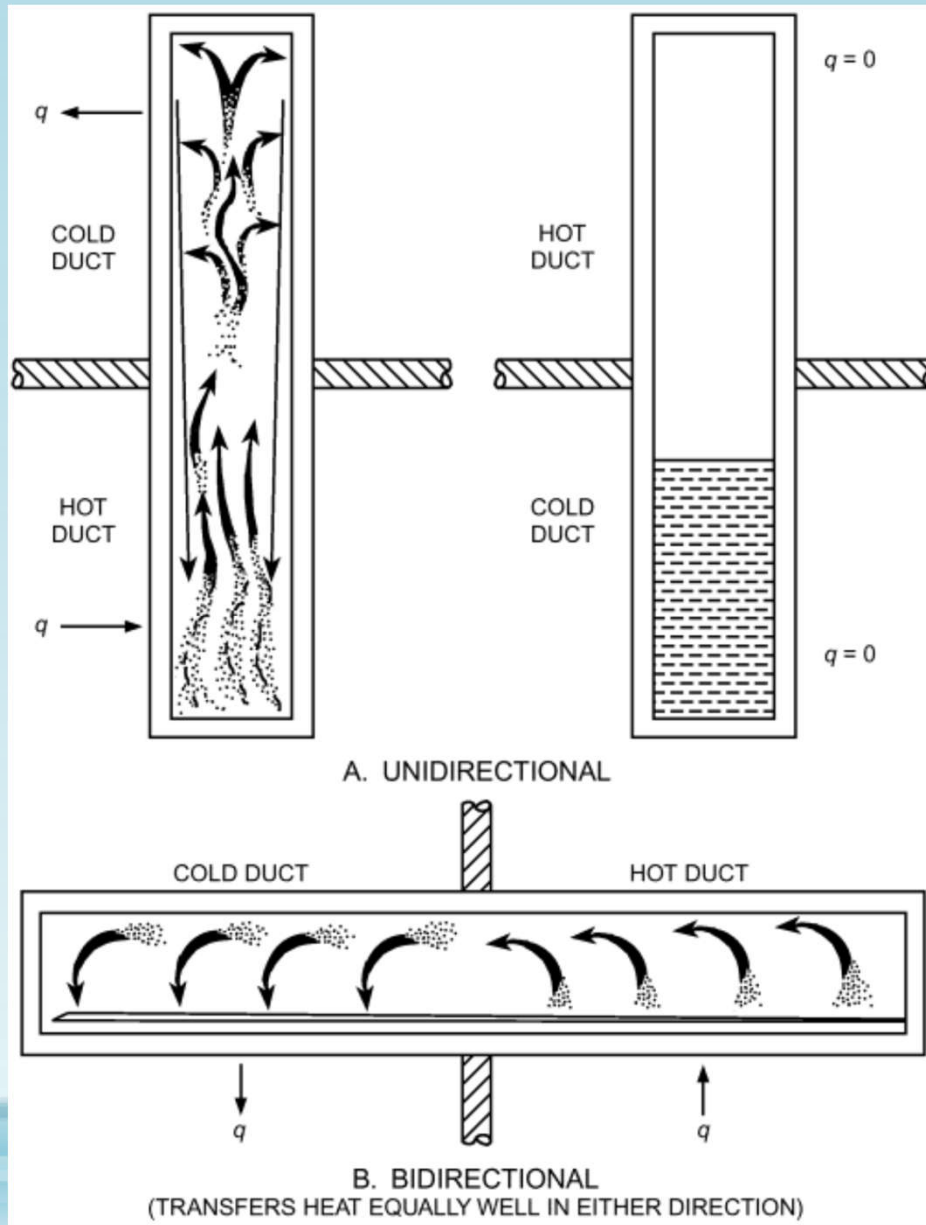
Run-around coil (sensible heat)



Heat pipe (sensible heat)



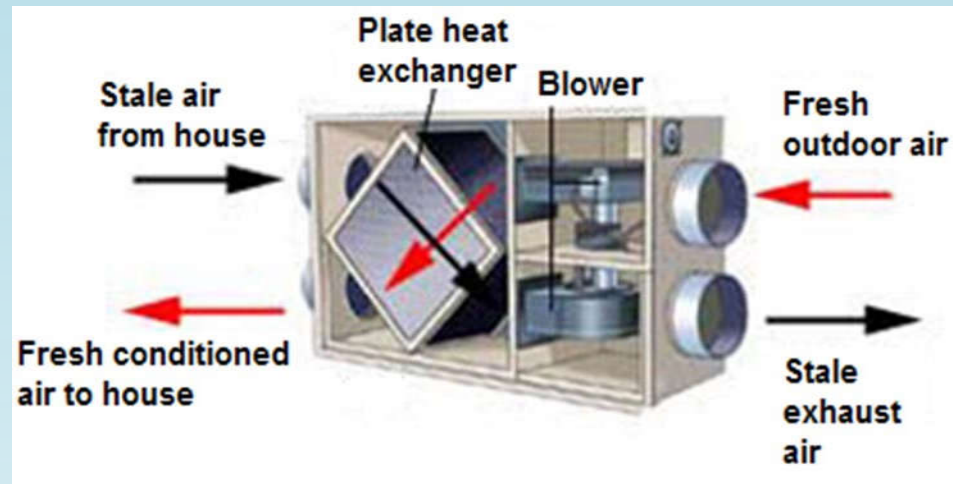
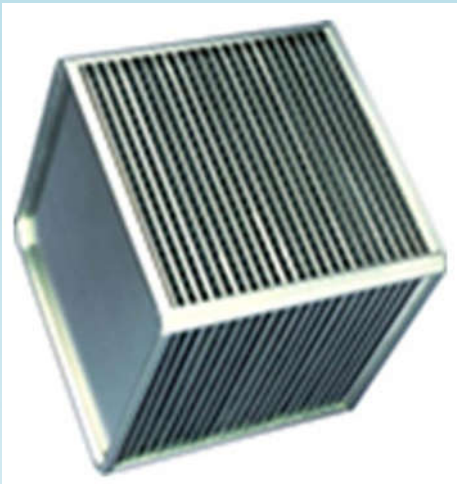
Heat pipe array intalled between two airstreams



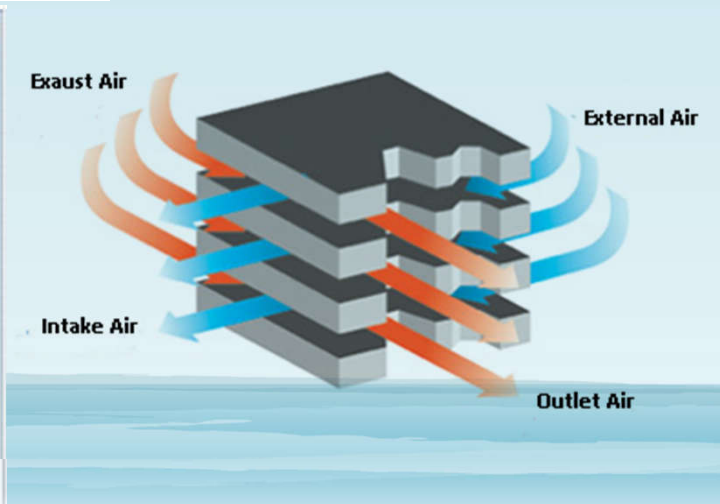
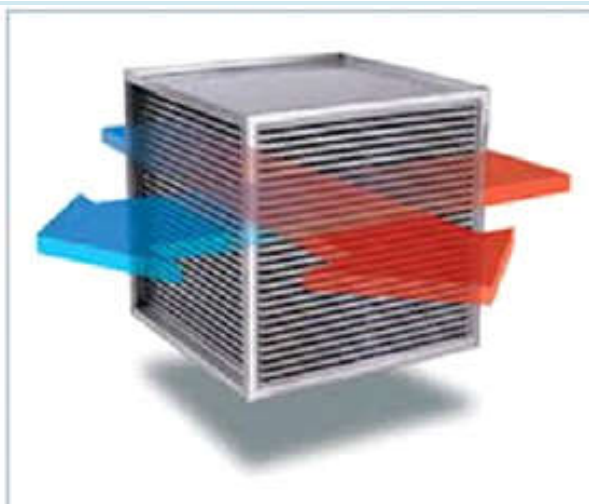
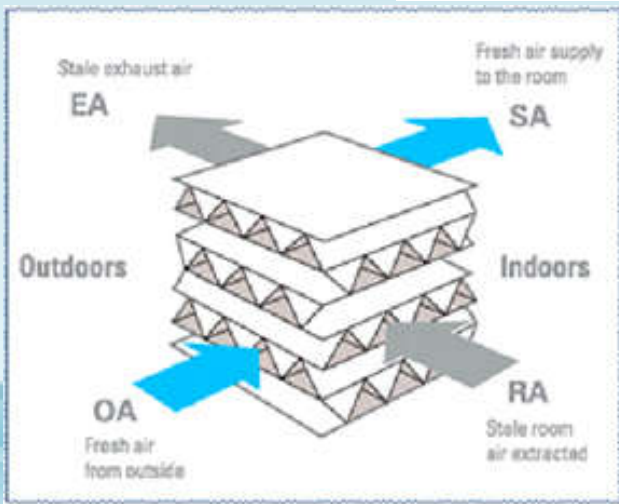
Sealed-tube thermosiphons

(Source: ASHRAE, 2020. *ASHRAE HVAC Systems and Equipment Handbook 2020*, SI edition, Chp. 9 Applied Heat Pump and Heat Recovery Systems)

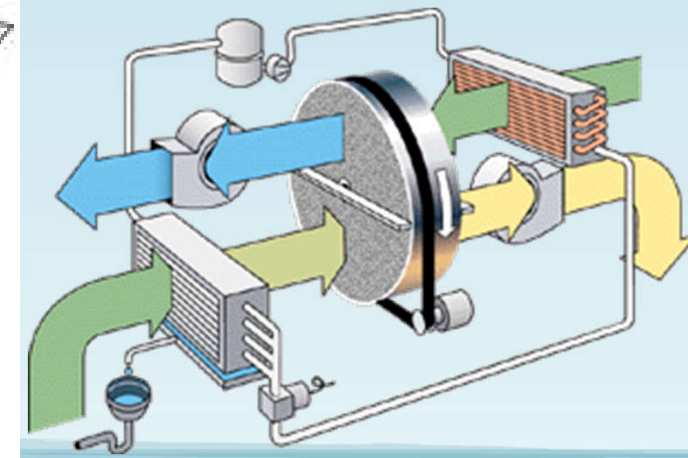
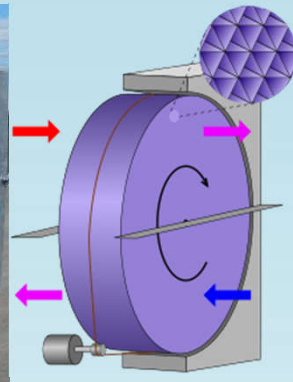
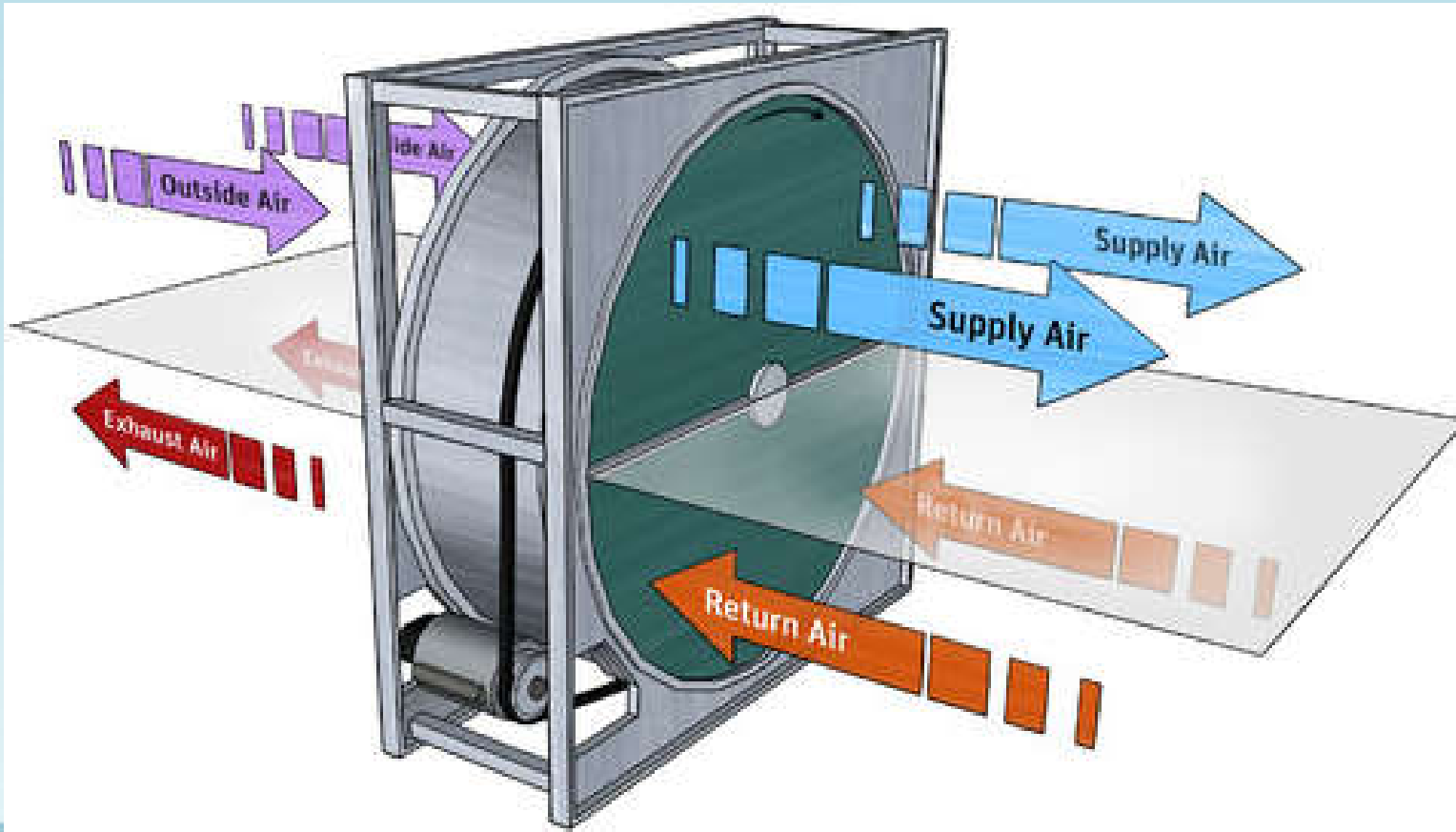
Plate heat exchanger (sensible heat)

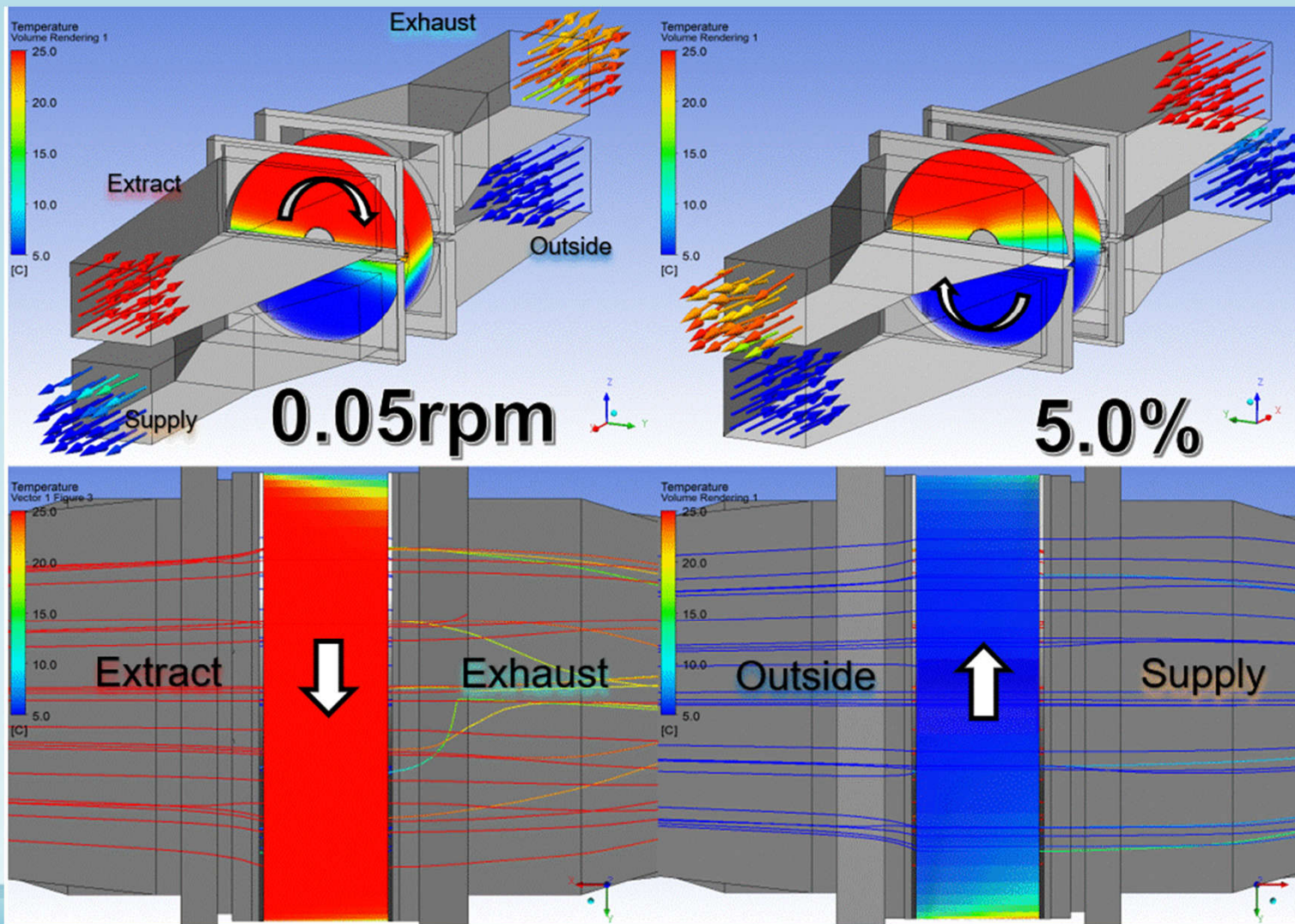


Two airstreams are separated by the plates to ensure no cross contamination.



Energy transfer wheel (sensible and/or latent)





Temperature distribution inside a thermal wheel energy recovery device

(Source: <https://swegonnorthamerica.com/learn/hvac-technology/air-to-air-energy-recovery/>)

Comparison of air-to-air energy recovery devices

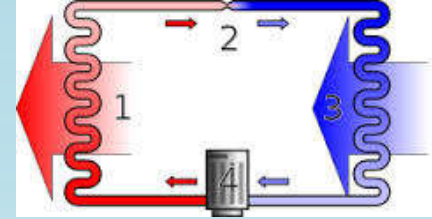
	Fixed Plate	Membrane Plate	Energy Wheel	Heat Wheel	Heat Pipe	Runaround Coil Loop	Thermosiphon
Airflow arrangements	Counterflow Cross flow ^a	Counterflow Cross flow ^a	Counterflow Parallel flow	Counterflow	Counterflow Parallel flow	—	Counterflow Parallel flow
Equipment size range, L/s	25 and up	25 and up	25 to 35 000 and up	25 to 35 000 and up	50 and up	50 and up	50 and up
Typical sensible effectiveness ($m_s = m_e$), % ^c	50 to 75	55 to 75	65 to 80	65 to 80	40 to 60 ^b	45 to 65 ^b	40 to 60
Typical latent effectiveness, * % ^c	0	25 to 60	50 to 80	0	0	0	0
Total effectiveness, * % ^c	20 to 50	35 to 70	55 to 80	25 to 60	15 to 35	—	—
Face velocity, m/s	1 to 5	1 to 3	2.5 to 5	2 to 5	2 to 4	1.5 to 3	2 to 4
Pressure drop, Pa	100 to 1000	100 to 500	100 to 300	100 to 300	150 to 500	150 to 500	150 to 500
EATR, %	0 to 2	0 to 5	0.5 to 10	0.5 to 10	0 to 1	0	0
OACF	0.97 to 1.06	0.97 to 1.06	0.99 to 1.1	1 to 1.2	0.99 to 1.01	1.0	1.0
Temperature range, °C	−60 to 800	−40 to 60	−55 to 800	−55 to 800	−40 to 93	−45 to 500	−40 to 40

Parameters of air leakage:
 EATR = exhaust air transfer ratio
 OACF = outdoor air correction factor

(Source: ASHRAE, 2020. *ASHRAE HVAC Systems and Equipment Handbook 2020*, Chapter 26. Air-to-Air Energy Recovery Equipment)

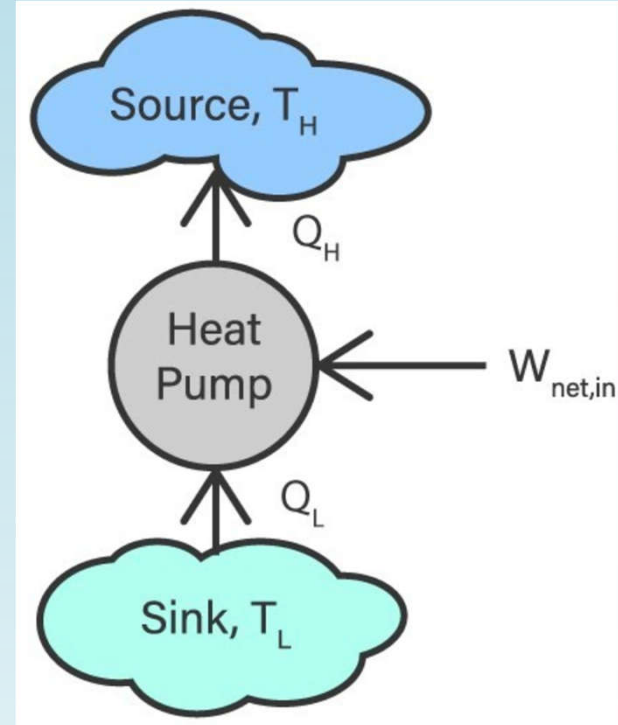
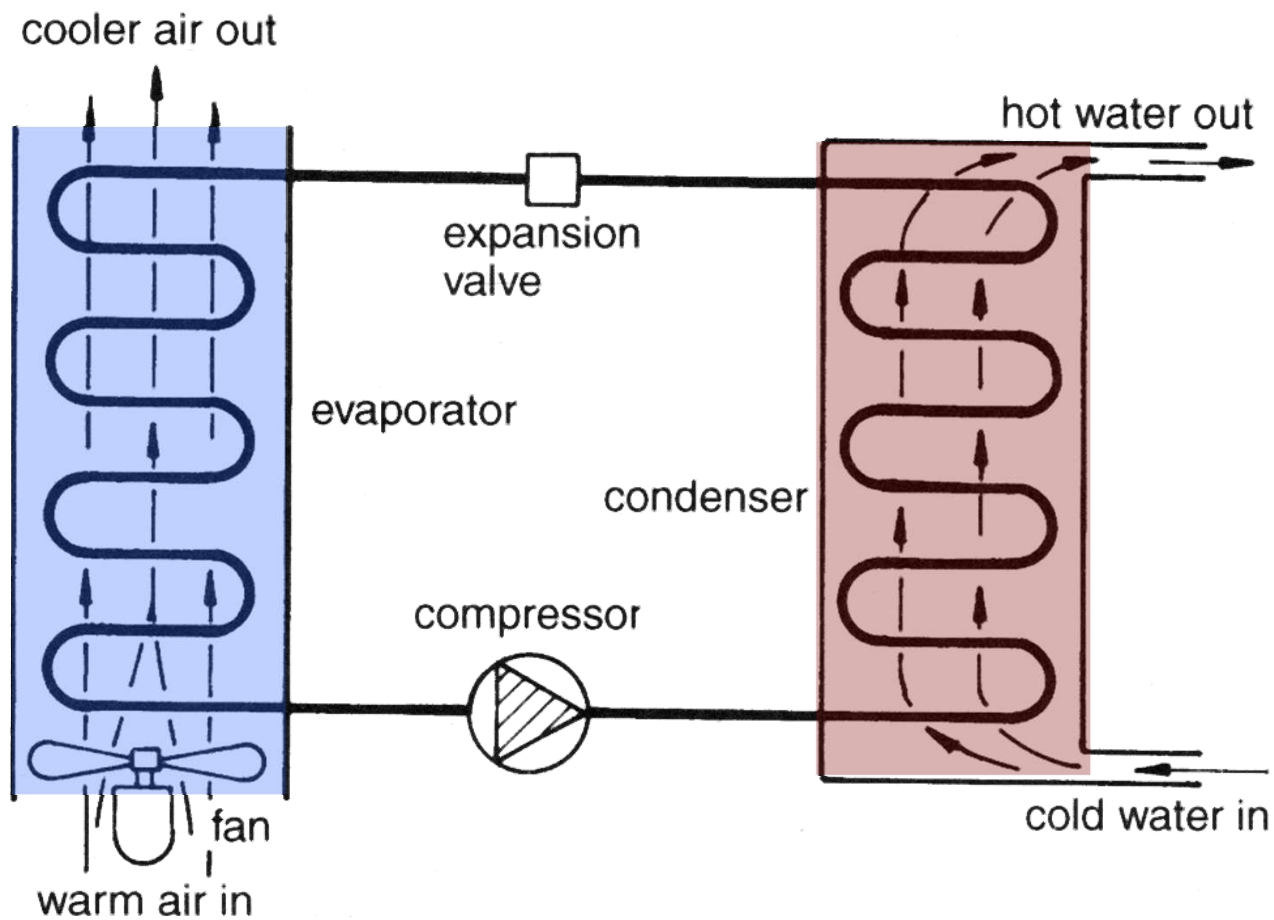
應用熱泵

Applied heat pumps



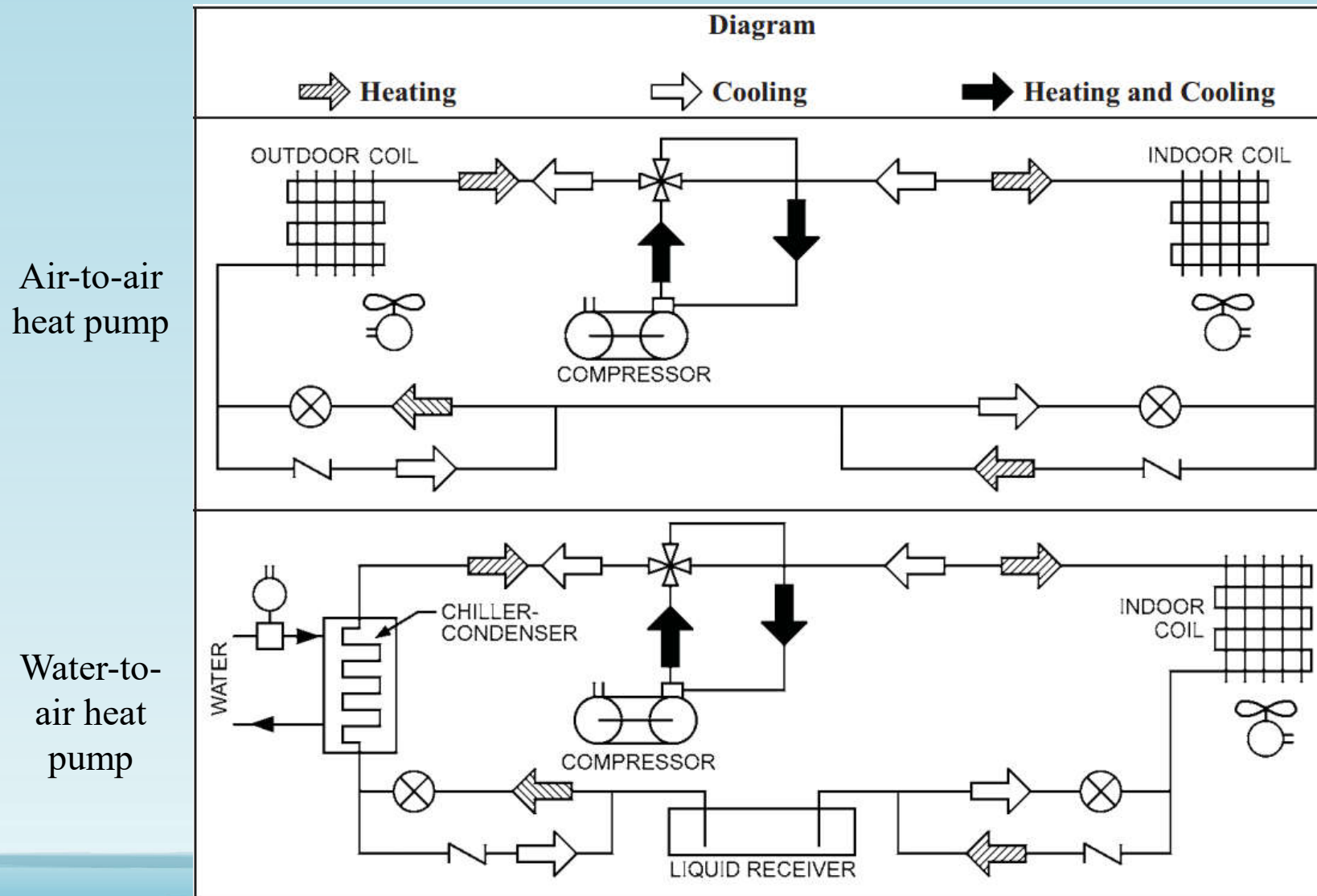
- A heat pump extracts heat from a source and transfers it to a sink at a higher temperature
- Common types of heat pumps
 - Air-to-air heat pump
 - Water-to-air heat pump
 - Ground water, surface water, internal-source, solar-assisted, wastewater-source
 - Water-to-water heat pump
 - Ground-coupled heat pump
 - Air-to-water heat pump (also called heat pump water heater)

Basic principles of heat pump



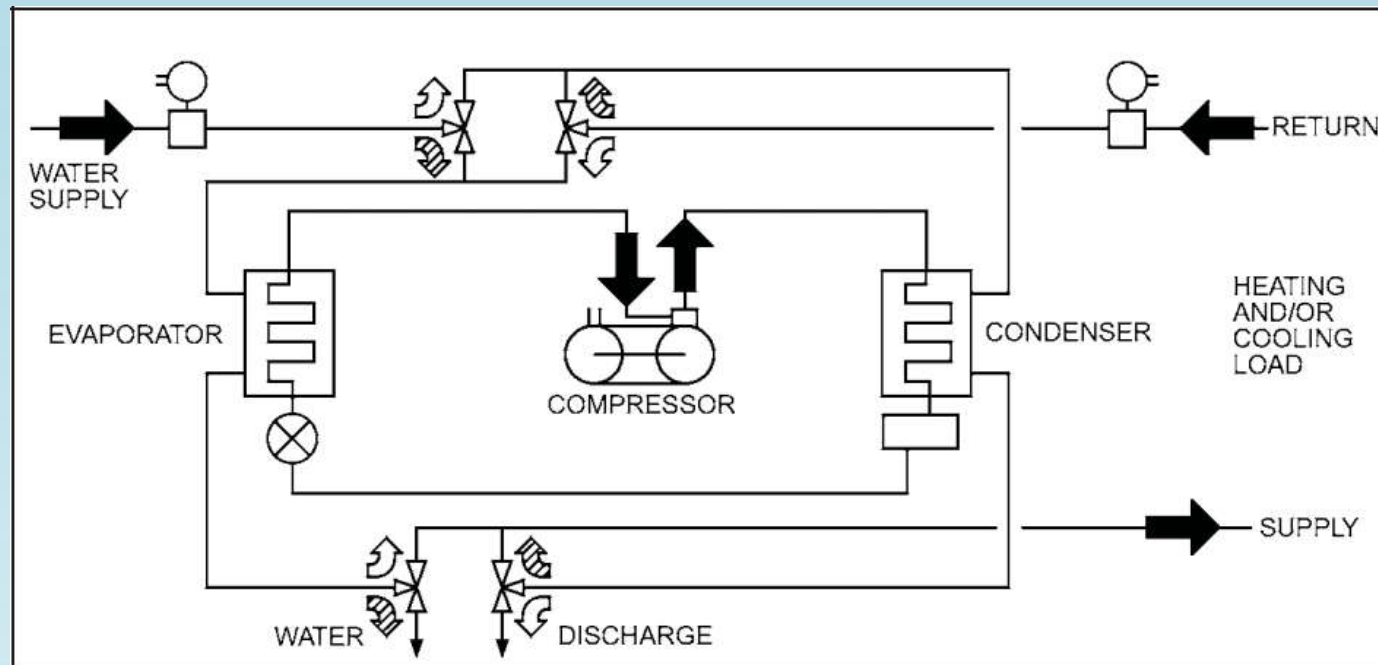
$$\begin{aligned} \text{COP}_{\text{HP}} &= \frac{\text{Heating Effect}}{\text{Work Input}} = \frac{|Q_H|}{W_{\text{net,in}}} \\ &= \frac{W_{\text{net,in}} + Q_L}{W_{\text{net,in}}} = 1 + \frac{Q_L}{W_{\text{net,in}}} \end{aligned}$$

(Source: Garrett, R. H., 2008. *Hot and Cold Water Supply*)

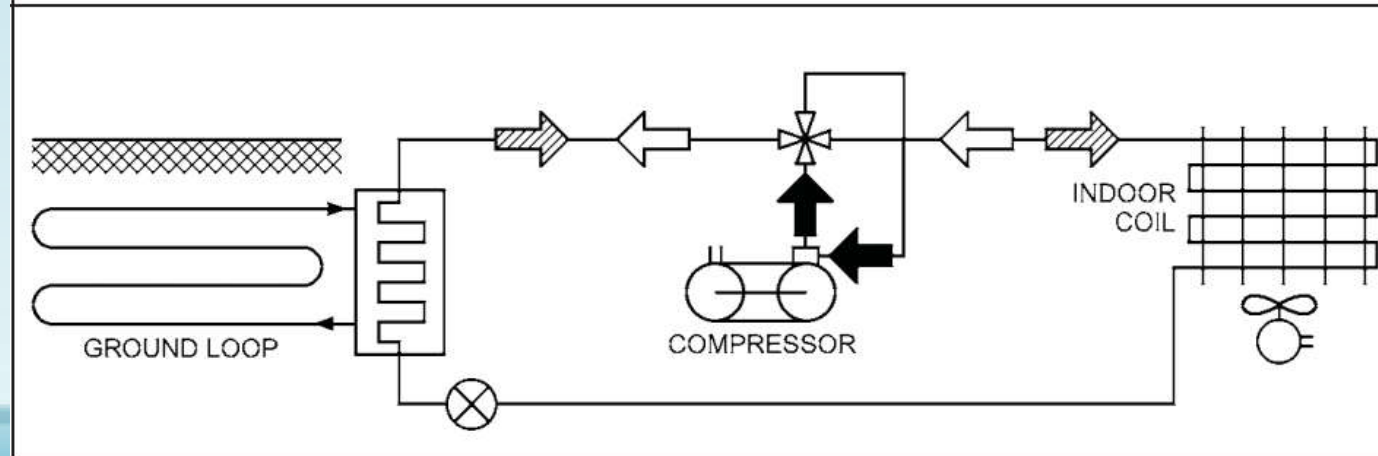


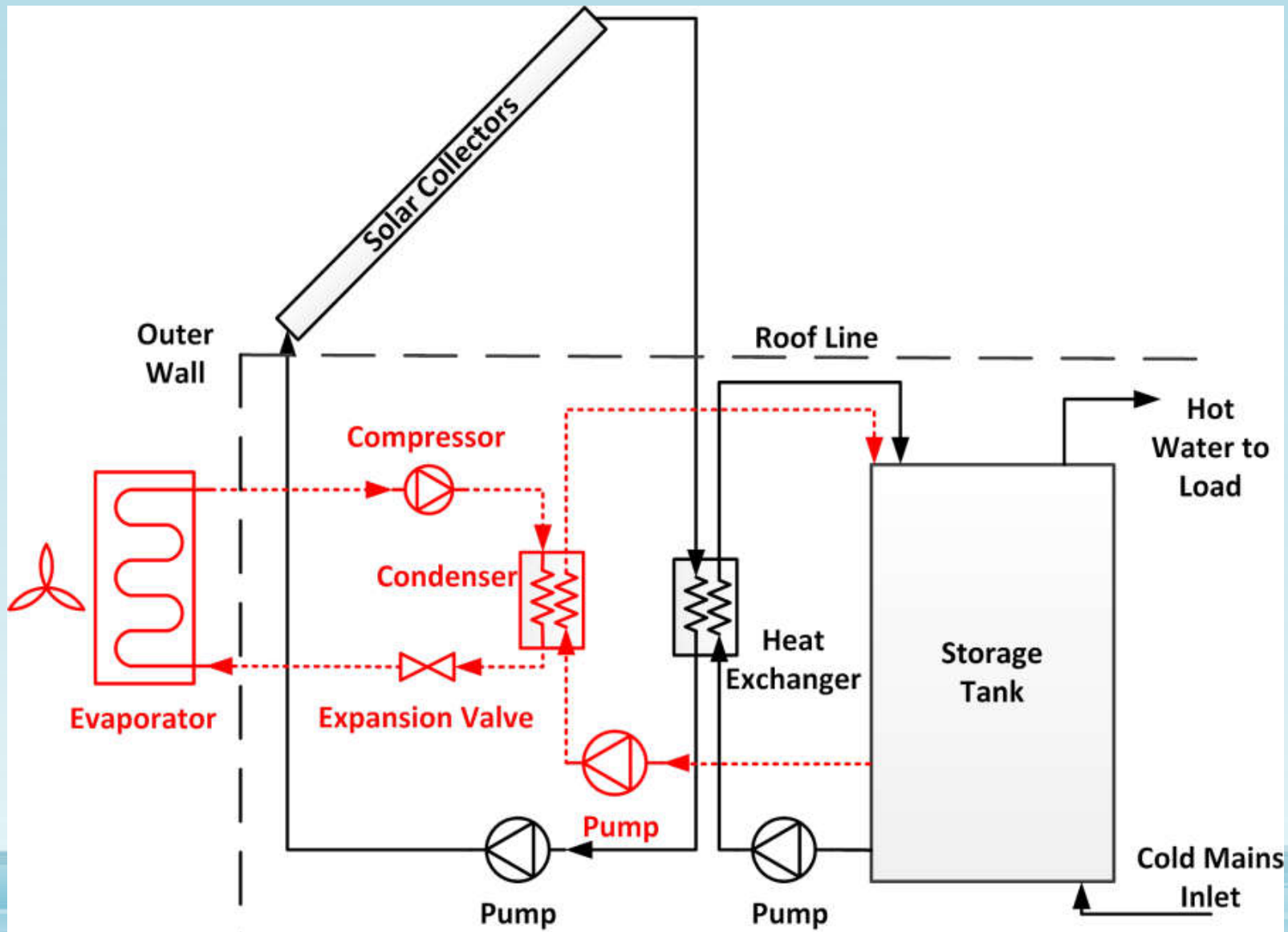
(Source: 2016 ASHRAE Handbook—HVAC Systems and Equipment, Chapter 9 – Applied Heat Pump and Heat Recovery Systems)

Water-to-water heat pump



Ground-coupled heat pump





Solar-assisted heat pump

(Source: Chu J. & Cruickshank C. A., 2014. Solar-assisted heat pump systems: a review of existing studies and their applicability to the Canadian residential sector, *Journal of Solar Energy Engineering*, 136 (4) 041013.

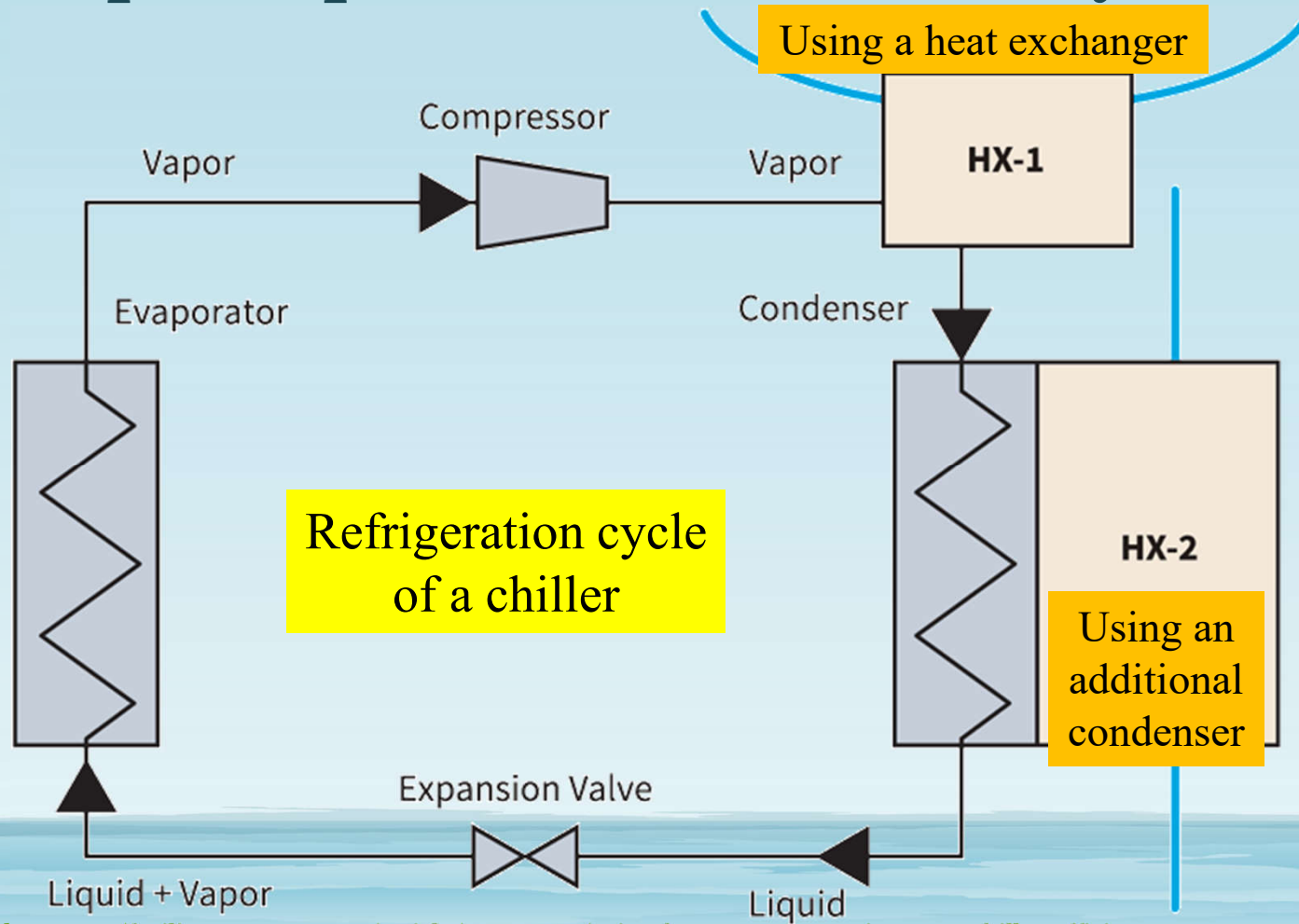
<https://doi.org/10.1115/1.4027735>)

Heat recovery chillers

- For both water or air-cooled chillers
- When there is a simultaneous need for chilled water and hot water, these chillers have the capability to operate in heat recovery mode
- The recovered heat can be redirected for various heating applications:
 - Building space heating
 - Service water pre-heating (e.g. laundry, dish washing)
 - Process hot water (e.g. swimming pool heating)

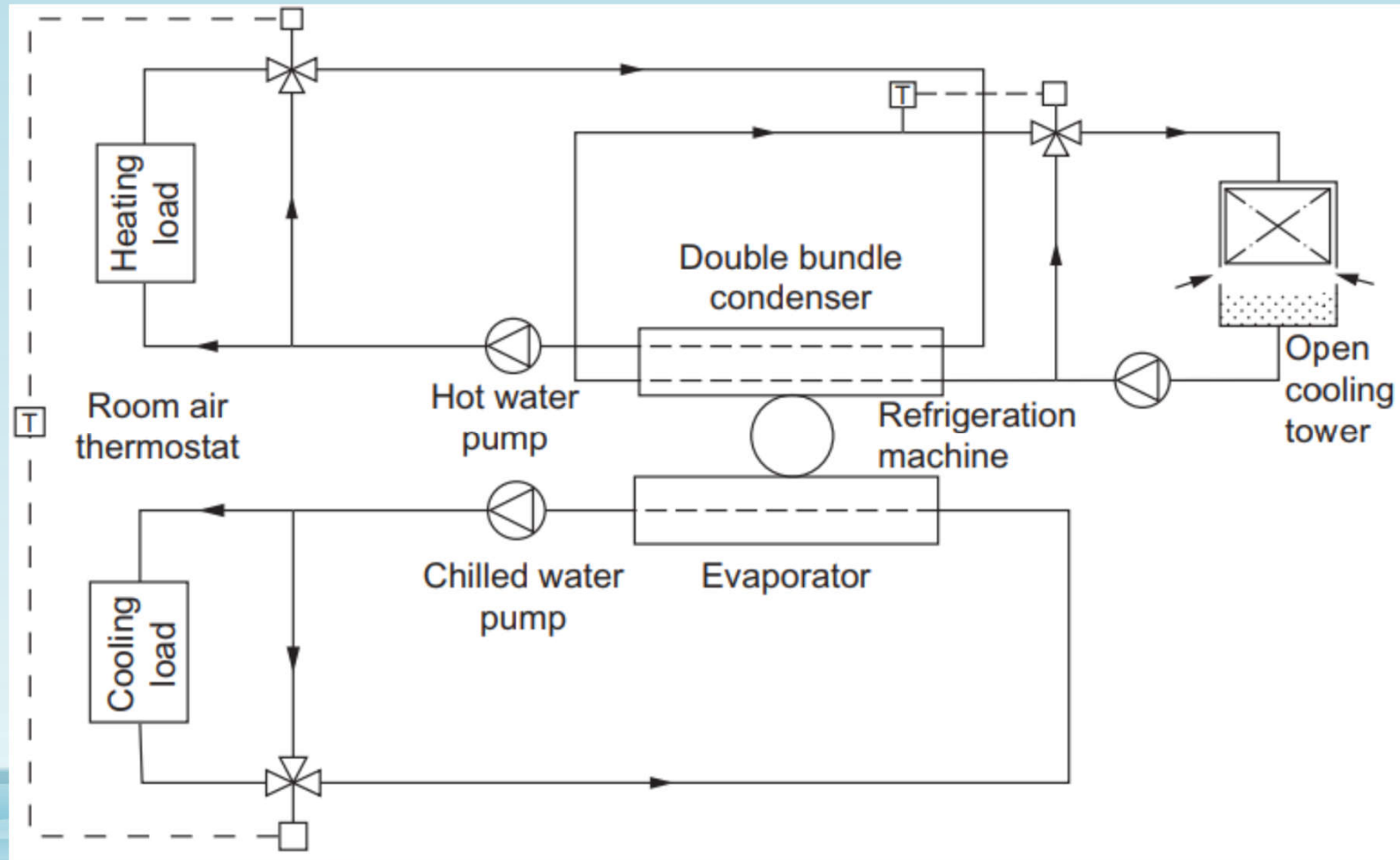


Basic principles of a heat recovery chiller

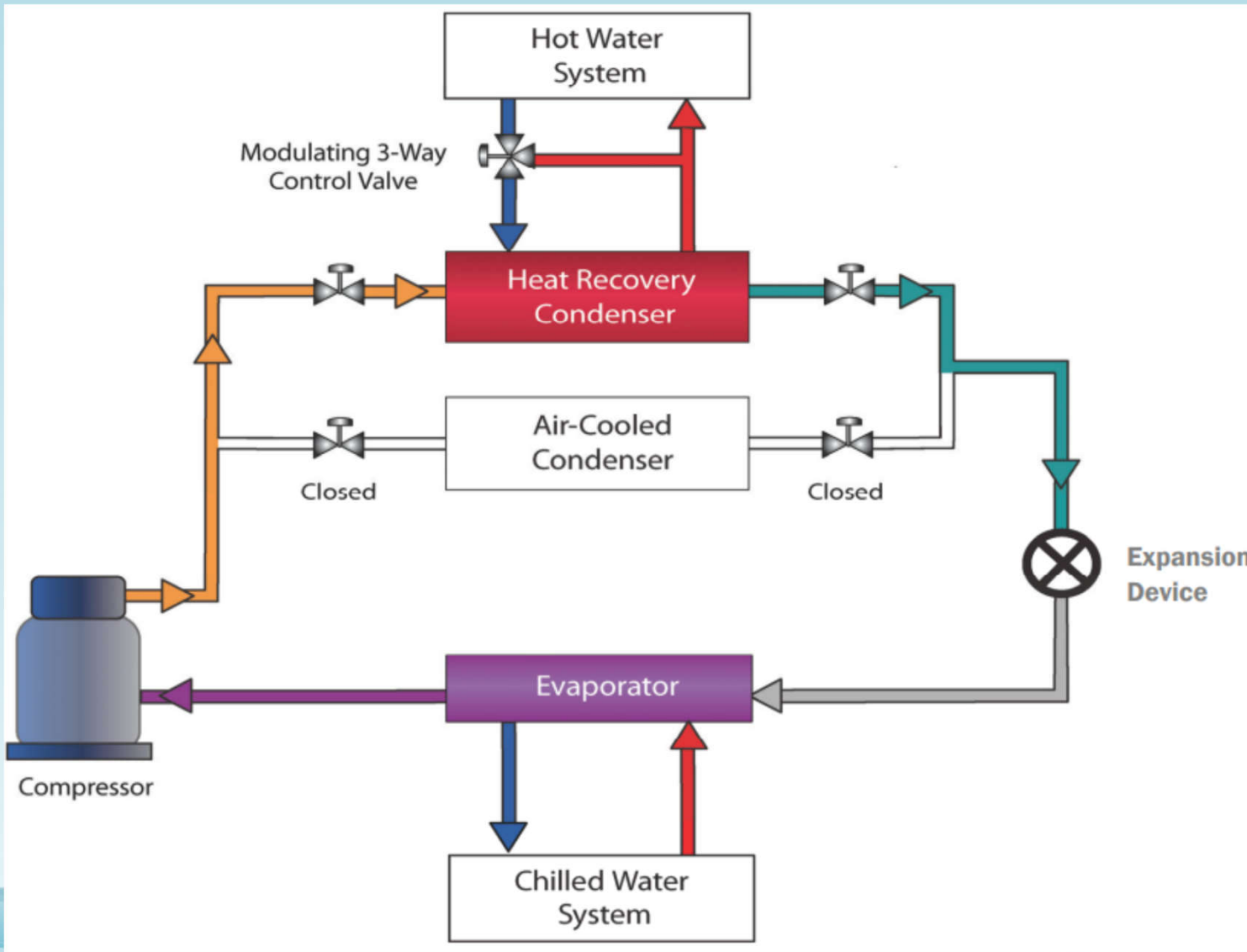


(Adapted from: <https://www.hpac.com/facility-management/article/20929701/using-heat-recovery-to-improve-chiller-efficiency>)

Heat recovery system with double-bundle condenser



(Source: Legg R., 2017. *Air Conditioning System Design*, Elsevier Science & Technology, Oxford.)



Air-cooled chiller with heat reclaim capabilities: heat recovery mode

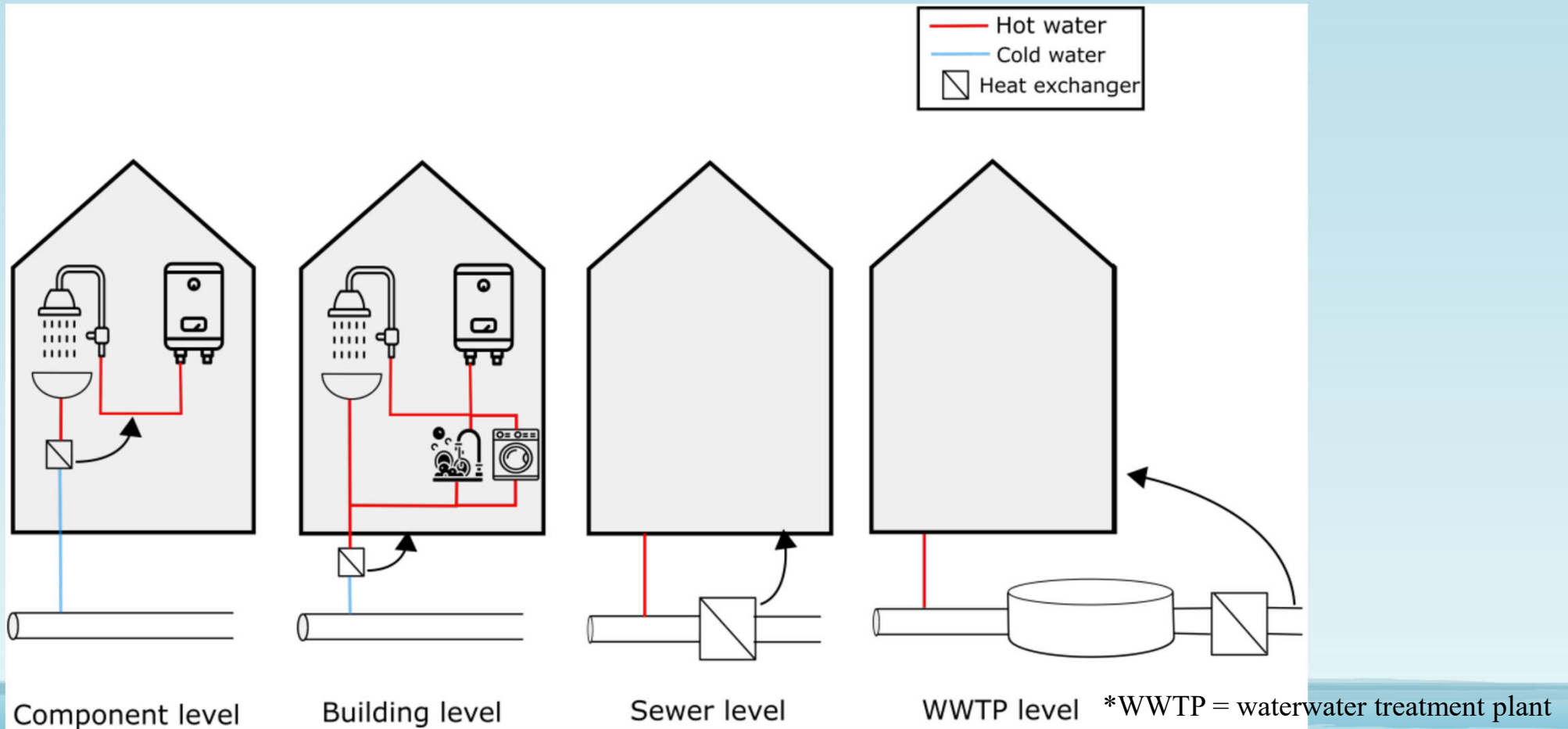
(Image source: Carrier Corporation)

Wastewater heat recovery



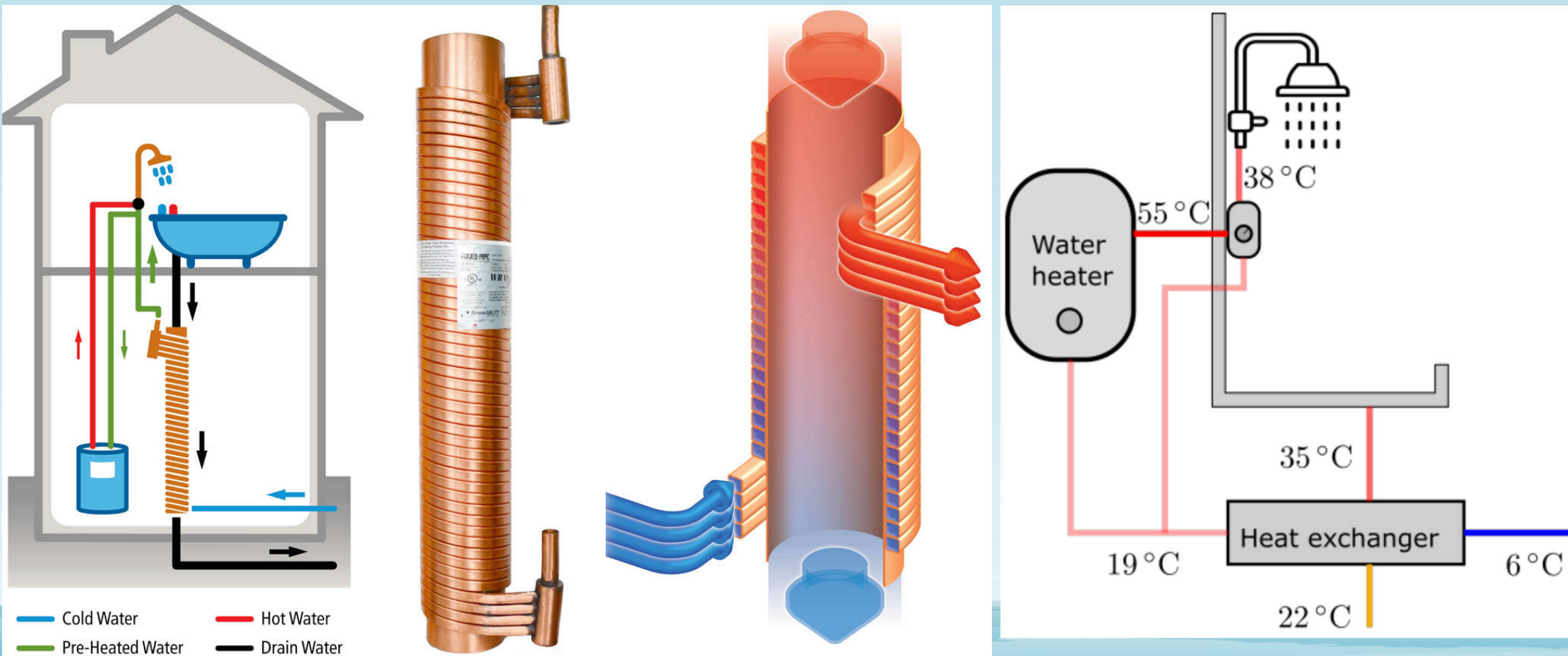
- Wastewater heat recovery (WWHR) systems
 - Captures the heat from wastewater to preheat incoming water for the domestic hot water tanks or for space heating
 - Drain wastewater (residential)(say, 10 to 25 °C)
 - Medium building wastewater (residential/commercial)
 - Trunk sewers (urban areas, sewage flow > 100 L/s)
 - Using external or in-sewer heat exchanger
 - Discharge effluent from the wastewater treatment plants
 - Recover heat in winter; reject heat in summer

Possible options of heat recovery from wastewater



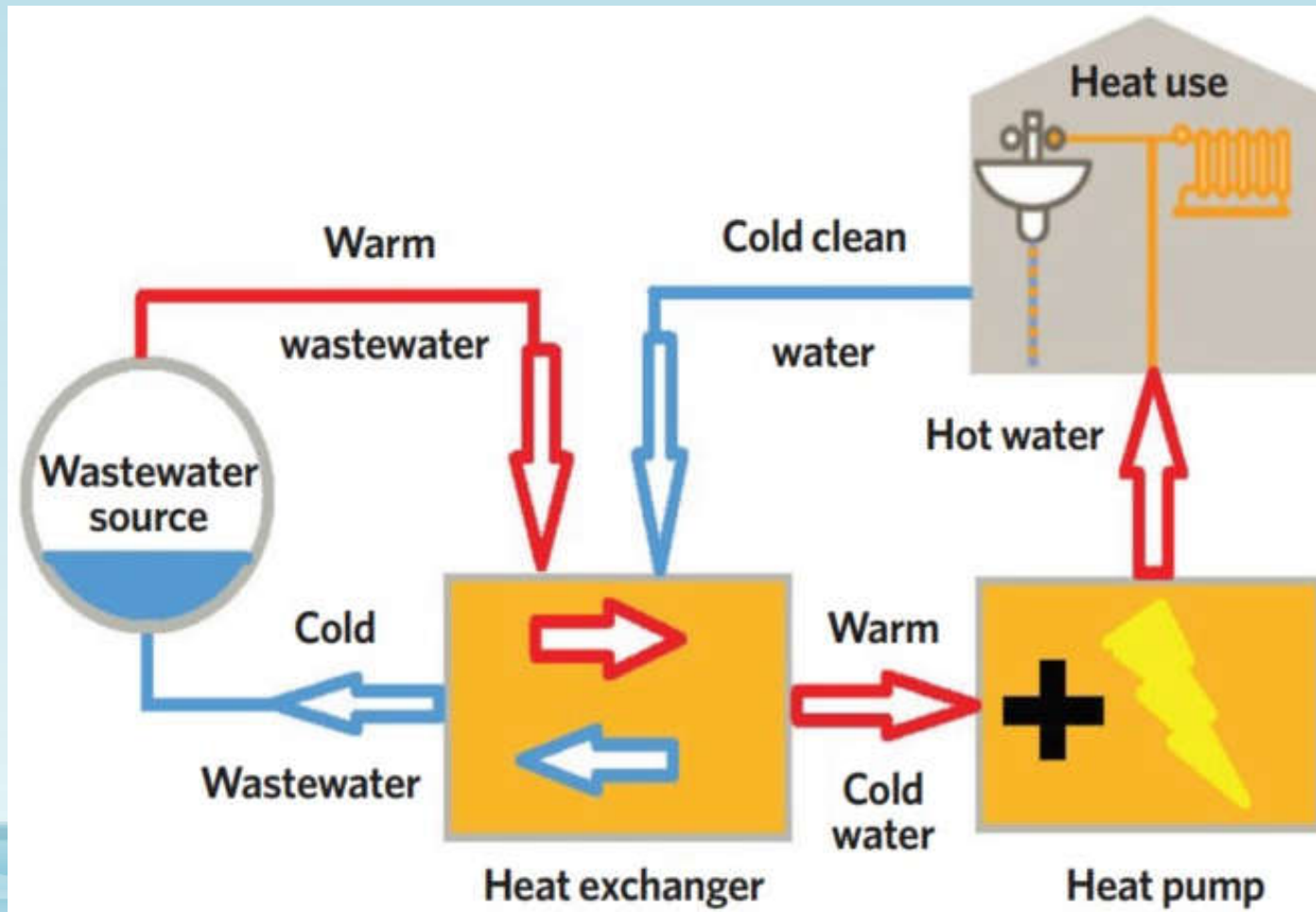
(Source: Nagpal H., Spriet J., Murali M. K. & McNabola A., 2021. Heat recovery from wastewater—a review of available resource, *Water*, 13 (9) 1274. <https://doi.org/10.3390/w13091274>)

Wastewater heat recovery for residential building



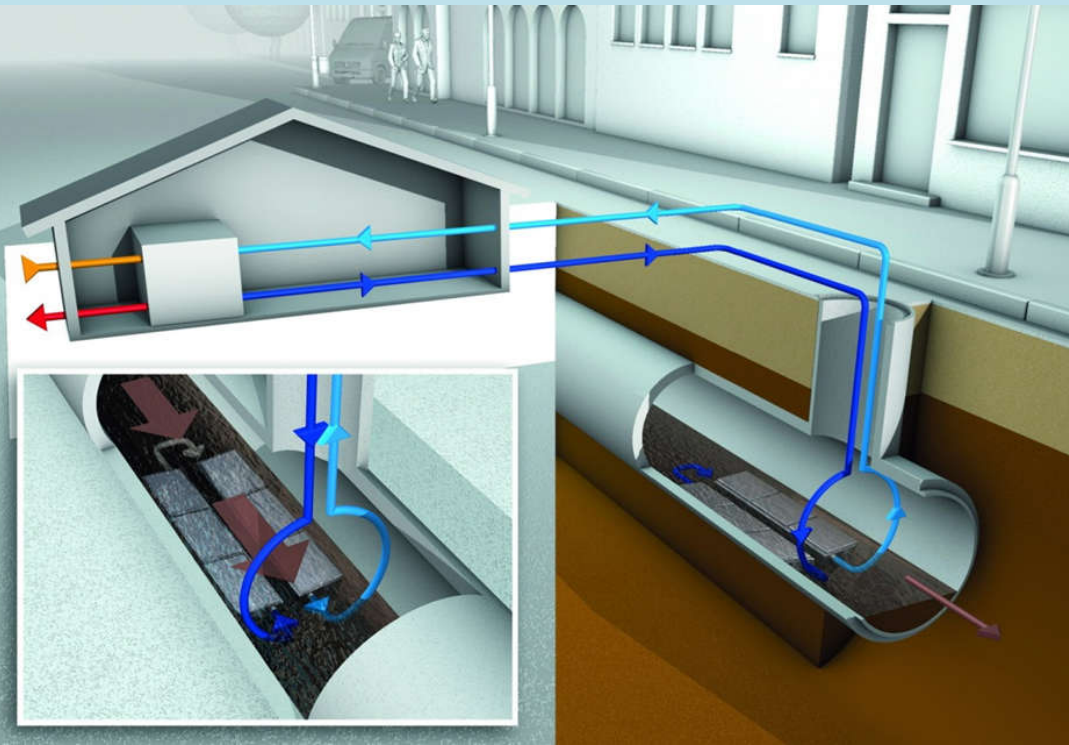
(Source: <https://www.phamnews.co.uk/wise-up-to-water-waste-heat-recovery/> & <https://www.energy.gov/energysaver/drain-water-heat-recovery>)

Wastewater heat recovery for residential building

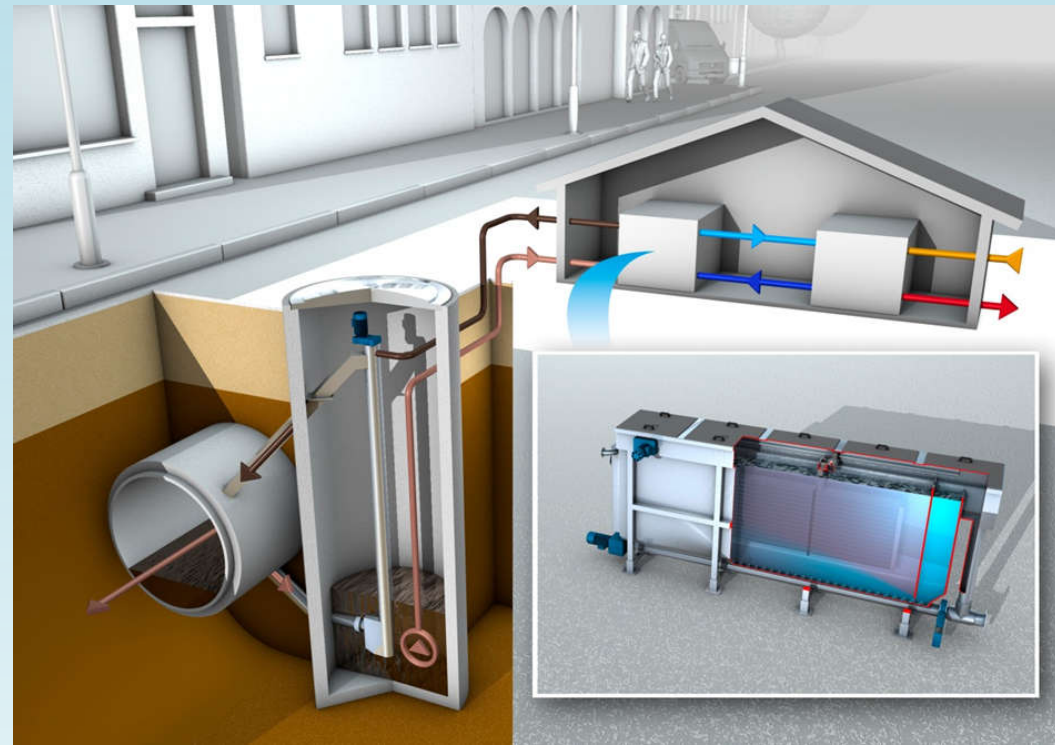


(Source: <https://www.cibsejournal.com/general/londons-hidden-energy-source-recovering-heat-from-sewage/>)

Sewer heat recovery systems



(a) In-sewer heat exchanger



(b) External heat exchanger

Conclusions



- Heat recovery technologies can play a key role in energy efficient buildings and can also aid in improving indoor environmental quality and occupants' comfort level (e.g. fresh air in air-to-air energy recovery)
- The potential of applying the technologies in hot and humid climate (like Hong Kong) is large
- More efforts are needed to study and adapt the heat recovery technologies in our society to promote a sustainable future for energy efficient buildings



Thank You