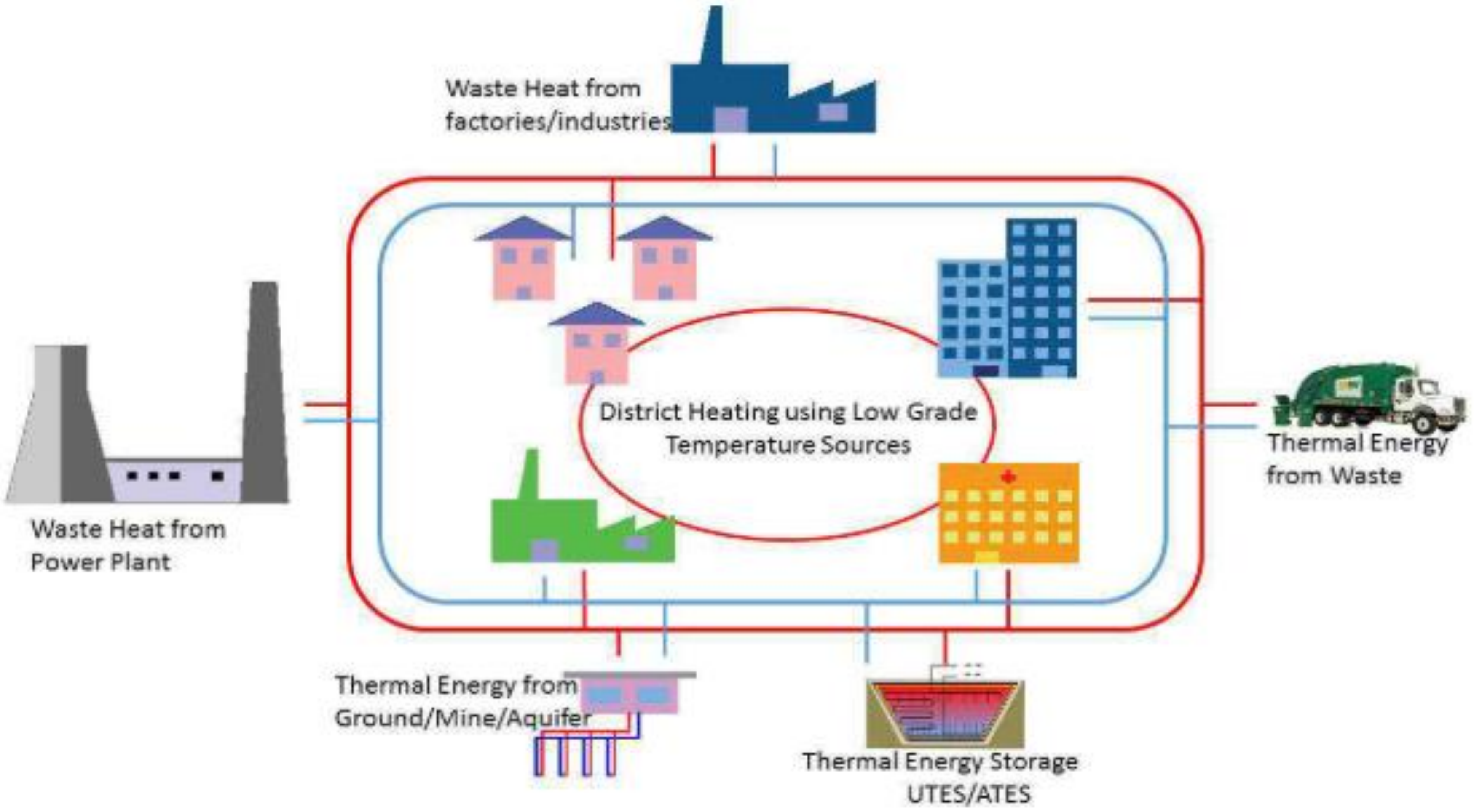
Module 3: Heat production

Module 3.2 Waste Heat Utilisation and Heat Pumps

SHaKE – Sharing Heat and Knowledge on Energy Communities
Erasmus+ KA220-HED Cooperation Partnerships in Higher Education
Developing institutions: Universitat Jaume I de Castellón and Budapest University of Technology and Economics
Authors: Ghad Alarnaout-Alarnaout, Dr. Adrián Mota-Babiloni, Dr. Balázs Bokor
Date: May 2026 Version 1.1

SHaKE
Sharing Knowledge on Energy Communities

1.1. WASTE HEAT BACKGROUND AND CLASSIFICATION



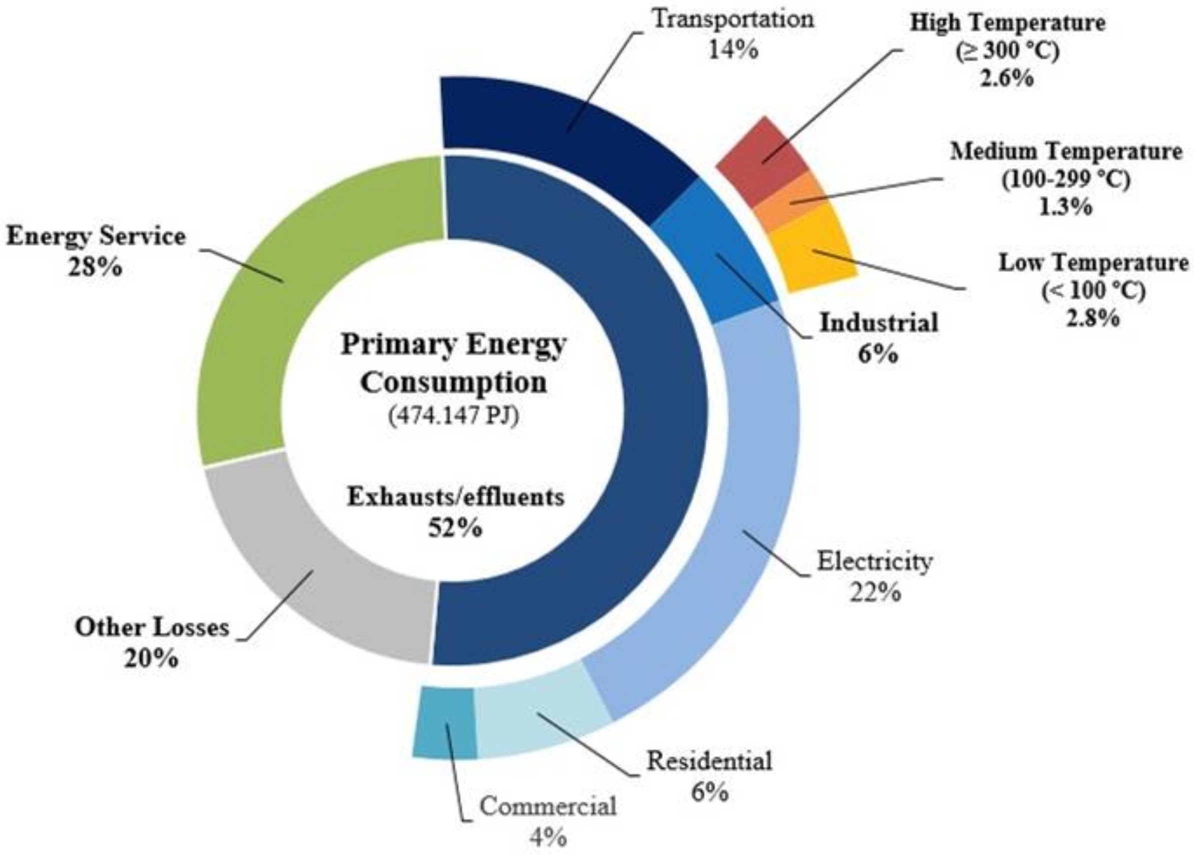
Source: Energy.nl

1.1. WASTE HEAT BACKGROUND AND CLASSIFICATION

A more detailed classification based on temperature ranges can be found (Oh et al., 2024):

Ultra-low-grade (T_{amb}-60)	Low-grade (60-100 °C)	Medium-grade (100-400 °C)	High-grade (>400 °C)
• Data centers • Energy storage system • HVAC facility • Waste water sewage • Geothermal • Biologic descomposition • Solar thermal	• Internal combustion engine (jacket coolant) • Industrial process stream (manufacturing) • Hidrothermal • Anaerobic digestion	• Internal combustion engine (exhaust gas) • Power plant exhaustIndustrial process stream (chemical & food) • Geothermal (volcanic areas • Fermentation processes	• Industrial process stream (iron & steel) • Power plant exhaust (gas turbine) • Inceneration processes

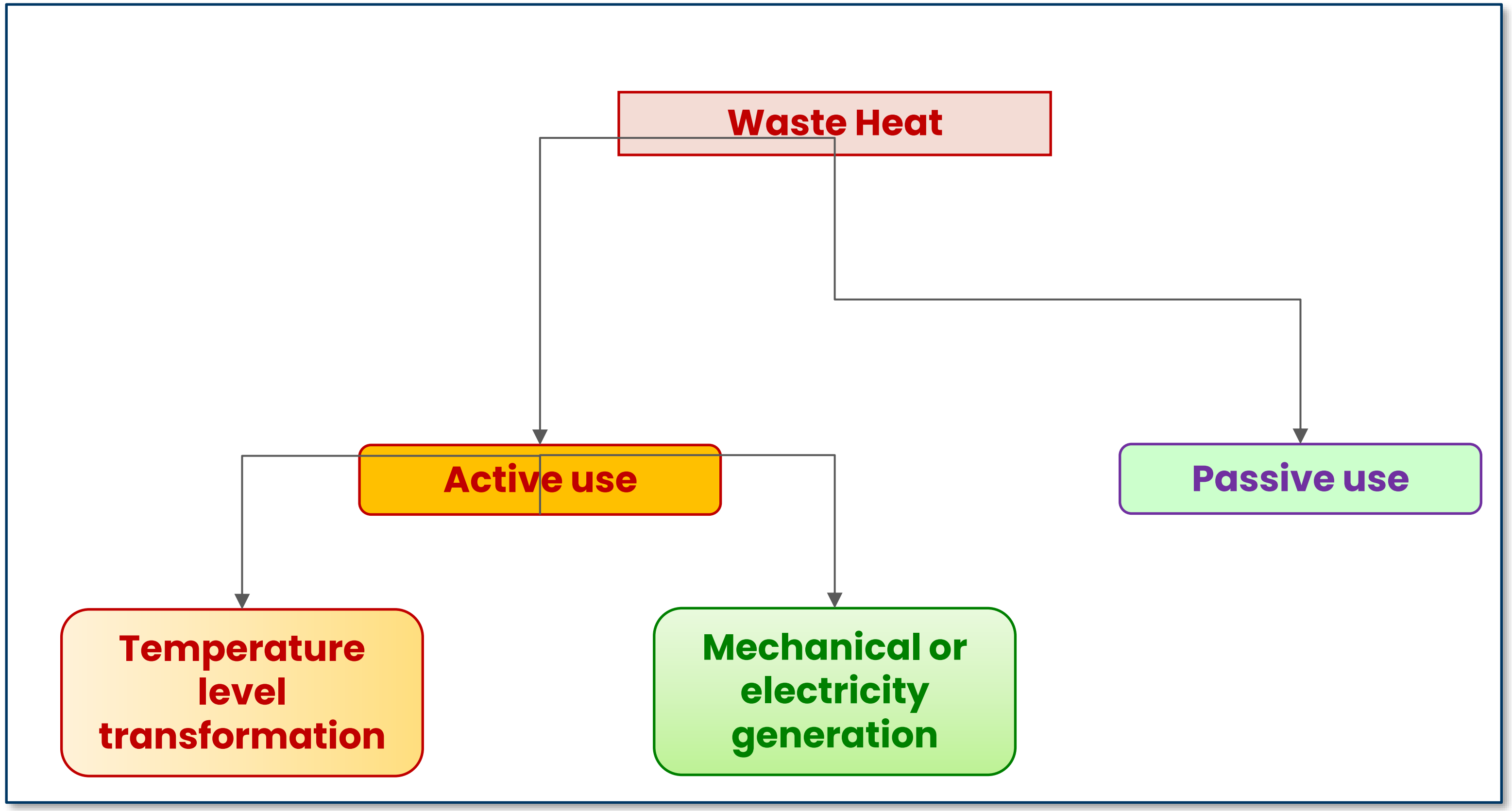
1.1. WASTE HEAT SOURCE CLASSIFICATION



Source: Forman et al. (2016)

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

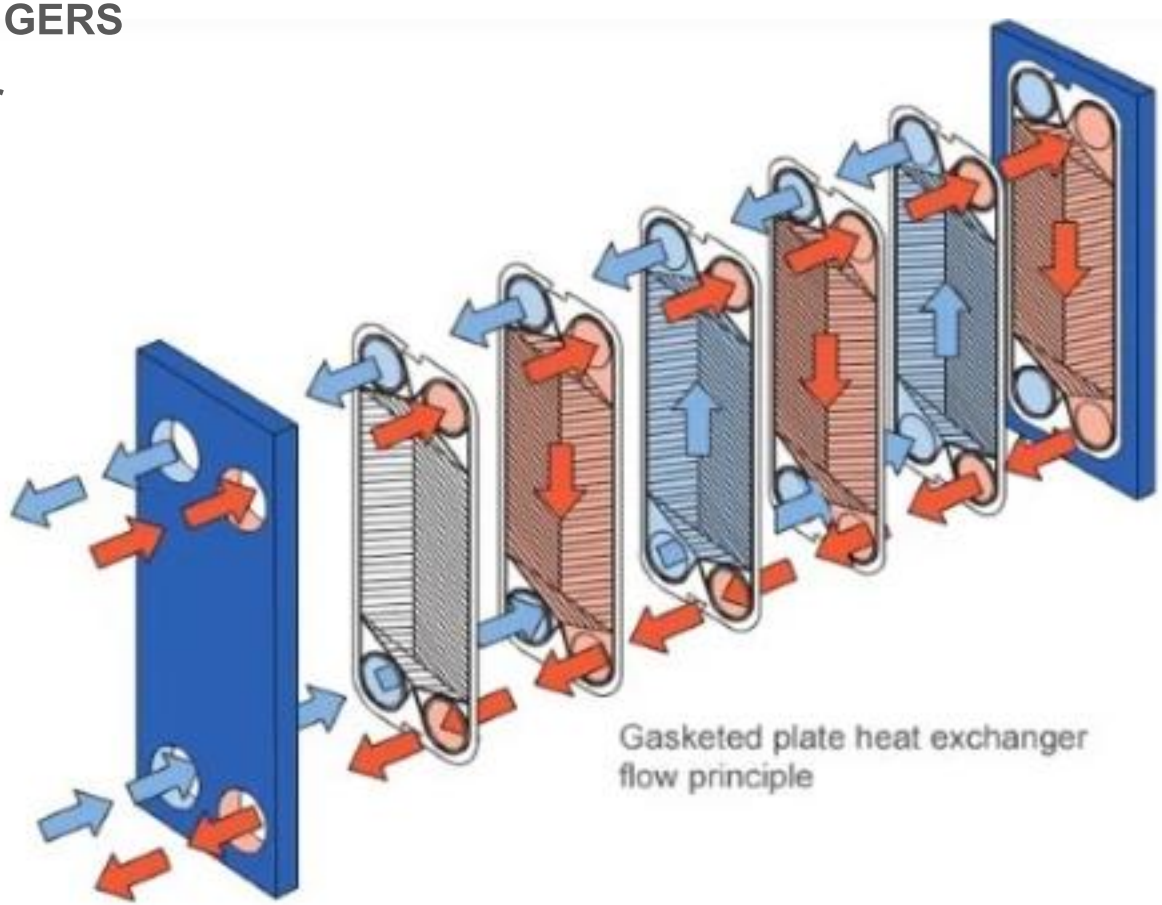
Waste heat can be either used directly, through passive use (simply using a heat exchanger) or transformed, through active technologies (transforming the temperature level or producing mechanical or electrical energy).



1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

1.2.1. HEAT EXCHANGERS

Plate heat exchanger

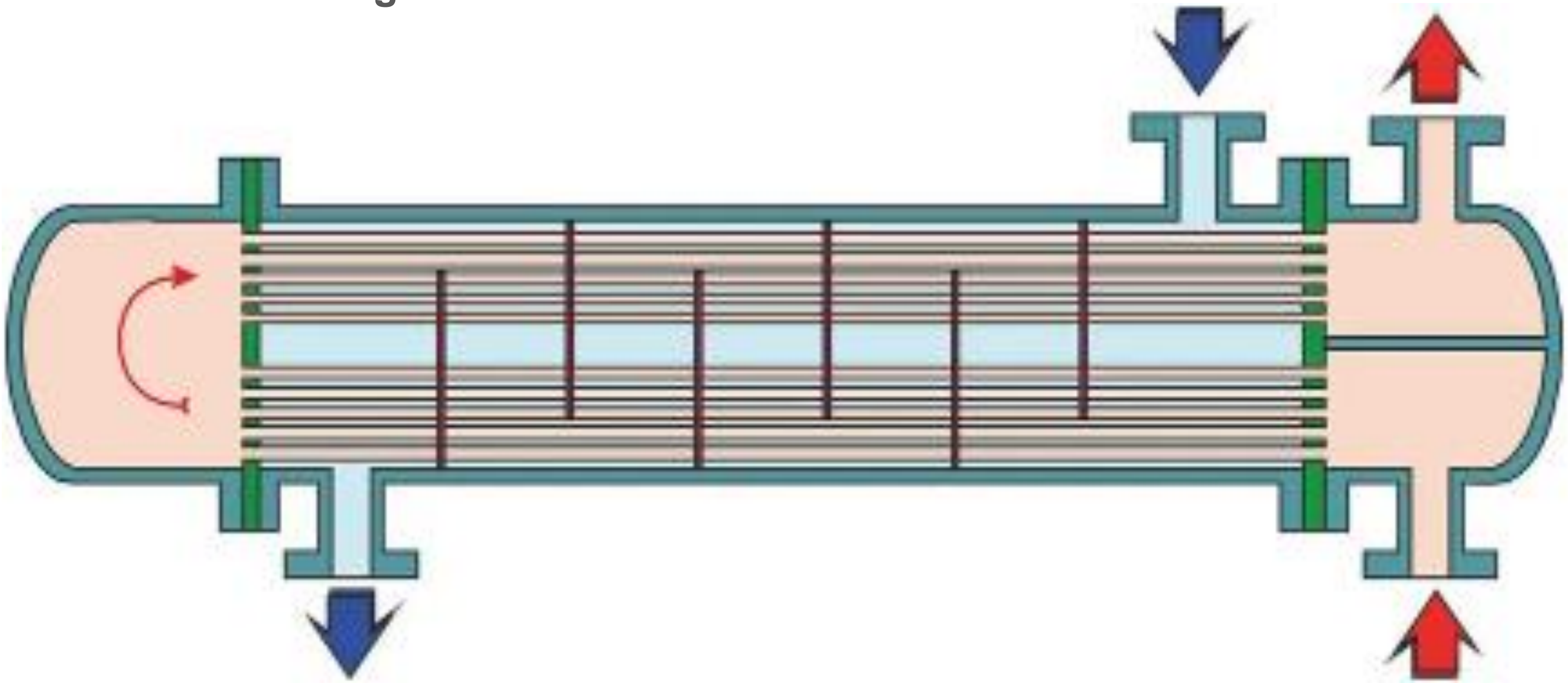


Source: Alfa Laval, 2024

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

1.2.1. HEAT EXCHANGERS

Shell and tube heat exchanger

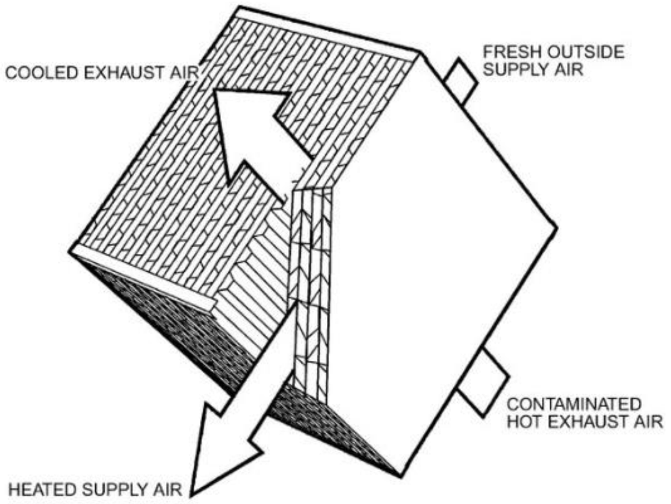


Source: Adobe Stock, 2024

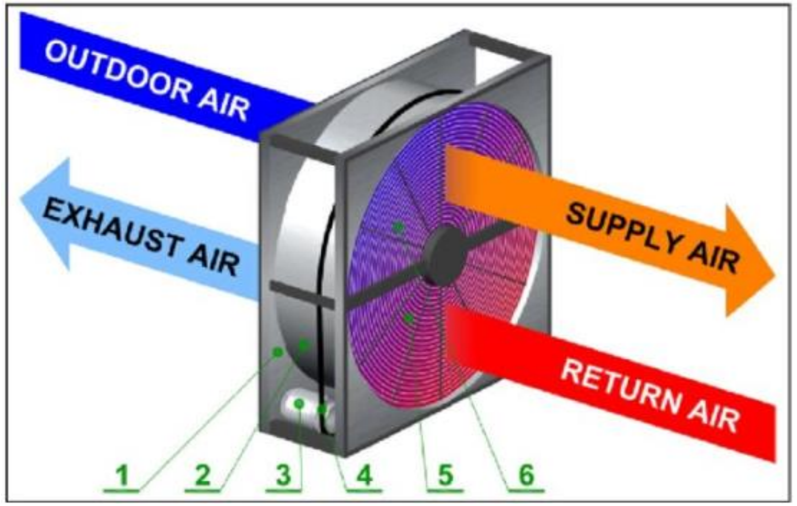
1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

1.2.1. HEAT EXCHANGERS

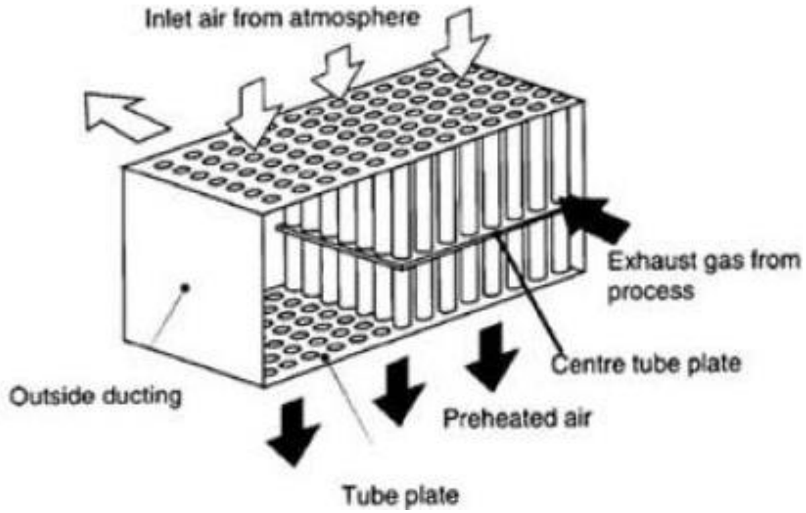
Air-to-air heat exchanger (recuperator)



Fixed Plate exchanger



Rotary heat exchanger



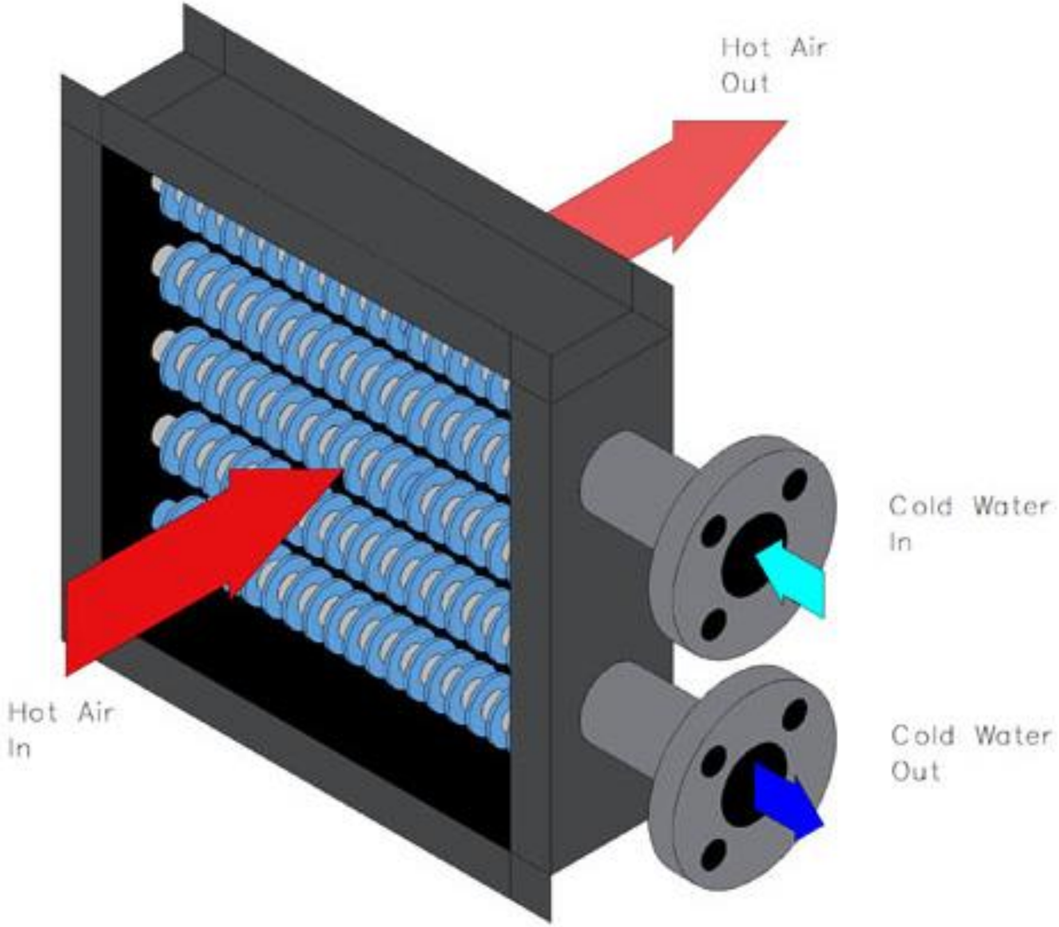
Heat pipe heat exchanger

Source: Commercial Waste Heat Recovery Devices, 2013

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

1.2.1. HEAT EXCHANGERS

Finned tube heat exchangers/Economizers

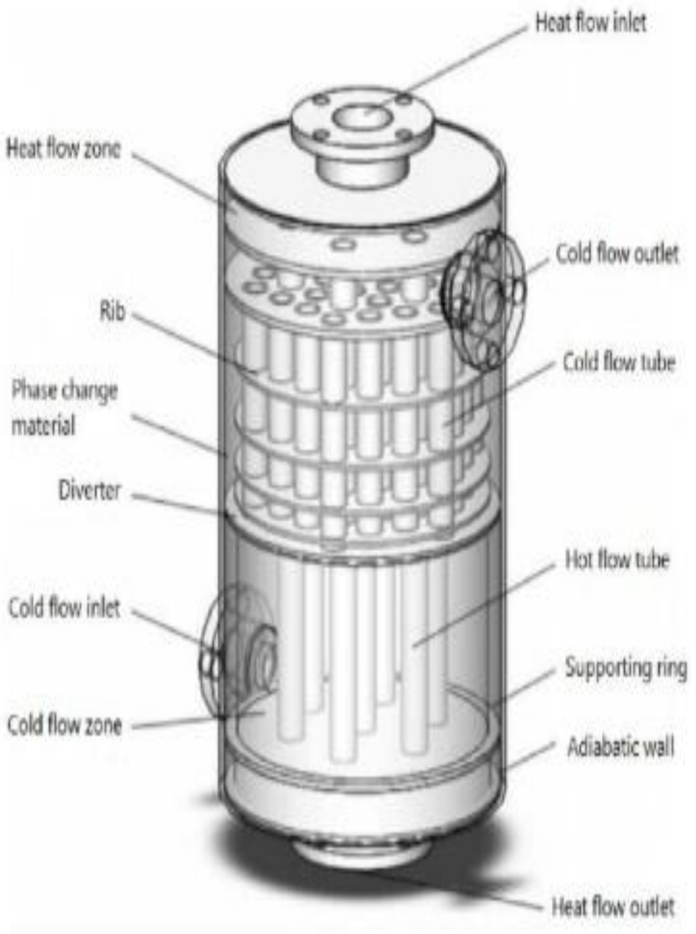


Source: Commercial Waste Heat Recovery Devices, 2013

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

1.2.1. HEAT EXCHANGERS

Regenerative heat exchangers

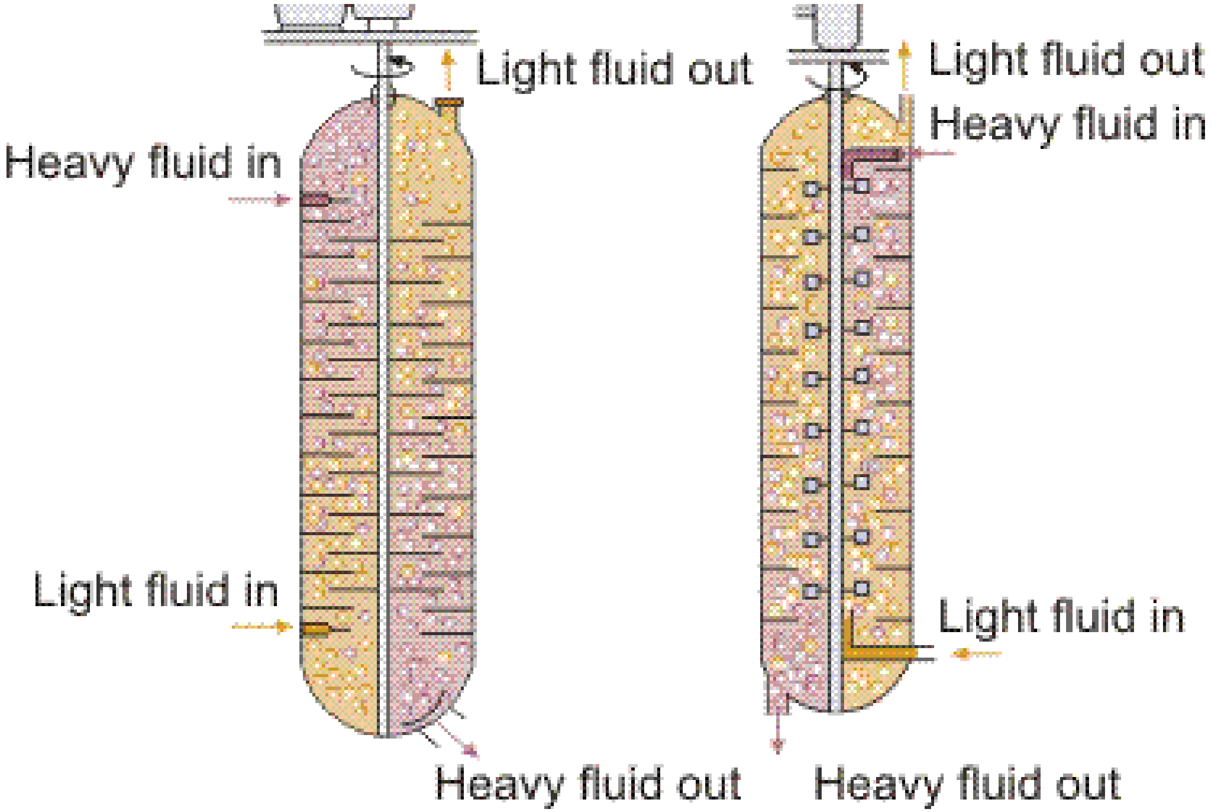


Source: Du et al. (2021)

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

1.2.1. HEAT EXCHANGERS

Direct contact heat exchangers

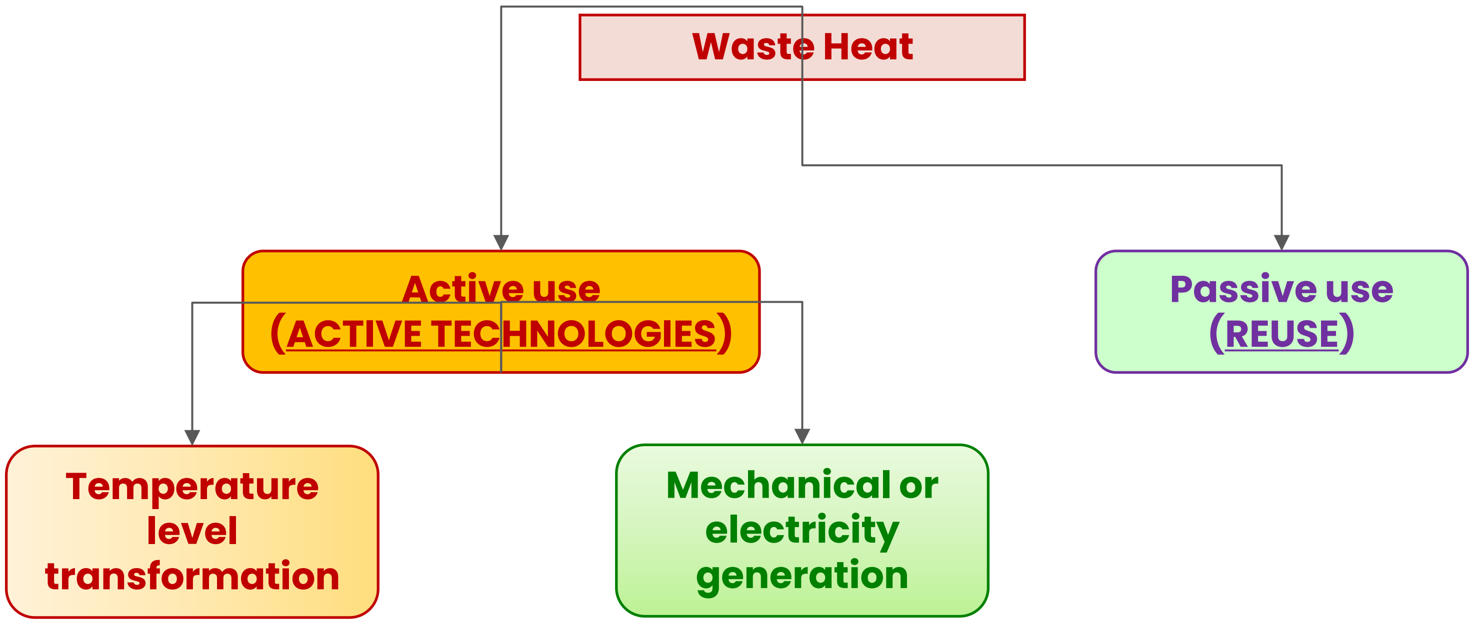


Source: THERMOPEDIA

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

1.2.1. WASTE HEAT REVALORIZATION

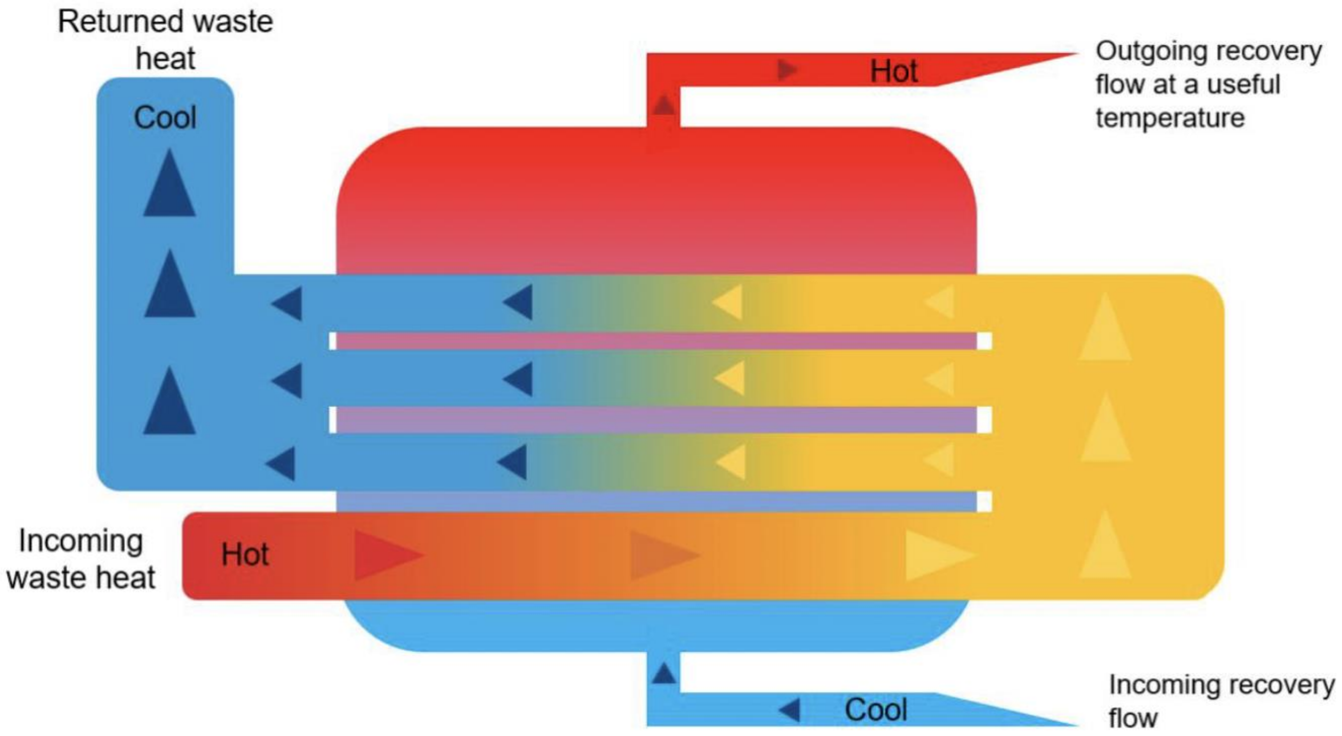
As mentioned before, heat exchangers are the most common technologies used for capturing waste heat. Once the waste heat is captured, it can be used directly (reuse) or several active technologies can be used to transform it into thermal energy at other temperature level or transform it into mechanical or electrical energy.



1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

1.2.2. REUSE

Heat recovery steam generators (HRSG): heat exchanger that captures and utilizes waste heat from hot exhaust gases to generate steam.



Source: Scottish Government, 2024

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

1.2.2. REUSE

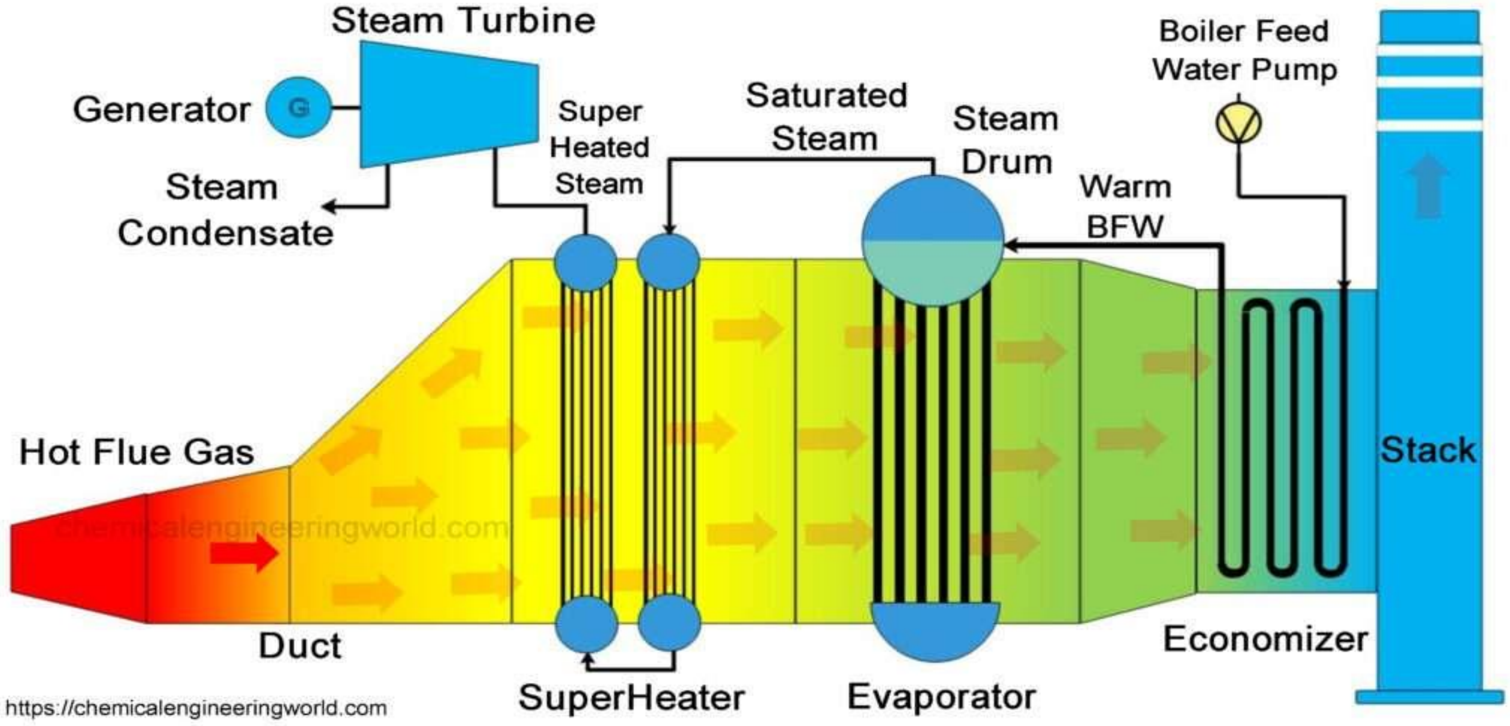
Economizers: heat exchanger that recovers waste heat from exhaust gases or process fluids to preheat water or air.

Source: Scottish Government, 2024

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

1.2.2. REUSE

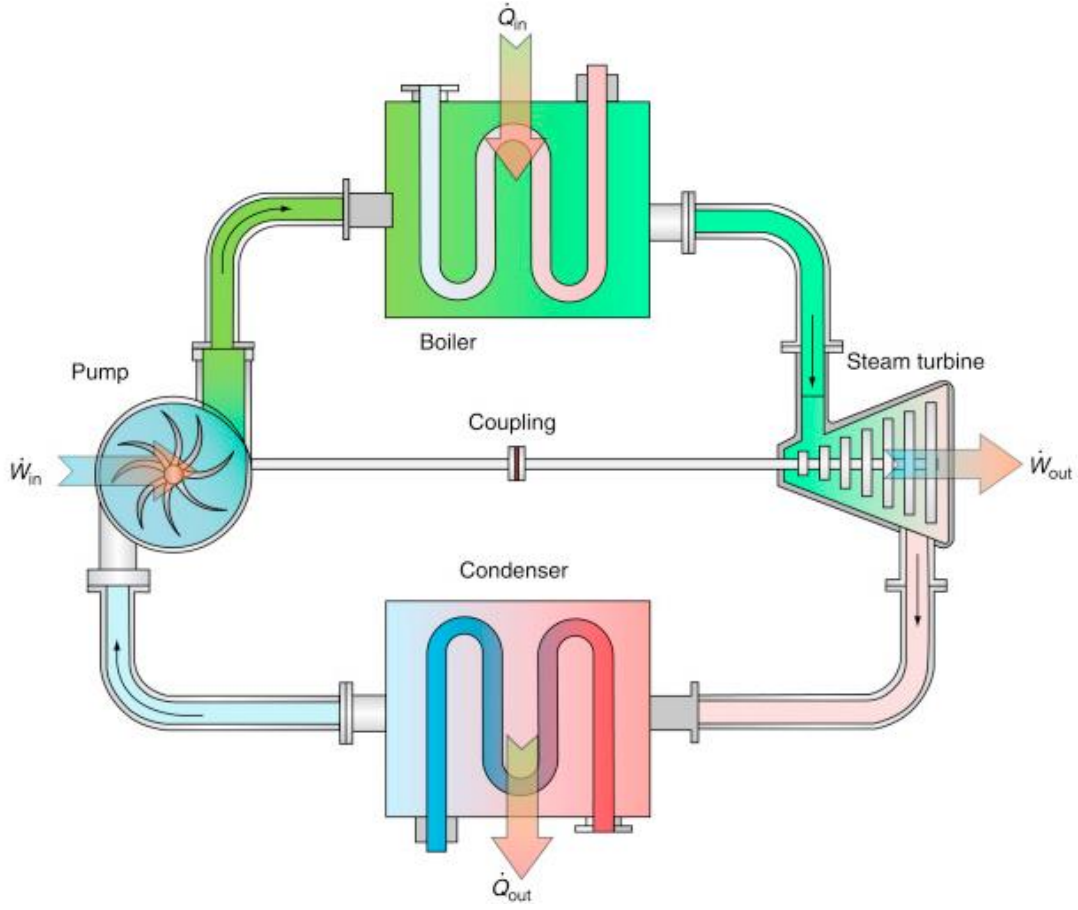
Heat recovery boilers: System that operates similarly to a gas boiler, but instead of using gas, it utilizes waste heat to heat a useful medium, typically water



Source: Scottish Government, 2024

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

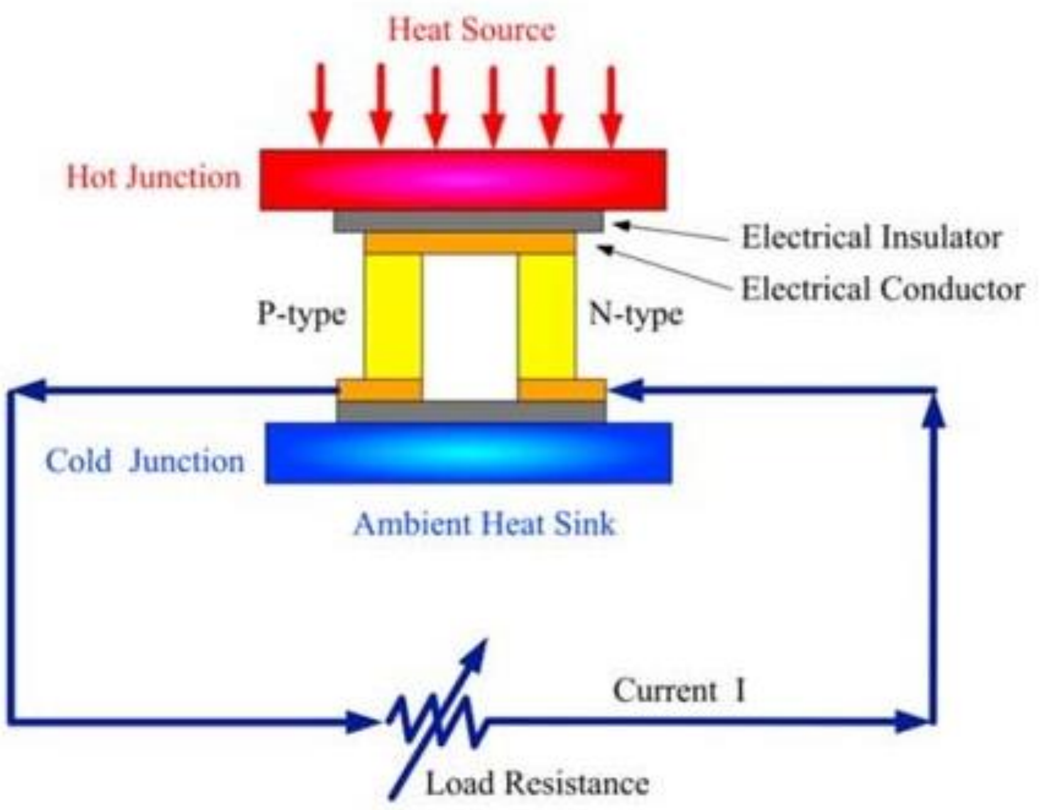
1.2.3. ACTIVE TECHNOLOGIES (WASTE HEAT TO POWER TECHNOLOGIES)



Source Dincer, 2018

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

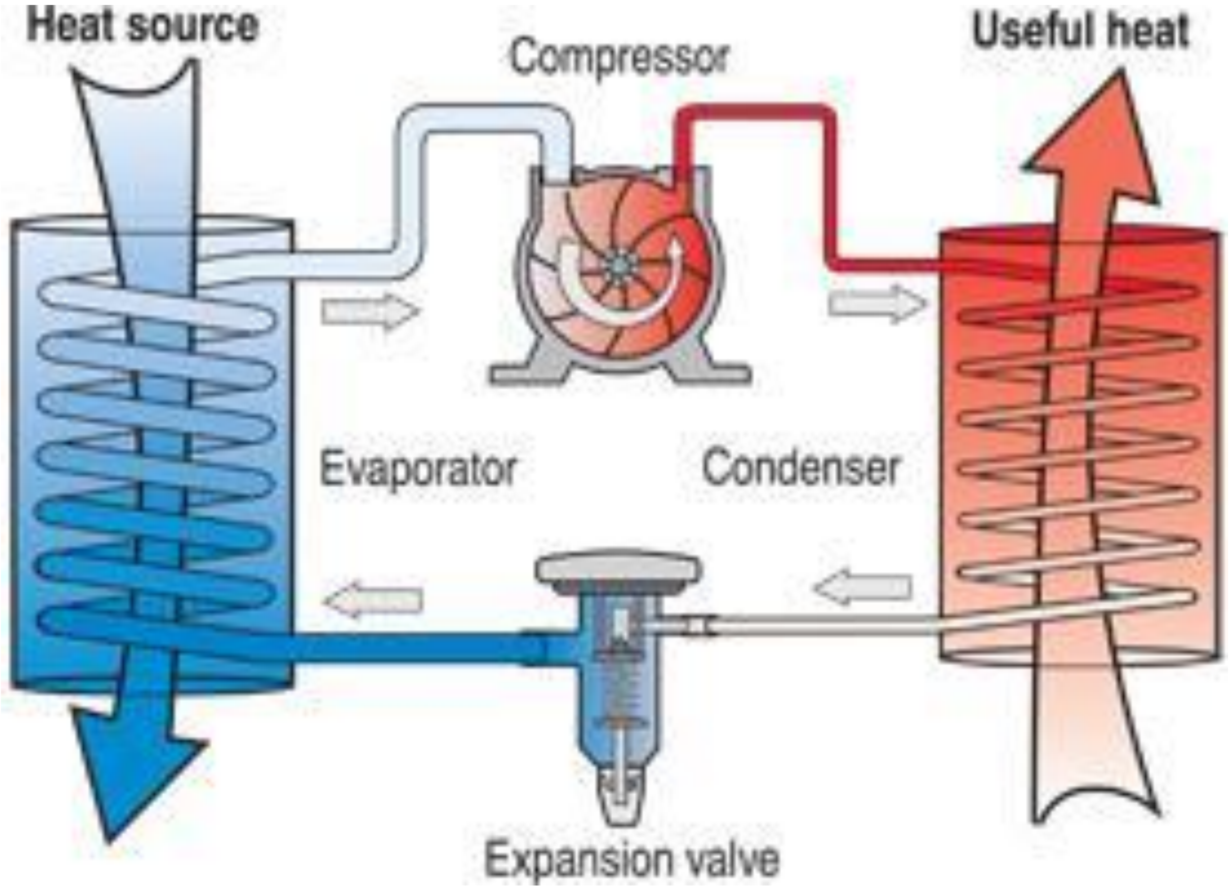
1.2.3. ACTIVE TECHNOLOGIES (WASTE HEAT TO POWER TECHNOLOGIES)



Source: Sugiartha & Negara, 2018

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

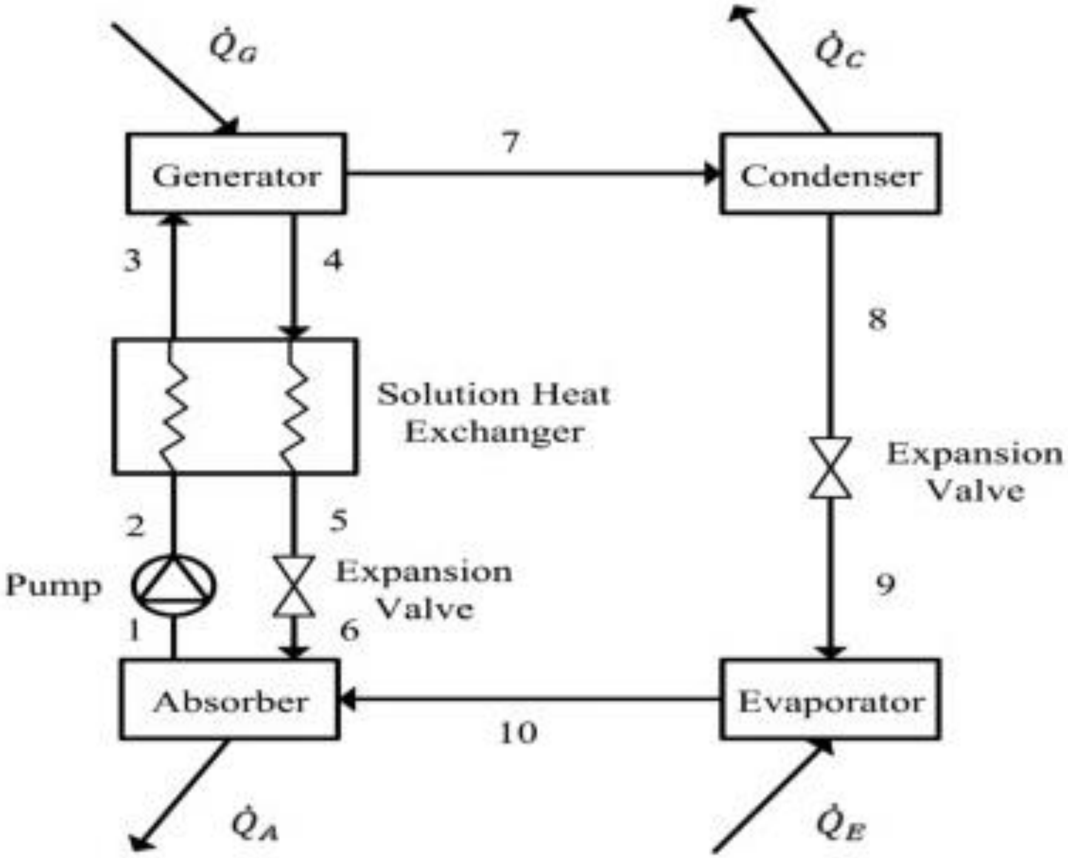
1.2.3. ACTIVE TECHNOLOGIES (WASTE HEAT TO COLD OR HEAT)



Source: IEA HPT

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

1.2.3. ACTIVE TECHNOLOGIES (WASTE HEAT TO COLD OR HEAT)



Source: El Haj Assad et al. (2021)

1.2. TECHNOLOGIES FOR CAPTURING AND UTILIZING WASTE HEAT

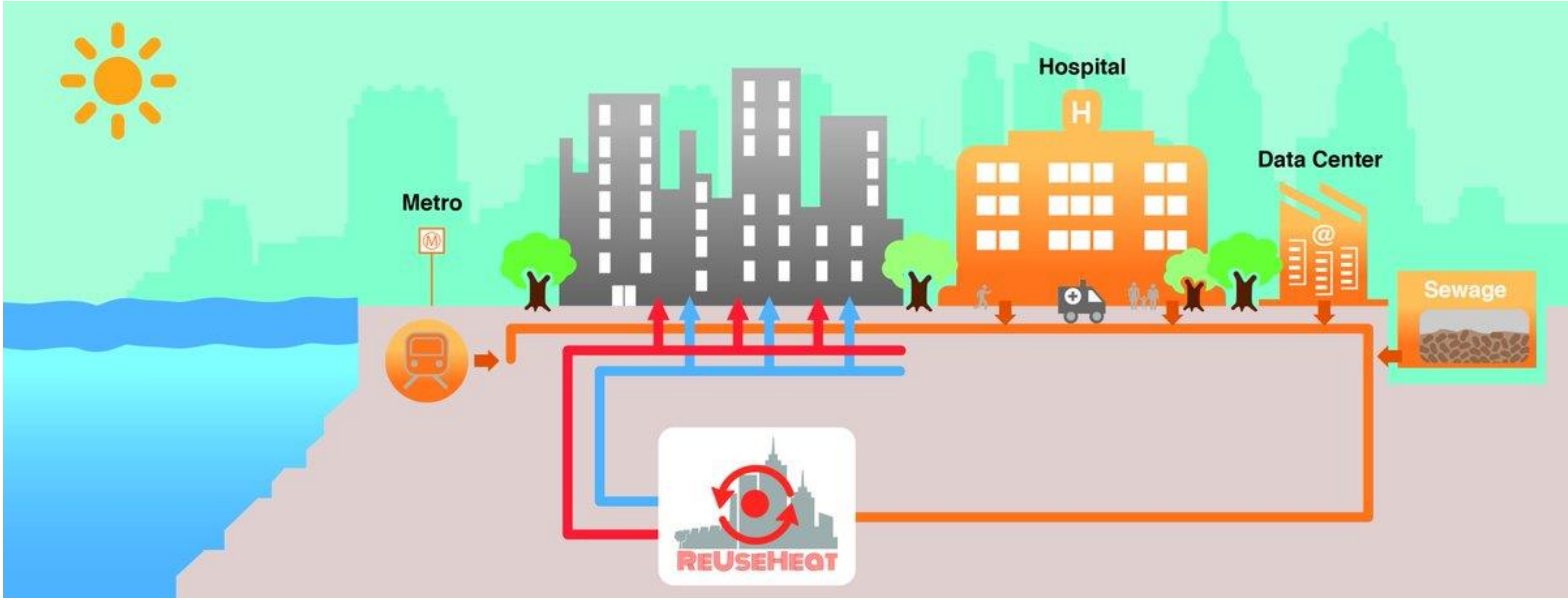
1.2.3. ACTIVE TECHNOLOGIES (VAPOR COMPRESSION HEAT PUMP)

Vapor Compression Heat Pumps (VCHPs)

- Recover and **upgrade low-grade waste heat** to high temperatures.
- Key for **decarbonization** through heat electrification.
- Widely applicable (e.g., **district heating**).
- **COP = condenser load / compressor power** (typically 2–6).
- Using waste heat boosts COP by reducing temperature lift.

Energy Communities In District Heating

Waste Heat Utilization



Source: www.reuseheat.eu

Energy Communities In District Heating

Utilization of Waste Heat from Data Centers

- Electricity consumption worldwide in 2010: 350 TWh
- This represents >1% of the world's electricity consumption in 2010
- Cooling is necessary for the safe operation of equipment
- Medium-sized data center:
- 1 MW IT capacity
- Heat emission: 3700 MWh/year with cooling
- 0.46 MWh_{th} waste heat for every 1 MW_{el} electricity consumption

Source: www.reuseheat.eu

Energy Communities In District Heating

Utilization of Waste Heat from Data Centers

- Electric Energy Consumption Of Data Centers In Europe:
  - 2007: 56 TWh/year
  - 2020: Expected to reach 104 TWh/year
- Growing Trends: Streaming, IoT
- Cooling accounts for 40% of the total energy consumption of data centers.
- Performance of Data Centers:
  - 5 MW IT performance (in some locations in Europe)
  - 500 kW – 5 MW (many centers)
  - Below 500 kW (most centers)

Source: www.reuseheat.eu, https://www.constructionglobal.com/cloud-computing/apple-construct-second-data-centre-china

Energy Communities In District Heating

Utilization of Waste Heat from Subway Tunnels

- **Heat source**
- When braking trainsets
- Ventilation of subway cars
- **Worldwide**
- In 148 cities
- 11000 km line
- 151 million passengers/day
- **In the European Union**
- 50 medium and large cities
- 2800 km of lines
- 31 million passengers/day
- 6.7-11.2 TWh/a waste heat
- **Average 1 km between two stations**
- **In a densely populated area**

Source: www.reuseheat.eu

Energy Communities In District Heating

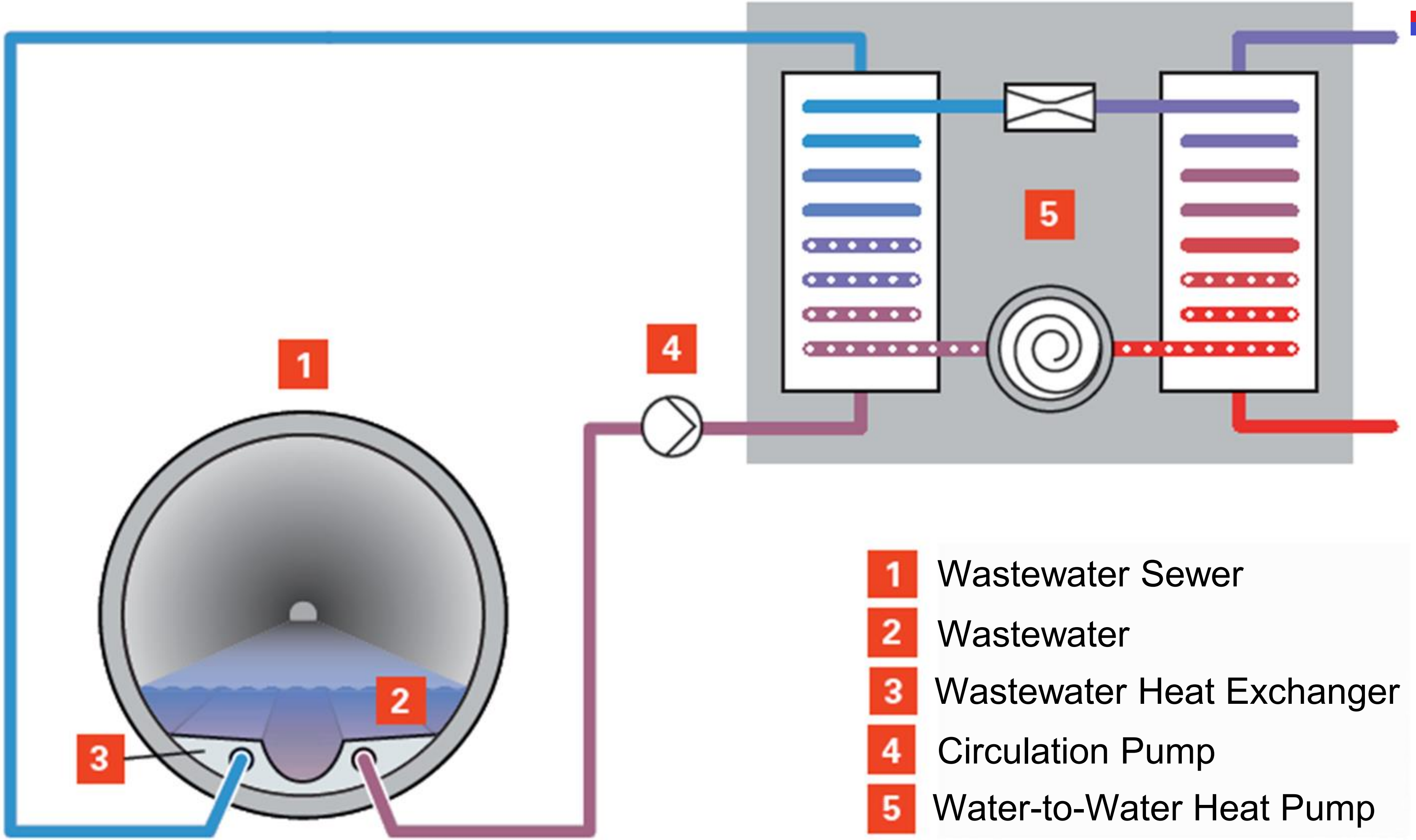
Utilization of Waste Heat from Sewer Networks Using Heat Pumps

- Heat source
  - Annual average 10-15 °C
  - In summer, it reaches 20 °C
- Application of heat pump technology:
  - In cities with more than 10,000 inhabitants
  - can cover 5% of total heat demand
  - 150 TWh/a
- In Germany
  - could supply 20% of the building stock
- Completed projects:
  - Cologne
  - Nice

Source: www.reuseheat.eu

Energy Communities In District Heating

Utilization of Waste Heat from Sewer Networks Using Heat Pumps



Source: www.reuseheat.eu

1.3. THERMODYNAMIC PRINCIPLES FOR HEAT PUMP OPERATION

A heat pump operates based on fundamental thermodynamic principles. It transfers heat from a lower-temperature source to a higher-temperature sink using external energy, typically electrical or mechanical work.

Second Law of Thermodynamics (Clausius Statement): Heat naturally flows from a higher temperature to a lower temperature. A heat pump reverses this process by using external work to move heat from a cold to a hot reservoir.

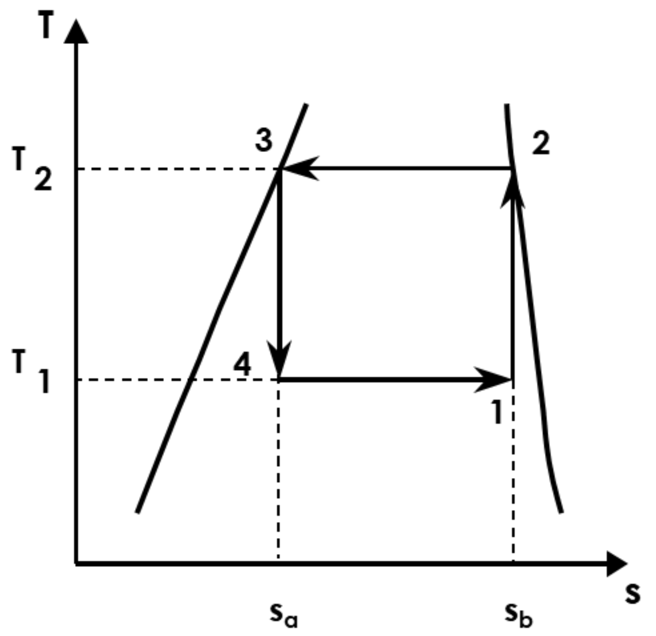
First Law of Thermodynamics (Energy Conservation): The total energy within a system remains constant:

$$Q_{in} + W = Q_{out}$$

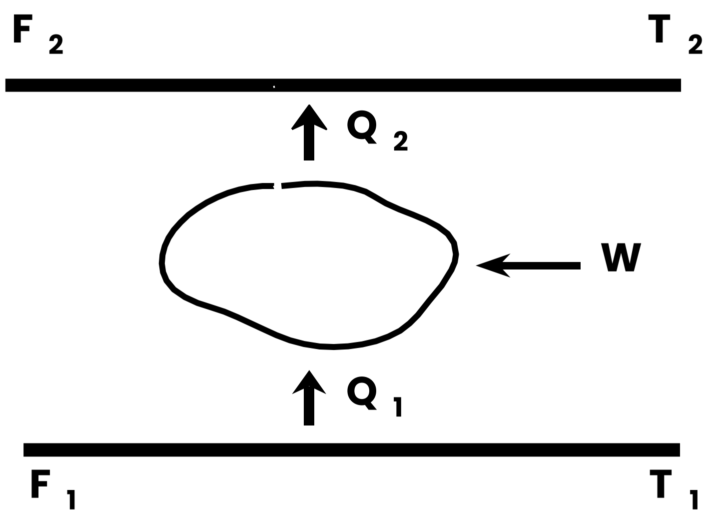
Q_{in} = Heat absorbed from the low-temperature source (evaporator)
W = Work input (compressor energy)
Q_{out} = Heat released at the high-temperature sink (condenser)

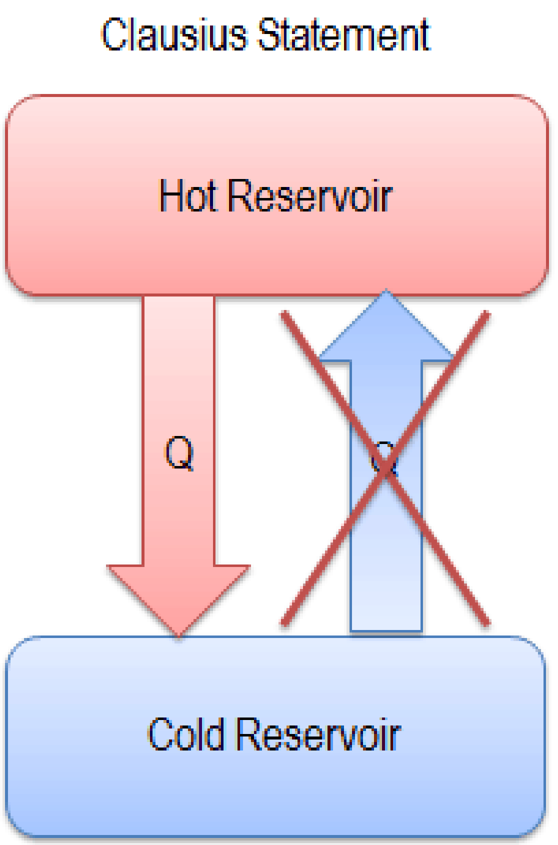
1.3. THERMODYNAMIC PRINCIPLES FOR HEAT PUMP OPERATION

HEAT PUMP (IDEAL CYCLE)



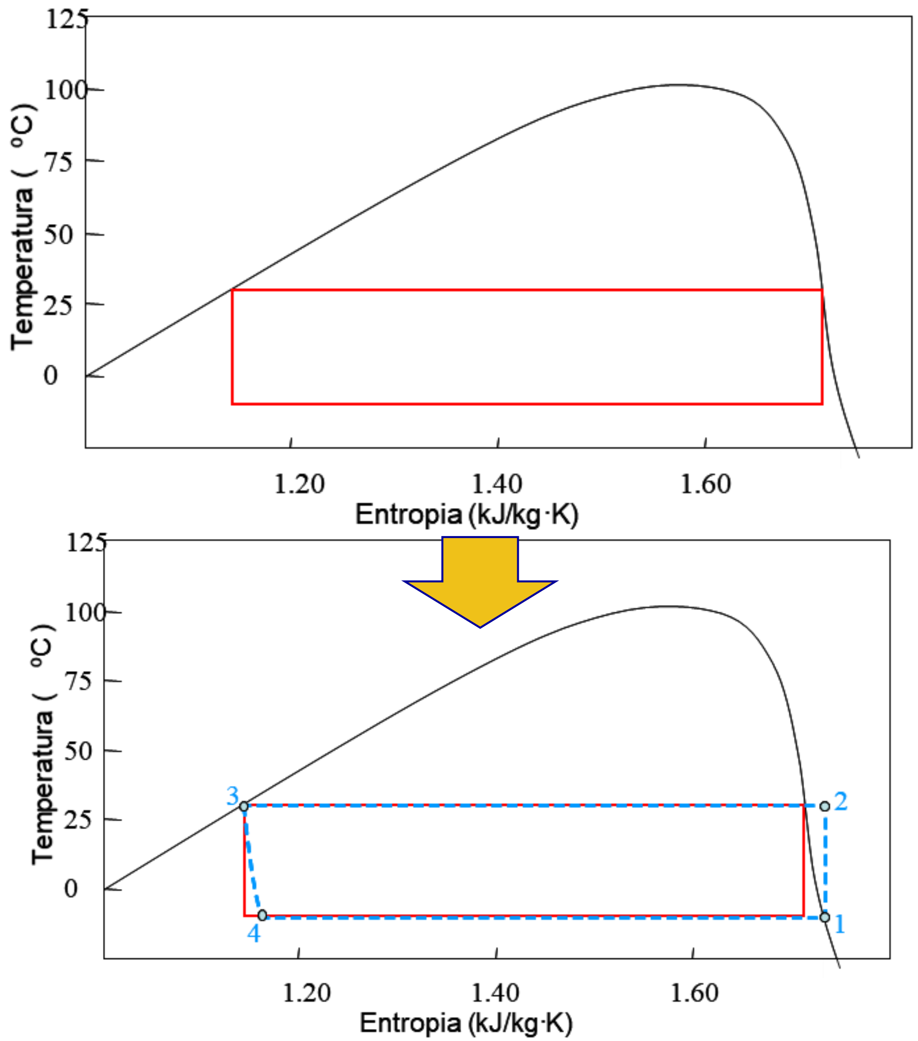
$$\eta_{BC(Carnot)} = \frac{T_2}{T_2 - T_1}$$

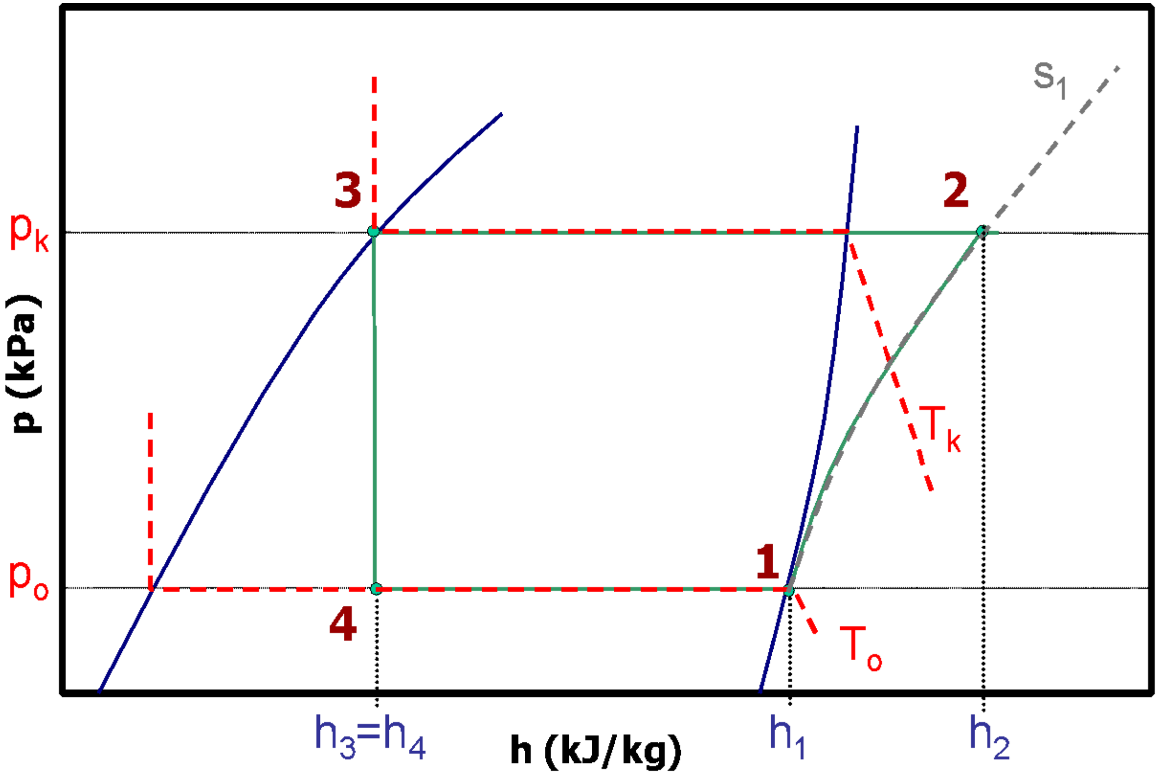




Source: Nuclear power

1.3. THERMODYNAMIC PRINCIPLES FOR HEAT PUMP OPERATION

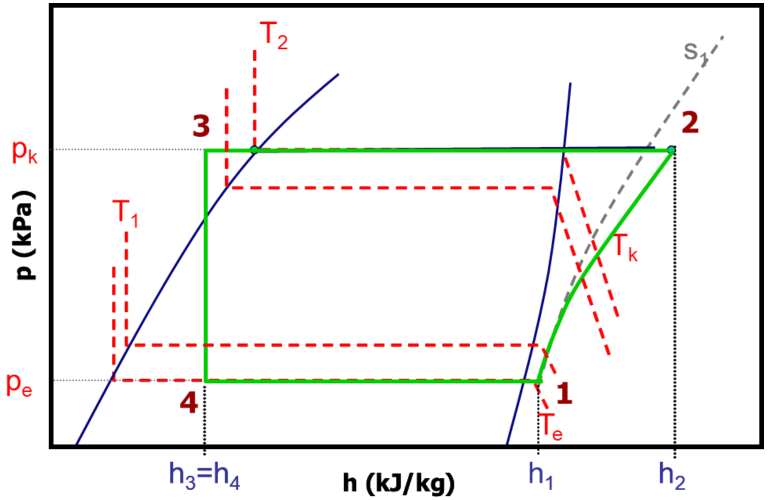


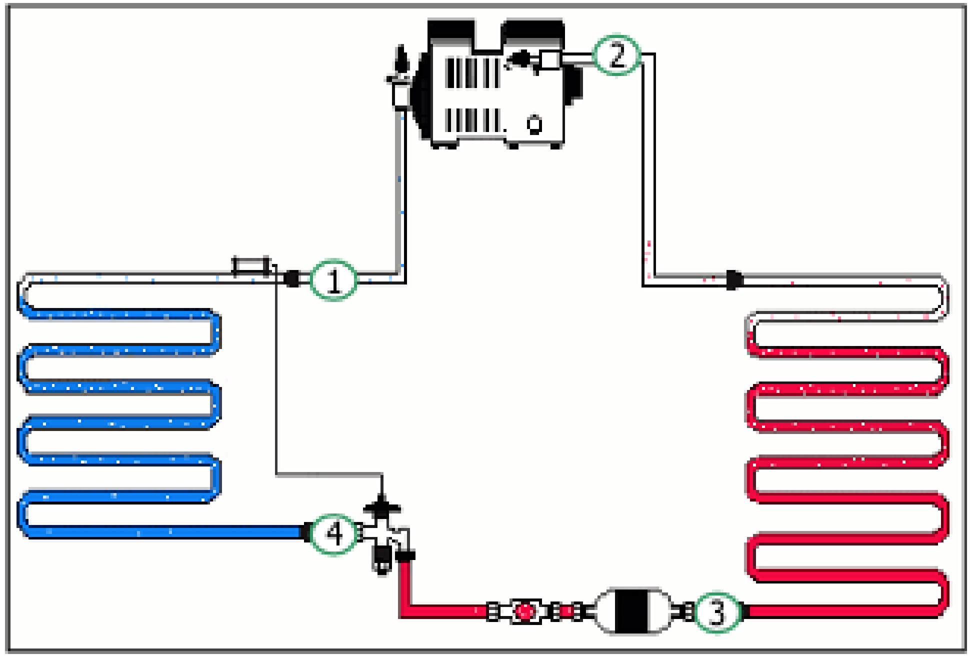


1.3. THERMODYNAMIC PRINCIPLES FOR HEAT PUMP OPERATION

HEAT PUMP (REAL CYCLE)

Refrigerant



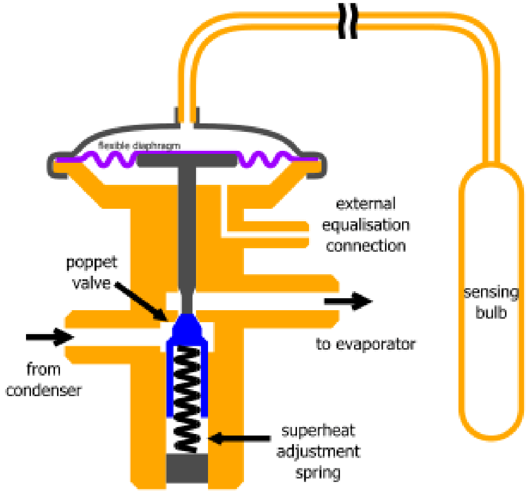


The refrigerant is the substance that flows through the different elements of the system in a cyclical manner, absorbing heat at low temperatures in the evaporator and releasing heat at higher temperatures in the condenser. Generally, these processes involve a change in the state of the fluid.

1.3. THERMODYNAMIC PRINCIPLES FOR HEAT PUMP OPERATION

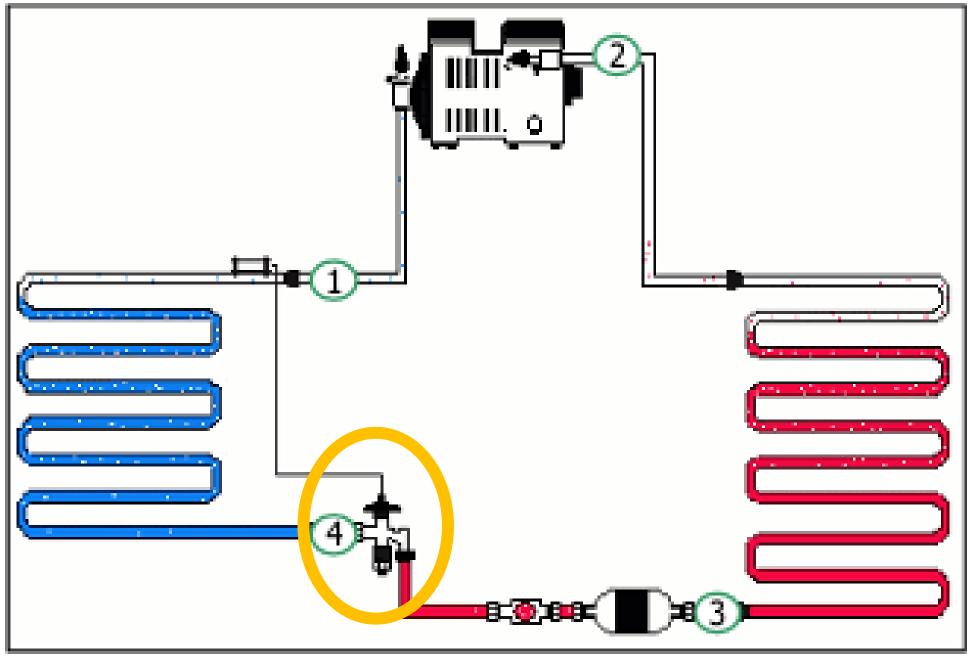
HEAT PUMP (REAL CYCLE)

Expander



Source: Wikipedia

Source: Parker NA



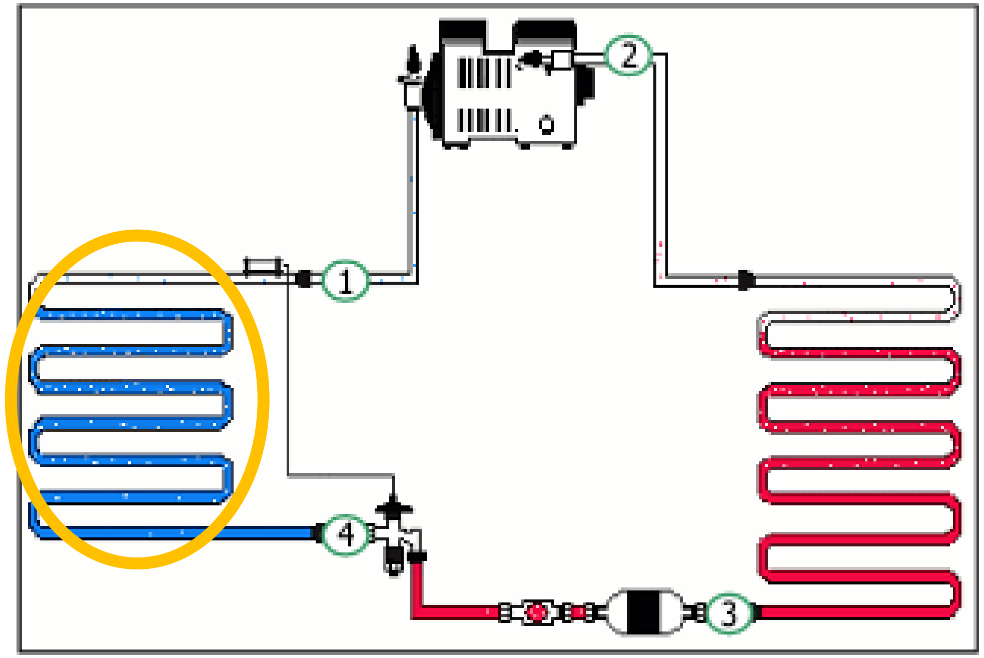
1.3. THERMODYNAMIC PRINCIPLES FOR HEAT PUMP OPERATION

HEAT PUMP (REAL CYCLE)

Evaporator

Source: AC Evaporator

Source: PAlfa Heating Supply



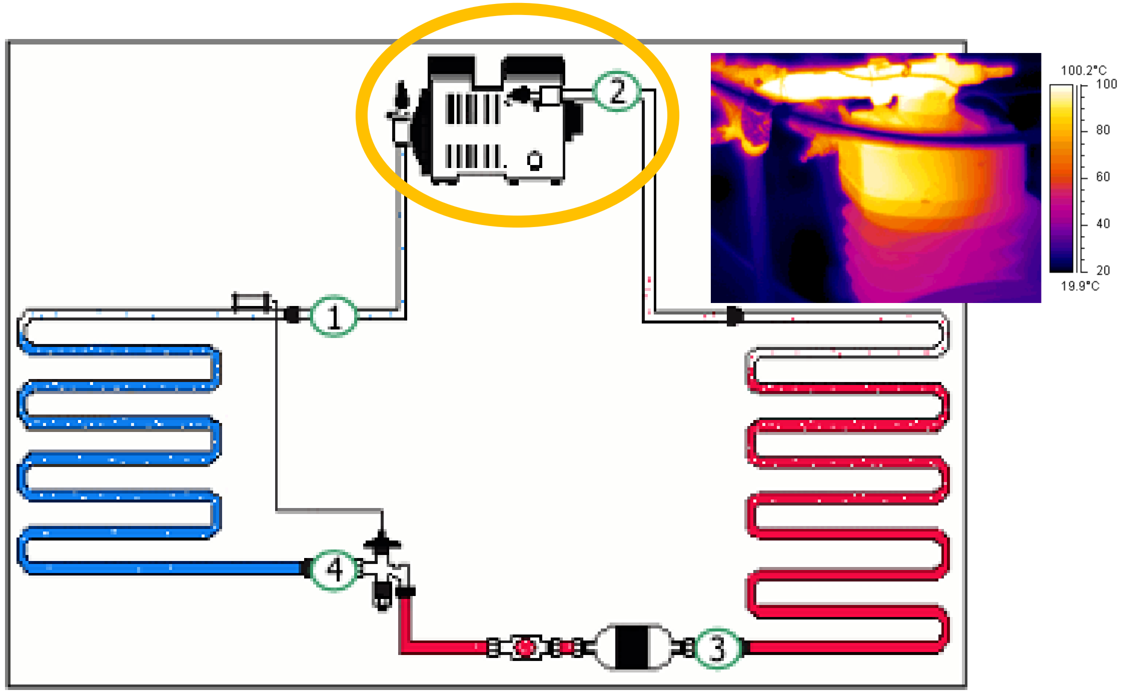
1.3. THERMODYNAMIC PRINCIPLES FOR HEAT PUMP OPERATION

Real vapor compression cycle

Compressor

Source: Bitzer

Source: Danfoss



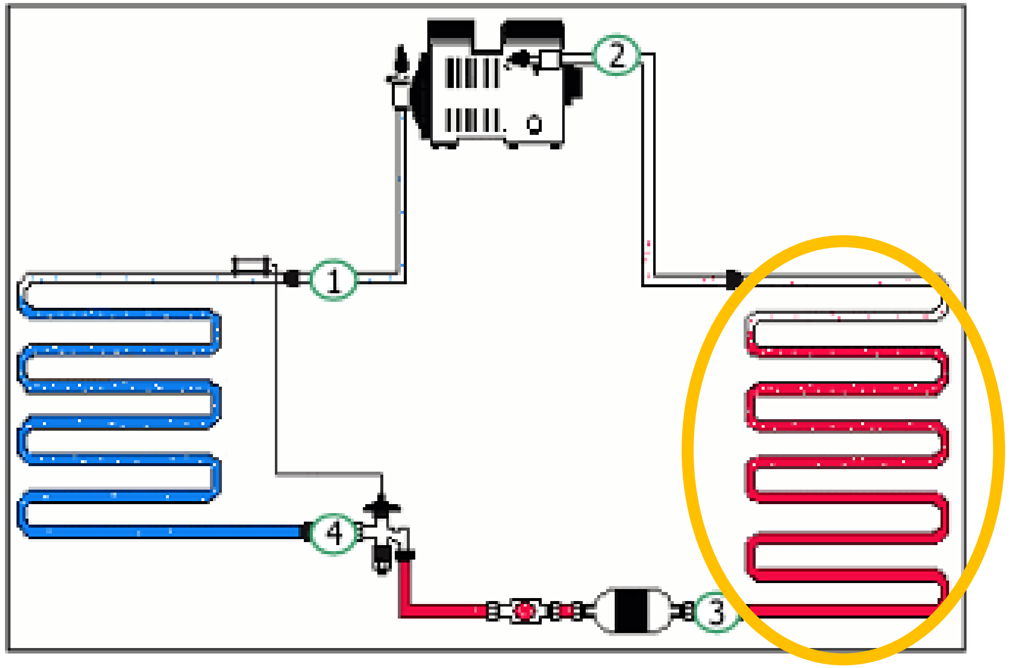
1.3. THERMODYNAMIC PRINCIPLES FOR HEAT PUMP OPERATION

Real vapor compression cycle

Condenser

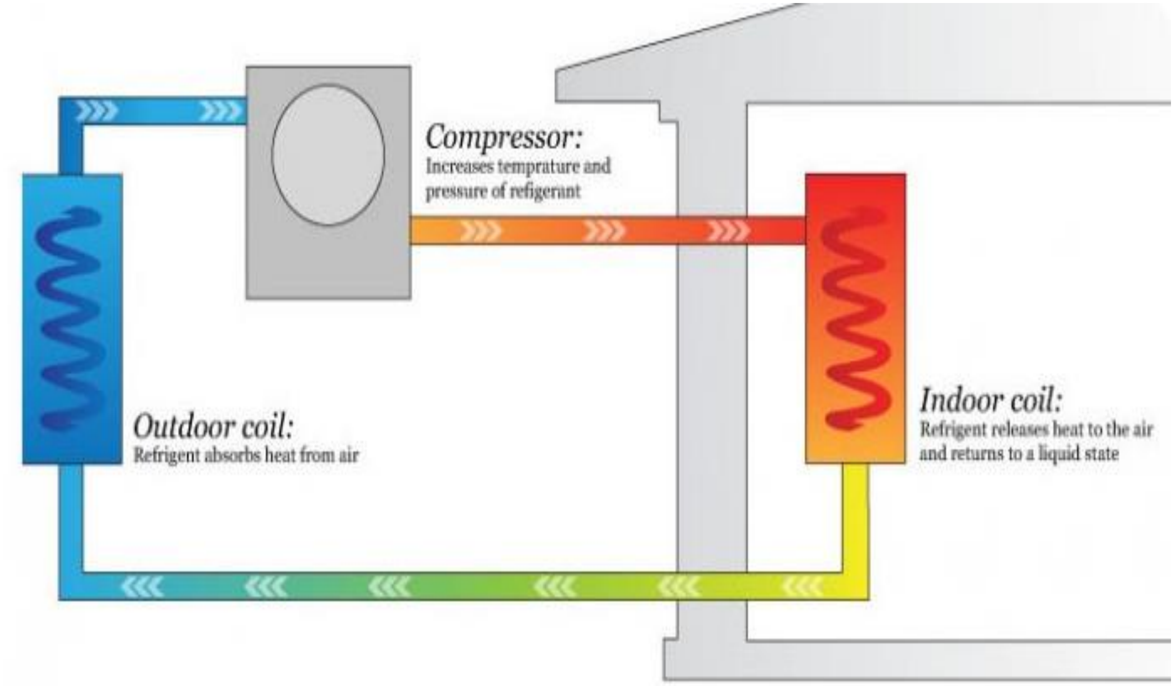
Source: Domicool

Source: PAlfa Heating Supply

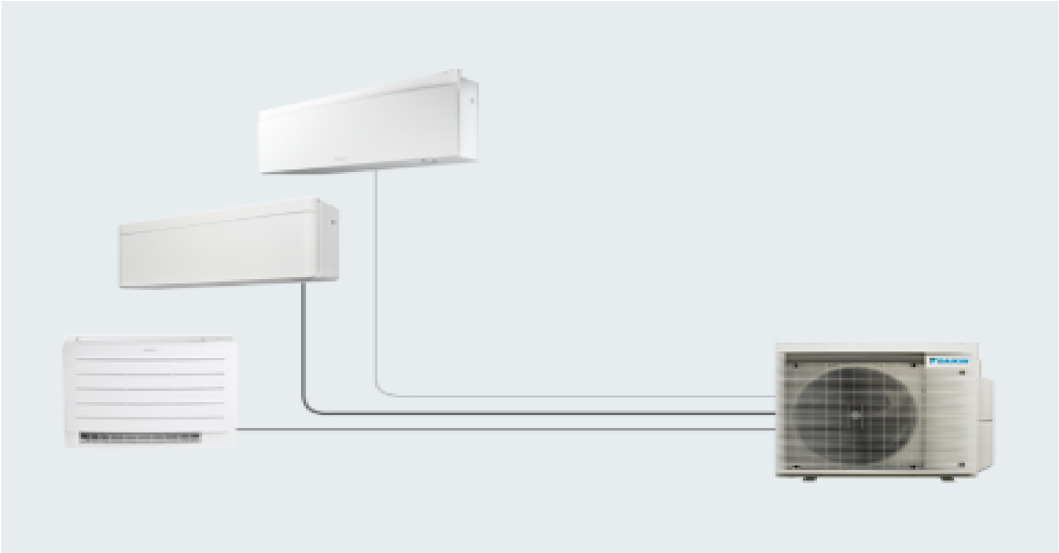


1.4. HEAT PUMP TECHNOLOGIES

Air-to-air heat pumps



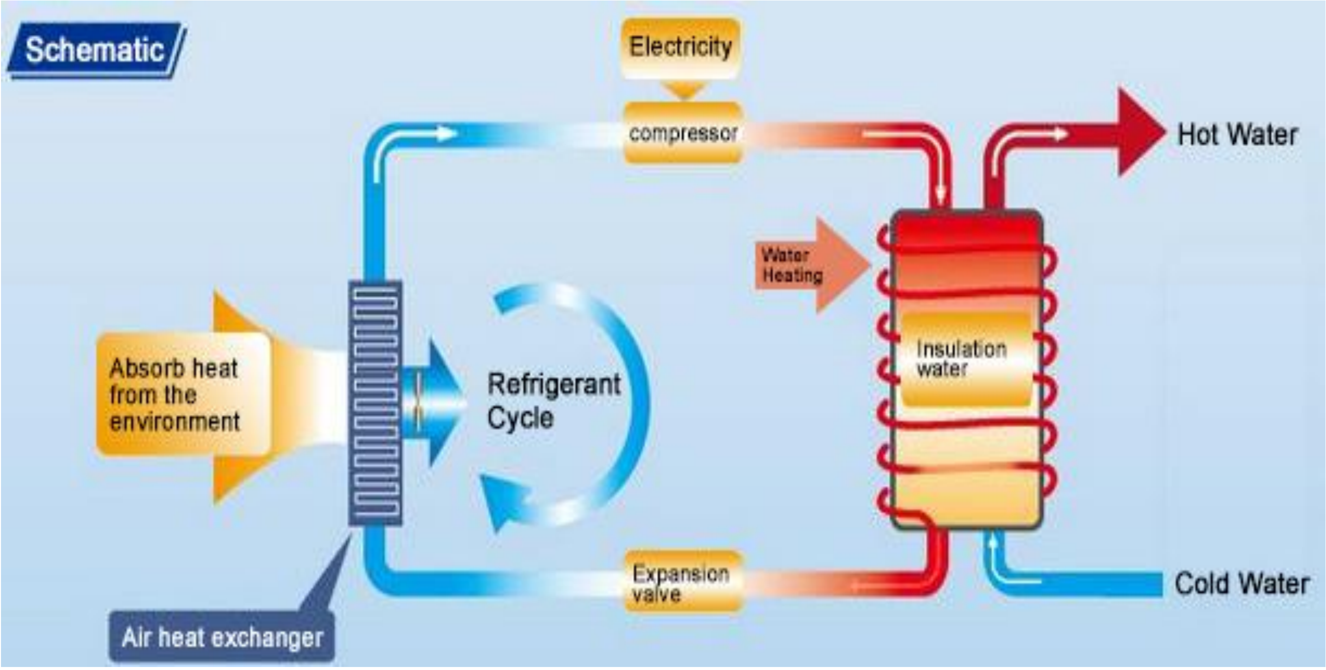
Source: MB Services



Source: Daikin

1.4. HEAT PUMP TECHNOLOGIES

Air to water heat pumps

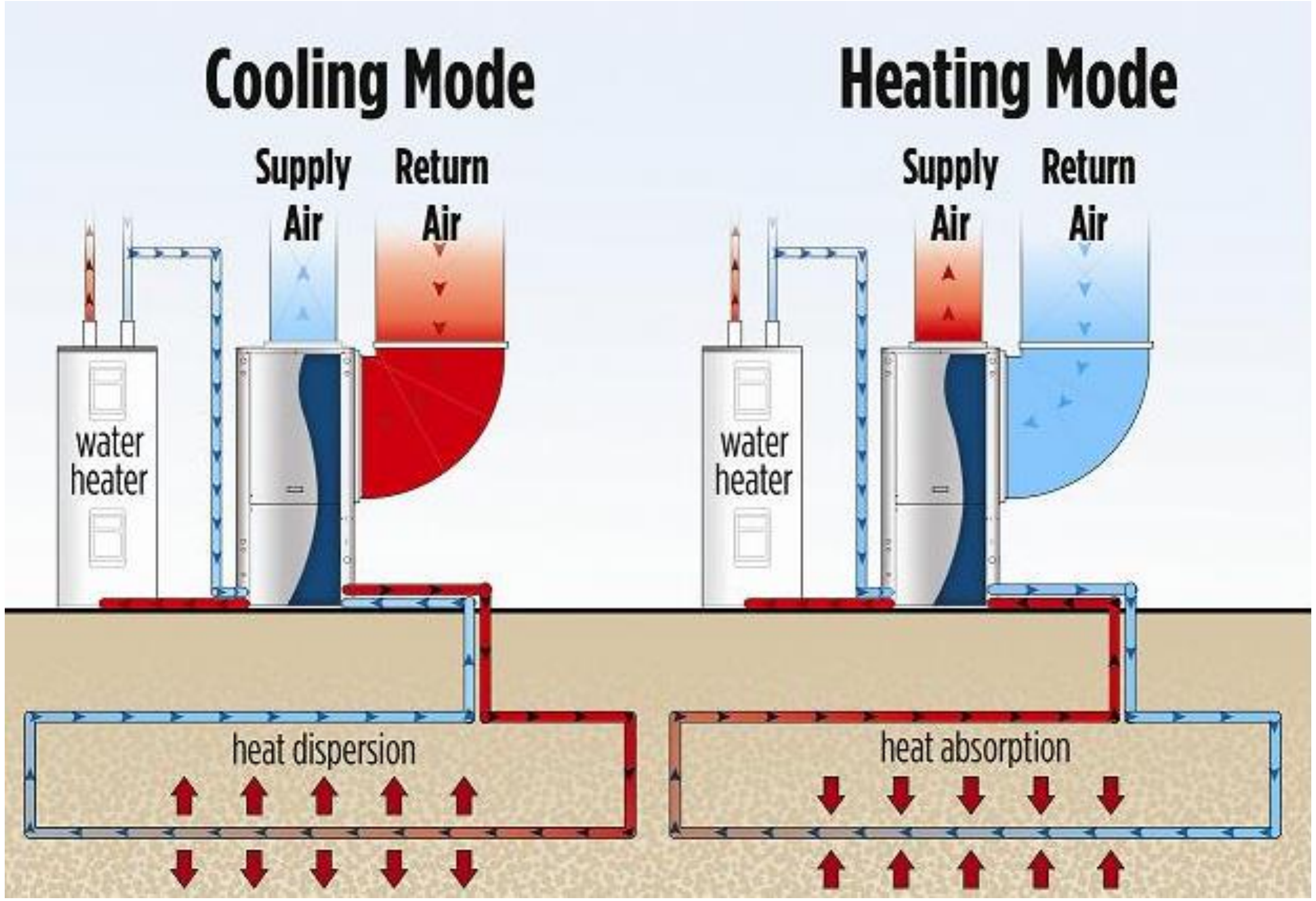


Source: Powerworld

Source: Indiamart,

1.4. HEAT PUMP TECHNOLOGIES

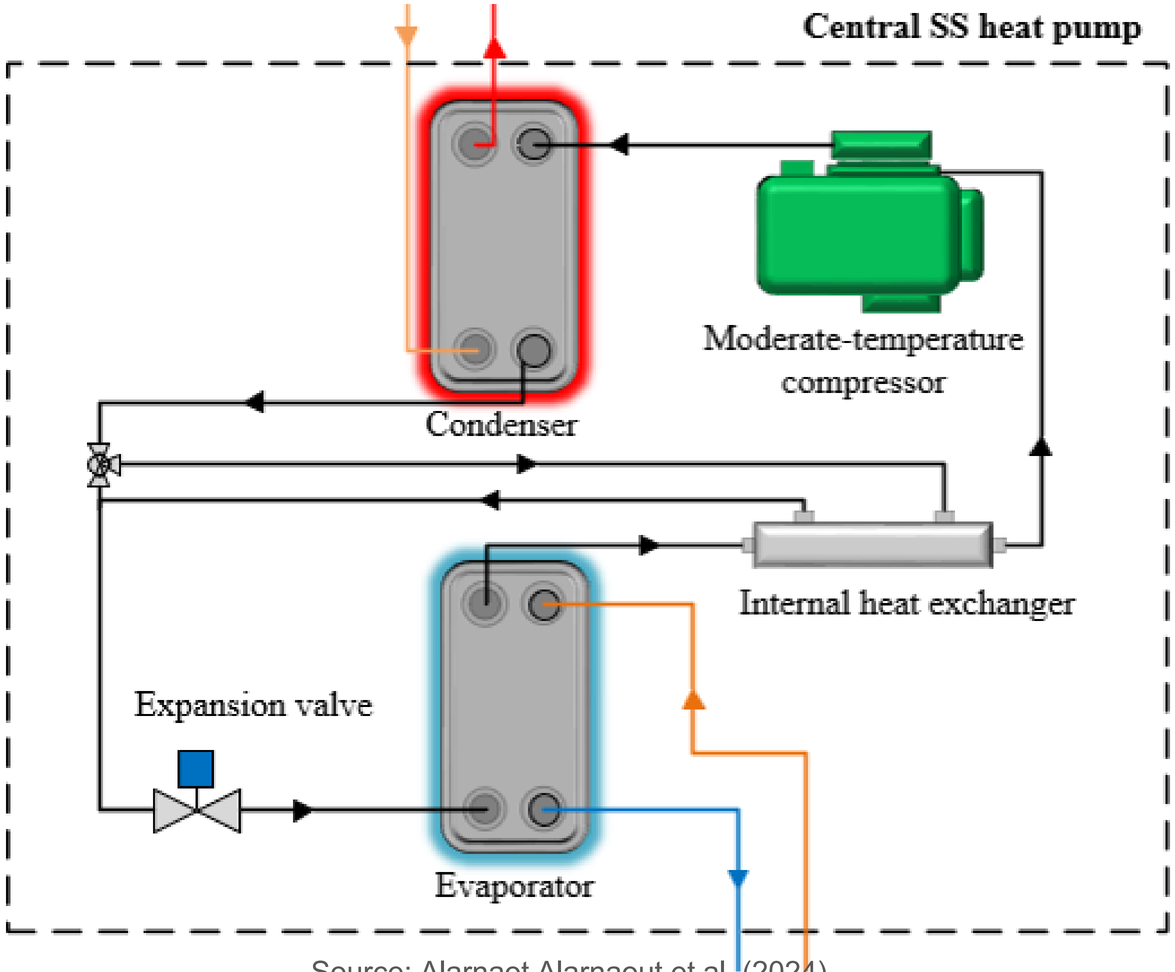
Geothermal heat pumps



Source: Energy Environmental

1.4. HEAT PUMP TECHNOLOGIES

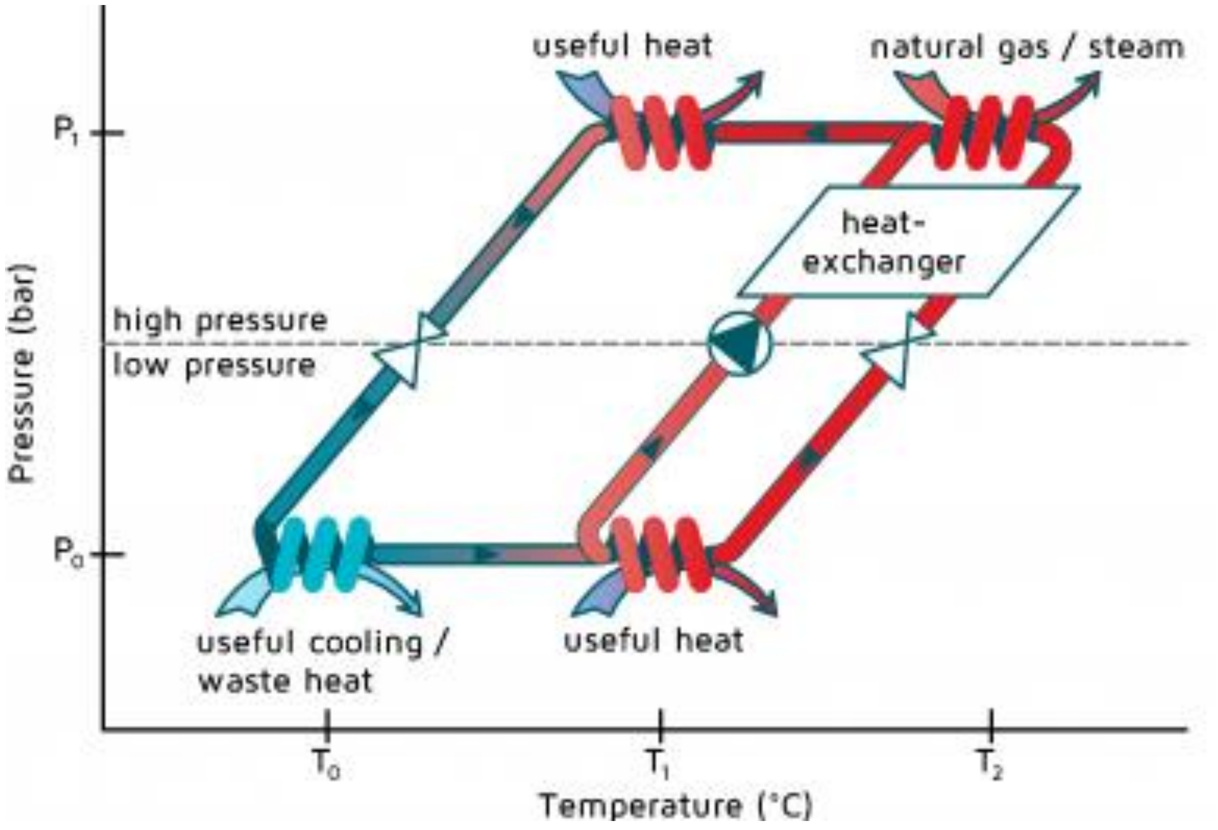
Water-to-water heat pumps



Source: Alarnaot Alarnaout et al. (2024)

1.4. HEAT PUMP TECHNOLOGIES

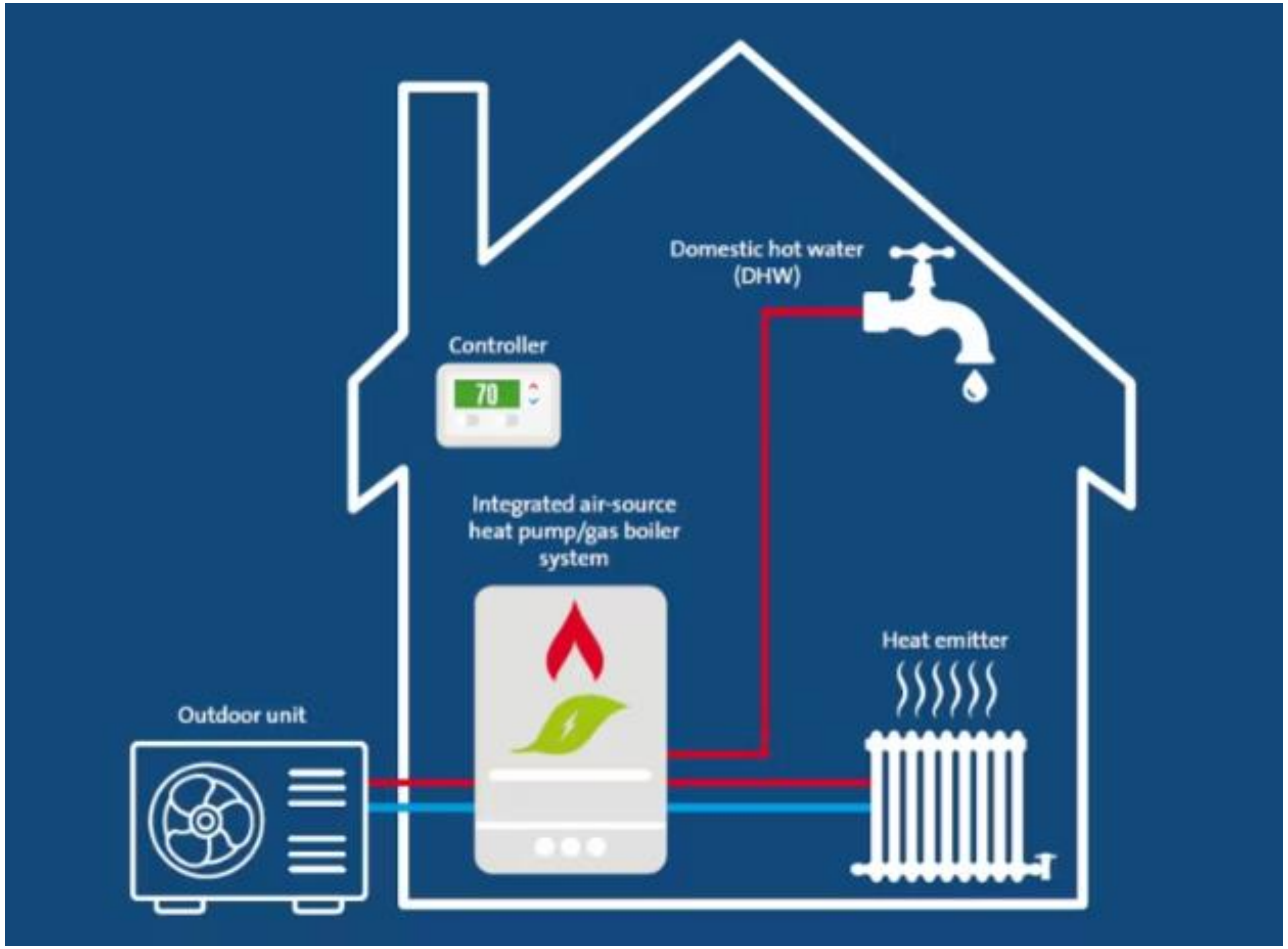
Absorption heat pumps



Source: Industrialheatpumps.Nl

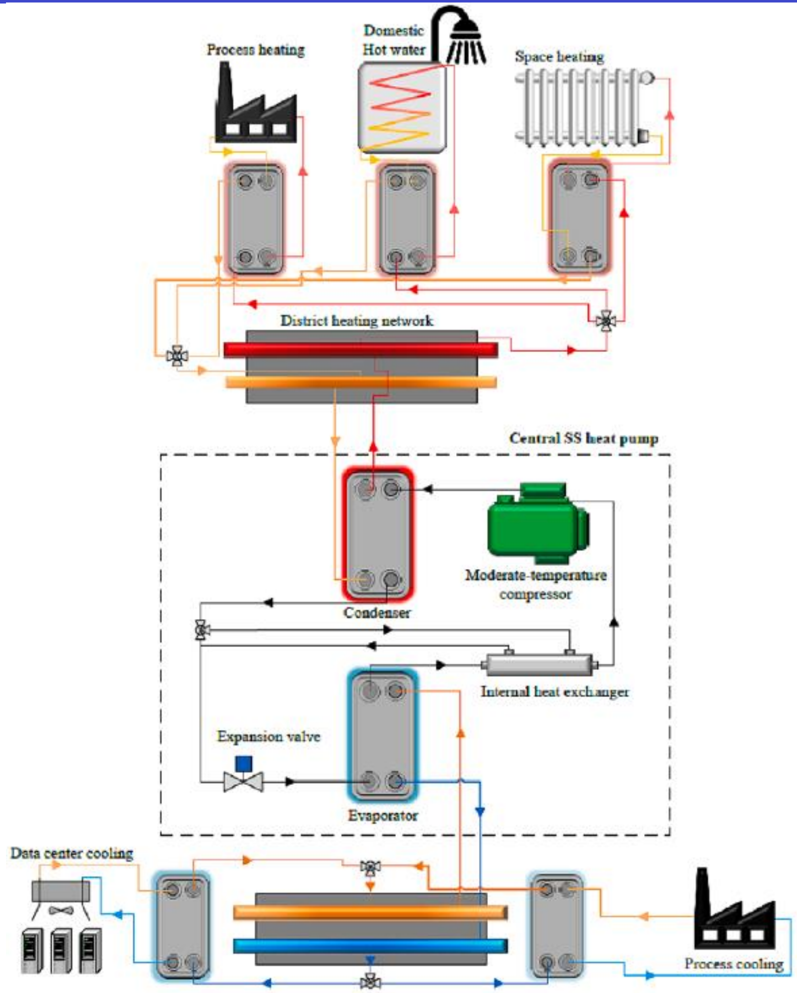
1.4. HEAT PUMP TECHNOLOGIES

Hybrid heat pumps



Source: Grundfos

Dual-service heat pumps

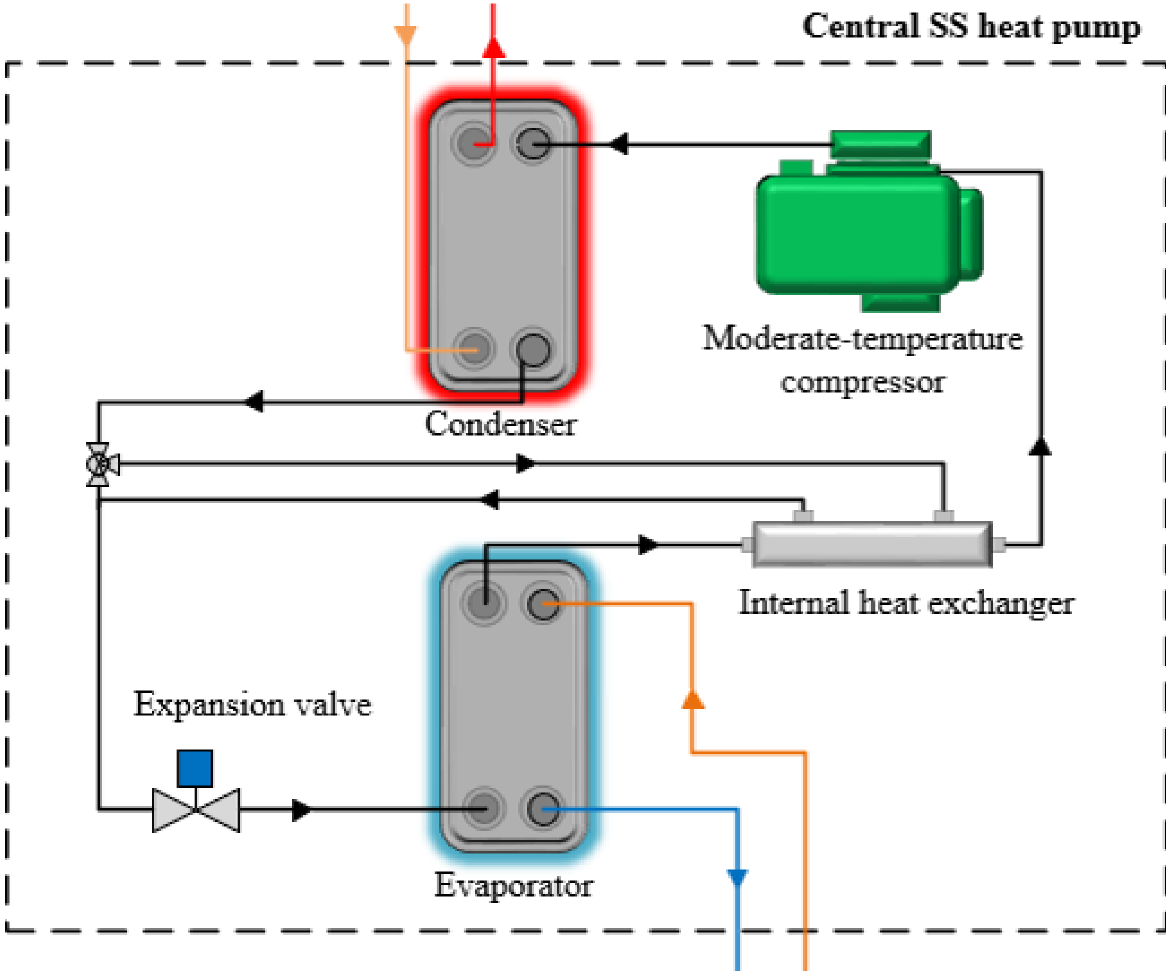


Source: Alarnaot Alarnaout et al. (2024)

1.4. HEAT PUMP TECHNOLOGIES

Inverter heat pumps

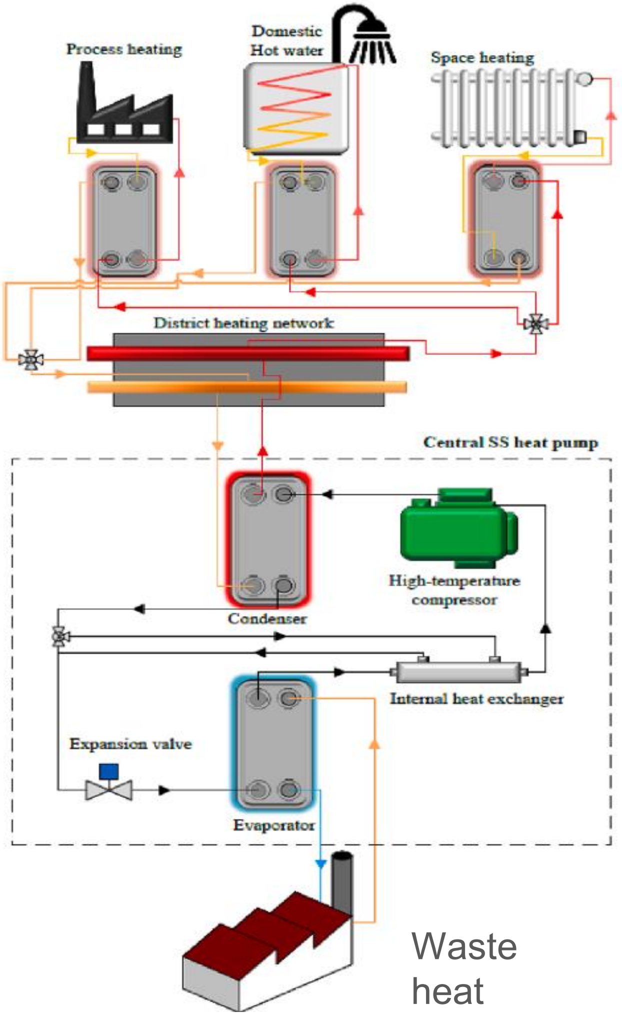
Operation: Inverter heat pumps utilize inverter technology, which allows the compressor speed to adjust based on the heating or cooling demand. This enables the system to operate more effectively in response to varying conditions.



Source: Alarnaot Alarnaout et al. (2024)

1.4. HEAT PUMP TECHNOLOGIES

Waste heat pumps



Source: Alarnaot Alarnaout et al. (2024)

1.4. HEAT PUMP TECHNOLOGIES

Heat pumps classification: Attending to the production temperature

Heat pumps are classified based on the temperature of the heat they produce, which determines their suitability for different applications. The classification typically includes:

- **Low-Temperature Heat Pumps (<45°C)**
  Typical Supply Temperature: 30°C - 45°C (space heating)

- **Medium-Temperature Heat Pumps (45°C – 75/90°C)**
  Typical Supply Temperature: 45°C - 75°C

- **High-Temperature Heat Pumps (>75/90°C)**
  Typical Supply Temperature: 75°C - 150°C and more

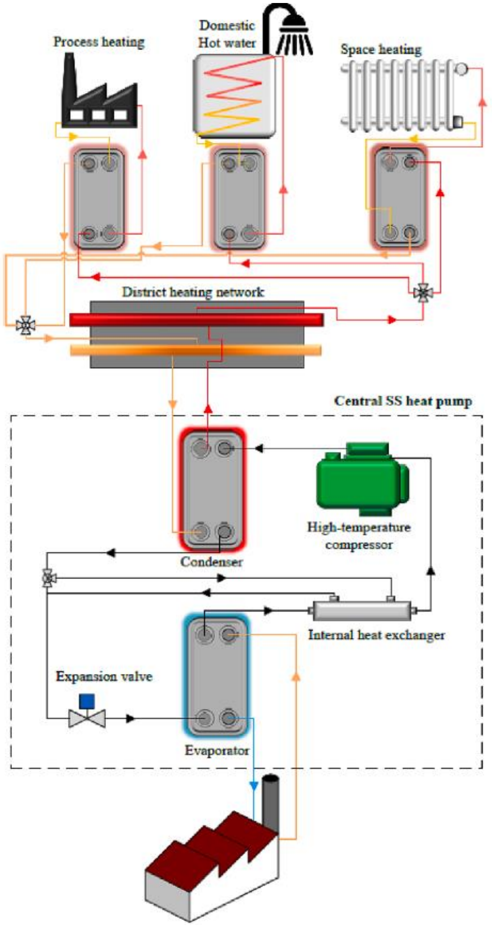
1.5. HEAT PUMP APPLICATION IN WASTE HEAT

Waste heat pumps

The most common applications of heat pumps for waste heat recovery include:

- Distilleries
- Industrial laundries
- Waste heat district heating
- Supermarkets
- Data centers

Source: LiquidStack

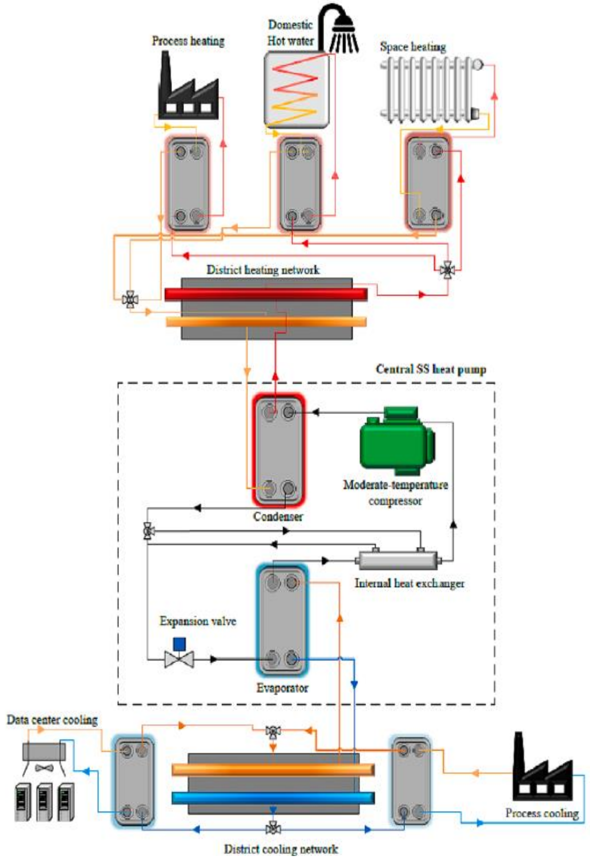


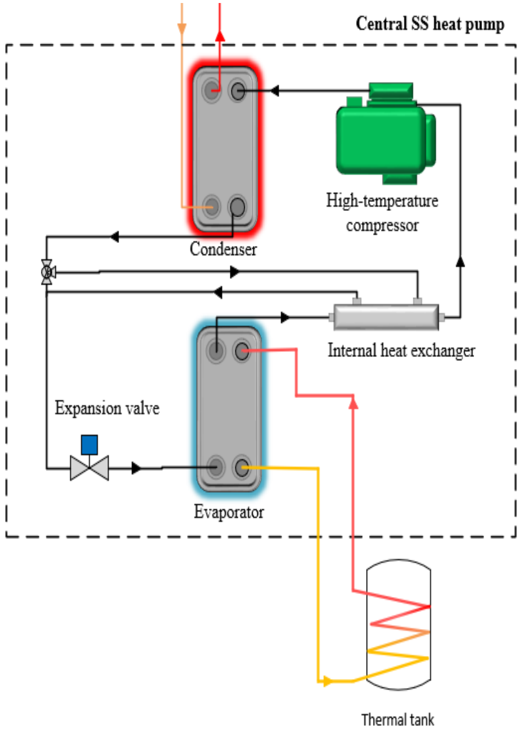
Source: Courtesy Port Ellen Distillery

Source: Speed Check Conveyor

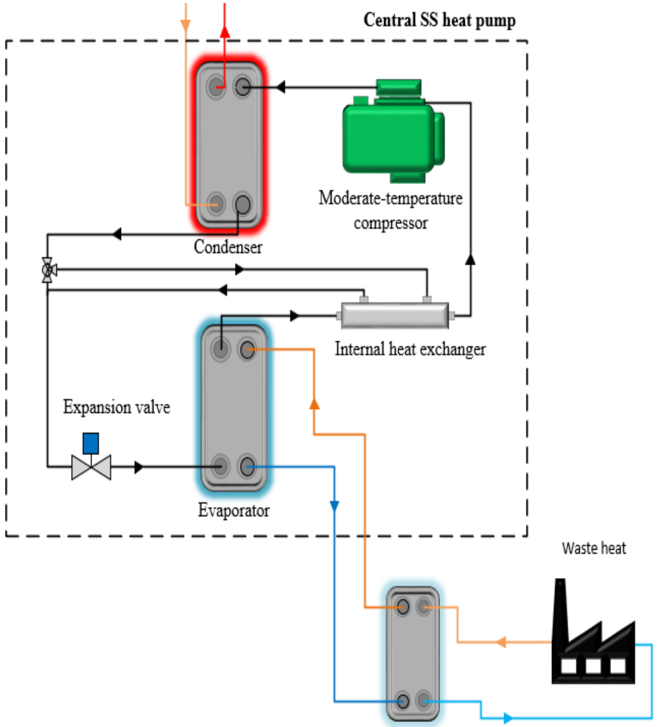
Source: Embraco's

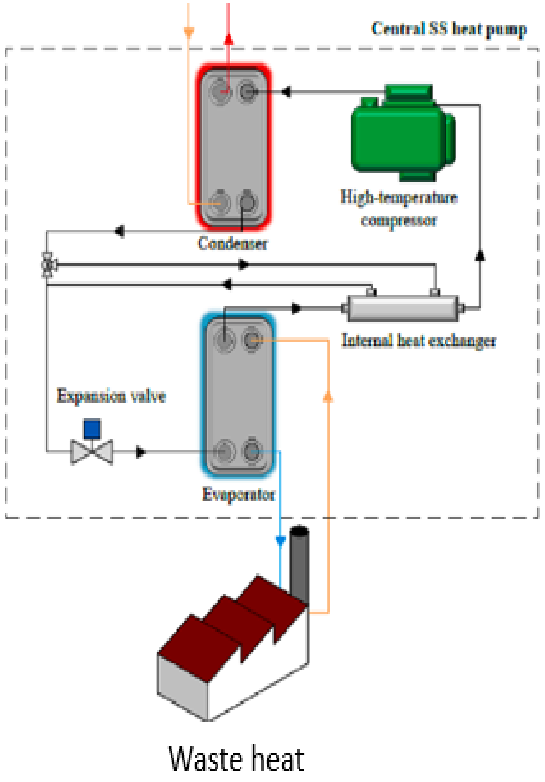
1.6. CONFIGURATIONS AND CONNECTIONS OF HEAT PUMPS FOR VARIOUS WASTE HEAT SOURCES





Storage Systems (Thermal Storage Tanks)





Closed-Loop System with Secondary Heat Fluids

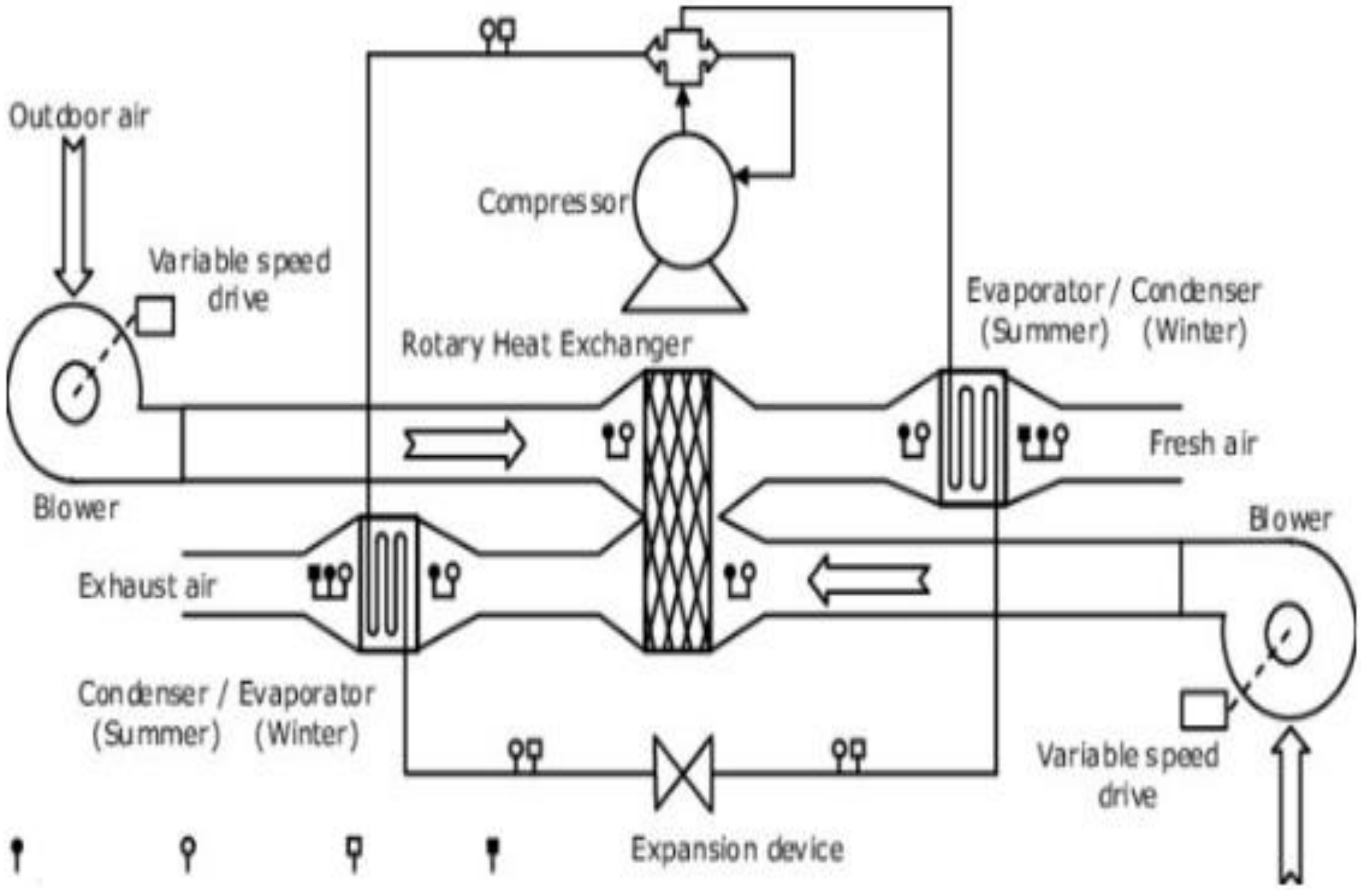
Intermediate Heat Exchanger (Indirect System)

Direct Connection to a Primary Circuit

Source: Alarnaot Alarnaout et al. (2024)

1.6. CONFIGURATIONS AND CONNECTIONS OF HEAT PUMPS FOR VARIOUS WASTE HEAT SOURCES

- **Integration with Air or Gas Flows**



Source: Žandeckis et al. (2015)

1.7. CASE STUDY OF HEAT PUMPS USING WASTE HEAT

Aurivo project (a case study in Finland)

Achievements:

- First plant in Ireland to use heat pump-generated water at 80 degrees.
- Reduced carbon by 780 tones annually.
- 8% decrease in electricity usage on site.

Source: SEAI

1.7. CASE STUDY OF HEAT PUMPS USING WASTE HEAT

Case study of three industrial heat pump installations operating in Canada.

Economic data

Three different waste heat-driven heat pump installations were used to reduce the energy cost at the various facilities:

	Oil manufacturer	Dairy Manufacturer	Mine
Electrical Energy use (kW)	97	103	60
Coefficient of Performance	5.4	3.8	5.3 4.5
Electrical Cost ($/kWh)	0.0322	0.028	0.038
Operational Time (hr/yr)	4021	1800	-
Cost Savings ($)	97690	21290	-
Installation Cost ($)	224096	101077	150643
Simple Payback	2.29	4.75	-

Source: Wright & Steward

1.7. CASE STUDY OF HEAT PUMPS USING WASTE HEAT

Case study on large-scale heat pumps in the modernization of the district heating system of Vienna, Austria.

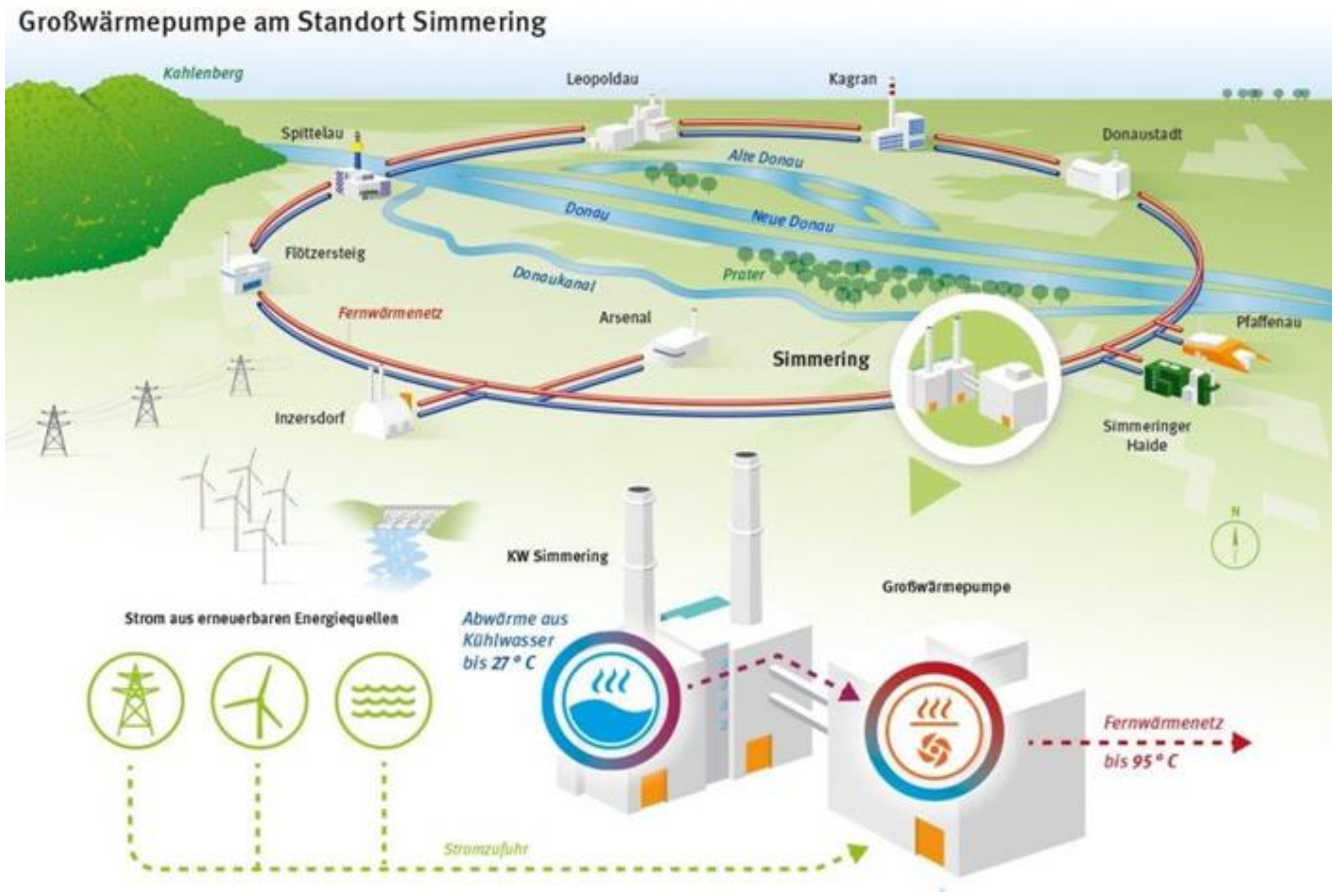
Technology specifications	
Set-up area	Vienna, Austria
Process applications	Waste heat recovery (water and power)
Heat capacity output	40 MW
Heating capacity equivalence	25000 households
Heat pump manufacturer	Friotherm
Commissioning	2018

Source: Bankwatch Network

1.7. CASE STUDY OF HEAT PUMPS USING WASTE HEAT

Case study on large-scale heat pumps in the modernization of the district heating system of Vienna, Austria.

- Largest heat pump in Central Europe (Vienna)
- EUR 15M investment by Wien Energy
- Heats 25,000 homes using Danube Canal waste heat
- Supplies district heating at 100–150 °C



Source: Bankwatch Network

SHaKE
Sharing Knowledge on Energy Communities

Thank you!

Module 3.2 – Waste Heat Utilisation and Heat Pumps
SHaKE – Sharing Heat and Knowledge on Energy Communities

https://www.shakeproject-dhc.eu/

Developed by

Dr. Adrián Mota-Babiloni | mota@uji.es
Ghad Alarnaot-Alarnaout | alarnaot@uji.es
Balázs Bokor | bokor.balazs@gpk.bme.hu

MŰEGYETEM 1782
UNIVERSITAT JAUME I
MINES PARIS | PSL

Co-funded by the European Union