INDUSTRIAL ENERGY MANAGEMENT

ABSORPTION/ADSORPTION CHILLERS

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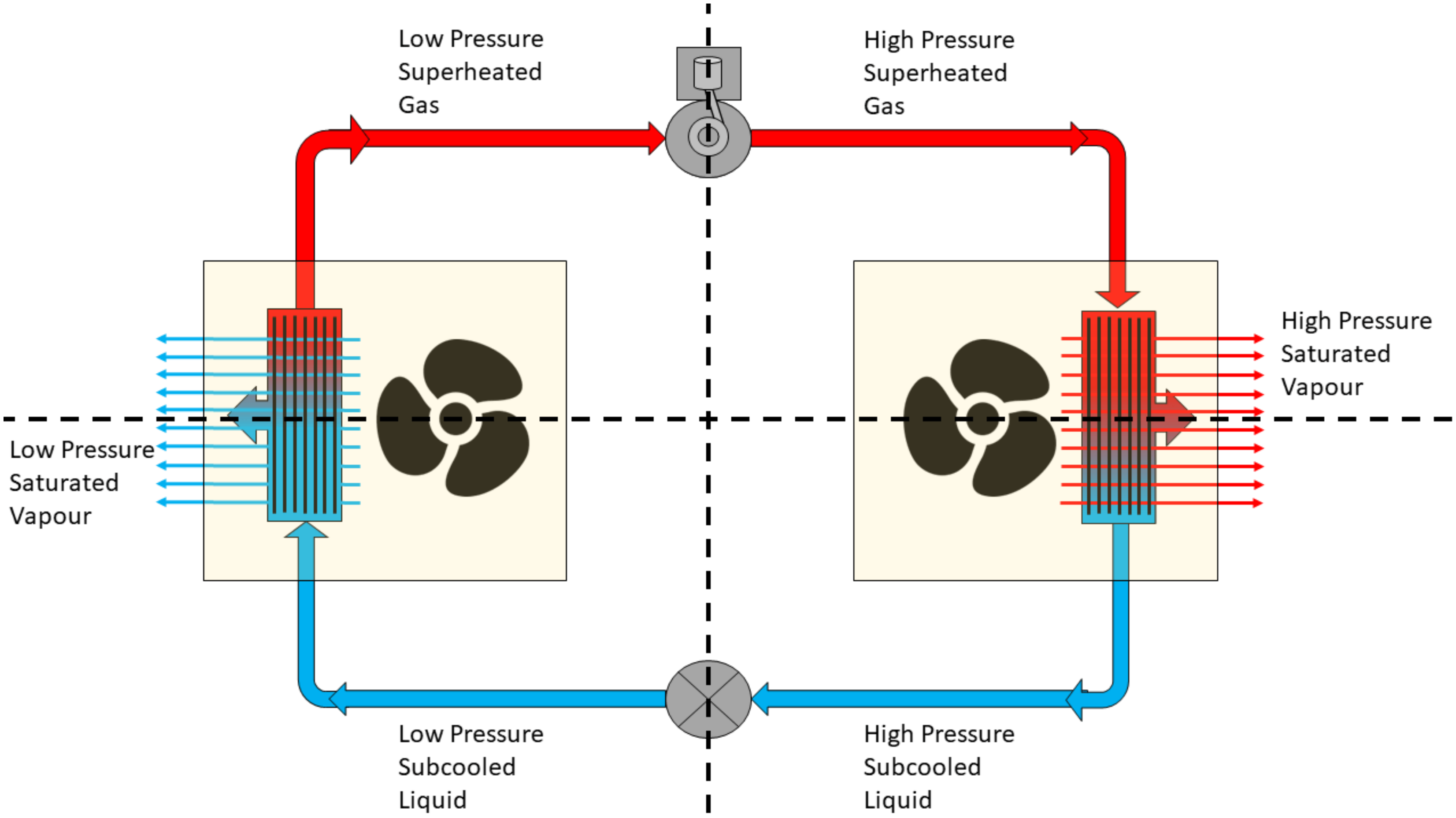
AY 2024 – 2025

Refrigeration cycle

From Engineering Thermodynamics:



Story of absorption chiller

The absorber is reliable and established technology over the years.

- 1777: development of the theory of refrigeration by absorption using sulfuric acid as an absorbent (E. Nairne, France);
- 1860: first absorption refrigeration machine with water-ammonia solution (Ferdinand Carré, France);
- 1923: first high-power LiBr absorption machine (USA);
- 1945: first LiBr gas absorption machine with direct flame (Japan);
- 1961: first double-effect steam-powered absorption machine;
- 1980: first double-effect gas and direct flame absorption machine (Japan);
- '90s :gas machines ,direct flame combined cold/heat production (Japan).

Source: www.yazakienergy.com

Absorption chiller

These cycles have some features in common with the vapor-compression cycles considered previously but differ in two important respects:

- One is the nature of the compression process. Instead of compressing a vapor between the evaporator and the condenser, the refrigerant of an absorption system is absorbed by a secondary substance, called an absorbent, to form a liquid solution. The liquid solution is then pumped to the higher pressure. Because the average specific volume of the liquid solution is much less than that of the refrigerant vapor, significantly less work is required. Accordingly, absorption refrigeration systems have the advantage of relatively small work input compared to vapor-compression systems.
- The other main difference between absorption and vapor-compression systems is that some means must be introduced in absorption systems to retrieve the refrigerant vapor from the liquid solution before the refrigerant enters the condenser. This involves heat transfer from a relatively high-temperature source. Steam or waste heat that otherwise would be discharged to the surroundings without use is particularly economical for this purpose. Natural gas or some other fuel can be burned to provide the heat source, and there have been practical applications of absorption refrigeration using alternative energy sources such as solar and geothermal energy.

Source: Moran et al., Fundamentals of Engineering Thermodynamics (2014, Wiley)

Absorption chiller

There are usually two types of cycles:

- Water (absorbent) and ammonia (refrigerant)
- Water (refrigerant) and lithium bromide (absorbent)

As for vapor compression chillers, the cycles could be:

- Single-effect
- Double-effect
- Triple-effect

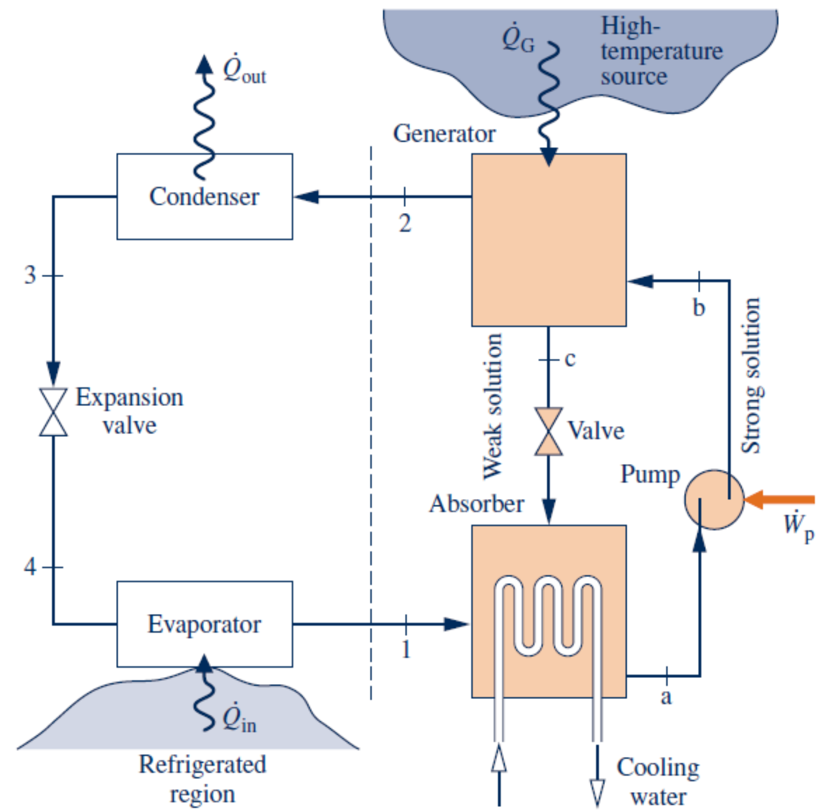
By increasing the number of pressure levels, the efficiency of the absorption chiller increases.

Source: Moran et al., Fundamentals of Engineering Thermodynamics (2014, Wiley)

Absorption chiller

In this example, ammonia is the refrigerant and water is the absorbent. Ammonia circulates through the condenser, expansion valve, and evaporator as in a vapor-compression system. However, the compressor is replaced by the absorber, pump, generator, and valve shown on the right side of the diagram.

- In the **absorber**, ammonia vapor coming from the evaporator at state 1 is absorbed by liquid water. The formation of this liquid solution is exothermic. Since the amount of ammonia that can be dissolved in water increases as the solution temperature decreases, cooling water is circulated around the absorber to remove the energy released as ammonia goes into solution and to maintain the temperature in the absorber as low as possible. The strong ammonia– water solution leaves the absorber at point a and enters the pump, where its pressure is increased to that of the generator.

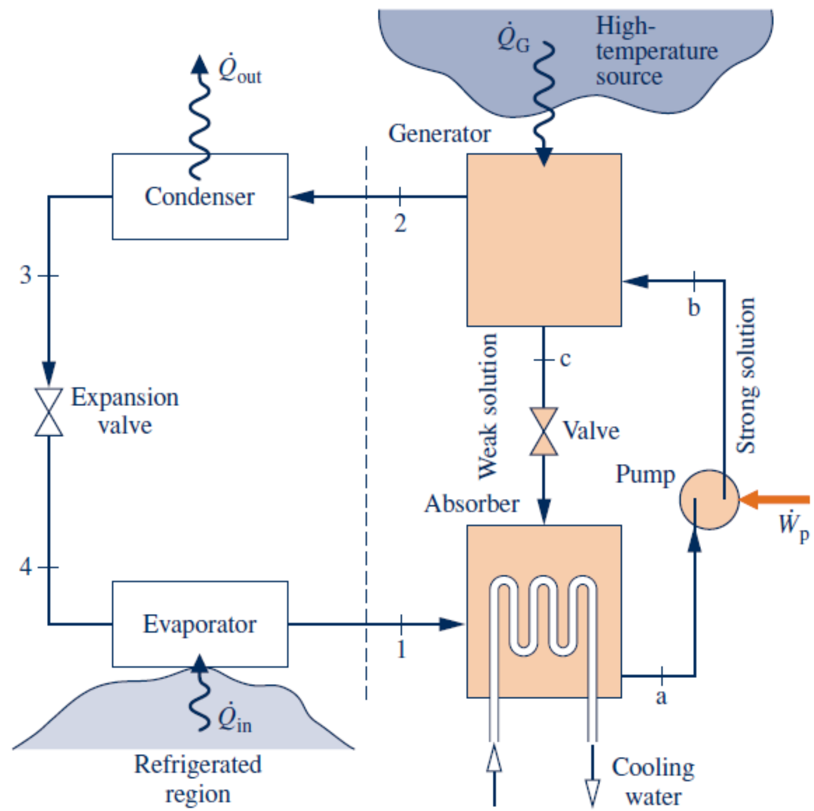


Source: Moran et al., Fundamentals of Engineering Thermodynamics (2014, Wiley)

Absorption chiller

➢ In the **generator**, heat transfer from a high-temperature source drives ammonia vapor out of the solution (an endothermic process), leaving a weak ammonia–water solution in the generator. The vapor liberated passes to the condenser at state 2, and the remaining weak solution at (c) flows back to the absorber through a valve.

The only work input is the power required to operate the pump, and this is small in comparison to the work that would be required to compress refrigerant vapor between the same pressure levels. However, costs associated with the heat source and extra equipment not required by vapor-compressor systems can cancel the advantage of a smaller work input.

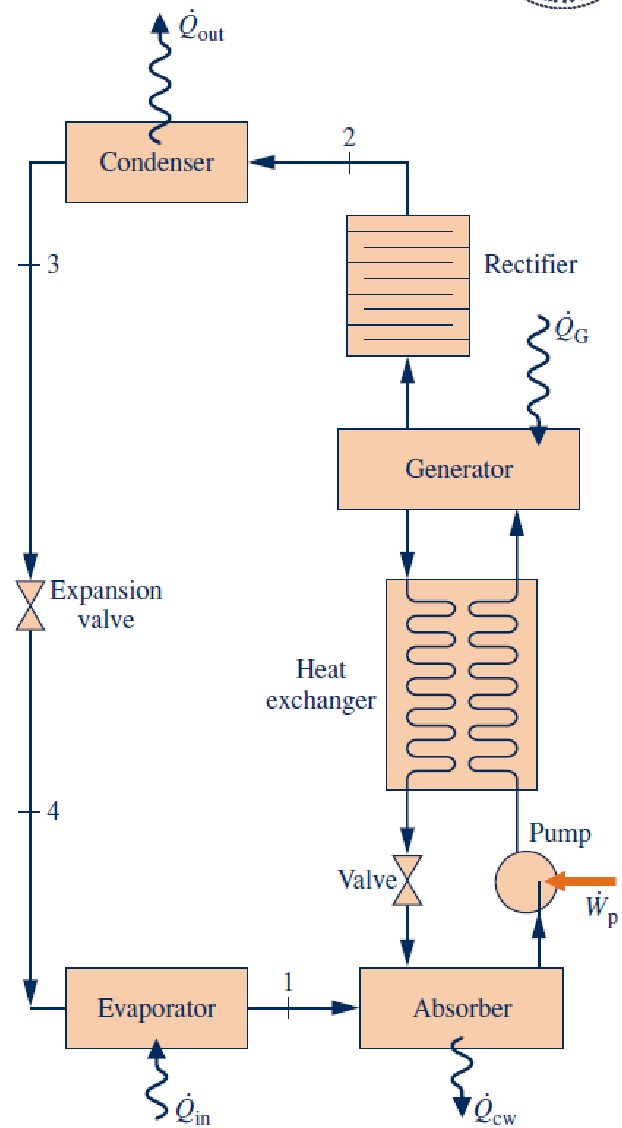


Source: Moran et al., Fundamentals of Engineering Thermodynamics (2014, Wiley)

Absorption chiller

Ammonia–water systems normally employ several modifications of the simple absorption cycle considered above. In particular, two modifications are presented:

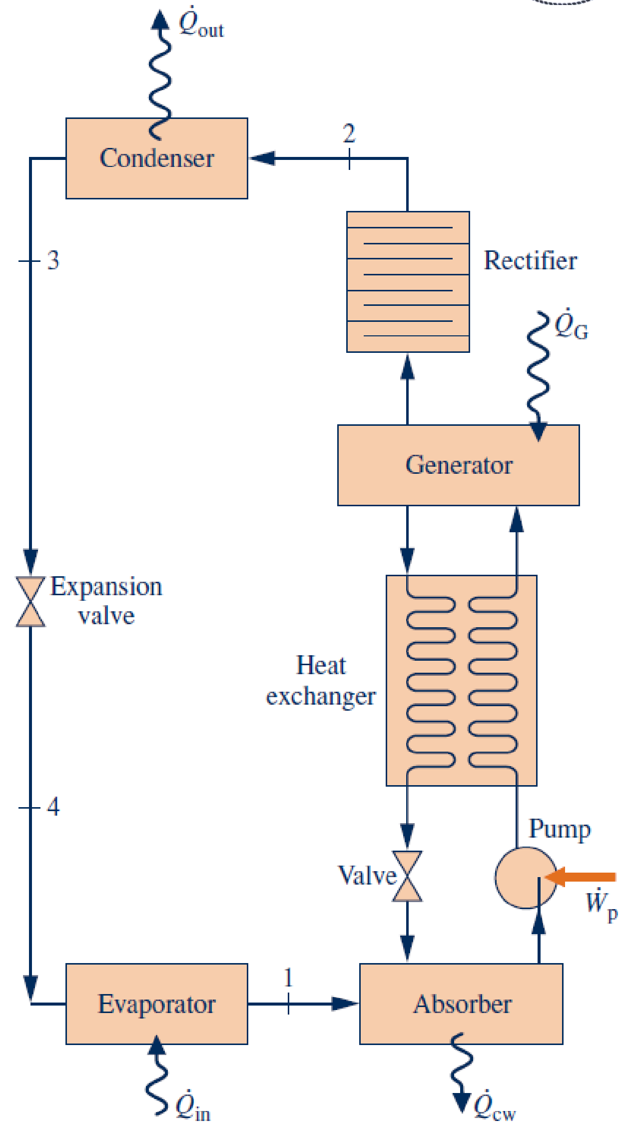
- a **heat exchanger** is included between the generator and the absorber that allows the strong water–ammonia solution entering the generator to be preheated by the weak solution returning from the generator to the absorber, thereby reducing the heat transfer to the generator, $\dot{Q}_G$
- A **rectifier** is placed between the generator and the condenser. The function of the rectifier is to remove any traces of water from the refrigerant before it enters the condenser. This eliminates the possibility of ice formation in the expansion valve and the evaporator.



Source: Moran et al., Fundamentals of Engineering Thermodynamics (2014, Wiley)

Absorption chiller

Another type of absorption system uses lithium bromide as the absorbent and water as the refrigerant. The basic principle of operation is the same as for ammonia–water systems. To achieve refrigeration at lower temperatures than are possible with water as the refrigerant, a lithium bromide–water absorption system may be combined with another cycle using a refrigerant with good low-temperature characteristics, such as ammonia, to form a cascade refrigeration system.



Source: Moran et al., Fundamentals of Engineering Thermodynamics (2014, Wiley)

Coefficient of performance (COP)

First Principle of Thermodynamic:

$$\dot{Q}_{in} + \dot{Q}_G + \dot{W}_p = |\dot{Q}_{cw}| + |\dot{Q}_{out}| + |\dot{Q}_{loss}|$$

$$\boldsymbol{\varepsilon_t = \frac{\dot{Q}_{in}}{\dot{Q}_G + \dot{W}_p} \simeq \frac{\dot{Q}_{in}}{\dot{Q}_G}}$$

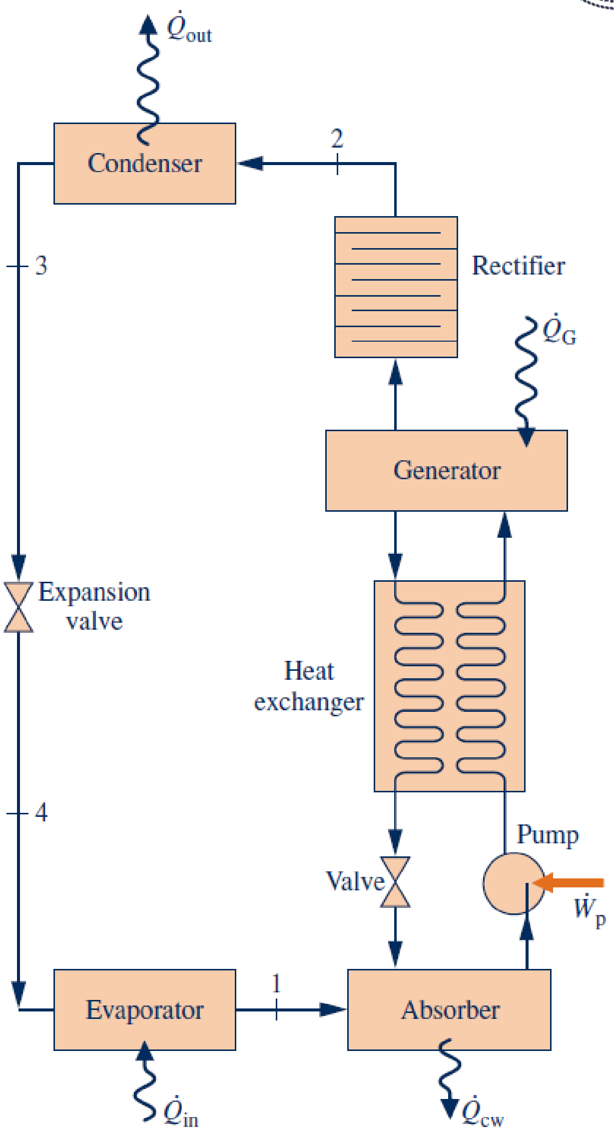
Second Principle of Thermodynamic:

$$\frac{\dot{Q}_{in}}{T_{in}} + \frac{\dot{Q}_G}{T_g} = \frac{|\dot{Q}_{cw}| + |\dot{Q}_{out}|}{T_a}$$

$$\frac{\dot{Q}_{in}}{T_{in}} + \frac{\dot{Q}_G}{T_g} = \frac{\dot{Q}_{in} + \dot{Q}_G}{T_a}$$

$$\boldsymbol{COP = \varepsilon_t^* = \frac{\dot{Q}_{in}}{\dot{Q}_G} = \frac{\frac{1}{T_a} - \frac{1}{T_g}}{\frac{1}{T_{in}} - \frac{1}{T_a}}}$$

Note: it is assumed that $T_a = T_c$



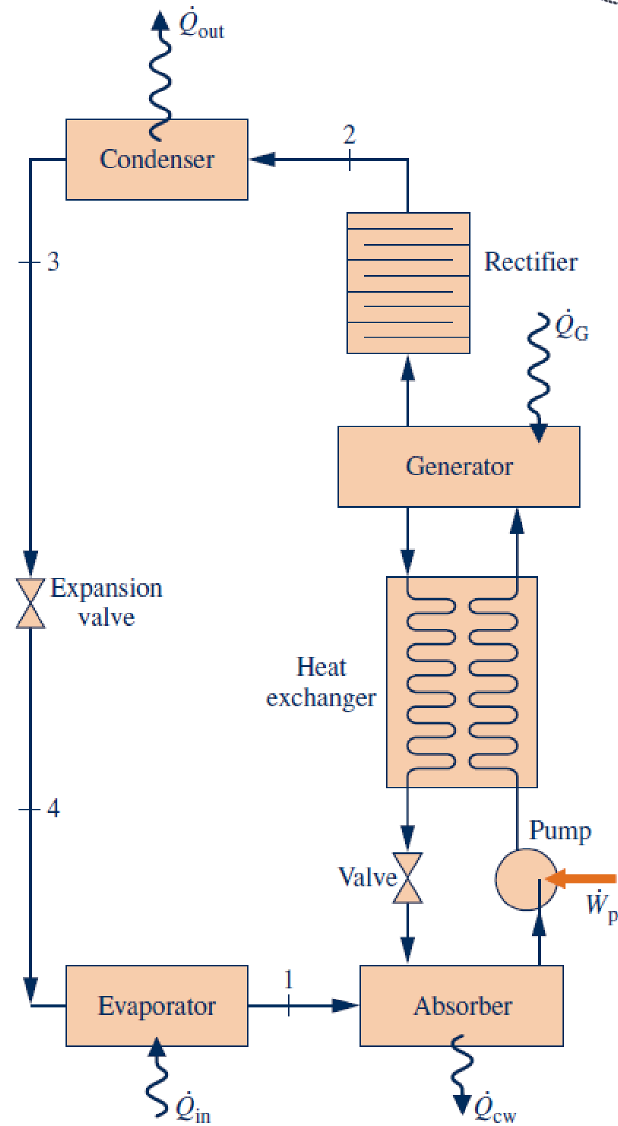
Coefficient of performance (COP)

Note that if Tg tends to become infinitely large, the value of ε_t^* approaches $\frac{T_0}{T_a - T_0}$, which is the value corresponding to the effective coefficient of a reversed Carnot cycle ε_c.The lower the Tg, the more the effective coefficient of an absorption cycle is lower than ε_c. For example, for a reversed Carnot cycle with Tin = 263 K and Ta=298 K, it follows that:

$$\varepsilon_c = \frac{263}{35} = 7.5$$

If Tg=373 K:

$$\varepsilon_t^* = \frac{\frac{1}{298} - \frac{1}{373}}{\frac{1}{263} - \frac{1}{298}} = 1.5$$

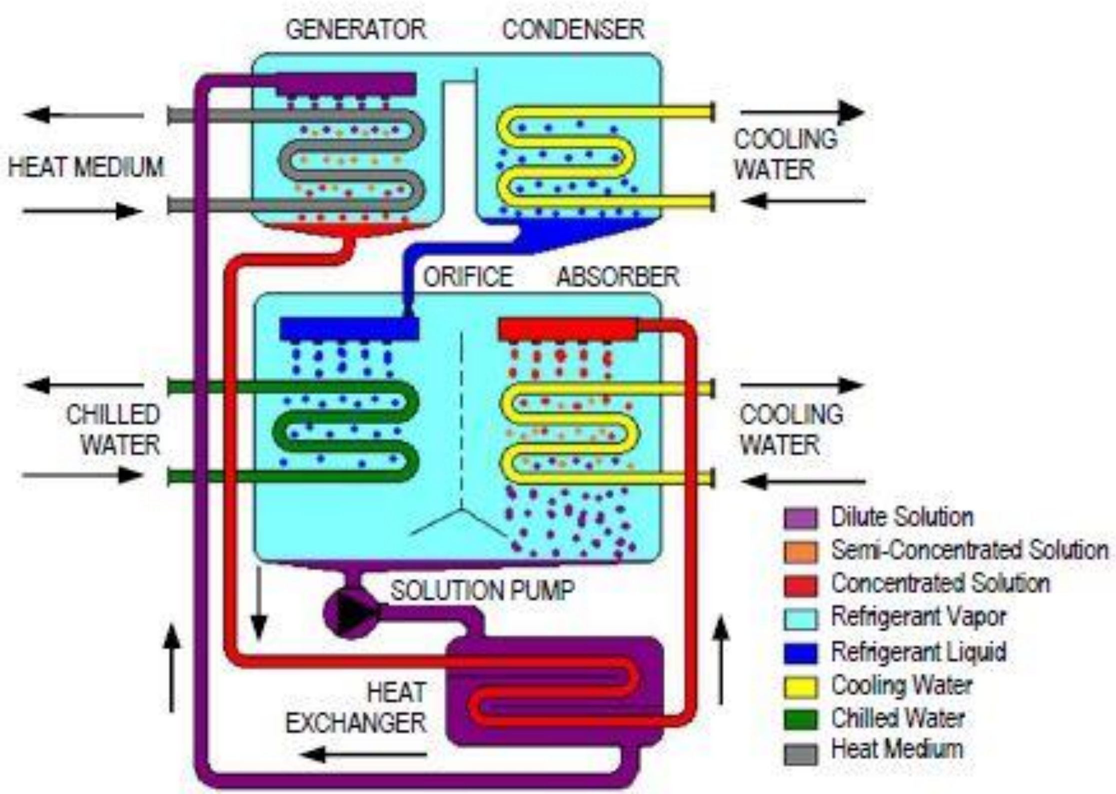


Absorption chiller

Given the very different quality of energy required for the operation of the absorption refrigeration chiller compared to that of vapor compression one, the COPs of the two chillers cannot be compared. In fact, compression refrigeration machines require mechanical energy for compression (high-quality energy);

- Mechanical energy is made available in most cases by using electric motors, and electrical energy is mostly derived from thermoelectric plants powered by fuel and/or thermal absorption;
- In thermoelectric power plants, the conversion from heat to electricity occurs with an average national efficiency of around 40%.

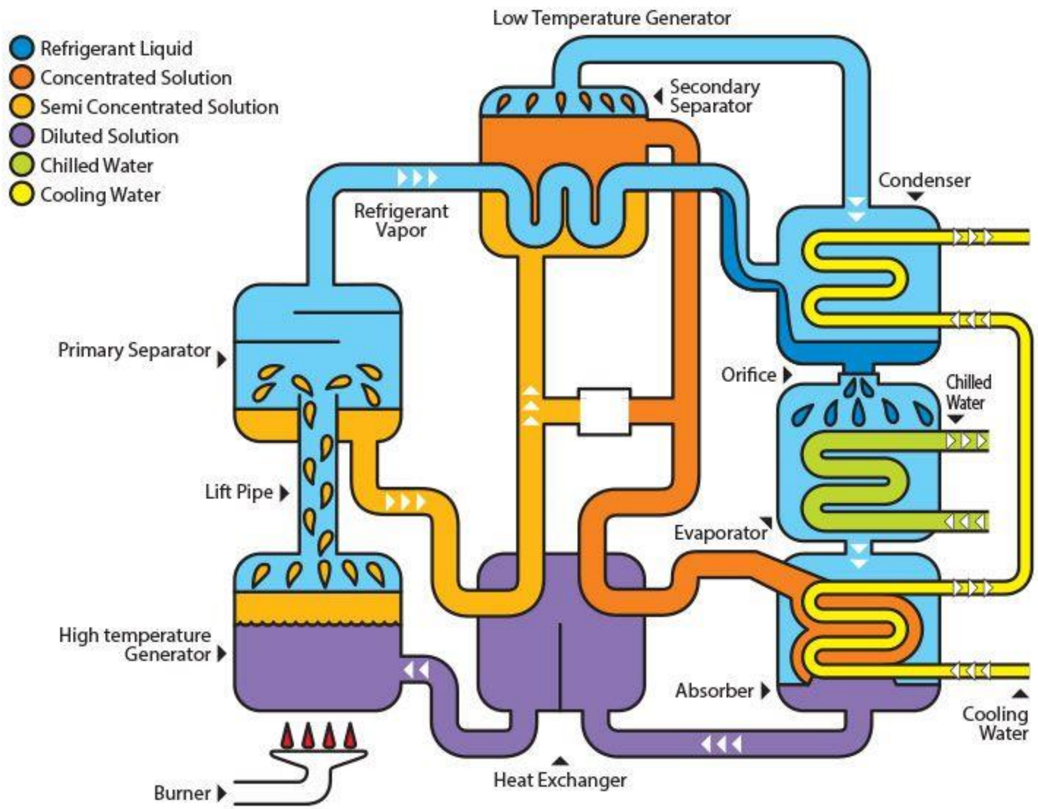
Water-fired single effect chiller



100 kW heat → COP=0.7 → 70 kW cooling

Source: www.yazakienergy.com

Gas Fired Double-Effect Chiller-Heater



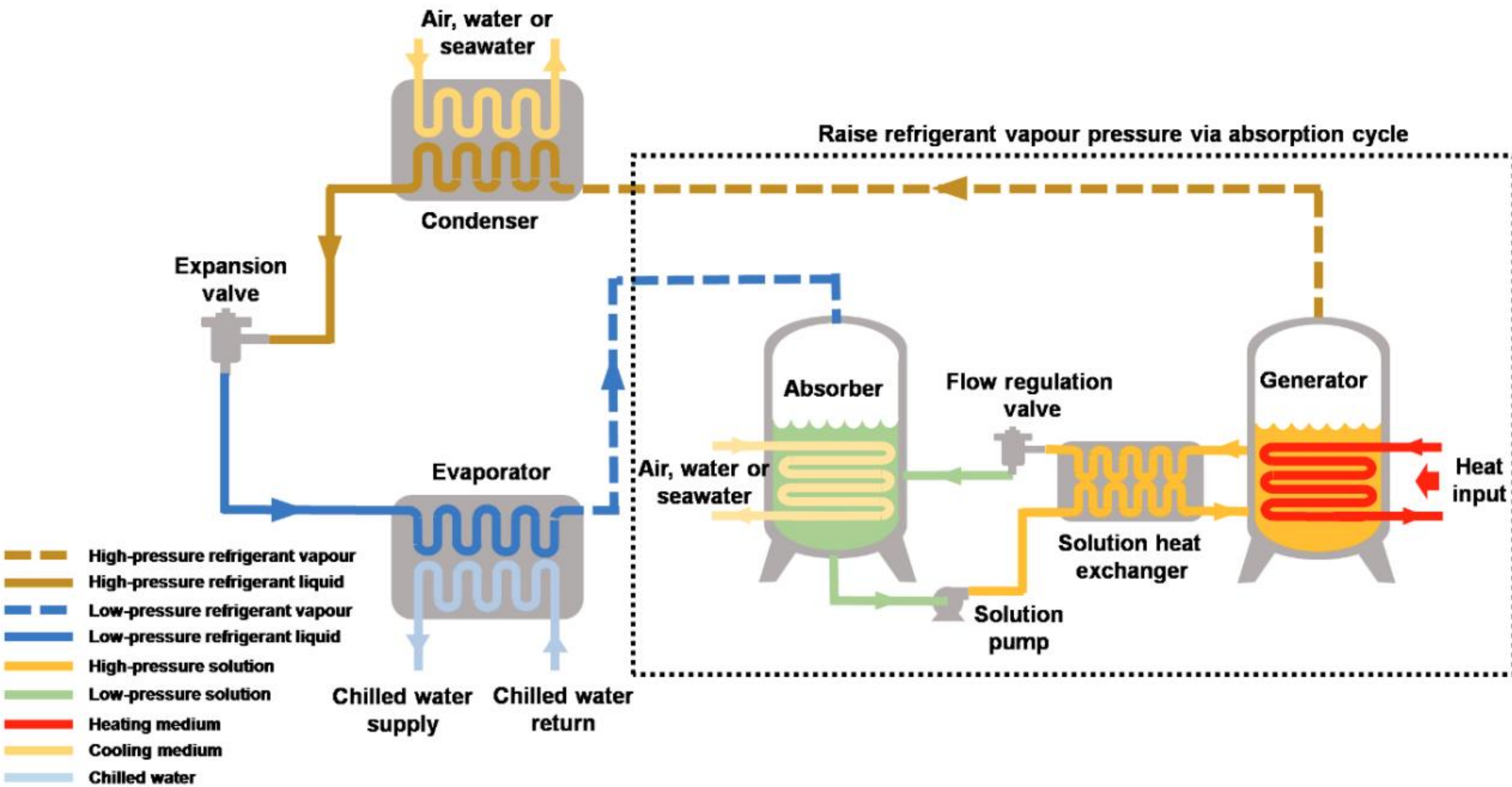
100 kW heat

COP=1

100 kW cooling

Source: www.yazakienergy.com

Single-effect absorption chiller



Source: Leung et al., Chillers of air-conditioning systems: An overview

Absorption chiller - Typical efficiency

Working fluids	Cycle configuration	Chilled water supply temperature (°C)	Heat source temperature (°C)	Capacity (kW)	COP
H_2O-LiBr	Single-effect	5 - 10	80 - 120	35 - 7000	0.5 - 0.7
H_2O-LiBr	Double-effect	5 - 10	120 - 170	20 - 11630	1.0 - 1.2
H_2O-LiBr	Triple-effect	5 - 10	200 - 230	530 - 1400	1.4 - 1.7
NH_3-H_2O	Single-effect	5 - 10	80 - 120	10 - 30	0.5 - 0.6
NH_3-H_2O	Double-effect	5 - 10	160 - 200	10 - 90	0.7 - 0.9
NH_3-H_2O	Triple-effect	5 - 10	170 - 200	< 110	0.8 - 1.2
NH_3-H_2O	Single-effect	-60 - 0	100 - 200	10 - 6500	0.25 - 0.6

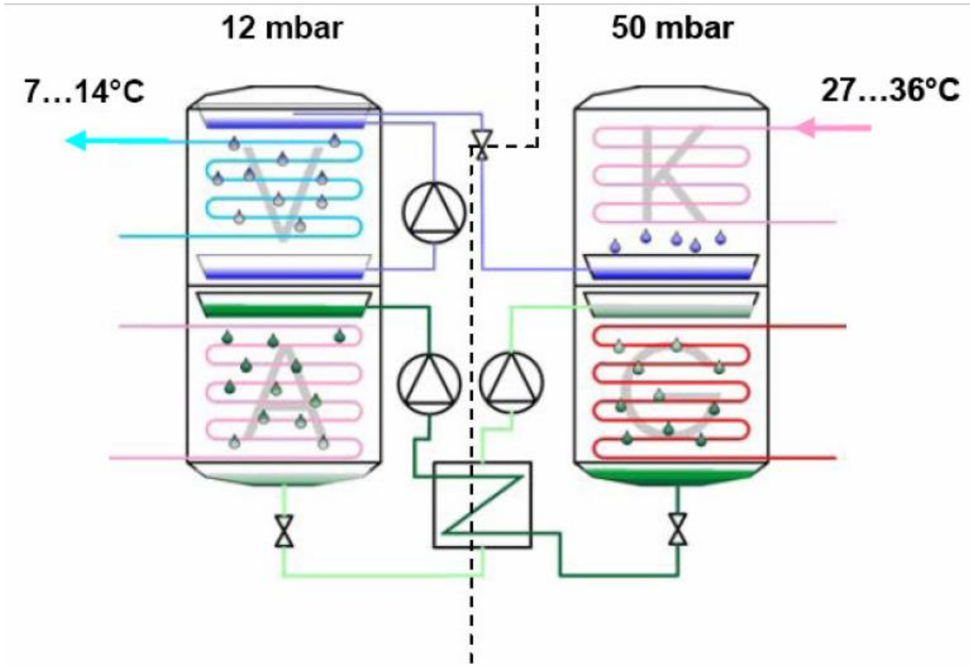
Source: Leung et al., Chillers of air-conditioning systems: An overview

Absorption chiller

The thermodynamic cycle operates between two pressure values, Pc and P0: the dashed line in the diagram separates the components that operate at different pressures.

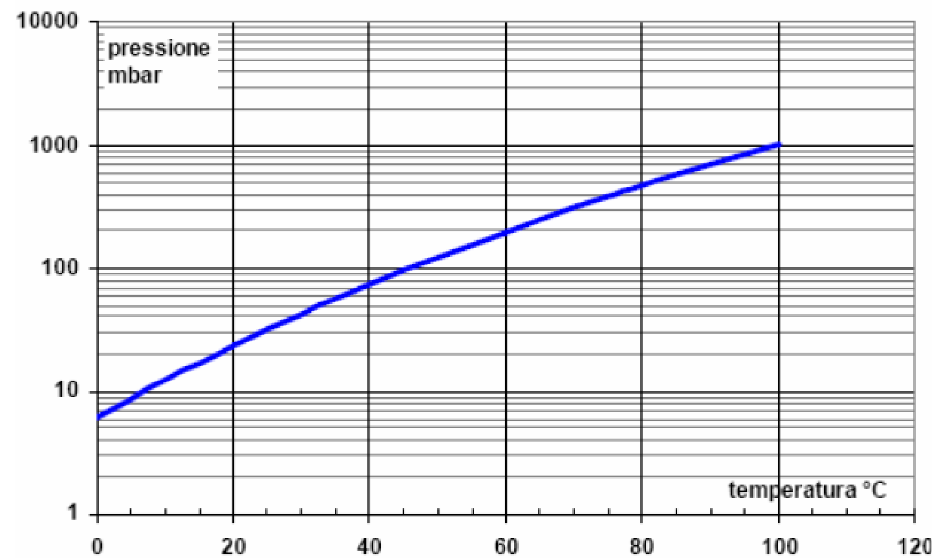
The pressure Pc (generator and condenser) is determined by the condensation temperature of the water in the condenser and therefore, ultimately, by the temperature of the water available in the cooling circuit.

The pressure P0 (evaporator and absorber) is determined by the evaporation temperature of the water and therefore, ultimately, by the temperature at which cooling is required.

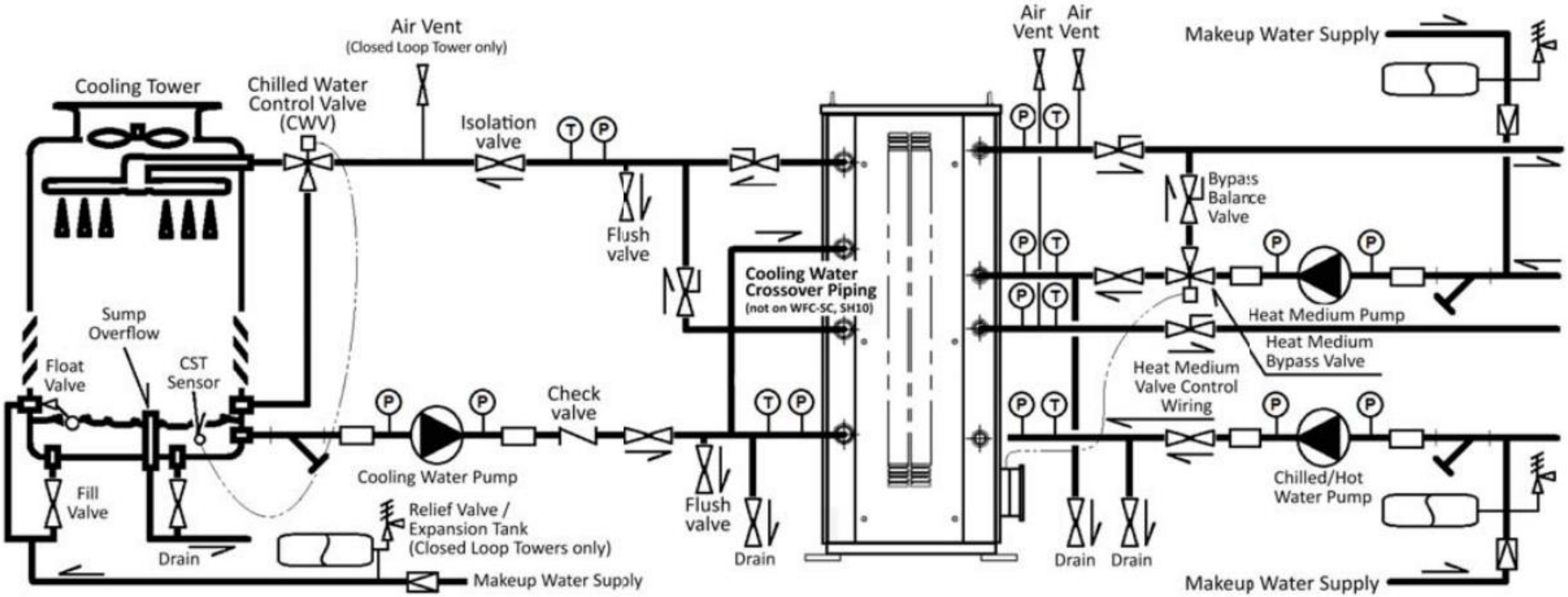


Absorption chiller

The graph represents the variation of saturated vapor pressure (boiling point) with temperature; considering the temperature of the water available in the cooling circuit (typically from 27°C to 36°C), it turns out that the pressure in the condenser is about 50 mbar; considering instead the temperature at which cooling is required (typically from 7°C to 14°C), it turns out that the pressure in the evaporator is about 12 mbar.

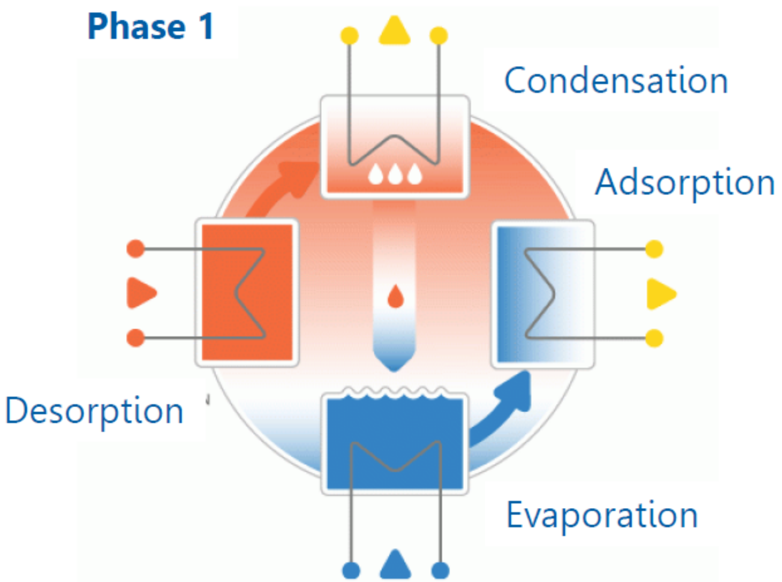


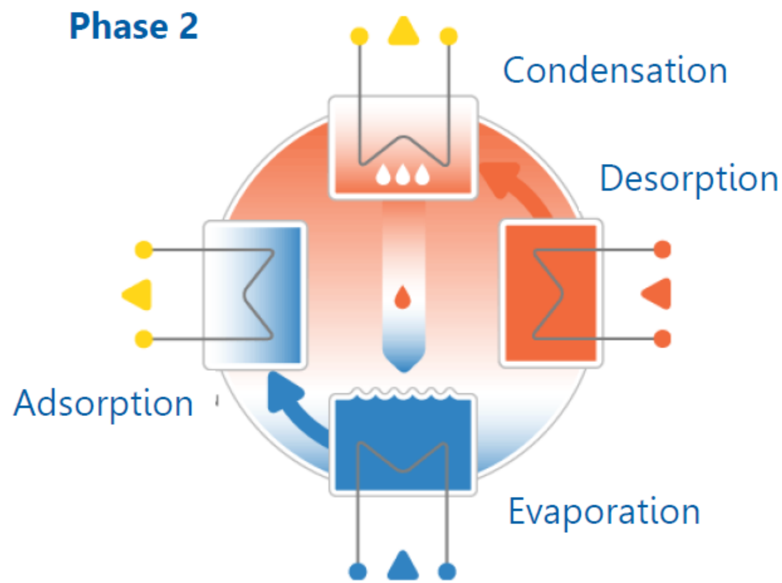
Absorption chiller - Typical piping



Source: www.yazakienergy.com

Adsorption chiller



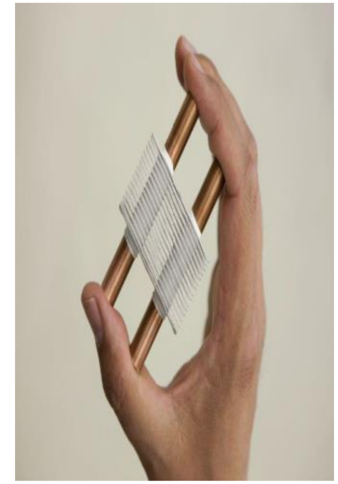


- Cooling – Uptake of energy of the evaporation
- Thermal drive – Heating of the Adsorbers
- Recooling – Heat removal out of the system

Source: www.aaasaveenergy.com and www.iea-shc.org

Adsorption chiller

Adsorbents



Silica gel
- amorphous SiO 2
- very high internal surface: >600 m² / gram

Zeolite
- Surface: >1000 m²/gram
- Material specially designed for heating and cooling applications

Water is the cooling media

Source: www.aaasaveenergy.com and www.iea-shc.org

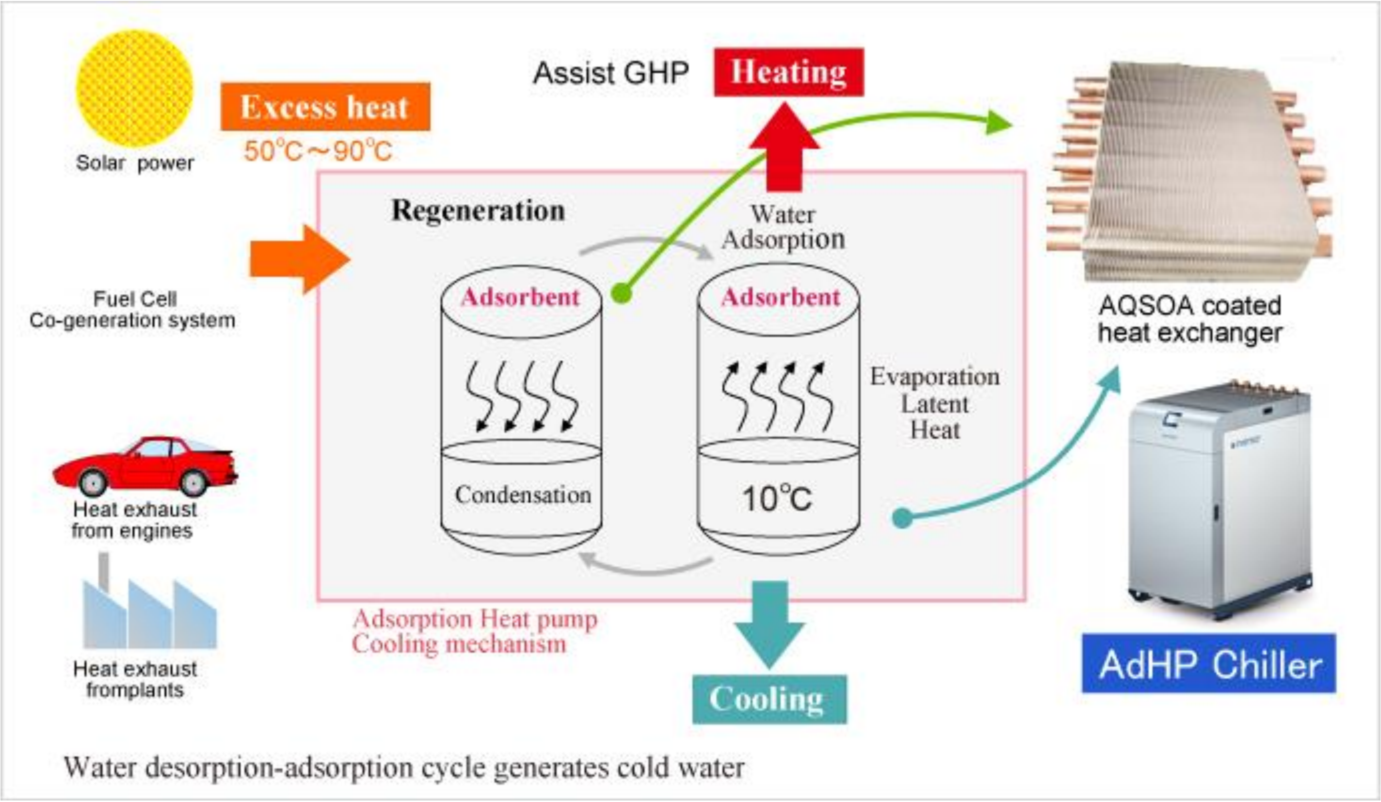
Adsorption chiller

Particularly wide range of services

- Cooling capacity between 30 and 105 kW
- Up to 70 % less power consumption compared to conventional compressors
- Incl. already installed hydraulics
- Ideal for industry
- Free cooling function at outside temperatures from approx. 15°C
- Internet interface, UDP interface

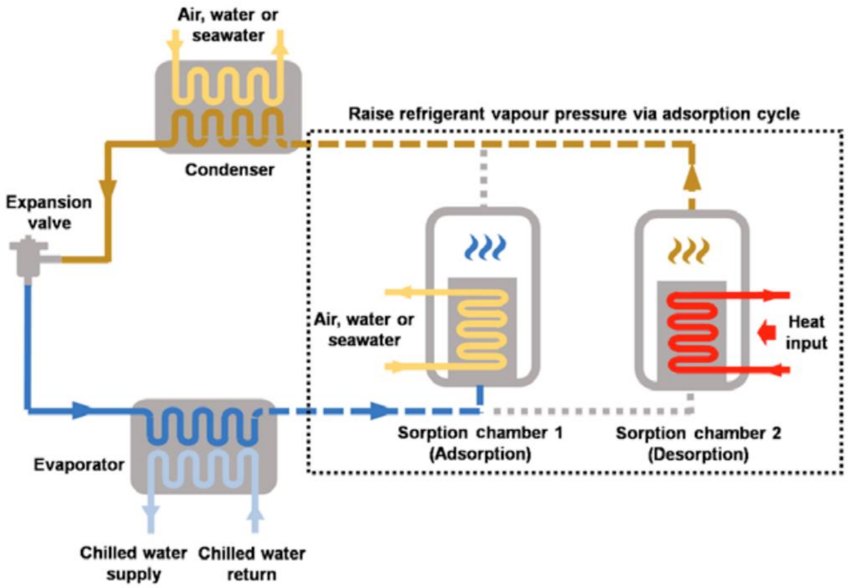
Source: www.aaasaveenergy.com and www.iea-shc.org

Adsorption chiller

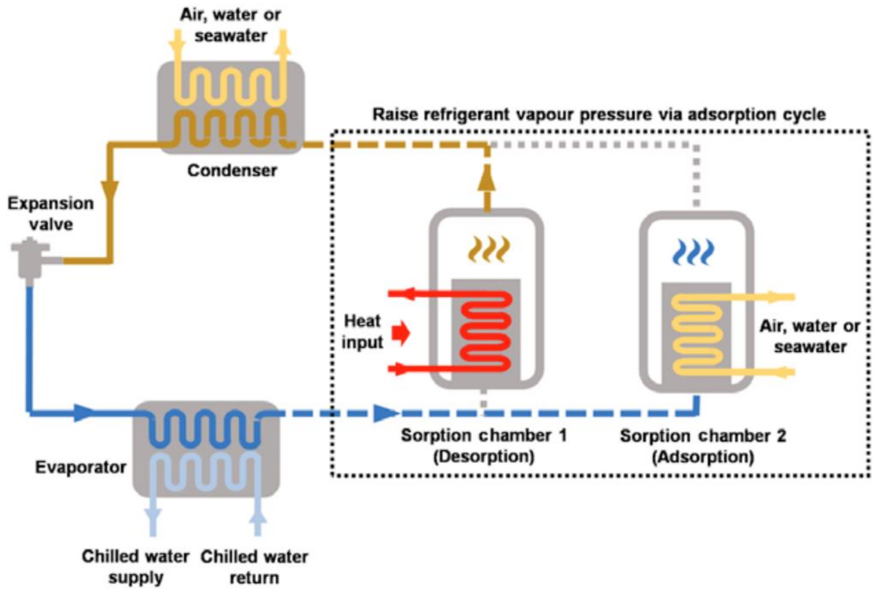


Source: www.aaasaveenergy.com

Adsorption chiller



Adsorption

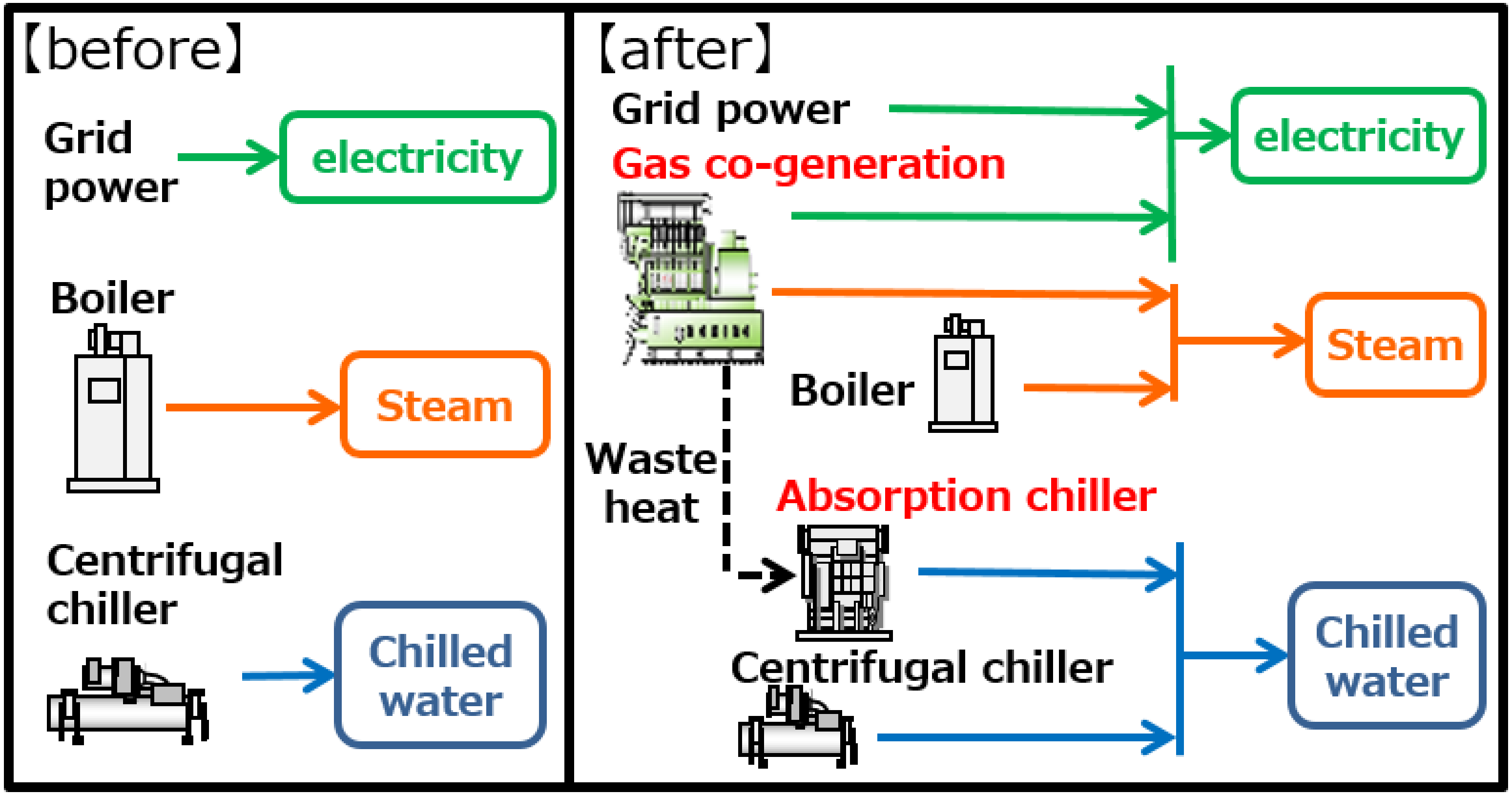


Desorption

Source: Leung et al., Chillers of air-conditioning systems: An overview

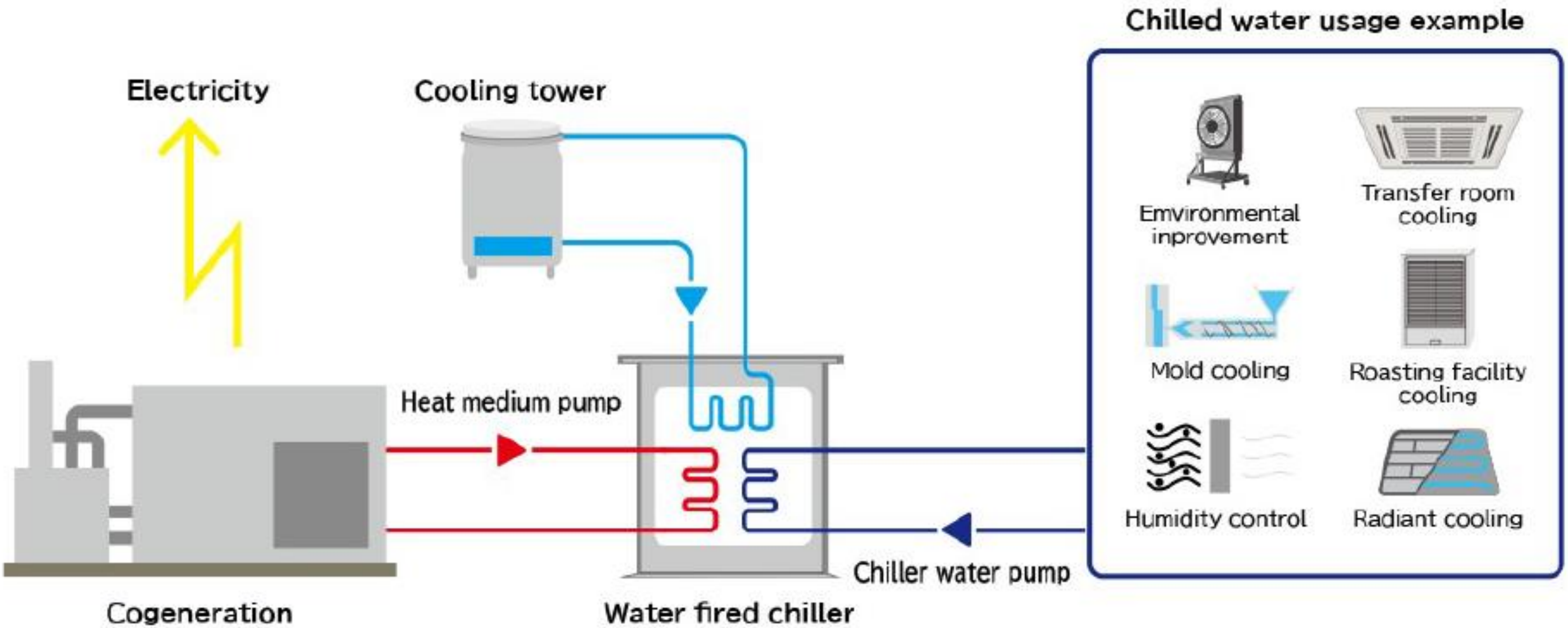
Trigeneration principles

An example:



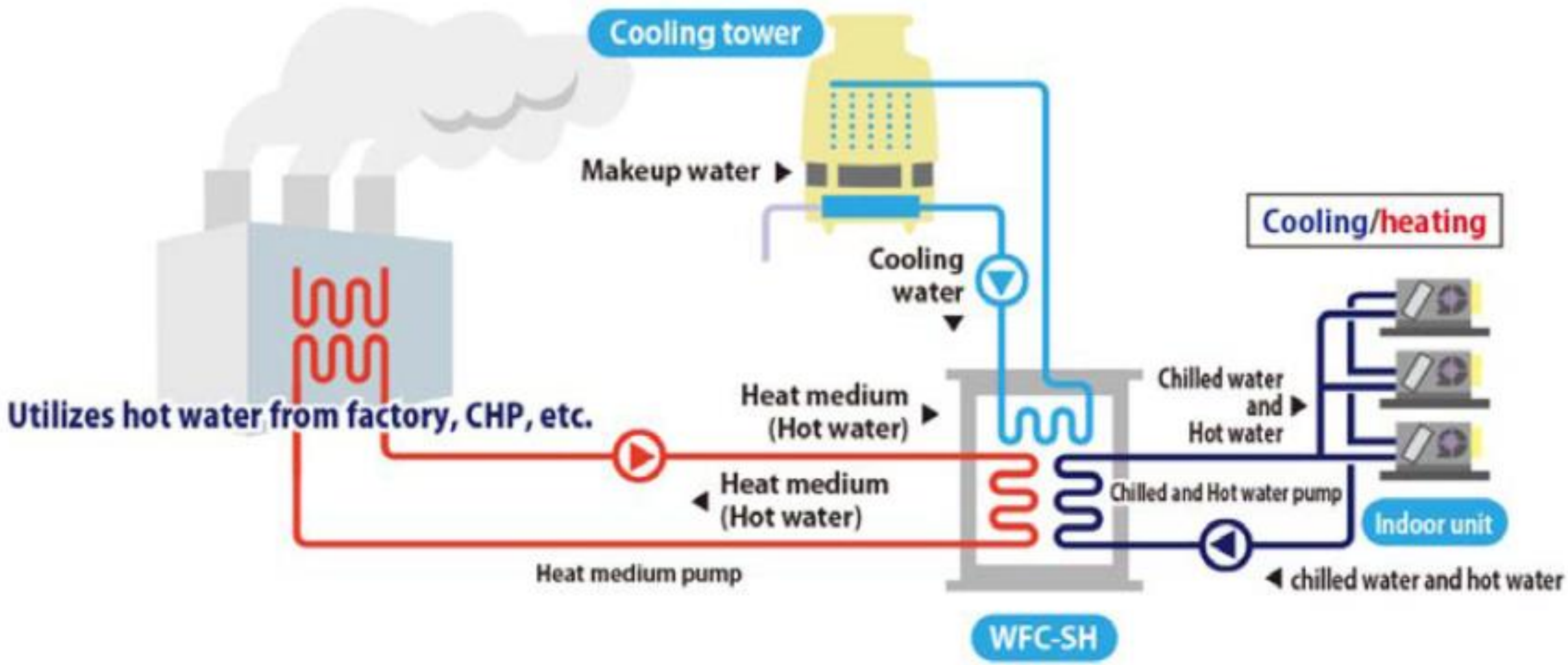
Source: https://gec.jp/jcm/

Example – trigeneration



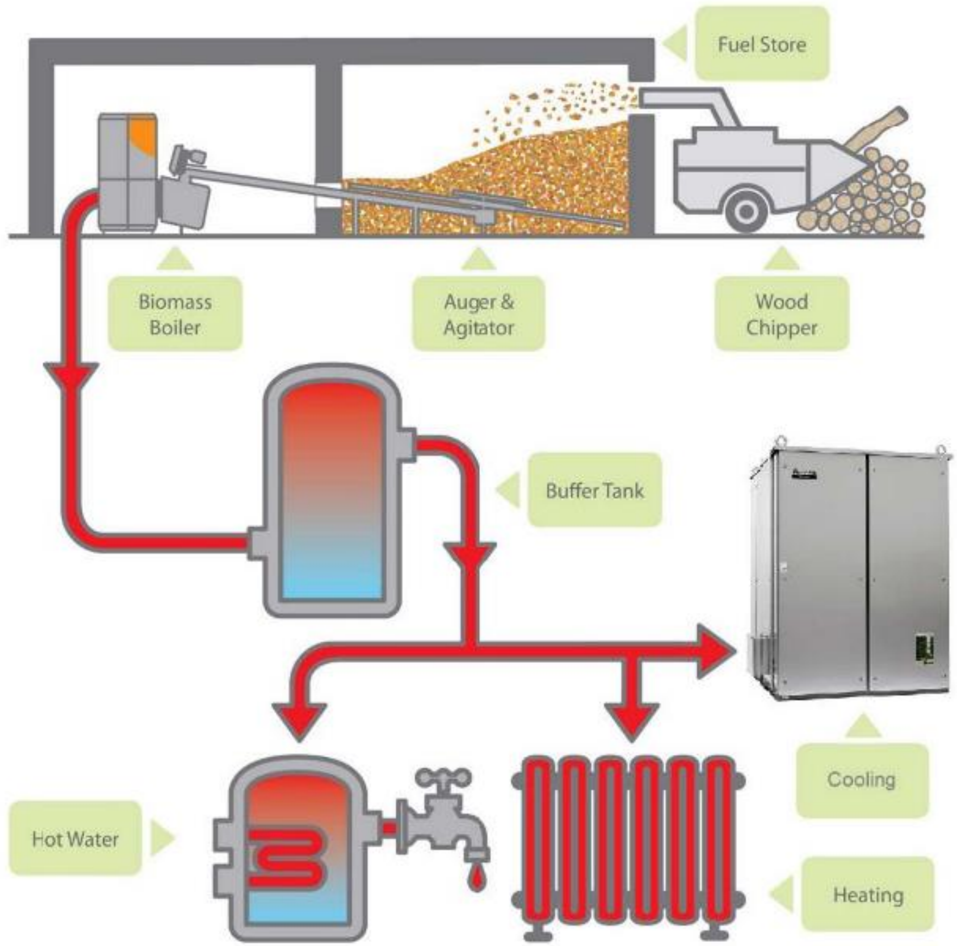
Source: www.yazakienergy.com

Example – waste heat



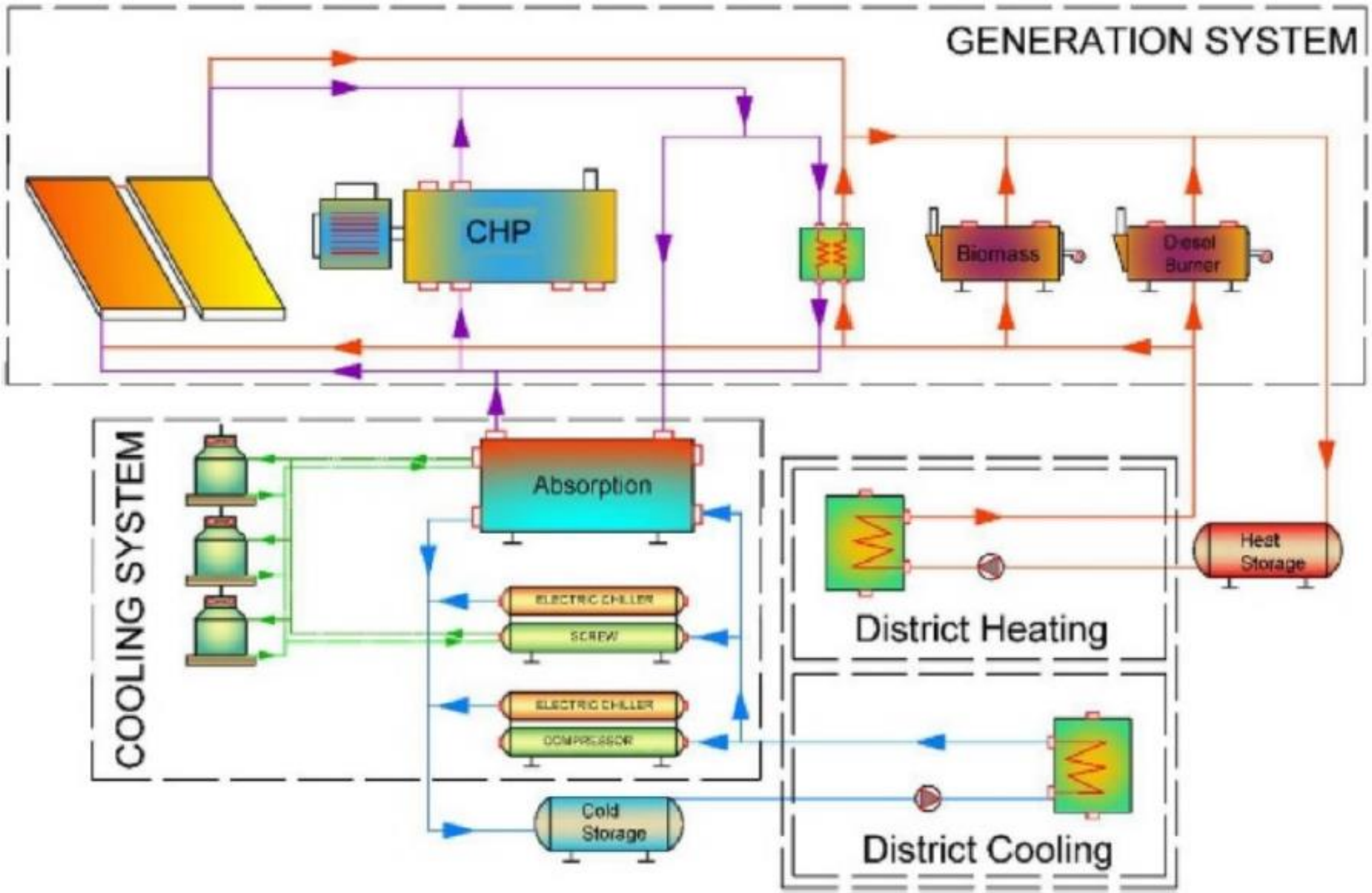
Source: www.yazakienergy.com

Example – biomass



Source: www.yazakienergy.com

Example – district heating and cooling



Source: www.yazakienergy.com

Cost comparison

Technology	€/kW
Boilers	25/60
Condensing Boilers	120
PCC Air-Air (2-4 kW)	80-350
PCC Air-Water (17 kW)	250
PCA H2O-NH3 (17 kW cold- 35 kW hot)	580 (cold) – 280 (hot)
Chiller H2O-LiBr (250 kW)	600 (cold)

Conclusions

Advantages of Compression chillers:

- Lower investment cost.
- Superior cooling performance.
- Wide range of sizes.
- Non-specialized maintenance.
- No exhaust gases (except models with internal combustion engines).
- Non-hazardous fluids (except anhydrous ammonia).

Advantages of Absorption/Adsorption chillers:

- The fluids used in absorption machines do not damage the ozone layer and do not contribute to the greenhouse effect.
- Heating performance is superior and less affected by climatic variations.
- Possibility to use energy sources.
- Greater silence and durability over time.
- Possibility to recover heat from waste (trigeneration).
- Solar Cooling is a very attractive technology for the future.

Example absorption chiller application

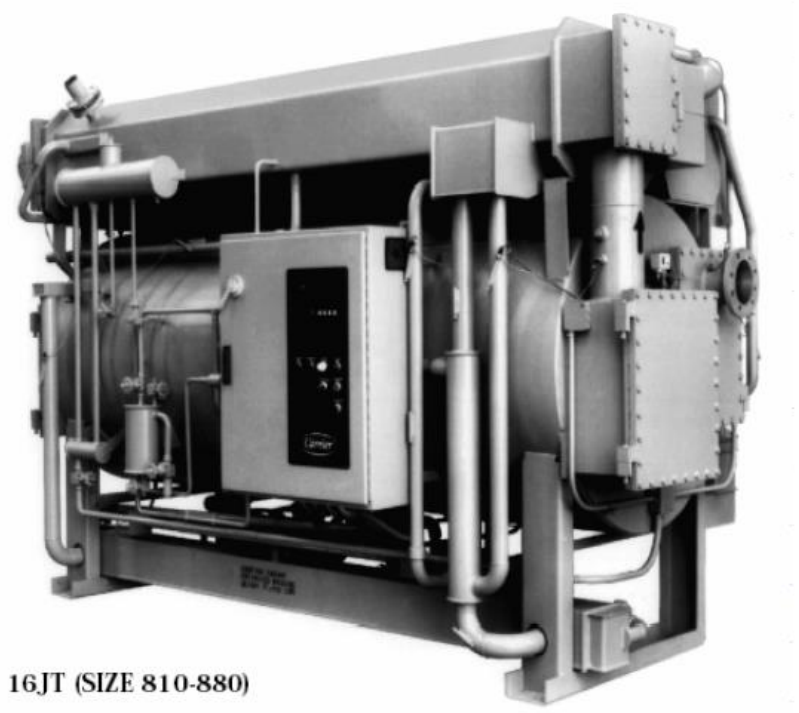
- Size: 28 kW cold - 48 kW hot
- Power supply: Gas
- Exchange: Air-Water; Water-Water
- Destination: cold, hot;
- Modularity: No
- COP: 1.60 hot - 0.95 cold

Example absorption chiller application

- Size: 17 kW cold
- Power supply: Gas
- Exchange: Air-Water;
- Function: cold
- Modularity: Yes
- COP: 0.65 cold

Example absorption chiller application

- Size: 150 - 5980 kW cold
- Power supply: Gas and Hot water;
- Steam Exchange: Water-Water
- Function: cold
- Control: continuous
- COP: 0.7 ; 1.1


16JT (SIZE 810-880)

Example adsorption chiller application Machine cooling

Miele & Cie. KG, Bünde, Germany

Chillers	11 InvenSor LTC 10 plus
Chilling capacity	110 kW
Driving energy	CHP Viessmann 370 kW th. / 240 kW el.
Cooling applications	Cooling of eroding maschines

In operation since April 2015

Example adsorption chiller application
Plastic injection molding-cooling

Busch-Jaeger Elektro GmbH, Bad Berleburg, Germany

Top 3 Industrie
Handelsblatt
ENERGY AWARDS
2017

Chillers	4 InvenSor LTC 30 e plus 3 InvenSor HTC 18 plus
Chilling capacity	174 kW
Driving energy	CHP 2G 290 kW th. / 250 kW el.
Cooling application	Tool cooling system

In operation since September 2016

Example adsorption chiller application
Room cooling

Marburg – Germany

Chillers	3x InvenSor LTC 09
Chilling capacity	27 kW
Driving energy	Solar thermal collectors
Cooling applications	Chilled air distribution

In operation since July 2011

Thank you for your attention!

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