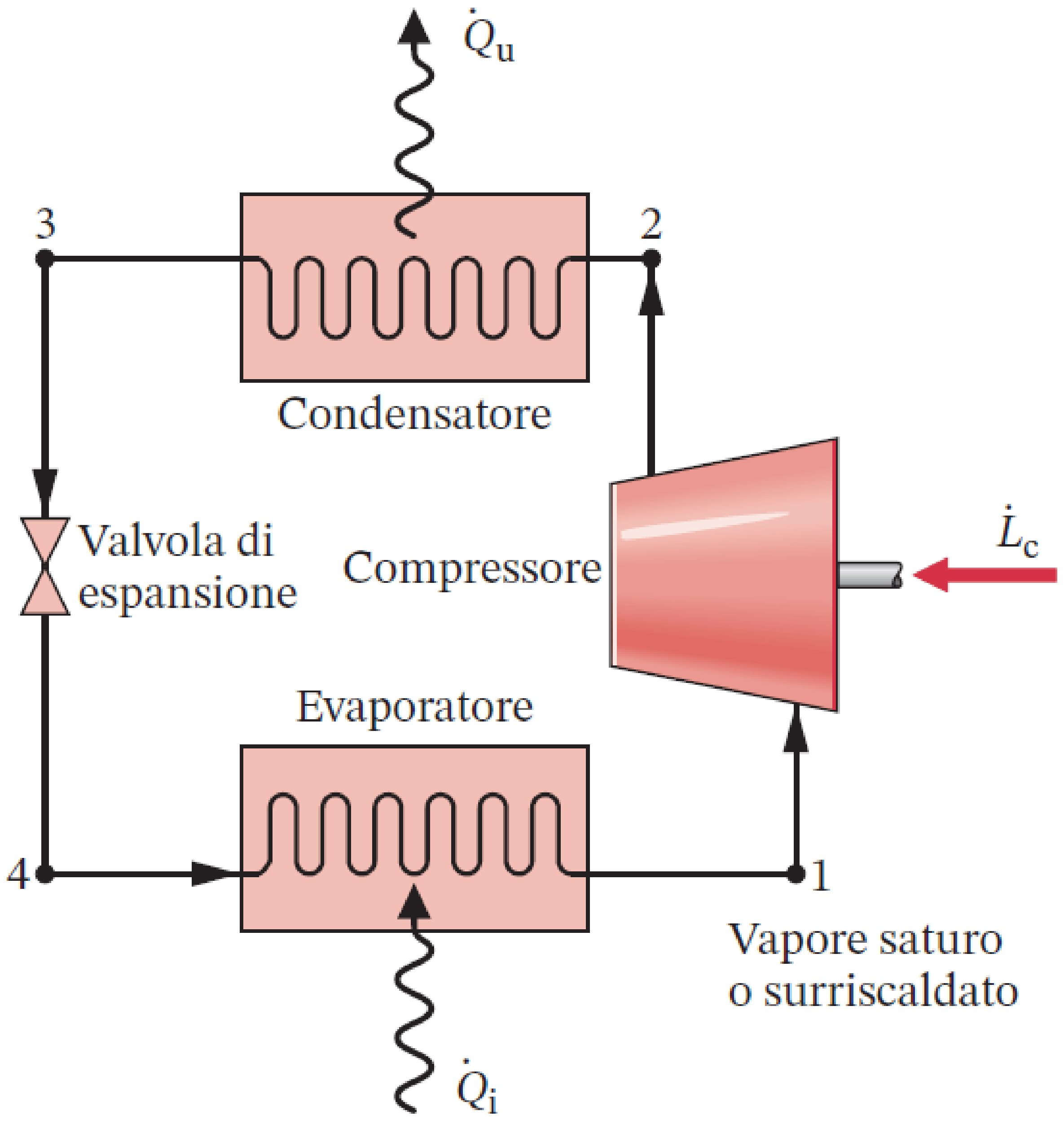
HVAC
System Design

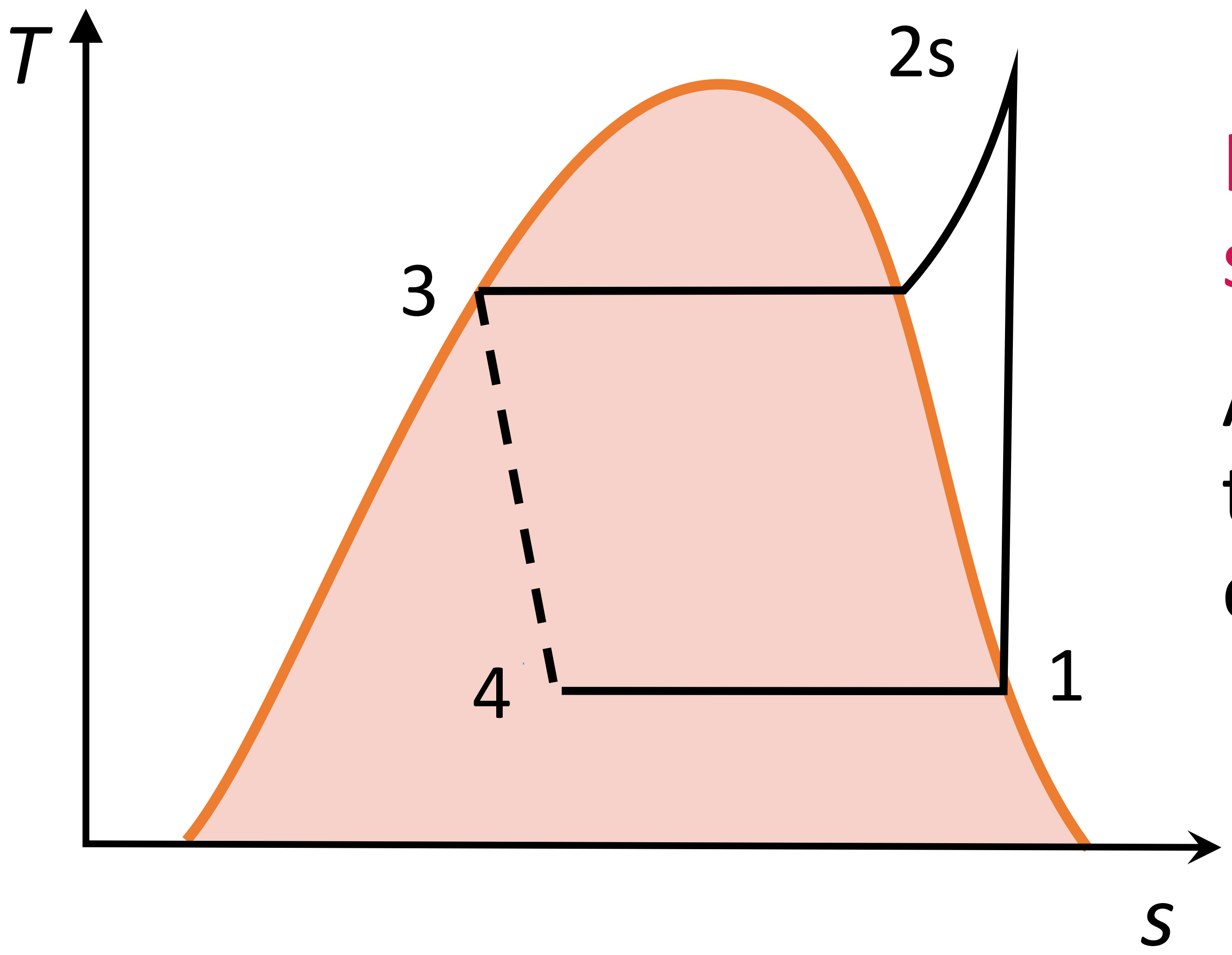
Refrigeration

Chiller

- An reverse system provides cold water
- With water the amount of refrigeration fluid is reduced
- Reference scheme: vapor compressor system

Ideal vapor compression cycle –T-s

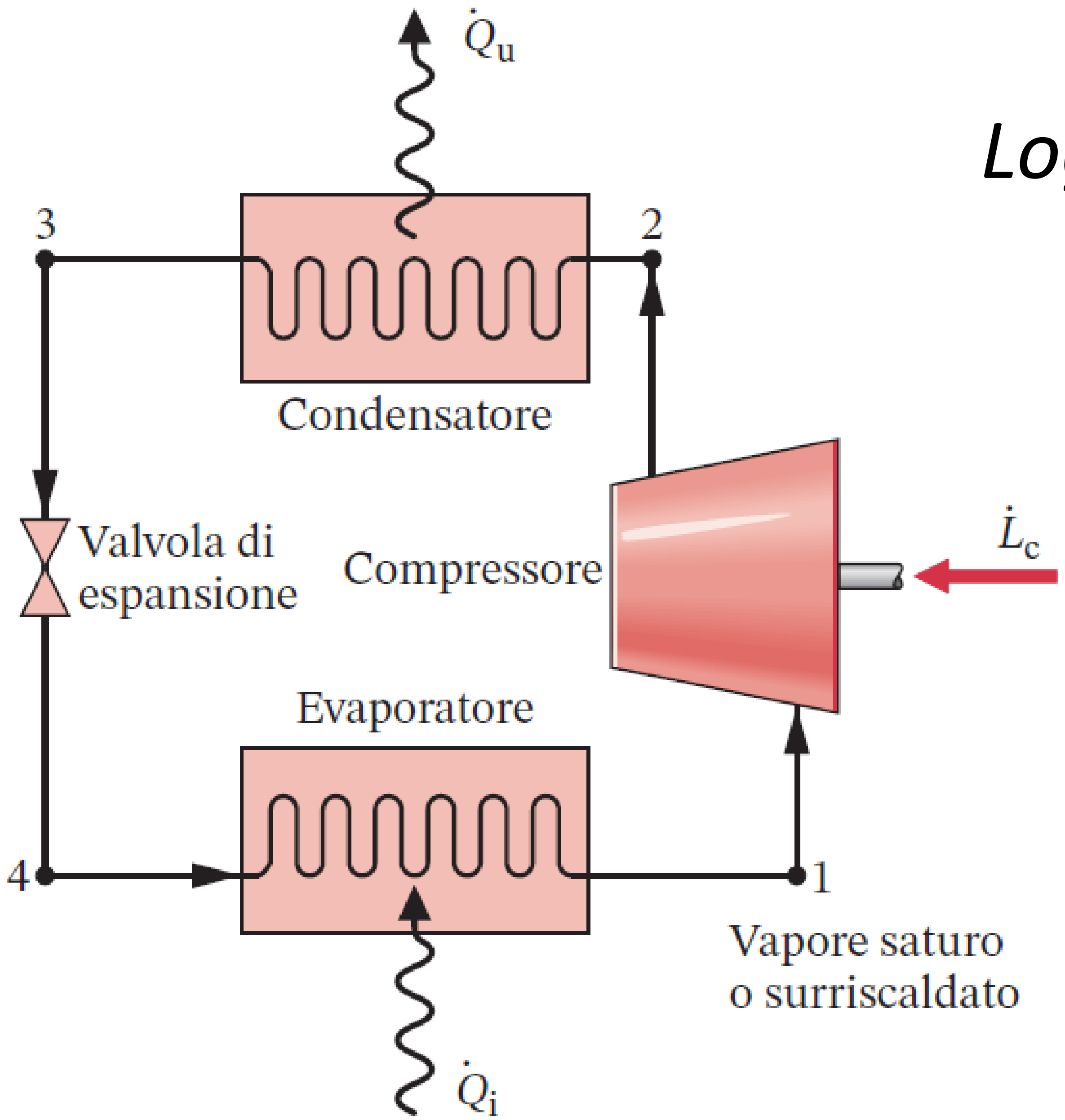


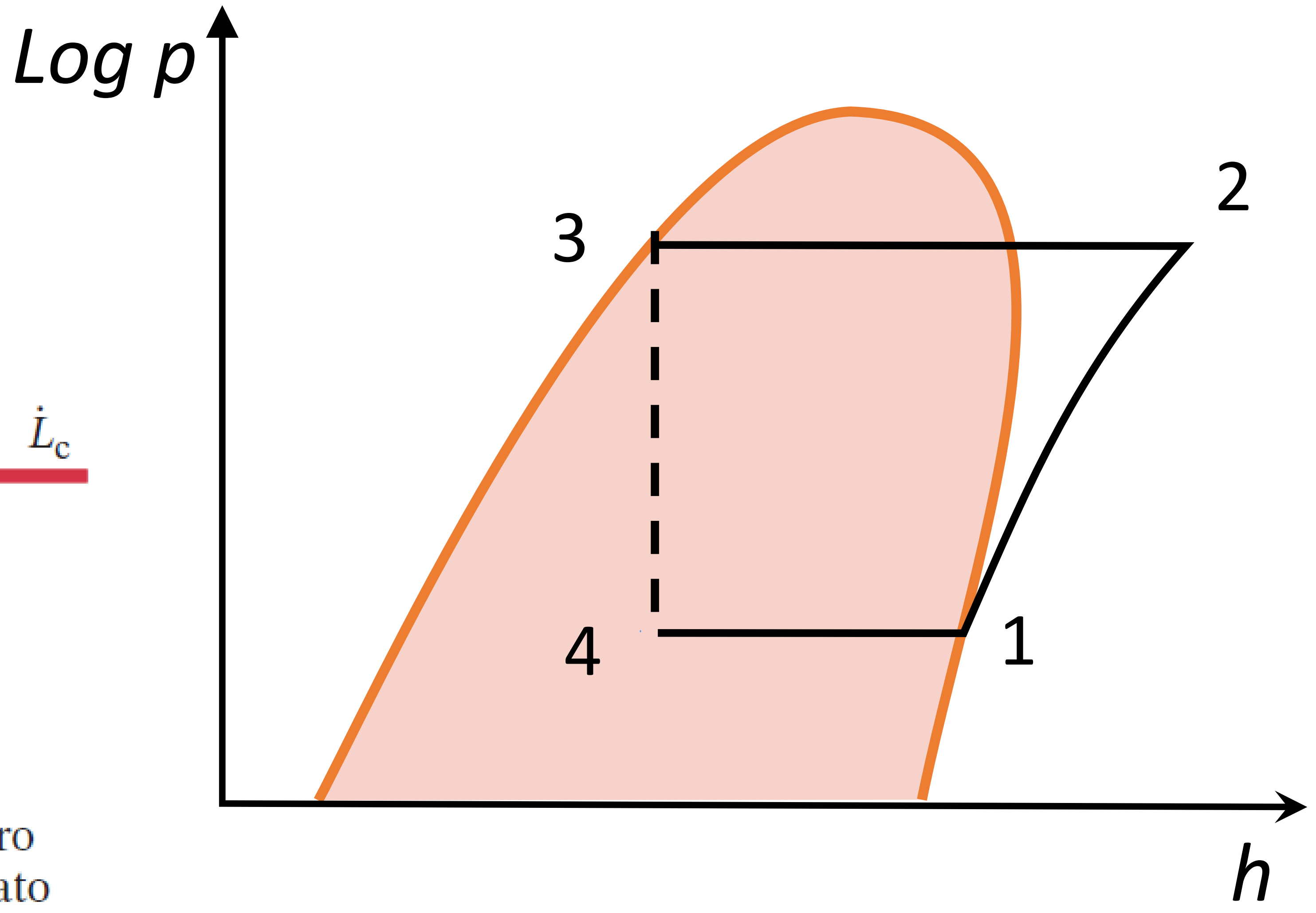


Ideal compression system

All reverible transformations, but expansion 3 – 4

Ideal vapor compression cycle – p-h

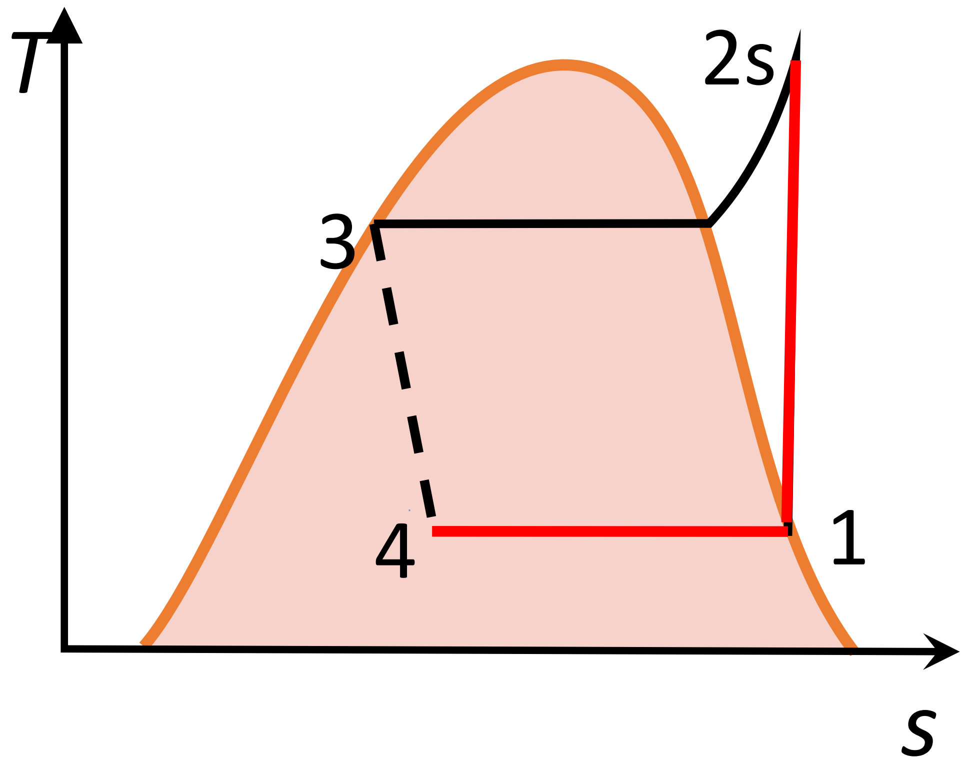


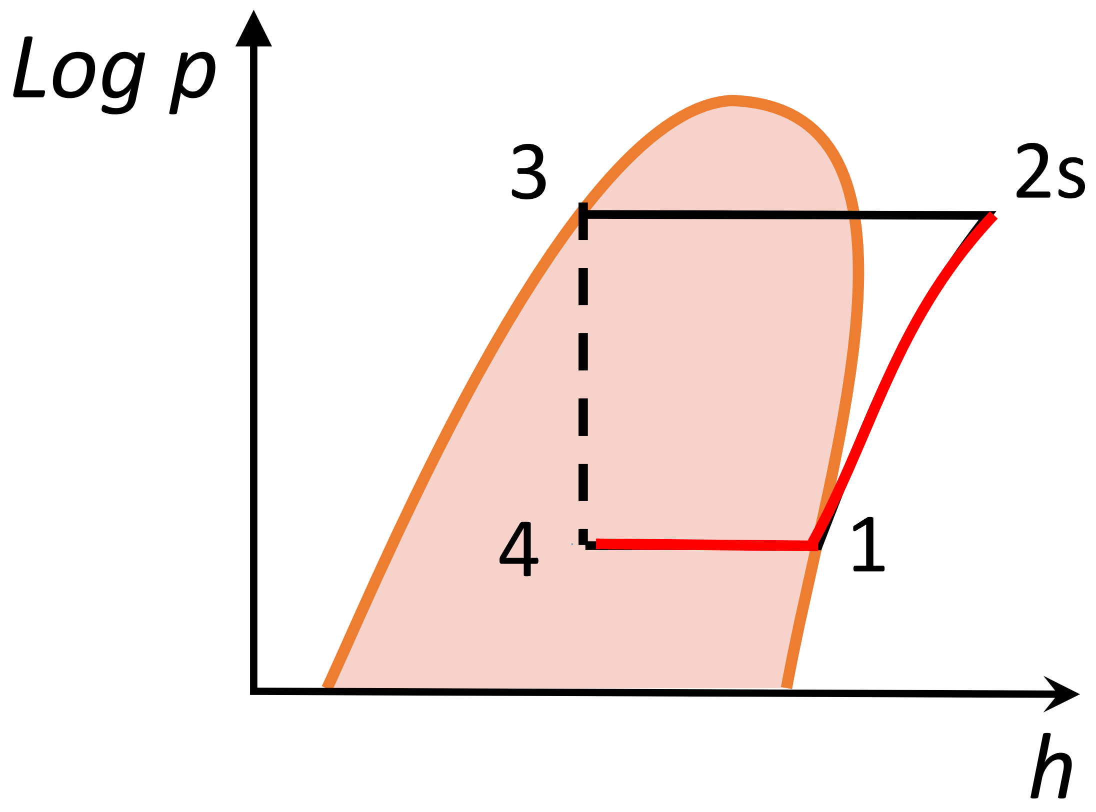


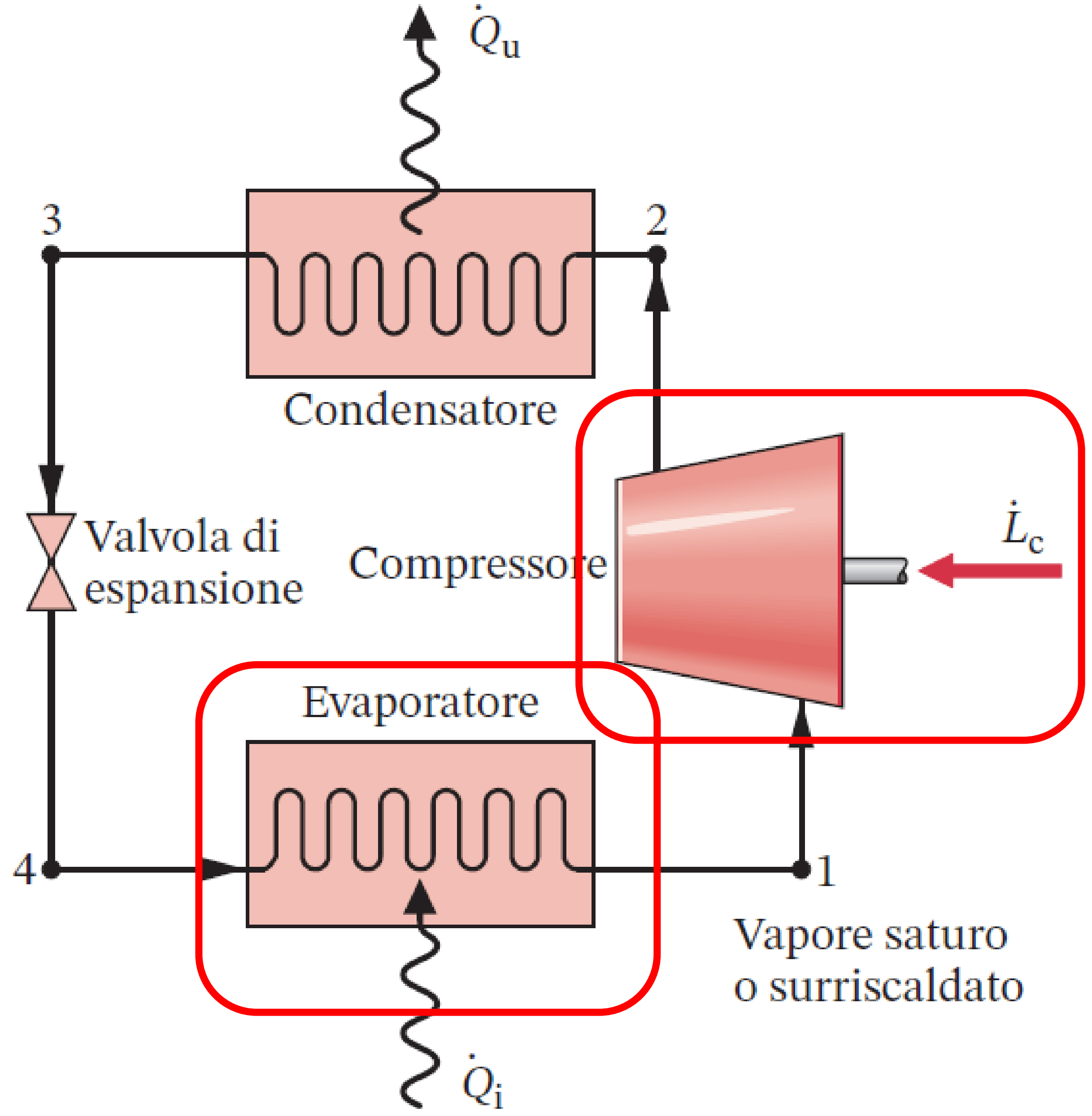
Ideal compression system

All reverible transformations, but expansion 3 – 4

Coefficient Of Performance





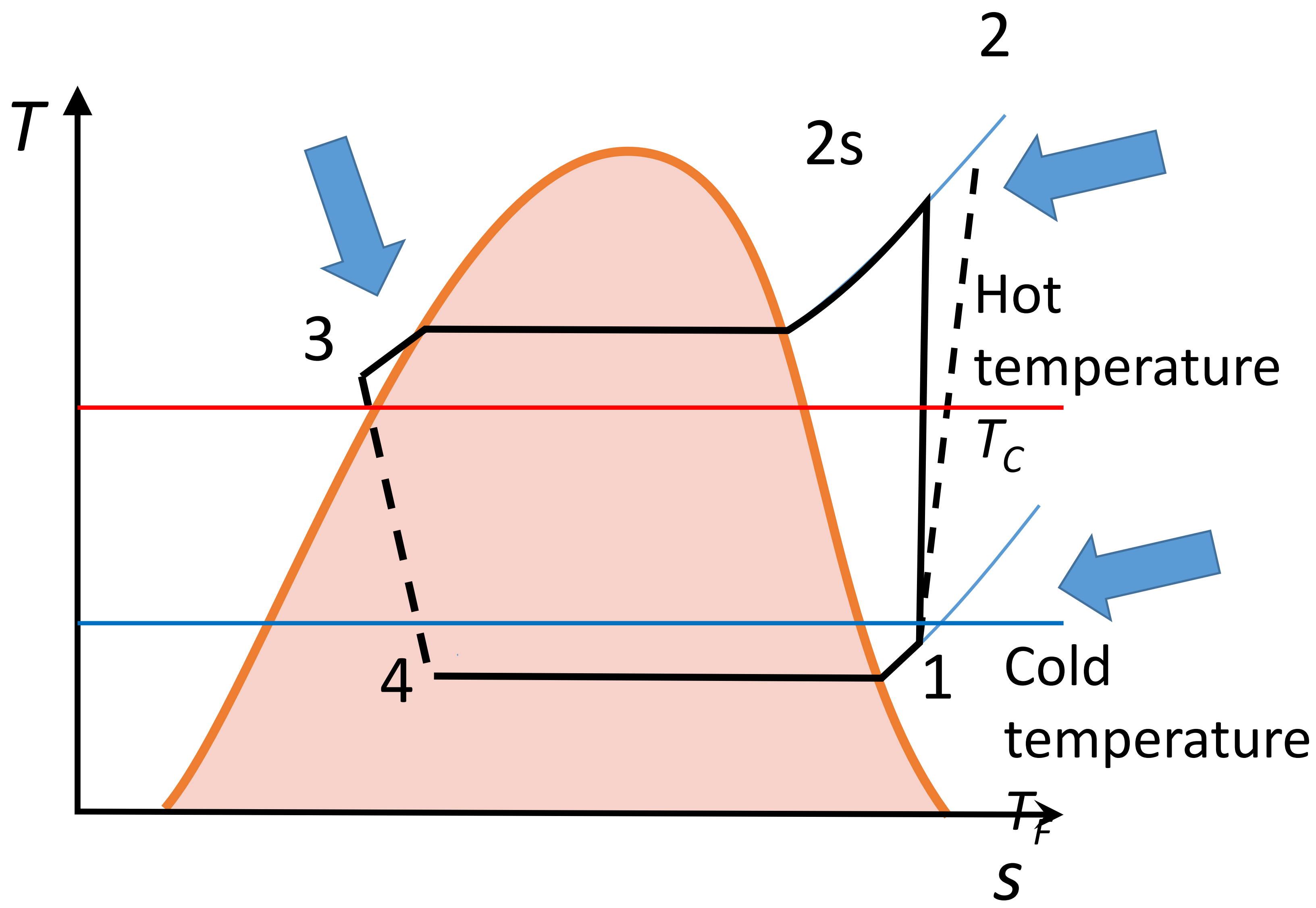


$$COP = \frac{\dot{Q}_E^{+}/\dot{m}}{\left|\dot{L}_C^{-}/\dot{m}\right|} = \frac{h_1 - h_4}{h_2 - h_1}$$

COP= Coefficient of performance

EER=energy efficiency ratio

Real vapor compression cycle

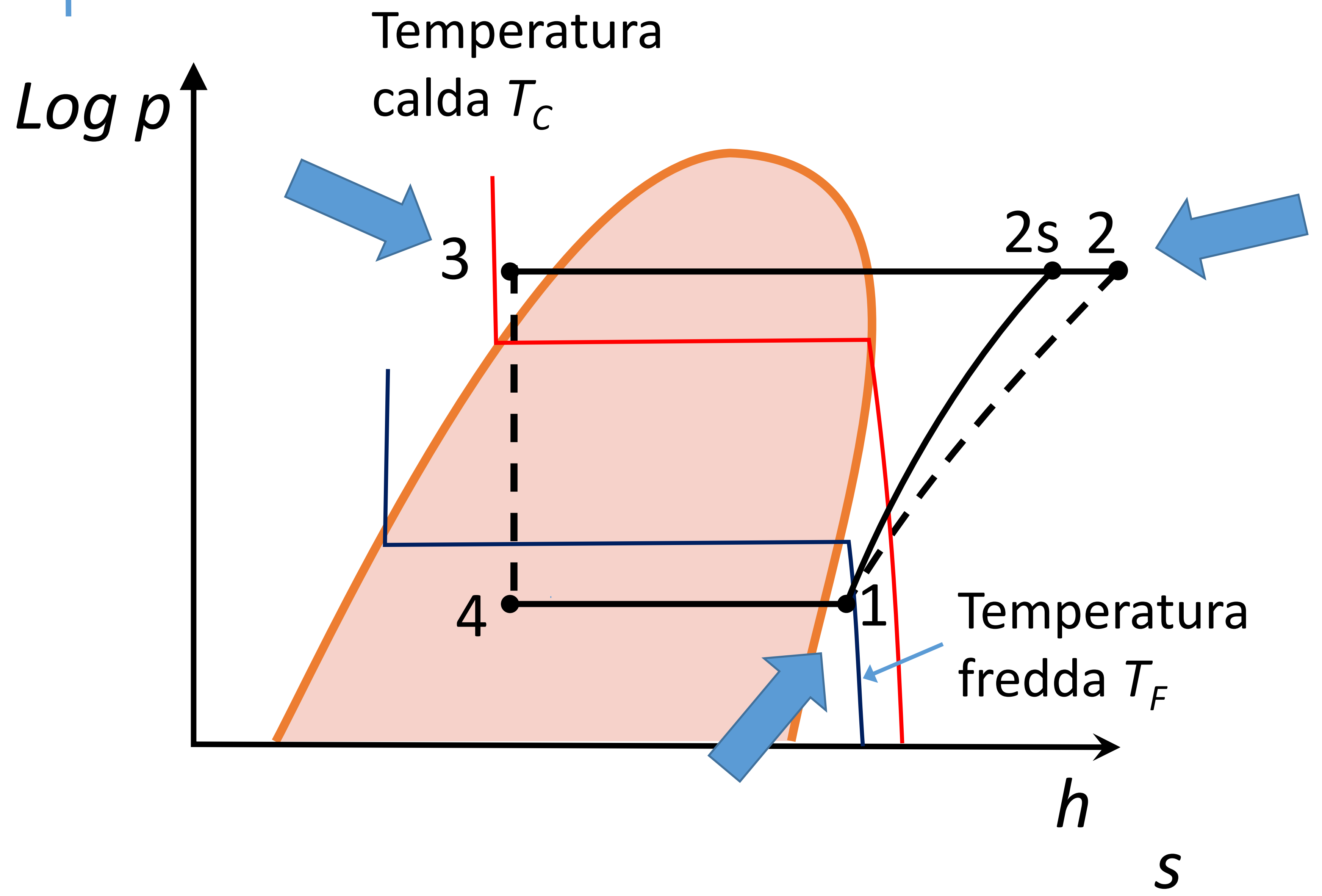


- Heat exchange under finite temperature differences
- Irreversibility in the compression process
- Exit from the evaporator (1) as superheated vapor
- Exit from the condenser (3) as subcooled liquid

$$\text{COP}=\frac{\dot{Q}_E^{+}/\dot{m}}{|\dot{L}_C^{-}/\dot{m}|}=\frac{h_1-h_4}{h_2-h_1}$$

$$\eta_c=\frac{(\dot{L}_c/\dot{m})_s}{\dot{L}_c/\dot{m}}=\frac{h_{2s}-h_1}{h_2-h_1}$$

Real vapor compression cycle

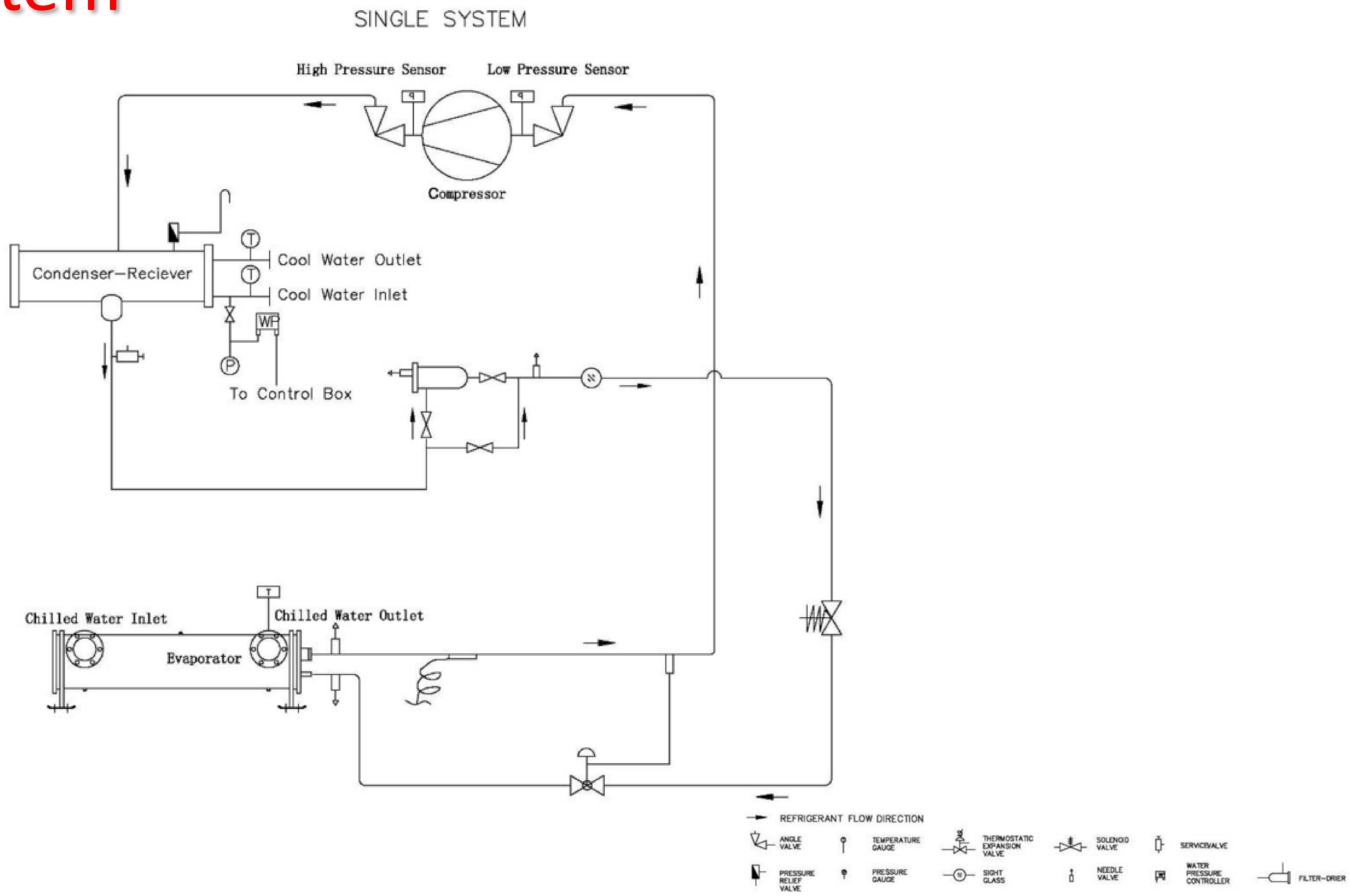


- Scambi termici sotto differenze finite di temperature
- Irreversibilità nel processo di compressione
- Uscita dall'evaporatore (1) in uno stato di vapore surriscaldato
- Uscita dal condensatore (3) in uno stato di liquido sottoraffreddato

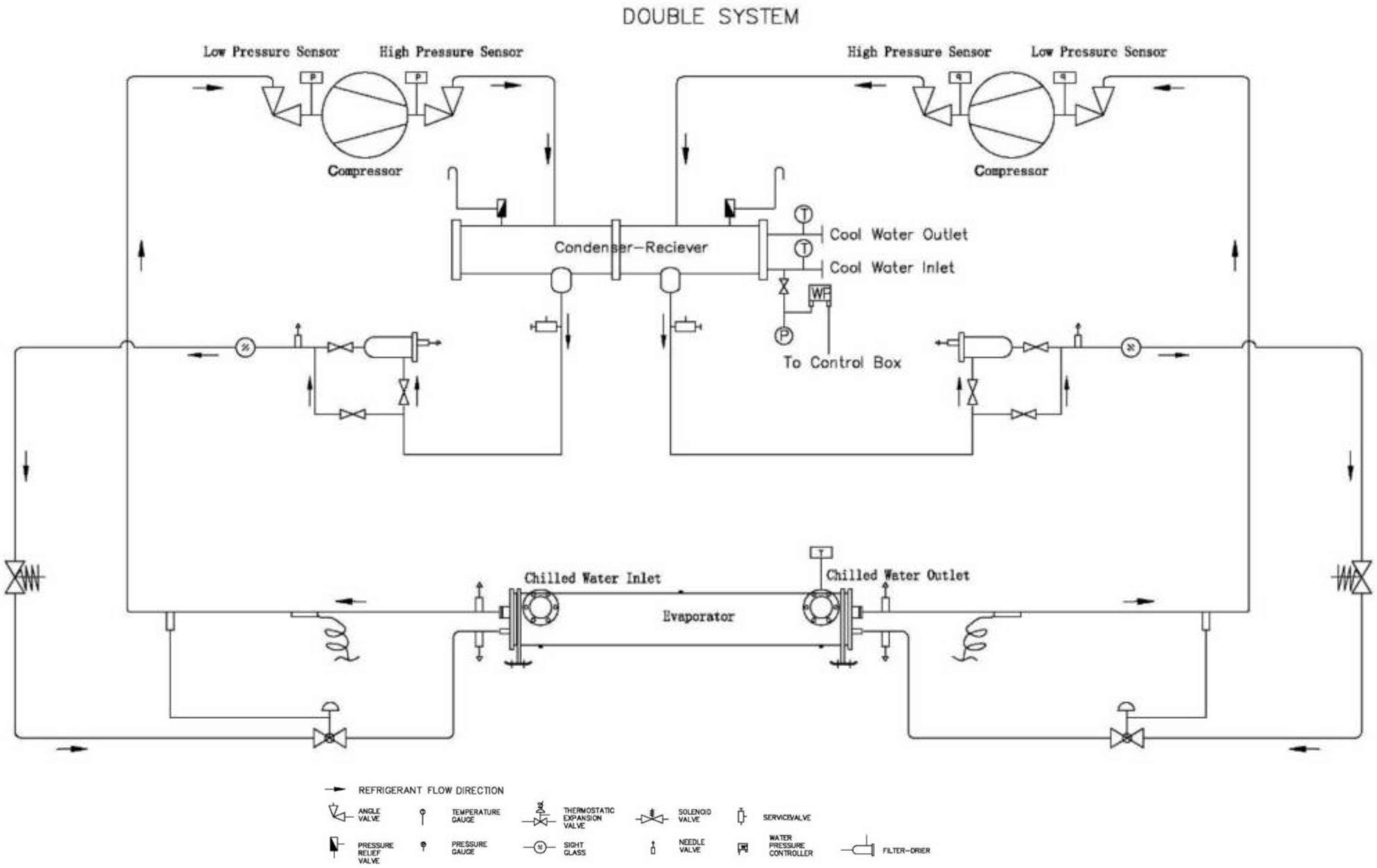
$$\text{COP}=\frac{\dot{Q}_E^+/\dot{m}}{|\dot{L}_C^-/\dot{m}|}=\frac{h_1-h_4}{h_2-h_1}$$

$$\eta_c=\frac{(\dot{L}_c/\dot{m})_s}{\dot{L}_c/\dot{m}}=\frac{h_{2s}-h_1}{h_2-h_1}$$

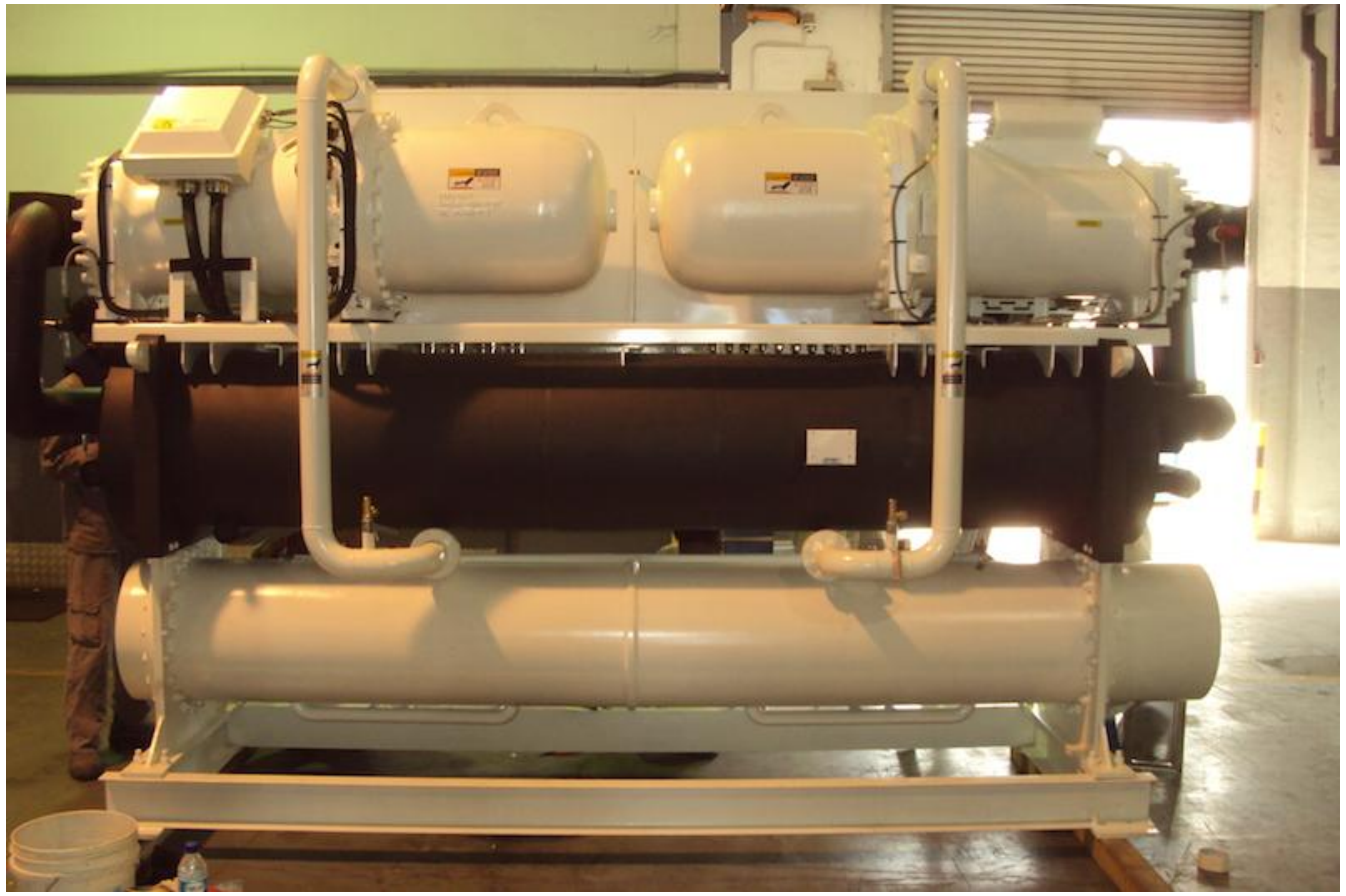
chiller single system



Dual system

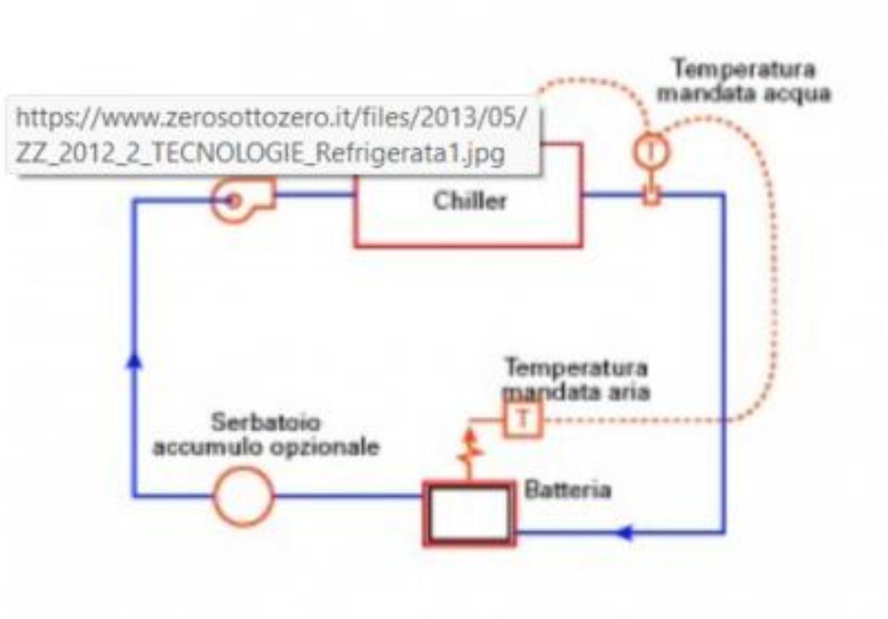

DOUBLE SYSTEM
Low Pressure Sensor
High Pressure Sensor
High Pressure Sensor
Low Pressure Sensor
Compressor
Compressor
Condenser–Reciever
Cool Water Outlet
Cool Water Inlet
WF
To Control Box
Chilled Water Inlet
Chilled Water Outlet
Evaporator
REFRIGERANT FLOW DIRECTION
ANGLE VALVE
TEMPERATURE GAUGE
THERMOSTATIC EXPANSION VALVE
SOLENOID VALVE
SERVICEVALVE
PRESSURE RELIEF VALVE
PRESSURE GAUGE
SIGHT GLASS
NEEDLE VALVE
WATER PRESSURE CONTROLLER
FILTER–DRIER

Chiller

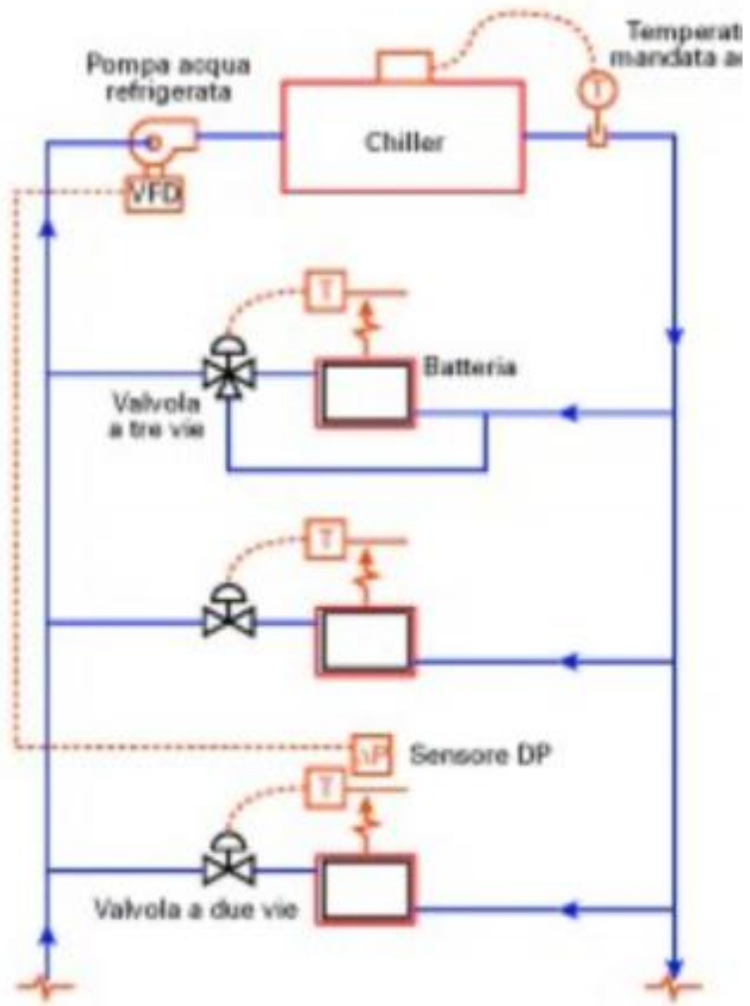


distribution

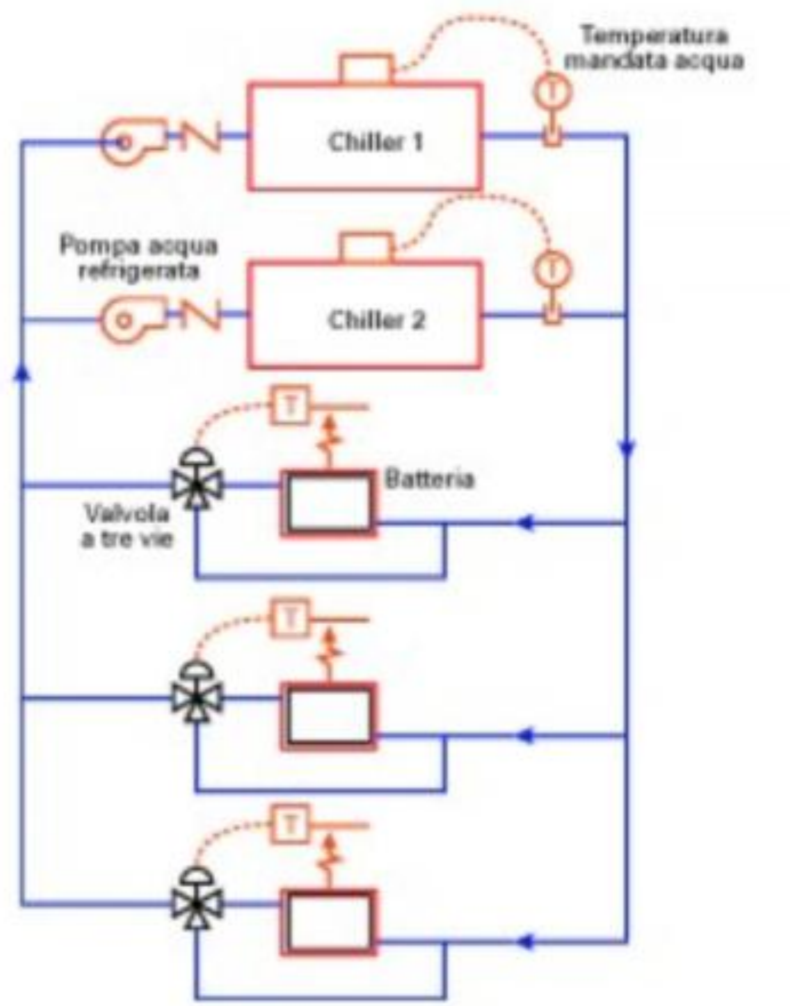
Only one loop



One loop and one chiller

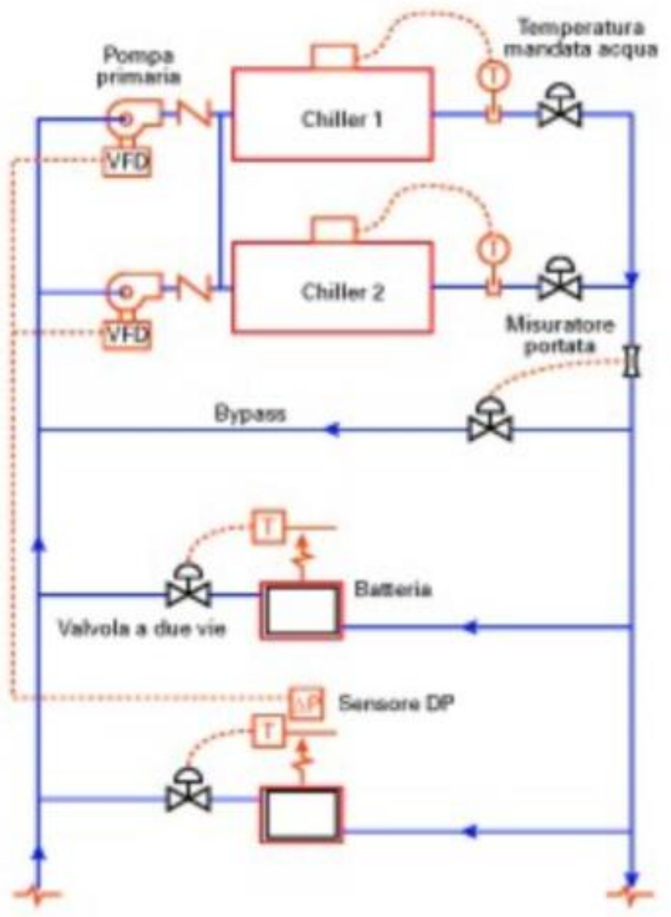


Primary and multiple chillers

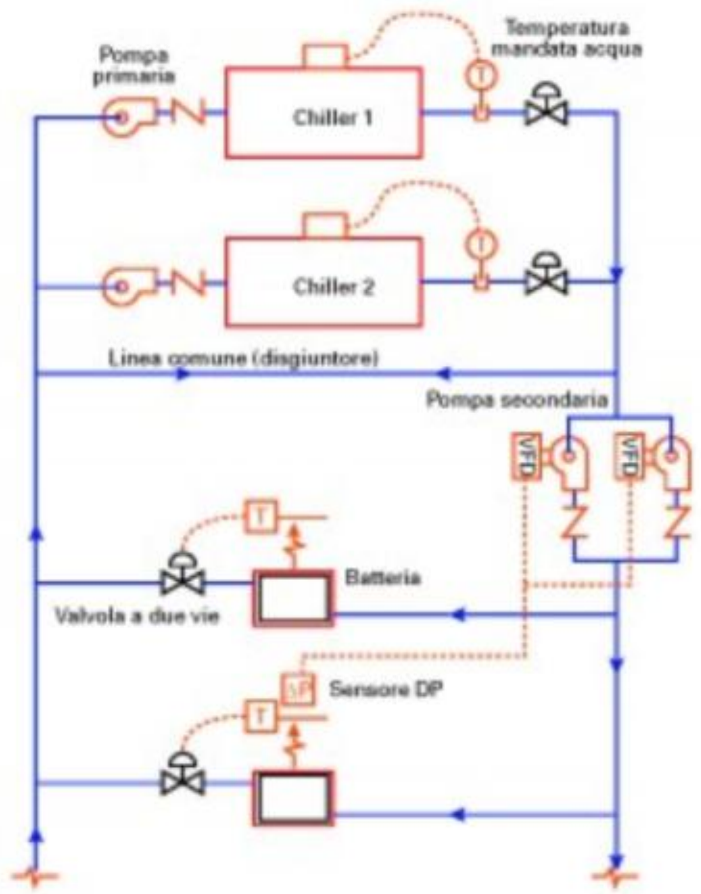


distribuzione

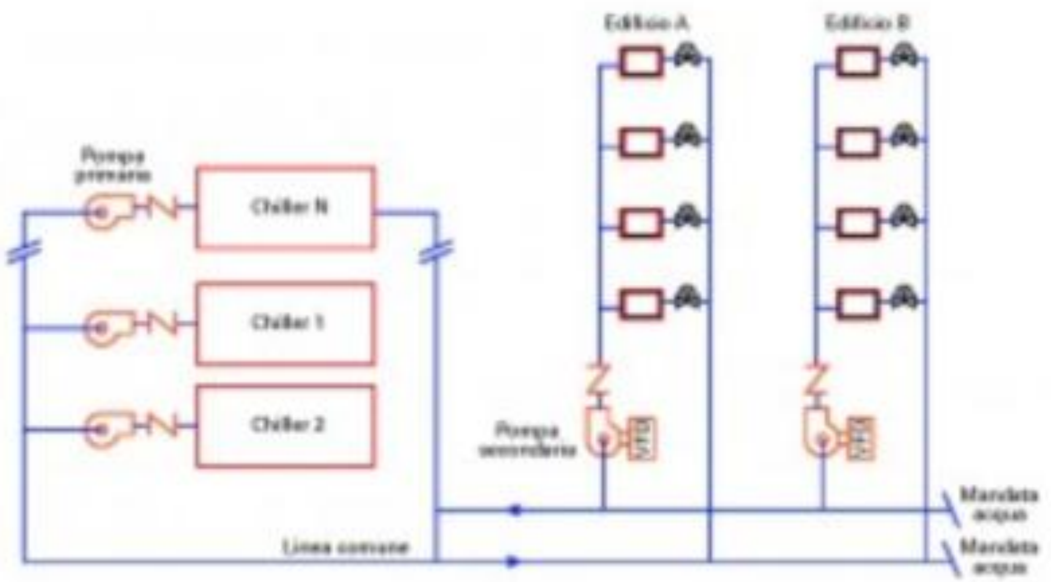
Primary circuit and v ariable flow



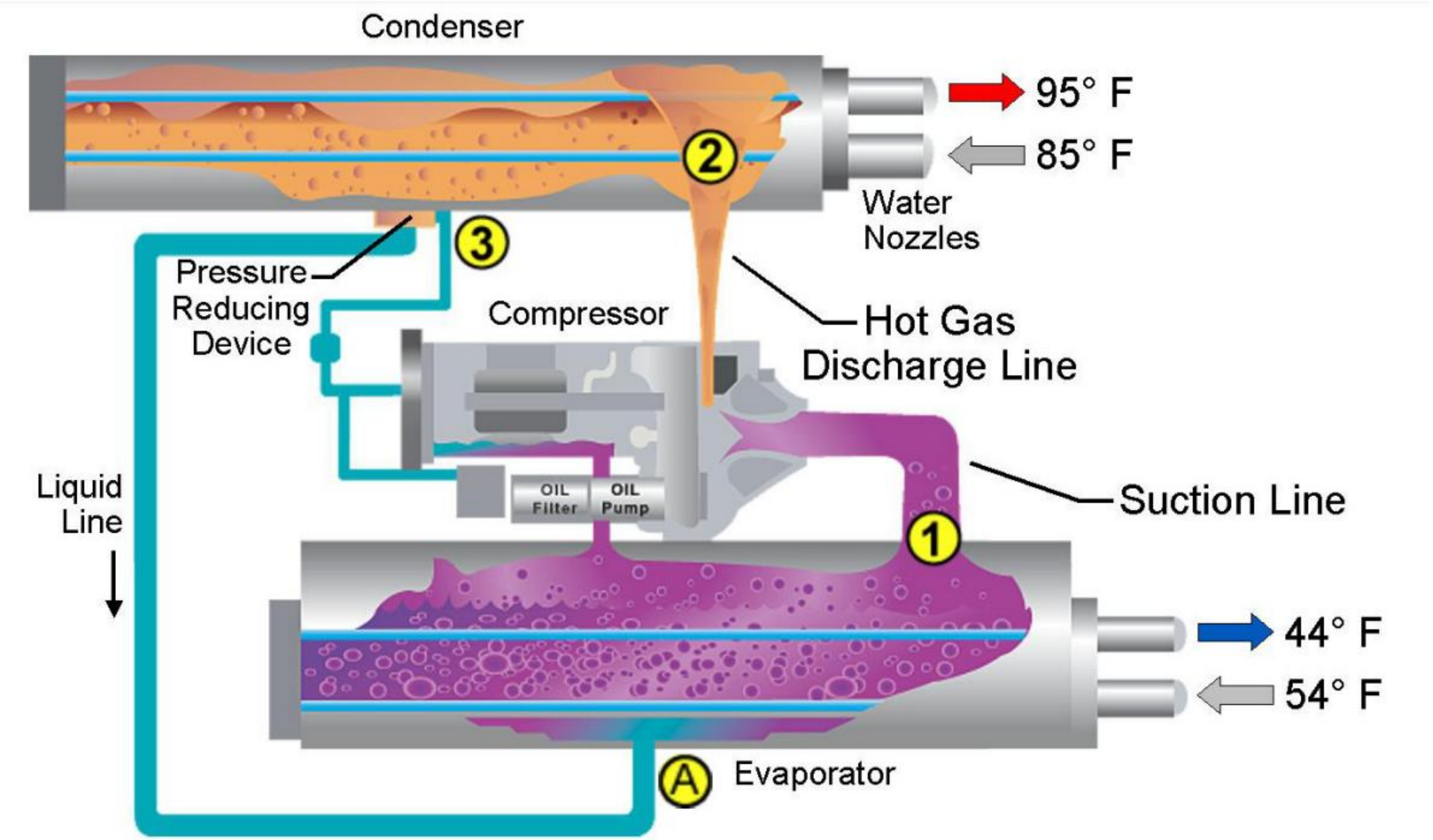
Primary and secondary circuits



Secondary distributiona

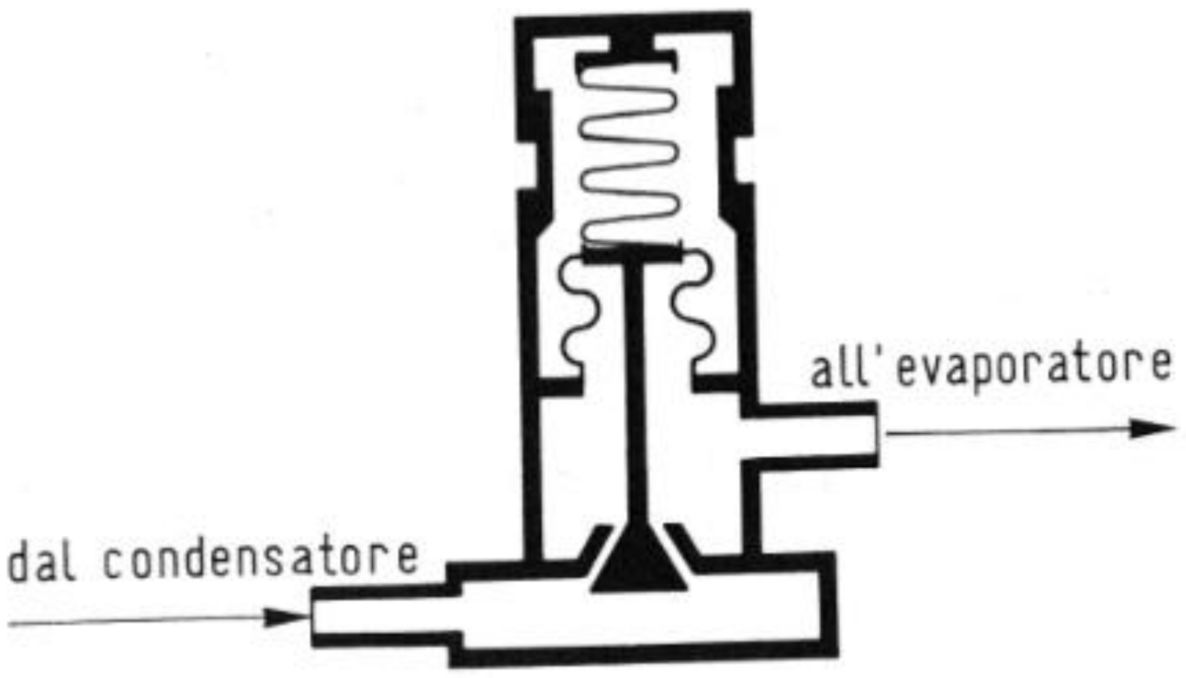


Water cooled chiller

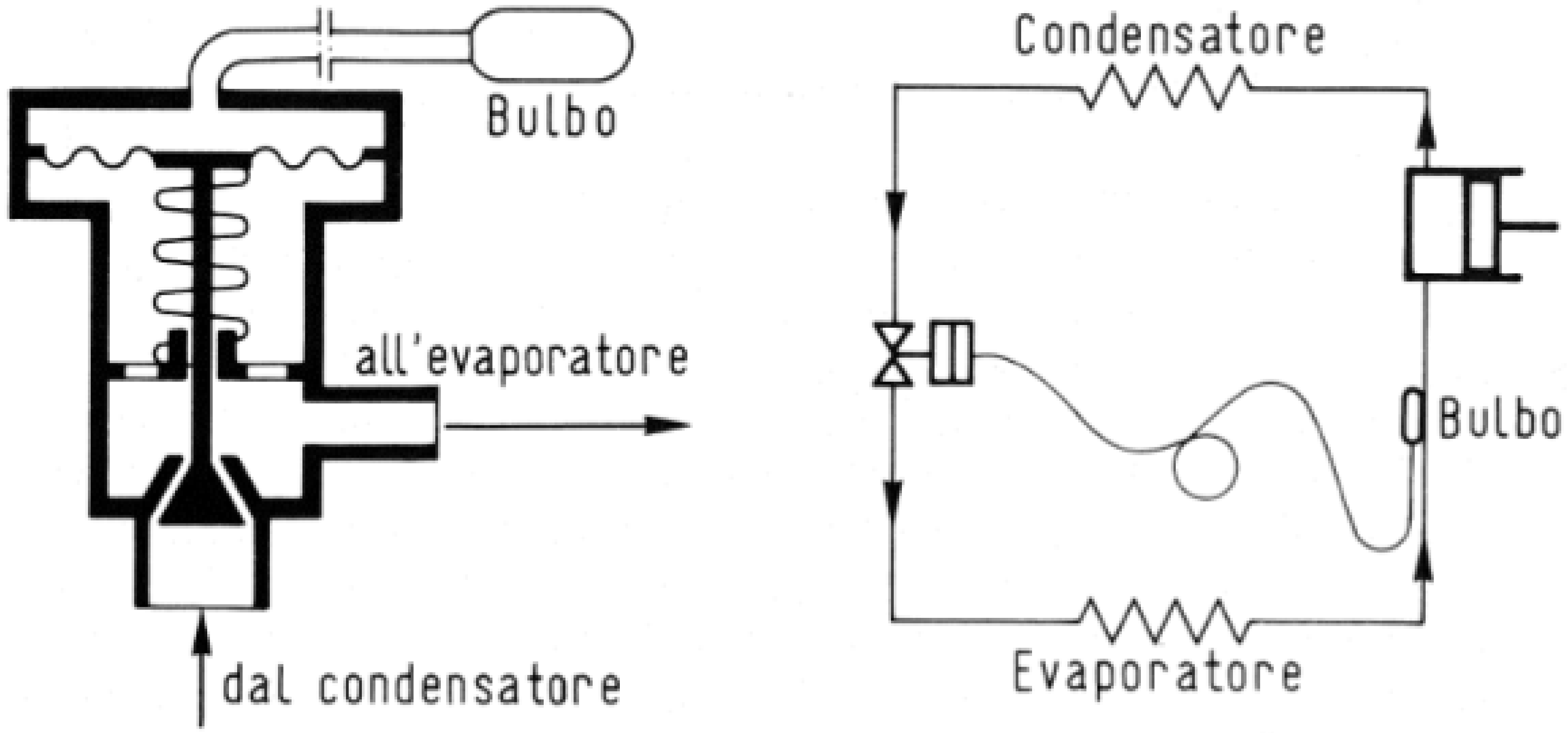


Thermal expansion valve

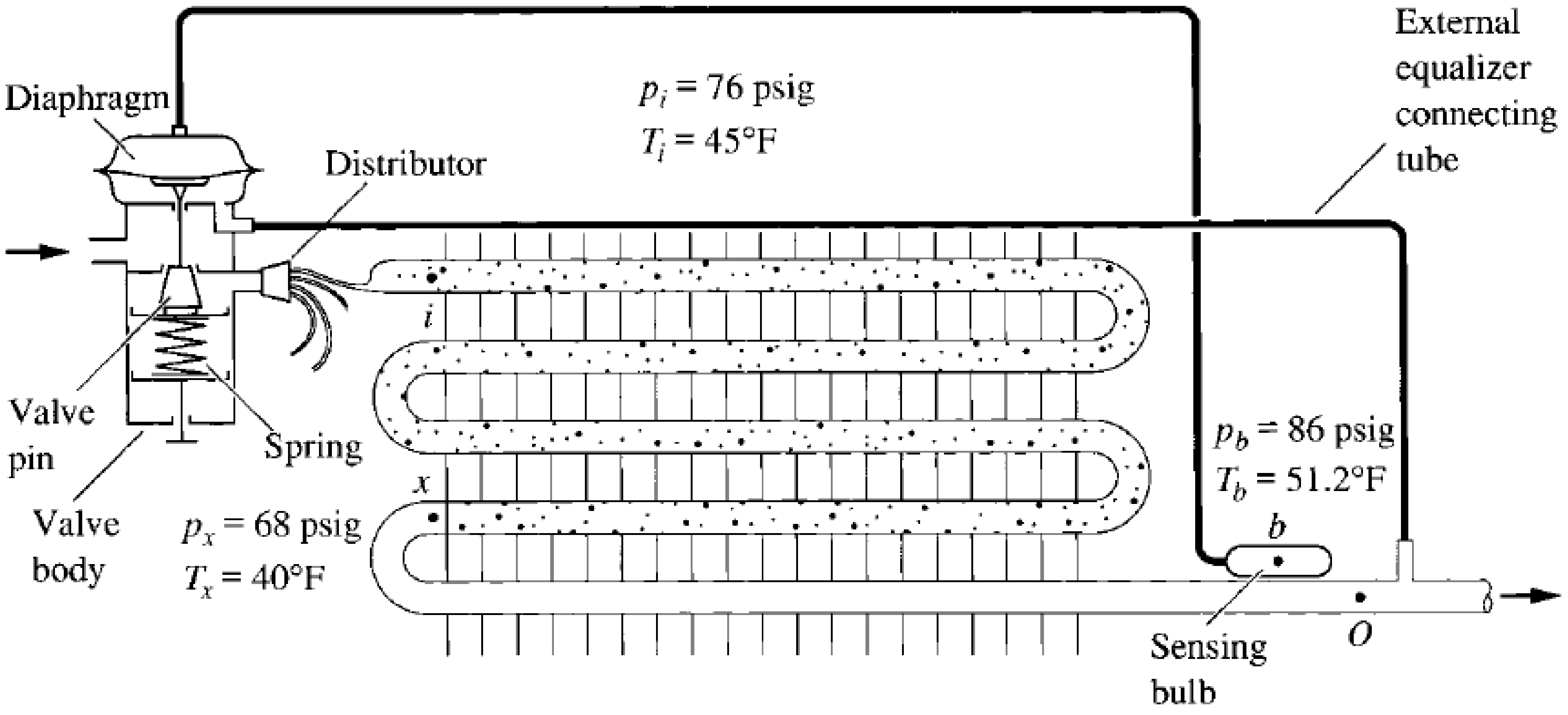
Constant pressure valve



Thermostatic valve



Thermostatic expansion valve



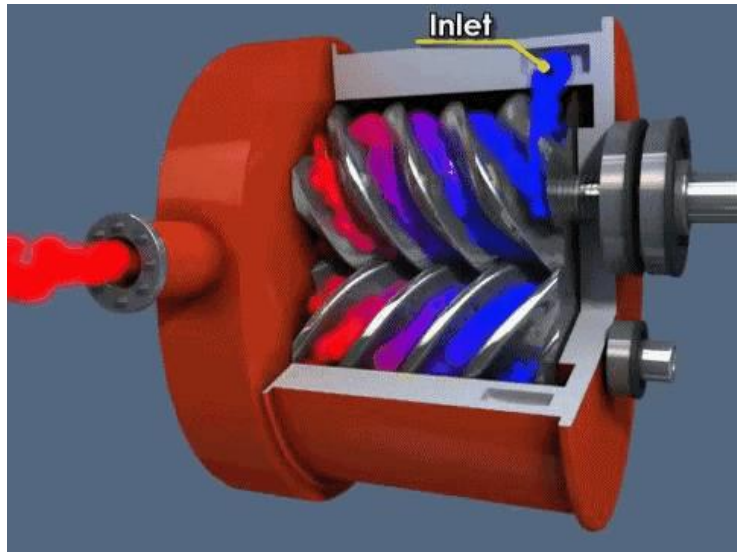
Compressors

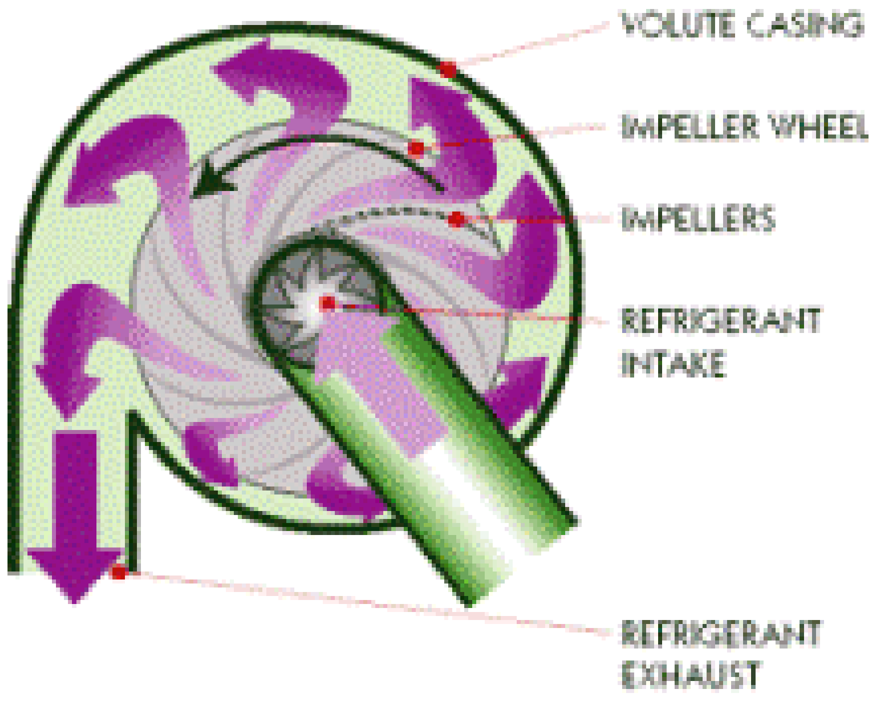
<table>
<tr><td rowspan="8">Volumetric compressors</td><td rowspan="3">Alternating</td><td colspan="2">Open</td></tr>
<tr><td colspan="2">Ermetic</td></tr>
<tr><td colspan="2">Semiermetic</td></tr>
<tr><td rowspan="5">Rotational</td><td>Two axes</td><td>Screw</td></tr>
<tr><td rowspan="4">One axis</td><td>piston</td></tr>
<tr><td>rotary</td></tr>
<tr><td>Scroll</td></tr>
<tr><td>Screw</td></tr>
<tr><td>Dynamic compressors</td><td colspan="3">Centrifugal</td></tr>
</table>

Compressors

Type	description
Hermetic	completely sealed away from the environment, with the casing welded shut. It cannot be accessed by any means.
Semi-Hermetic	both the compressor and the motor are fully protected from the environment within a sealed shell. Unlike the hermetic compressor, semi-hermetic models are designed so they can be opened for diagnosis and periodic maintenance
Open	the compressor itself and the motor are not protected from the elements in any way. It is possible to service this kind of compressor,but the environment must be carefully controlled or the compressor will fail due to dirt, debris, chemicals, and other contaminants

Compressors





Refrigerants

fluido	*p.e.n.*[1] *(glide)* [°C]	*temp. critica* [°C]	ODP	*vita media atmosferica* [anni]	GWP $CO_2 = 1$ 100 anni	gruppo sicurezza ASHRAE
R12	-29,8	112,0	0,9	102	10300	A1
R22	-40,8	96,2	0,05	12	1780	A1
R32	-51,7	78,1	0	5,4	704	A2L
R1234yf	-29,5	94,7	0	10,5 giorni	<1	A2L
R1234ze(E)	-19,0	109,4	0	16,4 giorni	<1	A2L
R1233zd(E)	18,3	166,5	0.00034	26 giorni	1	A1
R134a	-26,1	101,1	0	14	1360	A1
R152a	-24,0	113,3	0	1,6	148	A2
R290	-42,1	96,8	0	12,5 giorni	<1	A3
R600a	-11,7	135,0	0	6,0 giorni	<1	A3
R717	-33,3	132,3	0	1	<1	B2L
R744	-78,5 p. triplo -56,6	31,0	0	>50	1	A1
R404A R125/143a/134a (44/52/4)	-46,2 (0,8)	72,1	0	31/51/14	4200	A1
R407C R32/125/134a (23/25/52)	-43,6 (7,0)	86,1	0	5,4/31/14	1530	A1
R410A R32/125 (50/50)	-51,4 (0,08)	71,3	0	5,4/31	2100	A1
R507A R125/143a (50/50)	-46,7	70,6	0	31/51	4300	A1

[1] Per le miscele zeotropiche, il punto di ebollizione normale è stato convenzionalmente assimilato alla temperatura di bolla.

ASHRAE classification

Alta infiammabilità: ***LFL*** **≤ 0,10 kg/m³ a 23°C e 101 kPa**[2] **(or)**[1] **calore di combustione ≥ 19000 kJ/kg**	A3	B3
Moderata infiammabilità: ***LFL*** **> 0,10 kg/m³ a 23°C e 101 kPa**[2] **(and)**[1] **calore di combustione < 19000 kJ/kg**	A2	B2
Moderata infiammabilità: **come per classe 2, ma con inoltre velocità di avanzamento della fiamma <10 cm/s a 23 °C e 101 kPa**	A2L	B2L
Non propaga la fiamma a 60°C e 101 kPa	A1	B1
	Bassa tossicità: TLV-TWA ≥ 400 ppm	Alta tossicità: TLV-TWA < 400 ppm

[1] da intendersi come operatori logici
[2] da intendersi come massa di refrigerante per metro cubo di miscela con aria alla pressione e temperatura indicate

LFL Lower Flammability Limit
TLV-TWA Threshold Limit Value- Time Weighted Average, esposizione media per 8/h giorno, 40 h/settimana

Performance of refrigerants -20/+30 °C

fluido	*p. cond.* [bar]	*p. evap.* [bar]	*COP* [-]	Q_{ov} [kJ/m³]	t_{fc} [°C]
R12	7,44	1,51	4,06	1044	39,3
R22	11,9	2,45	4,03	1731	56,4
R32	19,3	4,06	3,90	2841	74,4
R134a	7,70	1,33	3,97	983	37,9
R1234yf	7,83	1,51	3,44	957	30,0
R1234ze(E)	5,78	0,97	3,68	706	30,0
R1233zd(E)	1,55	0,18	2,95	177	32,2
R152a	6,90	1,21	4,14	956	49,7
R290	10,8	2,45	3,92	1501	37,6
R600a	4,05	0,722	4,05	530	30,0
R717	11,7	1,90	4,11	1757	110,4
R744	72,1	19,7	2,32	6842	76,3
R404A R125/143a/134a (44/52/4)	14,2	3,02	3,61	1731	36,6
R407C R32/125/134a (23/25/52)	12,7	2,36	3,88	1655	49,4
R410A R32/125 (50/50)	18,9	4,00	3,79	2559	54,1
R507A R125/143a (50/50)	14,6	3,15	3,58	1768	36,0

Nomenclature

- Code + prefix and suffix.
- prefix R (Refrigerant) typology of refrigernat (CFC, HCFC, HFC, HC, HFO)
  - HFO HydroFluoroOlefins
  - HCFO HydroFluoroOlefins
- suffix number with different meanings
  - Pure fluid
  - mixture
  - Organic fluid
  - Inorganic fluid.

Pure fluid

- Two or three digit number
- First digit from the right: number of fluorine atoms
- Second digit n hydrogen atoms + 1
- Third digit number of carbon atoms – 1
- Third digit omitted if equal to 0
- If it contains bromine (halon) suffix followed by B and number of bromine atoms
- Number of chlorine atoms subtract the sum of fluorine, bromine, hydrogen atoms from the numbers of atoms bonded to carbon
- 4 for methane
- 6 for ethane
- Letter to identify isomers

examples

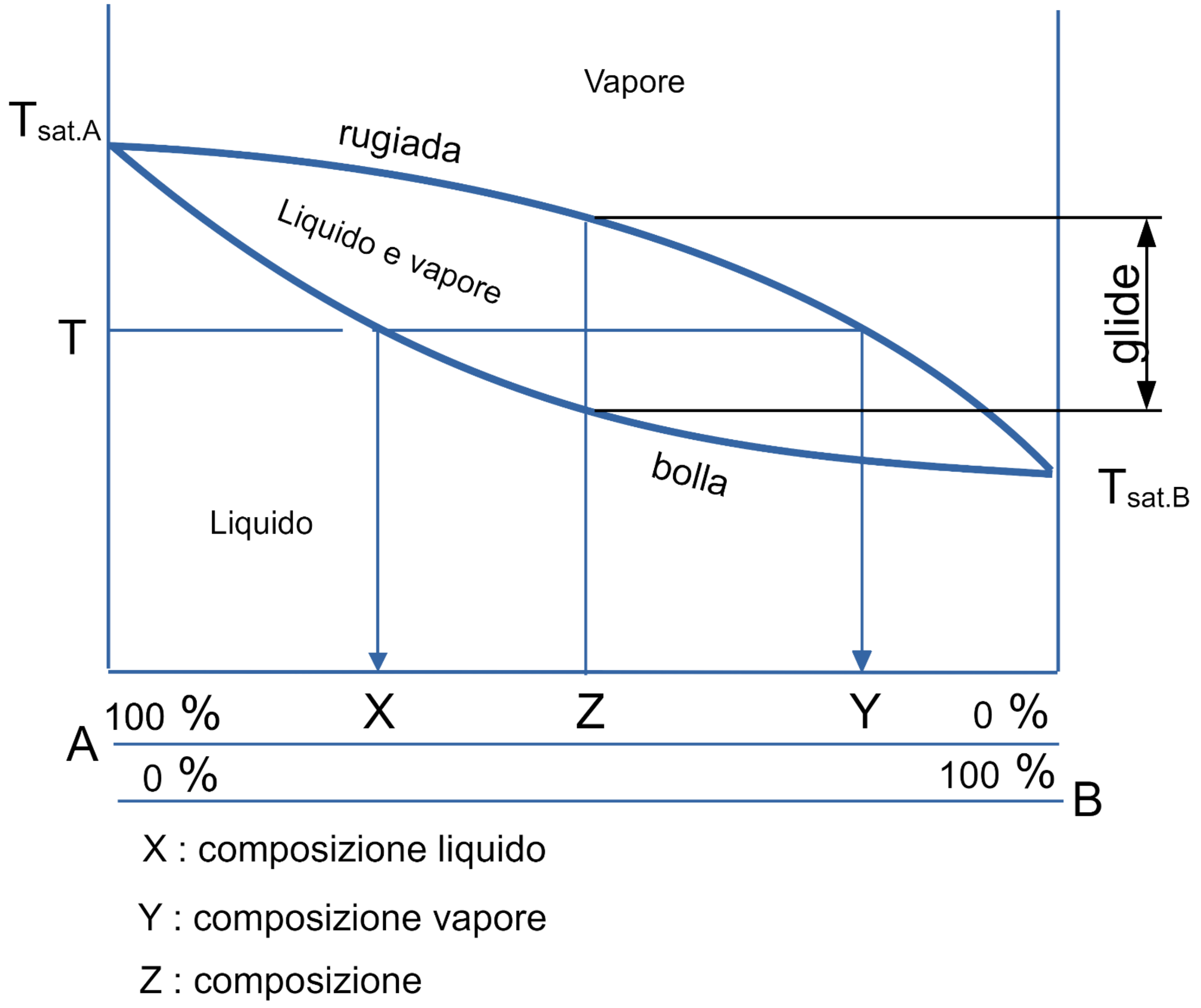
C_2H_6	CH_4	CH_4
R134a	R22 $\Rightarrow$R022	R32 $\Rightarrow$R032
4 atomi F	2 atomi F	2 atomi F
3-1=2 atomi H	2-1=1 atomi H	3-1=2 atomi H
1+1=2 atomi C	0+1=1 atomi C	0+1=1 atomi C
6-4-2 = 0 atomi Cl	4-2-1 = 1 atomi Cl	4-2-2 = 0 atomi Cl
$C_2H_2F_4$ (HFC)	$C\ H\ Cl\ F_2$ (HCFC)	$C\ H_2\ F_2$ (HFC)

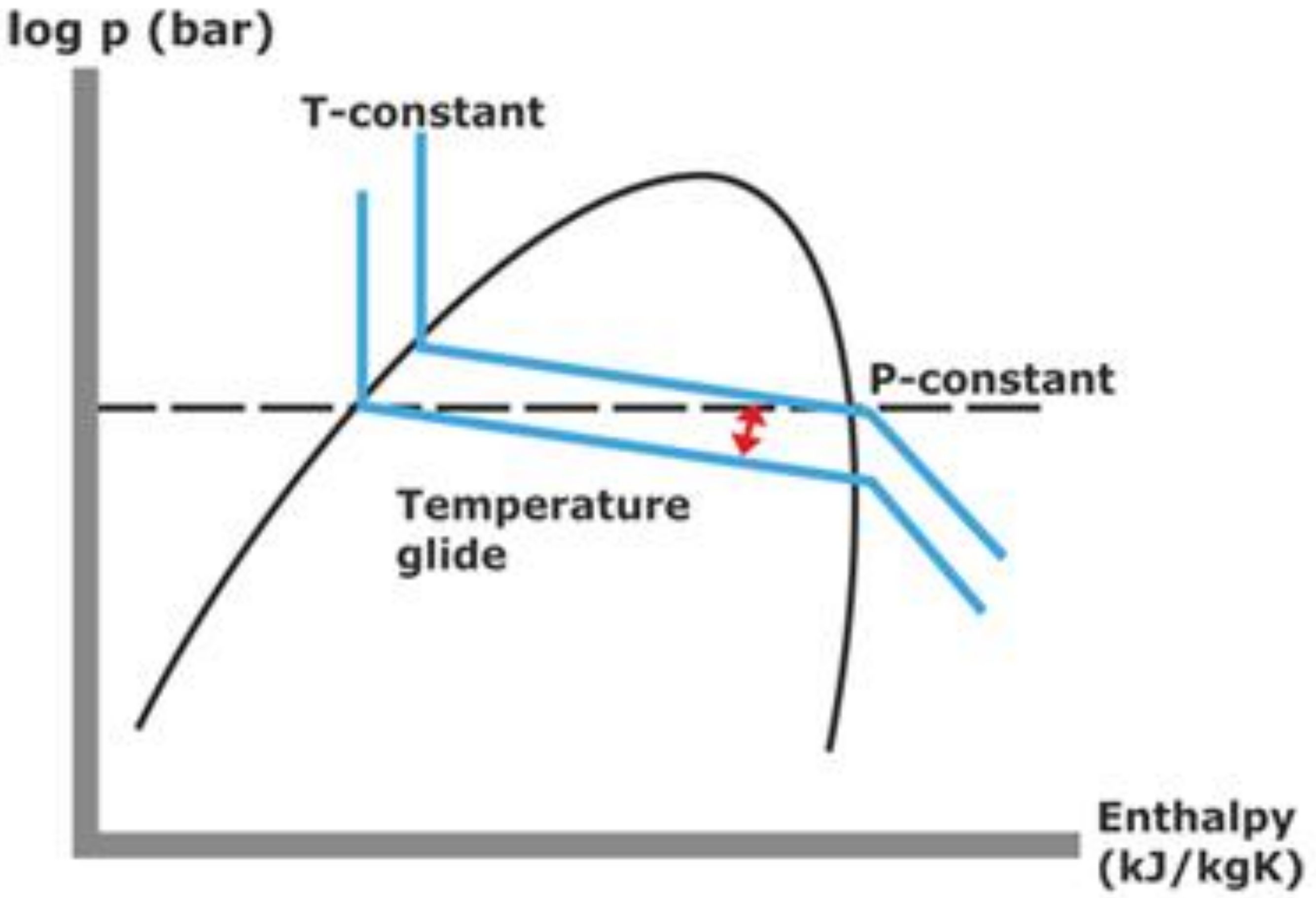
zeotrope e azeotrope mixtures mixture

- Zeotrope mixture: series 400, temperature change during phase change
  - *R404A, R409, R410A, R413A.*
- Azeotrope mixture: series 500. temperature doesn’t change during phase change
  - *R507A; R513A.*
- mixtures composed of the same components, but in different mass percentages, capital letter placed after the suffix

R407A (R32/R125/R134a nelle percentuali 20/40/40)
R407B (R32/R125/R134a nelle percentuali 10/70/20)
R407C (R32/R125/R134a nelle percentuali 23/25/52)
R407D (R32/R125/R134a nelle percentuali 15/15/70)
R407E (R32/R125/R134a nelle percentuali 25/15/60)

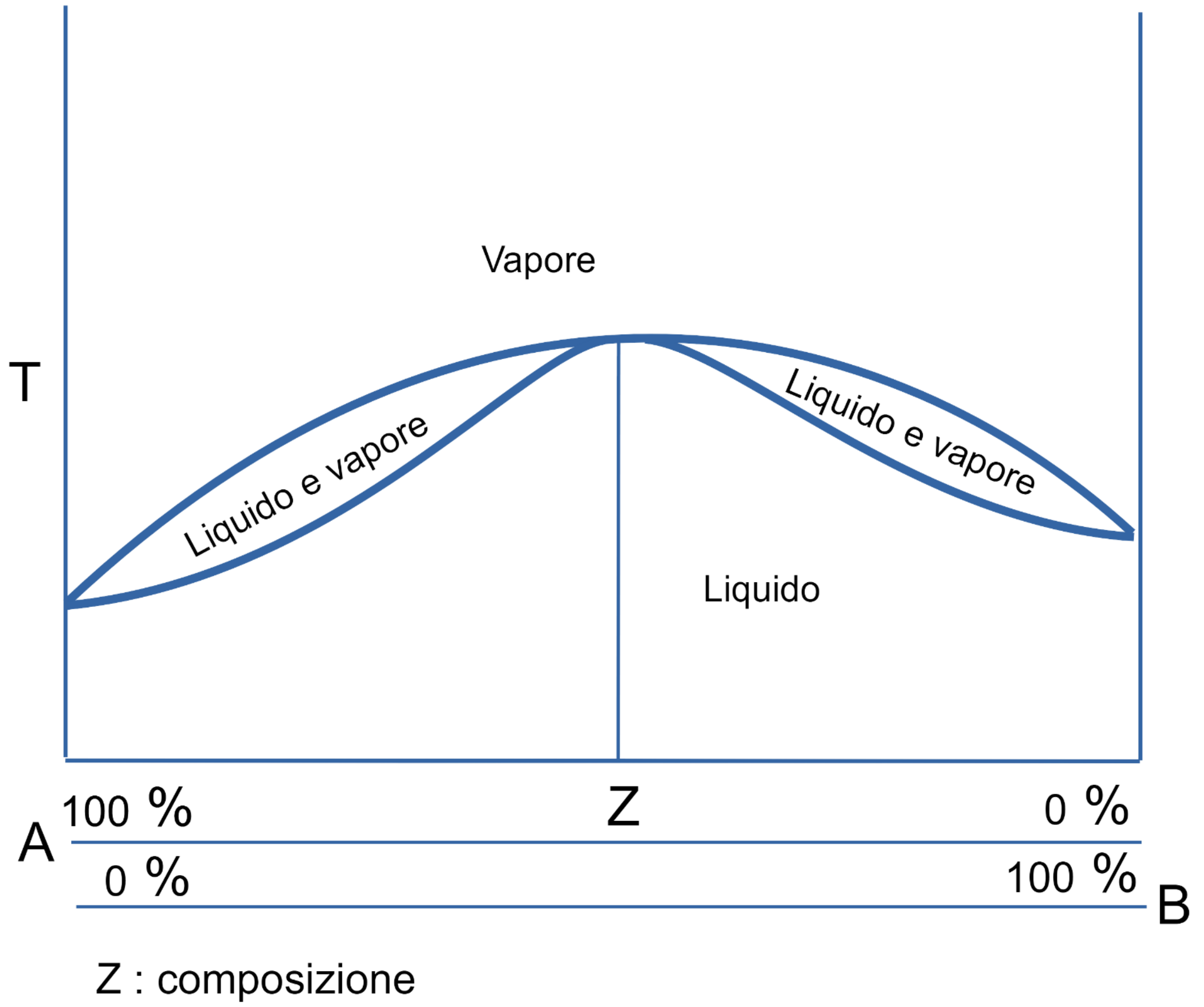
zeotrope mixtures- Glide





azeotrope mixture

- Azeotropic mixtures behave like pure substances
- The behavior occurs for specific compositions
- For other compositions they behave like zeotropic mixtures



Organic fluids

- numero appartenente alla serie 600

R-600	Butano	$CH_3CH_2CH_2CH_3$
R-600a	Isobutano	$CH(CH_3)_2CH_3$
R-601	Pentano	$CH_3CH_2CH_2CH_2CH_3$
R-601a	Isopentano	$(CH_3)_2CHCH_2CH_3$
R-610	Dietil etere	$C_2H_5OC_2H_5$
R-611	Metil formiato	C_2H_4O
R-630	Metilammina	CH_2NH_2
R-631	Etilammina	$C_2H_5NH_2$

Inorganic fluids

- Number of series 700
- After the 7 digit molecular weight
  - acqua R-718
  - azoto N_2 R-728
  - ossigeno O_2 R-732
  - anidride carbonica CO_2 R-744

Regulation EU FGas 2024/573

REGULATION (EU) 2024/573 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014

a) lays down rules on containment, use, recovery, recycling, reclamation and destruction of fluorinated greenhouse gases and on related ancillary measures, such as certification and training, which includes the safe handling of fluorinated greenhouse gases and of alternative substances that are not fluorinated;

b) imposes conditions on the production, import, export, placing on the market, subsequent supply and use of fluorinated greenhouse gases, and of specific products and equipment containing fluorinated greenhouse gases or whose functioning relies upon those gases;

c) imposes conditions on specific uses of fluorinated greenhouse gases;

d) establishes quantitative limits for the placing on the market of hydrofluorocarbons;

e) establishes rules on reporting.

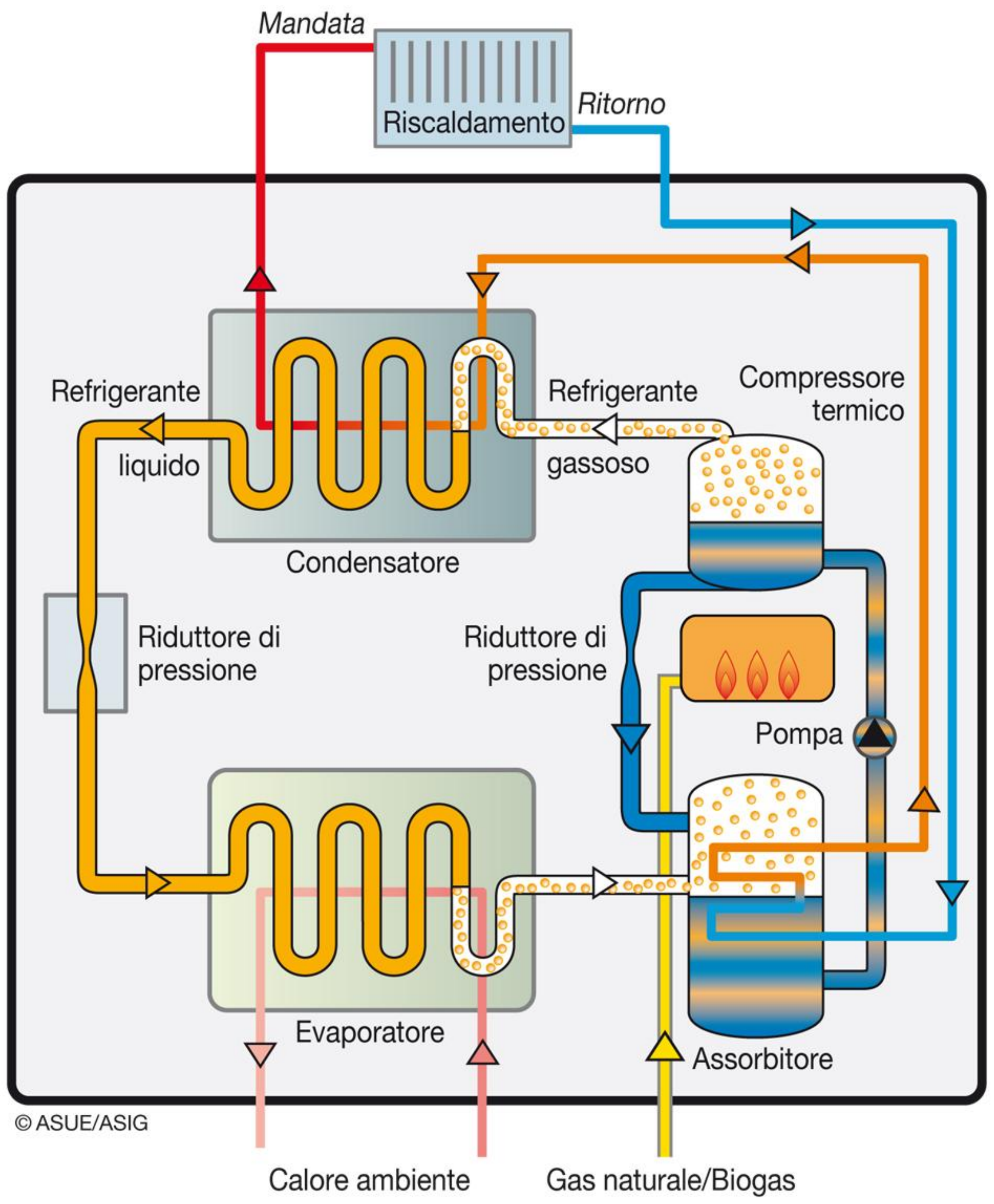
EU FGas 2024/573 prohibition

Products and equipment		Date of prohibition
STATIONARY CHILLERS		
(7) Chillers that contain, or whose functioning relies upon:	(a) HFCs with GWP of 2 500 or more except equipment intended for application designed to cool products to temperatures below – 50 °C;	1 January 2020
	(b) fluorinated greenhouse gases with a GWP of 150 GWP or more for chillers up to and including a rated capacity of 12 kW, except if required to meet safety requirements at the site of operation;	1 January 2027
	(c) fluorinated greenhouse gases for chillers up to and including a rated capacity of 12 kW, except if required to meet safety requirements at the site of operation;	1 January 2032
	(d) fluorinated greenhouse gases with a GWP of 750 for chillers above 12 kW, except if required to meet safety requirements at the site of operation.	1 January 2027

EU FGas 2024/573 prohibition

Products and equipment		Date of prohibition
(9) Split air-conditioning equipment and heat pumps ([1]):	(a) Single split systems, containing less than 3 kg of fluorinated greenhouse gases listed in Annex I, that contain, or whose functioning relies upon, fluorinated greenhouse gases listed in Annex I with GWP of 750 or more;	1 January 2025
	(b) Split air-to-water systems of a rated capacity up to and including 12 kW containing, or whose functioning relies upon, fluorinated greenhouse gases with GWP of 150 or more, except if required to meet safety requirements at the site of operation;	1 January 2027
	(c) Split air-to-air systems of a rated capacity up to and including 12 kW containing, or whose functioning relies upon, fluorinated greenhouse gases with GWP of 150 or more, except if required to meet safety requirements at the site of operation;	1 January 2029
	(d) Split systems of a rated capacity up to and including 12 kW containing, or whose functioning relies upon, fluorinated greenhouse gases, except if required to meet safety requirements at the site of operation;	1 January 2035

Absorption heat pump



Absorption heat pump

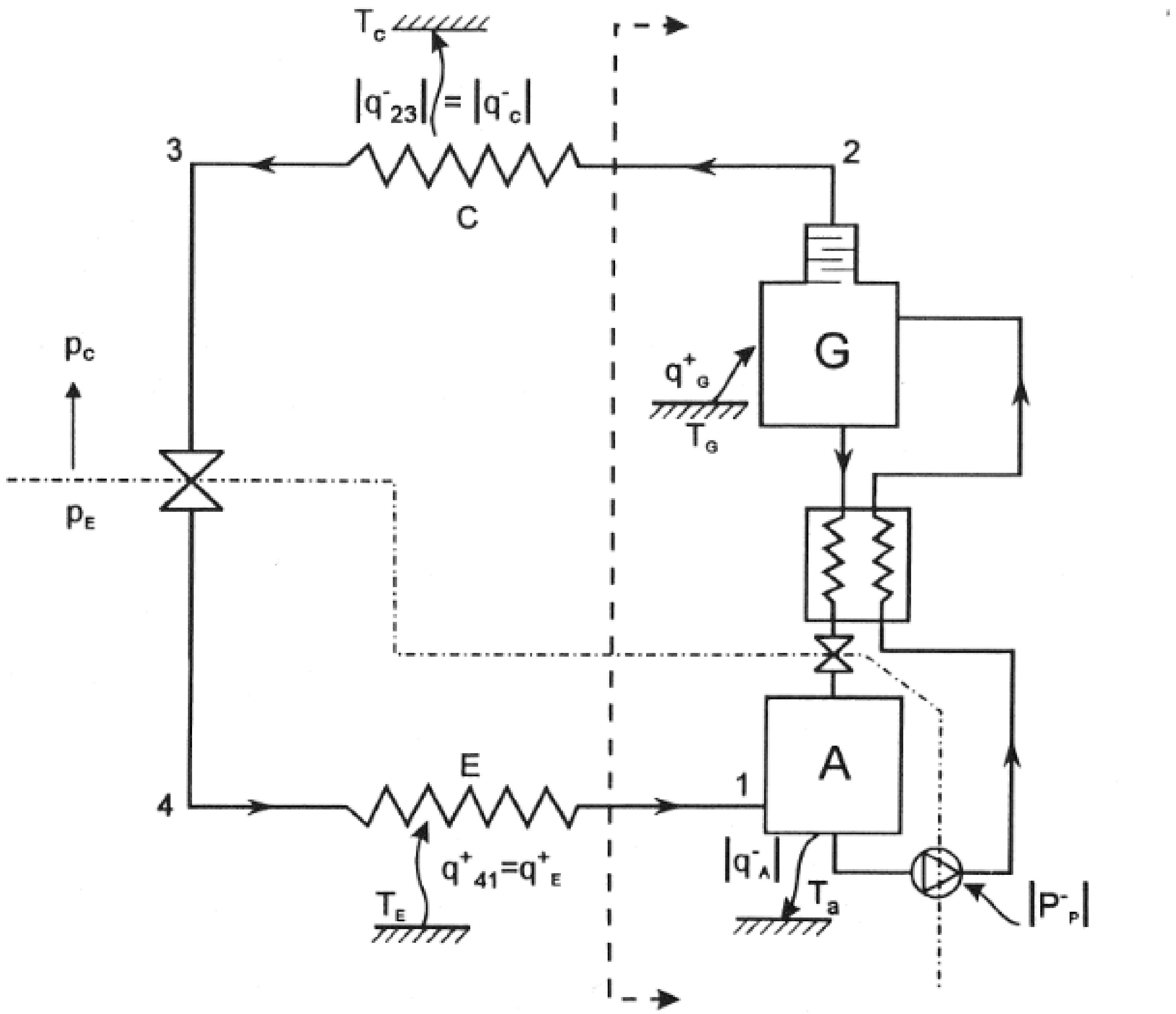
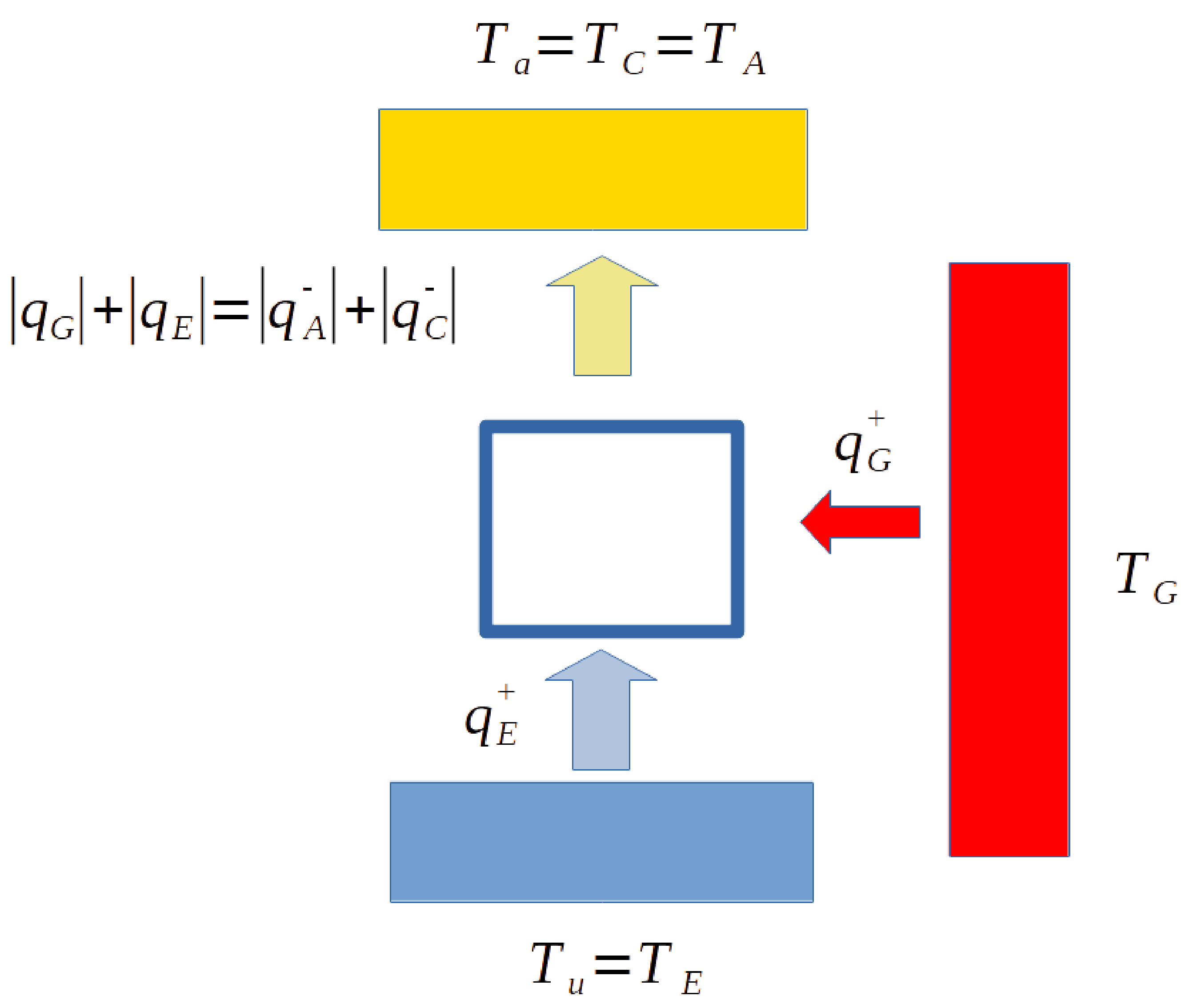


Figura 13.8 Schema funzionale di una macchina ad assorbimento ad acqua ed ammoniaca:
A = assorbitore, G = generatore, C = condensatore ed E = evaporatore.

Inverse machine, absorption heat pump

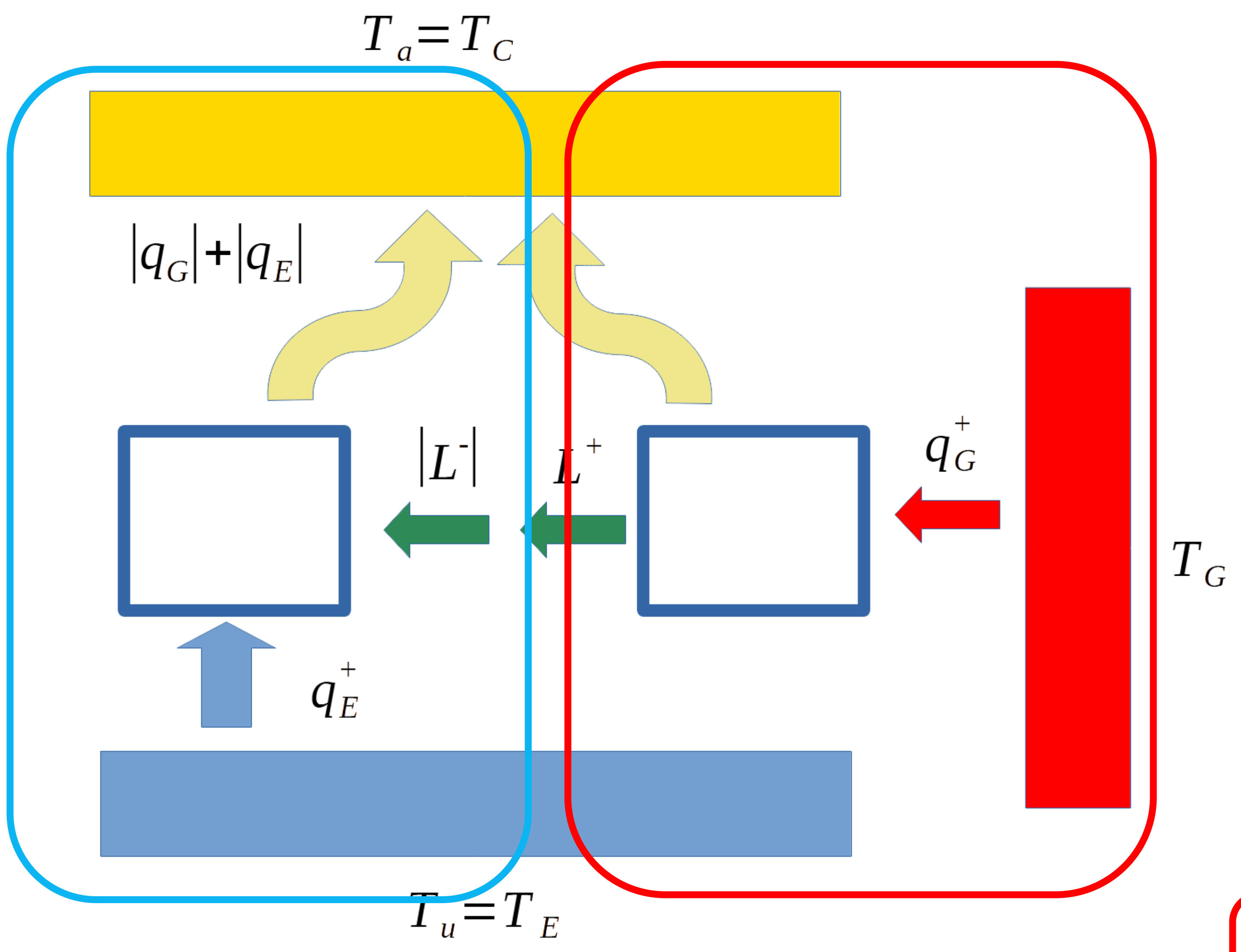


- Different way to define coefficient of performance

$$\varepsilon_f = \frac{q_E^+}{q_G^+}$$

- Absorption cycle can be viewed as a different plant system
  - one direct,
  - Inverse the latter

Ciclo frigorifero ad assorbimento



$$\eta_C = \left(\frac{L^+}{q_G^+}\right) = \frac{T_G - T_a}{T_G} \qquad L^+ = q_G^+ \cdot \frac{T_G - T_a}{T_G}$$

$$\varepsilon_C = \left(\frac{q_E}{|L^-|}\right) = \frac{T_u}{T_a - T_u} \qquad q_E^+ = |L^-| \cdot \frac{T_u}{T_a - T_u} \qquad L^+ = |L^-|$$

$$q_E^+ = q_G \cdot \frac{T_G - T_a}{T_G} \cdot \frac{T_u}{T_a - T_u}$$

$$\varepsilon_{max} = \left(\frac{q_E^+}{q_G^+}\right) = \frac{T_G - T_a}{T_G} \cdot \frac{T_u}{T_a - T_u}$$

$$\varepsilon_{max} = \eta_{carn}(T_G, T_a) \cdot \varepsilon_{carn}(T_u, T_a)$$