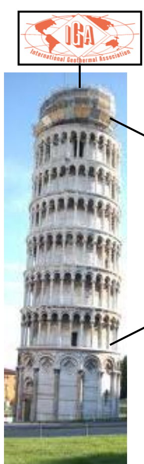


HOW HEAT PUMPS WORK

W. Grassi

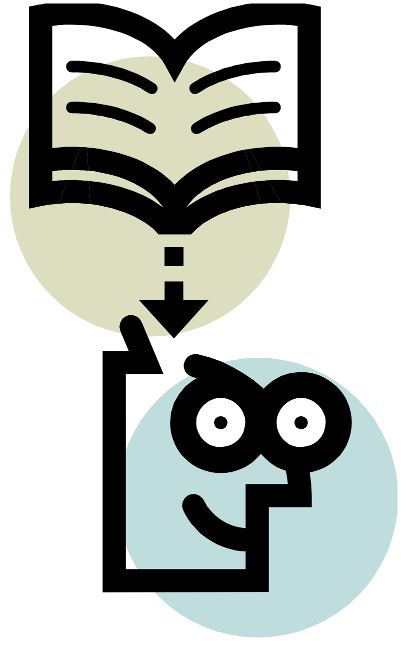
President U.G.I.

Prof. at DESTEC, University of Pisa

"International Short Courses in frame of the European Geothermal Congress 2013", June 2013, Pisa, Italy

CONTENTS

- *Basic theory*
- *Compression HP (EHP, GHP)*
- *Adsorption (HP) (AHP)*
- *Choice of HP power*
- *Components*
- *External sources*
- *Refrigerants*



HP BASIC THEORY

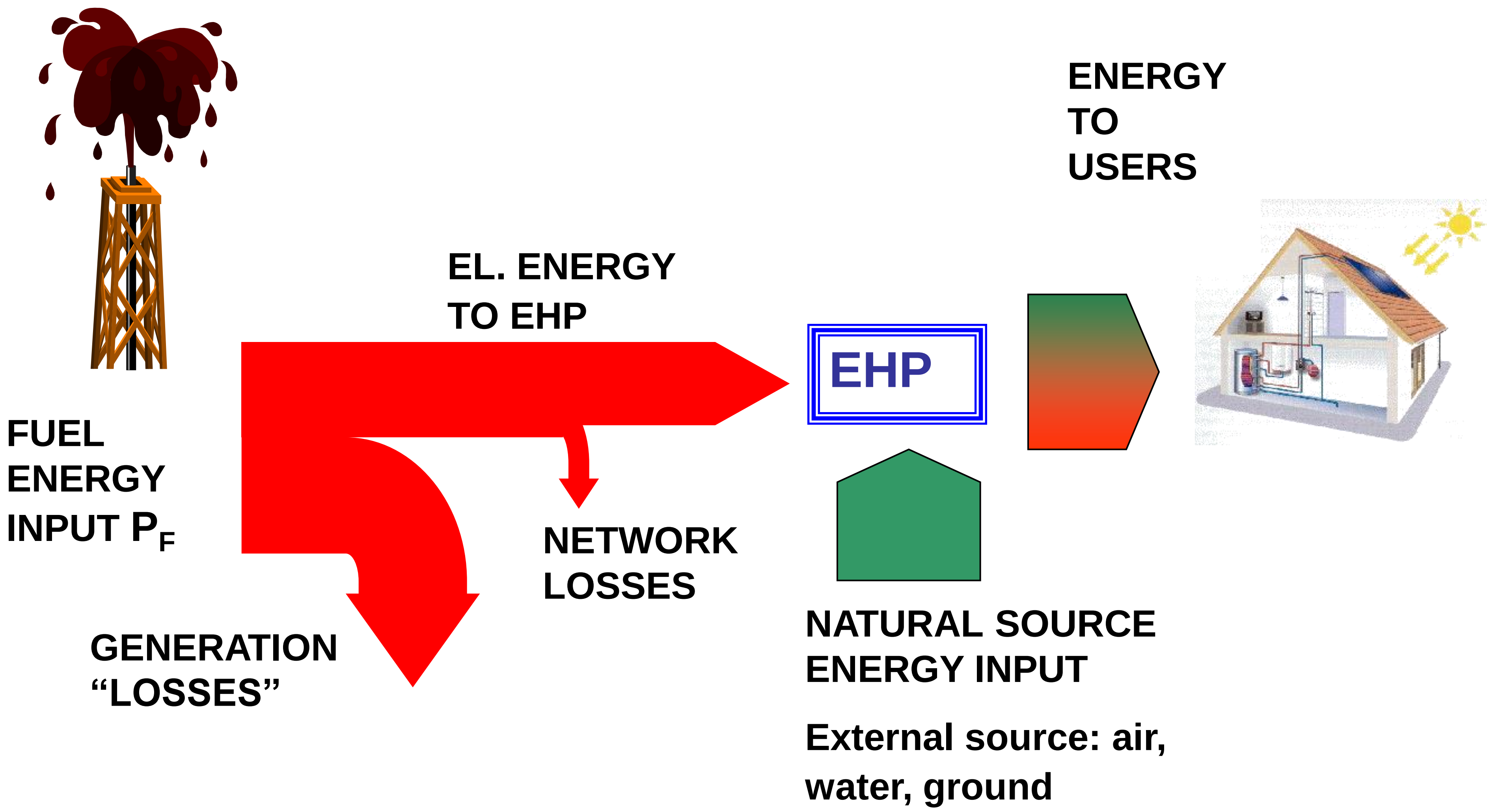
TRADITIONAL HEATING

FUEL ENERGY INPUT P_F

BOILER

ENERGY TO USERS

ELECTRIC HEAT PUMP

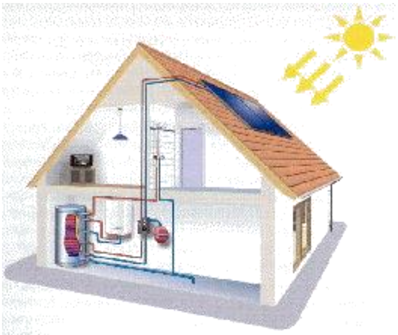


ABSORPTION HEAT PUMP

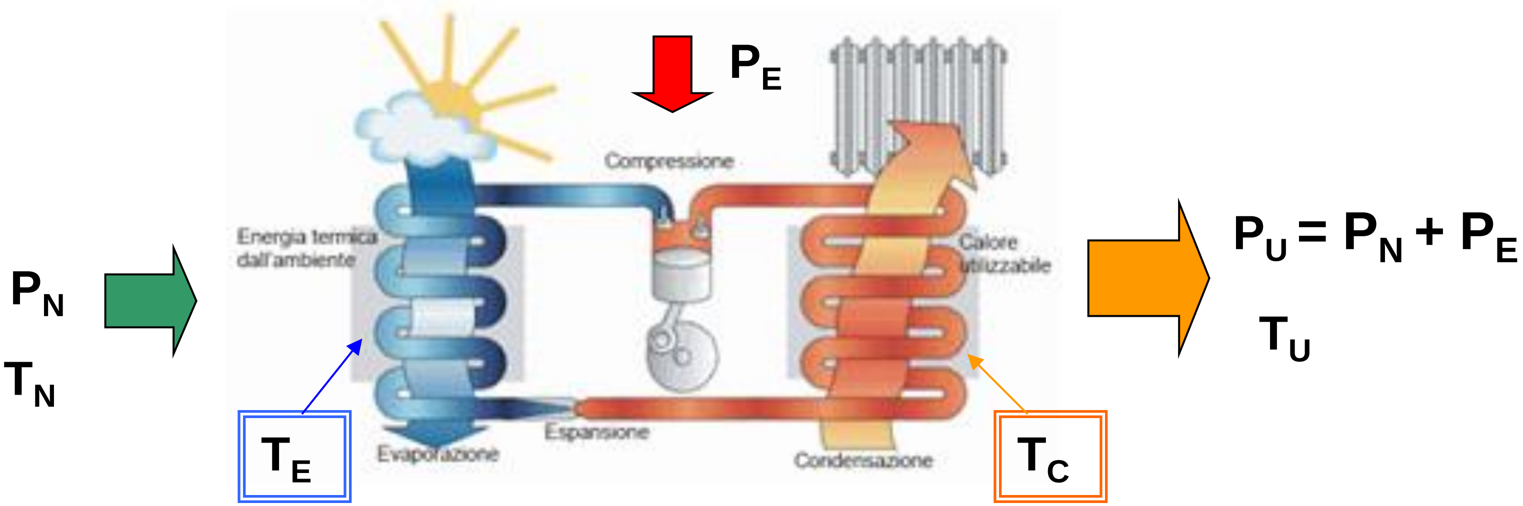
FUEL ENERGY INPUT P_F

ENERGY TO USERS

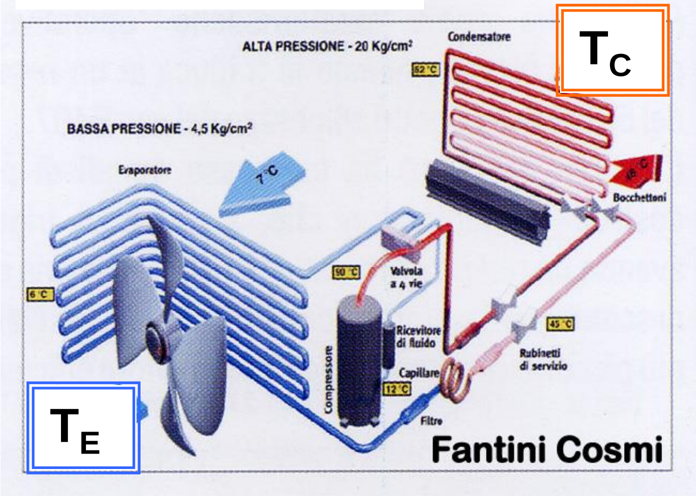
Gas HP



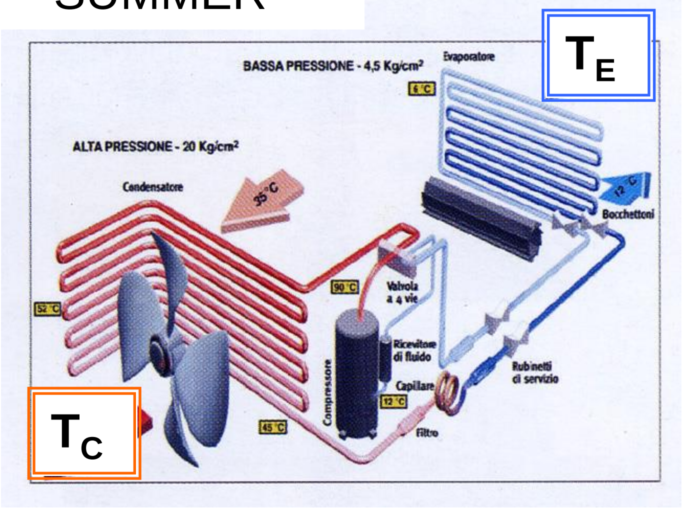
HP GENERAL WORKING SCHEME



WINTER

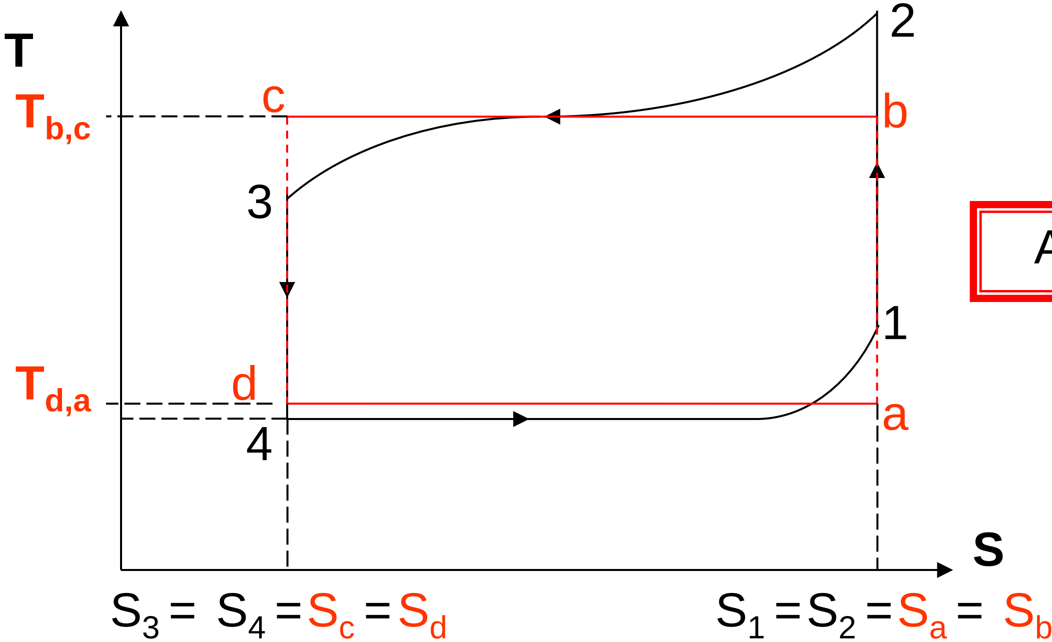


SUMMER



EQUIVALENT HEAT EXCHANGE TEMPERATUTE

AND REFEFEERENCE CARNOT CYCLE

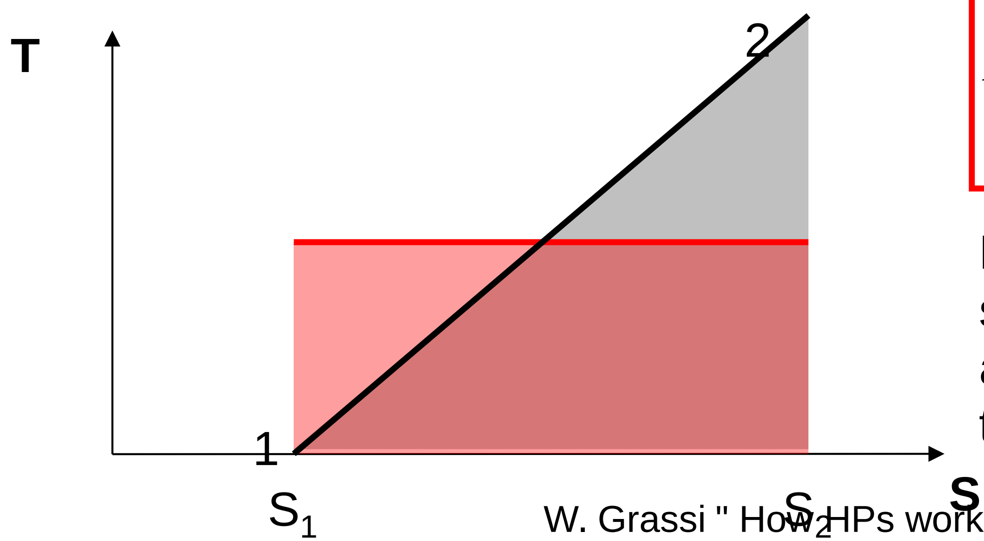


AREA(1,2,3,4)= AREA(a,b,c,d)

$$EER = \frac{Q_F}{L} \quad Q_C > 0 \quad Q_F < 0 \quad \frac{|Q_F|}{T_F} = \frac{Q_C}{T_C}$$

$$EER = \frac{1}{\frac{T_F}{T_C} - 1}$$

Summer



Heat exchanceg in 1-2 is the same as the one in a-b (see areas). The equivalent exchange temperature is $T_{eq.}$

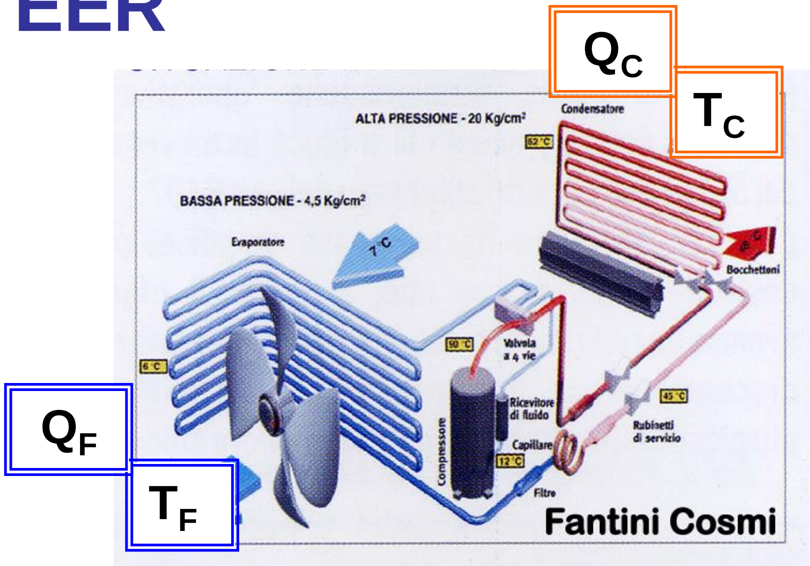
COP AND EER

$T_C = T_{b,c} \quad T_C = T_{b,c}$

$$COP = \frac{Q_C}{L} \quad Q_C < 0 \quad Q_F > 0 \quad \frac{|Q_C|}{T_C} = \frac{Q_F}{T_F}$$

$$COP = \frac{1}{1 - \frac{T_F}{T_C}}$$

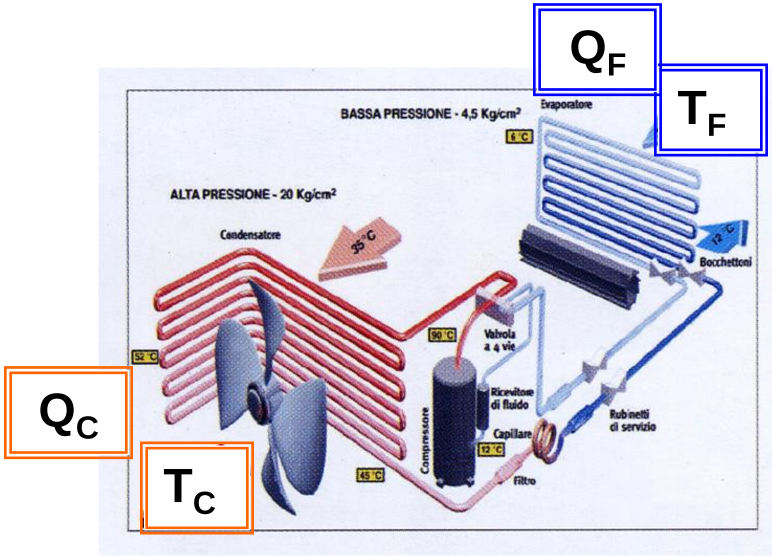
WINTER



$$EER = \frac{Q_F}{L} \quad Q_C > 0 \quad Q_F < 0 \quad \frac{|Q_F|}{T_F} = \frac{Q_C}{T_C}$$

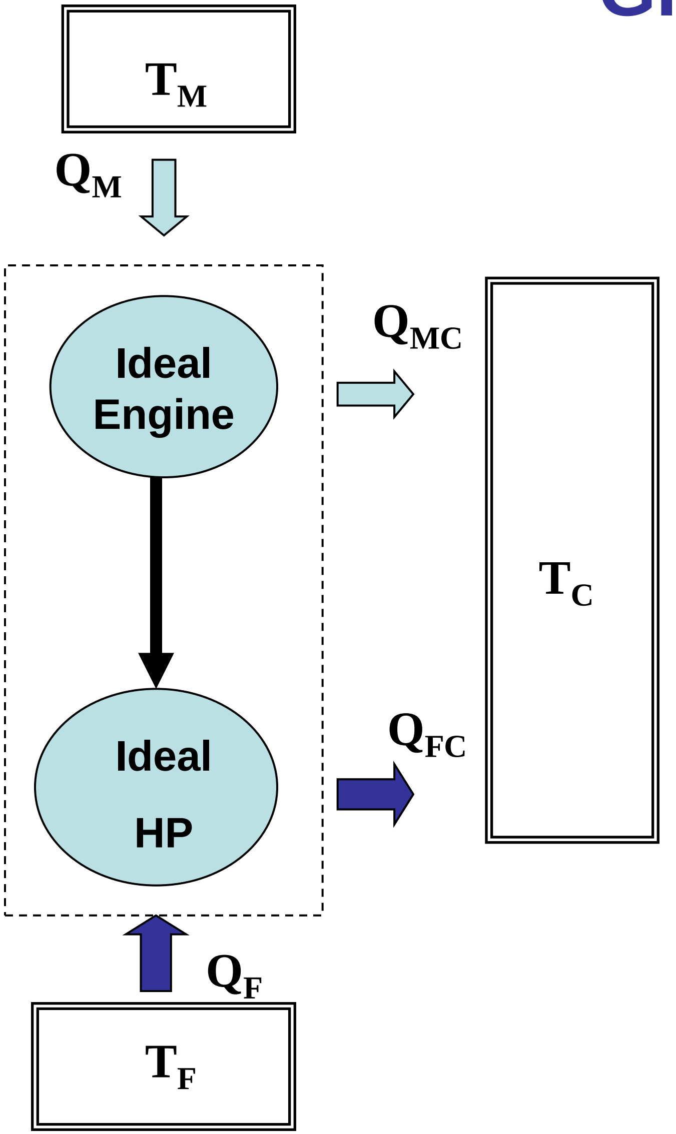
$$EER = \frac{1}{\frac{T_F}{T_C} - 1}$$

SUMMER



EHP

GHP PERFORMANCE



$$\frac{Q_M}{T_M}+\frac{Q_F}{T_F}-\frac{|Q_{MC}|+|Q_{FC}|}{T_C}=\frac{Q_M}{T_M}+\frac{Q_F}{T_F}-\frac{|Q_C|}{T_C}=0$$

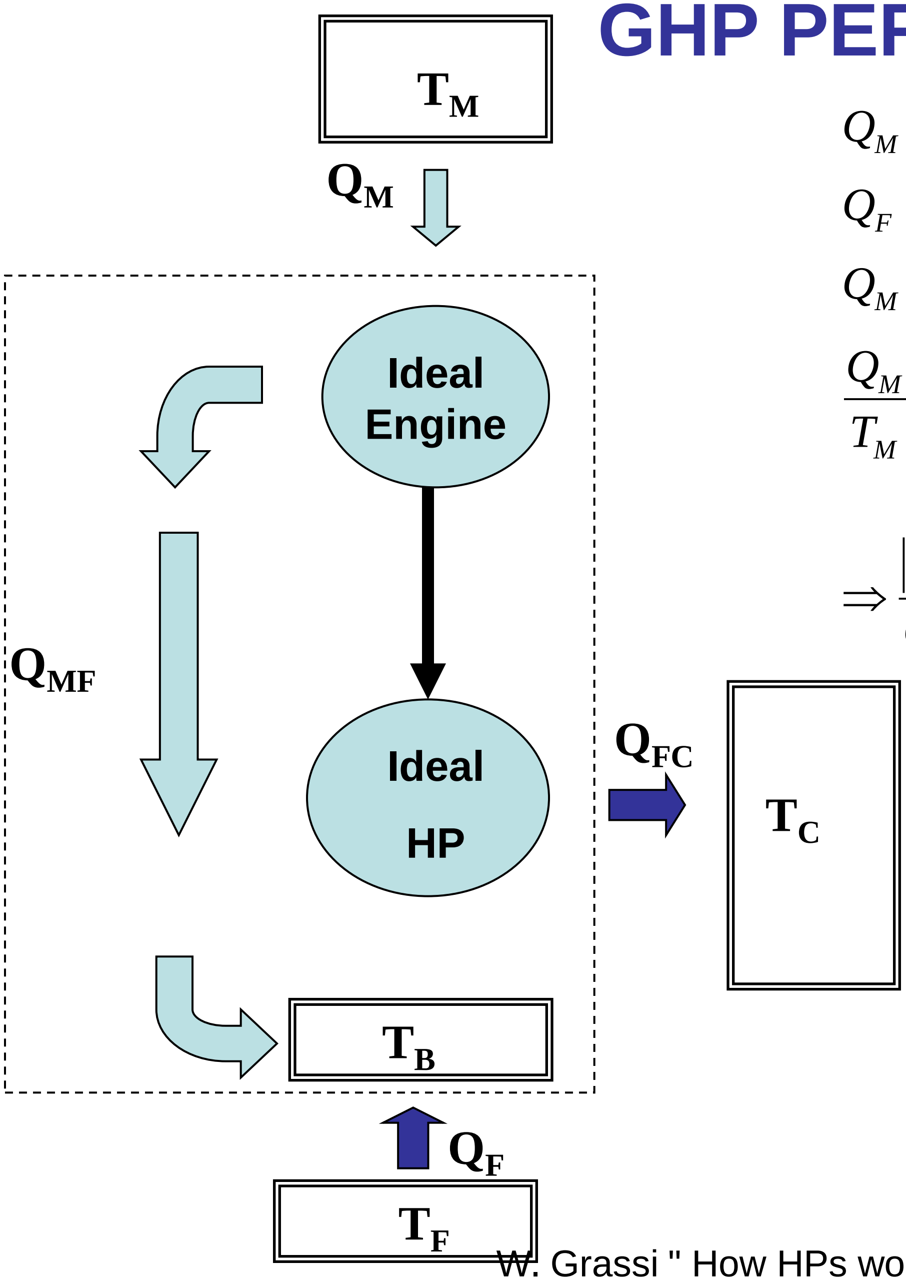
$$|L|=|Q_{FC}|-Q_F=Q_M-|Q_{MC}|$$

$$|Q_{FC}|+|Q_{MC}|=|Q_C|=Q_M+Q_F \Rightarrow$$

$$\Rightarrow \frac{Q_M}{T_M}+\frac{|Q_C|-Q_M}{T_F}-\frac{|Q_C|}{T_C}=0 \Rightarrow \frac{|Q_C|}{Q_M}=\frac{\frac{1}{T_M}-\frac{1}{T_F}}{\frac{1}{T_C}-\frac{1}{T_F}}$$

$$COP_M=\frac{|Q_C|}{Q_M}=\frac{1-\frac{T_F}{T_M}}{1-\frac{T_F}{T_C}}$$

GHP PERFORMANCE



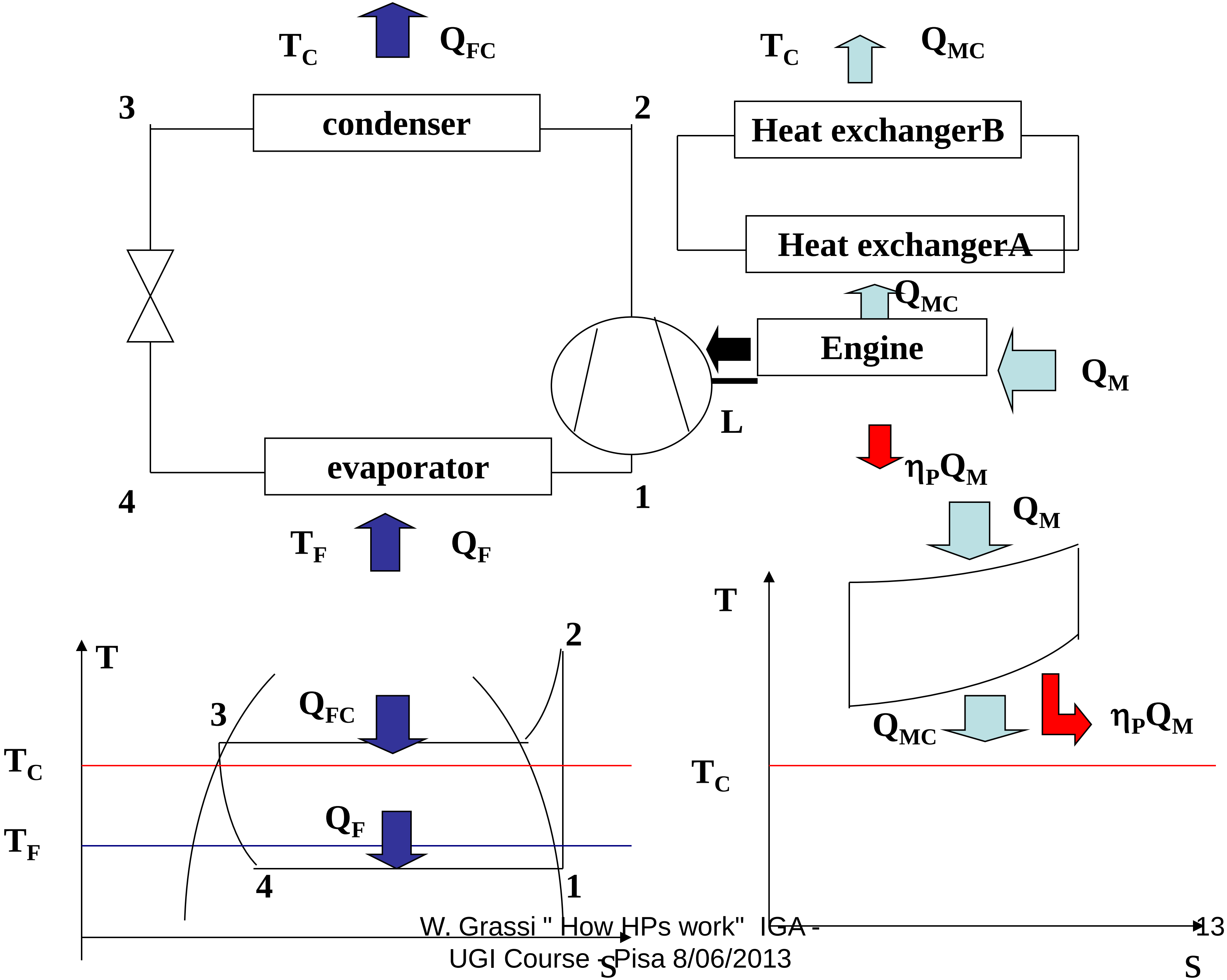
$$Q_M = |L| + |Q_{MF}|$$

$$Q_F + Q_{MF} - |Q_{FC}| = |L|$$

$$Q_M + Q_F = |Q_C|$$

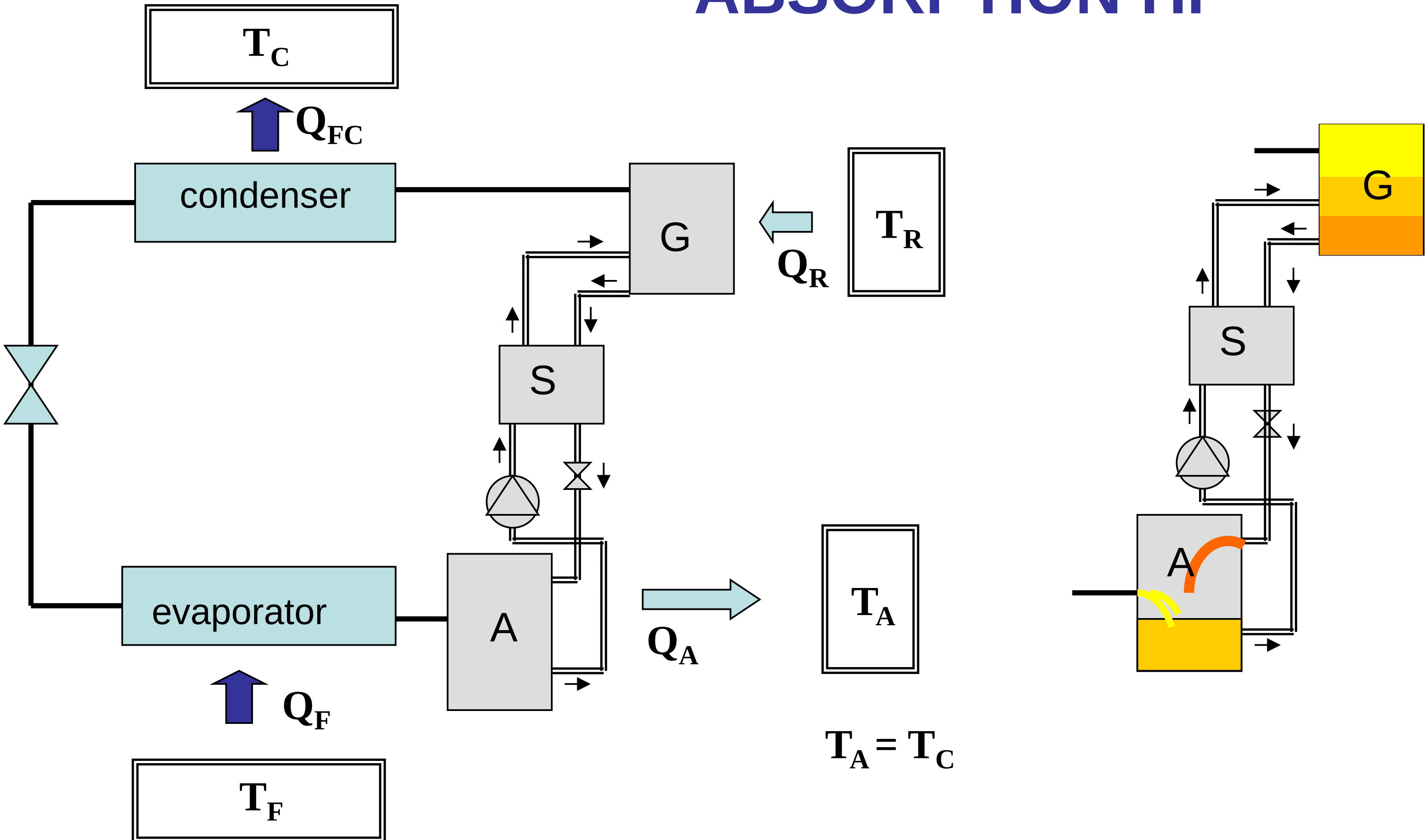
$$\frac{Q_M}{T_M} + \frac{Q_F}{T_F} = \frac{|Q_C|}{T_C} \Rightarrow \frac{Q_M}{T_M} + \frac{|Q_C| - Q_M}{T_F} = \frac{|Q_C|}{T_C} \Rightarrow$$

$$\Rightarrow \frac{|Q_C|}{Q_M} = \frac{\frac{1}{T_M} - \frac{1}{T_F}}{\frac{1}{T_C} - \frac{1}{T_F}} = \frac{1 - \frac{T_M}{T_F}}{1 - \frac{T_F}{T_C}}$$


T_C
Q_{FC}
3
condenser
2
T_C
Q_{MC}
Heat exchangerB
Heat exchangerA
Q_{MC}
Engine
Q_M
L
4
evaporator
1
$\eta_P Q_M$
T_F
Q_F
Q_M
T
2
T
3
Q_{FC}
Q_{MC}
$\eta_P Q_M$
T_C
T_C
T_F
Q_F
4
1
S
S

GHP

ABSORPTION HP



Pure ammonia

Poor solution

Rich solution

G - Generator

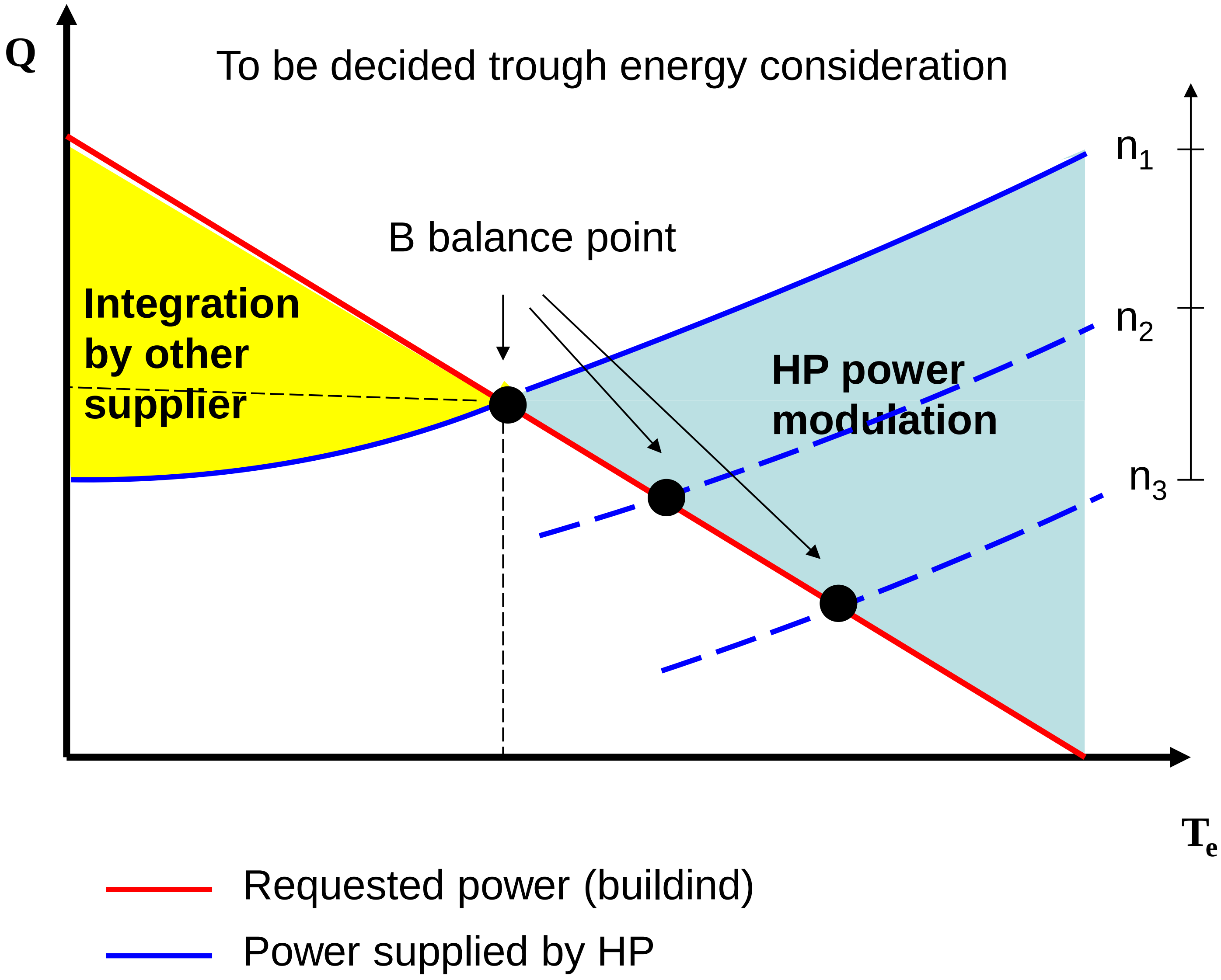
S - Exchanger

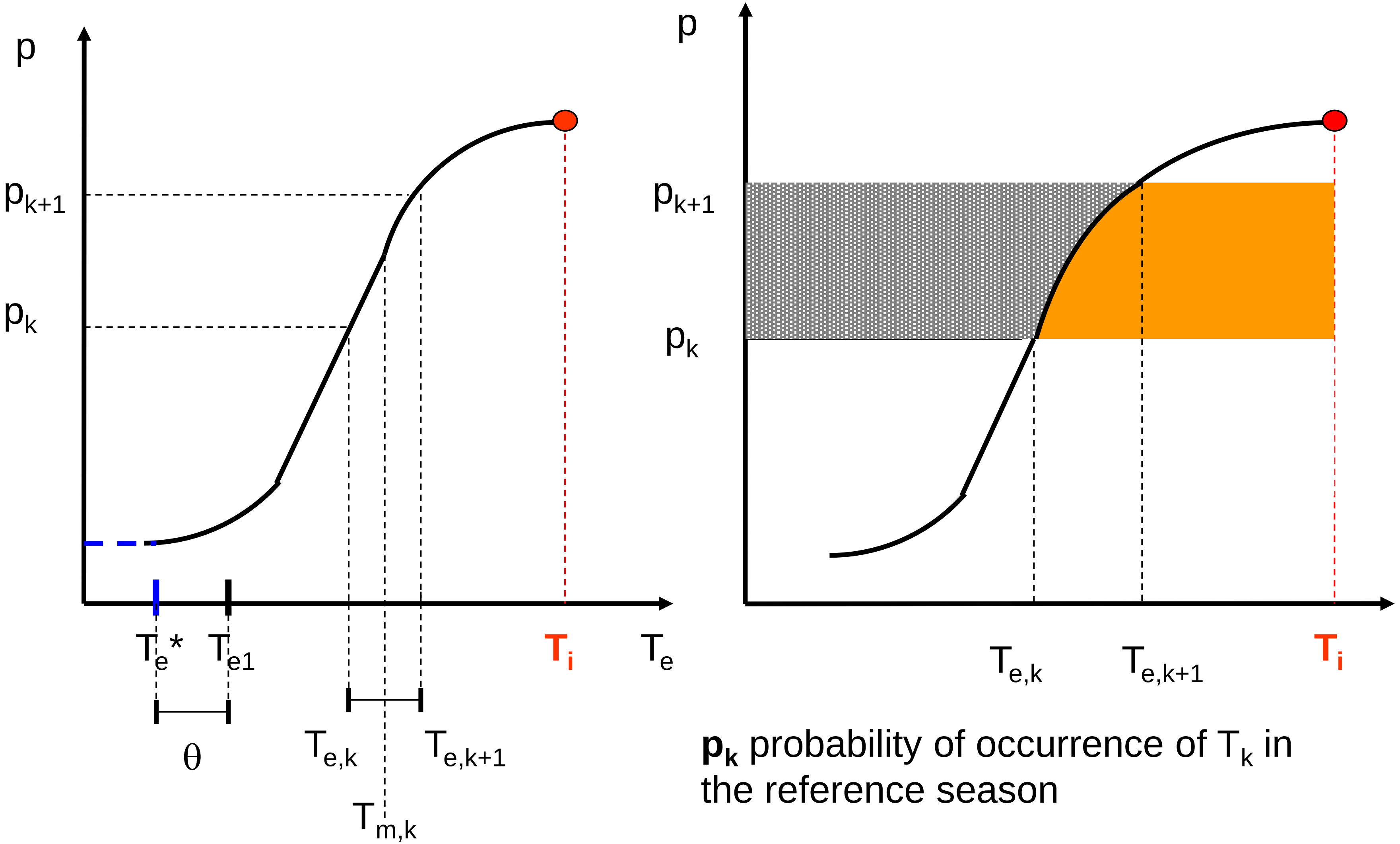
A - Absorber

AHP

Which size?

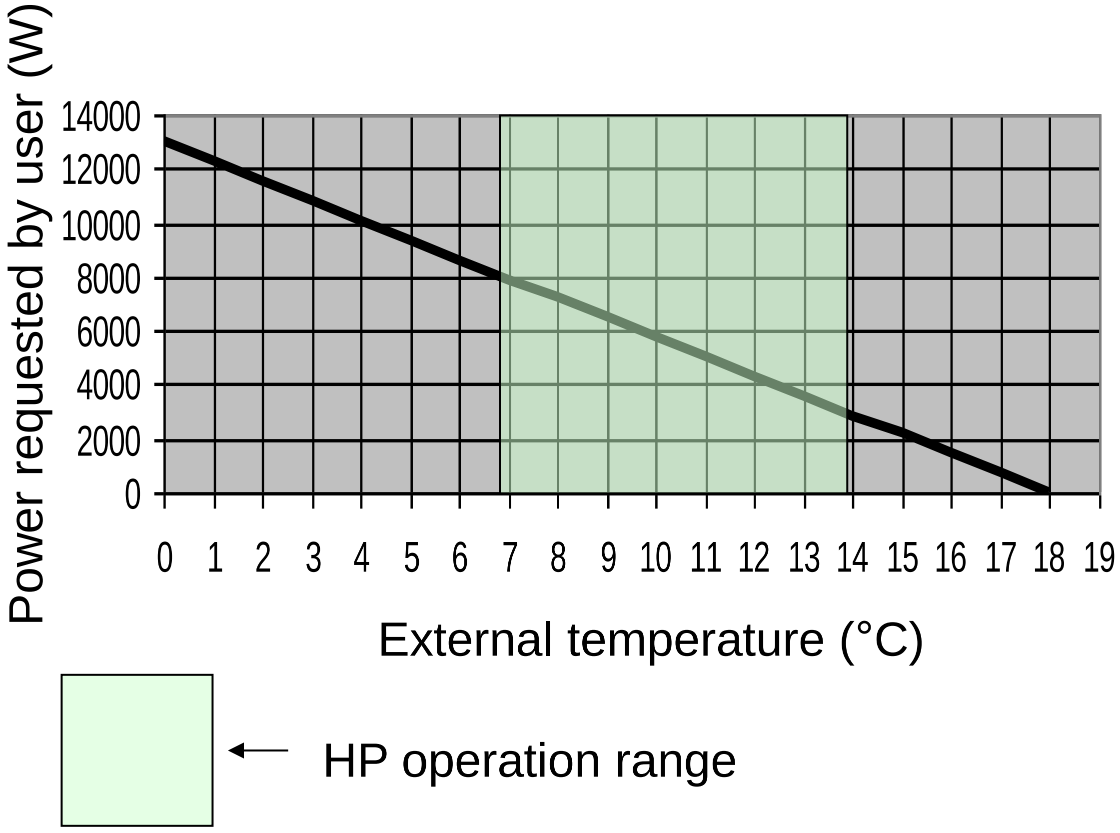
CHOICE OF HP POWER

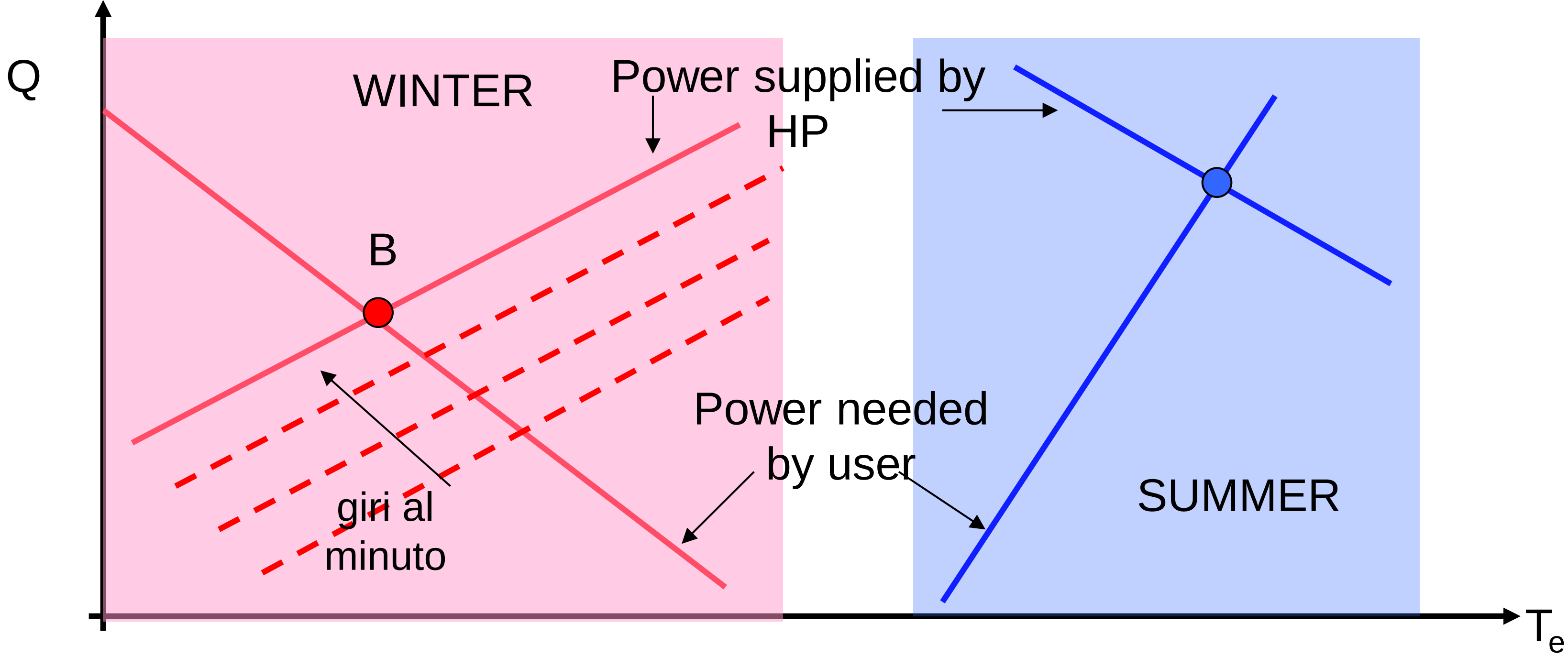

Q
To be decided trough energy consideration
B balance point
Integration by other supplier
HP power modulation
n_1
n_2
n_3
T_e
Requested power (buildind)
Power supplied by HP

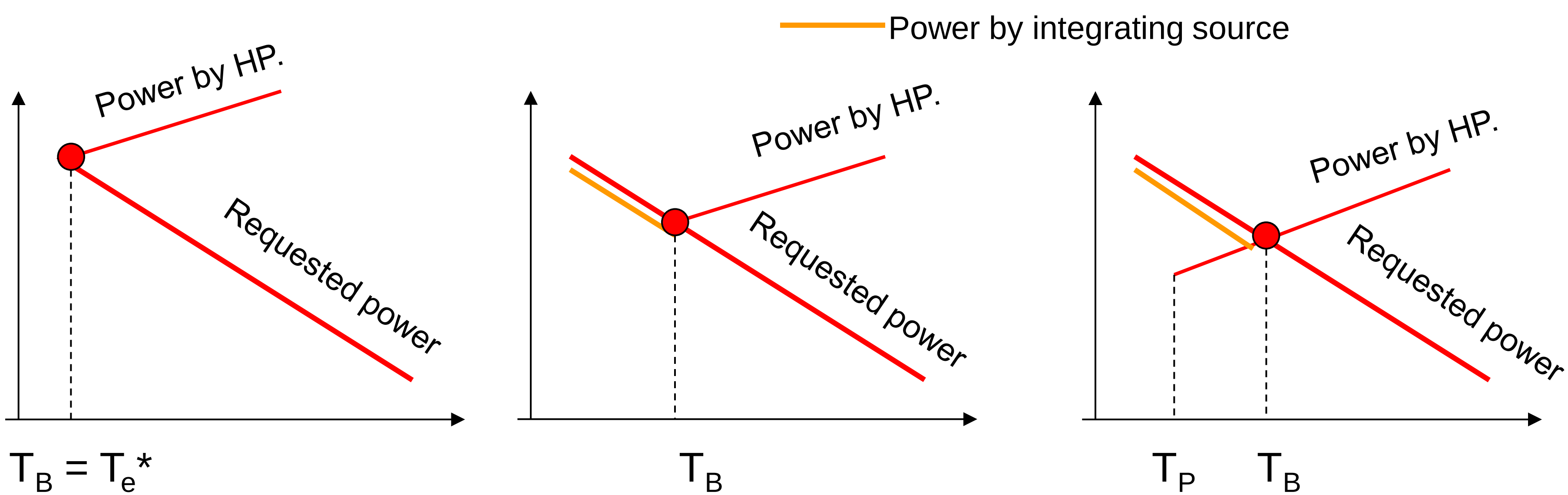


p_k probability of occurrence of T_k in the reference season

HP operational external temperature range




Q
WINTER
Power supplied by
HP
B
giri al
minuto
Power needed
by user
SUMMER
T
e


Power by integrating source
Power by HP.
Requested power
$T_B = T_e^*$
Power by HP.
Requested power
T_B
Power by HP.
Requested power
T_P
T_B

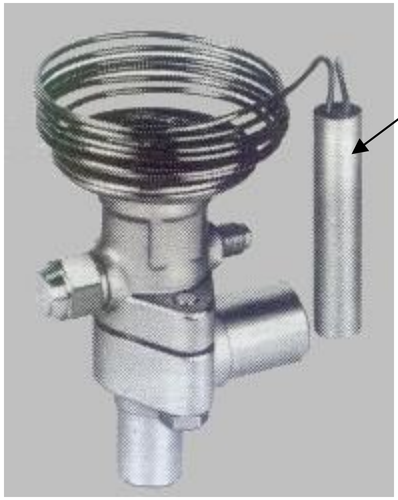
(a) (b) (c)

HP MAIN COMPONENTS

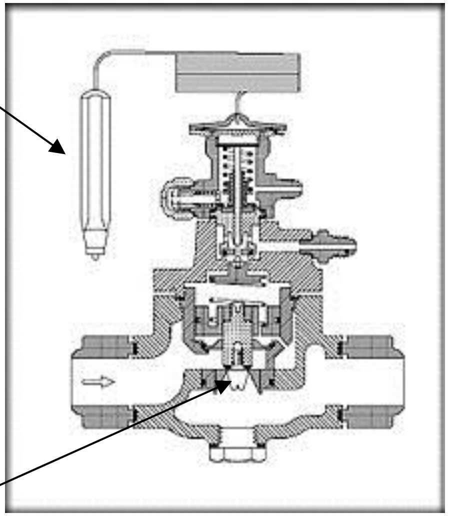
In particular compressor will be treated herein

Lamination valve

Determines the pressure drop from condenser to evaporatore. Normally is controlled by a temperature sensor placed at the evaporator exit. This in order to be sure that only vapor (no liquid at all) enters the compressor, through an appropriate opening and closing port.



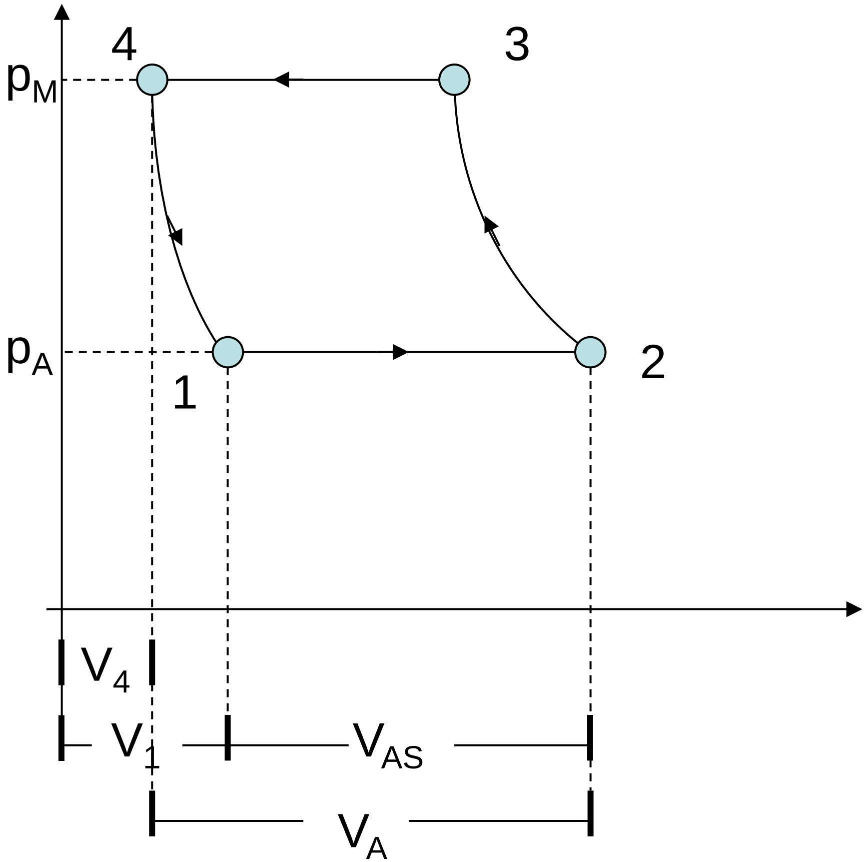
Temperature sensor

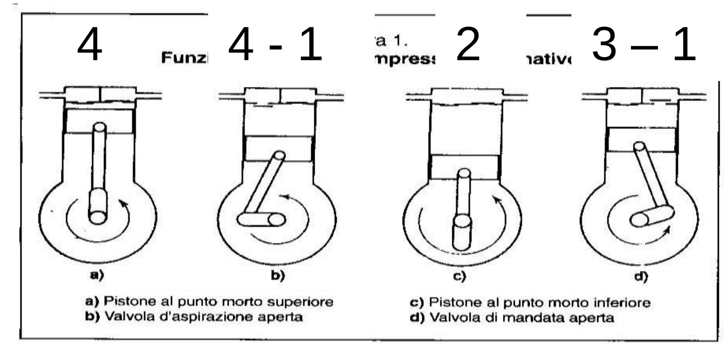


regulating port

(images from Wikipedia)

Alternating compressor





1) suction port opens;

1 -2) gas down intake to bottom dead center volume (V2);

2) suction port closes;

2 – 3) compression;

3) exaust port opens;

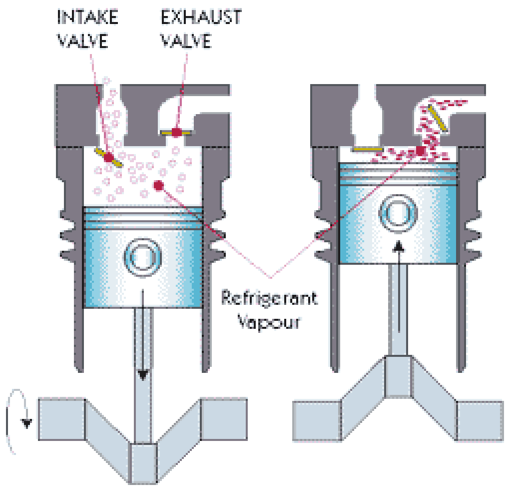
3 -4) exaust gas exit up to top dead center volume (V4);

4) exaust port closes;

4 – 1) gas (contained in V4) expansion.

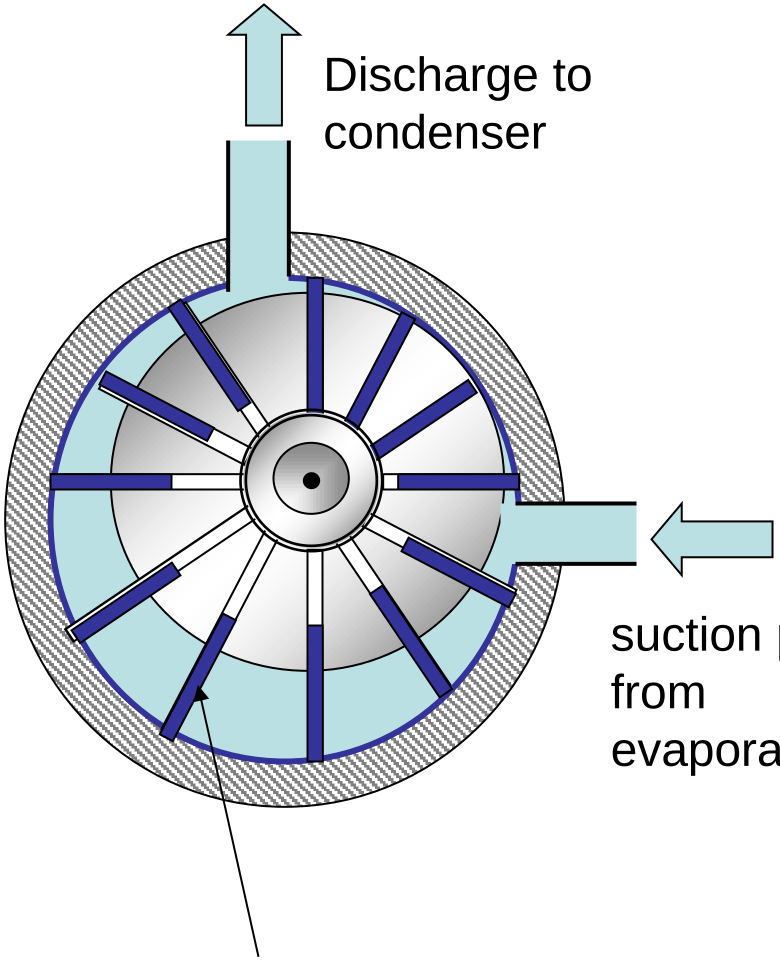
Alternating compressor

danfoss

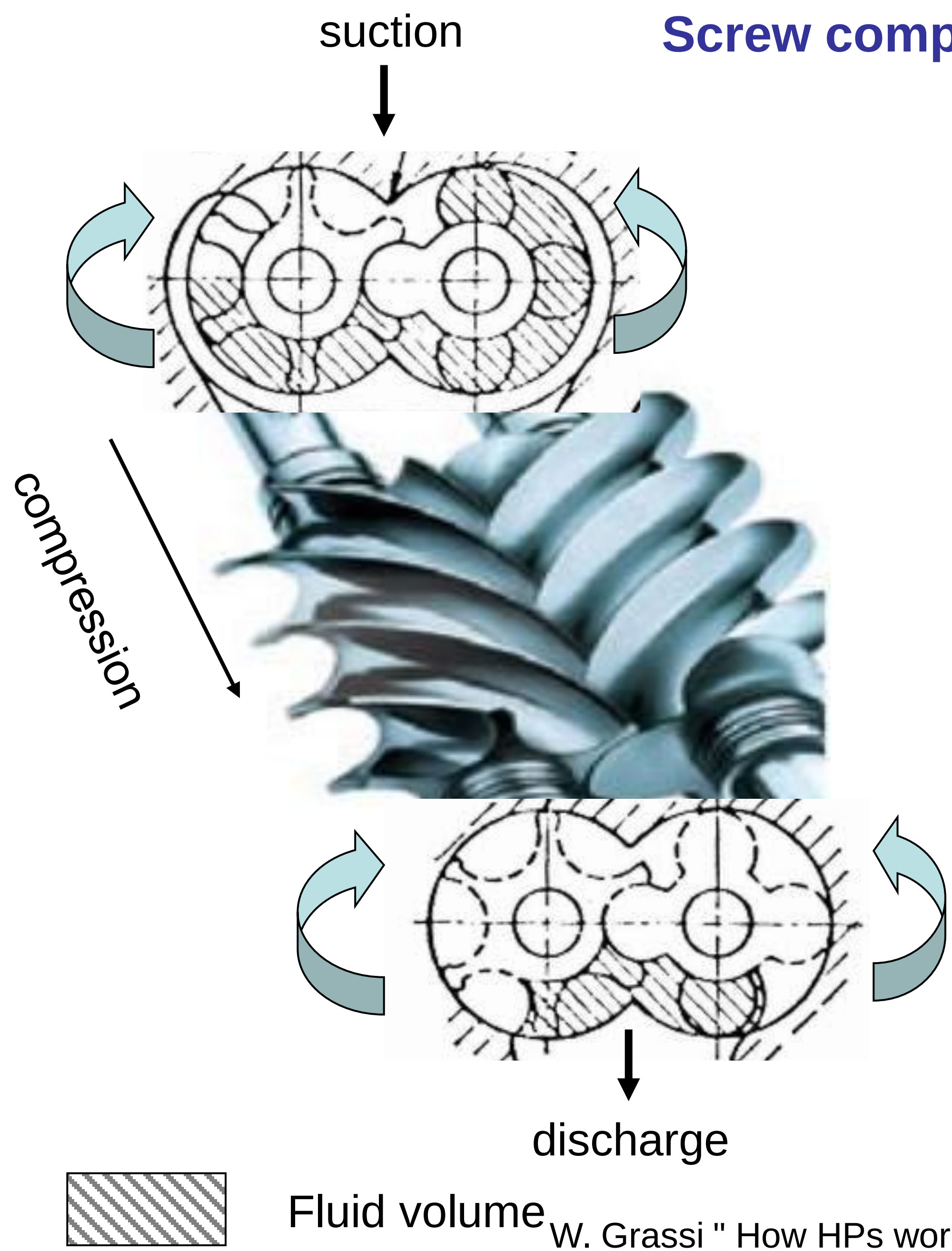


www. direct industry.it

Rotary vane compressor

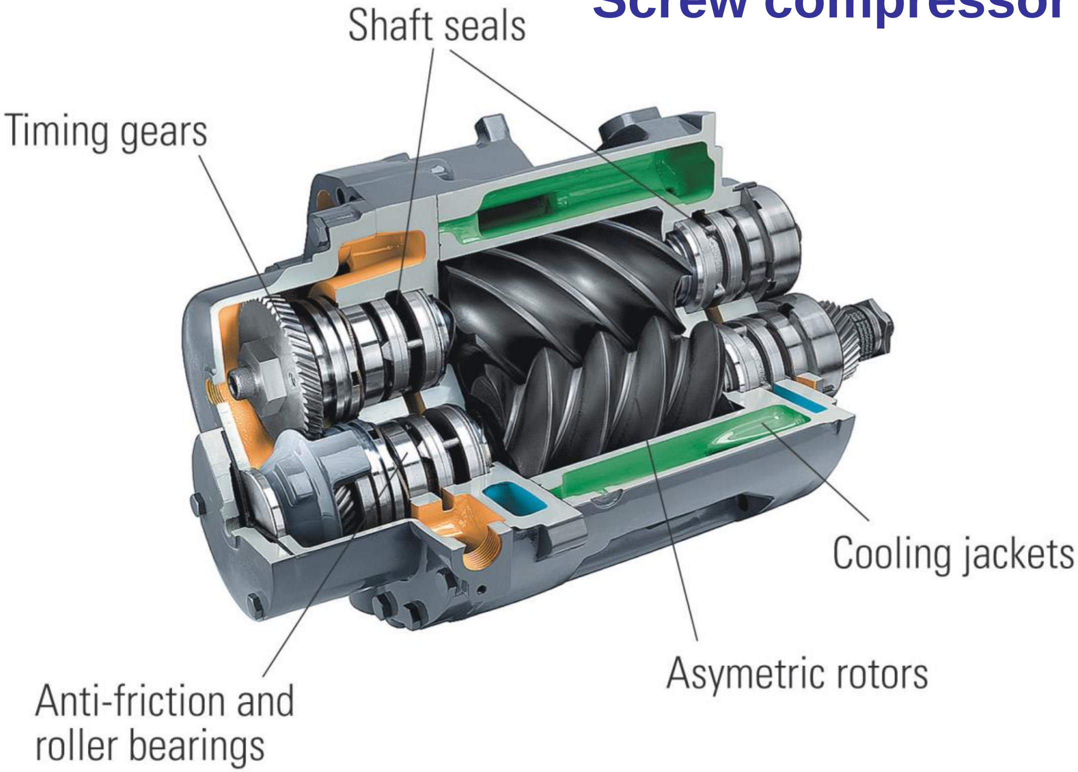


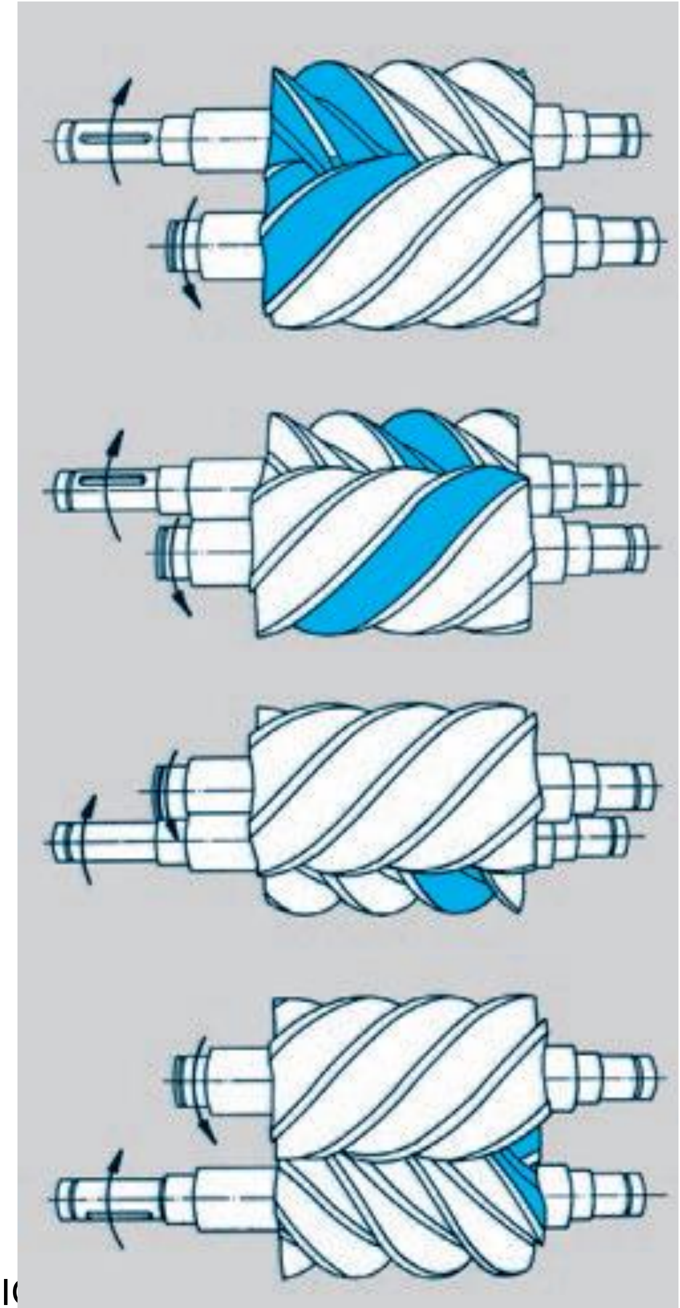
Screw compressor



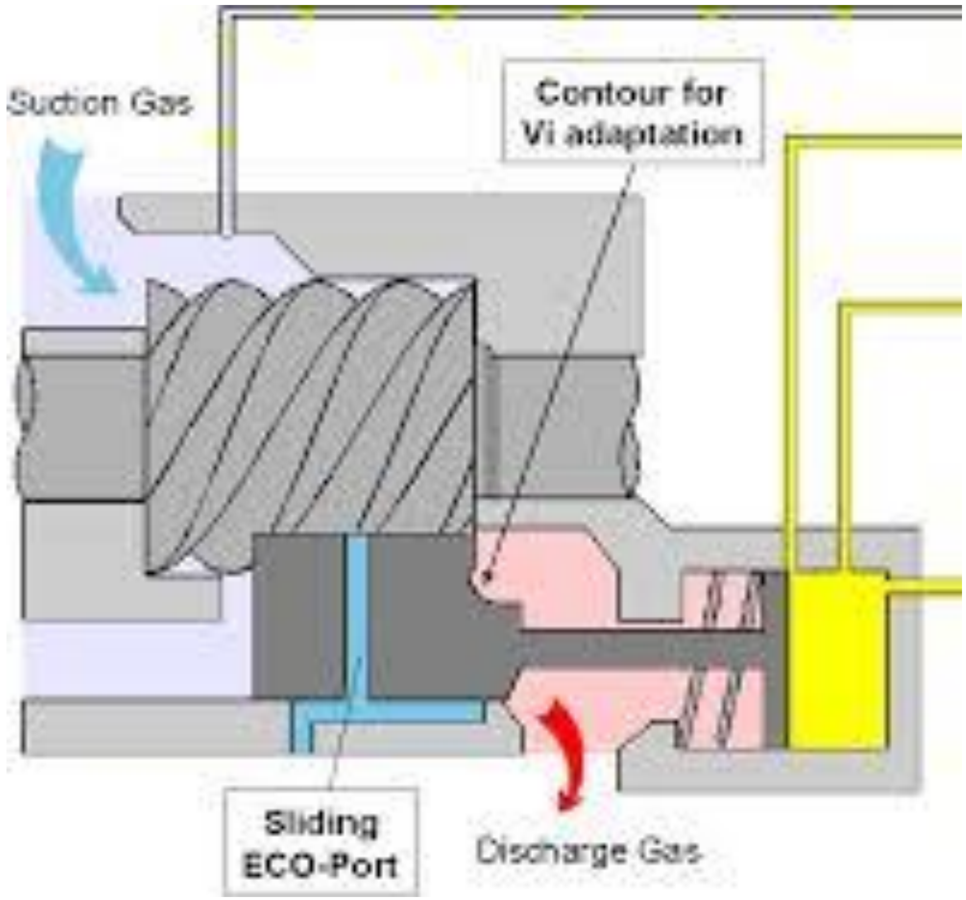
Fluid moves axially due to the rotating screws and is gradually compressed in the progressively reduced space within the two screws.

Screw compressor



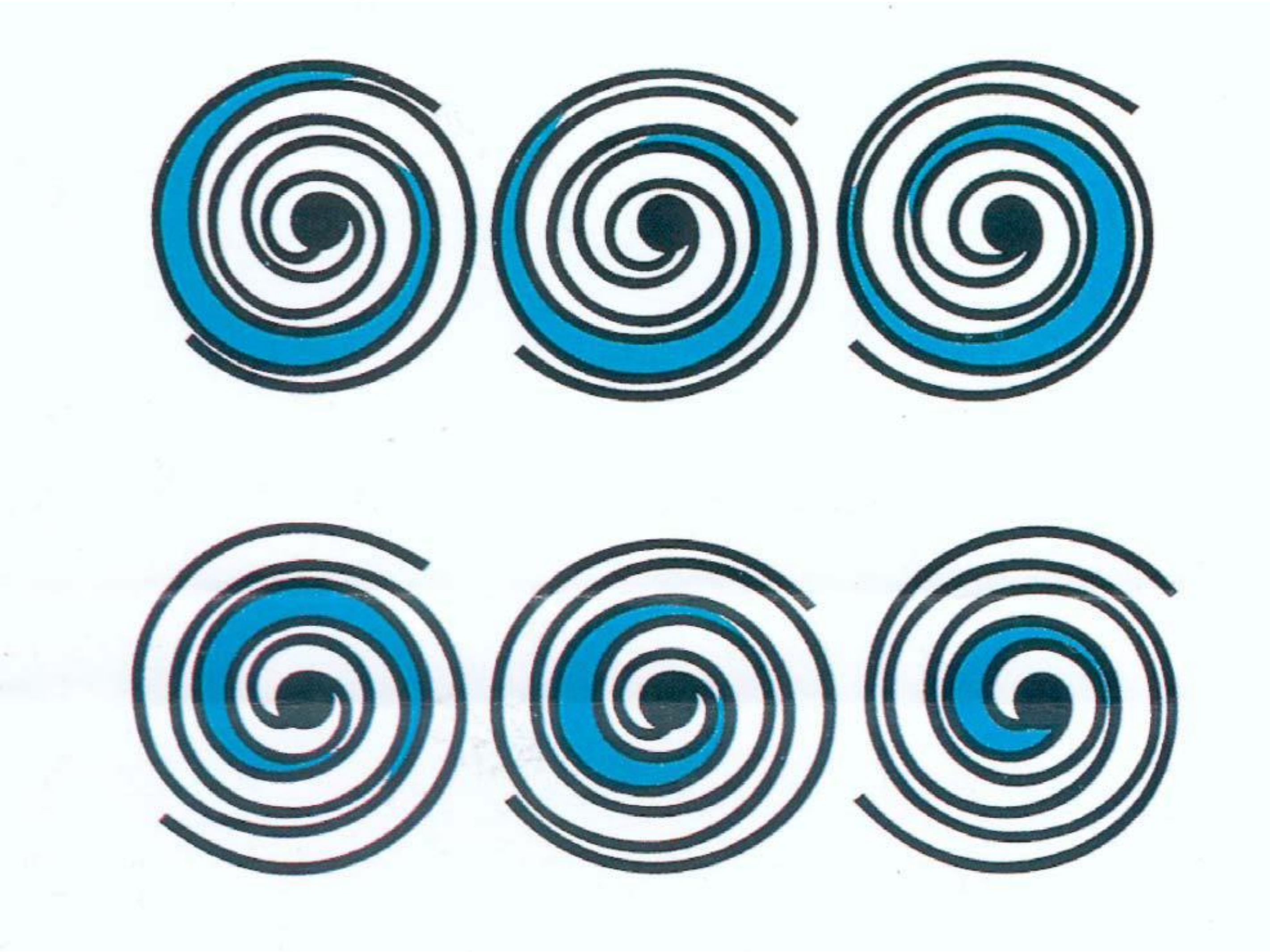


The eco port (valve) moved by a piston oil controlled by the evaporator overheating, sends part of the flow rate back.

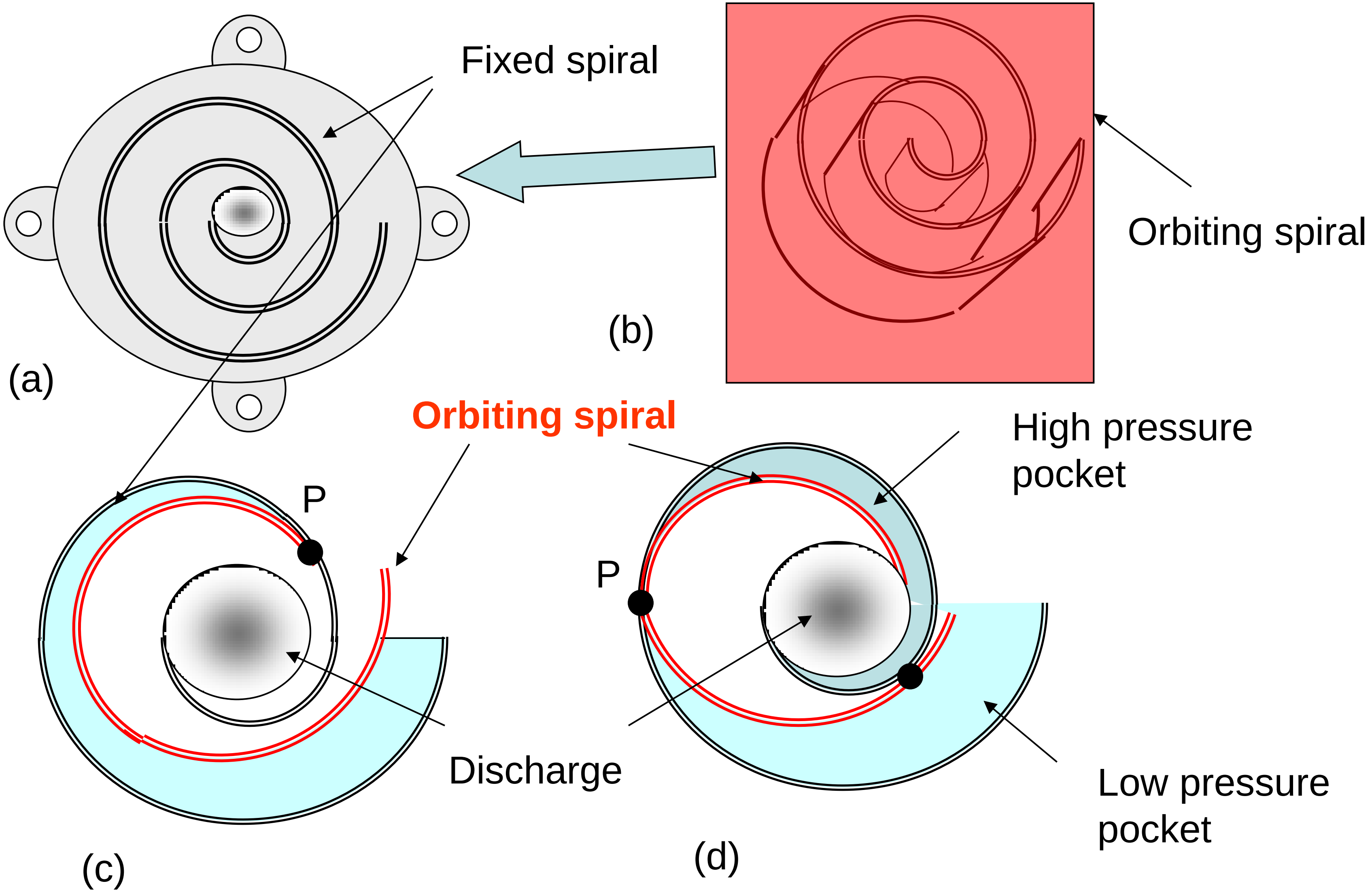


Rotary scroll compressor

Rotary scroll compressor



Rotary scroll compressor



The movable spiral, orbiting on the still one, figures (c) and (d), il forms di chambers (pockets) of progressively reducing volume.

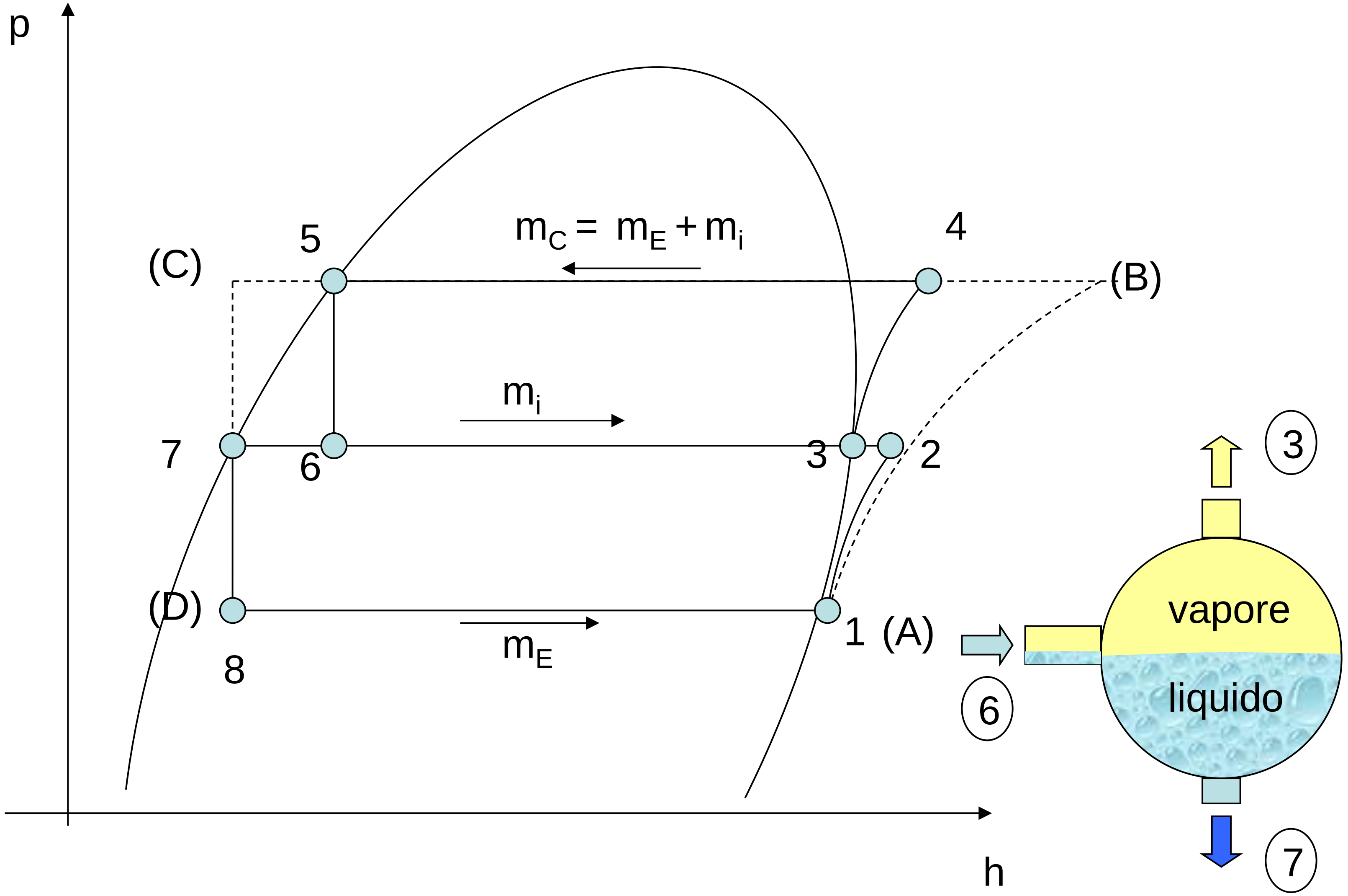
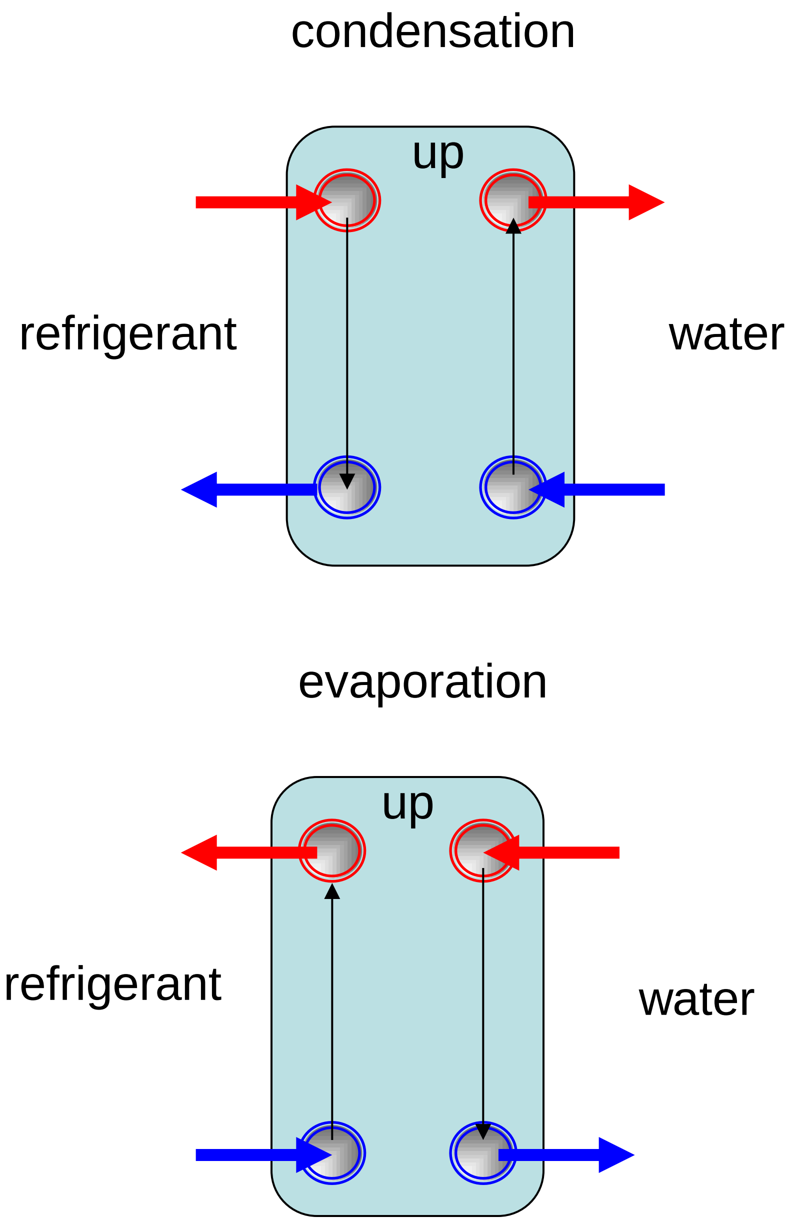

p
5
(C)
$m_C = m_E + m_i$
4
(B)
m_i
7
6
3
2
3
(D)
1 (A)
vapore
m_E
8
6
liquido
h
7

Plate heat exchanger



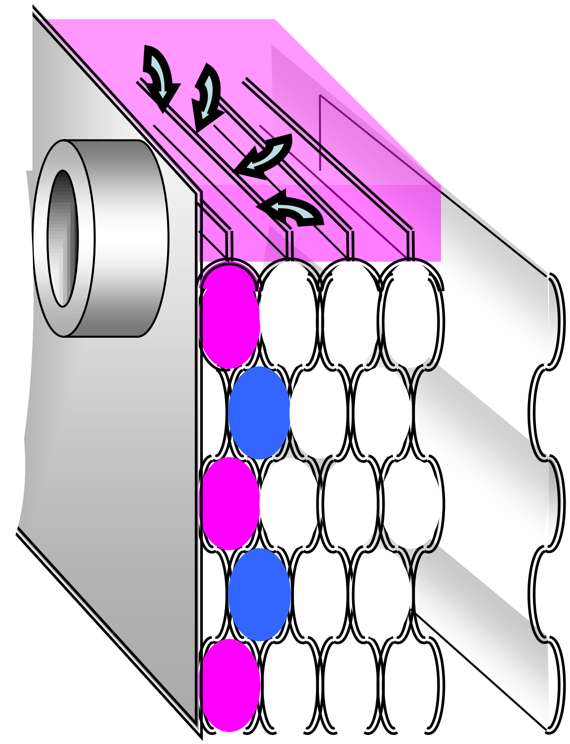
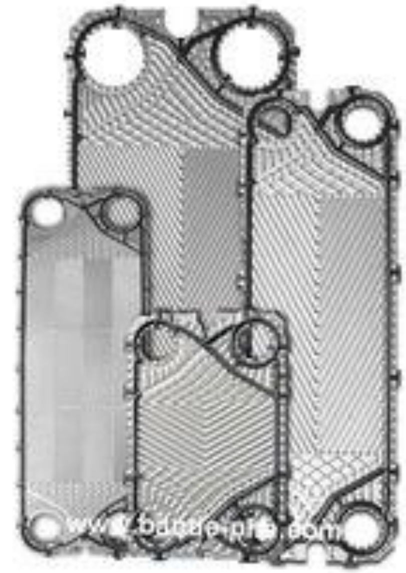
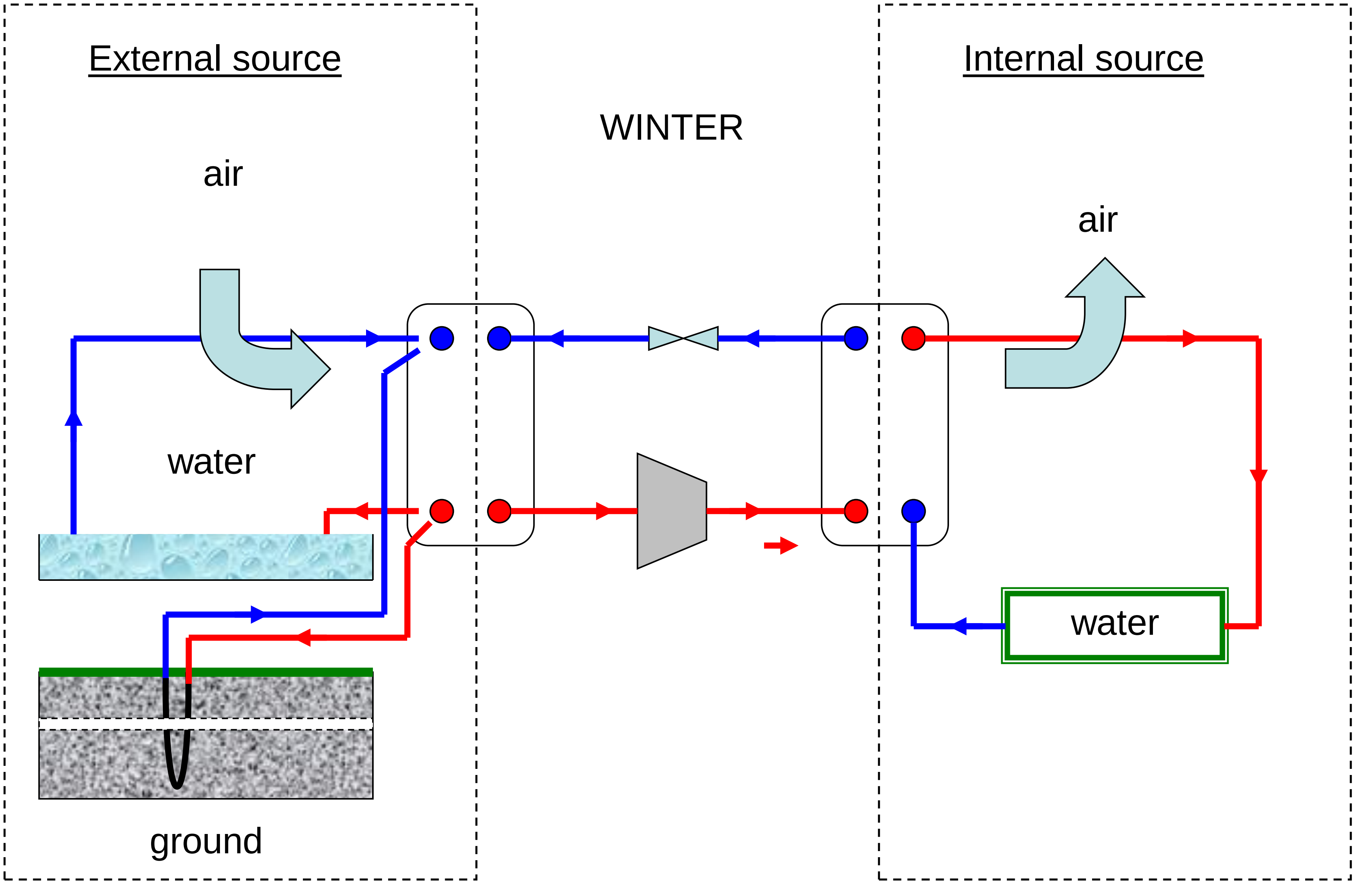
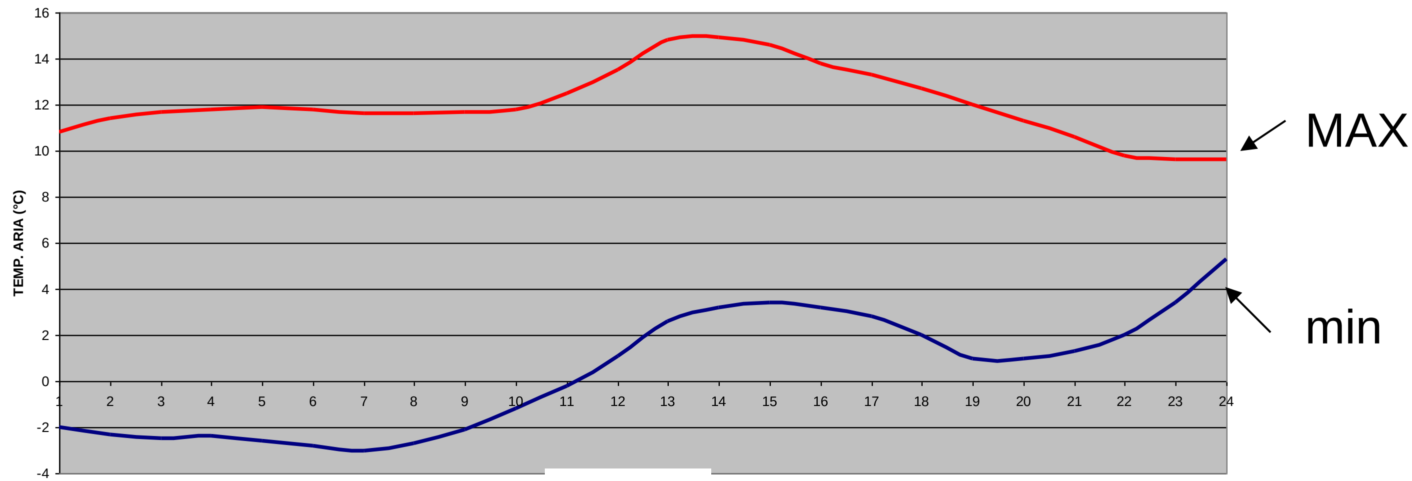


Plate heat exchanger



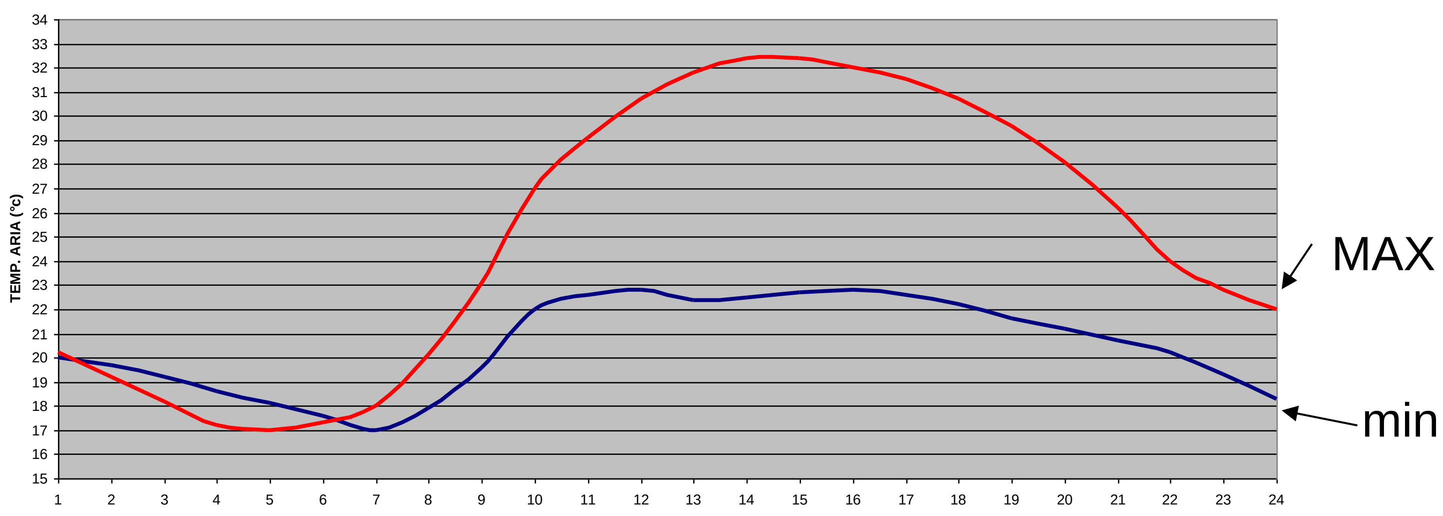

External source
Internal source
WINTER
air
air
water
water
ground

Typical air hourly temperature in a winter day



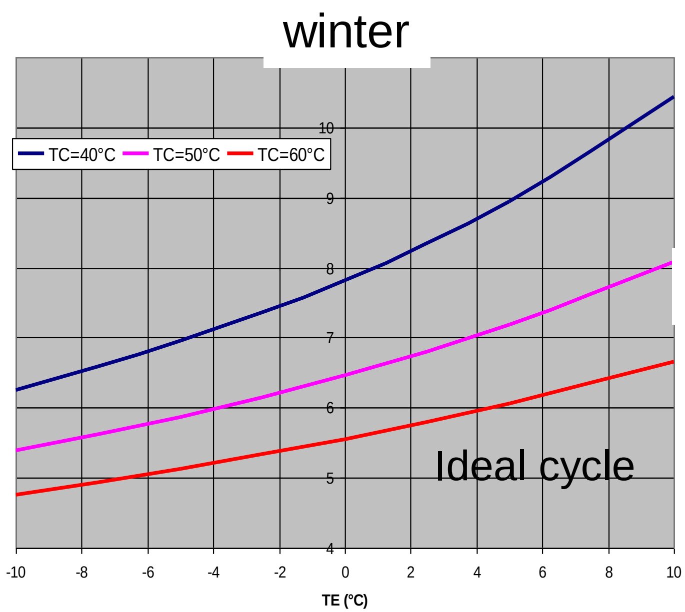
hour

Typical air hourly temperature in a summer day

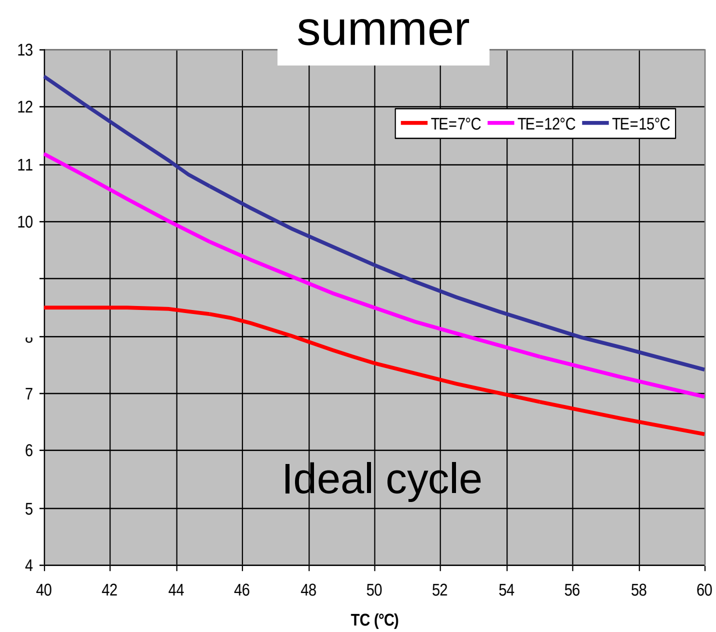


hour

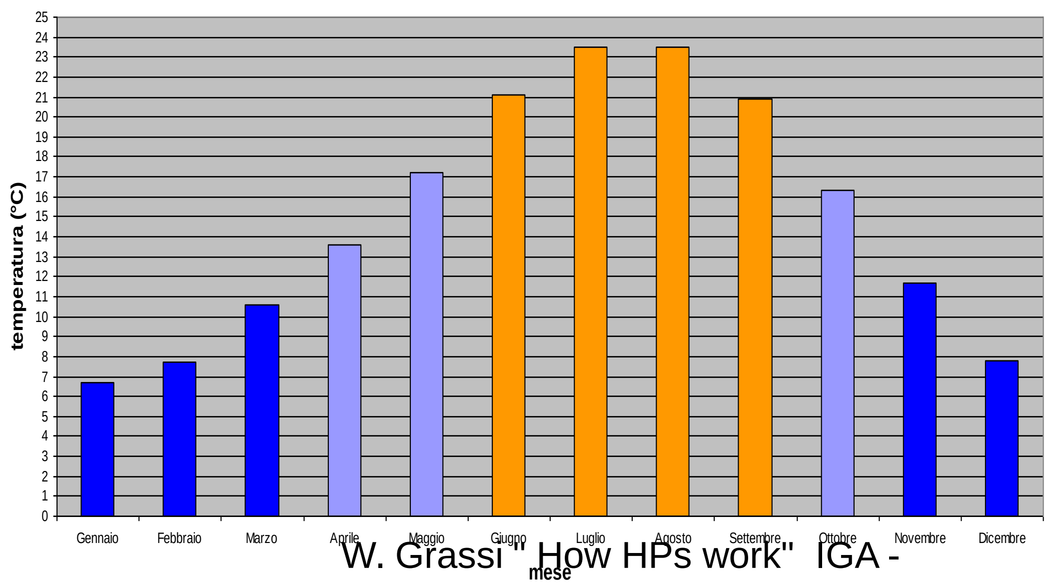
COP



EER



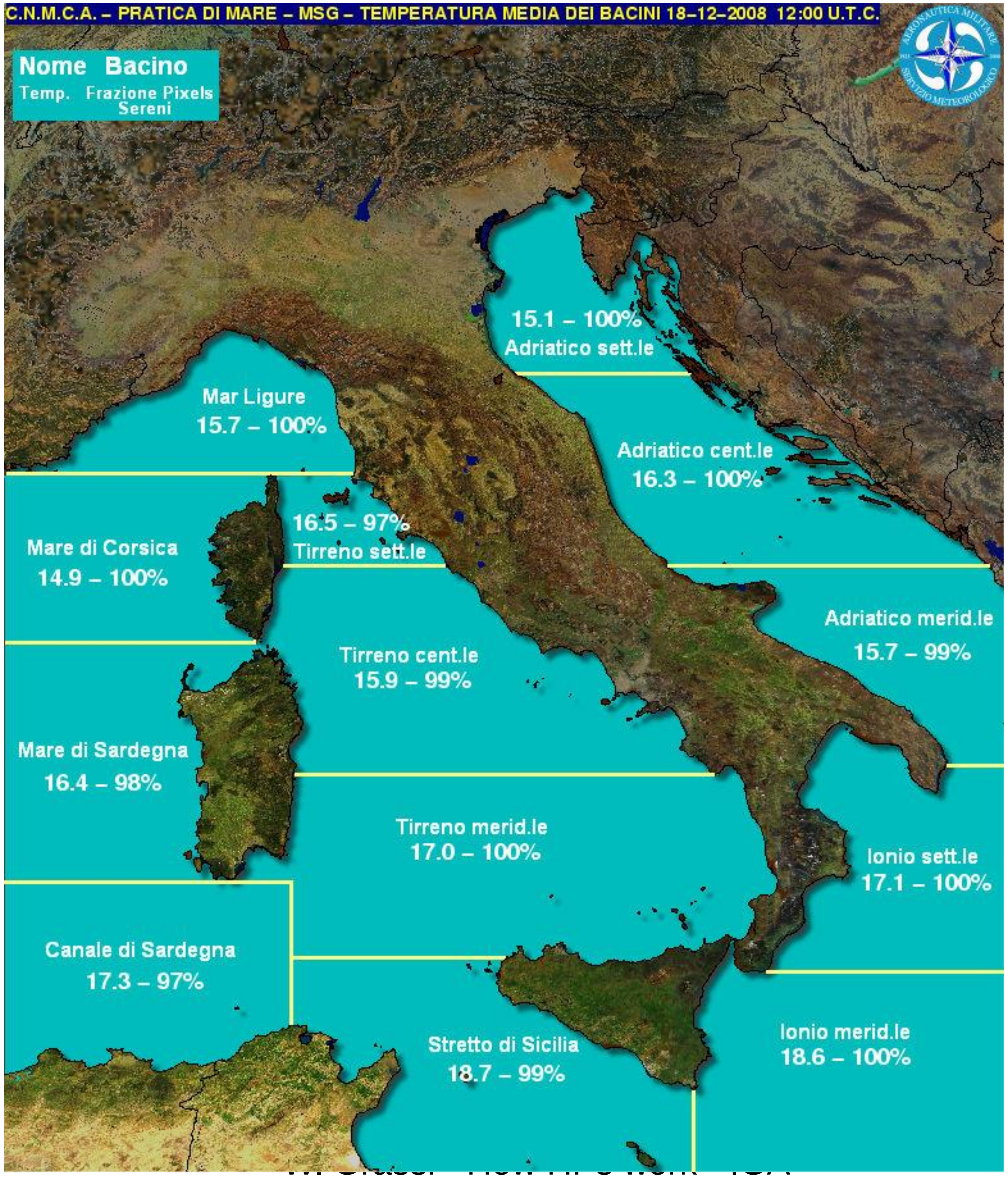
Air average month temperature in Pisa



External
unit

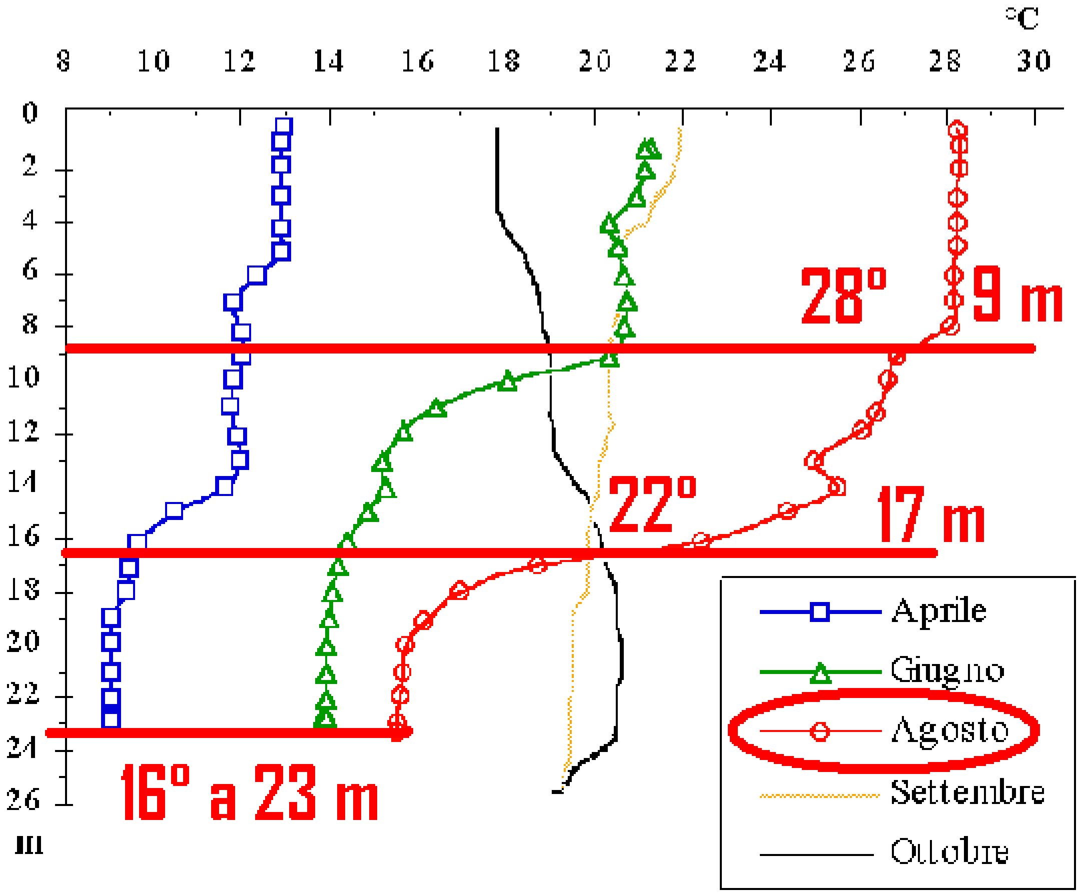
Internal
unit

Surface sea temperature in december



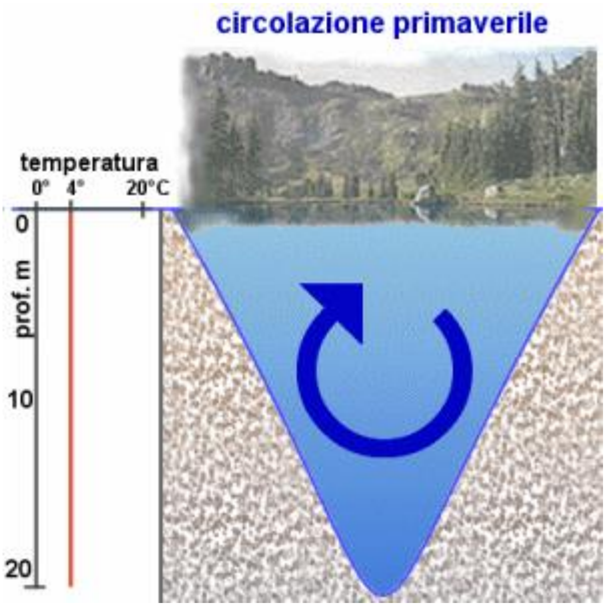
% refers to number of pixel from satellite image

sea temperature in spring summer and autumn



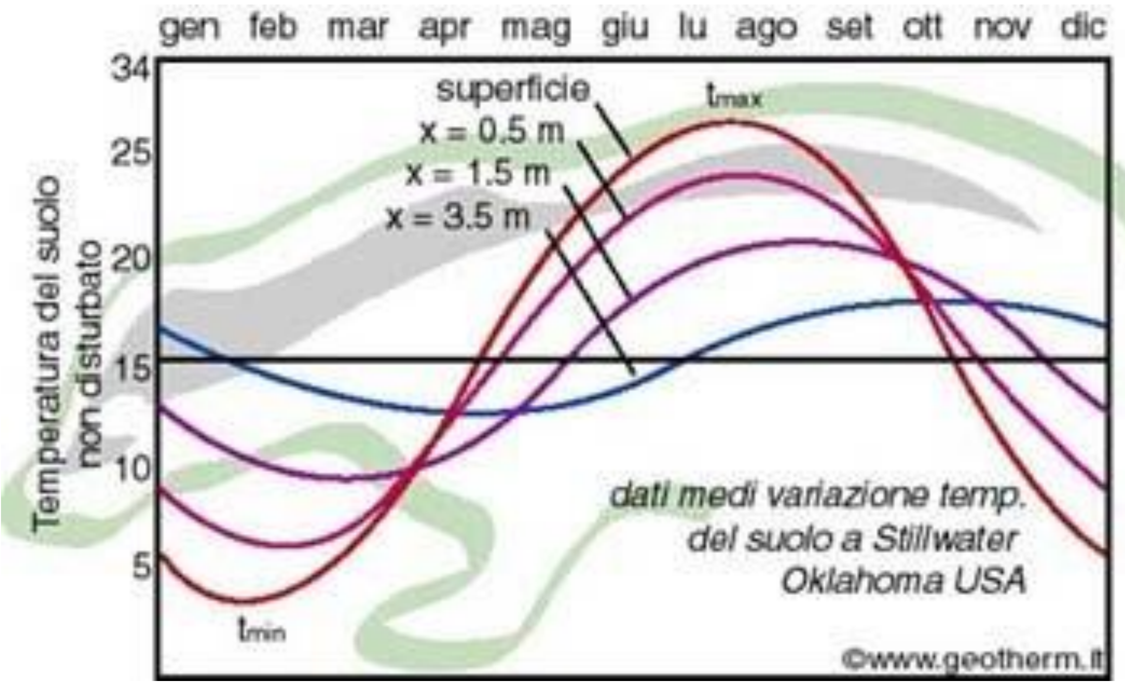
From ATMOSFERA TOSCANA

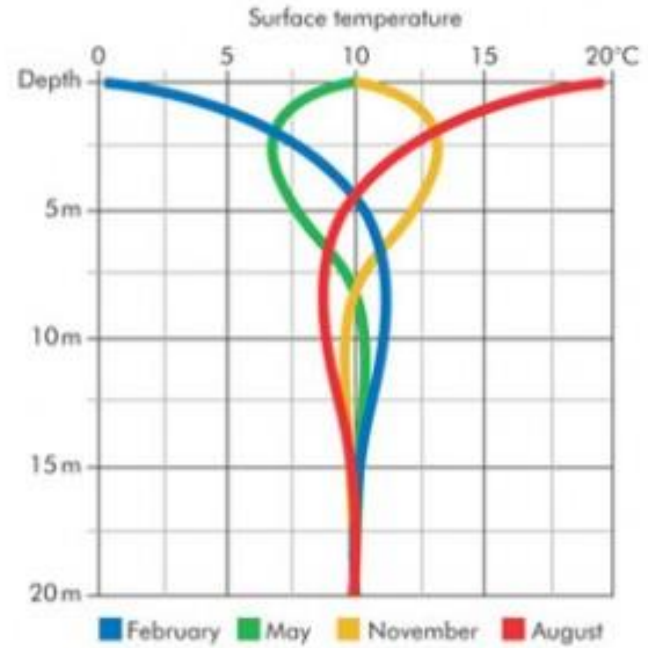
Mountain lake temperature in spring summer and autumn

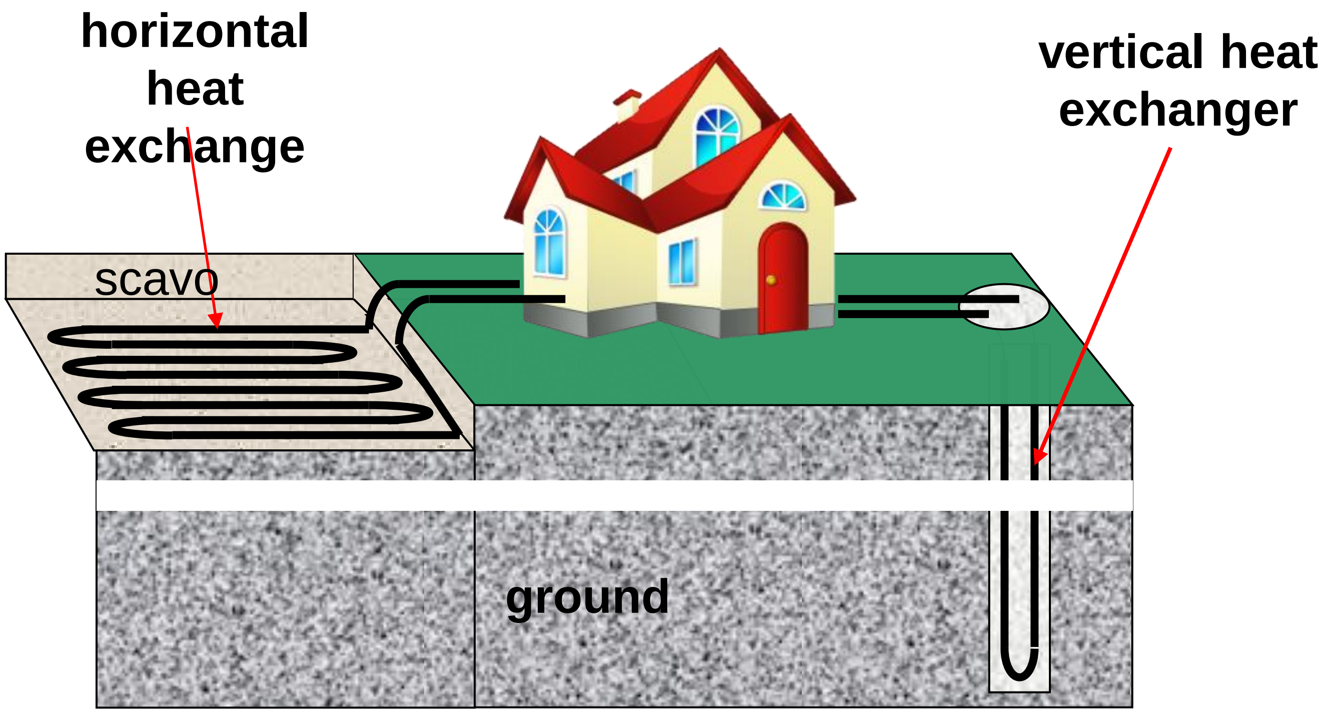


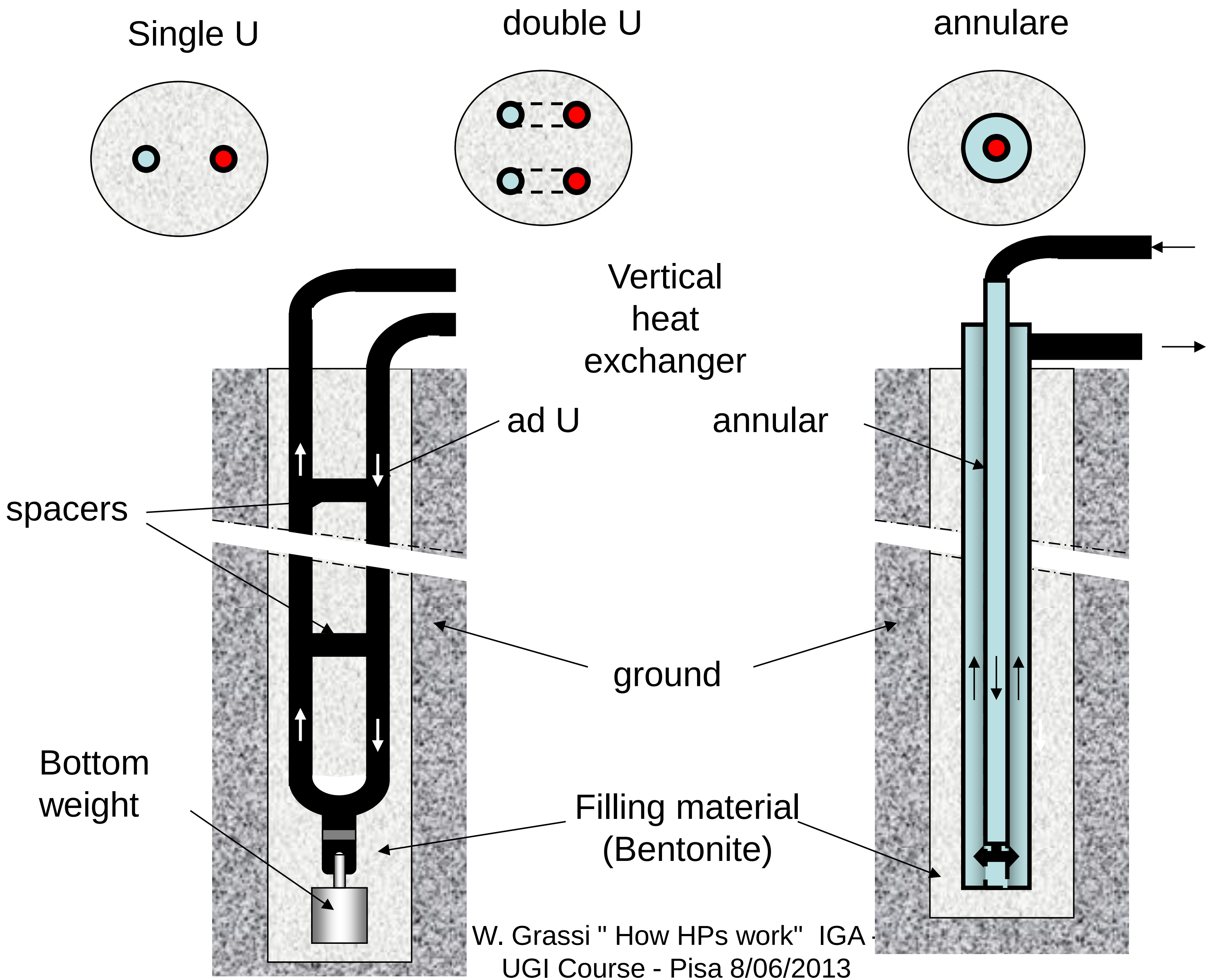
Underground water (not very deep) has more stable temperatures all over the year usually around 10-12°C.

Ground temperature



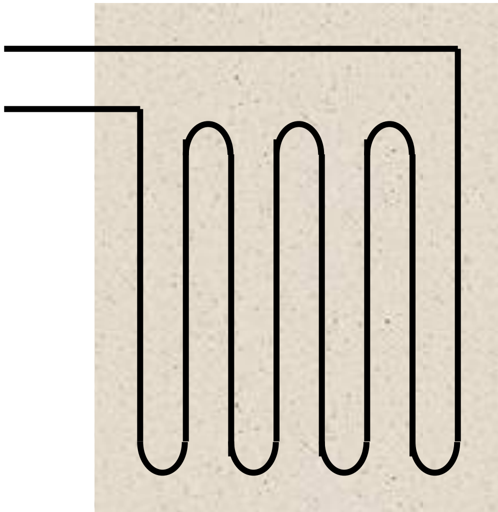



horizontal heat exchange
vertical heat exchanger
scavo
ground

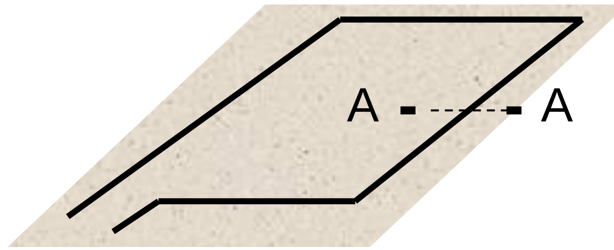


Single U
double U
annulare
Vertical
heat
exchanger
ad U
annular
spacers
ground
Bottom
weight
Filling material
(Bentonite)

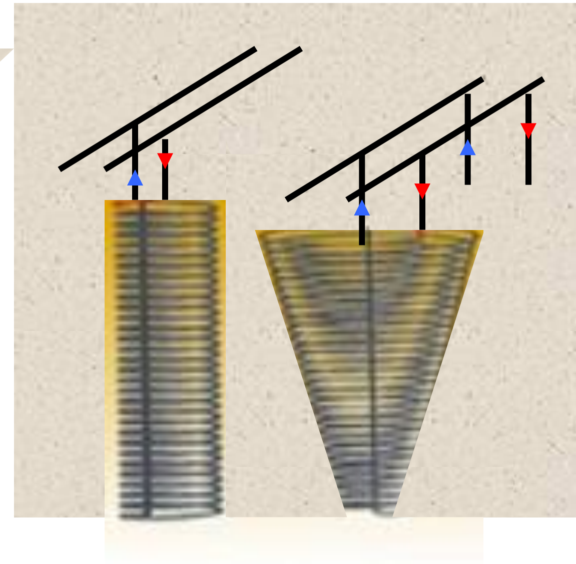
series layout

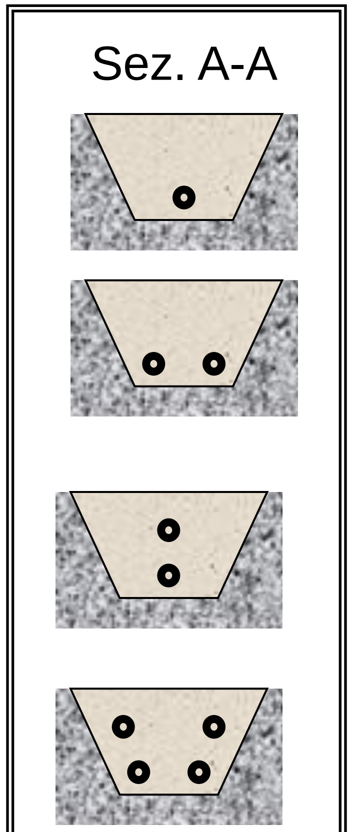


linear layout

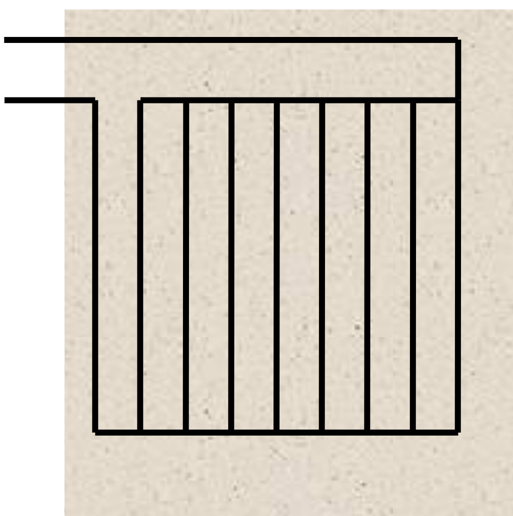


basket layout

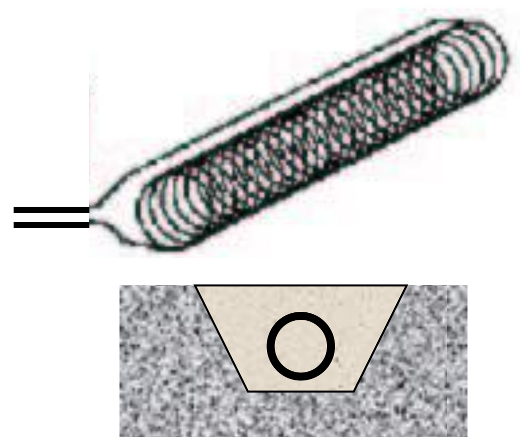


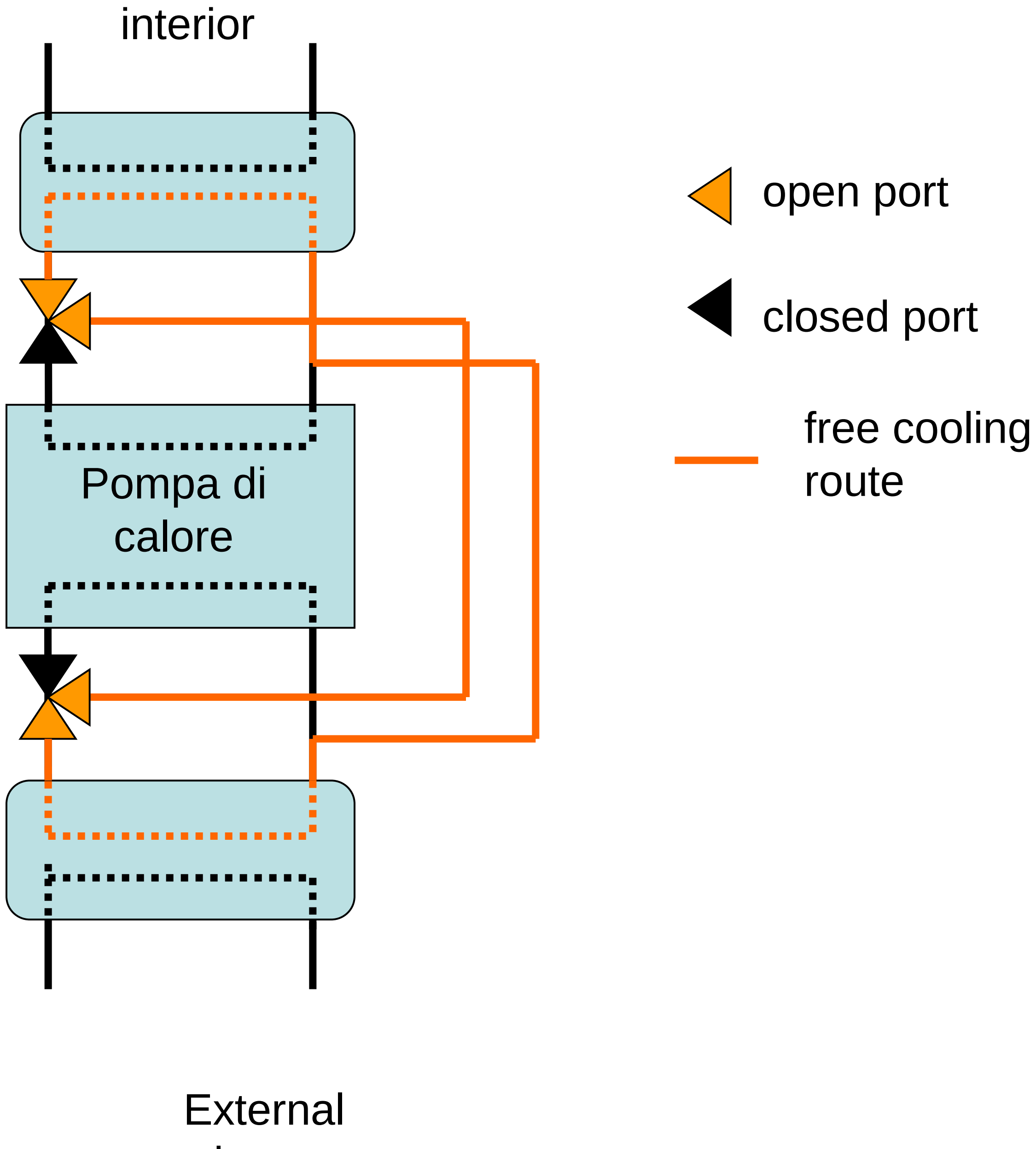


parallel layout



spiral layout

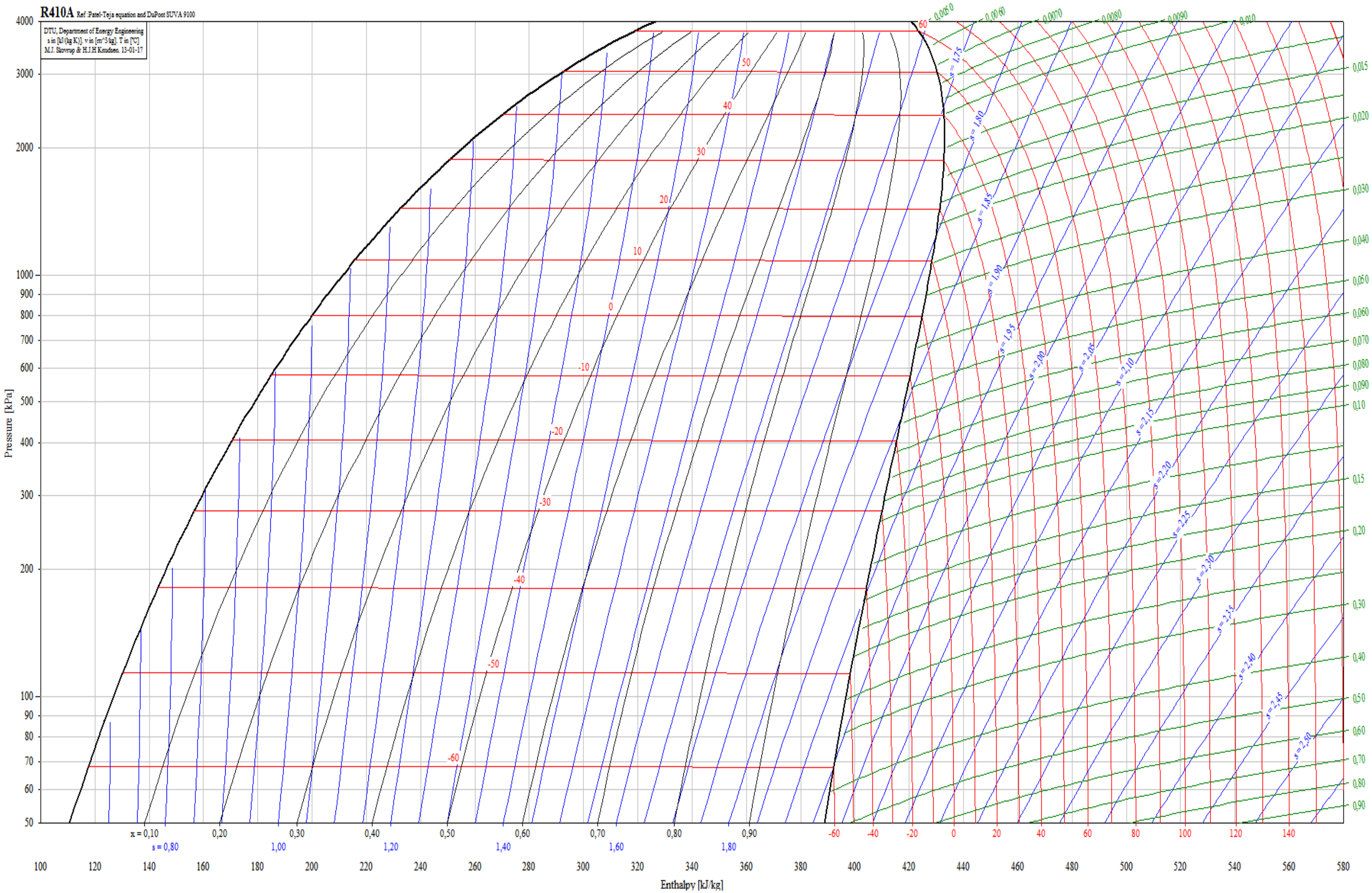


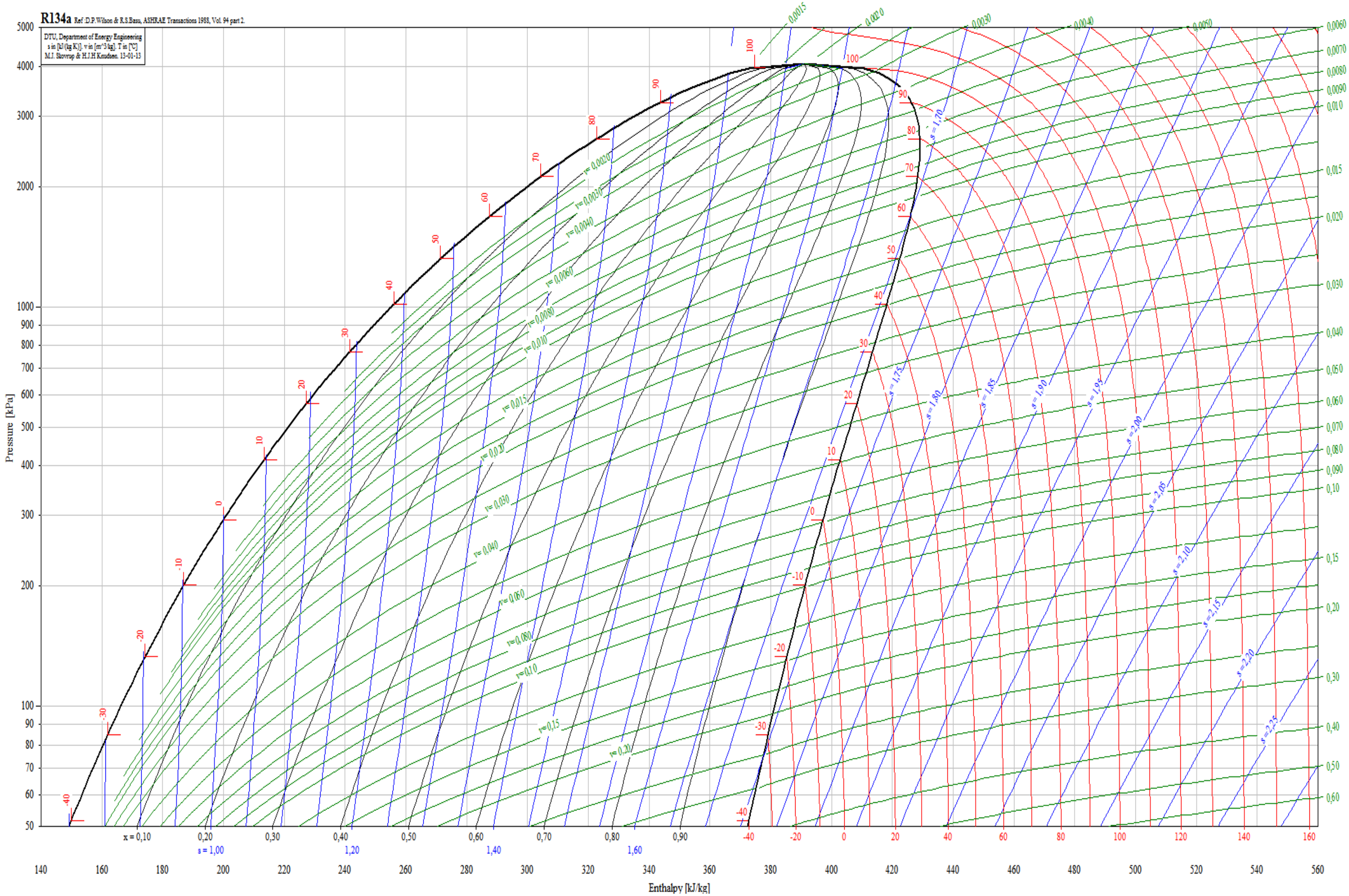

interior
Pompa di calore
open port
closed port
free cooling route
External environment

HP REFRIGERANTS

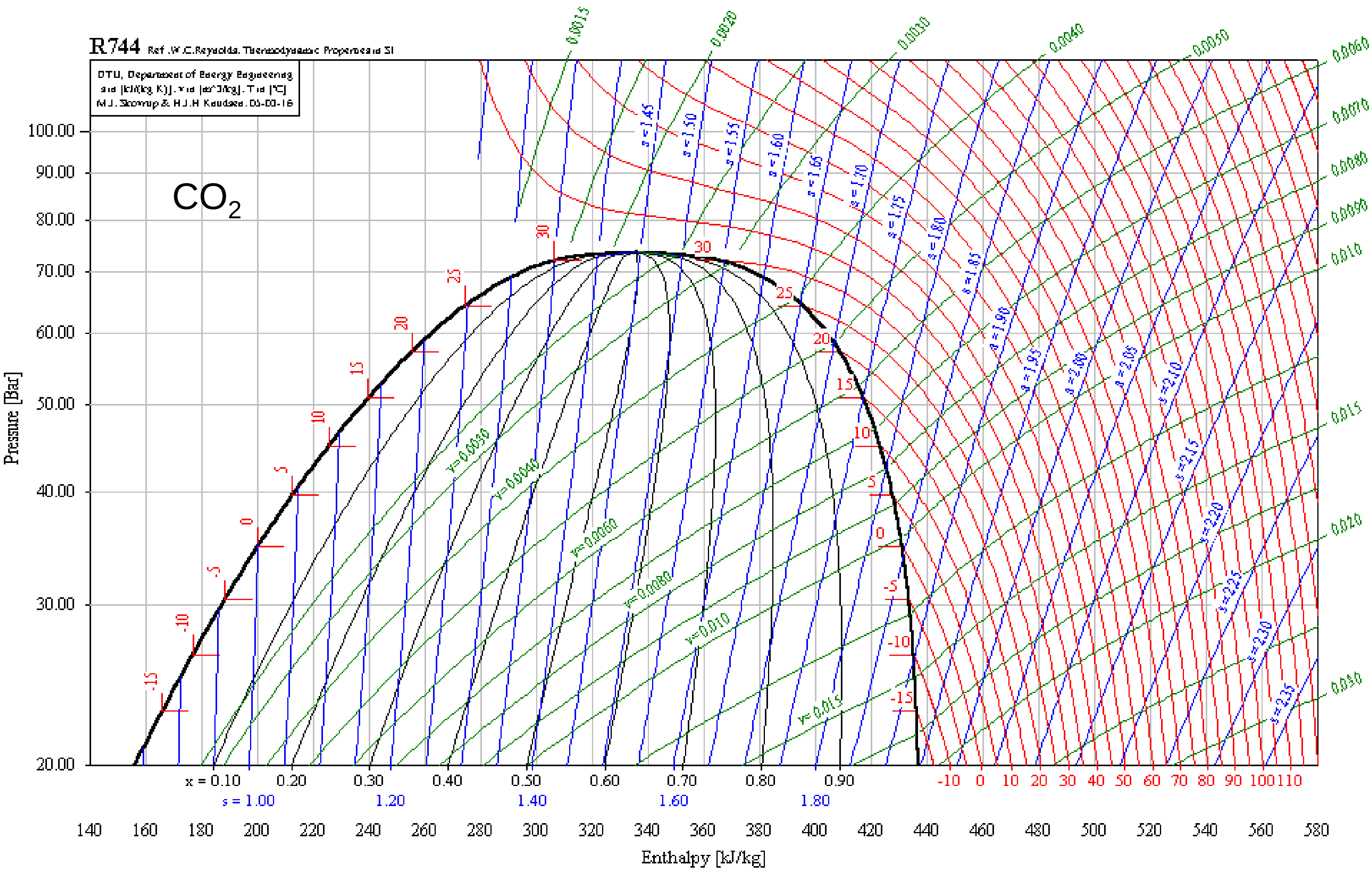
(enthalpy – pressure diagramms

R404A
Pressure [Bar]
40,00
30,00
20,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,90
0,80
0,70
0,60
0,50
120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480 500 520 540
Enthalpy [kJ/kg]


R410A Ref :Patel-Teja equation and DuPont SUVA 9100
DTU, Department of Energy Engineering
s in [kJ/(kg K)]. v in [m^3/kg]. T in [°C]
M.J. Skovrup & H.J.H Knudsen. 13-01-17
Pressure [kPa]
Enthalpy [kJ/kg]
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
x = 0,10
0,20
0,30
0,40
0,50
0,60
0,70
0,80
0,90
s = 0,80
1,00
1,20
1,40
1,60
1,80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580



From LCD Clima


R744 Ref.:W.C.Reynolds: Thermodynamic Properties in SI
DTU, Department of Energy Engineering
s in [kJ/(kg K)]. v in [m^3/kg]. T in [ºC]
M.J. Skovrup & H.J.H Knudsen. 05-03-16
CO2
Pressure [Bar]
Enthalpy [kJ/kg]
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
x = 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90
s = 1.00 1.20 1.40 1.60 1.80
-10 0 10 20 30 40 50 60 70 80 90 100 110
140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480 500 520 540 560 580

Before the lecture

MANY THANKS FOR YOUR

KIND ATTENTION

After the lecture