ATIC CONFERENCE - 16-11-2023

IEC or Indirect Evaporative Cooling

Air cooler and Water chiller

TUSSET Sylvano
ATIC

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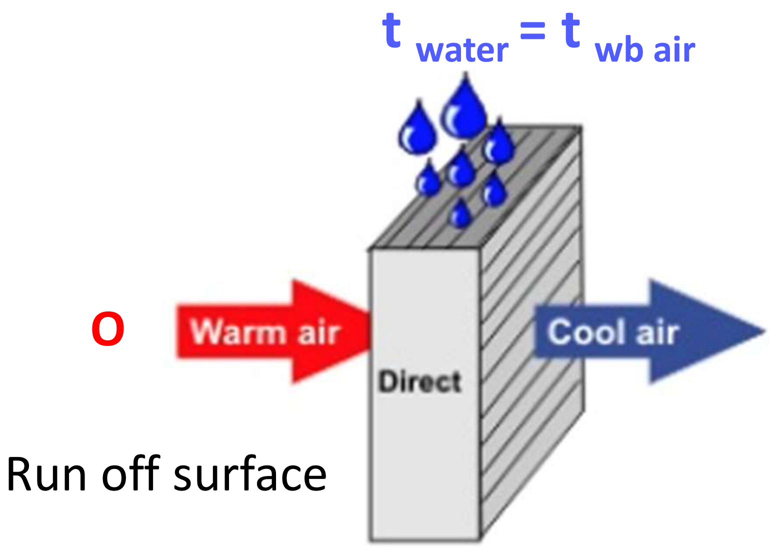
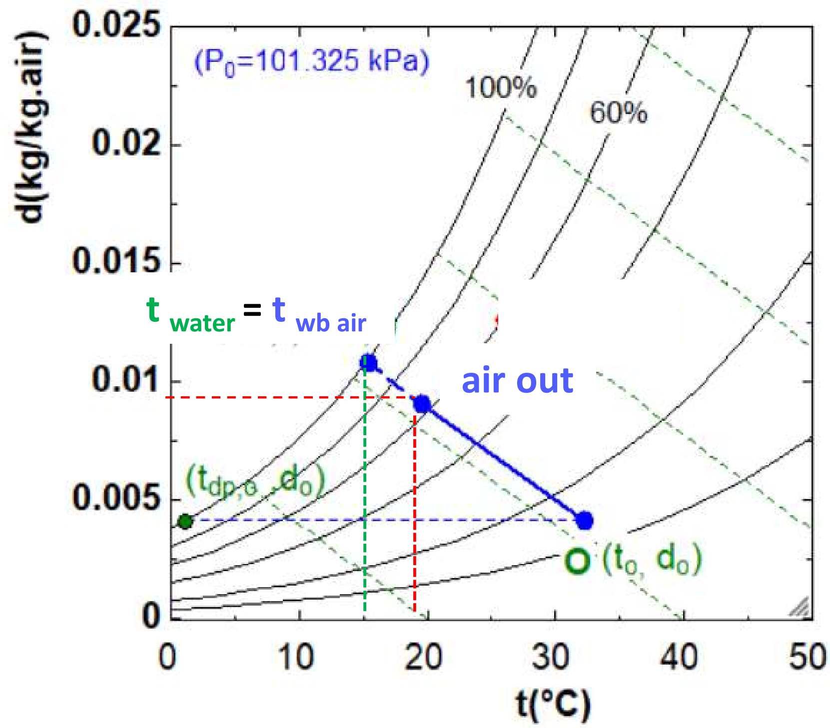
for HVAC professionals

Air Cooler

DEC : Direct cooling of air by evaporation of water



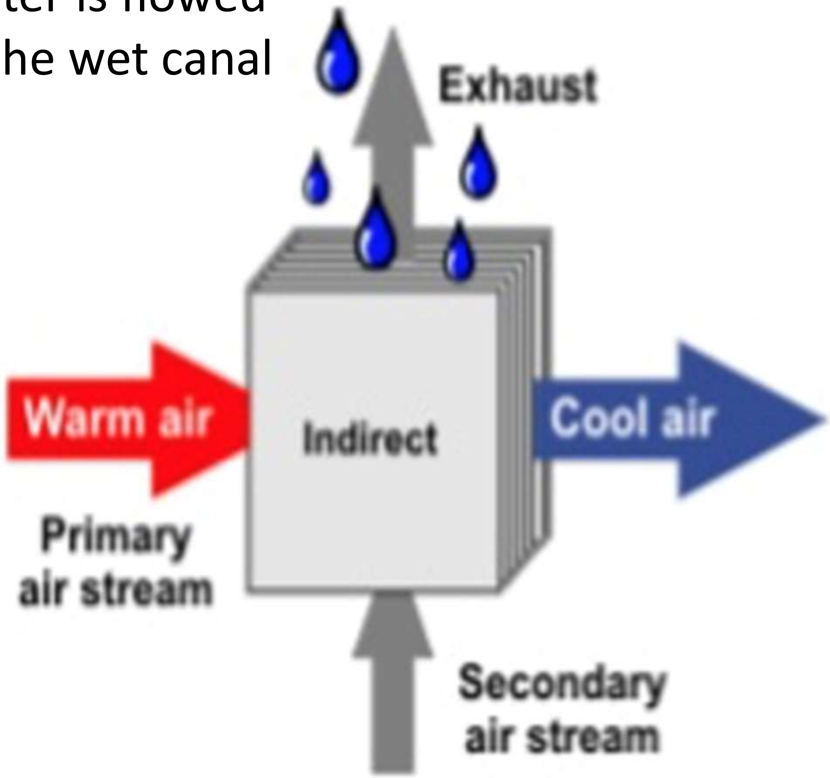


- When water flows along a runoff surface through the airflow. This air follows the line of the humid temperature (wb) if $t_{water} = t_{wb\ air}$ we have an almost adiabatic process
- The heat of vaporisation of water is drawn from the air stream, which is thus cooled and humidified
- The theorical lowest temperature (t_{out}) reached by the air is its humid temperature ($t_{wb,o}$)

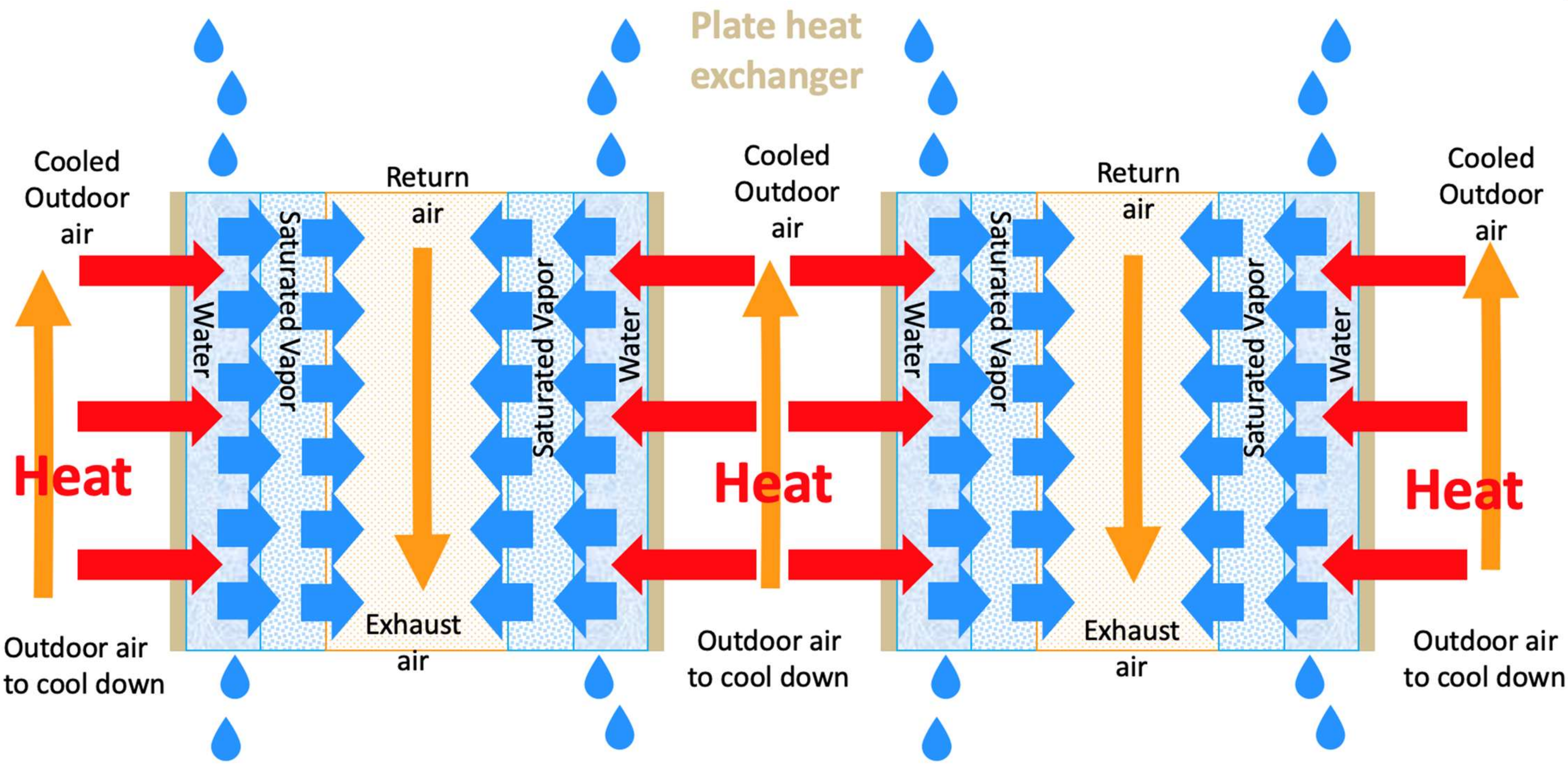
IEC : Indirect cooling of air by evaporation of water

The "IEC" process, or "indirect" evaporative cooling, is so called because an <u>air-to-air plate exchanger</u> has been integrated between a primary air flow and a secondary air flow.

Water is flowed in the wet canal



Evaporation of water in a plate heat exchanger



The evaporation of the water that runs off the plates is achieved by the heat coming from the primary air flow, which will thus cool.

In the secondary air flow, we have a simultaneous transfer of steam and heat

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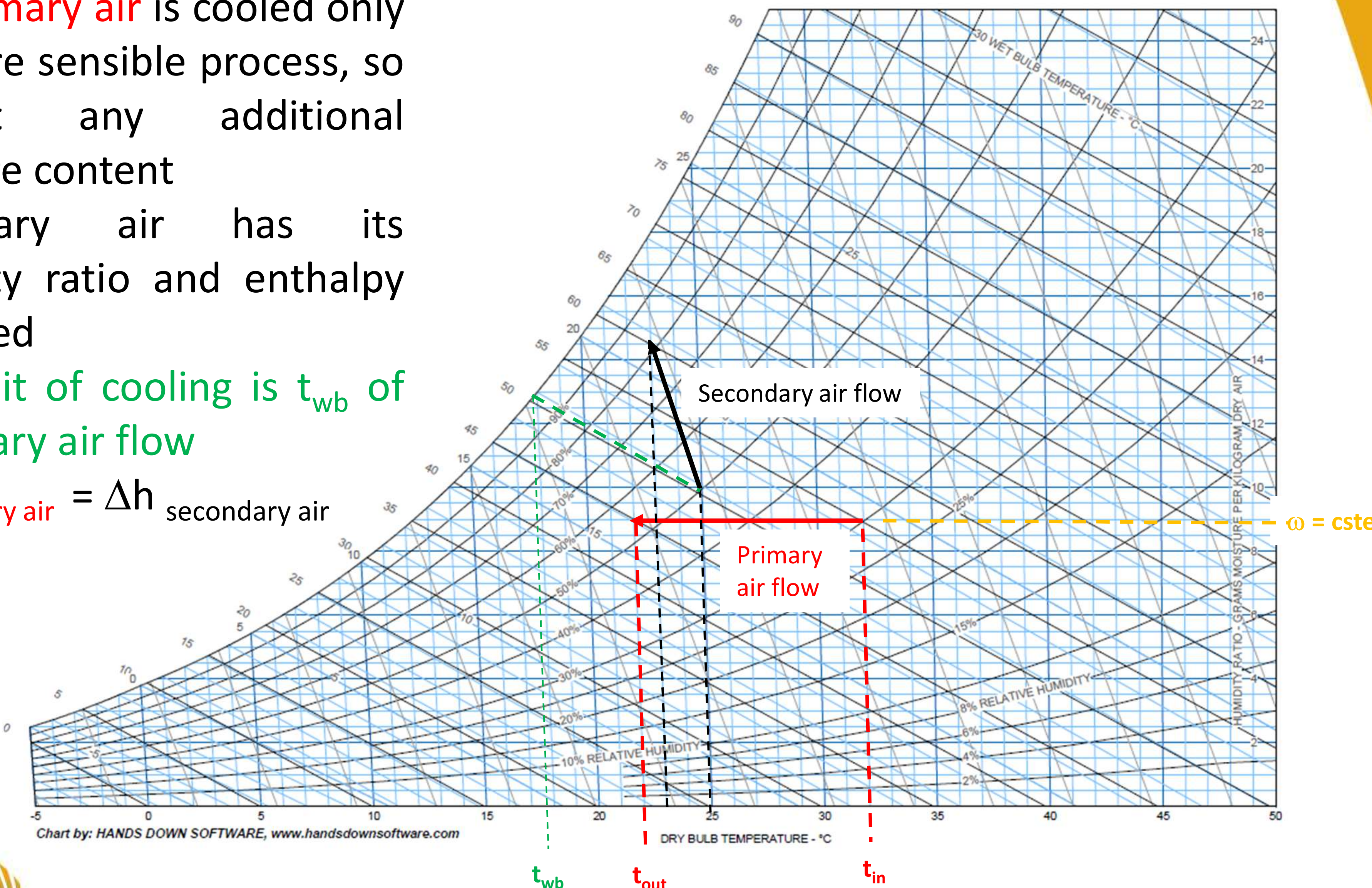
IEC : Indirect cooling of air by evaporation of water

The primary air is cooled only in a pure sensible process, so without any additional moisture content

Secondary air has its humidity ratio and enthalpy increased

The limit of cooling is t_{wb} of secondary air flow

$\Delta h_{\text{primary air}} = \Delta h_{\text{secondary air}}$



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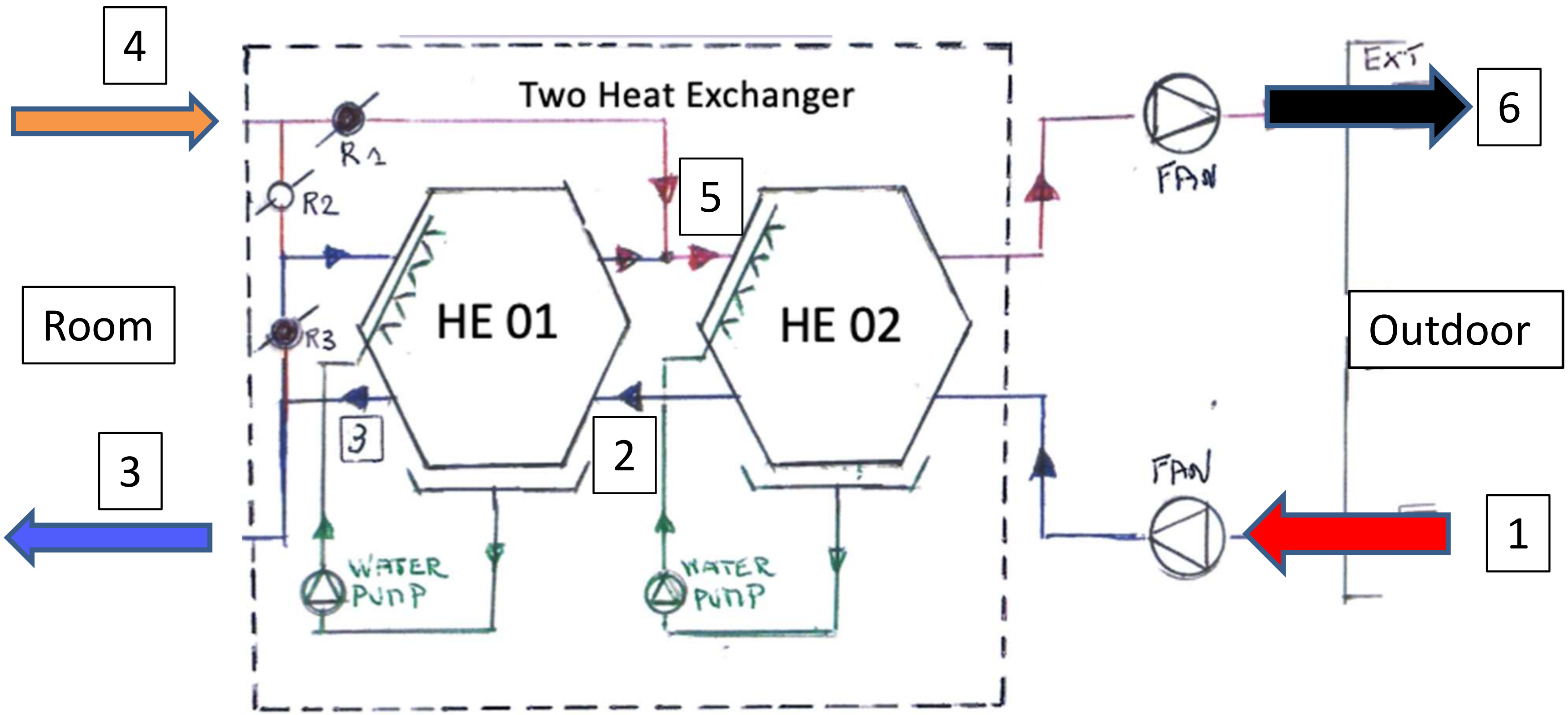
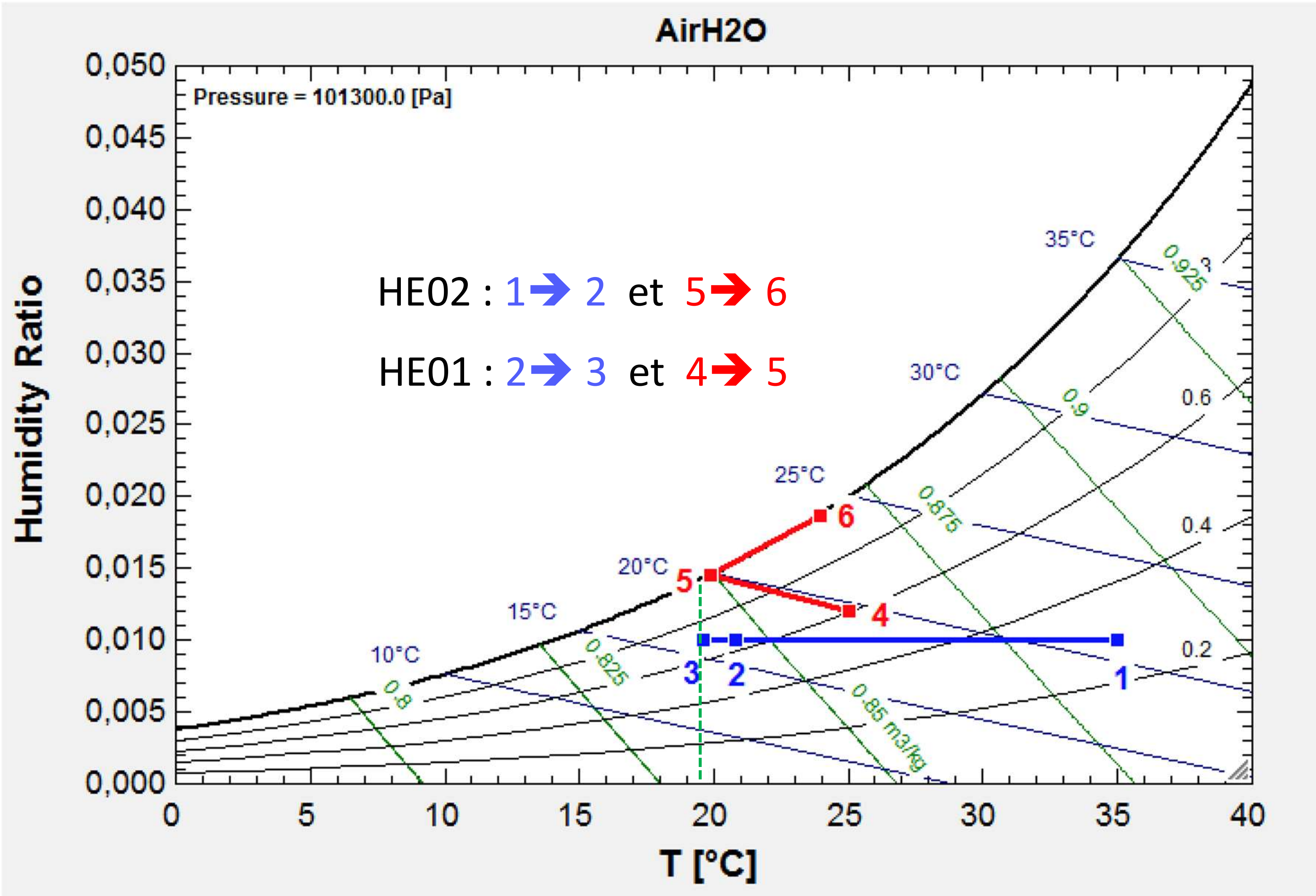
IEC : air cooler

There are several IEC air cooler configuration with one or two plate air/air exchangers that can be counter-current or cross-current.
The IEC air cooler can be separated (autonomous) or integrated in AHU.



Exchangers can operate in wet mode with sensible and latent heat exchange or in dry mode with sensible heat exchange only.

IEC : air cooler
Two Heat Exchanger with wetted plates



IEC : air cooler
Two Heat Exchanger with wetted plates

The simulation of the IEC air cooler is made on base of this Input conditions

- air flow 5000 m^3/h = 1,636 kg/s
- Outdoor climatic conditions : 35°/30%/ 0,0105 kg/kg/21,38° wb / 14,84° dp
- Secondary supply air or return temperature from the room t_4 set at 25°C/ 0.012 kg/kg /60 %

1 t_1 [C]	2 $rh_{HE02;prim;su}$ [-]	3 $T_{wb;HE02;prim;su}$ [C]	4 $t_{dp;HE02;prim;su}$ [C]	5 t_2 [C]	6 t_3 [C]	7 $T_{wb;HE01;second;su}$ [C]	8 t_4 [C]	9 t_6 [C]	10 t_5 [C]
35	0,2	18,69	8,707	20,78	19,58	19,49	25	23,91	19,87
35	0,3	21,38	14,84	20,79	19,59	19,49	25	23,93	19,87
35	0,5	26,02	23,02	20,82	19,59	19,49	25	23,99	19,88
32	0,2	16,81	6,252	20,57	19,57	19,49	25	23,05	19,81
32	0,3	19,25	12,27	20,58	19,57	19,49	25	23,07	19,81
32	0,5	23,56	20,28	20,6	19,57	19,49	25	23,11	19,82
30	0,2	15,55	4,613	20,42	19,56	19,49	25	22,49	19,77
30	0,3	17,84	10,55	20,43	19,56	19,49	25	22,5	19,77
30	0,5	21,91	18,45	20,44	19,56	19,49	25	22,53	19,78
30	0,6	23,74	21,39	20,45	19,56	19,49	25	22,54	19,78

The outlet temperature $t_3 \approx 19.6$°C

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Two Heat Exchanger with wetted plates

The simulation of the IEC air cooler is made on base of this Input conditions

- air flow 5000 m^3/h = 1,636 kg/s
- Outdoor climatic conditions : 35°/30%/ 0,0105 kg/kg/21,38° wb / 14,84° dp
- Secondary supply air or return temperature from the room t_4 set at 25°C/ 0.010 kg/kg 50 %

1 t_1 [C]	2 $rh_{HE02;prim;su}$ [-]	3 $T_{wb;HE02;prim;su}$ [C]	4 $t_{dp;HE02;prim;su}$ [C]	5 t_2 [C]	6 t_3 [C]	7 $T_{wb;HE01;second;su}$ [C]	8 t_4 [C]	9 t_6 [C]	10 t_5 [C]
35	0,2	18,69	8,707	19,47	18,03	17,9	25	22,93	18,44
35	0,3	21,38	14,84	19,48	18,03	17,9	25	22,96	18,45
35	0,5	26,02	23,02	19,52	18,04	17,9	25	23,02	18,47
32	0,2	16,81	6,252	19,24	18,01	17,9	25	22,07	18,38
32	0,3	19,25	12,27	19,25	18,01	17,9	25	22,1	18,38
32	0,5	23,56	20,28	19,28	18,02	17,9	25	22,14	18,39
30	0,2	15,55	4,613	19,08	18	17,9	25	21,51	18,33
30	0,3	17,84	10,55	19,09	18	17,9	25	21,52	18,34
30	0,5	21,91	18,45	19,11	18	17,9	25	21,55	18,35
30	0,6	23,74	21,39	19,12	18	17,9	25	21,57	18,35

The outlet temperature $t_3 \approx 18$°C

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IEC : air cooler
Two Heat Exchanger with wetted plates

The simulation of the IEC air cooler is made on base of this Input conditions

- air flow 5000 m^3/h = 1,636 kg/s
- Outdoor climatic conditions : 35°/30%/ 0,0105 kg/kg/21,38° wb / 14,84° dp
- Secondary supply air or return temperature from the room set at 25°C/ 0.012 kg/kg / 60 %

1 t_1 [C]	2 $rh_{HE02;prim;su}$ [-]	3 t_3 [C]	4 $T_{wb;HE01;second;su}$ [C]	5 $\dot{Q}_{useful}$ [W]	6 $\dot{Q}_{IEC}$ [W]	7 $\dot{W}_{fans}$ [W]	8 COP_{Useful}	9 COP_{IEC}	10 $\dot{M}_w$ [kg/s]
35	0,2	19,58	19,49	9068	25807	1643	5,52	15,71	0,01081
35	0,3	19,59	19,49	9064	25804	1655	5,477	15,59	0,01085
35	0,5	19,59	19,49	9057	25797	1681	5,389	15,35	0,01095
32	0,2	19,57	19,49	9094	20812	1630	5,58	12,77	0,00941
32	0,3	19,57	19,49	9091	20809	1640	5,543	12,69	0,00944
32	0,5	19,57	19,49	9087	20804	1661	5,47	12,52	0,009501
30	0,2	19,56	19,49	9112	17482	1622	5,62	10,78	0,008479
30	0,3	19,56	19,49	9111	17480	1631	5,587	10,72	0,008502
30	0,5	19,56	19,49	9107	17477	1649	5,522	10,6	0,008548
30	0,6	19,56	19,49	9105	17475	1659	5,49	10,54	0,008571

The COP useful is about ≈ 5.5 and the COP IEC from 10 to 15

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Two Heat Exchanger with wetted plates

The simulation of the IEC air cooler is made on base of this Input conditions

- air flow 5000 m^3/h = 1,636 kg/s
- Outdoor climatic conditions : 35°/30%/ 0,0105 kg/kg/21,38° wb / 14,84° dp
- Secondary supply air or return temperature from the room t_4 set at 25°C/ 0.010 kg/kg 50 %

1 t_1 [C]	2 $rh_{HE02;prim;su}$ [-]	3 t_3 [C]	4 $T_{wb;HE01;second;su}$ [C]	5 $\dot{Q}_{useful}$ [W]	6 $\dot{Q}_{IEC}$ [W]	7 $\dot{W}_{fans}$ [W]	8 COP_{Useful}	9 COP_{IEC}	10 $\dot{M}_w$ [kg/s]
35	0,2	18,03	17,9	11668	28408	1630	7,16	17,43	0,01248
35	0,3	18,03	17,9	11664	28403	1642	7,103	17,3	0,01252
35	0,5	18,04	17,9	11655	28394	1667	6,989	17,03	0,01262
32	0,2	18,01	17,9	11699	23417	1617	7,236	14,48	0,01107
32	0,3	18,01	17,9	11696	23413	1627	7,189	14,39	0,01111
32	0,5	18,02	17,9	11689	23407	1648	7,093	14,2	0,01118
30	0,2	18	17,9	11721	20091	1608	7,287	12,49	0,01015
30	0,3	18	17,9	11718	20088	1617	7,245	12,42	0,01017
30	0,5	18	17,9	11713	20083	1636	7,16	12,28	0,01022
30	0,6	18	17,9	11710	20080	1645	7,117	12,2	0,01025

The COP useful is about ≈ 7 and the COP IEC from 12 to 17

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IEC : air cooler : limit of temperature

The theoretical limit of cooled air is the humid temperature of the secondary inlet air t_4 : 25°/0,012 → wb = 19,49°C and 25°/0,010 → wb = 17,9°C

The small difference between the outlet temperature (t_3) of the air and the humid temperature of the secondary inlet air ($t_{wb\ secondary\ su}$) is due to the high efficiencies of the heat exchangers, which is too optimistic and will need to be reviewed

If the temperature limit was the dew point rather than the wet temperature, colder water could be produced and therefore allow wider use of the system. The dew point temperature dp is therefore a goal, and we will see how to approach it.

$\Delta_{wb\text{-}dp}$ = 4 à 7°C

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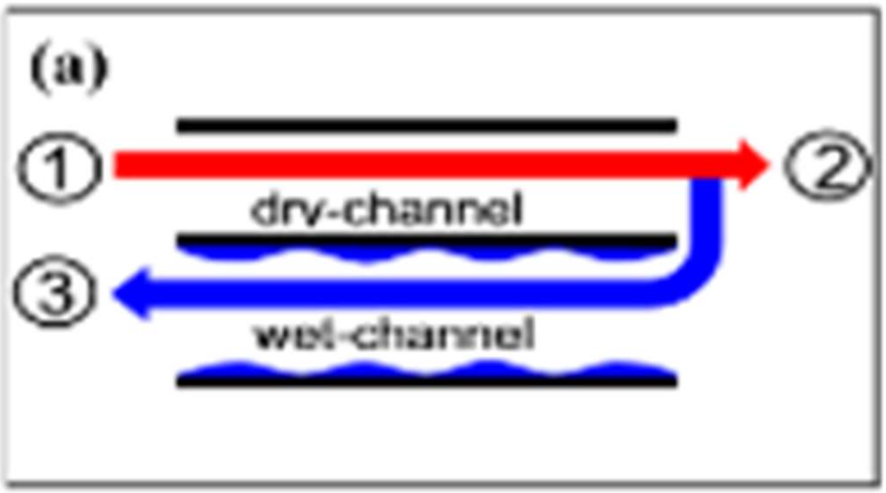
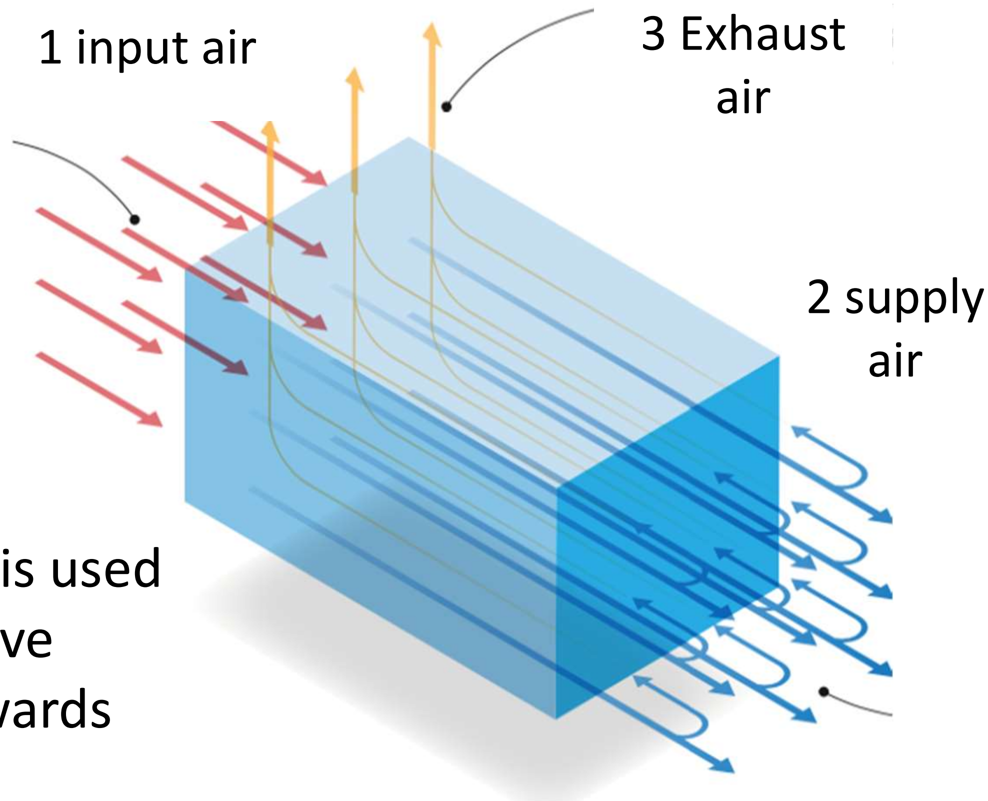
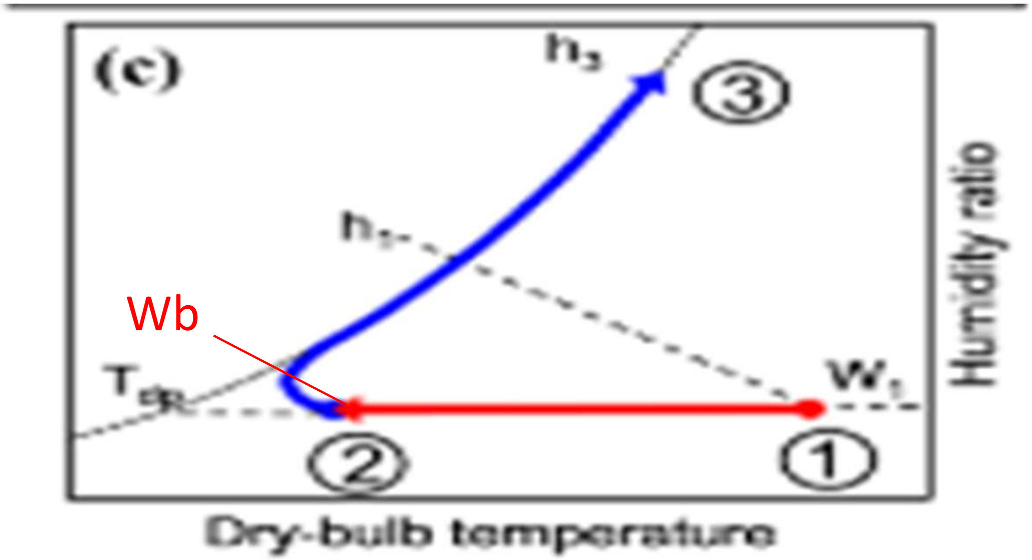
IEC : air cooler : Objectif dew point (dp)

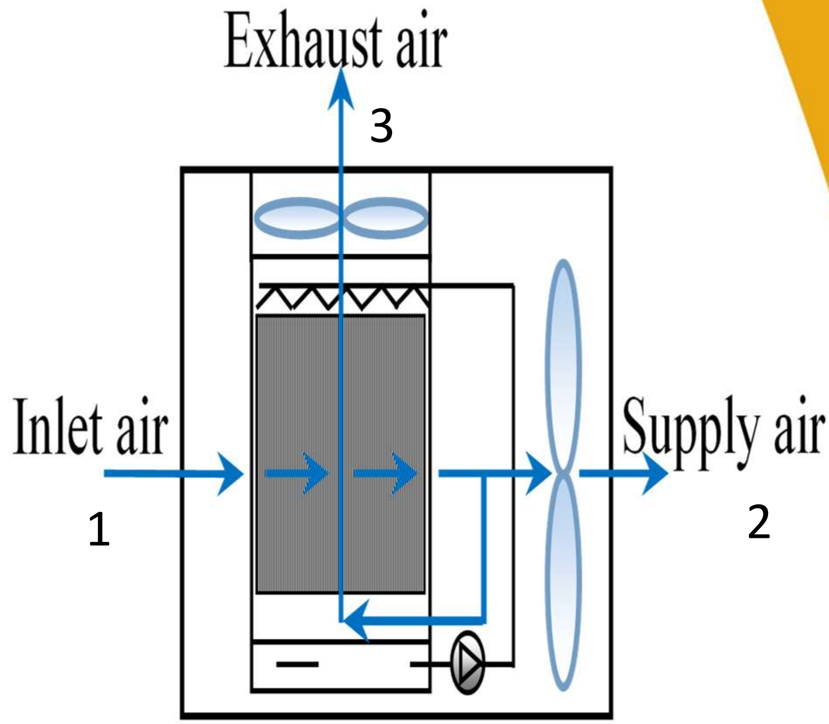




Part of the cooled primary air - point 2, is used as secondary inlet air into the evaporative exchanger, where the air will evolve towards point 3 along the saturation curve.

IEC : air cooler : Objectif dew point (dp)





The cooling limit temperature is now the dew point temperature (dew point or dp) of the inlet air (1) which is lower than its wet bulb temperature (wet bulb or wb)

The closer point A is to the saturation curve, the closer the wet bulb temperature is to the dew point temperature

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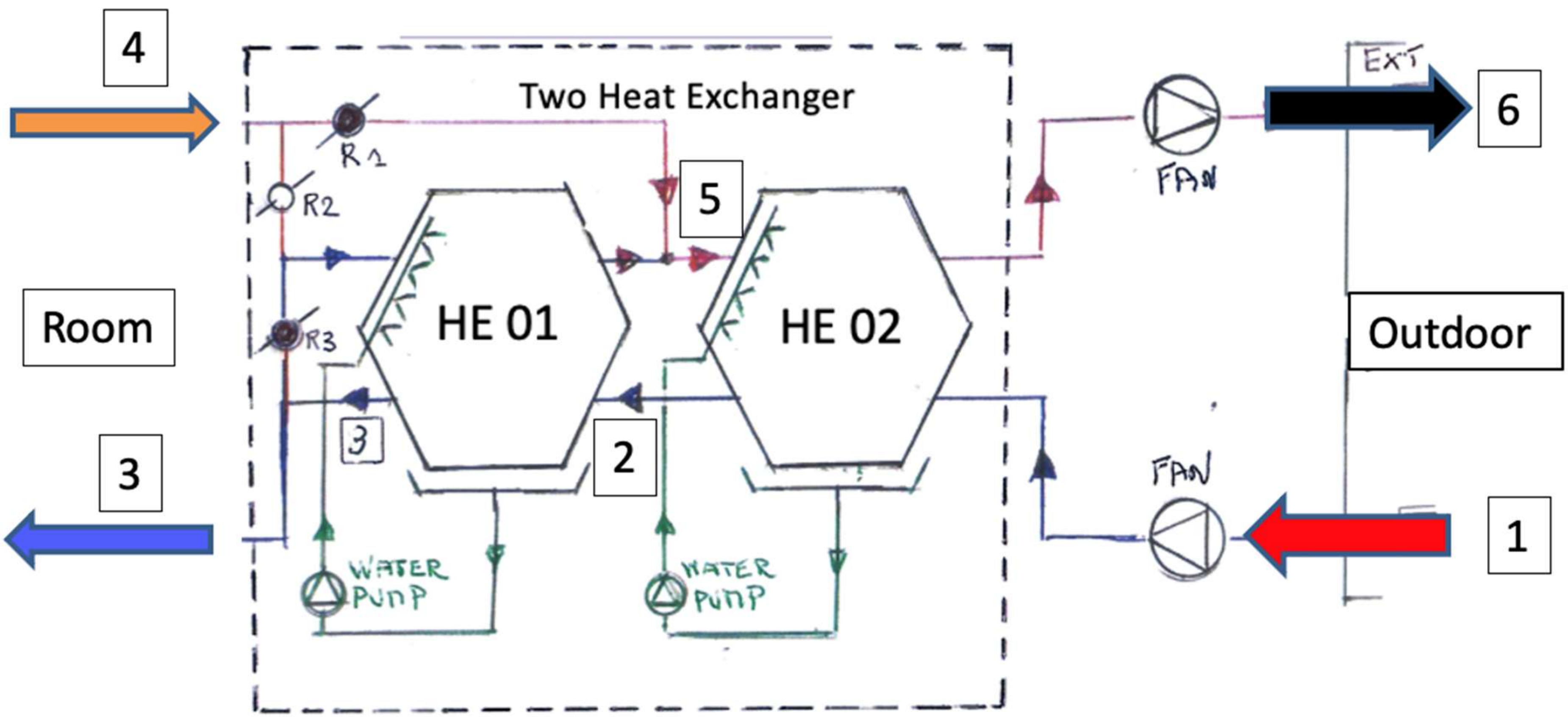
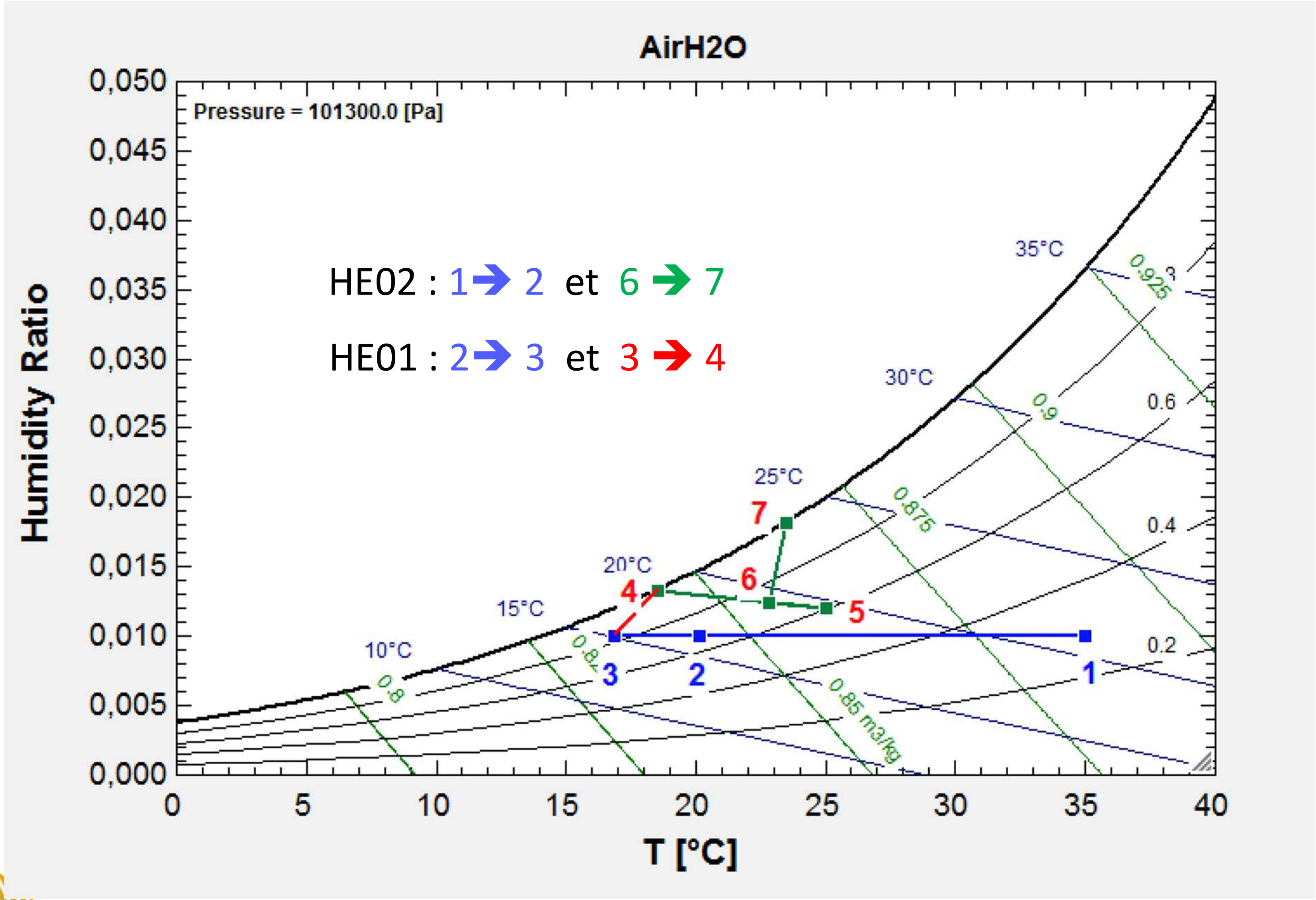
IEC : air cooler
Two Heat Exchanger with wetted plates and recycling

R2 closed and R1 and R3 open



IEC : air cooler
Two Heat Exchanger with wetted plates and recycling



IEC : air cooler

Two Heat Exchanger with wetted plates and recycling

The simulation of the IEC air cooler is made on base of this Input conditions

- air flow 5000 m^3/h = 1,636 kg/s
- air flow recirculated = 0,818 kg/s
- Outdoor climatic conditions : 35°/30%/ 0,0105 kg/kg/21,38° wb / 14,84° dp
- Secondary supply air or return temperature from the room t_4 set at 25°C/ 0.012 kg/kg /60 %

1 $T_{HE02;prim}$ [C]	2 $rh_{HE02;}$ [-]	3 $T_{wb;HE02;p}$	4 $t_{dp;HE02}$	5 $\dot{M}_{prim}$ [Kg/s]	6 $\dot{M}_{useful}$ [kg/s]	7 F_{recirc} [-]	8 $\dot{M}_{recirc}$ [kg/s]	9 t_1 [C]	10 t_2 [C]	11 t_3 [C]	12 $T_{wb;HE01;se}$ [C]	13 t_4 [C]	14 t_5 [C]	15 t_6 [C]	16 $T_{wb;HE02}$	17 t_7 [C]
35	0,2	18,69	8,707	2,454	1,636	0,5	0,818	35	19,79	14,51	11,25	17,28	25	22,42	18,74	23,19
35	0,3	21,38	14,84	2,454	1,636	0,5	0,818	35	20,23	17,28	15,71	18,73	25	22,91	19,23	23,53
35	0,5	26,02	23,02	2,454	1,636	0,5	0,818	35	21,21	22,38	22,84	21,85	25	23,94	20,31	24,31
32	0,2	16,81	6,252	2,454	1,636	0,5	0,818	32	19,46	13,53	9,682	16,7	25	22,23	18,55	22,26
32	0,3	19,25	12,27	2,454	1,636	0,5	0,818	32	19,82	15,93	13,7	17,92	25	22,64	18,95	22,53
32	0,5	23,56	20,28	2,454	1,636	0,5	0,818	32	20,62	20,41	20,31	20,48	25	23,49	19,83	23,15
30	0,2	15,55	4,613	2,454	1,636	0,5	0,818	30	19,24	12,93	8,717	16,34	25	22,12	18,44	21,65
30	0,3	17,84	10,55	2,454	1,636	0,5	0,818	30	19,56	15,1	12,43	17,42	25	22,47	18,79	21,89
30	0,5	21,91	18,45	2,454	1,636	0,5	0,818	30	20,25	19,19	18,68	19,67	25	23,22	19,55	22,41
30	0,6	23,74	21,39	2,454	1,636	0,5	0,818	30	20,63	21,1	21,3	20,86	25	23,61	19,96	22,7

The outlet temperature $t_3 \approx$ from 14.5°C to 22,4 °C

Atic for HVAC professionals

IEC : air cooler
Two Heat Exchanger with wetted plates and recycling

The simulation of the IEC air cooler is made on base of this Input conditions

- air flow 5000 m³/h = 1,636 kg/s
- air flow recirculated = 0,818 kg/s
- Outdoor climatic conditions : 35°/30%/ 0,0105 kg/kg/21,38° wb / 14,84° dp
- Secondary supply air or return temperature from the room t_4 set at 25°C/ 0.010 kg/kg /50 %

1 $T_{HE02;prim}$ [C]	2 $rh_{HE02;}$ [-]	3 $T_{wb;HE02;p}$	4 $t_{dp;HE02}$	5 $\dot{M}_{prim}$ [Kg/s]	6 $\dot{M}_{useful}$ [kg/s]	7 F_{recirc} [-]	8 $\dot{M}_{recirc}$ [kg/s]	9 t_1 [C]	10 t_2 [C]	11 t_3 [C]	12 $T_{wb;HE01;se}$ [C]	13 t_4 [C]	14 t_5 [C]	15 t_6 [C]	16 $T_{wb;HE02}$	17 t_7 [C]
35	0,2	18,69	8,707	2,454	1,636	0,5	0,818	35	18,6	13,97	11,02	16,46	25	22,15	17,39	22,35
35	0,3	21,38	14,84	2,454	1,636	0,5	0,818	35	19,06	16,78	15,53	17,95	25	22,64	17,9	22,69
35	0,5	26,02	23,02	2,454	1,636	0,5	0,818	35	20,07	21,97	22,73	21,09	25	23,69	19,02	23,46
32	0,2	16,81	6,252	2,454	1,636	0,5	0,818	32	18,26	12,97	9,437	15,86	25	21,95	17,19	21,42
32	0,3	19,25	12,27	2,454	1,636	0,5	0,818	32	18,63	15,4	13,49	17,11	25	22,36	17,61	21,69
32	0,5	23,56	20,28	2,454	1,636	0,5	0,818	32	19,46	19,95	20,17	19,71	25	23,23	18,52	22,3
30	0,2	15,55	4,613	2,454	1,636	0,5	0,818	30	18,03	12,36	8,461	15,48	25	21,82	17,07	20,8
30	0,3	17,84	10,55	2,454	1,636	0,5	0,818	30	18,36	14,56	12,21	16,6	25	22,19	17,43	21,04
30	0,5	21,91	18,45	2,454	1,636	0,5	0,818	30	19,08	18,7	18,52	18,89	25	22,96	18,23	21,56
30	0,6	23,74	21,39	2,454	1,636	0,5	0,818	30	19,46	20,65	21,17	20,09	25	23,35	18,66	21,85

The outlet temperature $t_3 \approx$ from 14°C to 22°C

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Two Heat Exchanger with wetted plates and recycling

The simulation of the IEC air cooler is made on base of this Input conditions

- air flow 5000 m^3/h = 1,636 kg/s
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1 $T_{HE02;prim}$ [C]	2 $rh_{HE02;}$ [-]	3 $T_{wb;HE02;p}$	4 $t_{dp;HE02}$	5 $\dot{M}_{prim}$ [Kg/s]	6 $\dot{M}_{useful}$ [kg/s]	7 F_{recirc} [-]	8 $\dot{M}_{recirc}$ [kg/s]	9 t_1 [C]	10 t_3 [C]	11 $T_{wb;HE01;second;su}$ [C]	12 $\dot{Q}_{useful}$ [W]	13 $\dot{Q}_{IEC}$ [W]	14 $\dot{W}_{fans}$ [W]	15 COP_{Useful} [-]	16 COP_{IEC} [-]	17 $\dot{M}_w$ [kg/s]
35	0,2	18,69	8,707	2,454	1,636	0,5	0,818	35	14,51	11,25	26348	51458	4197	6,278	12,26	0,01848
35	0,3	21,38	14,84	2,454	1,636	0,5	0,818	35	17,28	15,71	19378	44487	4251	4,558	10,47	0,01642
35	0,5	26,02	23,02	2,454	1,636	0,5	0,818	35	22,38	22,84	6570	31679	4365	1,505	7,258	0,01243
32	0,2	16,81	6,252	2,454	1,636	0,5	0,818	32	13,53	9,682	28802	46379	4150	6,94	11,18	0,01707
32	0,3	19,25	12,27	2,454	1,636	0,5	0,818	32	15,93	13,7	22778	40354	4195	5,43	9,62	0,0153
32	0,5	23,56	20,28	2,454	1,636	0,5	0,818	32	20,41	20,31	11535	29112	4288	2,69	6,789	0,01186
30	0,2	15,55	4,613	2,454	1,636	0,5	0,818	30	12,93	8,717	30298	42853	4120	7,353	10,4	0,0161
30	0,3	17,84	10,55	2,454	1,636	0,5	0,818	30	15,1	12,43	24855	37409	4160	5,975	8,993	0,0145
30	0,5	21,91	18,45	2,454	1,636	0,5	0,818	30	19,19	18,68	14600	27155	4241	3,442	6,402	0,01139
30	0,6	23,74	21,39	2,454	1,636	0,5	0,818	30	21,1	21,3	9788	22343	4284	2,285	5,216	0,009868

The COP useful is about ≈ from 1,5 to 7,3 and the COP IEC ≈ From 5 to 12

Atic for HVAC professionals

IEC : air cooler
Two Heat Exchanger with wetted plates and recycling

The simulation of the IEC air cooler is made on base of this Input conditions

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1 $T_{HE02;prim}$ [C]	2 $rh_{HE02;}$ [-]	3 $T_{wb;HE02;p}$	4 $t_{dp;HE02}$	5 $\dot{M}_{prim}$ [Kg/s]	6 $\dot{M}_{useful}$ [kg/s]	7 F_{recirc} [-]	8 $\dot{M}_{recirc}$ [kg/s]	9 t_1 [C]	10 t_3 [C]	11 $T_{wb;HE01;second;su}$ [C]	12 $\dot{Q}_{useful}$ [W]	13 $\dot{Q}_{IEC}$ [W]	14 $\dot{W}_{fans}$ [W]	15 COP_{Useful} [-]	16 COP_{IEC} [-]	17 $\dot{M}_w$ [kg/s]
35	0,2	18,69	8,707	2,454	1,636	0,5	0,818	35	14,51	11,25	26348	51458	4197	6,278	12,26	0,01848
35	0,3	21,38	14,84	2,454	1,636	0,5	0,818	35	17,28	15,71	19378	44487	4251	4,558	10,47	0,01642
35	0,5	26,02	23,02	2,454	1,636	0,5	0,818	35	22,38	22,84	6570	31679	4365	1,505	7,258	0,01243
32	0,2	16,81	6,252	2,454	1,636	0,5	0,818	32	13,53	9,682	28802	46379	4150	6,94	11,18	0,01707
32	0,3	19,25	12,27	2,454	1,636	0,5	0,818	32	15,93	13,7	22778	40354	4195	5,43	9,62	0,0153
32	0,5	23,56	20,28	2,454	1,636	0,5	0,818	32	20,41	20,31	11535	29112	4288	2,69	6,789	0,01186
30	0,2	15,55	4,613	2,454	1,636	0,5	0,818	30	12,93	8,717	30298	42853	4120	7,353	10,4	0,0161
30	0,3	17,84	10,55	2,454	1,636	0,5	0,818	30	15,1	12,43	24855	37409	4160	5,975	8,993	0,0145
30	0,5	21,91	18,45	2,454	1,636	0,5	0,818	30	19,19	18,68	14600	27155	4241	3,442	6,402	0,01139
30	0,6	23,74	21,39	2,454	1,636	0,5	0,818	30	21,1	21,3	9788	22343	4284	2,285	5,216	0,009868

The COP useful is about ≈ from 1,5 to 7,3 and the COP IEC ≈ from 5 to 12

Atic for HVAC professionals

2ème partie

Water cooling

Cooling Towers

- Previous processes (IEC air cooler) were designed to cool air. We will now look at processes designed to cool water with cooling tower.
- In office buildings and industry, cooling towers are used to cool water from condensers in refrigeration machines.
- But it can also be used to produce cold water when climatic conditions allow, known as "free chilling".
- It is possible to produce cold water for a longer period of time even when the external climatic conditions no longer allow free chilling.

The principle of a cooling tower

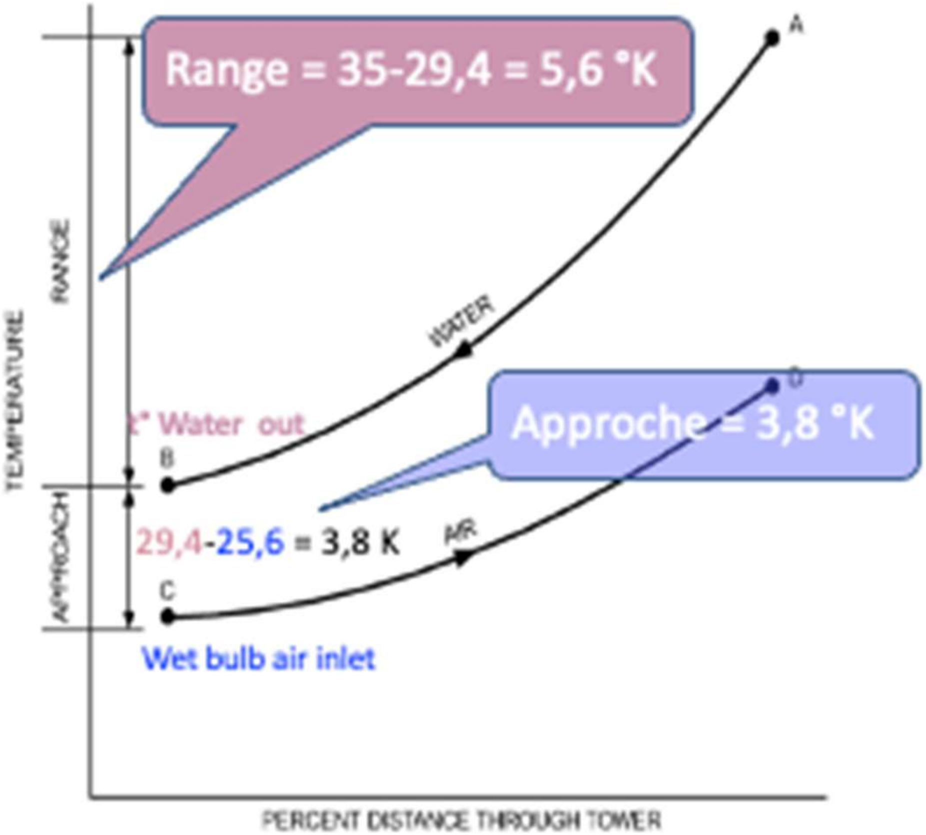
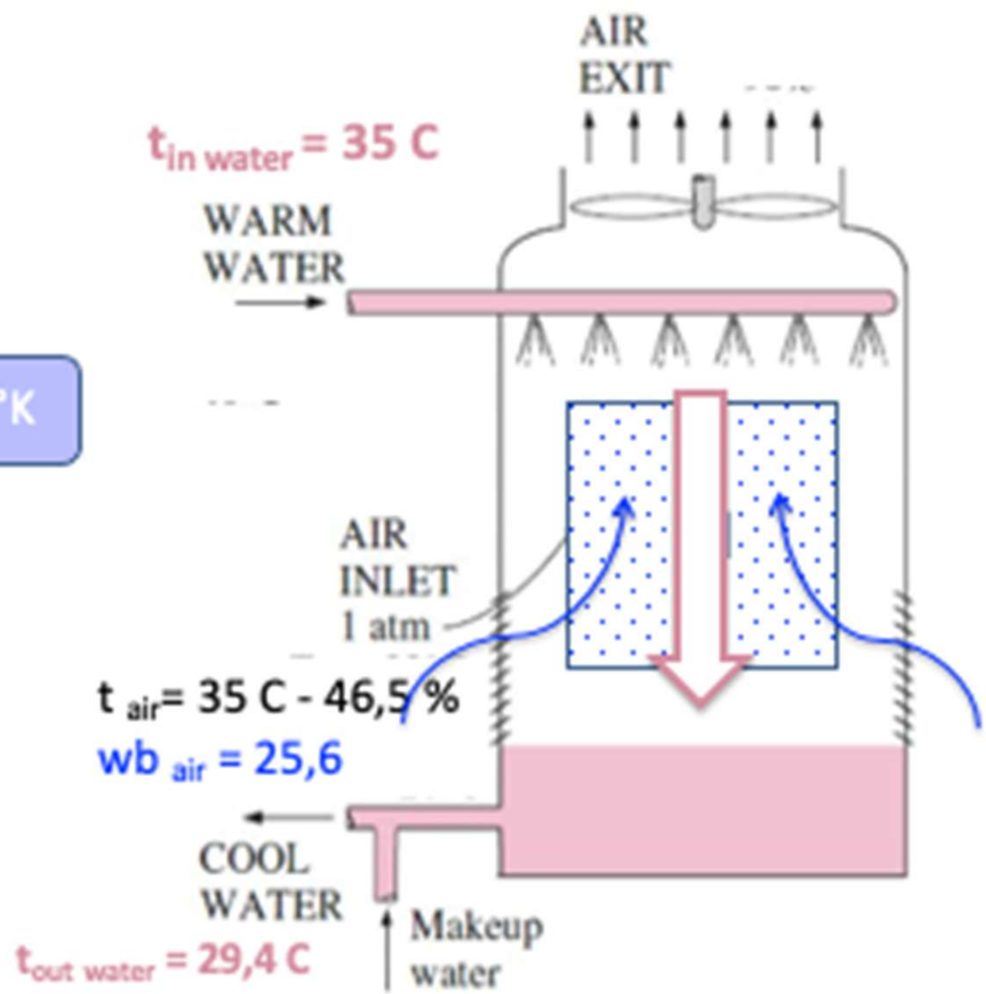


Fig. 1 Temperature Relationship Between Water and Air in Counterflow Cooling Tower

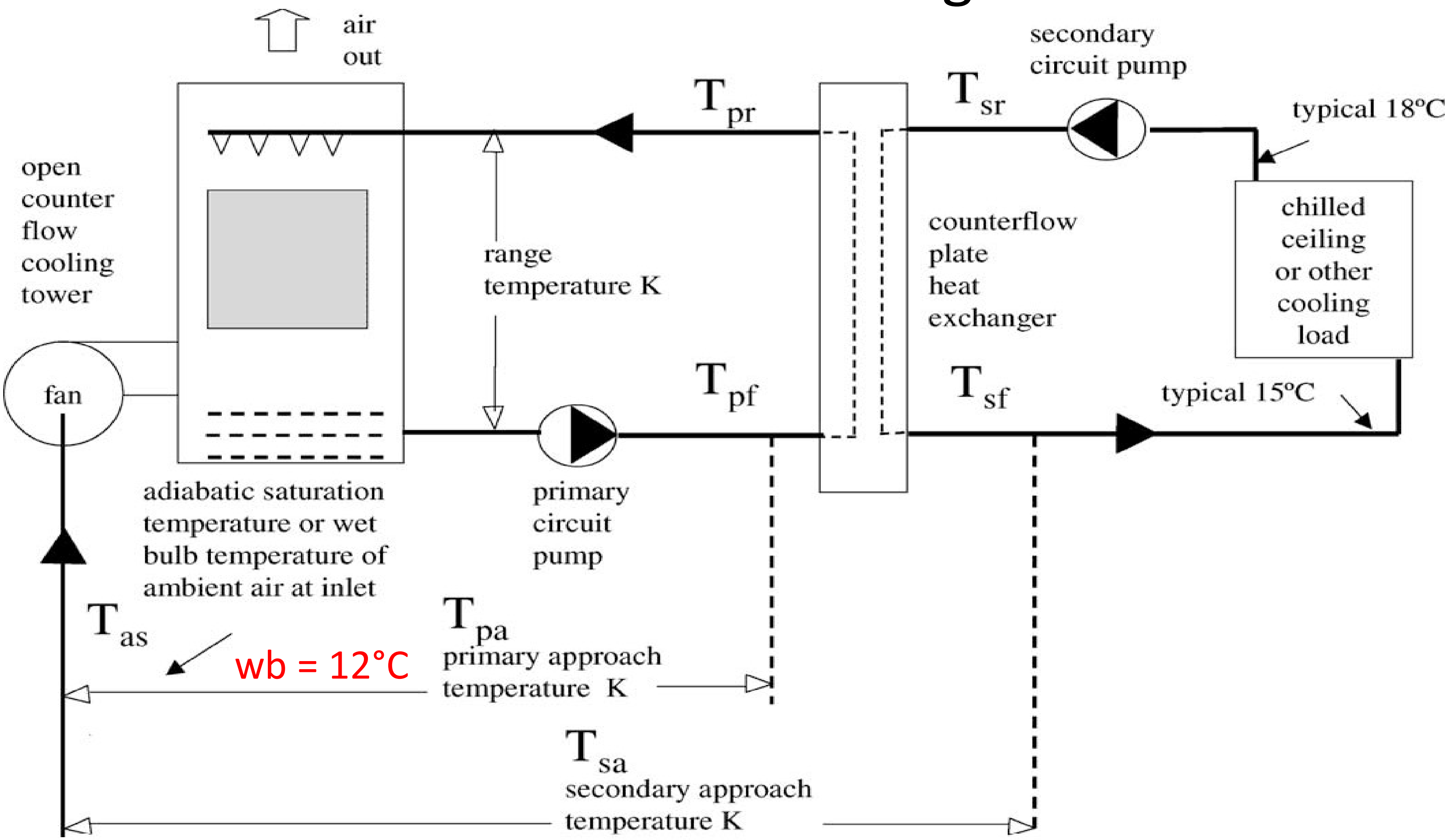


The lowest theoretical cold-water temperature that can be produced is the wet bulb temperature of the outside air or the air entering the tower. But the actual temperature of the water leaving the practical devices is about 3 to 4° higher than the temperature of the wet bulb of the outside air

(this is known as the tower selection approach) .

TS1

« Free » Chilling



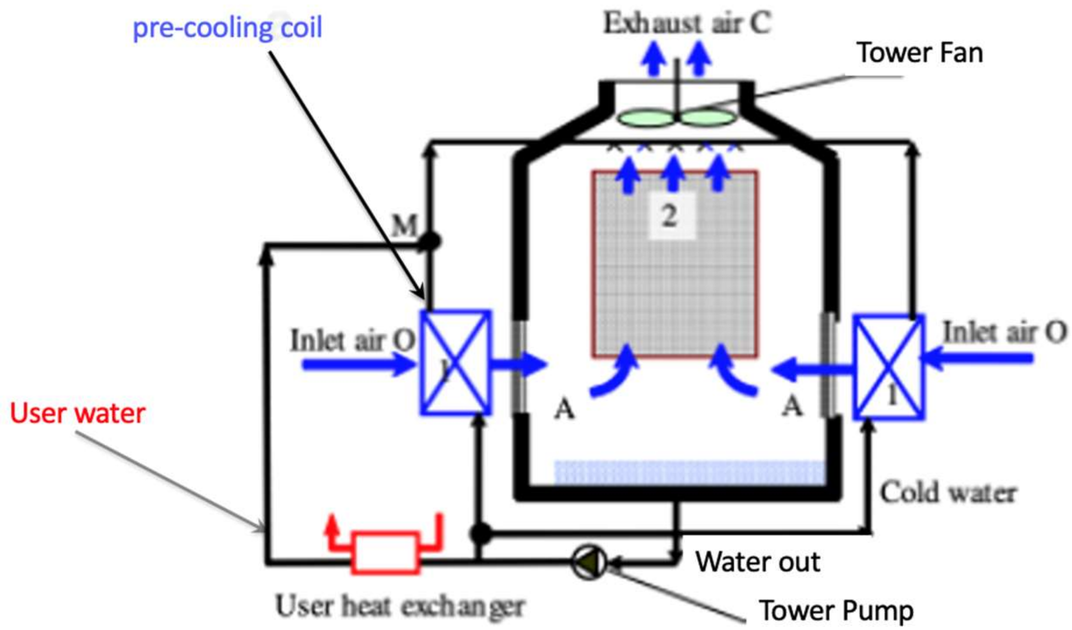
Free chilling is effective up to outdoor temperatures of a maximum of 18°C (dry) or wb = 12°C, which means that water can be produced at a minimum of 15°C, compatible with terminal units such as chilled ceilings.

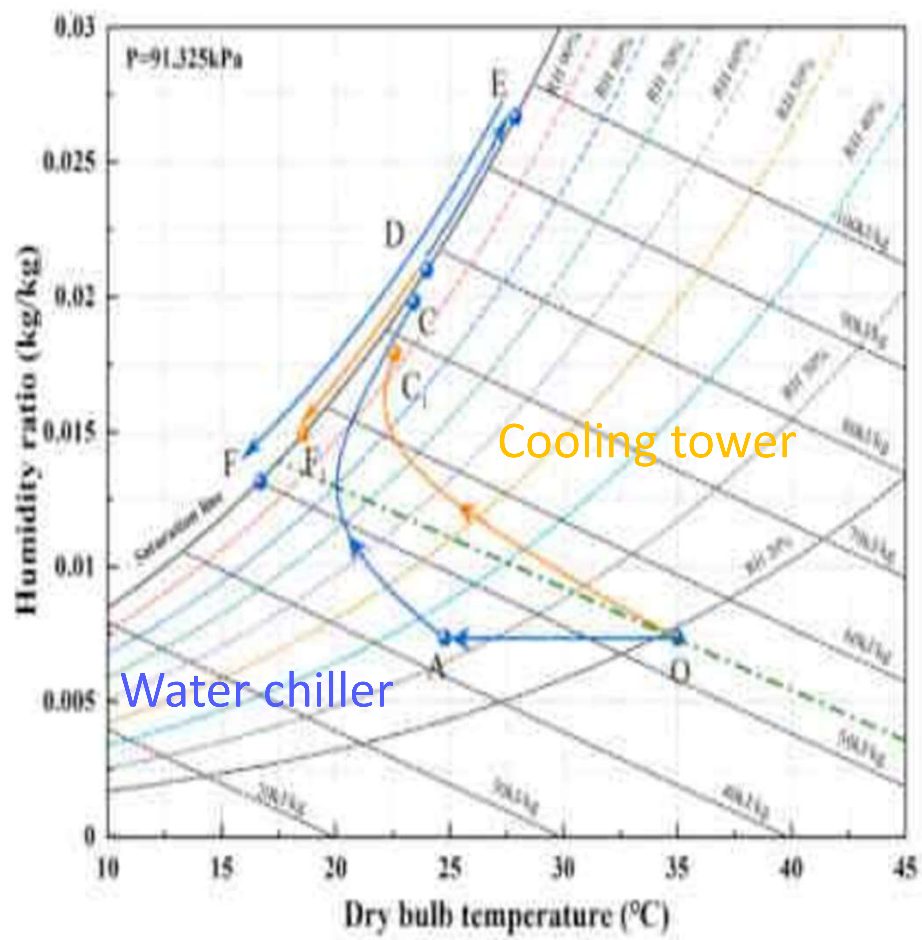
Dia 25

TS1 Idem pour le free shilling jusqu'a quelle t° et W

TUSSET Sylvano; 24/03/2021

IEC : Water Chiller





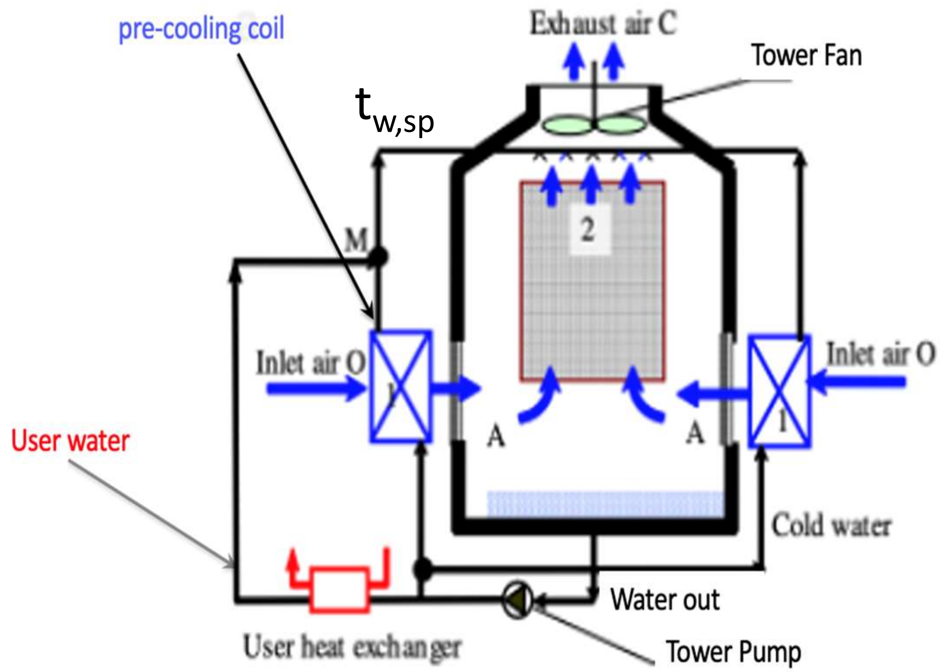
The indirect evaporative water chiller Includes two main components:

[1] the water-air counter-current heat exchanger (coil) and

[2] the air-water counter-current evaporative heat exchanger: the padding or fill of the tower

Atic for HVAC professionals

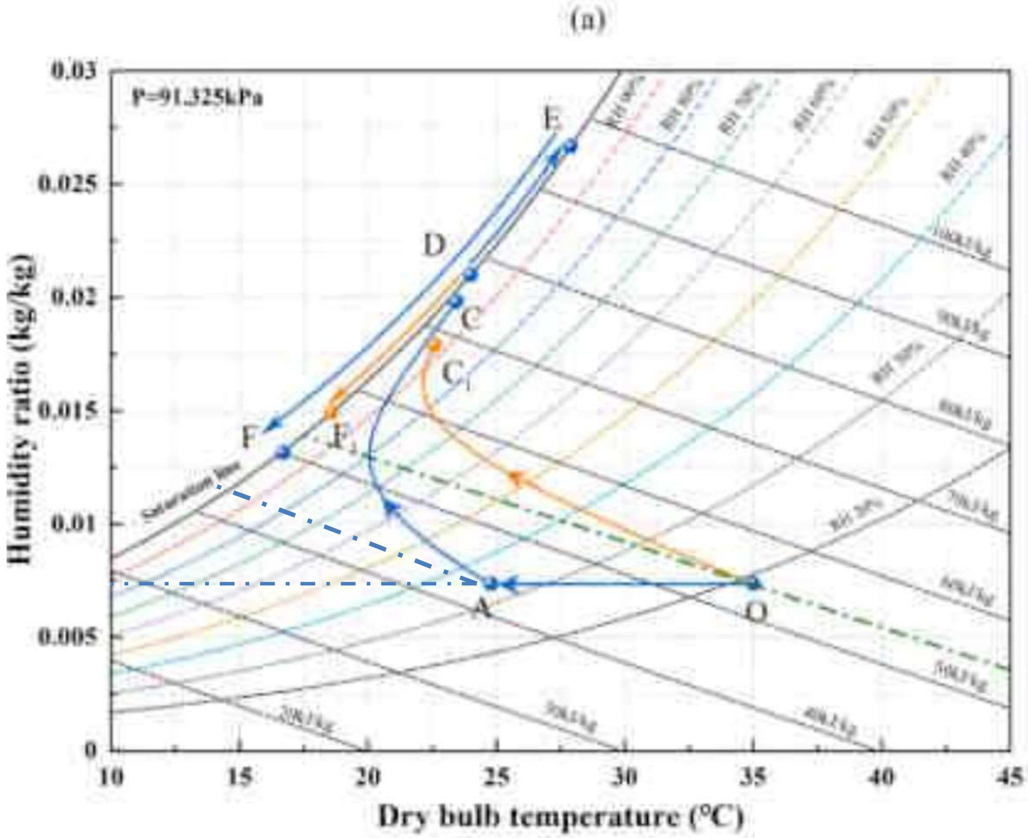
IEC : Water Chiller



Water sprayed at temperature $t_{w,sp}$, flows down from the top of the tower and is cooled across the padding [2] by the direct evaporative cooling process. The heat required to evaporate the water is draw from water, which finally reaches the $t_{w,out}$ temperature at the bottom of the tower.

The water flowing from the bottom of the tower at temperature $t_{w,out}$ is then split into two streams: the smaller part of the water is sent to the water-air counter-current heat exchanger (coil) [1] to pre-cool the incoming air, and the larger part is sent to building terminals, such as fan coil units or radiant ceilings, where it absorbs heat from the building and then returns to the tower. The return water flows from the two streams are mixed at temperature $t_{w,sp}$ and the cycle starts again

IEC : Water Chiller



Cooling tower

Water chiller

- the limit temperature of the water $t_{w,out}$ leaving the evaporative cooler [2] is the wet bulb temperature of the air : $t_{wb,A}$

  ➔ $t_{w,out} > t_{wb,A} > t_{dp\ A}$

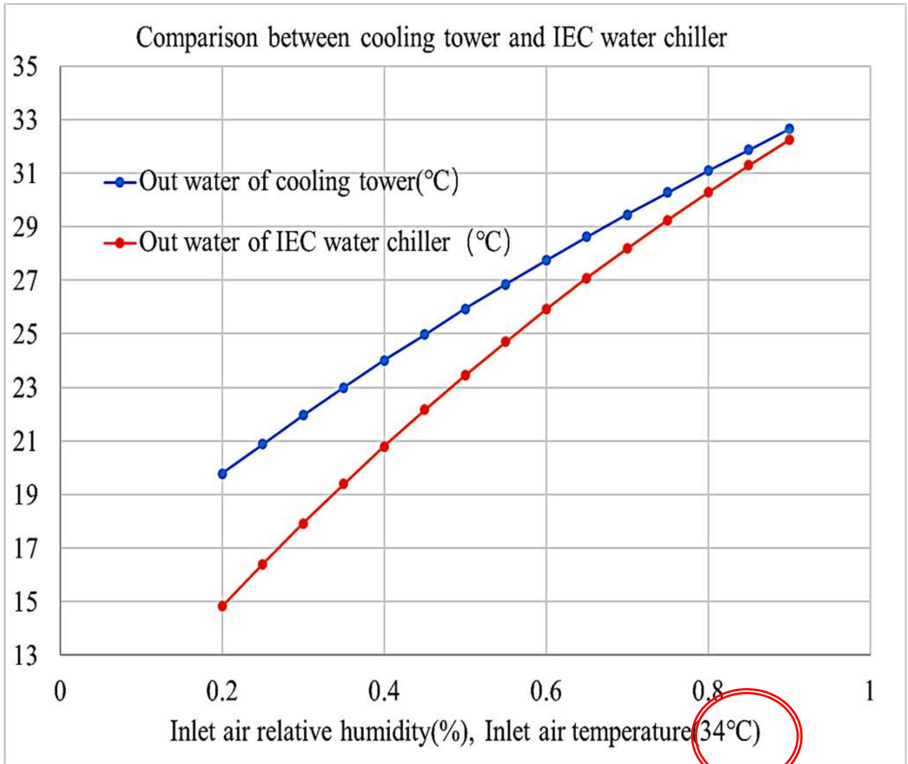
  $t_{w,out} = t_{wb,A}$ + **approche**

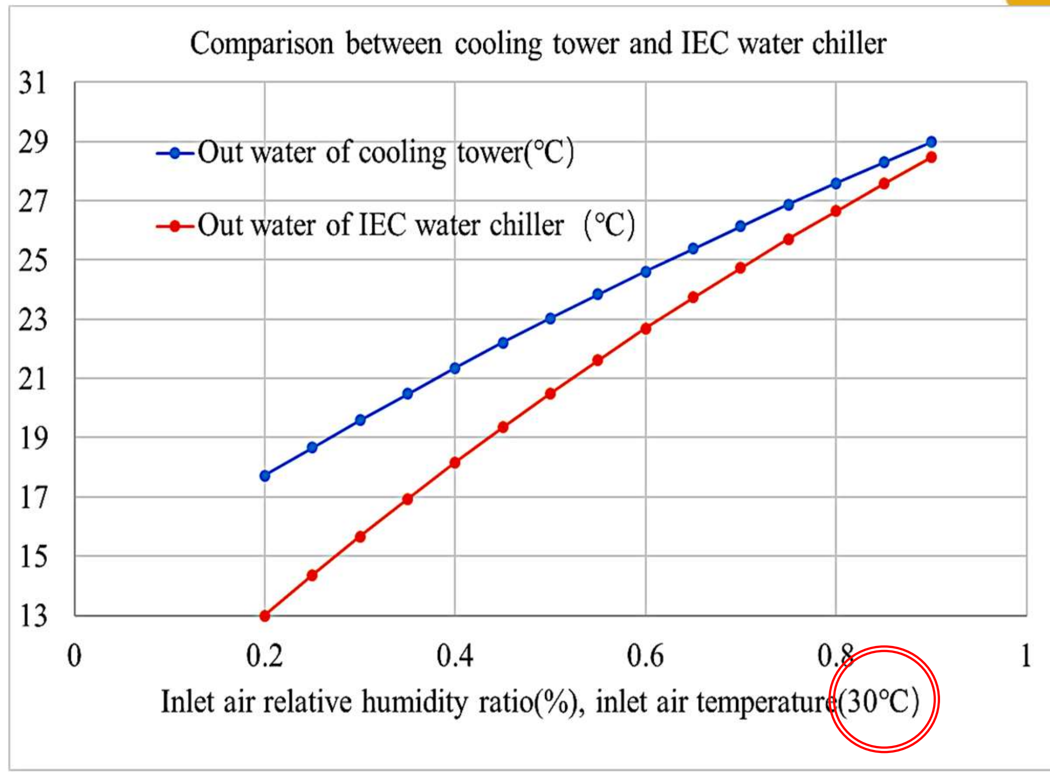
- the limit temperature of the air leaving the cooling coil [1] is the temperature of the air dew point : $t_{dp,A}$

  t_A ➔ $t_{dp\ A} = t_{dp\ O}$

- The closer point A is to the saturation curve, the closer $t_{wb,A}$ is closer to $t_{dp,A}$

IEC : $t_{w\ out}$ - Water Chiller versus Cooling Tower





The efficiency of water chiller is higher in dry climates.
The lower humidity, the lower the water temperature $t_{w,out}$

IEC

- The characteristics and performances of the IEC Water Chiller will be explained in my second presentation.

- In conformity with the rules of the annex, we don’t have mention of manufacturers’ name