ATIC CONFERENCE – 16-11-2023

Evaporative cooling
Example of IEC water chiller installation

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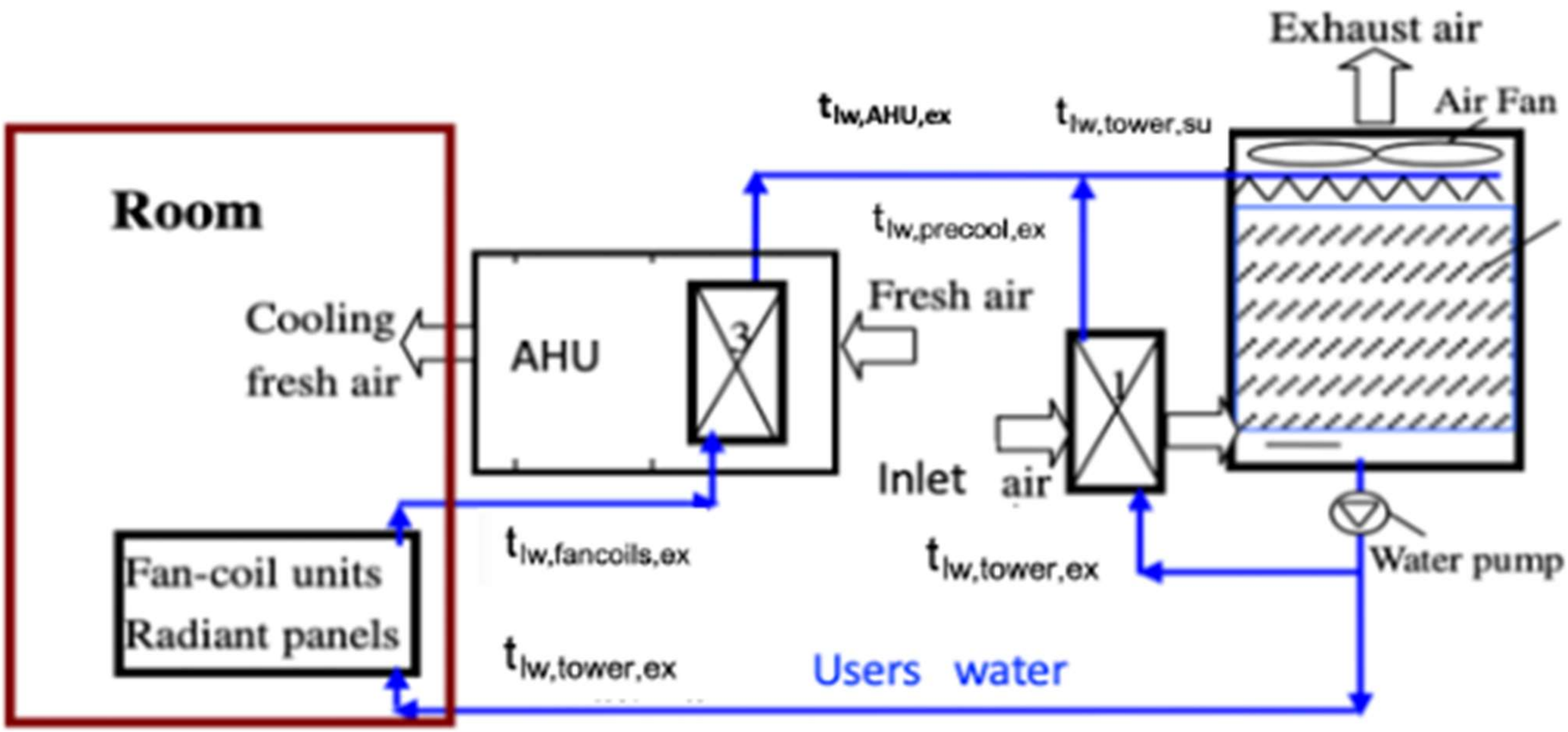
IEC : Water Chiller Installation

As there are no installations of this type in Belgium, we will analyse an existing installation in China, which was the subject of a presentation in annex 85, by the Department of Building Science and Technology, Tsinghua University, Beijing 100084, China.

The water chiller is an evolution of "free-chilling" technology well known in Belgium.

To determine the characteristics and performance of the water chiller, we will use the EES calculator to simulate the system under different conditions

Diagram IEC Water Chiller



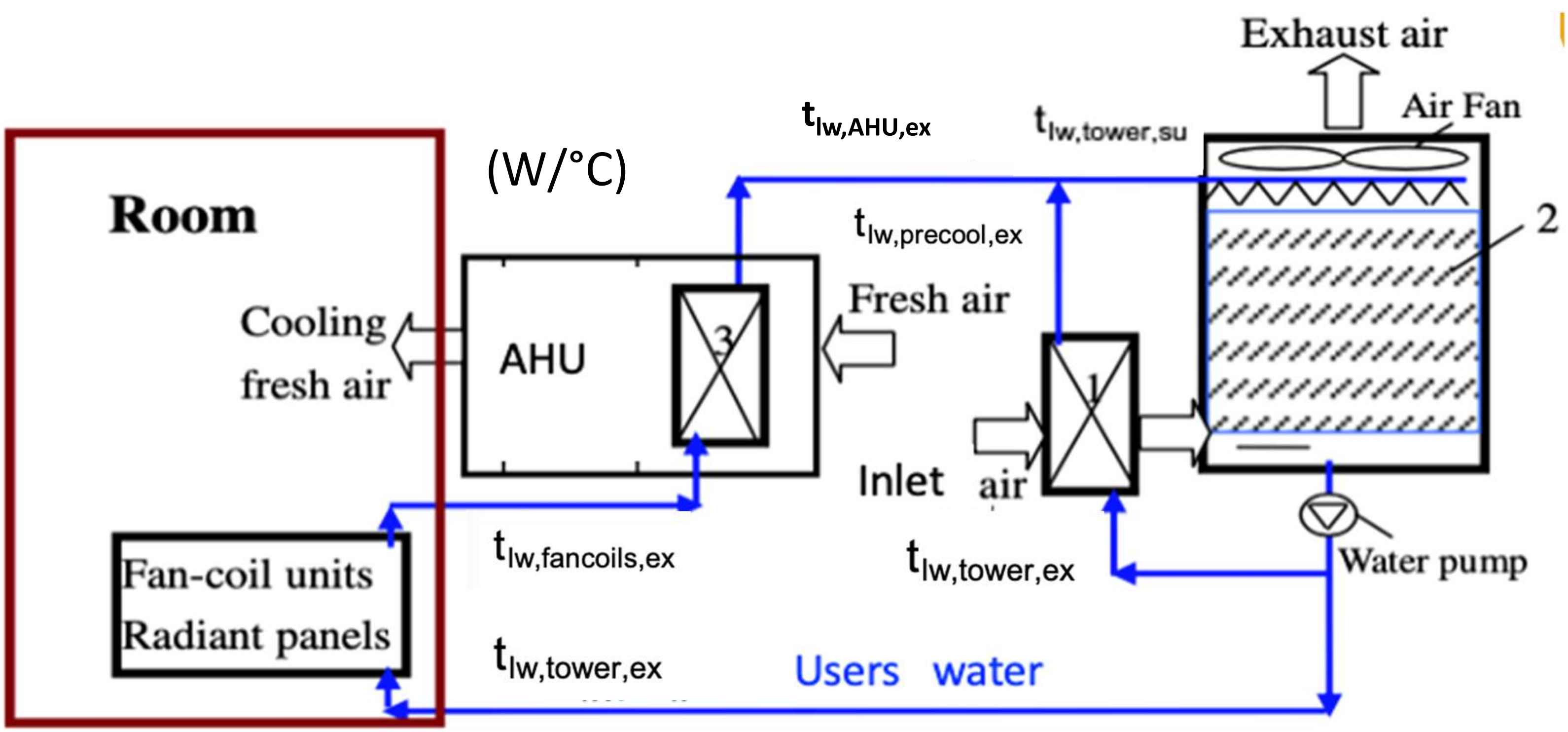
The chilled water produced by the indirect evaporation chiller is first used to feed indoor terminal units, such as fan coil units or radiant ceilings, to absorb the heat and maintain the indoor temperature in the premises. The water leaving the terminal units then used to feed an outdoor air handling unit (AHU) to pre-cool the fresh air, and finally the water leaving the fresh air cooler returns to the cooling tower.

Specifications

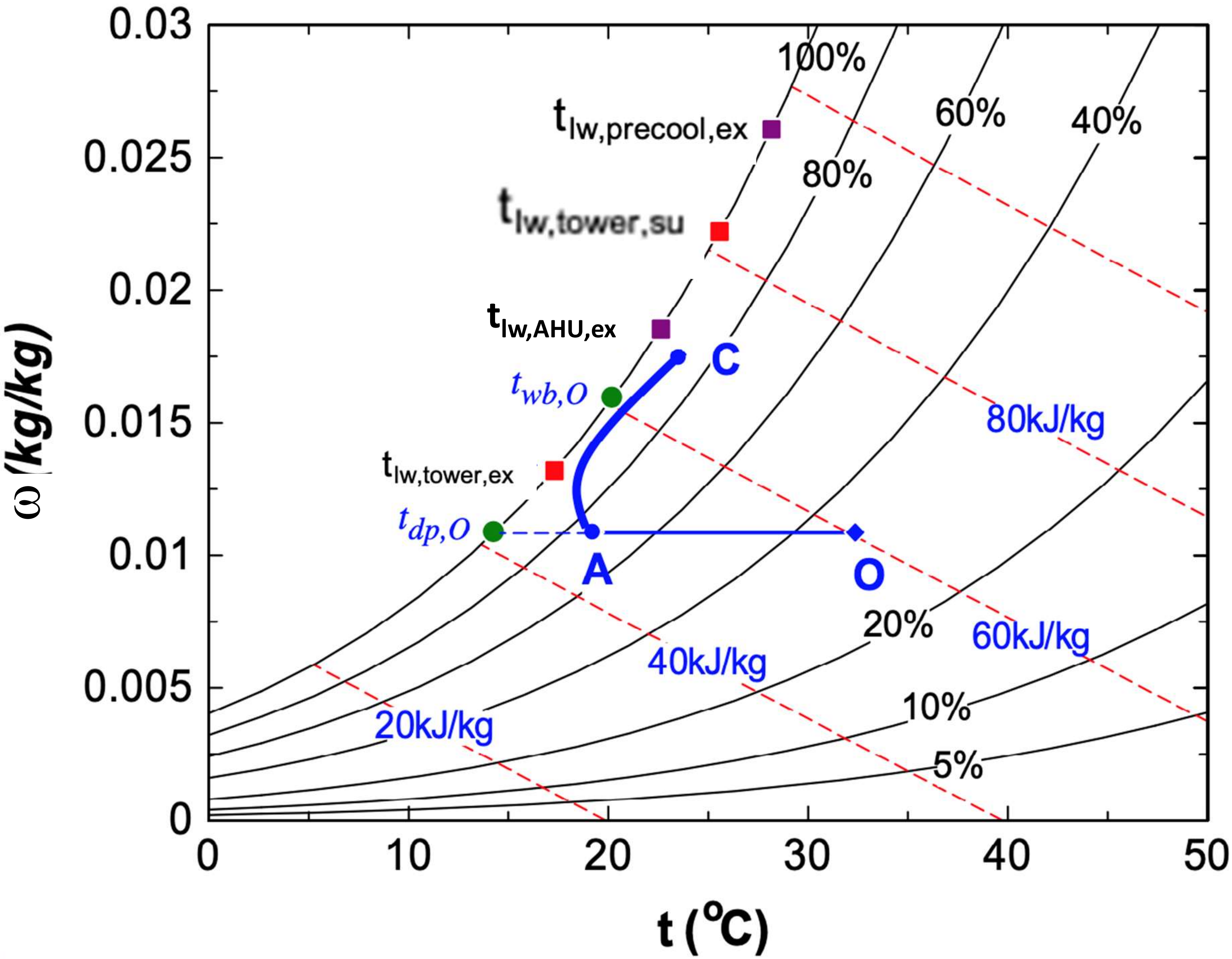
Designed conditions of the indirect evaporative chiller. $c_{p,dryair}$ = 1005 J/kg.K c_{lw} = 4187 J/kg.K $c_{p,wv}$ = 1820 J/kg.K

Atmospheric pressure (kPa)	Inlet air flow rate (kg/s)	User water flow rate (kg/s)	Fresh air flow rate (kg/s)	Pre-cooler UA (W/°C)	Cooling tower UA_f =(W/°C)	Indoor fan-coil UA =(W/°C)	AHU air cooling UA (W/°C)
101.325	1	0.6	0.6	2990	3520	2500	1000

Air : $t_{Outdoor}$ = 35°C $\omega_{outdoor}$ = 0,007 kg_w/kg t_{indoor} = 25°C



Psychrometric Diagram .



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IEC Water Chiller : Simulation EES

The water outlet temperature $\mathbf{t_{lw,tower,ex}}$ from the tower depends on the wet temperature of the incoming air,. which depends on the characteristics of the outside air and of the air pre-cooler, which also requires the temperature of the water outlet from the tower. The calculation is therefore iterative.

The NTU calculation method was used to determine the characteristics of the fluids

The most important formulas and results of the EES simulation have been summarized below.

IEC Water Chiller : Cooling tower

Heat capacitive flow

$$\dot{C}_{lw;tower} = \dot{M}_{lw;tower} \cdot c_{lw}$$

C $_{lw,tower}$ = 3768 [W/K]

$$\dot{C}_{f;air;tower} = \dot{M}_{dryair;tower} \cdot c_{pf;air;tower}$$

C $_{f\ air\ tower}$ = 3116 [W/K]

$$C_{tower} = \frac{\dot{C}_{min;tower}}{\dot{C}_{max;tower}}$$

C $_{tower}$ = 0,8269 [-]

$$c_{pf;air;tower} = \frac{h_{air;tower;ex} - h_{air;tower;su}}{t_{wb;tower;ex} - t_{wb;tower;su}}$$

Iterative calculation ➔

c $_{pf,air,tower}$ = 3116 [J/kg-K]

$$AU_{f;tower} = AU_{tower} \cdot \frac{c_{pf;air;tower}}{c_{p;air;outdoor}}$$

AU $_{f,tower}$=10777 [W/K]

$$NTU_{tower} = \frac{AU_{f;tower}}{\dot{C}_{min;tower}}$$

NTU $_{tower}$=3,459 [-]

$$\varepsilon_{tower} = \frac{1 - \mathbf{exp}\left(-NTU_{tower} \cdot (1 - C_{tower})\right)}{1 - C_{tower} \cdot \mathbf{exp}\left(-NTU_{tower} \cdot (1 - C_{tower})\right)}$$

ε $_{tower}$=0,8256 [-]

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IEC Water Chiller : Cooling tower

$$\dot{Q}_{tower} = \varepsilon_{tower} \cdot \dot{C}_{min;tower} \cdot (t_{lw;tower;su} - t_{wb;tower;su})$$

$Q_{dot,tower} = 25812[W]$

$$t_{lw;tower;su} = t_{lw;mixing}$$

$$t_{lw;mixing} = \frac{\dot{C}_{lw;AHU} \cdot t_{lw;AHU;ex} + \dot{C}_{lw;precool} \cdot t_{lw;precool;ex}}{\dot{C}_{lw;fancoils} + \dot{C}_{lw;precool}}$$

$t_{lw,mixing} = 25{,}05$ [C]

$$t_{wb;tower;su} = \mathbf{WB}\ (AIRH2O\ ; T = t_{air;tower;su}; w = \omega_{tower;su}; P = p\ )$$

$t_{wb,tower,su} = 15{,}02$ [C]

$$t_{air;tower;su} = t_{air;precool;ex}$$

$t_{air,tower,su} = 23{,}89$ [C]

$$t_{lw;tower;ex} = t_{lw;tower;su} - \frac{\dot{Q}_{tower}}{\dot{C}_{lw;tower}}$$

$\mathbf{t_{lw,tower,ex} = 18{,}2}$ **[C]**

$$\omega_{tower;su} = \omega_{outdoor}$$

$\omega_{,tower,su} = 0{,}007$ [-]

$\omega_{tower,ex}$ = **humrat**(***AirH2O*** ; ***h***=$h_{air,tower,ex}$;***R***=1 ;***P***=P)

$\omega_{,tower,ex} = 0{,}01757$ [-]

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IEC Water Chiller : Precooler

Heat capacitive flow

$C_{air,precool}$ = 1018 [W/K].
$C_{lw,precool}$ = 1256 [W/K]
$C_{precool}$ = 0,8102 [-]
AU pre-cooler =2990[W/K]
$NTU_{\_precool}$=2,938 [-]
$\varepsilon_{,precool}$=0,6612 [-]
$Q_{precool}$=11304 [W]

ratio of precooler capacitive flow

$C_{lw,precool} \backslash C_{air,\ precool}$=1,234 [-]

$$t_{air;precool;su} = t_{outdoor}$$

= 35 [°C]

$$t_{lw;precool;su} = t_{lw;tower;ex}$$

$t_{lw,tower,ex}$=18,2 [C]

$$t_{air;precool;ex} = t_{air;precool;su} - \frac{\dot{Q}_{precool}}{\dot{C}_{air;precool}}$$

$t_{air,precool,ex}$ = 23,89 [C]

$$t_{lw;precool;ex} = t_{lw;precool;su} + \frac{\dot{Q}_{precool}}{\dot{C}_{lw;precool}}$$

$t_{lw,precool,ex}$ = 27,2 [C].

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IEC Water Chiller : Fancoils

$$\dot{M}_{lw;fancoils} = \dot{M}_{lw;users}$$

$= 0,6$ [kg/s]

Heat capacitive flow

$$\dot{C}_{air;fancoils} = \dot{C}_{lw;fancoils}$$

$$\dot{M}_{dryair;fancoils} = \frac{\dot{C}_{air;fancoils}}{c_{p;air;fancoils;su}}$$

$$\varepsilon_{fancoils} = \frac{NTU_{fancoils}}{1 + NTU_{fancoils}}$$

$$\dot{Q}_{fancoils} = \mathbf{Max}\left(0 ;\ \varepsilon_{fancoils} \cdot \dot{C}_{lw;fancoils} \cdot \left(t_{air;fancoils;su} - t_{lw;fancoils;su}\right)\right)$$

$$t_{lw;fancoils;su} = t_{lw;tower;ex}$$

$$t_{lw;fancoils;ex} = t_{lw;fancoils;su} + \frac{\dot{Q}_{fancoils}}{\dot{C}_{lw;fancoils}}$$

$$t_{air;fancoils;su} = t_{indoor}$$

$C_{air,fancoils}$=2512 [W/K]

$C_{lw,fancoils}$=2512 [W/K]

$M_{dryair,fancoils}$=2,468 [kg/s]

$AU_{fancoils}$=2500 [W/K]

$NTU_{fancoils}$=0,9951 [-]

$\varepsilon_{fancoils}$=0,4988 [-]

$Q_{Fancoils}$ = 8518 [W]

$T_{lw,Fancoils,su}$=18,2[C]

$t_{lw,Fancoils,ex}$=21,59 [C]

= 25 [C]

IEC Water Chiller : AHU fresh air

$$\dot{M}_{dryair;AHU} = \dot{M}_{dryair;fresh}$$

$M_{dryair,fresh} = 0{,}6$ [kg/s]

$$t_{air;AHU;su} = t_{outdoor}$$

$t_{air,AHU,su} = 35$ [C]

Heat capacitive flow

$$\dot{C}_{lw;AHU} = \dot{M}_{lw;AHU} \cdot c_{lw}$$

$C_{lw,AHU} = 2512$ [W/K]

$$\dot{C}_{AHU} = \dot{M}_{dryair;AHU} \cdot c_{p;air;AHU;su}$$

$C_{air,AHU} = 610{,}6$ [W/K]

$$C_{AHU} = \frac{\dot{C}_{min;AHU}}{\dot{C}_{max;AHU}}$$

$C_{AHU} = 0{,}2431$ [-]

$AU_{AHU} = 1000$ [W/K]

$$NTU_{AHU} = \frac{AU_{AHU}}{\dot{C}_{min;AHU}}$$

$NTU_{AHU} = 1{,}638$ [-]

$$\varepsilon_{AHU} = \frac{1 - \mathbf{exp}\left(-C_{AHU} \cdot \left(1 - \mathbf{exp}\left(-NTU_{AHU}\right)\right)\right)}{C_{AHU}}$$

$\varepsilon_{AHU} = 0{,}7316$ [-]

$$\dot{Q}_{AHU} = \mathbf{Max}\left(0 ; \varepsilon_{AHU} \cdot \dot{C}_{min;AHU} \cdot \left(t_{air;AHU;su} - t_{lw;AHU;su}\right)\right)$$

$Q_{AHU} = 5990$ [W]

$$t_{lw;AHU;ex} = t_{lw;AHU;su} + \frac{\dot{Q}_{AHU}}{\dot{C}_{lw;AHU}}$$

$t_{lw,AHU,ex} = 23{,}98$ [C]

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Power Balance of IEC water Chiller

- Tower (2) = Q_{tower} = 25812 [W]
- Precooler (1) = $Q_{precool.}$ = 11304 [W]

$$\dot{Q}_{users} = \dot{Q}_{fancoils} + \dot{Q}_{AHU}$$

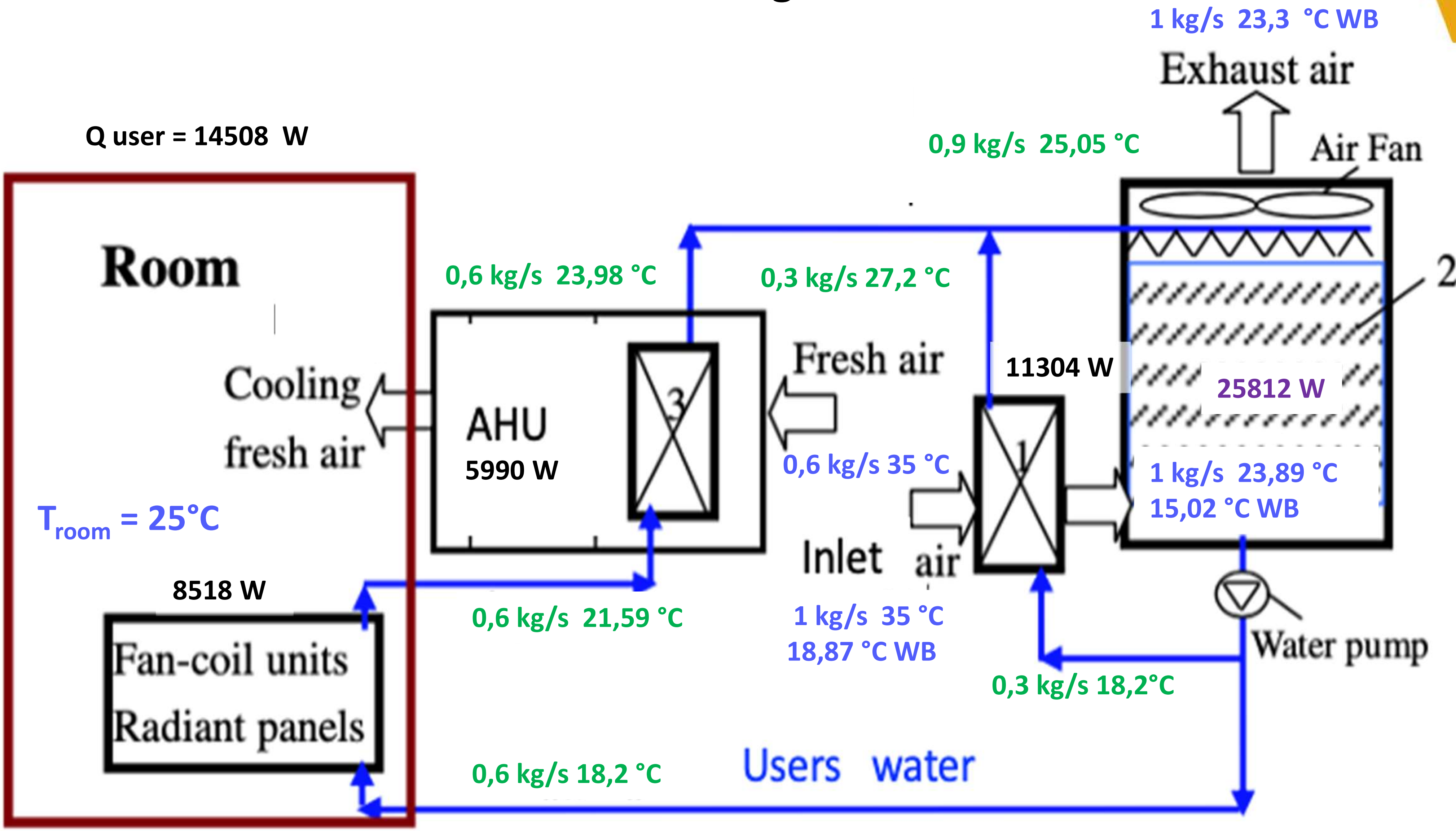
- Fan-coil = $Q_{Fancoils}$ = 8518 [W]
- AHU- Hygienic Air = Q_{AHU} = 5990 [W]

- Cooling power user = Q_{users} = 14508 [W]

- Cooling power user = 0,9 . 4187 . (25,05 -18,2) = 25812 [W]

IEC water Chiller - Diagram – Results

Q user = 14508 W



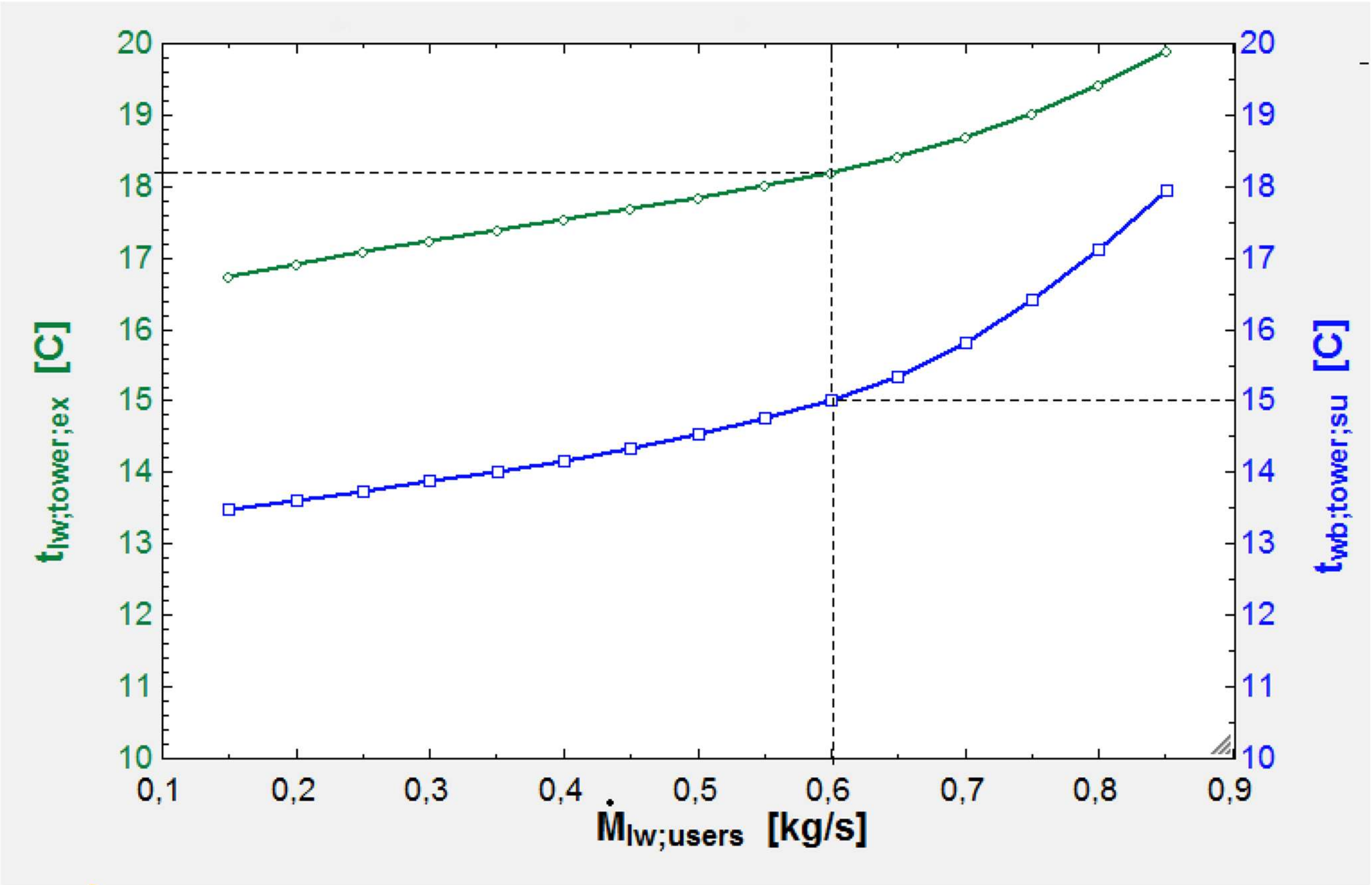
IEC Water Chiller : EES Results

1 $\dot{M}_{lw;users}$ [kg/s]	2 $\dot{M}_{w;tower;loss}$ [kg/s]	3 $\dot{M}_{lw;tower}$ [kg/s]	4 $\dot{M}_{lw;precool}$ [kg/s]	5 $\dot{M}_{lw;fancoils}$ [kg/s]	6 $\dot{M}_{lw;AHU}$ [kg/s]	7 $t_{lw;tower;ex}$ [C]	8 $t_{wb;tower;su}$ [C]	9 $Clw\backslash Cair_{precool}$ [-]	10 $\varepsilon_{dp;system}$ [-]	11 $AU_{f;tower}$ [W/K]	12 $AU_{fancoils}$ [W/K]	13 $AU_{precool}$ [W/K]
0,15	0,008505	0,9	0,75	0,15	0,15	16,73	13,48	3,086	0,4282	10054	967,5	3364
0,2	0,008873	0,9	0,7	0,2	0,2	16,93	13,61	2,88	0,4328	10161	1179	3342
0,25	0,009186	0,9	0,65	0,25	0,25	17,1	13,74	2,674	0,4358	10254	1374	3317
0,3	0,00946	0,9	0,6	0,3	0,3	17,25	13,87	2,468	0,4374	10338	1557	3289
0,35	0,009703	0,9	0,55	0,35	0,35	17,4	14,01	2,263	0,4379	10416	1730	3258
0,4	0,009921	0,9	0,5	0,4	0,4	17,55	14,17	2,057	0,4373	10490	1895	3221
0,45	0,01012	0,9	0,45	0,45	0,45	17,7	14,34	1,851	0,4354	10562	2054	3178
0,5	0,01029	0,9	0,4	0,5	0,5	17,85	14,53	1,646	0,4321	10633	2208	3127
0,55	0,01044	0,9	0,35	0,55	0,55	18,02	14,75	1,44	0,4271	10704	2356	3066
0,6	0,01057	0,9	0,3	0,6	0,6	18,2	15,02	1,234	0,4198	10777	2500	2990
0,65	0,01068	0,9	0,25	0,65	0,65	18,41	15,34	1,029	0,4094	10853	2640	2893
0,7	0,01073	0,9	0,2	0,7	0,7	18,69	15,82	0,8228	0,3913	10942	2777	2764
0,75	0,01073	0,9	0,15	0,75	0,75	19,03	16,42	0,6171	0,3664	11037	2911	2581
0,8	0,01068	0,9	0,1	0,8	0,8	19,44	17,13	0,4114	0,3337	11133	3042	2298
0,85	0,01057	0,9	0,05	0,85	0,85	19,9	17,95	0,2057	0,292	11221	3170	1777

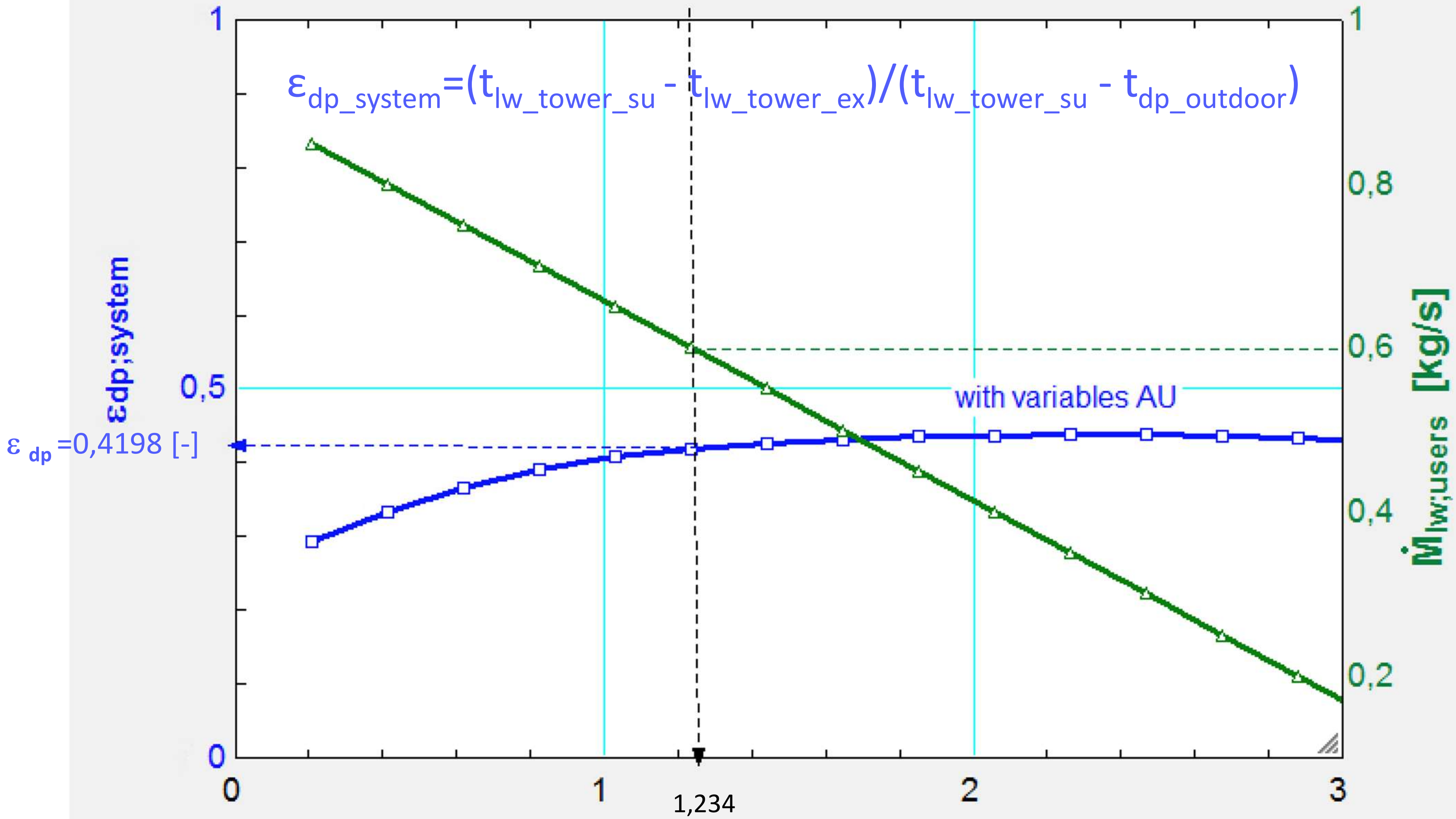
IEC Water Chiller : EES Results

14 $\Delta p_{lw;chiller}$ [Pa]	15 $\Delta p_{lw;precool}$ [Pa]	16 $\Delta p_{lw;fancoils}$ [Pa]	17 $\Delta p_{lw;AHU}$ [Pa]	18 Δp_{tower} [Pa]	19 $\Delta p_{fancoils}$ [Pa]	20 $\Delta p_{chiller}$ [Pa]	21 $\Delta p_{precool}$ [Pa]	22 Δp_{AHU} [Pa]	23 $COP_{chiller}$ [-]	24 $\dot{Q}_{users}$ [W]	25 $\dot{W}_{tower;fan;pump}$ [W]	26 $\dot{W}_{towerfan}$ [W]	27 $\dot{W}_{towerpump}$ [W]
208094	158094	1581	1581	300	7,911	540	240	500	5,738	7179	1251	923,7	327,5
187717	137717	2811	2811	300	13,39	540	240	500	7,034	8502	1209	925,5	283,1
168746	118746	4391	4391	300	20,15	540	240	500	8,209	9618	1172	927	244,7
151180	101180	6324	6324	300	28,13	540	240	500	9,289	10589	1140	928,3	211,7
135019	85019	8607	8607	300	37,29	540	240	500	10,29	11449	1113	929,4	183,8
120264	70264	11242	11242	300	47,62	540	240	500	11,2	12218	1091	930,4	160,5
106914	56914	14228	14228	300	59,07	540	240	500	12,03	12906	1073	931,3	141,4
94969	44969	17566	17566	300	71,63	540	240	500	12,77	13518	1058	932,1	126,1
84429	34429	21255	21255	300	85,28	540	240	500	13,42	14054	1047	932,8	114,3
75295	25295	25295	25295	300	100	540	240	500	13,97	14508	1039	933,4	105,3
67566	17566	29686	29686	300	115,8	540	240	500	14,39	14865	1033	933,8	98,93
61242	11242	34429	34429	300	132,6	540	240	500	14,62	15042	1029	934,1	94,64
56324	6324	39523	39523	300	150,4	540	240	500	14,67	15050	1026	934,1	92,04
52811	2811	44969	44969	300	169,3	540	240	500	14,52	14874	1025	933,8	90,71
50703	702,6	50766	50766	300	189,2	540	240	500	14,16	14499	1024	933,4	90,23

IEC Water Chiller : $M_{lw,users}$ $t_{lw,tower\ ex}$ $t_{wb,tower,su}$



IEC Water Chiller : $C_{lw,precool}$ /$C_{air,Precool}$ ε_{dp} $M_{lw,users}$



$C_{lw,precool}$ = 1256 [W/K] $C_{air,precool}$ = 1018 [W/K].

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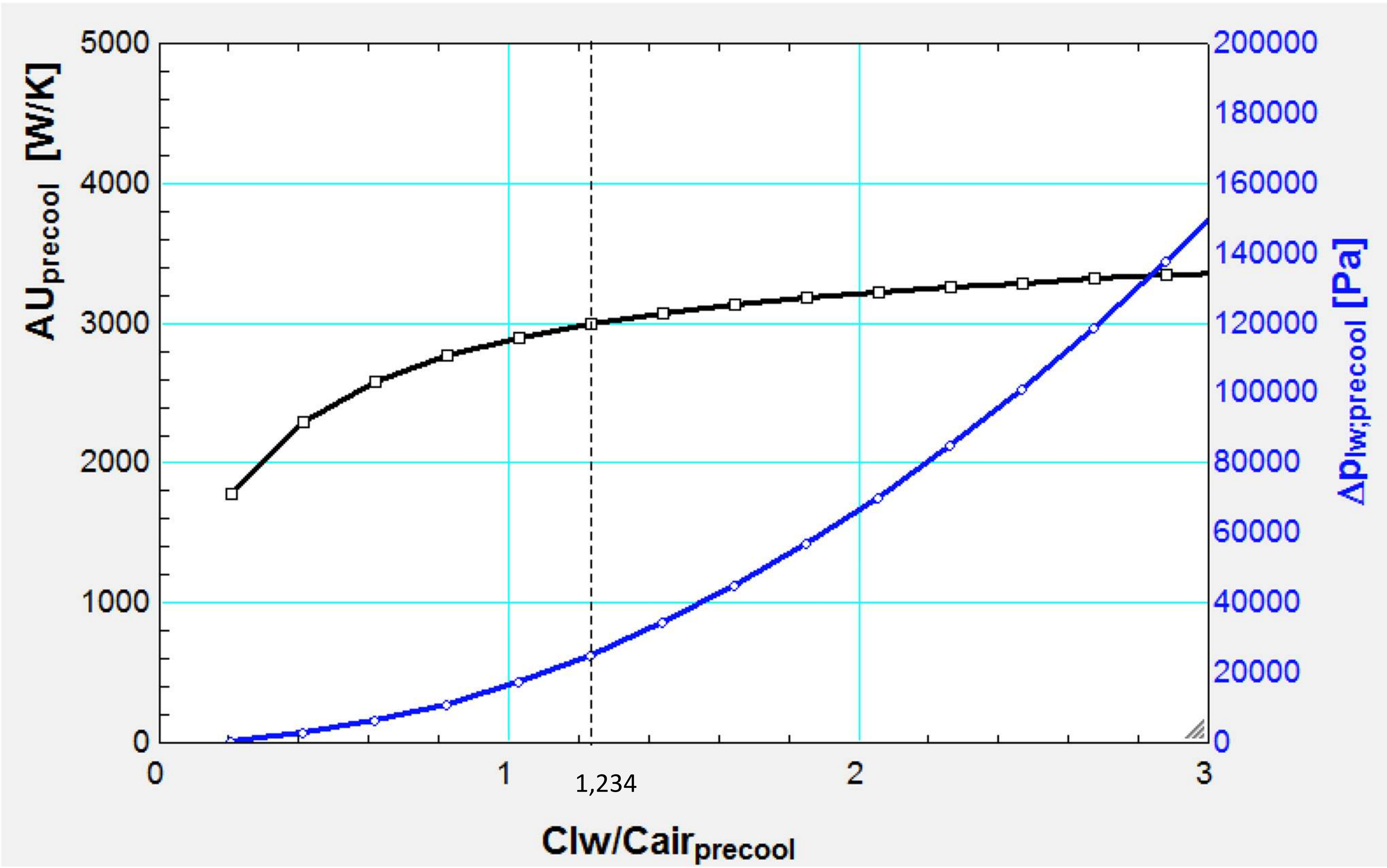
IEC Water Chiller: $C_{lw,precool}/C_{air,Precool}$ $AU_{precool}$ $\Delta P_{lw,precool}$



Water consumption of IEC water chiller

$M_{water} = M_a\ (\omega_{out} - \omega_{in}) = 1(0{,}01757 - 0{,}007) = 0{,}01057\ kg/s = 38{,}2\ [l/h]$
M_dot_w_tower_loss=0,01062 [kg/s] ≈ 1% of M_dot_tower

It was considered that the relative humidity at the exit of the tower was 100%. rh_tower_ex=1 [-]
The enthalpy of the exhaust air is h_air_tower_ex=67636 [J/kg]

The enthalpy of point X, having :

- a temperature of t_tower_ex=23,3 [C] equal to the temperature of the air at the outlet of the tower with rh_tower_ex=1 [-]
- and a specific humidity of 0.007 kg / kg equal to the specific humidity of the outdoor air
- ➔ h_x=41207 [J/kg])

$M_{water} = M_a\ .\ \Delta hx/\ hfg = 1\ .(67636 - 41207)/\ 2501000 = 0{,}00106\ kg/s = 38{,}2\ l/h$
Δhx represents the latent enthalpy or specific energy required for water evaporation

We need to add the water that is drawn out of the tower by the exhaust air, and additional water for calcium deconcentrating.

IEC water chiller - ΔP

- AIR - $\Delta p_{a\ [1}$: DELTAp_precool=240 [Pa] and $\Delta p_{a\ [2\ ]}$: DELTAp_tower =300 [Pa] represents the air pressure drop of the counterflow air cooler and counterflow padding tower. Δp_chiller=540 [Pa]

$$\Delta p_{chiller} = \Delta p_{tower} + \Delta p_{precool}$$

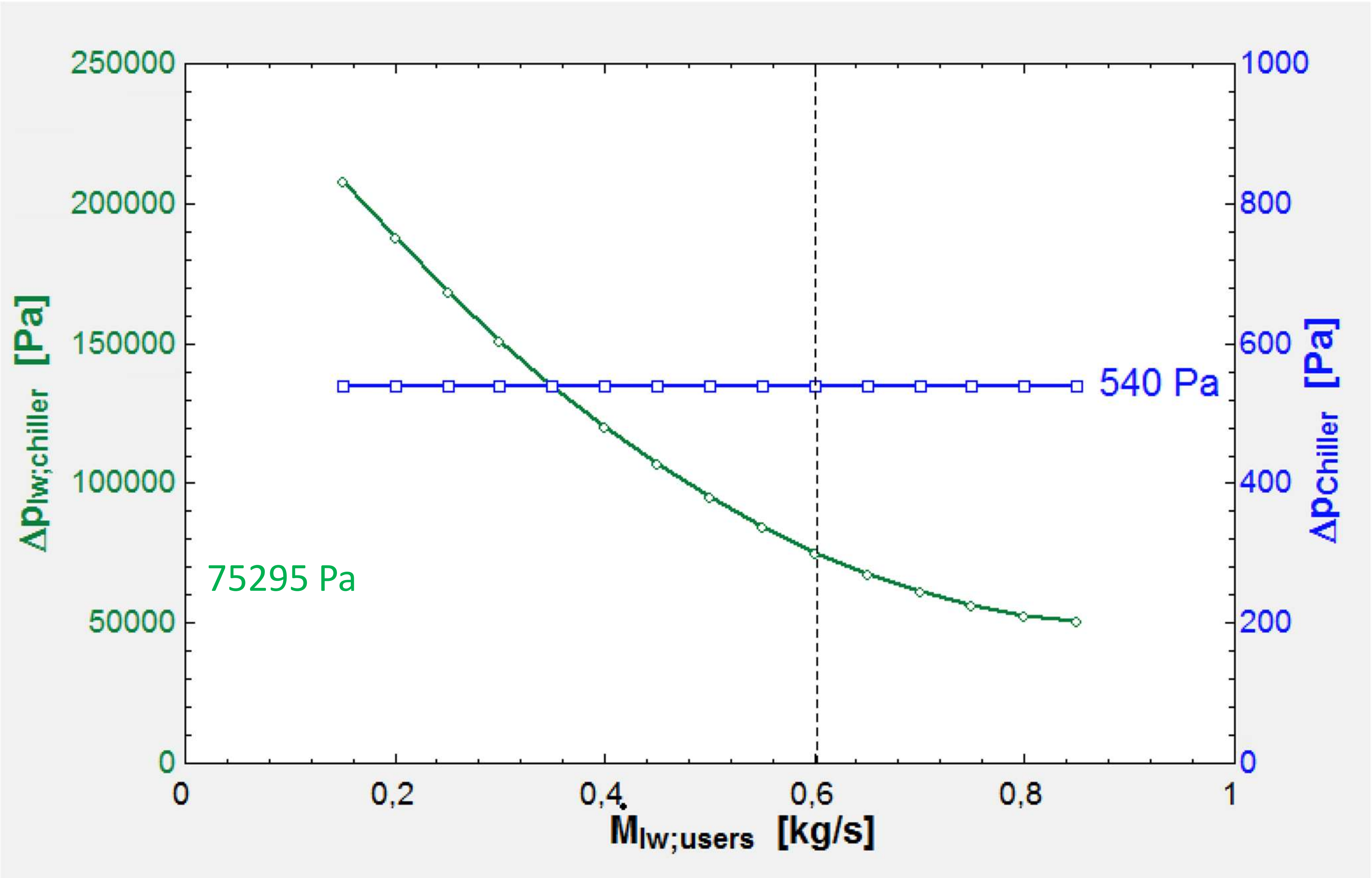
- Water - $\Delta P_{w\ [1]}$: DELTAp_lw_precool=25295 [Pa] and $\Delta P_{w\ [2]}$: DELTAp_lw_tower=50000 [Pa] represents the water pressure drop of counterflow air cooler and counterflow padding tower

$$\Delta p_{lw;chiller} = \Delta p_{lw;tower} + \Delta p_{lw;precool}$$

- We did not take into account the pressure loss of the users : Δp_lw_user=50590 [Pa] (fan coils and AHUs) because it is not related to the IEC water cooler but to the operating circuits, which is necessary for all kinds of air conditioning systems

- This values of Δp should be confirmed by fabricants

IEC water chiller: $M_{lw,users}$ $\Delta P_{lw,chiller}$ $\Delta P_{air,chiller}$



IEC Water Chiller : COP

$$\dot{W}_{towerfan} = \dot{V}_{tower;ex} \cdot \frac{\Delta p_{chiller}}{\eta_{towerfan}}$$

W $_{tower\ fan}$ = 933,4 [W]

$$\dot{W}_{towerpump} = \dot{V}_{lw;tower} \cdot \frac{\Delta p_{lw;tower}}{\eta_{towerpump}} + \dot{V}_{lw;precool} \cdot \frac{\Delta p_{lw;precool}}{\eta_{towerpump}}$$

W $_{tower\ pump}$ = 105,3 [W]

$$\dot{W}_{tower;fan;pump} = \dot{W}_{towerfan} + \dot{W}_{towerpump}$$

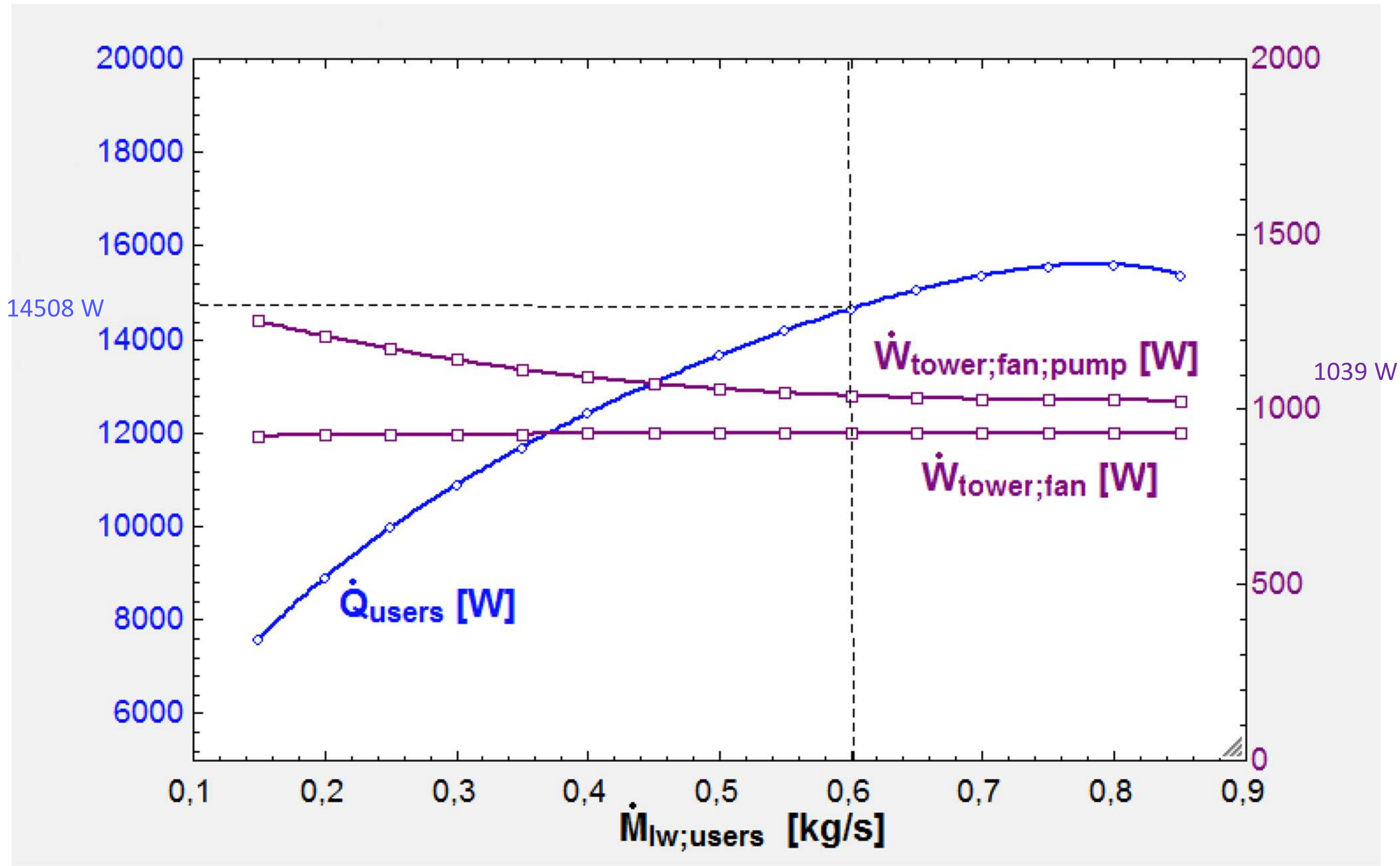
W $_{tower,fan,pump}$ = 1039 [W]

$$COP_{chiller} = \frac{\dot{Q}_{users}}{\dot{W}_{tower;fan;pump}}$$

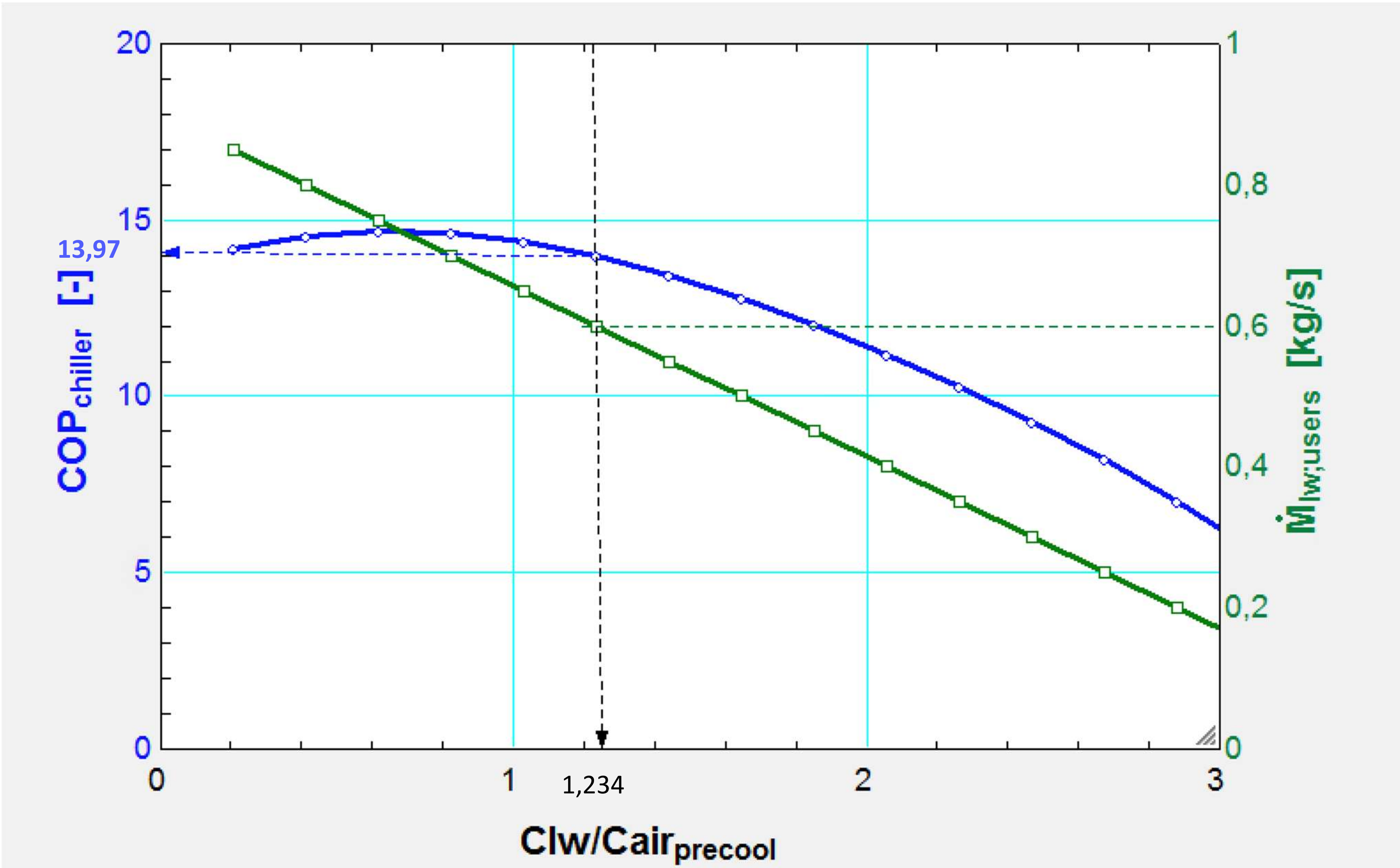
COP $_{chiller}$=13,97 [-]

η_{fan} and η_{pump} represents the efficiency of the exhaust air fan and water pump of the tower (= 0,5)

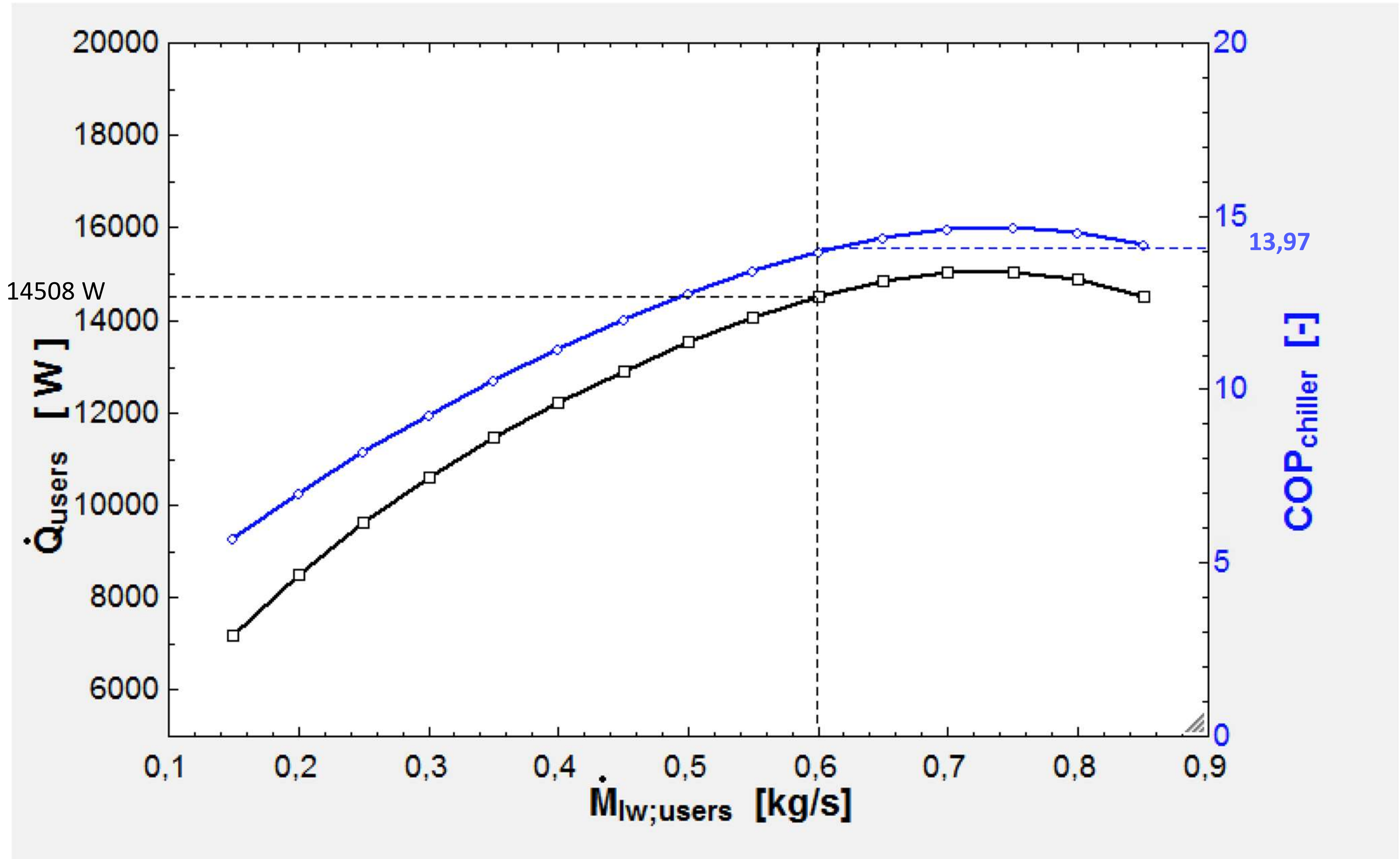
IEC Water Chiller : $M_{lw,users}$ $W_{tower\ fan\ pump}$ Q_{users}



IEC Water Chiller : $C_{lw,precool}/C_{air,Precool}$ $COP_{chiller}$ $M_{lw,users}$



IEC Water Chiller: $M_{lw,users}$ Q_{users} $COP_{chiller}$



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