IEA-EBC Annex 85

Energy in Buildings and Communities Programme

Performance of indicators for IEC processes under various climate conditions

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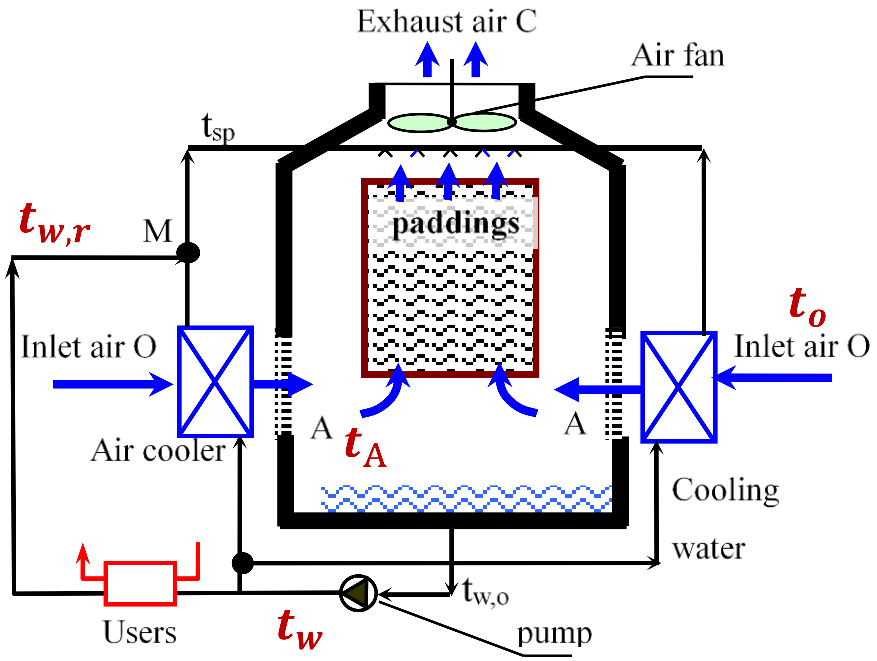
Indicators performance of IEC processes

- IEC water chiller process
- IEC air cooler process

IEC water chiller processes

- Indicators for cooling performance
  - Two efficiencies identified, for air cooler and padding tower， which could be used to express the outlet water temperature
  - the evaporative cooling efficiency $\boldsymbol{\eta_{ev}}$ and the sensible cooling efficiency $\boldsymbol{\eta_c}$



Sensible cooling efficiency: $$\eta_c = \frac{t_o - t_A}{t_o - t_{o,dp}}$$

Evaporative cooling efficiency: $$\eta_{ev} = \frac{t_{w,r} - t_w}{t_{w,r} - t_{A,wb}}$$

t_o: inlet air temperature;
$t_{o,dp}$: inlet air dewpoint temperature;
t_A: air past air−cooler temperature;
$t_{A,wb}$: air past air−cooler wet bulb temperature;
$t_{w,r}$: inlet water temperature;
t_w : outlet water temperature.

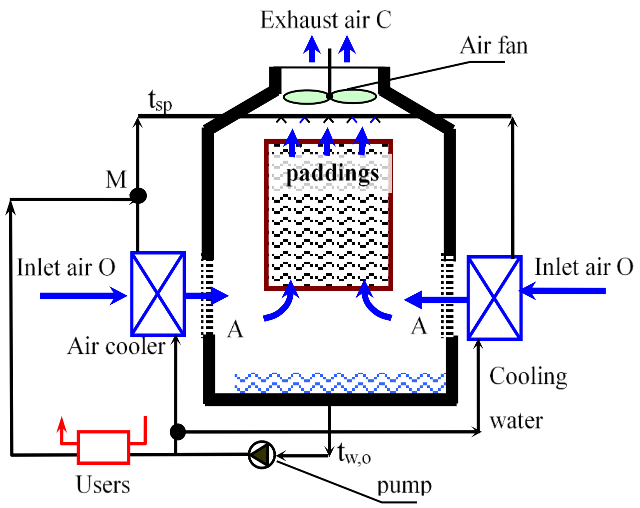
Thus, t_w could be described as the follow equation:

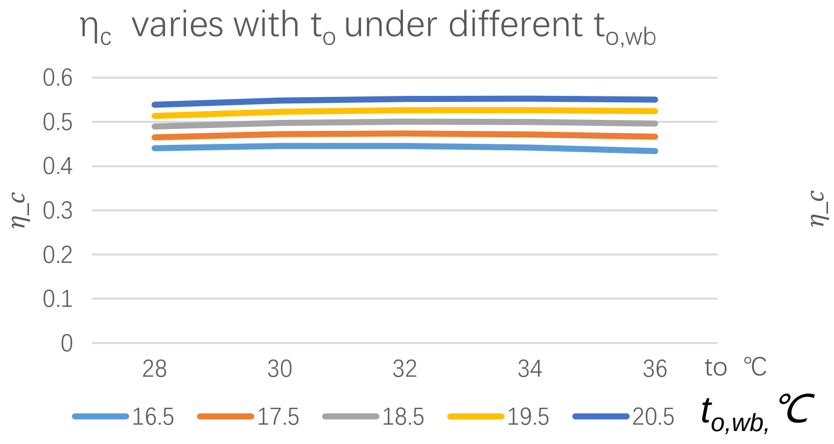
$$t_w = t_{w,r} - \eta_{ev} * \{t_{w,r} - [t_{o,wb} - \eta_c * (t_{o,wb} - t_{o,dp})]\}$$

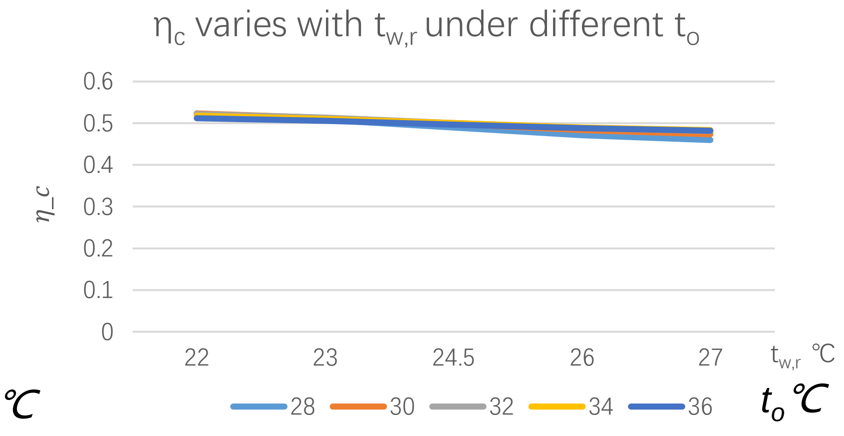
IEC water chiller processes

- For **parallel-connected** IEC water chillers

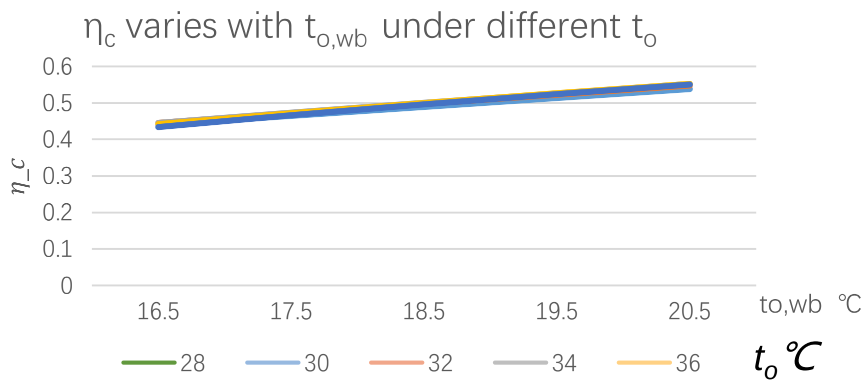
$$\eta_c = \frac{t_o - t_A}{t_o - t_{o,dp}}$$







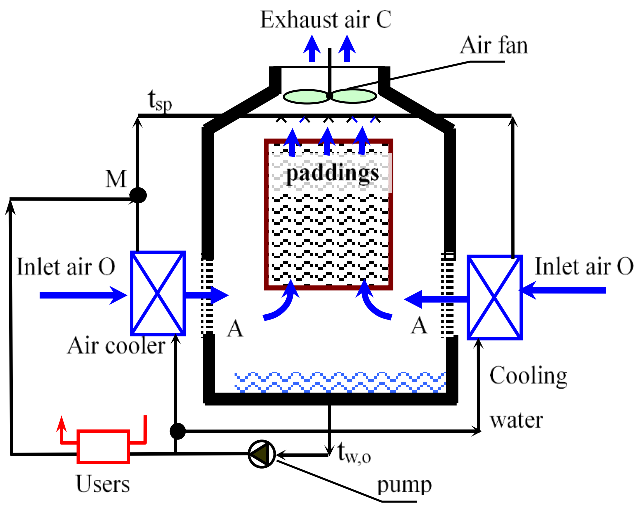
parameter	design value
inlet air dry-bulb temperature t_O ℃	34^{+2}_{-7} ℃
inlet air wet-bulb temperature $t_{O,wb}$	18.5^{+2}_{-2} ℃
returned water temperature $t_{w,r}$	$24.5^{+2.5}_{-2.5}$ ℃
Flow rate $G_a/G_{w,r}$	2. 25
capacity of heat exchanger	$Ntu_{ex}=2$
capacity of padding	$Ntu_{padding}=1.5$



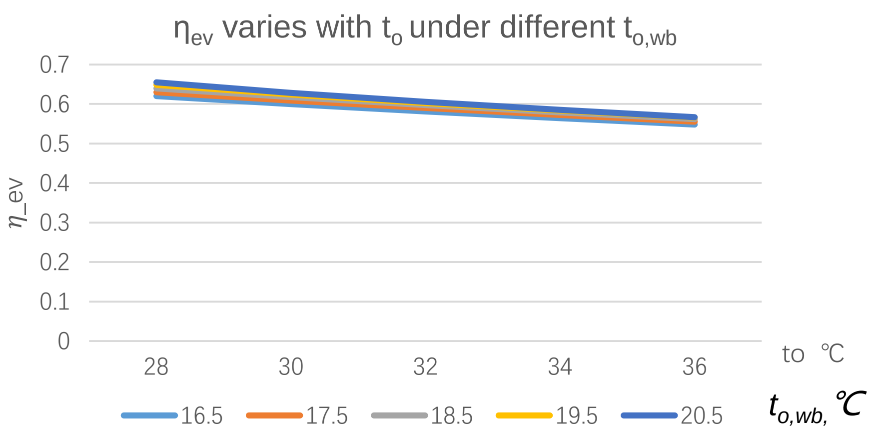
η_c varies slightly when t_O , $t_{O,wb}$,t_{wr}, changes

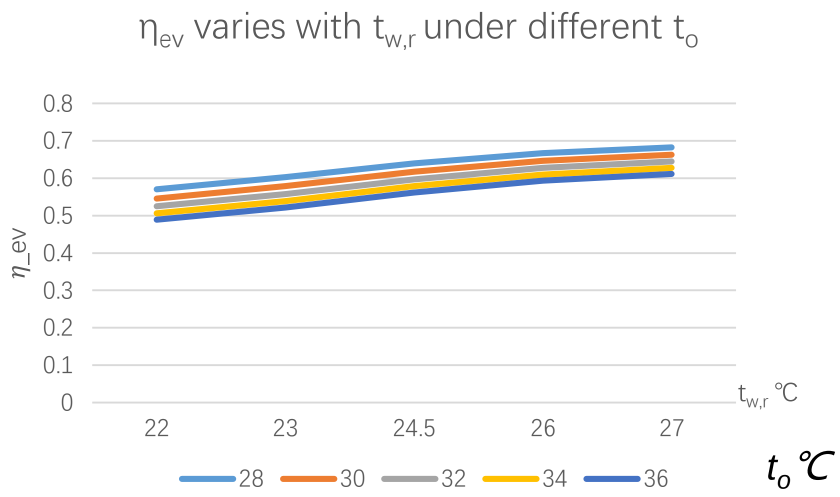
IEC water chiller processes

- For **parallel-connected** IEC water chillers



$$\eta_{ev} = \frac{t_{w,r} - t_w}{t_{w,r} - t_{A,wb}}$$





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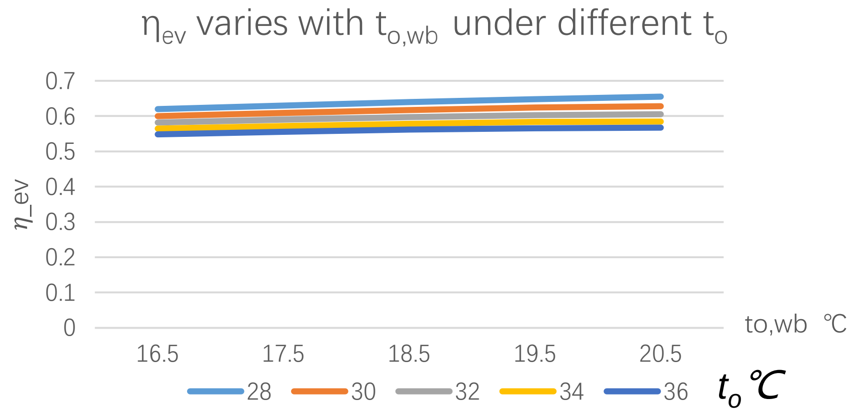
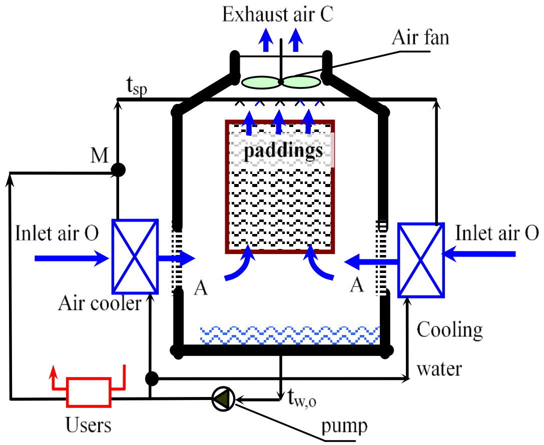


η_{ev} varies slightly when t_O , $t_{O,wb}$, t_{wr}, changes

For **parallel-connected** IEC water chillers:

When NTU increased,



$$\eta_c = \frac{t_o - t_A}{t_o - t_{o,dp}}$$

parameter	design value
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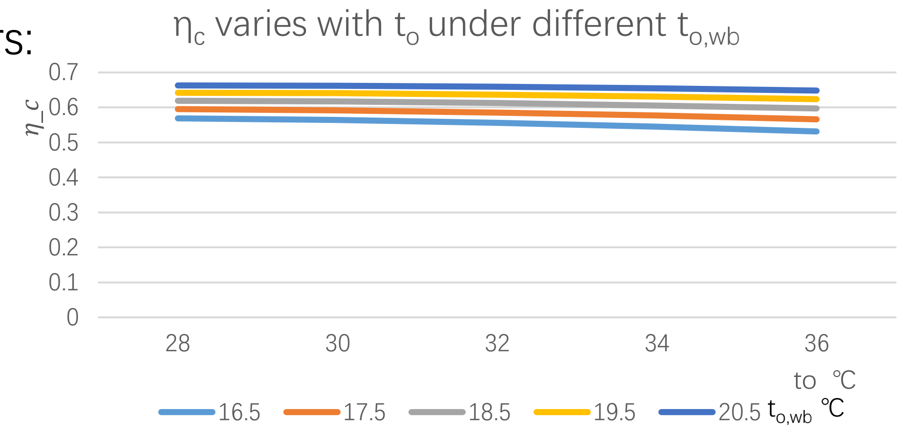
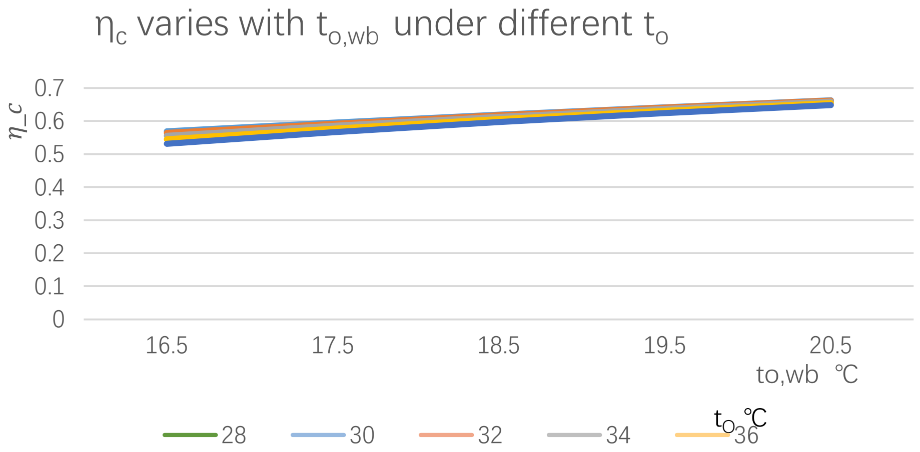
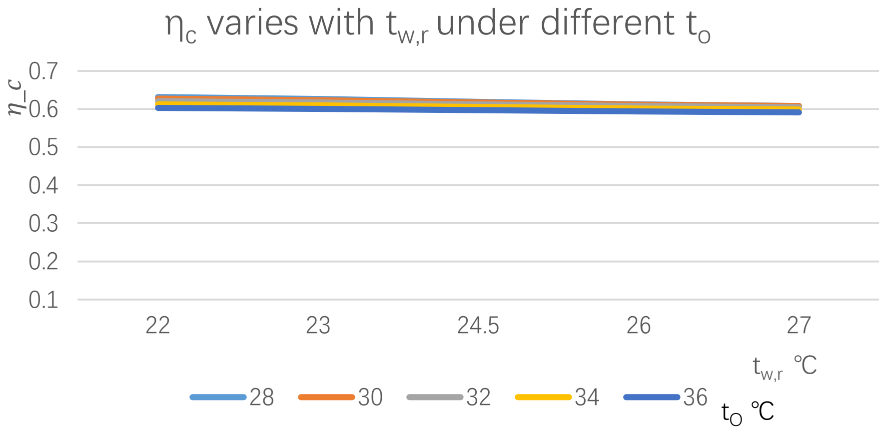


η_c has little change when t_O varies



η_c increases when $t_{O,wb}$ increases

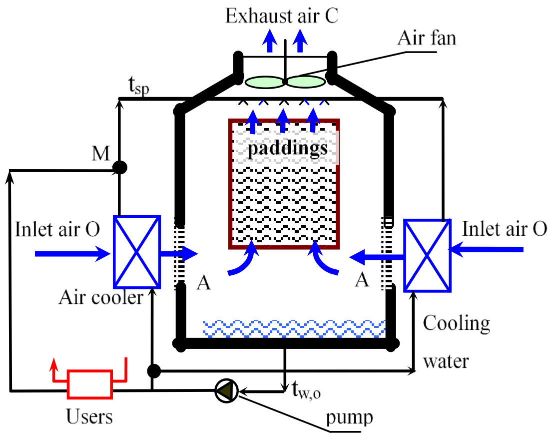


η_c has little change when $t_{w,r}$ decreases

The data grows while the tendency keeps the same

For **parallel-connected** IEC water chillers:

When NTU increased,



$$\eta_{ev} = \frac{t_{w,r} - t_w}{t_{w,r} - t_{A,wb}}$$

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Flow rate $G_a/G_{w,r}$	2. 25
capacity of heat exchanger	$Ntu_{ex}=2$
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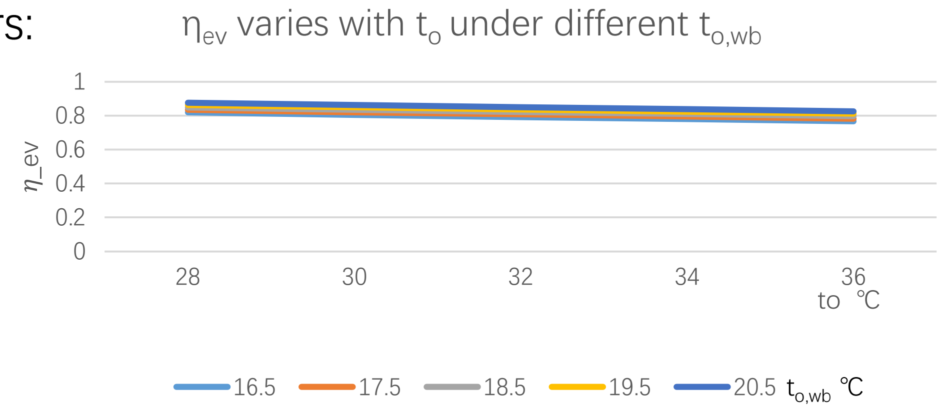
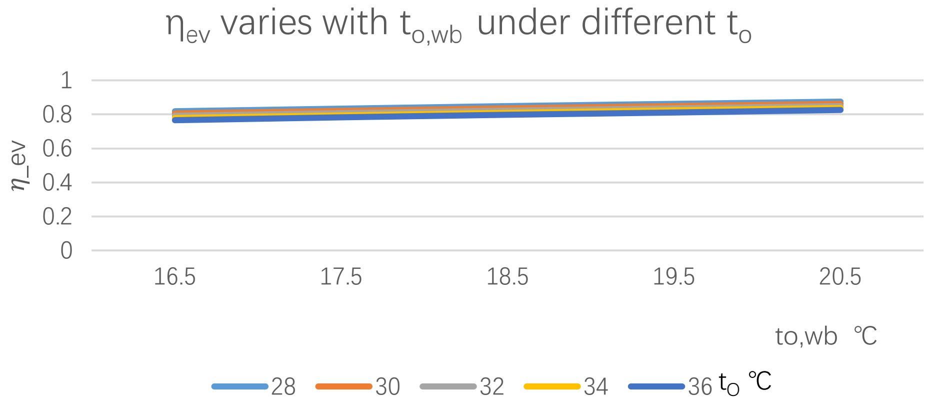
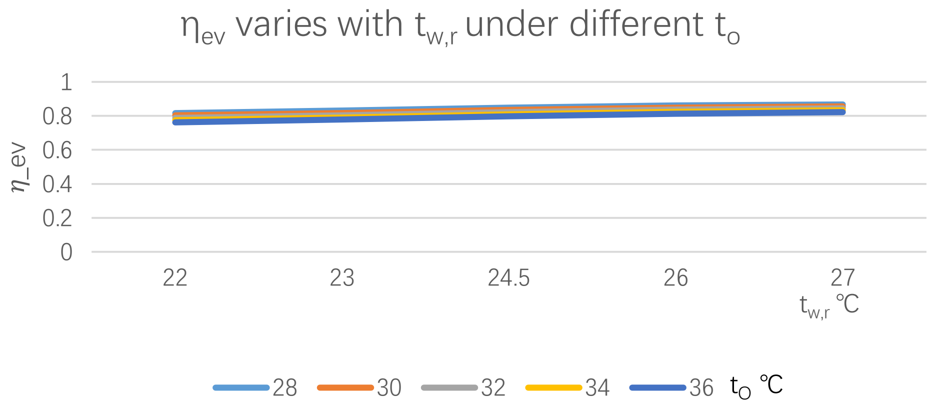


η_{ev} decreases when t_O increases



η_{ev} increases when $t_{O,wb}$ increases



η_{ev} increases when t_{wr} increases

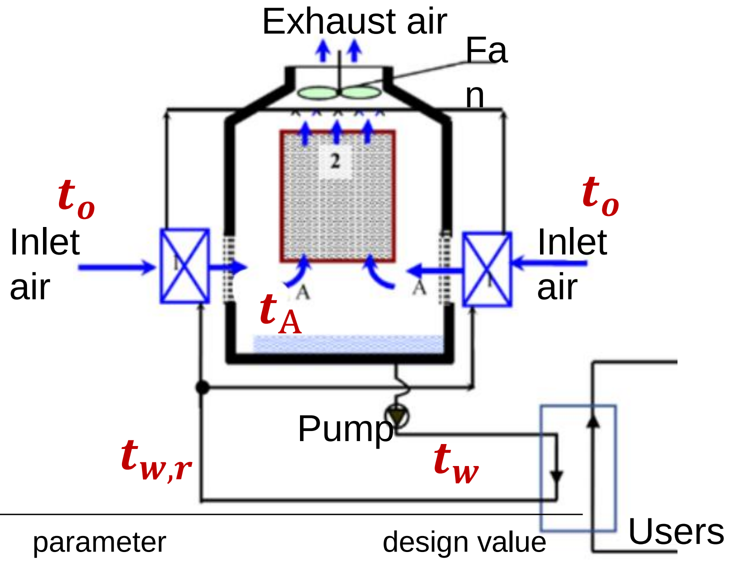
The data grows while the tendency keeps the same

IEC water chiller processes

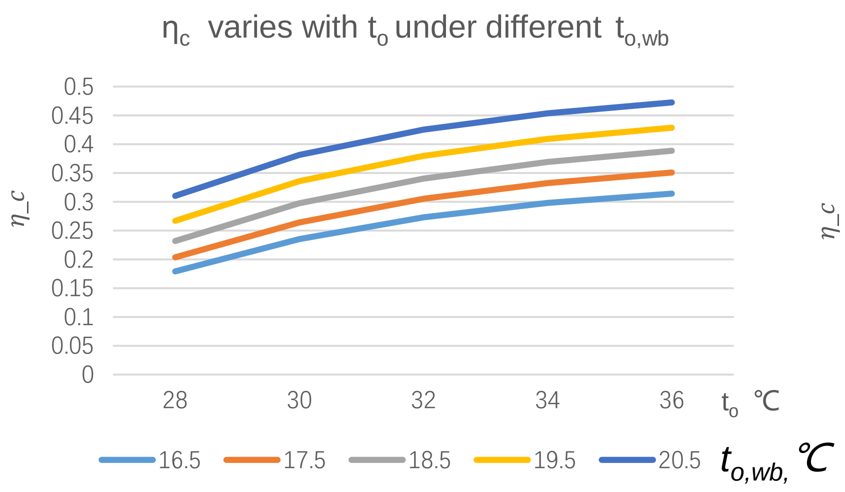
- Performance of the two efficiencies under different climates under different NTU

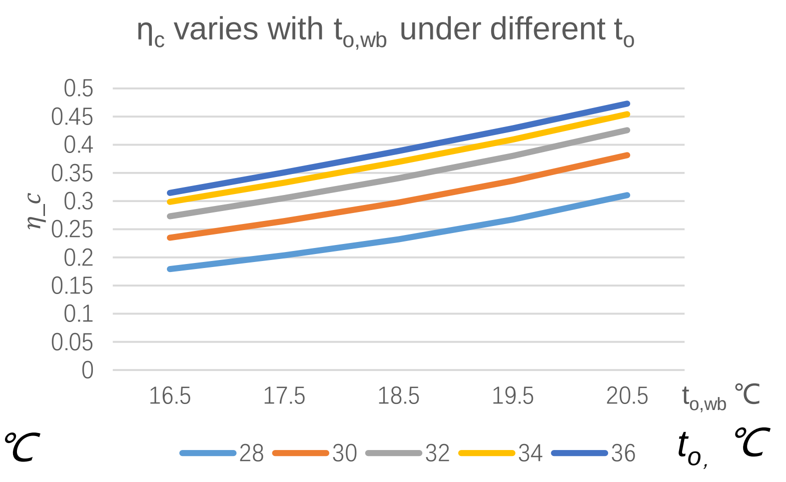
For **series-connected** IEC water chillers:

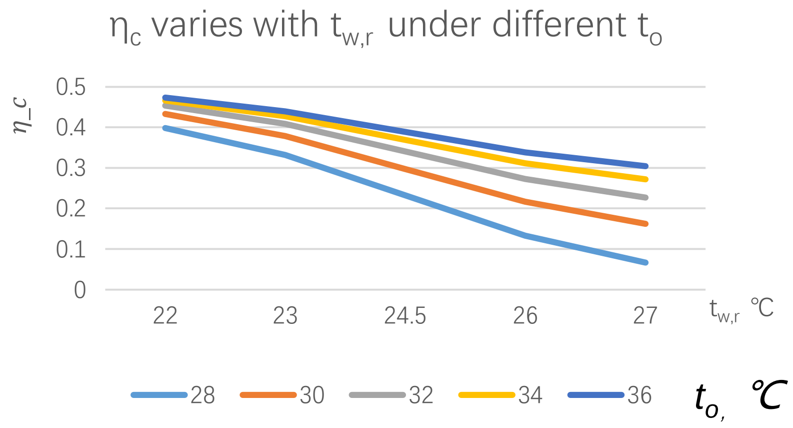
$$\eta_c = \frac{t_o - t_A}{t_o - t_{o,dp}}$$



parameter	design value
inlet air dry-bulb temperature t_O ℃	34^{+2}_{-7} ℃
inlet air wet-bulb temperature $t_{O,wb}$	18.5^{+2}_{-2} ℃
returned water temperature $t_{w,r}$	$24.5^{+2.5}_{-2.5}$ ℃
Flow rate G_a/G_w	1.5
capacity of heat exchanger	$Ntu_{ex}=2$
capacity of padding	$Ntu_{padding}=1.5$





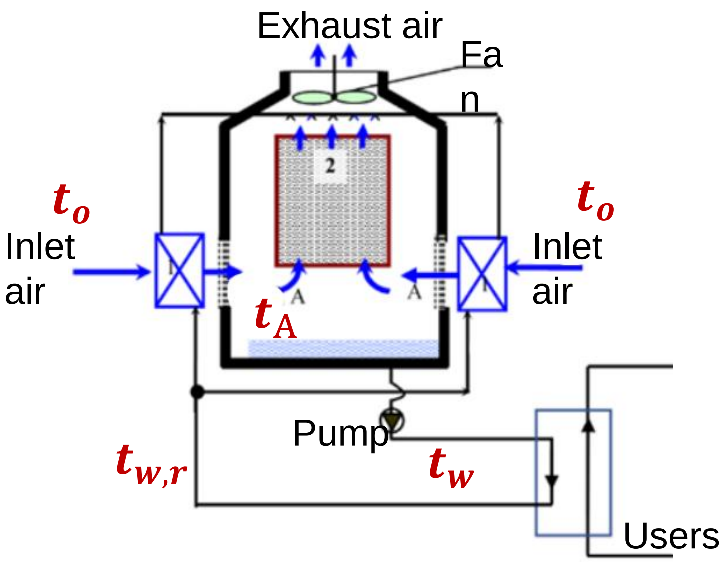


η_c increases when t_O increases

η_c increases when $t_{O,wb}$ increases

η_c decreases when $t_{w,r}$ increases

For **series-connected** IEC water chillers



$$\eta_{ev} = \frac{t_{w,r} - t_w}{t_{w,r} - t_{A,wb}}$$

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Flow rate G_a/G_w	1. 5
capacity of heat exchanger	$Ntu_{ex}=2$
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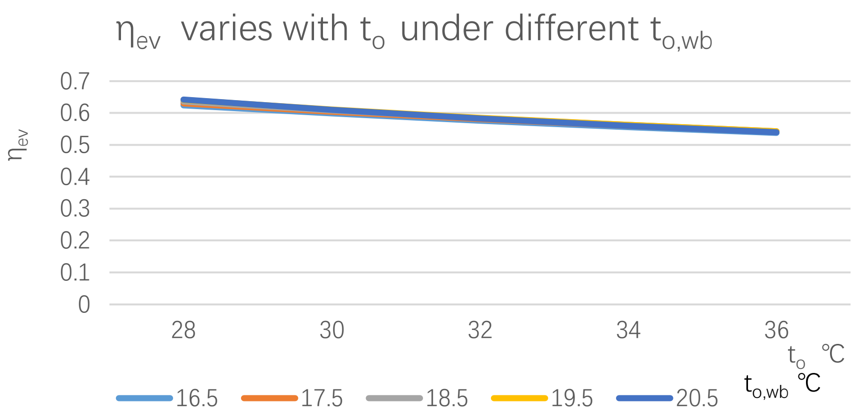
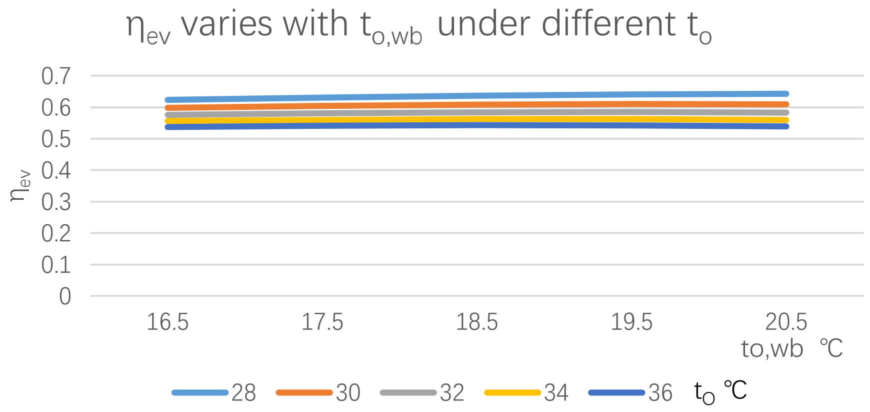
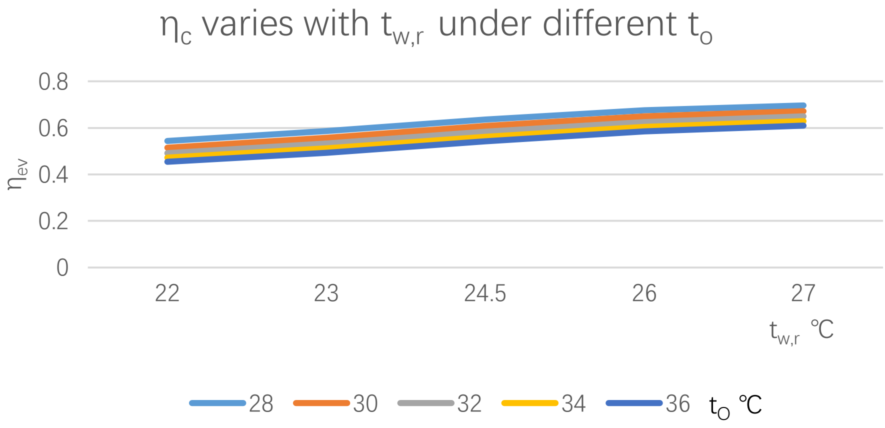


η_{ev} decreases when t_O increases



η_{ev} has little change when $t_{O,wb}$ increases



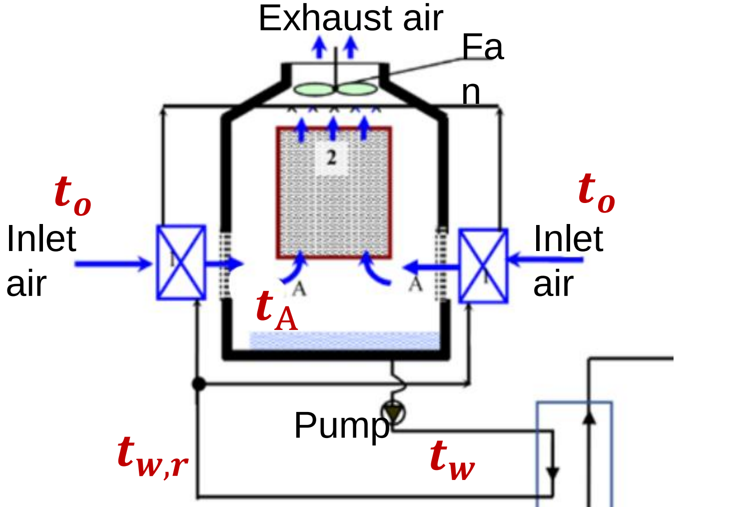
η_{ev} increases when t_{wr} increases

IEC water chiller processes

- When NTU increased,

For **series-connected** IEC water chillers:

$$\eta_c = \frac{t_o - t_A}{t_o - t_{o,dp}}$$



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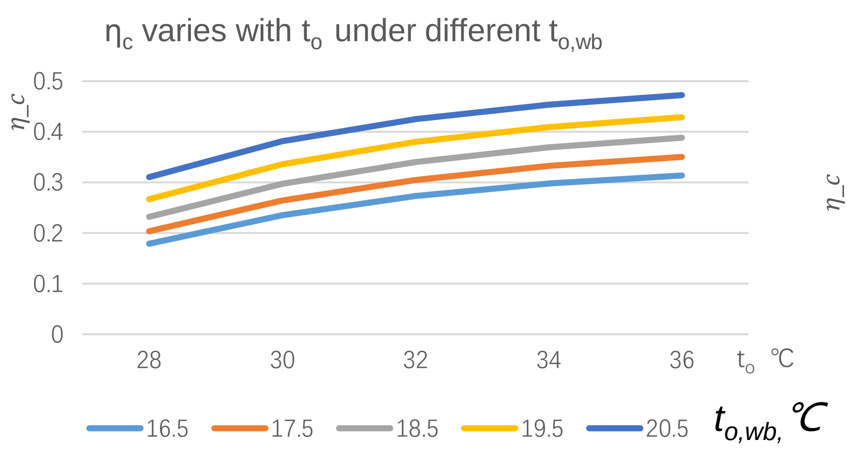
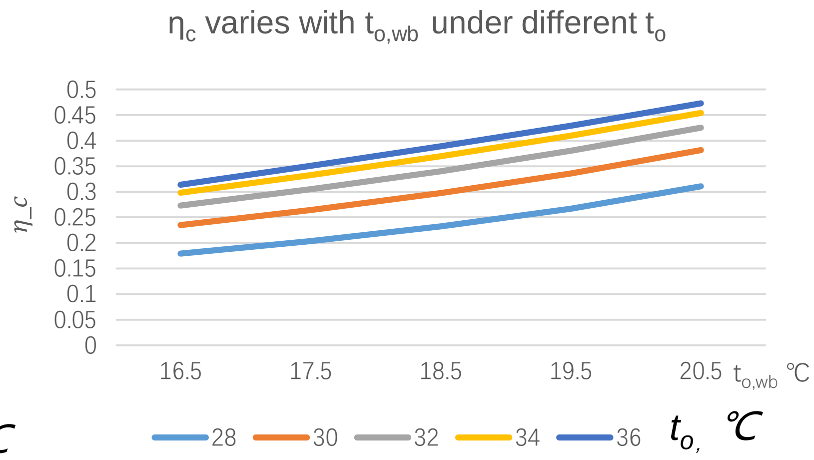
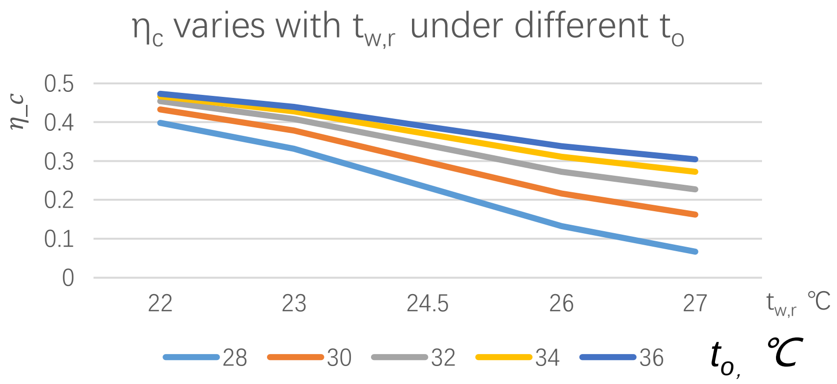


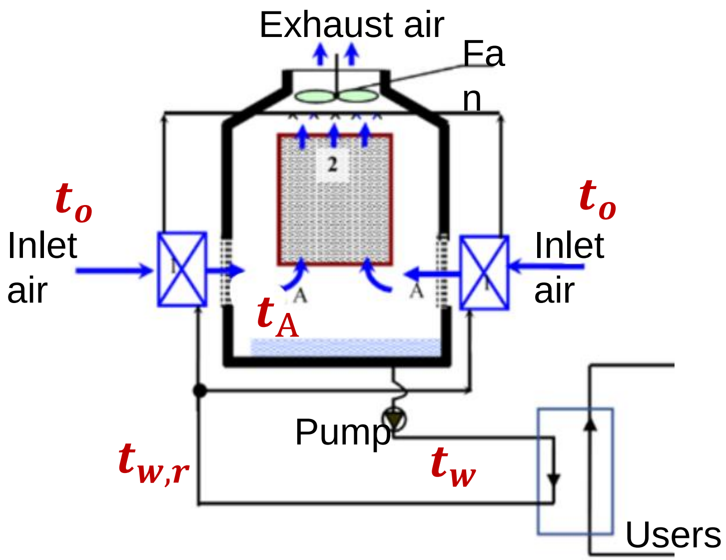




η_c increases when t_O increases
η_c increases when $t_{O,wb}$ increases
η_c decreases when $t_{w,r}$ increases

η_c is exactly stable when changing $Ntu_{padding}$

For **series-connected** IEC water chillers



$$\eta_{ev} = \frac{t_{w,r} - t_w}{t_{w,r} - t_{A,wb}}$$

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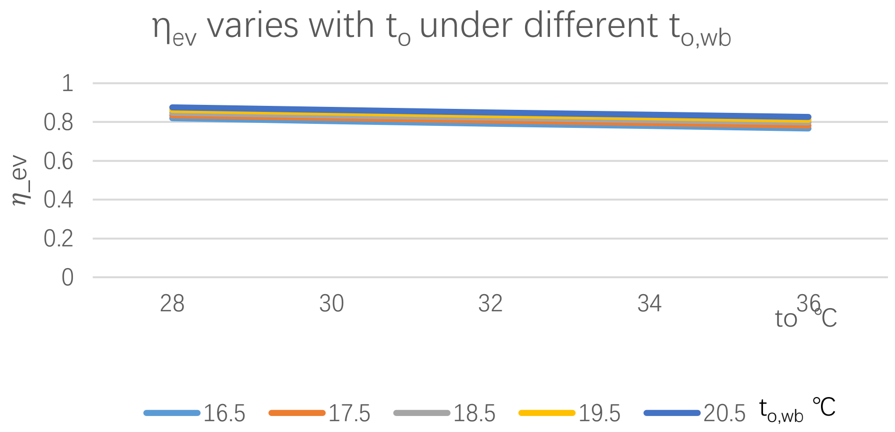
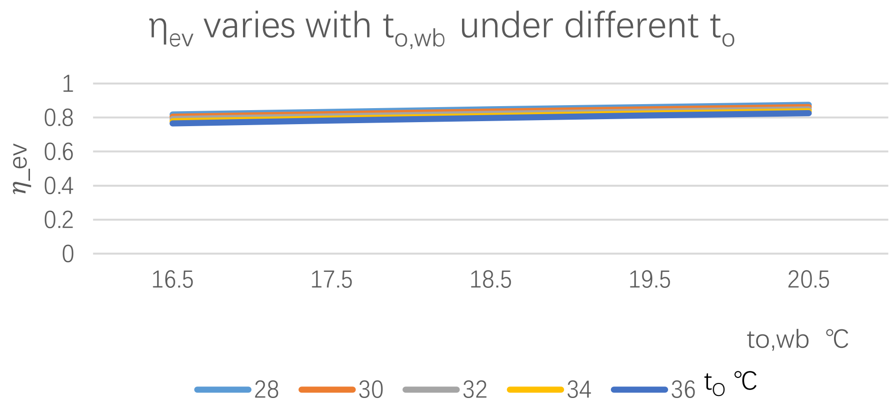
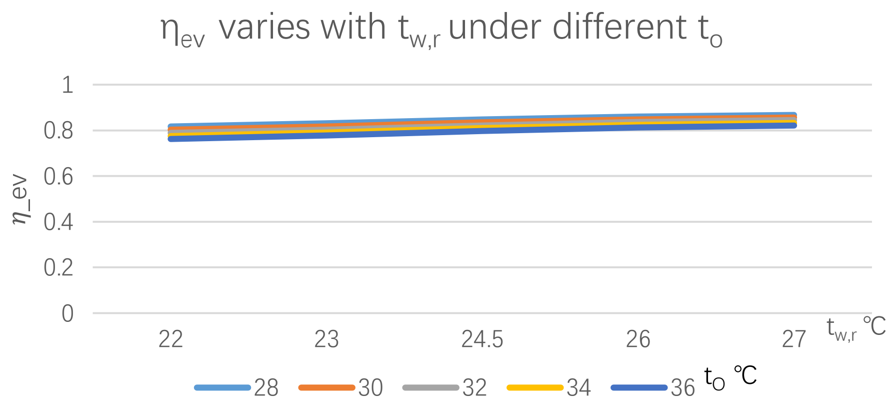






When NTU increased,
η_{ev} grows while the trends when changing t_o and $t_{o,wb}$ keep the same.

IEC water chiller processes

- If only define one efficiency-Dew point temperature efficiency, to express the cooling performance.

$$\eta_{dew} = \frac{t_{w,r} - t_w}{t_{w,r} - t_{O,dp}}$$

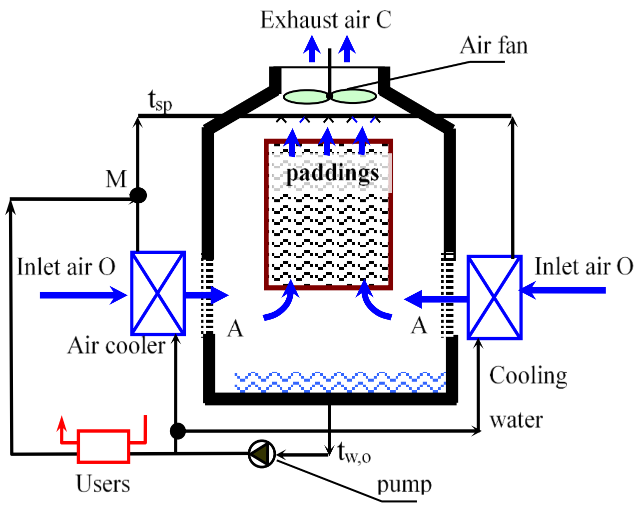
Thus, t_w could be described as the follow equation:

$$t_w = t_{w,r} - \eta_{dew} * \{t_{w,r} - t_{O,dp}\}$$

t_o: inlet air temperature;
$t_{o,dp}$: inlet air dewpoint temperature;
$t_{w,r}$: inlet water temperature;
t_w : outlet water temperature.

IEC water chiller processes

- For **parallel-connected** IEC water chillers



$$\eta_{dew} = \frac{t_{w,r} - t_w}{t_{w,r} - t_{O,dp}}$$

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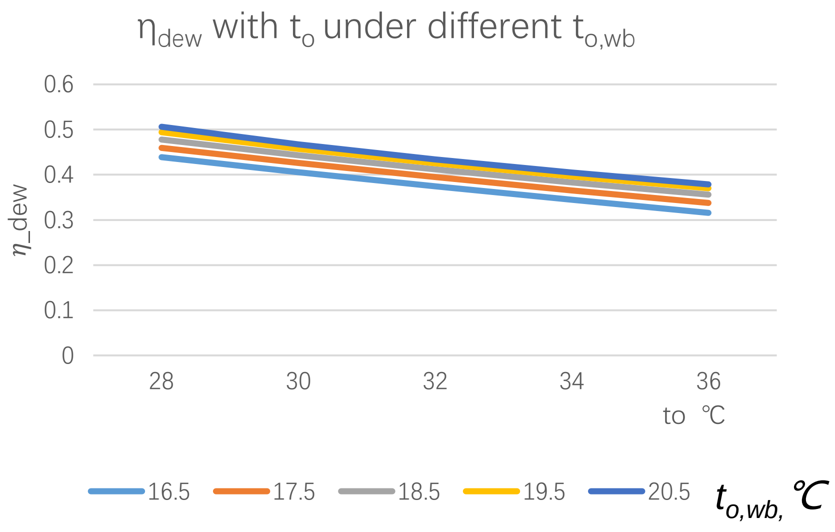
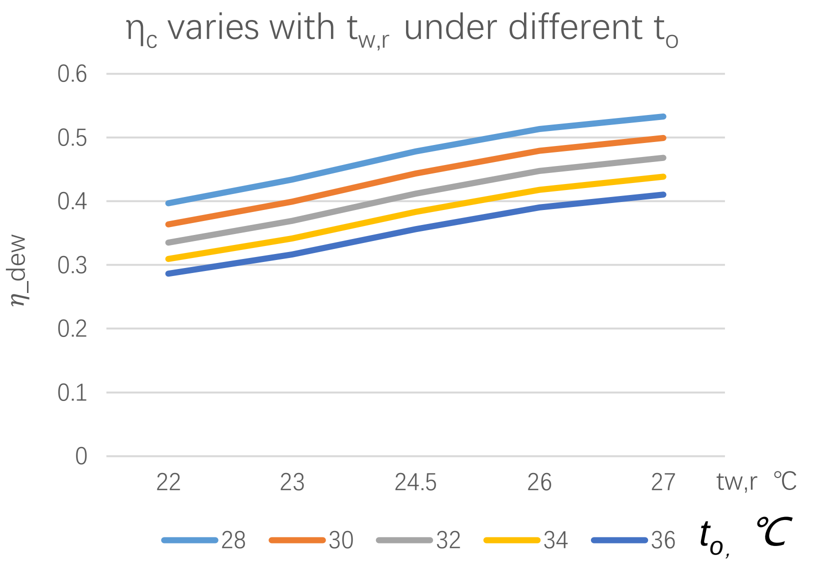
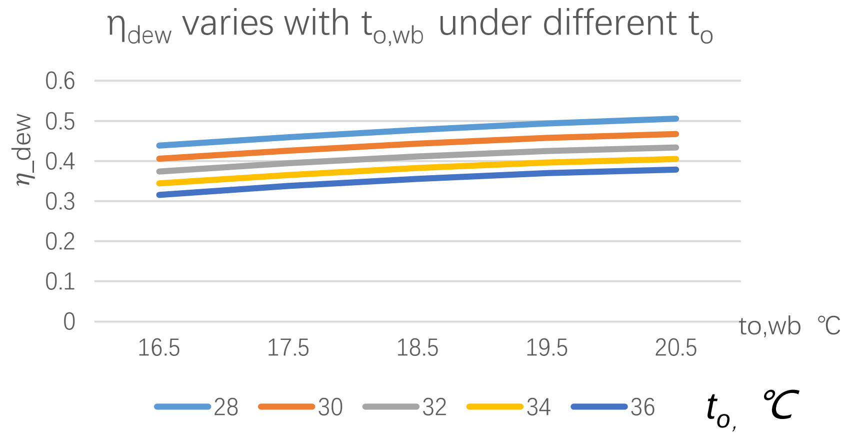




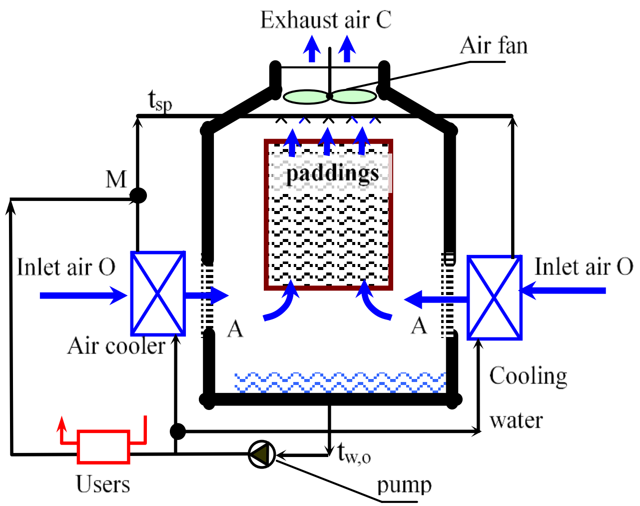


η_{dew} varies larger than η_c and η_{ev} when t_O , $t_{O,wb}$,t_{wr}, changes
η_c and η_{ev} are more suitable than η_{dew} as indicators.

IEC water chiller processes

- For **parallel-connected** IEC water chillers, when Ntu of padding increases

$$\eta_{dew} = \frac{t_{w,r} - t_w}{t_{w,r} - t_{O,dp}}$$



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capacity of heat exchanger	$Ntu_{ex}=2$
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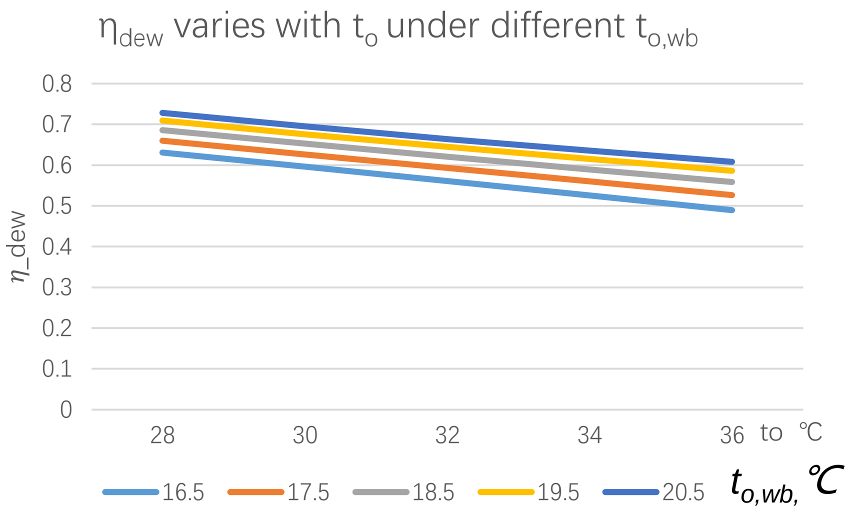
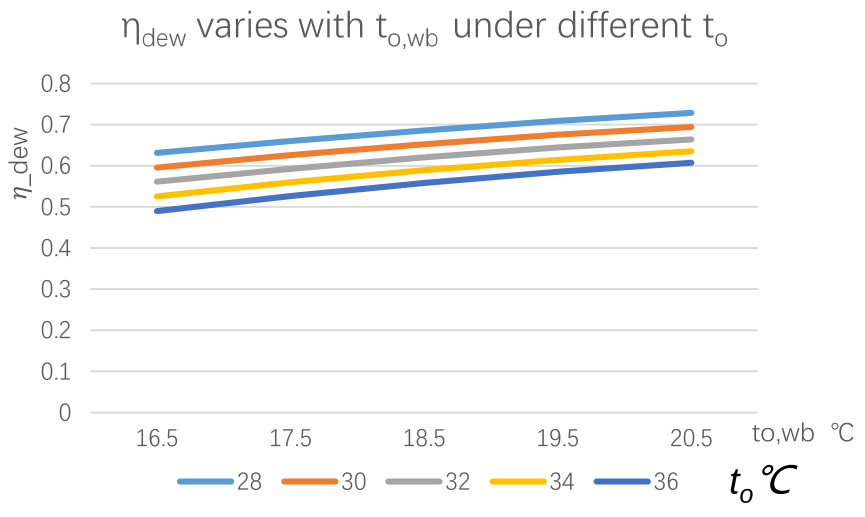
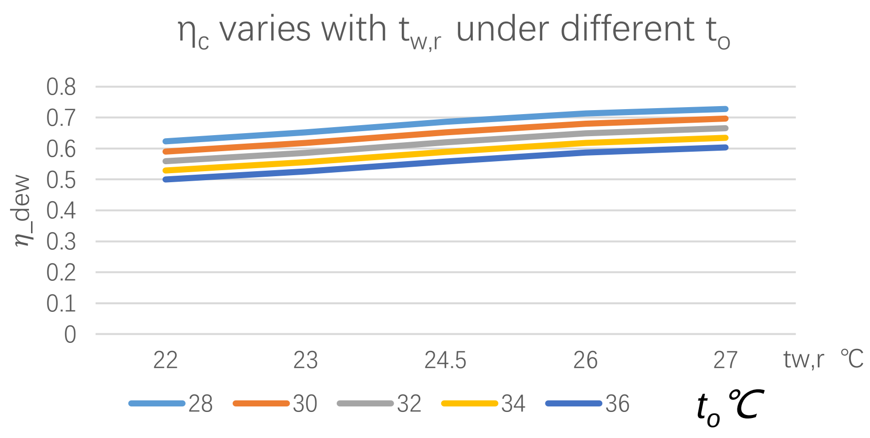


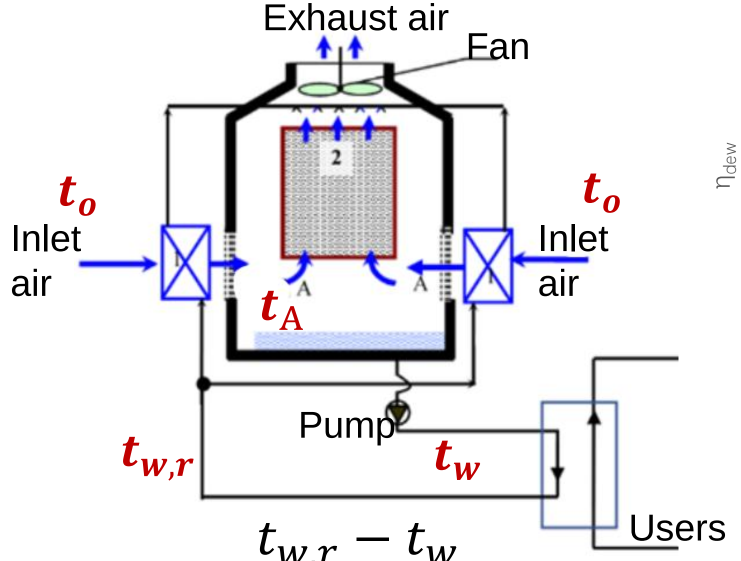




When NTU of padding increased, the trend of η_{dew} with t_O changes.

IEC water chiller processes

For **series-connected** IEC water chillers:



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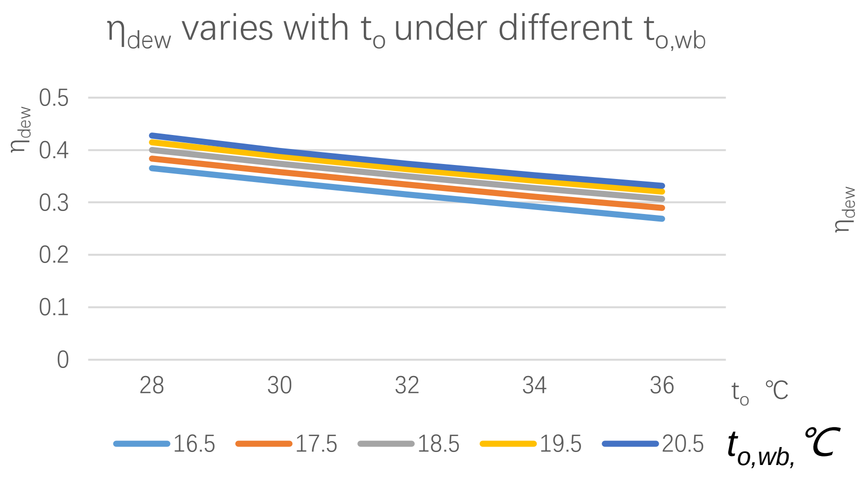
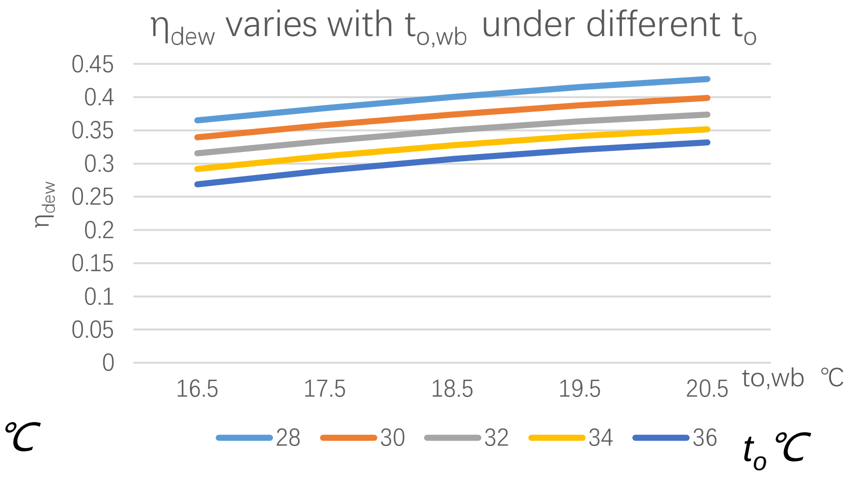
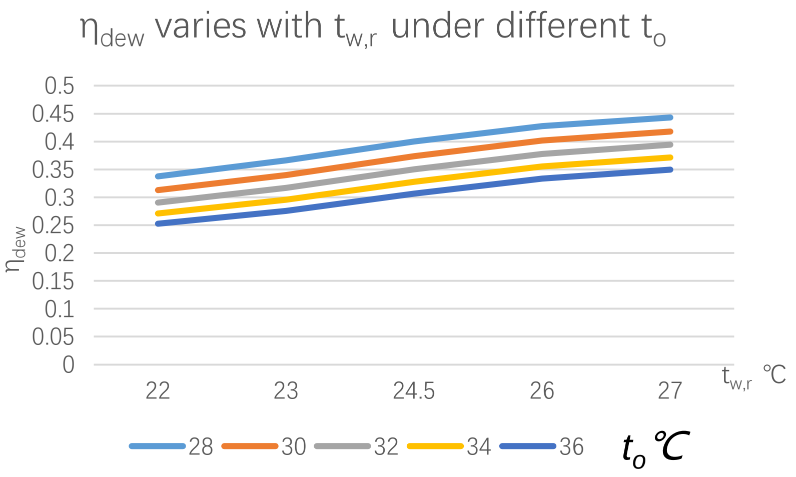
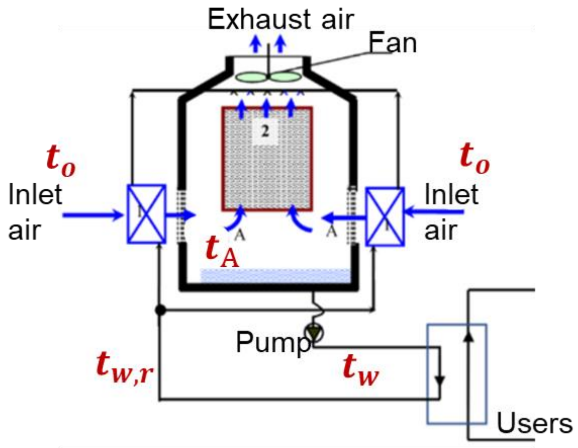






For **series-connected** IEC water chillers



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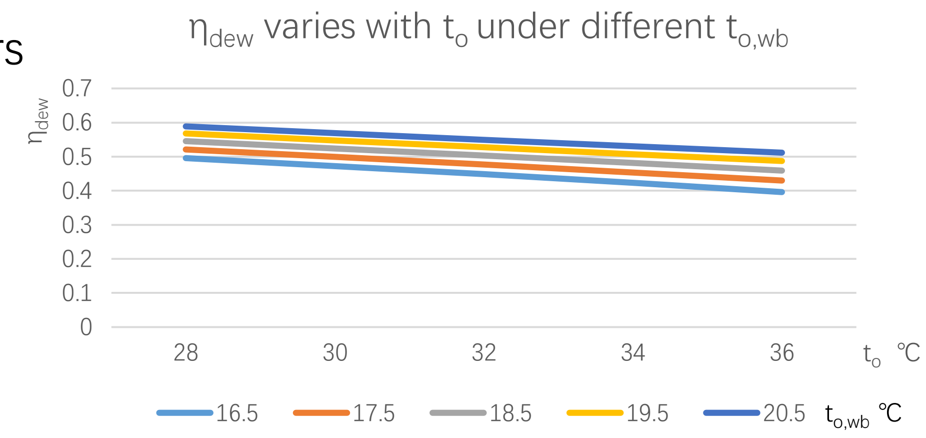
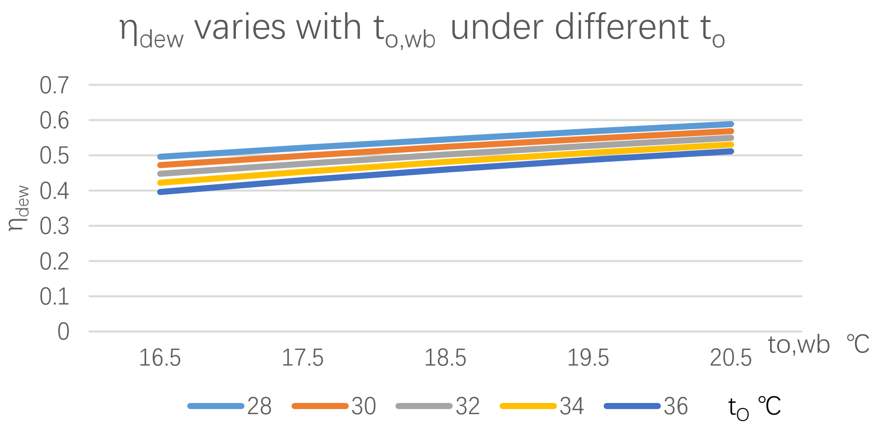
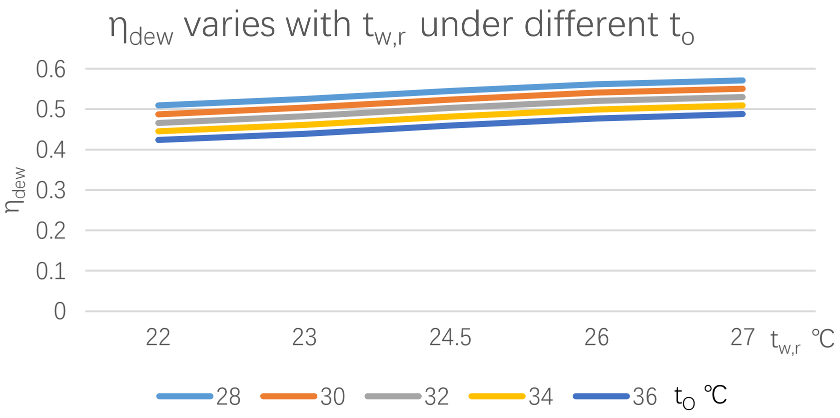
capacity of heat exchanger	$Ntu_{ex}=2$
capacity of padding	$Ntu_{padding}=4$



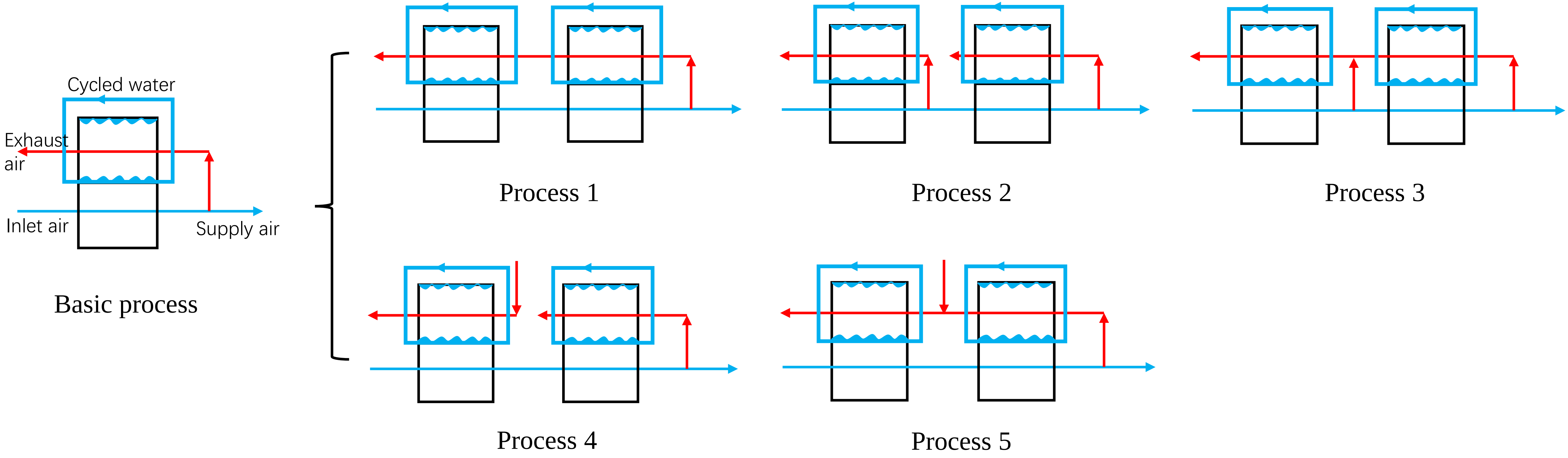




- Suitable indicators could be found, which varies slightly when climates changes, that could help us to identify the basic performance of IEC processes.
- Different process structures, the performance of indicators are different, while we still expect to found unified indicators.

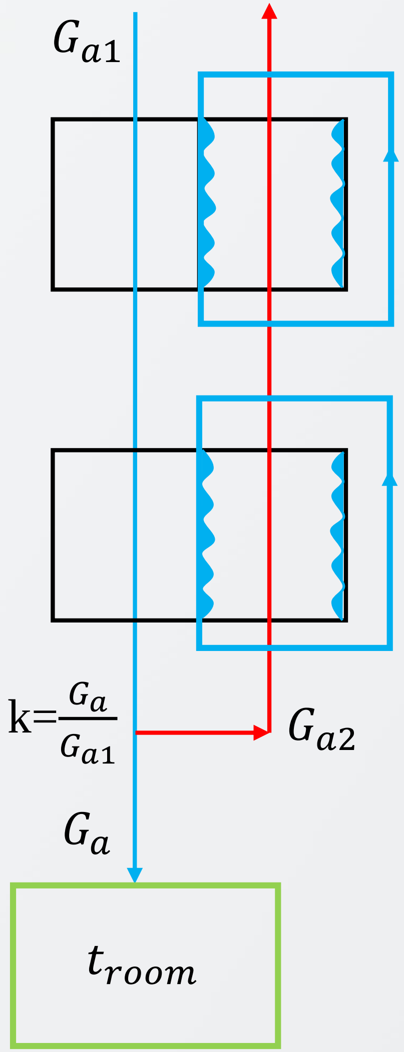
Indicators discussion for different processes for IEC air coolers

- **Just a very preliminary discussion**



parameter

parameter	design value
air supply volume flow G_a m^3/h	3000 m^3/h
inlet air volume flow G_{a1} m^3/h	3000/k m^3/h (4300-7200)
air volume flow G_{a2} m^3/h	$(G_{a1}-G_a)$ m^3/h
$\frac{Air\ mass\ flow}{Water\ \text{mass flow}}$	4
capacity of heat exchanger	NTU_{ex}=3
capacity of padding	$NTU_{padding}$=2



Indicators definition

- **Dew-point effectiveness**

Dew-point effectiveness is the ratio of the temperature difference between the inlet and outlet product air to the difference between the inlet product air's dry bulb and inlet working air's dew point temperature.

$$\varepsilon_{dp} = \frac{t_{p,db,in} - t_{p,db,out}}{t_{p,db,in} - t_{p,dp,in}}$$

- **Energy efficiency**

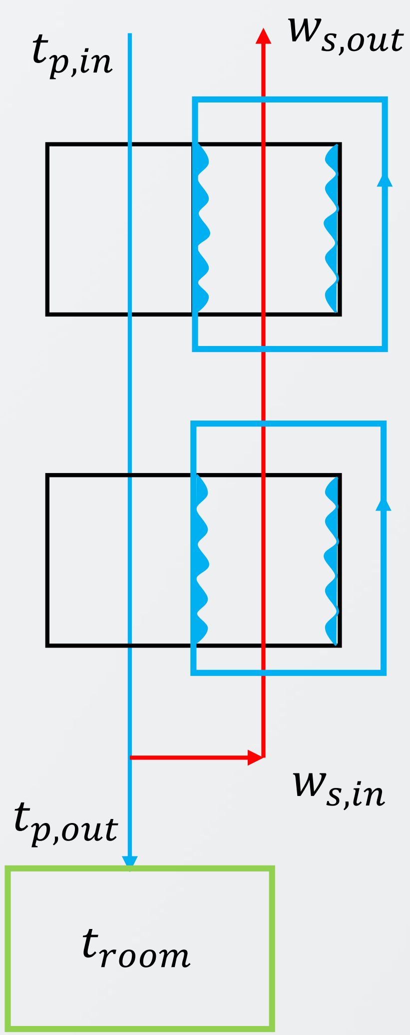
Energy efficiency, known as 'coefficient of performance (COP), is the ratio of the cooling capacity of the IEC to the power consumption of the system.

$$COP = \frac{Q}{W} = \frac{\rho_f G_a (t_{room} - t_{p,out})}{W}$$

- **Water evaporation rate**

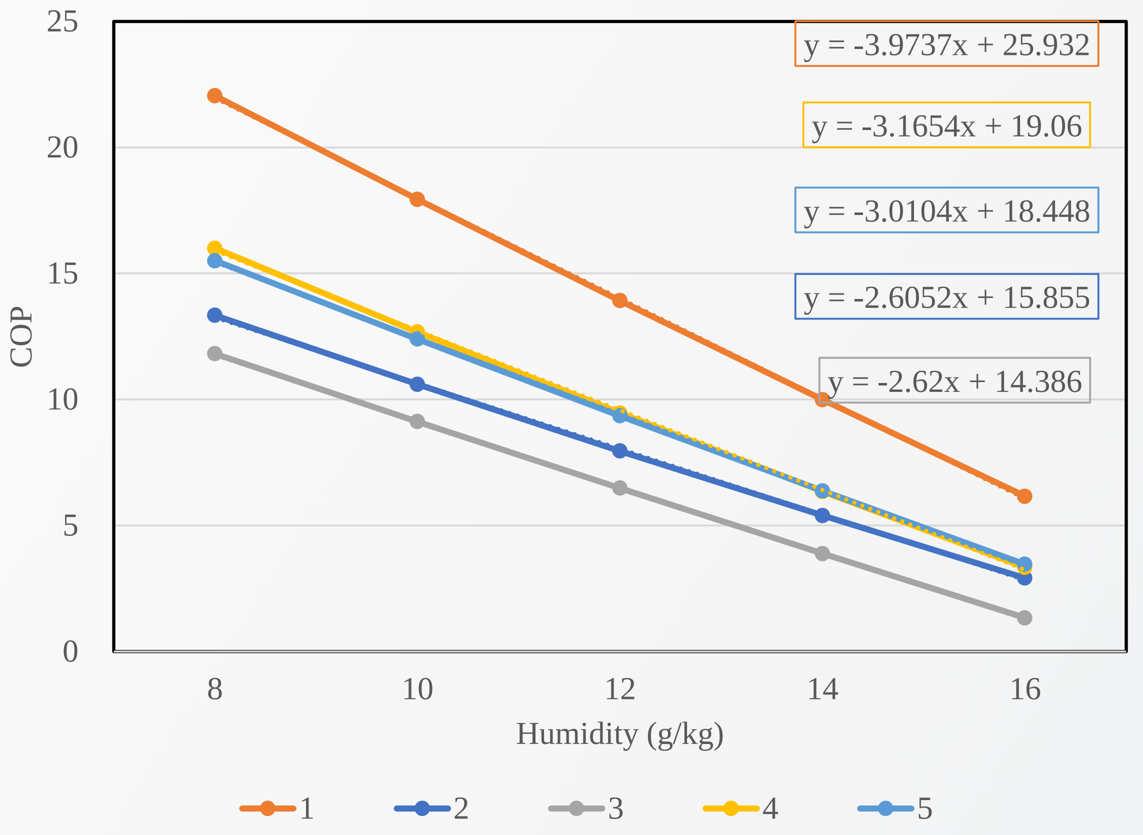
Water evaporation rate is equal to the volume of the moisture increase in the working air during its indirect cooling operation.

$$V_w = \frac{\rho_{s,f} V_{s,out}}{\rho_w} (w_{s,out} - w_{s,in})$$

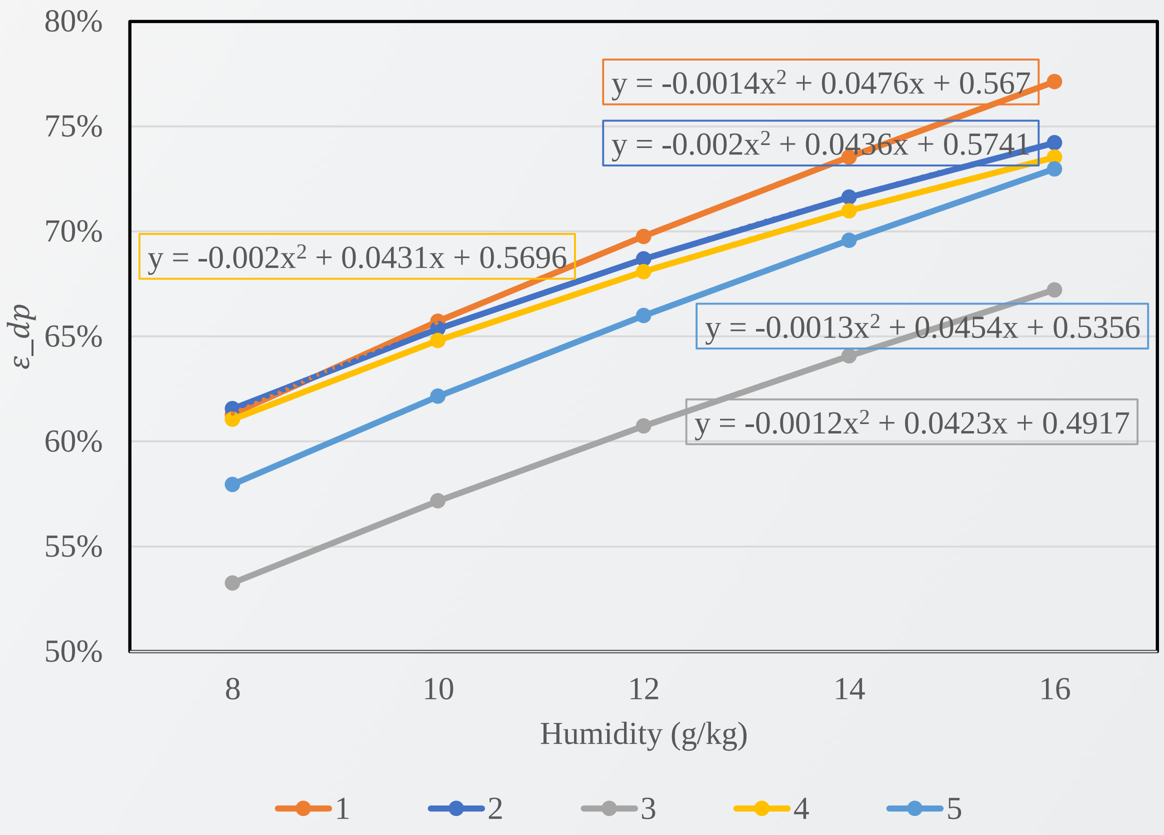


Indicators varies with outdoor humidity ratio

- As the humidity increases, the COP of each process decreases

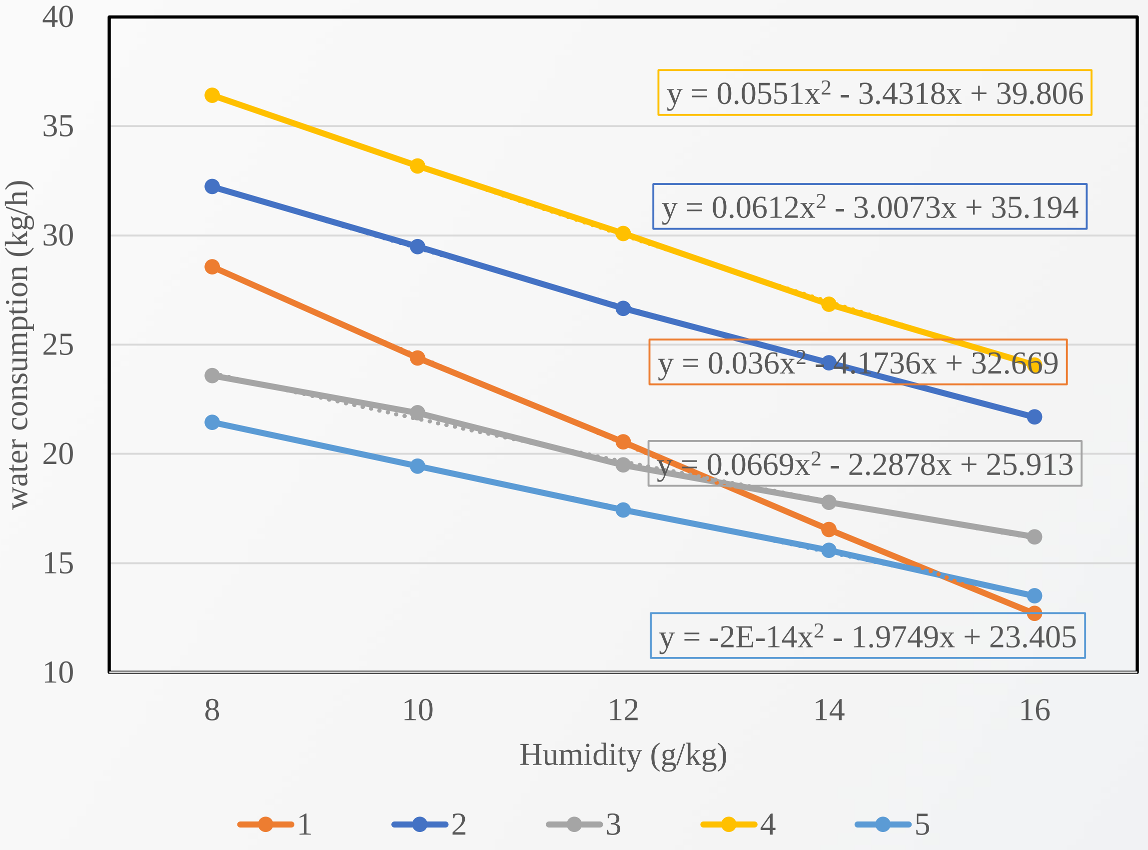


- As the humidity increases, the ε_{dp} of each process increases

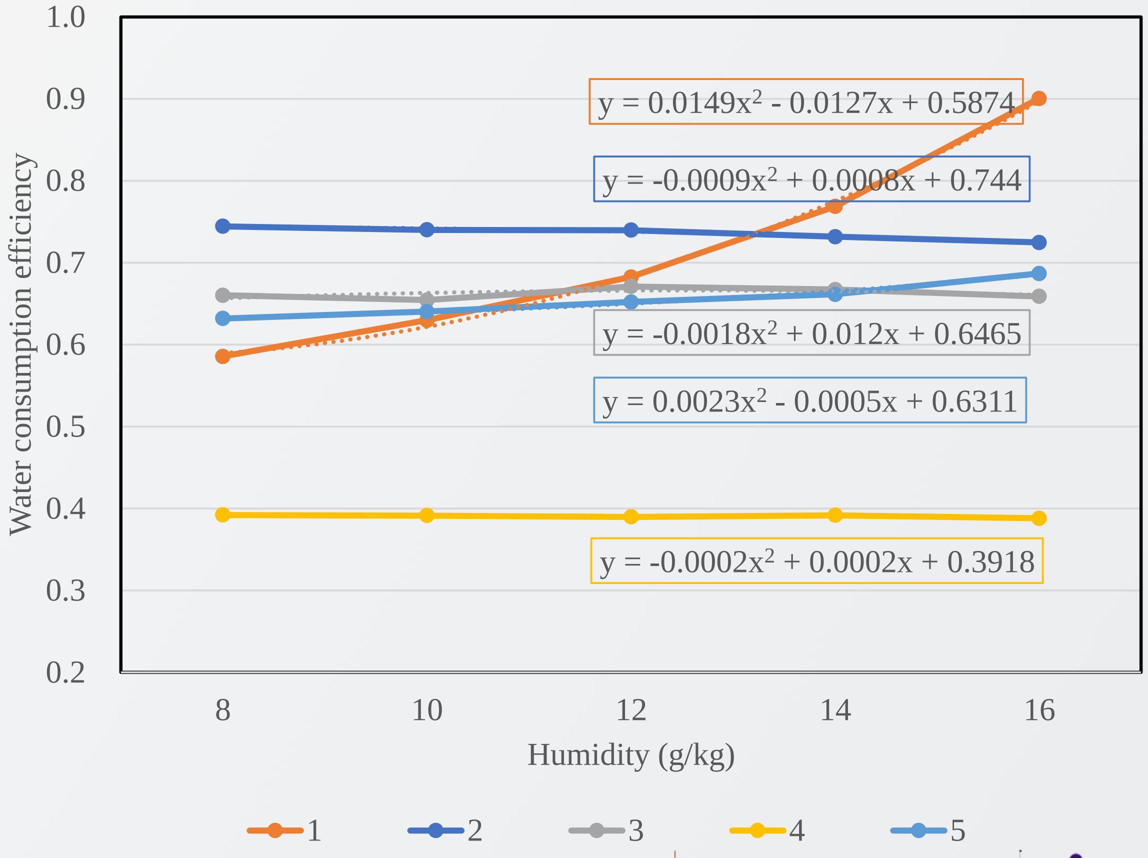


Indicators varies with outdoor humidity

- As the humidity increases, the Water evaporation rate of each process decreases

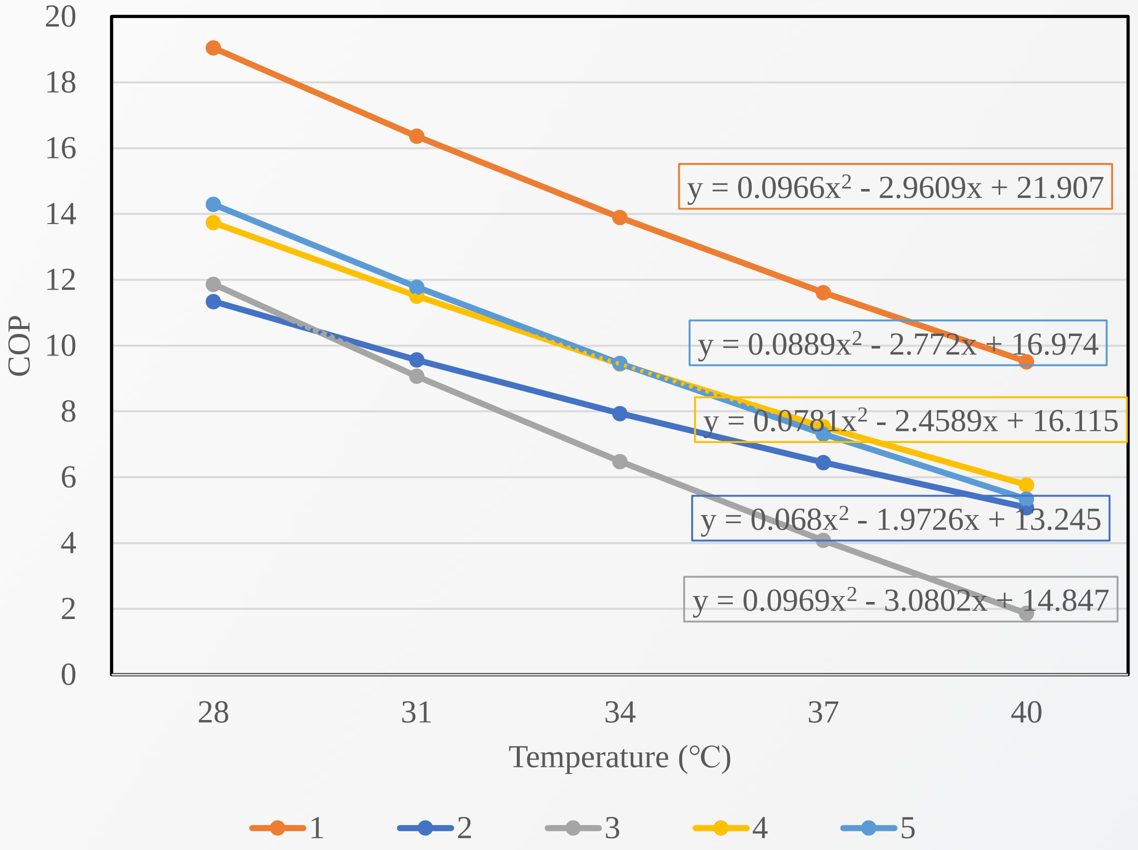


- As the humidity increases, the Water consumption efficiency of process 1,5 increases, process 2,3,4 decreases

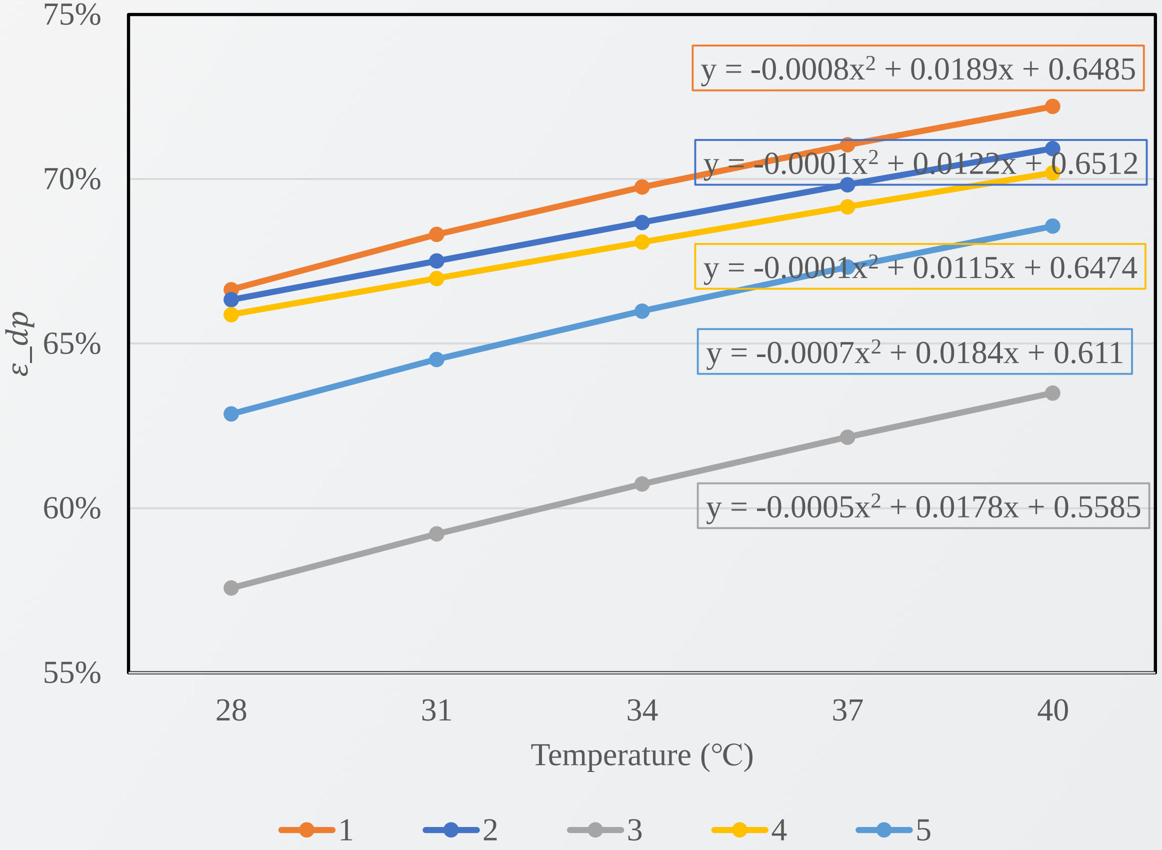


Indicators varies with outdoor temperature

- As the temperature increases, the COP of each process decreases



- As the temperature increases, the ε_{dp} of each process increases



Indicators varies with outdoor temperature

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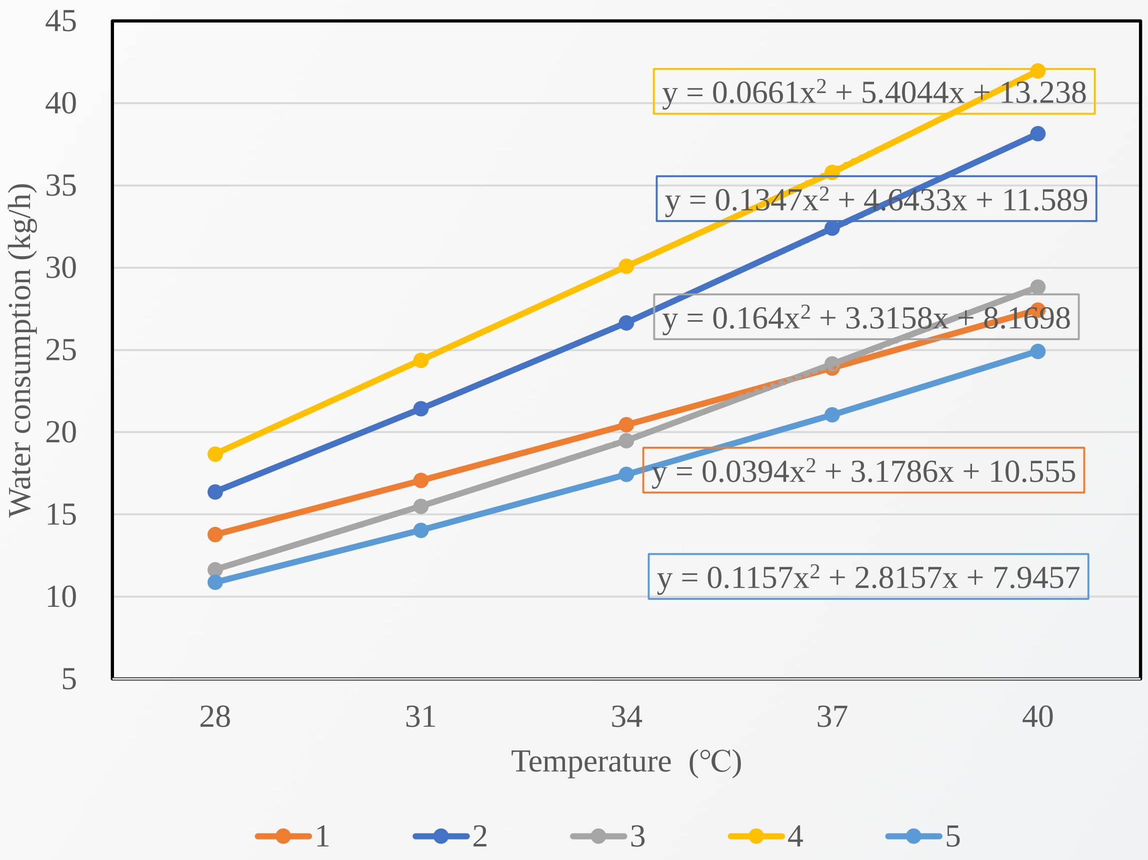
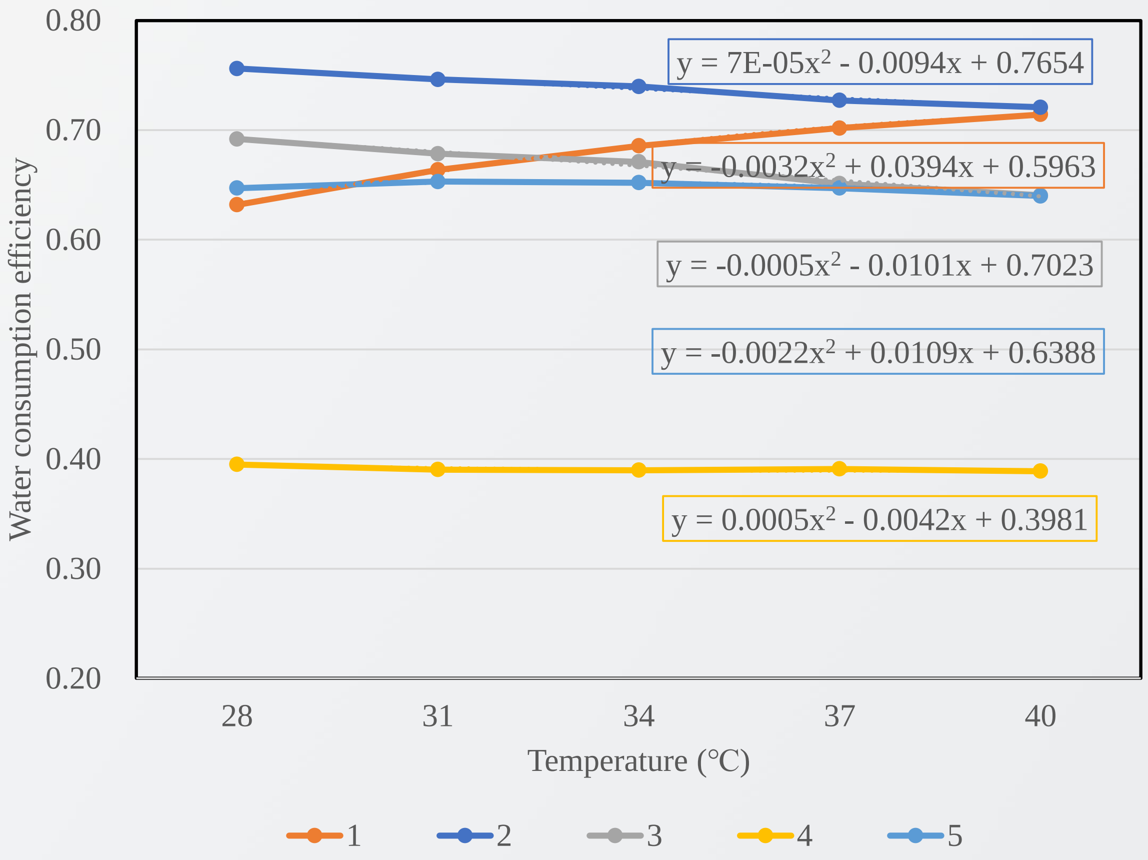
- As the temperature increases, the Water evaporation rate of each process increases



- As the humidity increases, the Water consumption efficiency of process 1 increases, process 2,3,4,5 decreases



- When the indicators changes largely with climates, we could get some fitting formulas to describe the change and used to predetermine the performance under different climates.
- The comparison results of different processes could be changed under different climates.
- Further discussions are needed to be carried out.

Thank you very much for your attention!