Modeling, loss analysis and indicators discussion of IEC air coolers

Jiale Fan

Tsinghua University, Beijing, China

2022.10

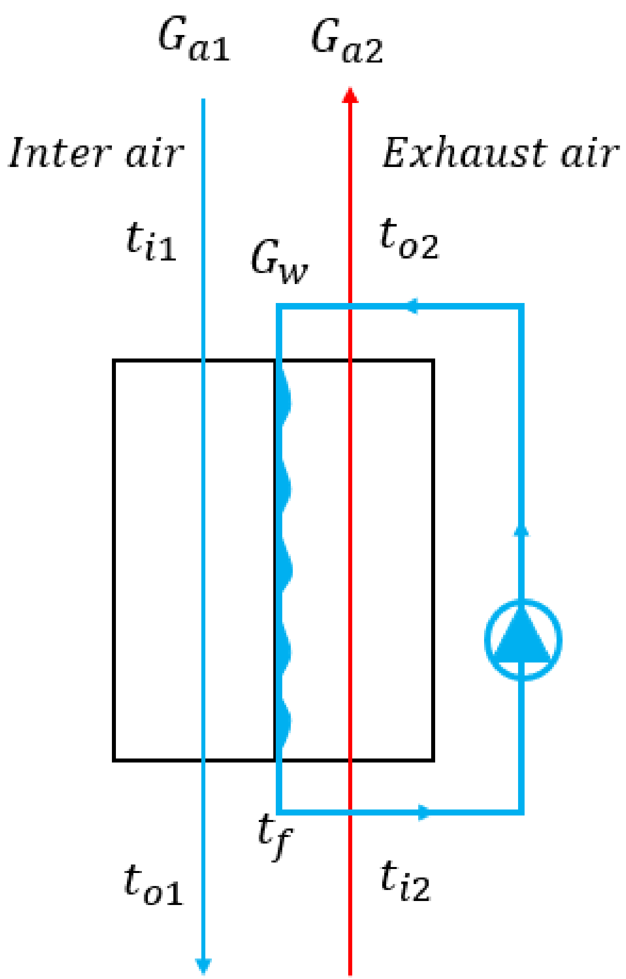
The support from National key research and development program of China (key projects of international cooperation in science and technology innovation) (Grant number 2019YFE0102700)

M-cycle indirect evaporative air cooler process

- Modeling
- Loss analysis
- Indicators discussion

Modeling

- three-stream model



Flow direction

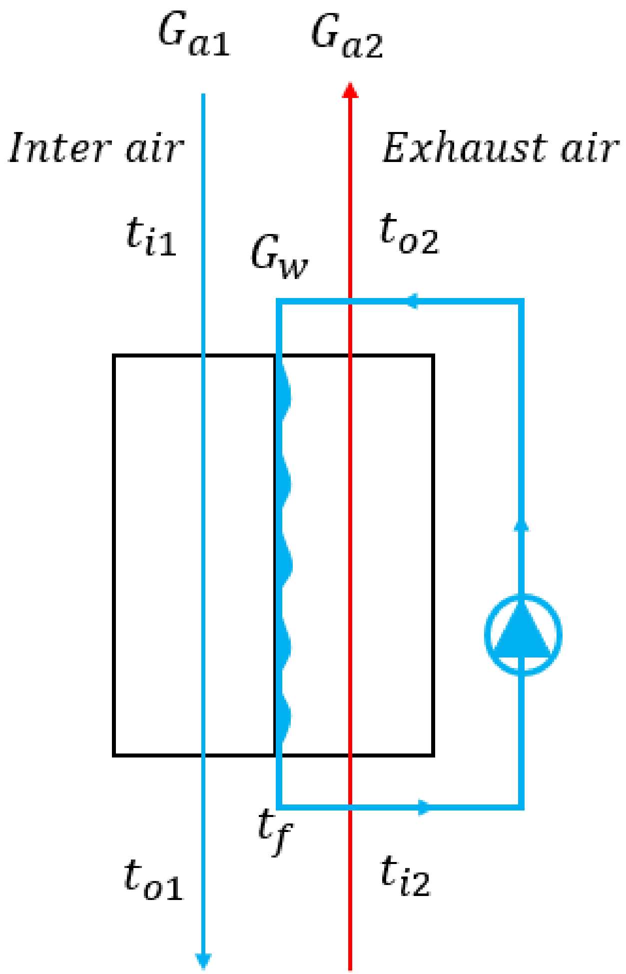
- The primary air on the left side enters the dry channel from top to bottom
- The secondary air on the right side enters the wet channel from bottom to top
- The spray water is cycled water, which flows from top to bottom in the wet channel and then circulates back through the water pump

Assumptions:

1. The latent heat of evaporation is provided by water.
2. The water at the air surface is equated as a saturated wet air layer.
3. The water is recycled.

Modeling

- three-stream model



- Wet channel
- In the wet channel, heat is transferred by air directly contacting with water in countercurrent mode, including sensible heat exchange and latent heat exchange, which meet the relationship of energy conservation and heat and mass transfer.

- Formulas:

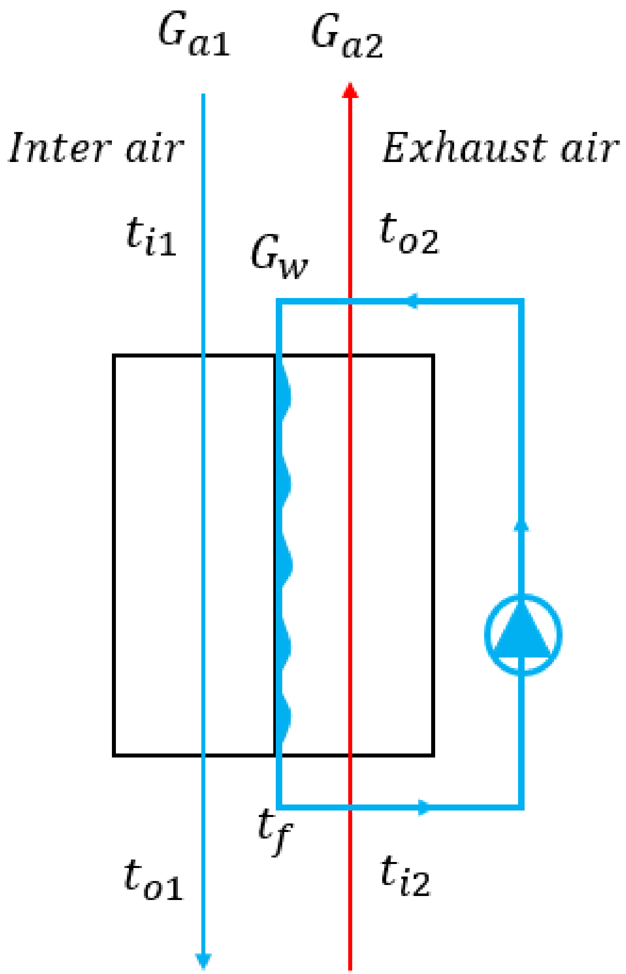
$$G_{a2}C_{pa}dt_2 = K_s\left(t_f - t_a\right)dA$$

$$G_{a2}dh_2 = K_d(h_{wa} - h_a)dA$$

$$G_{a2}d\omega_2 = K_d(d_{wa} - d_a)dA$$

Modeling

- three-stream model



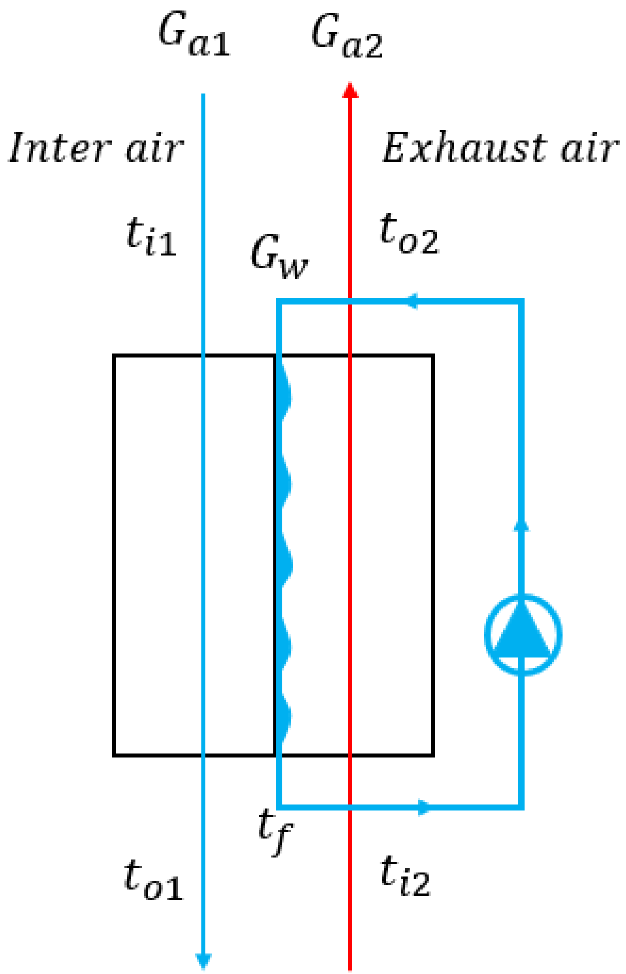
- Dry channel
- In the dry channel, air and water exchange heat in the downstream direction, and there is no direct contact between them. There is only sensible heat exchange in the whole process, which meets the conservation of energy and Fourier law.

- Formulas:

$$G_{a1}C_{pa}dt_1 = U(t_{i1} - t_f)dA$$

Modeling

- three-stream model

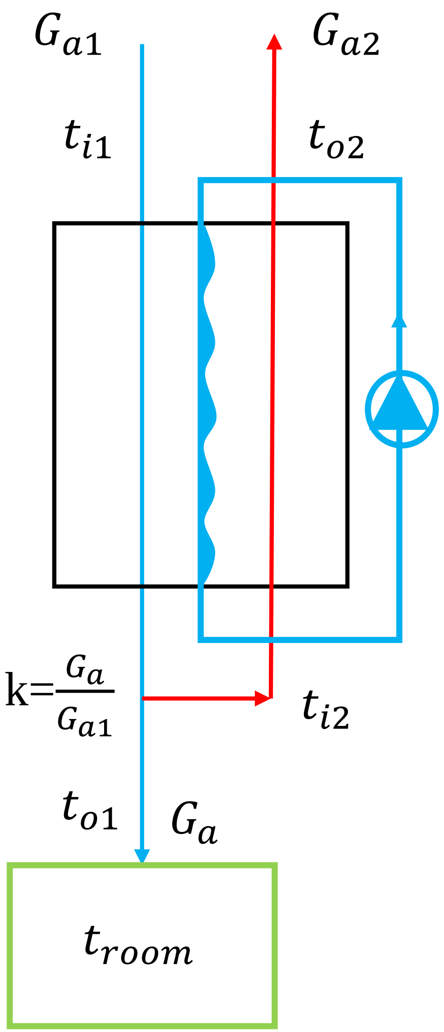


- Cycled water
- For the circulating water, it exchanges sensible heat with the primary air at the dry channel side and heat and mass with the secondary air at the wet channel side. The whole process meets the law of conservation of energy.

- Formulas:

$$G_w C_{pw} dt_w = K_d[1.01(t_a - t_w) + (r_0 + 1.84t_a)\omega_a - (r_0 + 1.84t_w)\omega_w]dA + U(t_{i1} - t_f)dA$$

parameter



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

loss analysis

• Single-stage process

- In the primary channel, the entransy dissipation is:

$$\Delta J_1 = \int_0^A K(t_{db1} - t_w)dQ$$

- In the secondary channel, the entransy dissipation is:

$$\Delta J_2 = \int_0^A K(t_w - t_{dp2})dQ$$

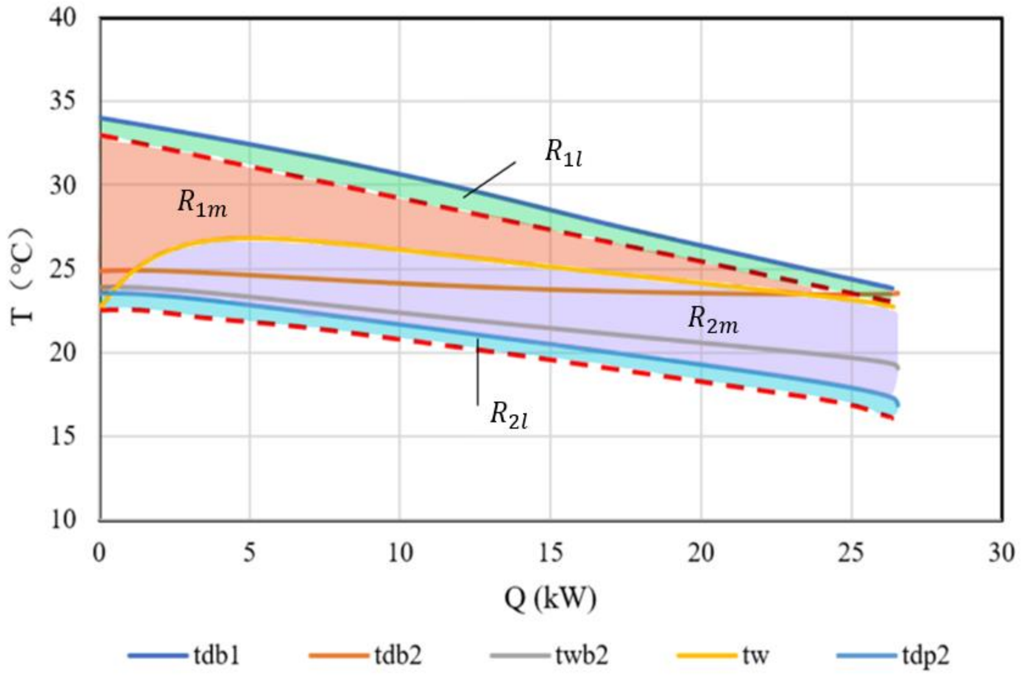
- The total entransy dissipation is:

$$\Delta J = \Delta J_1 + \Delta J_2 = \int_0^A K(t_{db1} - t_{dp2})dQ$$

- The total entransy dissipation ΔJ is the envelope area of the dry bulb temperature of the dry channel (t_{db1}) and the dew point temperature of the wet channel (t_{dp2}).

- The thermal resistance during heat transfer is:

$$R = \frac{\Delta J}{Q^2}$$



- the total entransy dissipation

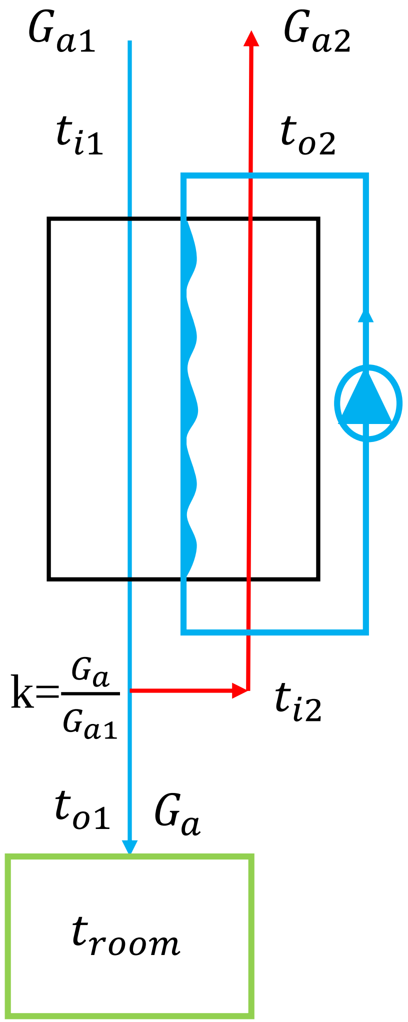
$$\Delta J = \Delta J_l + \Delta J_m$$

- The total thermal resistance

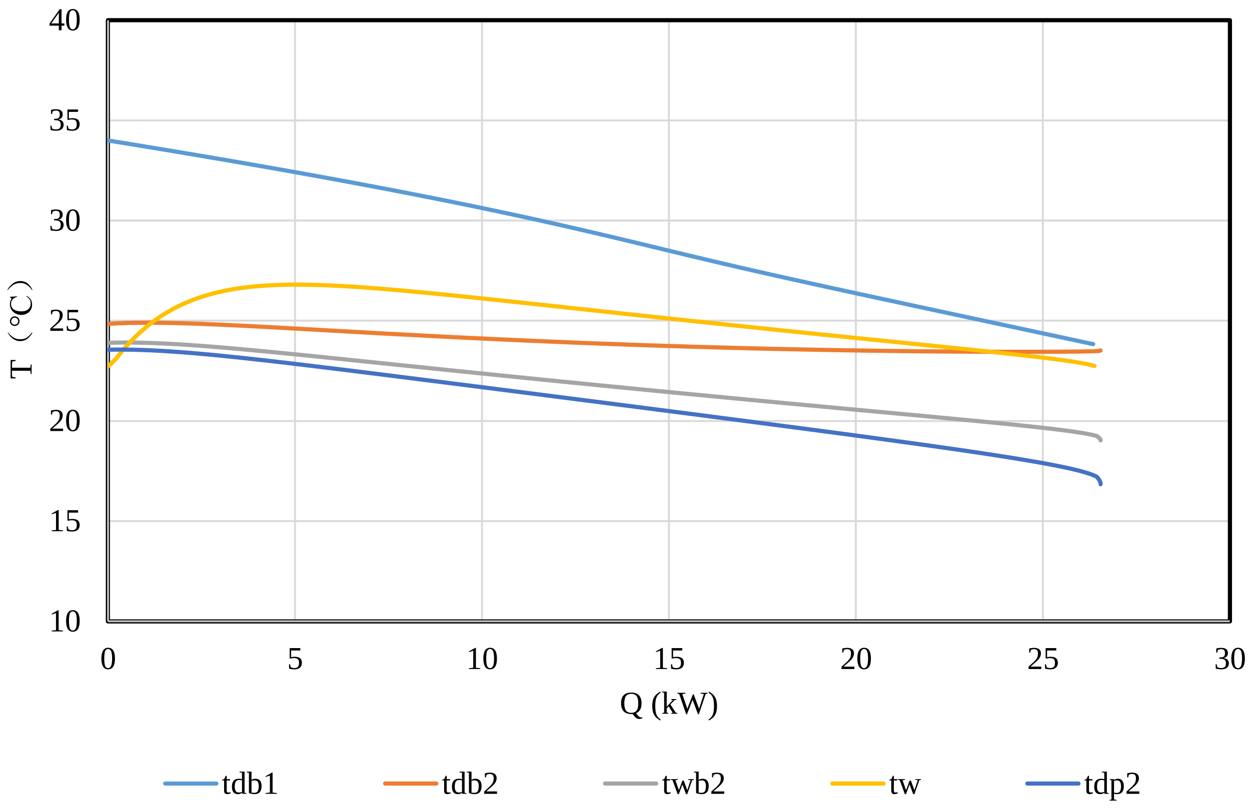
$$R = R_l + R_m = \frac{\Delta J_l}{Q^2} + \frac{\Delta J_m}{Q^2}$$

loss analysis

- Single-stage process

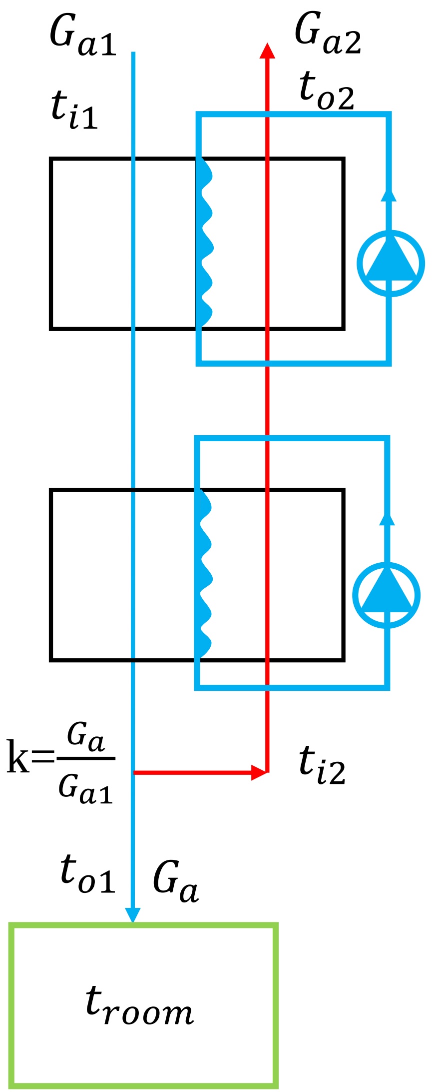


- $G_a = 3000\ \mathrm{m}^3/h$
- k=0.5
- $t_{o1} = 23.8$℃

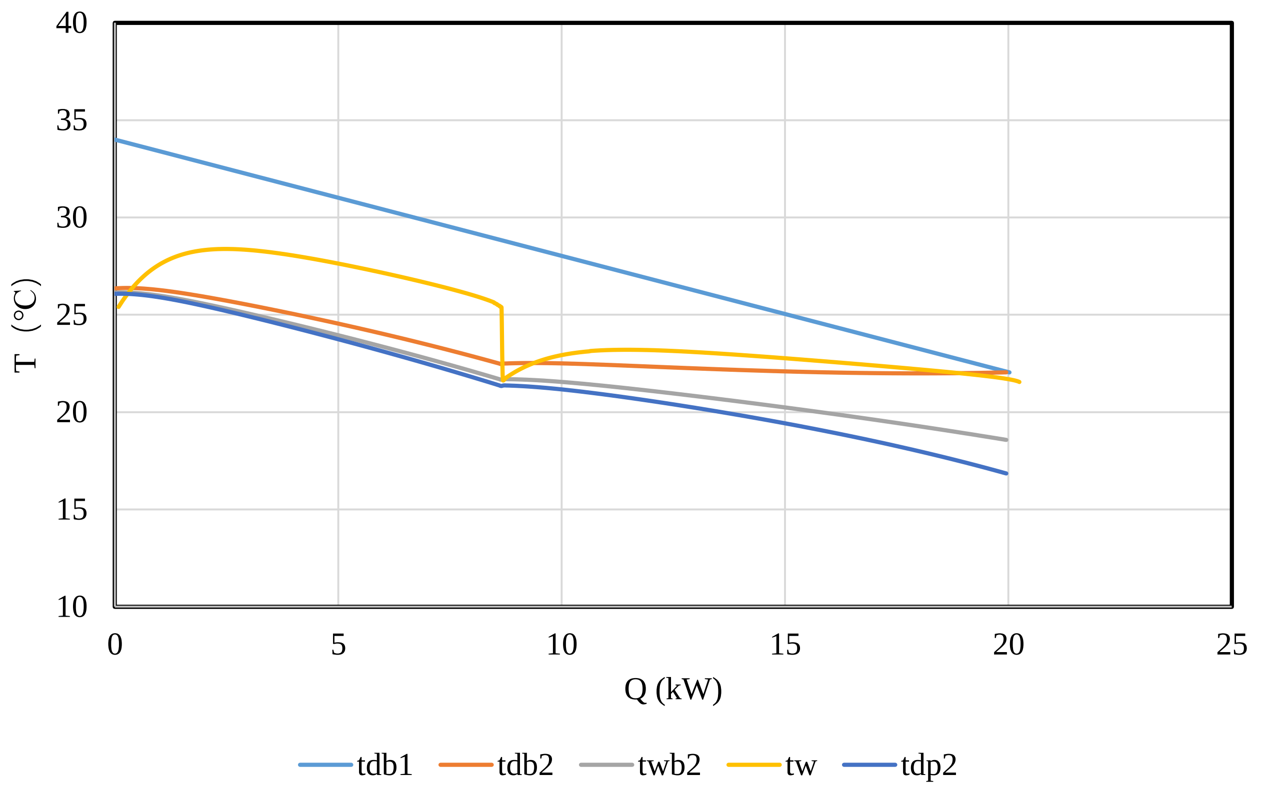


loss analysis

- Two-stage process



- $G_a = 3000\ \mathrm{m}^3/h$
- k=0.4
- $t_{o1} = 22.0$℃



loss analysis

- Single-stage and two-stage process

		Single-stage	Two-stage
Entransy dispassion	J_l	51.38	89.95
	J_m	139.55	86.01
	J_t	190.93	169.96
Primary channel thermal resistance	R_{1l}	0.04	0.05
	R_{1m}	0.12	0.06
	R_{1t}	0.16	0.11
Secondary channel thermal resistance	R_{2l}	0.03	0.10
	R_{2m}	0.09	0.09
	R_{2t}	0.12	0.19
Total thermal resistance	R_l	0.07	0.15
	R_m	0.20	0.15
	R_t	0.27	0.30
mismatched / Total	R_{1m}/R_{1t}	73.2%	54.5%
	R_{2m}/R_{1t}	73.0%	46.5%
	R_m/R_t	73.1%	50.5%

	Single-stage	Two-stage
t_{o1} (℃)	24.9	24.6

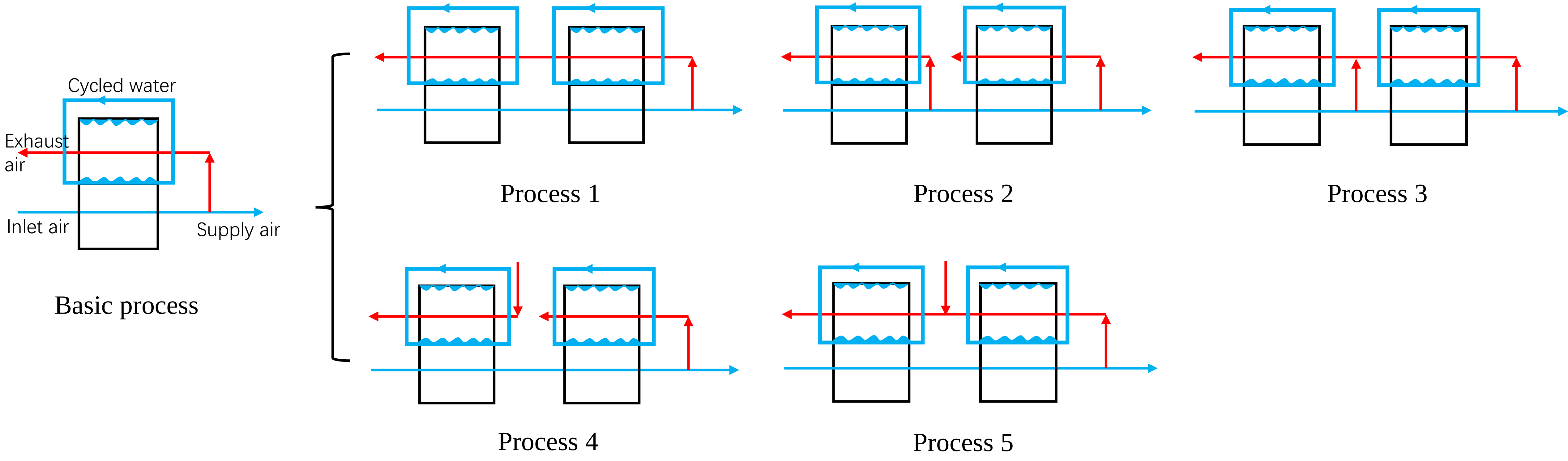
- the total entransy dissipation：$J_{ts} > J_{tt}$
- air supply temperature: $t_{o1s} > t_{o1t}$

- the two-stage process can reduce the mismatch dissipation on the primary channel side

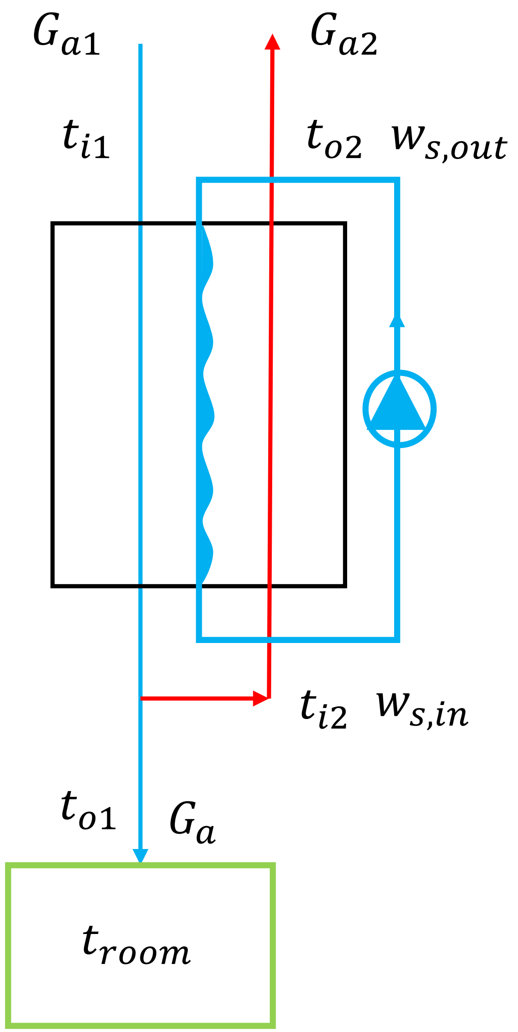
- The supply air temperature may depend more on the mismatched thermal resistance.

Indicators discussion for different processes for IEC air coolers

- outdoor humidity ratio
- outdoor temperature



Indicators discussion for different processes for IEC air coolers



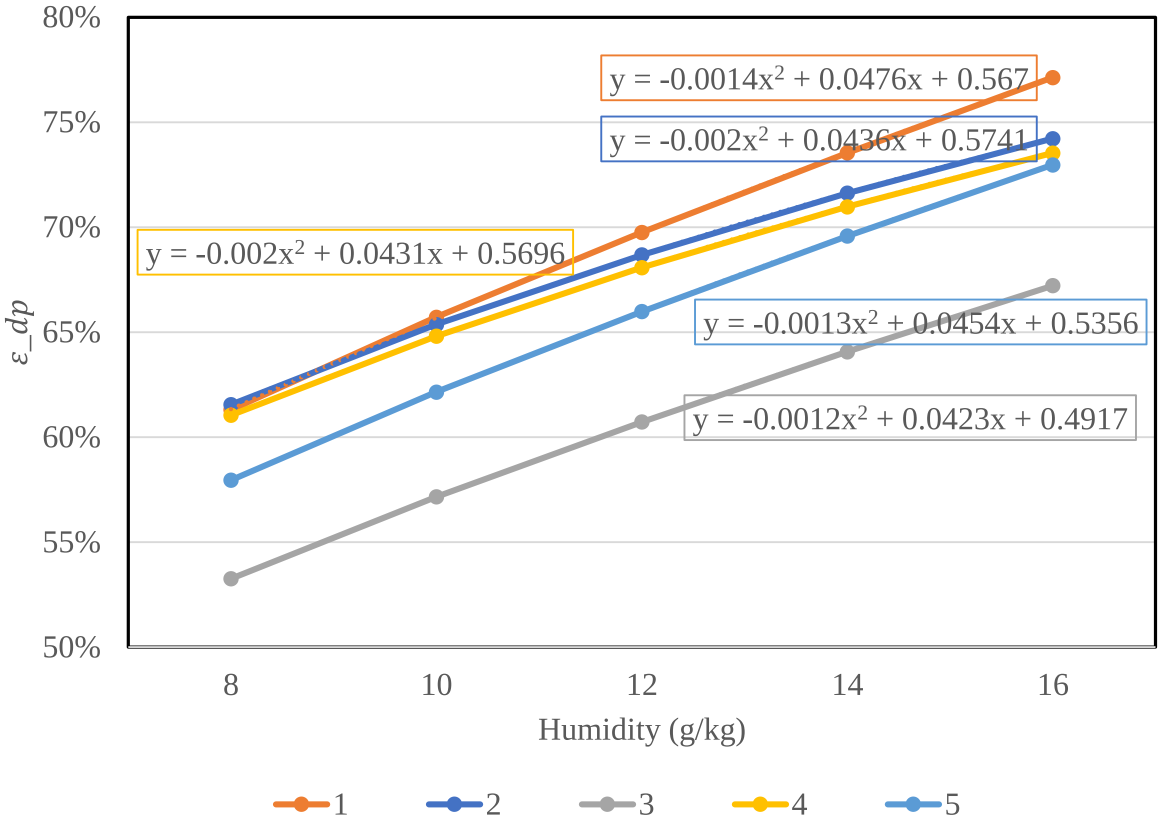
- Dew-point effectiveness

$$\varepsilon_{dp} = \frac{t_{db,i1} - t_{db,o1}}{t_{db,i1} - t_{\mathrm{dp},i1}}$$

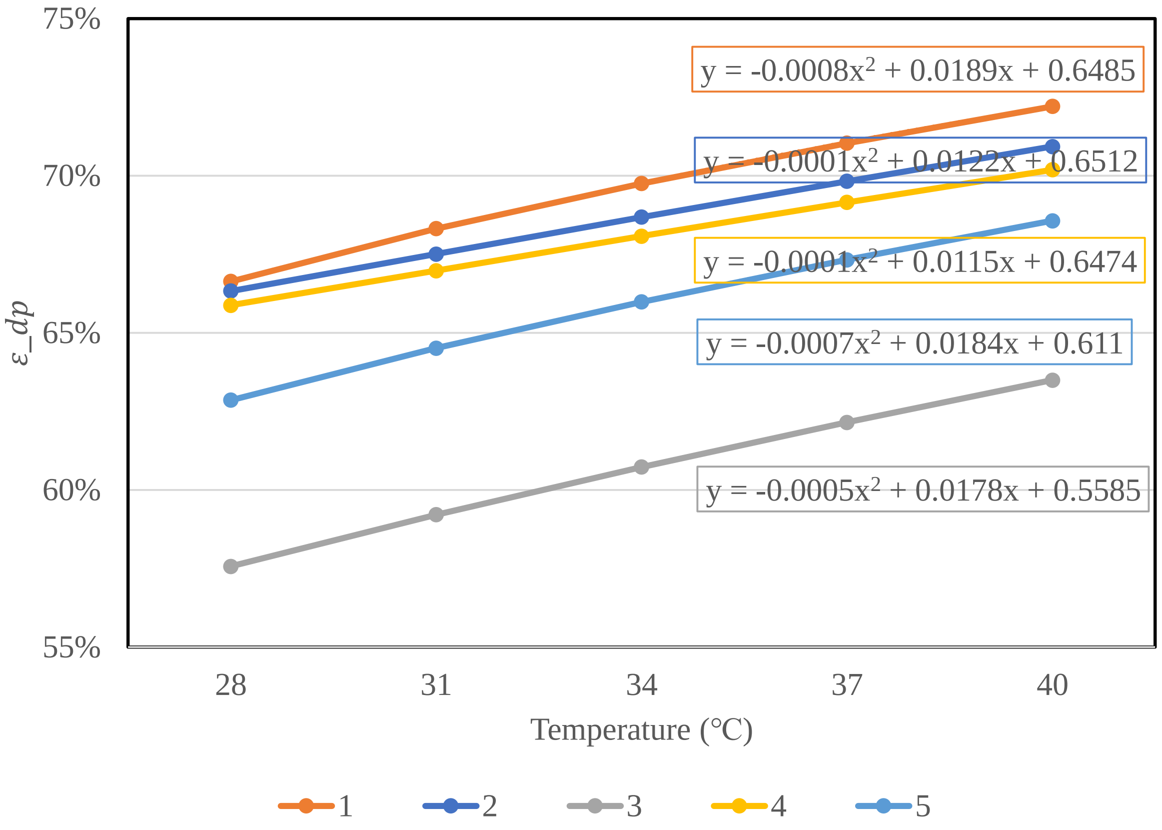
- Dew-point effectiveness is the ratio of the temperature difference between the inlet and outlet product air to the difference between the inlet product air's dry bulb and inlet working air's dew point temperature.

Indicators discussion for different processes for IEC air coolers

- As the humidity increases, the ε_{dp} increases

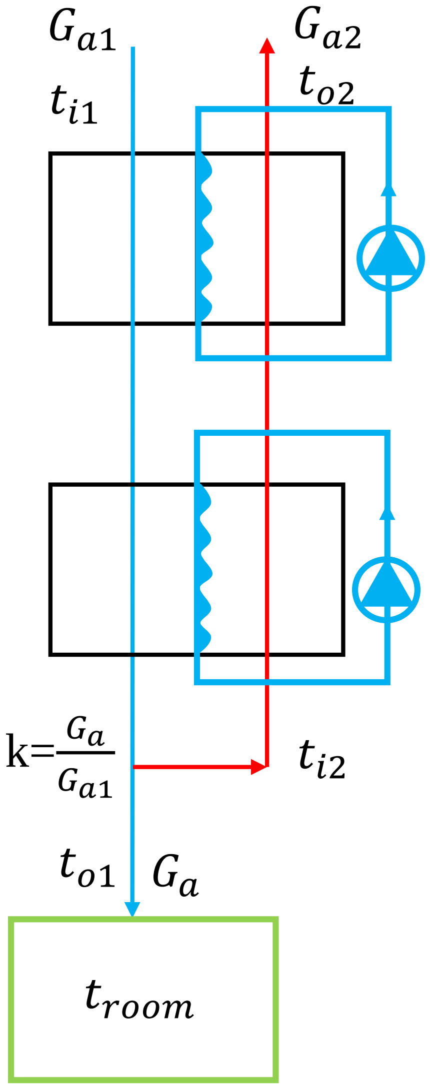


- As the temperature increases, the ε_{dp} increases

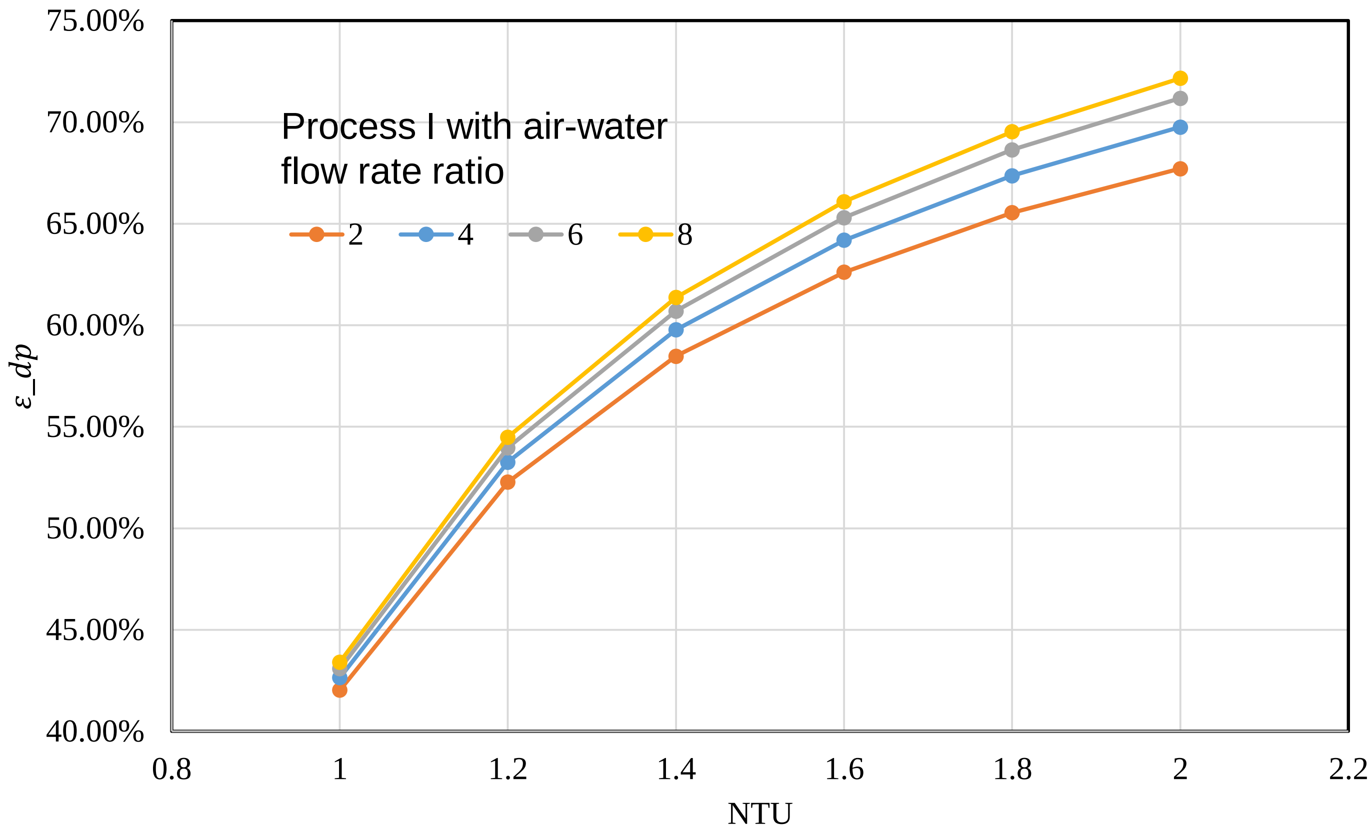


- The indicators (ε_{dp}) changes largely with climates, we could get some fitting formulas to describe the change and used to predetermine the performance under different climates.

Indicators discussion for different processes for IEC air coolers



➢ get a group of curves for indicators (ε_{dp}) with NTU and flowrate ratio, for Two-stage process 1



Thank you very much and welcome comments and discussion.