EBC

Energy in Buildings and Communities Programme

Testing performance of IEC water chiller and its components

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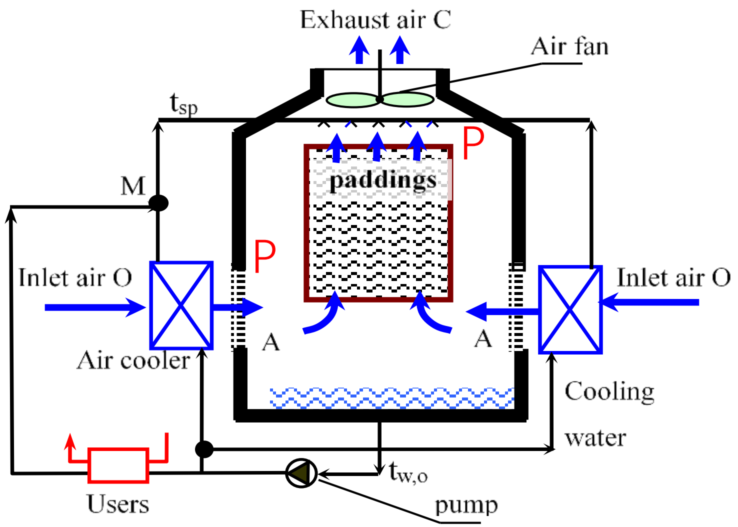
Testing pressure of IEC water chillers

- Pressure drop of air coolers and padding towers-tested data by ourselves

Heights of tested paddings (m)	Electricity consumption of fan(kW)	Total air flow rate (m3/h)	Pressure drop of air cooler (Pa)	Total pressure drop(Pa)	Air velocity of air cooler (m/s)	Air velocity of paddings (m/s)
3	7.46	28840		193	2.0	2.0
2.5	7.42	28880	87	183	2.0	2.0
2	7.27	29724	89	174	2.1	2.1
1.5	7.3	30256	91	165	2.1	2.1
1	7.26	30980	93	156	2.2	2.2
0.5	7.3	31160	96	149	2.2	2.2
0	7.29	32660	101	140	2.3	2.3



Testing instrument: Micro differential pressure gauge

For IEC water chiller with 3 meters high paddings, for the tested air velocity:

Total pressure drop of paddings (Pa)	53
Pressure drop of air coolers with 8 rows (Pa)	101
Other local resistance, like air turning, et al.(Pa)	39

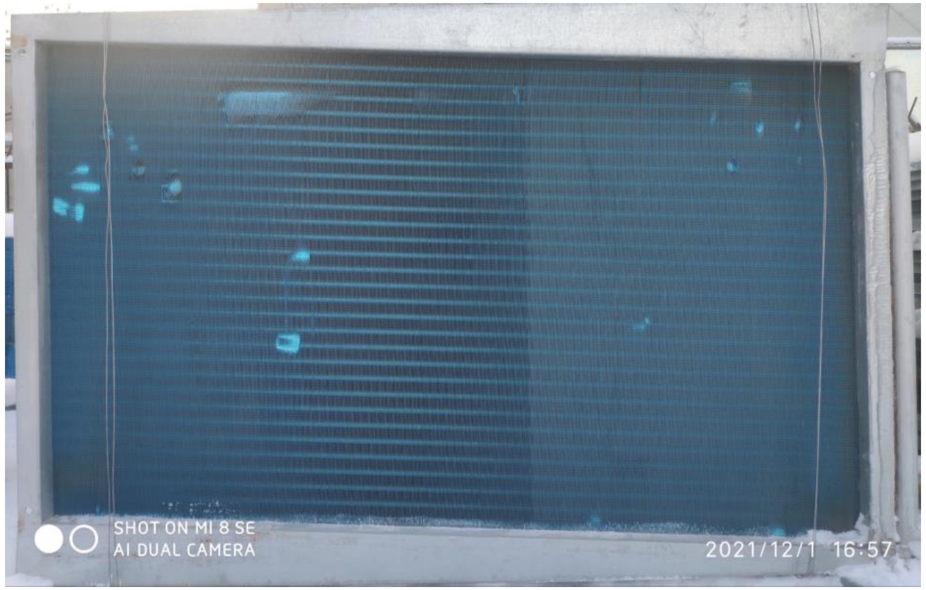
Pressure drop of air coolers

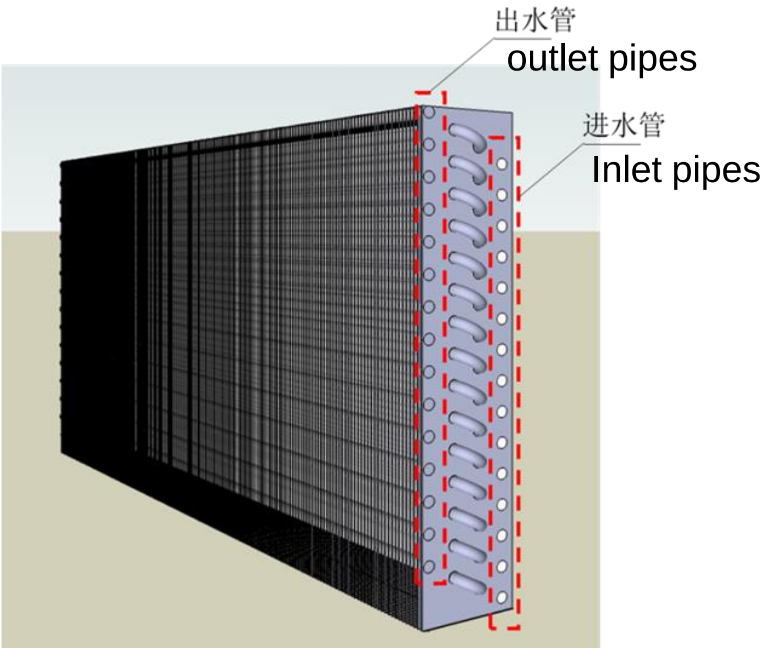
air velocity (m/s)	Pressure drop (Pa/row)
2.3	12.6
2.78	19

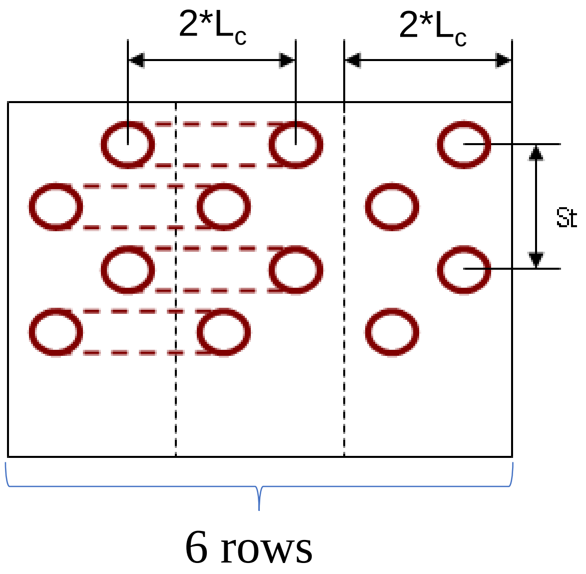
Pressure drop of paddings with 3 meters high

air velocity (m/s)	Pressure drop (Pa/m)
2.16	18.8
2.78	31

Design of air coolers







Diameter (mm)	Pipe thickness (mm)	St (mm)	2*Lc (mm)	Fin pitch (mm)	Fin thickness (mm)	Fin type
15.88	0.41	38	2*32.9	2.8	0.12	continuous Sine wave

Testing performance of air coolers

- Size of testing air cooler I and air cooler II

Rows	Up wind area, height	Up wind area, length	Heat transfer area of each row	Total heat transfer area
	m	m	(m2/row)	(m2)
6	1.14	3.4	74.65	447.9

- Testing performance of air cooler I and air cooler II

Air cooler I

Inlet water	Outlet water	water flow rate	Heat of water side	Energy unbalance rate
℃	℃	t/h	kW	
15.8	19.8	11.5	54.2	0.216
Inlet air	Outlet air	air flow rate	Heat of air side	Heat transfer coefficient calculated by water side
℃	℃	m3/h	kW	$W/(m^2 \bullet K)$
25.8	18.9	31500	65.9	23.8

Air cooler II

Inlet water	Outlet water	Water flow rate	Heat of water side	Energy unbalance rate
℃	℃	t/h	kW	
15.8	20.4	13	68.8	0.008
Inlet air	Outlet air	Air flow rate	Heat of air side	Heat transfer coefficient calculated by water side
℃	℃	m3/h	kW	$W/(m^2 \bullet K)$
25.8	18.7	32500	69.4	37.6

Testing performance of air coolers——modified

- Size of testing air cooler I and air cooler II

Rows	Up wind area, height	Up wind area, length	Heat transfer area of each row	Total heat transfer area
	m	m	(m2/row)	(m2)
6	1.14	3.4	74.65	447.9

- Testing performance of air cooler I and air cooler II

Air cooler I

Inlet water	Outlet water	water flow rate	Heat of water side		Energy unbalance rate
℃	℃	t/h	kW		
15.78	19.84	11.5	54.21		
Inlet air	Outlet air	air flow rate	Air Density	Heat of air side	Heat transfer coefficient calculated by water side
℃	℃	m3/h	Kg/m3	kW	$W/(m^2•K)$
25.77725	18.86558	31500	1.082	65.76	23.8

Air cooler II

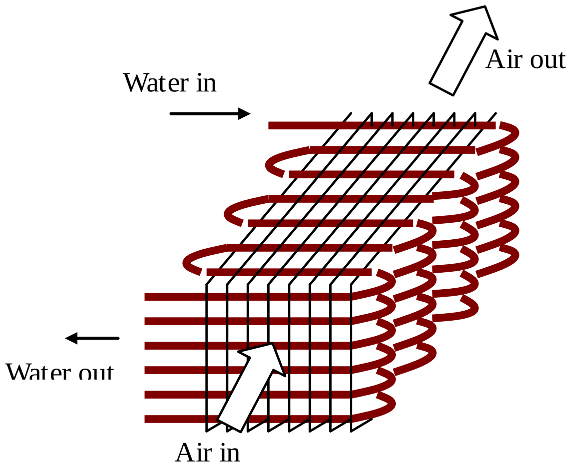
Inlet water	Outlet water	Water flow rate	Heat of water side	Energy unbalance rate
℃	℃	t/h	kW	
15.8	20.4	13	68.8	0.008
Inlet air	Outlet air	Air flow rate	Heat of air side	Heat transfer coefficient calculated by water side
℃	℃	m3/h	kW	$W/(m^2•K)$
25.8	18.7	32500	69.4	37.6

Information from manufactures

- For pressure drop of air coolers, the pressure correlations given by the manufactures is shown here, which is higher than our tested value

4 rows： $\Delta P=30.714*V^{1.593}*E^{0.001}$
6 rows： $\Delta P=31.332*V^{1.663}*E^{0.005}$
8 rows： $\Delta P=45.217*V^{1.66}*E^{0.033}$

V is air face velocity，m/s
E is moisture absorption coefficient;



Information from manufactures

- For different type of paddings, with better performance than what we tested

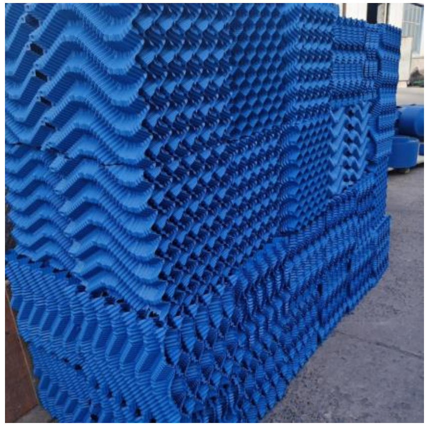
Height of paddings (m)	Air velocity va (m/s)	Spraying density of water (t/h/m2)	Air mass velocity g (kg/m2/s)	Water volumetric velocity q (m3/h/m2)	Mass transfer coefficient of padding I Ka (kg/m3/h)	Mass transfer coefficient of padding II Ka(kg/m3/h)	Padding I a	Padding I m	Pressure drop of padding I (Pa)	Padding I a	Padding II m	Pressure drop of padding II (Pa)
1	2.77	10	3.324	10	23716.43772	23341.83426	1.0944	1.7353	62.90428568	1.2624	1.9914	94.19334
1.25	2.77	10	3.324	10	21235.89251	20248.05915	1.2704	2.0038	95.99540688	1.3919	1.9824	102.908
1.5	2.77	10	3.324	10	18514.19988	18317.43047	1.4604	2.0059	110.588763	1.4757	1.9894	109.8845

Mass transfer coefficient of Paddings: $Ka=C*g^{a1}q^{b1}$

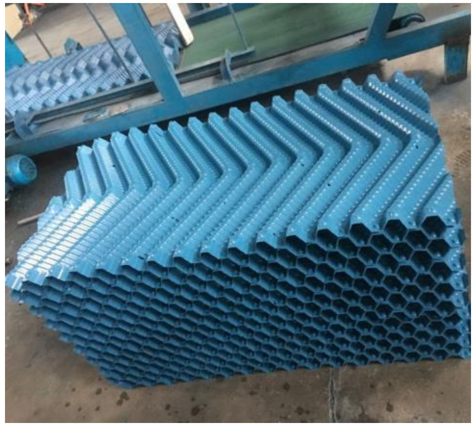
C is a constant, g is air mass velocity, q is water volumetric velocity;

Mass transfer coefficient of padding I: C=4488, a1=0.6, b1=0.41; (height=1m)
C=4055, a1=0.65, b1=0.38; (height=1.25m)
C=3713, a1=0.59,b1=0.39; (height=1.5m)

Mass transfer coefficient of padding II: C=4508, a1=0.68, b1=0.36; (height=1m)
C=3917, a1=0.62, b1=0.39; (height=1.25m)
C=3839, a1=0.63, b1=0.35; (height=1.5m)



Padding I:
S type padding



Padding II:
oblique refraction padding

Pressure drop of Paddings: $\Delta P=9.81*a*va^{m}$

padding I: a=-0.0017*q^2+0.0652*q+0.6124; m=0.0023*q^2-0.0522*q+2.0273 (height=1m)
a= -0.0015*q^2+0.0516*q+0.9044; m= 0.0001*q^2-0.0008*q+2.0018 (height=1.25m)
a=-0.0013*q^2+0.0483*q+1.1074; m=0.0001*q^2-0.0006*q+2.0019(height=1.5m)

padding II: a=-0.0002*q^2+0.0321*q+0.9614; m=-0.0001*q^2-0.0002*q+2.0034 (height=1m)
a= -0.001*q^2+0.0424*q+1.0679; m= 0.0001*q^2-0.0027*q+1.9994 (height=1.25m)
a=-0.0004*q^2+0.0329*q+1.1867; m=0.0001*q^2-0.0018*q+1.9974 (height=1.5m)

Tested mass transfer coefficient of paddings

- Case I: testing results of padding performance in one indirect evaporative chiller

Padding size: 11m (length)* 2m(width)*3m(height)

Padding type: countercurrent padding, S type padding
Atmospheric pressure: 93.2 kPa

Testing working conditions	Air flow rate (m3/h)	Water flow rate (m3/h)	Windward sectional area	Height of paddings（m)	Spraying density of water (t/h/m2)	Water volumetric velocity q (m3/h/m2)	Air mass velocity g (kg/m2/s)	Spraying water temperature（℃)	Testing outlet water temperature(℃)	Calculated outlet water temperature(℃)	Inlet air temperature of paddings（℃)	Inlet air humidity ratio of paddings(kg/kg.air)	Exhuast air temperature (℃)	Exhaust air relative humidity （%)	Exhaust air enthalpy (kJ/kg)	Mass transfer coefficient of padding I Ka (kg/m3/h)
1	71152	97.6	22	3	4.44	4.4	0.99	18.6	15.5	15.6	17.4	0.008512	19.4	93.5	55.97	6295
2	71152	97.6	22	3	4.44	4.4	0.99	18.4	15.1	15.4	17.1	0.008668	18.7	96.7	54.88	8760
3	71152	77.4	22	3	3.52	3.5	0.99	18.6	14.4	15.4	17.0	0.008555	18.2	95.9	52.93	4385
4	71152	77.4	22	3	3.52	3.5	0.99	18.4	14.3	14.7	16.8	0.008252	18.7	94.5	54.04	6278

The mass transfer coefficient is calculate using tested air flow rate, water flow rate, inlet air temperature, inlet air humidity ratio, exhaust air enthalpy and inlet water temperature of the padding. By the way, the conditions of exhaust air is a little difficult to be tested accurately, in this case, just the enthalpy of the exhaust air is used for calculation

Tested mass transfer coefficient of paddings

- Case II: testing results of padding performance in another indirect evaporative chiller

  Padding size: 20m (length)* 2m(width)*3m(height)

  Padding type: countercurrent padding, S type padding

Atmospheric pressure (kPa)	Air flow rate (m3/h)	Water flow rate (m3/h)	Windward sectional area (m2)	Height of paddings (m)	Spraying density of water (t/h/m2)	Water volumetric velocity q (m3/h/m2)	Air mass velocity g (kg/m2/s)	Spraying water temperature (℃)	Testing outlet water temperature(℃)	Inlet air temperature of paddings (℃)	Inlet air humidity ratio of paddings (kg/kg.air)	Exhaust air temperature (℃)	Exhaust air wet bulb temperature (℃)	Exhaust air enthalpy (kJ/kg)	Calculated air enthalpy (kJ/kg)	Mass transfer coefficient of padding Ka (kg/m3/h)
93.2	217600	241.6	40	3	6.04	6.04	1.66	20.65	15.6	19.75	0.007206	20.85	20.13	61.2	59.24	7455

Pressure drop testing

Pressure drop of air coolers(Pa)	Pressure drop of paddings (Pa)	Number of rows of air cooler	Height of padding (m)	Pressure drop of air cooler (Pa/ 1 row)	Pressure drop of paddings (Pa/m)
103.5	94.1	8	3	13	31

Replies for Prof. Jean Lebrun for questions and deep discussions

For Slide 4. Testing performance of air coolers——modified

- Size of testing air cooler I and air cooler II

Rows	Up wind area, height	Up wind area, length	Heat transfer area of each row	Total heat transfer area	Total heat transfer area, considering the fin efficiency (95%)
	m	m	(m2/row)	(m2)	(m2)
6	1.14	3.4	74.65	470.3	447.9

- Testing performance of air cooler I and air cooler II

Air cooler I

Inlet water	Outlet water	water flow rate	Heat of water side		Energy unbalance rate
℃	℃	t/h	kW		
15.78	19.84	11.5	54.21		
Inlet air	Outlet air	air flow rate	Air Density	Heat of air side	Heat transfer coefficient calculated by water side
℃	℃	m3/h	Kg/m3	kW	W/(m^2•K)
25.77725	18.86558	31500	1.082	**65.76**	**23.8**

Air cooler II

Inlet water	Outlet water	Water flow rate	Heat of water side	Energy unbalance rate
℃	℃	t/h	kW	
15.8	20.4	13	68.8	0.008
Inlet air	Outlet air	Air flow rate	Heat of air side	Heat transfer coefficient calculated by water side
℃	℃	m3/h	kW	W/(m^2•K)
25.8	18.7	32500	69.4	37.6

Two ways to compute the value of the air-cool AU.

- Calculated by EES software
- Calculated by experiential formulas

For Slide 4, Calculation of air cooler heat transfer coefficients

Calculated by EES software

- The inlet and outlet water temperature are settled ($t_{w,su}$ & $t_{w,ex}$)
- The water flow rate is settled ($\dot{M}_{w,T/h}$)
- The inlet air temperature is settled ($t_{a,su}$)
- The air flow rate is settled ($V_{a,m3/h}$)

The AU of the air-cooler and the outlet air temperature are solved out by energy balance and energy transfer equations (the program is attached)

	AU kW/K	A m^2	U $W/(m^2K)$
run1	12.29	470.3	26.1
run2	21.4	470.3	45.5

Calculated by experiential formulas

- Air-cooler related parameters are settled ($D_{pipe,out}$ & e_{fin} & H_{coil} & e_{fin} & $L_{coil,N,rows}$ & N_{fins} & N_{tubes} & $S_{T,soil}$ & $finpitch$ & $H_{coil/N,tubes/row}$ & L_{coil} & N_{rows} & $N_{tubes/row}$ & $S_{l,coil}$ & W_{coil})
- The water flow rate is settled ($\dot{M}_{w,T/h}$)
- The air flow rate is settled ($V_{a,m3/h}$)

The total heat transfer area ($A_{total,coil}$) is solved out by related parameters

The heat transfer coefficient ($\dot{U}$) is calculated by the comprehensive effect of the convective heat transfer coefficient on outer surface, the convective heat transfer coefficient of inner surface and the thermal conductivity of copper tubes

AU is given when multiplying $A_{total,coil}$ by $\dot{U}$

	AU kW/K	$A_{total,coil}$ m^2	$\dot{U}$ $W/K/m^2$
run1	19.7	470.3	41.9
run2	20.5	470.3	43.6

Two ways to compute the value of the air-cool AU.

- Calculated by EES software
- **Calculated by experiential formulas**

For Slide 4， Calculation of air cooler heat transfer coefficients

- *the value of $\dot{U}$*

$$U = [\frac{1}{h_{out}} + \frac{\tau * e_{pipe}}{\lambda} + \frac{\tau}{h_{in}}]^{-1}$$

- the convective heat transfer coefficient on outer surface (α_w)
- the convective heat transfer coefficient on inner surface (α_n)
- the thermal conductivity of copper tubes (λ)
- rib effect coefficient (τ)

$$Nu_{in} = 0.012 * \left(Re_f^{0.87} - 280\right) * Pr_f^{0.4} * \left[1 + (\frac{d}{l})^{2/3}\right] * (\frac{Pr_f}{Pr_w})^{0.11}$$

$$Nu_{in} = \frac{h_{in} * d_{in}}{\lambda_w}$$

$$Nu_{out} = 0.35 * Re_f^{0.6} * Pr_f^{0.36} * (\frac{Pr_f}{Pr_w})^{0.25} * (\frac{S_1}{S_2})^{0.2}$$

$$Nu_{out} = \frac{h_{out} * d_{out}}{\lambda_a}$$

$$\tau = \frac{A_2}{A_1} = \frac{rib\ wall\ surface\ area}{light\ pipe\ area}$$

Modification of original data of Slide 7

Testing working conditions	Spraying water temperature (℃)	Testing outlet water temperature (℃)	Calculated outlet water temperature (℃)	Inlet air temperature of paddings (℃)	Inlet air humidity ratio of paddings(kg/kg.air)	Inlet air enthalpy(kJ/kg)	Exhaust air temperature (℃)	Exhaust air relative humidity (%)	Exhaust air enthalpy (kJ/kg)	Produced cooling energy (kW)	Logarithmic mean enthalpy difference(kJ/kg)	Mass transfer coefficient of padding I Ka (kg/m3/h)
1	19	15.45	15.63	17.4	0.008512	38.62	19.4	93.5	55.97	382.3	3.317	6295
2	18.5	15.05	15.42	17.05	0.008668	39.07	18.7	96.7	54.88	348.8	2.174	8760
3	18.9	14.4	15.41	16.98	0.008555	38.71	18.2	95.9	52.93	314.1	3.909	4385
4	18.7	14.25	14.7	16.8	0.008252	37.76	18.7	94.5	54.04	359.3	3.124	6278

Testing working conditions	Air flow rate (m3/h)	**Air density (kg/m3)**	**Air Flow rate (kg/s)**	Water flow rate (m3/h)	Water flow rate (kg/s)	Windward sectional area	Height of paddings (m)	Spraying density of water (t/h/m2)	Water volumetric velocity q (m3/h/m2)	Air mass velocity g (kg/m2/s)
1	71152	**1.115**	**22.04**	97.6	27.11	22	3	4.44	4.4	0.99
2	71152	**1.116**	**22.06**	97.6	27.11	22	3	4.44	4.4	0.99
3	71152	**1.117**	**22.08**	77.4	21.5	22	3	3.52	3.5	0.99
4	71152	**1.117**	**22.07**	77.4	21.5	22	3	3.52	3.5	0.99

Calculation method of mass transfer coefficient(kg/(m^{3}h) used for slide 7

There are the equations used for getting the original mass transfer coefficient in slide 7.

- Q calculated by air side:

$$Q = \dot{M}(h_{ex} - h_{su})$$

- Log mean enthalpy difference:

$$\Delta h_m = \frac{((h_{a,wo} - h_{su}) - (h_{a,win} - h_{ex}))}{\ln \frac{(h_{a,wo} - h_{su})}{(h_{a,win} - h_{ex})}}$$

- Mass transfer coefficient:

$$AU_m = \frac{Q}{\Delta h_m} \qquad AU_{m,\backslash vol,h} = \frac{Q}{\Delta h_m} \bullet \frac{1}{Volume} \bullet 3600$$

- Air density(kg/m^3),only considering temperature and pressure, not accurate

$$\rho_{su} = \rho_0 \frac{p}{p_0} \cdot \frac{T_0}{(T_{su} + T_{ex})/2}$$

Assumed ρ_0=1.293, at 101.325kPa, 0℃

Modifications for the original calculations for slide 7

1. The Log mean enthalpy difference method is not accurate, because:

(1) the accurate parameter is the log mean temperature difference, as shown:

$$\Delta t_m = \frac{((t_{w,ex} - t_{wb,su}) - (t_{w,su} - t_{wb,ex}))}{\ln \frac{(t_{w,ex} - t_{wb,su})}{(t_{w,su} - t_{wb,ex})}}$$

$$Q = AU_m \cdot c_{p,f} \Delta t_m$$

the log mean temperature difference method

$$\Delta h_m = \frac{((h_{a,wo} - h_{su}) - (h_{a,win} - h_{ex}))}{\ln \frac{(h_{a,wo} - h_{su})}{(h_{a,win} - h_{ex})}}$$

$$Q = AU_m \Delta h_m$$

the log mean enthalpy difference method

As $\boldsymbol{c_{p,f}}$ is defined using air enthalpy not the enthalpy of saturated air of water, which caused the difference of the above two methods

(2). The Log mean enthalpy difference calculated by the real tested air and water conditions, as there is an energy unbalance, which causes difference with ε-NTU method that Prof. Lebrun used (JL220625-01bis slide 7).

Modifications for the original calculations for slide 7

2. The air density is not accurate as the humidity was not considered, change the air density calculation method according to “JL220625-01bis slide 7”, thus the air mass flowrate is changed a little.

v_su=**volume**(***AirH2O***,***T***=T_su,***w***=omega_su,***P***=P)

M_dot=V_dot/v_su

Modifications for the original calculations for slide 7

- **Thus, three modifications are made for mass transfer coefficient calculation:**
- (1) using the log mean temperature difference Δt_m.
- (2) Q is calculated by air side, and the calculated water outlet temperature is used for calculating Δt_m

$$\Delta t_m = \frac{((t_{w,ex,calc1} - t_{wb,su}) - (t_{w,su} - t_{wb,ex}))}{\ln \dfrac{(t_{w,ex,calc1} - t_{wb,su})}{(t_{w,su} - t_{wb,ex})}}$$

$$Q = AU_m \cdot c_{p,f} \Delta t_m$$

- (3) The air density calculation method is used according to “JL220625-01bis slide 7”

New results for slide 7

Testing working conditions	Spraying water temperature (℃)	Testing outlet water temperature (℃)	Calculated outlet water temperature (℃)	Inlet air temperature of paddings (℃)	Inlet air humidity ratio of paddings(kg/kg.air)	Inlet air enthalpy(kJ/kg)	Exhaust air temperature (℃)	Exhaust air relative humidity (%)	Exhaust air enthalpy (kJ/kg)	Produced cooling energy (air side)(kW)	Logarithmic mean temperature difference(℃)	Mass transfer coefficient of padding I Ka (kg/m3/h)
1	19	15.45	15.63	17.4	0.008512	38.62	19.4	93.5	55.97	378.5	**1.13**	**5954**
2	18.5	15.05	15.42	17.05	0.008668	39.07	18.7	96.7	54.88	344.8	**0.8132**	**7557**
3	18.9	14.4	15.41	16.98	0.008555	38.71	18.2	95.9	52.93	310.3	**1.708**	**3286**
4	18.7	14.25	14.7	16.8	0.008252	37.76	18.7	94.5	54.04	355.5	**1.197**	**5372**

Testing working conditions	Air flow rate (m3/h)	**Air density (kg/m3)**	**Air Flow rate (kg/s)**	Water flow rate (m3/h)	Water flow rate (kg/s)	Windward sectional area	Height of paddings (m)	Spraying density of water (t/h/m2)	Water volumetric velocity q (m3/h/m2)	Air mass velocity g (kg/m2/s)
1	71152	**1.104**	**27.11**	97.6	27.11	22	3	4.44	4.4	0.99
2	71152	**1.103**	**27.11**	97.6	27.11	22	3	4.44	4.4	0.99
3	71152	**1.104**	**21.5**	77.4	21.5	22	3	3.52	3.5	0.99
4	71152	**1.105**	**21.5**	77.4	21.5	22	3	3.52	3.5	0.99

The new results could be fully agree with the results of ε-NTU method that Prof. Lebrun used.

Original data of Slide 8

- Case II: testing results of padding performance in another indirect evaporative chiller

  Padding size: 20m (length)* 2m(width)*3m(height)

  Padding type: countercurrent padding, S type padding

Atmospheric pressure (kPa)	Air flow rate (m3/h)	Water flow rate (m3/h)	Windward sectional area (m2)	Height of paddings (m)	Spraying density of water (t/h/m2)	Water volumetric velocity q (m3/h/m2)	Air mass velocity g (kg/m2/s)	Spraying water temperature (℃)	Testing outlet water temperature(℃)	Inlet air temperature of paddings (℃)	Inlet air humidity ratio of paddings (kg/kg.air)	Exhaust air temperature (℃)	Exhaust air wet bulb temperature (℃)	Exhaust air enthalpy (kJ/kg)	Calculated air enthalpy (kJ/kg)	Mass transfer coefficient of padding Ka (kg/m3/h)
93.2	217600	241.6	40	3	6.04	6.04	1.66	20.65	15.6	19.75	0.007206	20.85	20.13	61.2	59.24	7455

Pressure drop testing

Pressure drop of air coolers(Pa)	Pressure drop of paddings (Pa)	Number of rows of air cooler	Height of padding (m)	Pressure drop of air cooler (Pa/ 1 row)	Pressure drop of paddings (Pa/m)
103.5	94.1	8	3	13	31

Slide 8: calculation of mass transfer coefficient

- The mass transfer coefficient is calculated using tested air flow rate, water flow rate, inlet air temperature, inlet air humidity ratio, inlet water temperature and outlet water temperature of the padding.
- Q is calculated by water side parameters, thus enthalpy of the exhaust air is calculated and used for mass transfer coefficient calculation using log mean enthalpy difference method.

Spraying water temperature (℃)	Testing outlet water temperature(℃)	Inlet air temperature of paddings (℃)	Inlet air humidity ratio of paddings (kg/kg.air)	Exhaust air temperature (℃)	Exhaust air wet bulb temperature (℃)	Exhaust air enthalpy (kJ/kg)	Calculated air enthalpy (kJ/kg)	**Logarithmic mean enthalpy difference (kJ/kg)**	Mass transfer coefficient of padding Ka (kg/m3/h)
20.65	15.6	19.75	0.007206	20.85	20.13	61.2	59.24	**5.7**	7455

Atmospheric pressure (kPa)	Air flow rate (m3/h)	**Air density (kg/m3)**	**Air Flow rate (kg/s)**	Water flow rate (m3/h)	Water flow rate (kg/s)	Windward sectional area	Height of paddings (m)	Spraying density of water (t/h/m2)	Water volumetric velocity q (m3/h/m2)	Air mass velocity g (kg/m2/s)
93.2	217600	**1.109**	**67.06**	241.6	67.11	40	3	6.04	6.04	1.66

$$Q = \dot{M}_w c_w (t_{w,su} - t_{w,ex})$$

$$Q = \dot{M} (h_{ex,calc} - h_{su})$$

$$\Delta h_m = \frac{((h_{a,wo} - h_{su}) - (h_{a,win} - h_{ex,calc}))}{\ln \dfrac{(h_{a,wo} - h_{su})}{(h_{a,win} - h_{ex,calc})}}$$

The log mean enthalpy difference is calculated by this formula, using the testing water side parameters and the inlet air enthalpy, the calculated outlet air enthalpy.

$$Q = AU_m \Delta h_m \qquad AU_{m,\backslash vol,h} = \frac{Q}{\Delta h_m} \bullet \frac{1}{Volume} \bullet 3600$$

- Air density(kg/m³),only considering temperature and pressure,

$$\rho_{su} = \rho_0 \frac{p}{p_0} \cdot \frac{T_0}{(T_{su} + T_{ex})/2}$$

Assumed ρ_0=1.293, at 101.325kPa, 0℃

Modifications for the original calculations for slide 8

- **Thus, three modifications are made for mass transfer coefficient calculation:**
- (1) using the log mean temperature difference Δt_m.
- (2) Q is calculated by water side, and the calculated air outlet wet bulb temperature is used for calculating Δt_m

$$\Delta t_m = \frac{((t_{w,ex} - t_{wb,su}) - (t_{w,su} - t_{wb,ex,calc}))}{\ln \dfrac{(t_{w,ex} - t_{wb,su})}{(t_{w,su} - t_{wb,ex,calc})}}$$

$$Q = AU_m \cdot c_{p,f} \Delta t_m$$

- (3) The air density calculation method is used according to "JL220625-01bis slide 7"

Slide 8: new calculation results of mass transfer coefficient

Spraying water temperature（℃）	Testing outlet water temperature(℃)	Inlet air temperature of paddings （℃）	Inlet air humidity ratio of paddings（kg/kg.air)	Exhaust air temperature (℃)	Exhaust air wet bulb temperature （℃）	Exhaust air enthalpy (kJ/kg)	Calculated air enthalpy (kJ/kg)	**Calculated exhaust air wet bulb temperature (℃)**	**Logarithmic mean temperature difference (℃)**	**Mass transfer coefficient of padding Ka (kg/m3/h)**
20.65	15.6	19.75	0.007206	20.85	20.13	61.2	59.24	**20.35**	**1.351**	**7906**

Atmospheric pressure (kPa)	Air flow rate (m3/h)	**Air density (kg/m3)**	**Air Flow rate (kg/s)**	Water flow rate (m3/h)	Water flow rate (kg/s)	Windward sectional area	Height of paddings (m)	Spraying density of water (t/h/m2)	Water volumetric velocity q (m3/h/m2)	Air mass velocity g (kg/m2/s)
93.2	217600	**1.096**	**66.24**	241.6	67.11	40	3	6.04	6.04	1.656

Thank you very much for your attention