Experimental Investigation into the Cooling Water Distribution Parameters of a Unique Indirect Evaporative Cooler in Subway Station

Yecong He[1], Shan Liu[2]

Department of Building Environment and Energy Application Engineering, Changsha University of Science and Technology, Changsha 410114, China

Abstract: ***Put forward a unique indirect evaporative cooler with rotary cooling water distribution device which is driven by a low-speed motor to solve the installation location problem of the cooling tower in subway station. This study investigates the air parameters of the Guangzhou subway station's exhaust channel in summer and winter, and optimizes the cooling water distribution method and the heat transfer performance of the indirect evaporative cooler. Results show that moving the cooling tower into the exhaust channel was feasible. Performance tests are conducted on an evaporative cooler consisting of heat exchanger coil that is cooled by a rotary cooling water distribution device, which flank spray cooling water on both sides of the coil. From the orthogonal experiment results, it is found that the air flow parallel to the normal direction of the heat exchanger, the thermal performance of heat exchanger is optimal, the water distribution device's best speed is 76 rpm, heat transfer performance increase with the mass flow rate of the cooling water and hot water, the cooling water inlet temperature and the air velocity. The increase of the water temperature and the air temperature declined the heat exchange performance, the cooling water inlet temperature change affect the heat exchange performance is the most significant, when the hot water temperature rise from 35℃ to 39℃, the heat transfer performance improved 37.62%.***

Keywords: Indirect Evaporative Cooling; Heat transfer; Subway

1. Introduction

At present, China's subway construction is in a rapid development period, by the end of 2015, its urban rail operation mileages will reach 3500 kilometers, and the total planning operation mileages will more than 7300 kilometers. In order to provide a comfortable environment for the underground subway station, the cooling tower is usually installed on the platform to exhaust the heat of the subway station, but due to the city's downtowns area and the main road are often along the metro lines, it is difficult to find places which both coordinated with the surrounding environment around the MTR station, and satisfy the position for installing the cooling tower [1]. In some cases, because there is no suitable place for installing cooling tower, we have to give up the most stable and efficient heat and cold source schemes, and even are forced to adopt air-conditioning system which initial investment and operating cost is higher. Therefore, it is important to develop a new type cooler, which can be installed in the subway station's exhaust tunnel, to solve the problem of installation cooling tower in the underground station, which is of great important engineering value and social significance.

Because of the characteristics of energy saving, high efficiency and compact structure, the evaporative cooler is widely used in the fields of air conditioning, refrigeration, chemical engineering, electric power and so on [1-4]. The mechanism of heat transfer performance and heat and mass transfer enhancement mechanism had been studied. The effects of the cooling water flow rate, air flow velocity, air temperature, air humidity, spray density, structure parameters had been analyzed. Leiden [5-12] pointed out that the evaporative cooler's heat transfer performance depend on the water film's uniformity and integrity on the heat exchanger surface .Huang Xiang [13] adopted wrapping water absorbent material, improving the structure and the arrangement of the water distributor to consummate the water film uniformity and integrity, so as to enhance the efficiency of heat and mass transfer. The author of this paper had discussed the cooling method of air conditioning system in subway station, and compared the existing heat and mass transfer technology, and put forward a unique indirect evaporative cooler with rotary cooling water distribution device which is driven by the compressed air and water, to solve the installation location problem of the cooling tower in subway station. The research shown that the by wrapping water absorbent material on the surface of the heat exchanger, the heat transfer performance is improved at early stage, but after running a period of time, the heat transfer performance is falling rapidly result from the thermal resistance increases of the water absorbent material; compared with the fixed spray cooling, the heat transfer efficiency by flanking rotary spray water on both sides of the coil unit has been increased 32%,and compared with cooling at the top of the coil, and the cooling capacity has been increased 80%,but there are a lot of disadvantages of the water distributor, such as unstable, high energy consumption and serious leakage, On the basis of the document [14], Jiang bin[15] had analyzed the heat transfer performance of a plate evaporative cooler in concurrent flow, countercurrent flow and cross flow conditions, the study found that its Nusselt number was maximum under the condition of the cross flow, and the plate evaporative cooler's performance is best when it is installed on the level section of the subway station exhaust tunnel.

In view of the shortage of the evaporative cooler in literature

[14], this paper proposes a novel water distributor to overcome the problem of water distributor in literature [14], such as unstable, high energy consumption and serious leakage. Based on this, a new indirect evaporative cooler with rotary cooling water distribution device which is driven by a low-speed motor is developed, and optimized the influence of these factors on the heat transfer performance, for example ,the cooling water volume flow rate, spray water quantity, spray water temperature ,air speed and so on.

2. Feasibility Analysis

In order to study the feasibility of moving the cooling tower into the underground ventilation tunnel, the author measured the air parameters of the haizhu square station in Guangzhou metro line 2, the Tiyu Xilu station, the Shipaiqiao station and the Tianhe Coach Terminal station in Guangzhou metro line 3, and analyzed the influence of the wet source and hot source in the underground ventilation tunnels on the air. In the test process, we uniformly arranged five points in the fresh air tunnel, the first exhaust tunnel and the second exhaust tunnel, to measure the outdoor air temperature and the exhaust air parameters at 13:00 on July, the measurement results as shown in table 1, 2.

Table 1: The parameters in the exhaust tunnel of Guangzhou subway station on July

Station	ta_1	ts_1	ha_1	ta_2	ts_2	ha_2	ta	ts	ha
	℃	℃	kJ/kg	℃	℃	kJ/kg	℃	℃	kJ/kg
Haizhu Square	31.71	26.30	82.59	32.31	26.40	83.29	37.58	30.20	101.56
Tiyu Xilu	29.29	25.60	79.68	28.91	25.40	79.06	36.30	29.60	98.36
Shipaiqiao	28.85	25.40	78.80	----			35.39	28.30	91.77
Tianhe Coach Terminal	26.58	22.30	69.59	28.84	26.10	81.87	36.83	28.50	92.90

Note：The ta, Φ and ha were the air dry bulb temperature, the wet bulb temperature and the enthalpy respectively; the subscript 1, 2 were the first exhaust tunnel and the second exhaust tunnel.

Table 1 shows the air parameters in the Haizhu Square station in the Guangzhou metro line 2,the Tiyu Xilu station, the Shipaiqiao station and the Tianhe Coach Terminal station in the Guangzhou metroline 3 on July. As shown in table 1, the exhaust air dry bulb temperature is 26.58~31.71℃, the wet bulb temperature is 22. ~26.3℃ and the air enthalpy is 70~70 kJ/kg in the first tunnel on summer; the exhaust air dry bulb temperature is 25~28℃, the wet bulb temperature is 25.4~26.4℃, the air enthalpy is 80~83 kJ/kg. Compared with the parameters of outdoor air, the exhaust air dry bulb temperature, the wet bulb temperature and the enthalpy are greatly reduced, the heat transfer capacity of exhaust air is deeply increased, and it shows that after moving the cooling tower to the exhaust tunnel, the heat transfer capacity is not reduced, or even to a certain increase, the reason is that there is a energy difference between the air in the exhaust tunnel between the outdoor air, which to the benefit of heat and mass transfer, and the exhaust tunnel can precooking the exhaust air.

Table 2: The parameters in the exhaust channel of Guangzhou subway station on November

Station	ta_1	ts_1	ha_1	ta_2	ts_2	ha_2	ta	ts	ha
	℃	℃	kJ/kg	℃	℃	kJ/kg	℃	℃	kJ/kg
Haizhu square	27.18	13.98	39.52	28.00	14.04	39.85	27.12	15.34	43.51
Tiyu xilu	25.28	13.80	39.22	24.98	13.60	38.67	24.36	12.53	35.87
Shipaiqiao	22.16	11.91	34.29	---			22.16	11.19	30.07
Tianhe Coach Terminal	24.52	11.90	34.25	26.34	13.22	37.64	25.24	12.28	35.40

Note：the ta, Φ and ha were the air dry bulb temperature, the wet bulb temperature and the enthalpy respectively; the subscript 1, 2 were the first exhaust tunnel and the second exhaust tunnel.

Table 2 shows the air parameters in the Haizhu Square station in the Guangzhou metro line 2 that running in all fresh air air-conditioning mode. As shown in table 2, on November, the air enthalpy and the humidity in the Tiyu Xilu station, the Shipaiqiao station and the second exhaust tunnel of the Tianhe Coach Terminal station exhaust tunnel in the Guangzhou metroline 3 is increase, the air enthalpy of the Haizhu square station in the Guangzhou metro line 2 and the first exhaust tunnel of the Tianhe station in the Guangzhou metroline 3 is decreased slightly. On certain tunnel geological condition, the tunnel wall may even take away part of the heat and moisture of the air, the heat removal capability of the exhaust air in tunnel is improved.

The above test data show that the heat and wet source in the exhaust channel had little effect on the heat transfer ability of the air in the exhaust channel of Guangzhou Metro station, the heat removal capacity of the exhaust air is not reduced, some of the station even develop to the direction that benefit for the heat exchange, therefore, moving the cooling tower into the exhaust channel of the subway station is feasible.

3. Apparatus

Above study shows that moving the cooling tower into the subway exhaust tunnel is feasible, but due to the particularity of the underground exhaust tunnel, it must be satisfied with the following conditions: it could not significantly increase the original exhaust resistance of tunnel ventilation system, otherwise, it will lead to significantly increase of energy consumption of the exhaust fan, and result in the loss outweighs the gain. Therefore, the existing cooling towers are not meet the requirements, it is important to strengthen the heat and mass transfer process between the water film and the air, and then to improve utilization rate of the heat removal capability of the exhaust air in tunnel, to optimize the heat transfer and resistance performance, and even we may sacrifice the thermal performance to ensure the resistance performance at the air side, to meet the urgent engineering requirements of moving the cooling tower into the subway exhaust tunnel, to solve the problem of installation the cooling tower in the underground station, which is of great important engineering value and social significance.

According to the above requirements, this paper puts forward that the cooler coil is divided into several parallel coil units, each coil unit is composed of several groups of cross arrayed coil, and each coil is cooled by a rotary cooling water distribution device to improve the integrity and uniformity of the water film, which flank spray cooling water on both sides of the coil, and to reduce the cooler air resistance at the same time. Thus, there are three kinds arrangement mode for the water distributor and the cooler coil, this article [16] will optimization analysis the heat transfer performance and resistance performance of three kinds arrangement mode by orthogonal experiment, three arrangement modes is shown in figure 1:1)the heat exchanger vertical to the XOY, XOZ plane ,the flow direction parallel to the Y axis, the water distributor spray water on the surface of heat exchanger in YOZ plane; 2) the heat exchanger vertical to the XOZ, YOZ plane ,the flow direction parallel to the Y axis, the water distributor spray water on the surface of heat exchanger in XOY plane; 3) the heat exchanger vertical to the XOY, YOZ plane ,the flow direction parallel to the Y axis, the water distributor spray water on the surface of heat exchanger in XOZ plane.

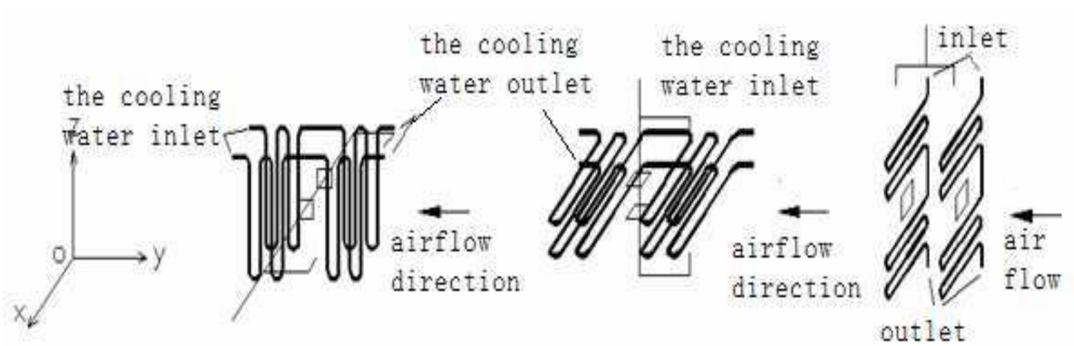

Figure 1: Heat exchanger arrangement

In order to analysis the influence of the cooling water volume flow rate, spray water quantity, spray water temperature, air speed and so on, on the heat performance with different arrangement modes for the water distributor and the cooler coil, this paper set up a test system as shown in fig.2, which composed of wind tunnel system, spray water system, cooling water system and data acquisition system, including a constant temperature control system for the wind tunnel system and the cooling water system.

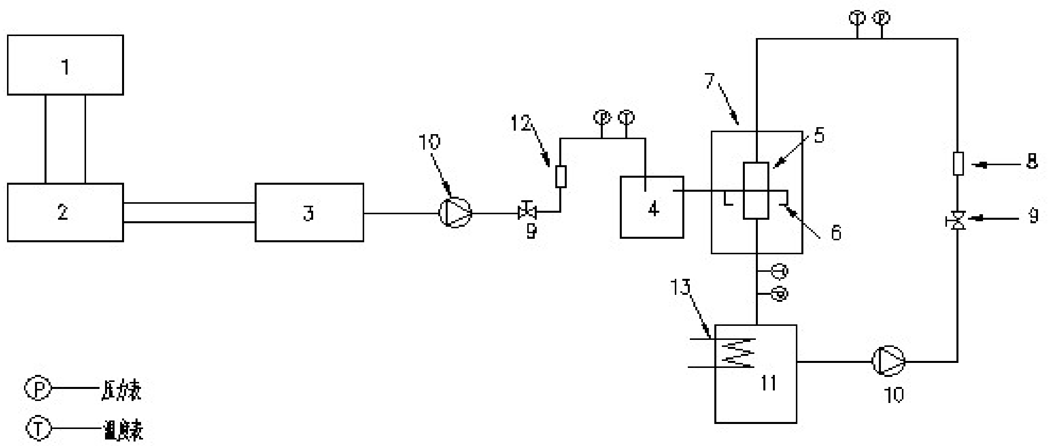

Figure 2: Schematic of the experiment system

1 Cooling tower. 2 Water-cooled heat pump chiller. 3 Chilled water tank; 4 Rotary spray water distributor; 5 Heat exchanger coil; 6. Spray nozzle; 7.Wind tunnel; 8.Electromagnetic flow meter; 9 Flow control valve; 10 Pump; 11 Cooling water tank; 12 Rotameter; 13 Eelectric heater

Wind Tunnel System

According to the basic requirement of the low speed wind tunnel, a closed low-speed wind tunnel system was established, including three component, i.e. the air temperature and humidity control system and air distribution system and test system, the air distribution system consists of inlet section, uniform flow section, contraction section, static flow section, experimental section, diffusion section and fan, etc. Air of the constant temperature and humidity room is inhaled into the wind tunnel, flow through the inlet section, uniform flow section, contraction section, static flow section, to the experimental section, in which the heat and mass transfer take place between the air and the water film on the surface of the coil, and then go back to the constant temperature and humidity room. By adjusting the frequency of the fan to change the air velocity, and uniformly set nine points in the wind tunnel test section to measure the air temperature and humidity with a German portable temperature and humidity instrument (testo635) at the entrance and the exit of wind tunnel test section, and using QDF- 3 hot ball electric anemometer to measure the air volume flow rate.

Cooling Water System

The cooling water system includes cooling water transmission and distribution system and cooling water temperature control system, which composed of cooling water pump, needle valve, bypass valve, cooling water tank and cooling water temperature control system, the hot water tank is installed with 40kW temperature control electric heater for automatic heating.

Spray Water System

Is mainly composed of cooling towers, water-cooled heat pump chiller, chilled water tank, chilled water pump and water transmission and distribution system. The water-cooled heat pump chiller provides for constant temperature water that the temperature and flow rate can be adjusted.

The device under test

1) The rotary spray water distributor, which is driven by a stepless speed regulating motor. The main water distribution pipe that connected with the motor axis is rotating with the coil surface's normal line in the plane that parallel to the plane of the heat exchanger coil surface, and a plurality of vertical water distribution pipes which vertical to the motor axis are installed on main water distribution pipe, and the nozzles are installed on the vertical water distribution pipes. Among them, except the first and the last of the vertical water distribution pipe, along the vertical axis line, are only set one group nozzles, the remaining ones along the vertical axis are set up two group nozzles, and these two nozzles on the same axis, inject direction is on the opposite . Two sets of heat exchanger coil are arranged between the in the vertical water distribution pipes to form a heat exchange unit，thus, the improved assumption of flank rotary spray water on both sides of the coil units is come true , and several heat exchange units are arranged in parallel along the main water distribution pipe axis to for the heat exchanger. The spray water is atomized into small drops by a pressure water distribution system, and the corresponding temperature spray water is provided by the water-cooled heat pump chiller, and its temperature is measured with mercury thermometer that the accuracy is 0.1℃. And the volume flow rate is measured with the LZB-15S glass rotor flow meter, its measurement range is16~160L/h.

2) The cooler coil, which is composed of two sets of cross arranged fin tube bundles, i.e., a heat transfer unit. The Fin tube bundle size is 200mm × 44mm × 210mm, the copper pipe diameter is 10mm ×0.33 mm, the fin distance is 2.2 mm, and the tube spacing is 25 mm, a hole sized 30mm x 25mm x 44mm is set in the center of the coil. In order to guarantee the reliability of the experimental data, using a mercury thermometer that the accuracy of 0.1℃to check the temperature that measured by the LCD-280S digital thermometer, which is installed at the inlet and outlet of the heat exchanger. By comparing with the results of the temperature sensor and the mercury thermometer in the cooling water system, to reduce the error of the experimental data.

Data Acquisition System

Recoding data with cooling water and chilled water dynamic control system which based on configuration software, according to the experiment conditions to choose appropriate the cooling water volume flow rate, the cooling water temperature, and the chilled water temperature, recorded experimental data include the cooling water volume flow rate, the cooling water temperature and pressure at the inlet and outlet of the heat exchanger, the cooling water temperature in the hot water tank, and the chilled water temperature in the cold water tank, etc.

4. The Results

According to three kind of arrangement modes that is shown in fig.1 to carry out orthogonal experiment research, based on the recommended water velocity in literature [14, 17],the water velocity is 0.97～ 1.59 m/s, the cooling water volume flow rate are 800, 1000, 600 l/h, respectively, to ensure that the tube fluid is in turbulent flow condition; According to the air parameters of the underground tunnel ventilation in tab.1 and tab.2f, air temperature is 26±2 ℃;in order to According to reduce the loss of spray water and the best of air velocity requirement, the air velocity is 2.86 m/s, Due to in practical engineering application, the spray water is the municipal water , so the spray water temperature is the average temperature of municipal water , that is ,27.9±0.5 ℃, According to the foundation of literature [14] ,the spray water volume flow rate is 50 l/h, the rotational speed of the water distributor is 76 RPM, the cooling water temperature using is 37 ±0.5 ℃, it is also the temperature of the cooling tower water temperature .The experimental results are shown in Tab3.

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Table 3: Data of the orthogonal experiment result

arrangement mode	Q_s L/h	T_{L1} ℃	T_{L2} ℃	△T ℃	P_1 Mpa	P_2 Mpa	△P Mpa
1	600	37.7	36.0	1.7	0.06	0.03	0.03
	800	37.8	36.5	1.3	0.09	0.03	0.06
	1000	37.8	36.8	1.0	0.13	0.03	0.10
2	600	37.7	35.5	2.2	0.06	0.03	0.03
	800	37.7	36.0	1.7	0.09	0.03	0.06
	1000	37.8	36.4	1.4	0.13	0.03	0.10
3	600	37.6	35.0	2.6	0.06	0.03	0.03
	800	37.7	35.6	2.1	0.09	0.03	0.06
	1000	37.8	36.1	1.7	0.13	0.03	0.10

Note: Qs--cooling water volume flow rate; $T_{L1,2}$-- inlet/outlet temperature of the cooling water; $p_{1,2}$-- inlet/outlet pressure of the cooling water.

As shown in Tab.3, with the increase of the cooling water volume flow rate, the temperature difference between the inlet and outlet of the heat exchanger decreases and the heat exchange amount increases. Compared with 600L/h, the cooling water volume flow rate is 800L/h; the heat transfer amount in the first arrangement mode increased by 4.17%, the second arrangement mode increased by 6.06%, the third arrangement increased by 8.97%, and the last one is the largest. Compared with the first arrangement mode and second arrangement mode, the heat transfer amount increased by 61.47% and 61.47%, respectively, the reason is as following: 1) In first arrangement mode, its water film on the surface on the surface of the coil was more uneven than the other two arrangement modes, and after the heat and mass transfer between the air and the water film, it can not be quickly discharged, the thickness of the water film increased, thus lead to the heat resistance increased, therefore, the thermal efficiency declined; 2) In the fist arrangement mode and the second arrangement mode, because of the heat and mass transfer between the water film and the air , which lead to the air vapor pressure increased, its mass transfer ability weakened constantly, result in its heat transfer capability declined, which give full priority to the latent heat exchange , however, in the third arrangement, the air can flow though the coil in a short time, the air could be quickly discharged, and then replaced by fresh air. Therefore, because of its excellent water film performance and the maximum utilization of the air heat transfer capacity, the heat transfer performance in the third arrangement mode is the best, and it is the best optimal heat exchanger arrangement mode, In the third heat exchanger arrangement mode, the orthogonal experiment was designed according to the following factors as shown in tab.4: the spray water volume flow rate, temperature, the cooling water volume flow rate and temperature, the air temperature and velocity, the rotating speed of the water distributor. And the orthogonal test table was L27 (313). The test results are shown in tab.5 and tab.6.

Table 4: Level of the orthogonal experiment factor

Factor / level	Qs L/h	ts ℃	n r/min	ta ℃	v m/s	QL L/h	TL ℃
1	40	27	50	24	2.5	600	35
2	50	29	76	26	2.75	800	37
3	60	31	100	28	3	1000	39

Note: Qs--cooling water volume flow rate; Ts--spray water temperature; N--rotating speed of the water distributor; Ta--air temperature; V--air velocity; Q_L--spray water volume flow rate; T_L-- the cooling water inlet temperature; Q – heat transfer amount..

Table 5: Result of the orthogonal experiment

factor / order	Qs L/h	ts ℃	n r/min	ta ℃	v m/s	Q_L L/h	T_L ℃	Q kw
1	1	1	1	1	1	1	1	1.40
2	1	1	1	1	2	2	2	1.77
3	1	1	1	1	3	3	3	2.22
4	1	2	2	2	1	1	1	1.26
5	1	2	2	2	2	2	2	1.59
6	1	2	2	2	3	3	3	1.98
7	1	3	3	3	1	1	1	1.05
8	1	3	3	3	2	2	2	1.31
9	1	3	3	3	3	3	3	1.75
10	2	1	2	3	1	2	3	1.77
11	2	1	2	3	2	3	1	1.40
12	2	1	2	3	3	1	2	1.61
13	2	2	3	1	1	2	3	1.96
14	2	2	3	1	2	3	1	1.52
15	2	2	3	1	3	1	2	1.89
16	2	3	1	2	1	2	3	1.77

17	2	3	1	2	2	3	1	1.40
18	2	3	1	2	3	1	2	1.54
19	3	1	3	2	1	3	2	1.75
20	3	1	3	2	2	1	3	2.03
21	3	1	3	2	3	2	1	1.59
22	3	2	1	3	1	3	2	1.63
23	3	2	1	3	2	1	3	1.82
24	3	2	1	3	3	2	1	1.31
25	3	3	2	1	1	3	2	1.75
26	3	3	2	1	2	1	3	2.03
27	3	3	2	1	3	2	1	1.68
K1	14.33	15.54	14.86	16.22	14.35	14.63	12.60	44.78
K2	14.86	14.96	15.07	14.91	14.86	14.75	14.84	
K3	15.59	14.28	14.84	13.65	15.56	15.40	17.34	
Range	1.26	1.26	0.23	2.57	1.21	0.77	4.74	

Note: Qs--cooling water volume flow rate; Ts--spray water temperature; N--rotating speed of the water distributor; Ta--air temperature; V--air velocity; Q_L--spray water volume flow rate; T_L-- the cooling water inlet temperature; Q – heat transfer amount.

As the tab.5 shown that the heat transfer amount of the third experiment was the maximum, and it was the optimal scheme: the spray water volume flow rate was 40L/h, the spray water temperature was 27℃, the rotating speed of the water distributor was 50r/min, the air temperature was 24℃, the air velocity was 3m/s, the cooling water volume flow rate was 1000L/h, the cooling water inlet temperature was 39℃.

From the tab.5, the heat transfer amount increased with the increment of the spray water volume flow rate, the air velocity, the cooling water volume flow rate, the cooling water inlet temperature. compared with 40 L/h of the spray water volume flow rate, the heat transfer amount increased by 3.70% and 8.79%, respectively, when the spray water volume flow rate increased from 40 L/h to 60 L/h, and for each per additional 10 L/h of the spray water volume flow rate, and the amount rise up or 2%, So its influence on the heat exchange performance impact was small; compared with 2.5 m/s of the air velocity ,when it was increased from 2.5 m/s to 3 m/s , the heat transfer amount increased by 3.55% and 8.43%, respectively, it means for each per additional 0.1 m/s of the air velocity, the heat transfer performance increased by about 1.5%; compared with 600 L/h of the cooling water volume flow rate ,when it increased from 600 L/h to 1000 L/h, the capability increased by 0.82% and 5.26%, respectively; for the cooling water inlet temperature , when it increased from35 ℃ to 39 ℃, compared with the 35 ℃,its performance increased by 17.78% and 37.62% , respectively, that was, when the temperature enhanced 1 ℃, the capacity increased by about 8%, the higher of the cooling medium temperature, the better performance of heat exchanger, and the influence on the heat exchange performance is more apparently, it shows that the heat exchanger is more suitable for high temperature medium, therefore, this cooler can be improved to a evaporative condenser.

With the increase of the spray water temperature, the air temperature, the performance monotonously decreased. Compared with 27 ℃, when the spray water temperature increased from 27 ℃ up to 31 ℃, the heat transfer capability decreased by 3.73% and 8.11%, respectively, when the temperature enhanced 1 ℃, the capacity decreased by about 2%;When the air temperature rise from 24 ℃ to 28 ℃, compared with 24 ℃, the heat transfer performance reduced by 8.08% and 15.84% respectively, it shown that the factor of air temperature was very important. When the rotating speed of the water distributor was 75 r/min, compared with the speed was 50 r/min, the capacity increased by 1.41%, compared with the speed is 100 r/min, the capacity increased by 1.57%, with the increase of the rotating speed of the water distributor, the heat transfer performance increased first, but then decreased, i.e. There was a best optimal rotating speed of the water distributor for the third arrangement mode, but the influence can be ignored.

Based on the sum of the results corresponding to the factors level as shown in tab.5, the best optimal levels were as following: the spray water volume flow rate was the third level, the spray water temperature was the first level, the rotating speed of the water distributor was the first level, the air temperature was the first level, the air velocity was the third level, the cooling water volume flow rate was the third level, the cooling water inlet temperature was the third level. As shown in tab.5, according to the range of the sum of the results corresponding to the factors level, the order of the factors that influenced on the performance of heat exchanger was: the cooling water inlet temperature >the air temperature > the spray water volume flow rate, the spray water temperature >the air velocity > the cooling water volume flow rate > the rotating speed of the water distributor.

Table 6: Orthogonal experiment anova table

Variance sources	Sum of square	DOF	mean square	F	critical value	Experimental error
Qs	0.089	2	0.045	16.95	$F_{0.005}(2,16)=7.51$ $F_{0.001}(2,16)=10.97$	0.051
Ts	0.088	2	0.044	16.762		
Ts	0.366	2	0.183	69.71		
v	0.082	2	0.041	15.62		
TL	1.248	2	0.624	237.71		
QL	0.038	2	0.019	7.24		
n	0.004	2	0.0026			
vacant column	0.038	14				
error	0.042	16				

Note: Qs--cooling water volume flow rate; Ts--spray water temperature; N--rotating speed of the water distributor; Ta--air temperature; V--air velocity; Q_L--spray water volume flow rate; T_L-- the cooling water inlet temperature; Q – heat transfer amount..

As shown in tab.6, the above factors' primary and secondary order of the transfer process is: the cooling water inlet temperature, the air temperature, the spray water volume flow rate, the spray water temperature, the air velocity, the cooling water volume flow rate. Due to the rotation speed has little effect on the performance of the heat exchanger; it can be taken for a secondary factor, the same as the sequence based on the range analysis.

5. Conclusions

In this paper, the analysis of the air parameters of the exhaust tunnel in Guangzhou subway station in summer shows that moving the cooling tower into the exhaust channel of the subway station is feasible. From the orthogonal experiment results, it is found the third arrangement mode that the air flow parallel to the normal direction of the heat exchanger, the *water distribution device's best speed was 76* rpm, The increase of the water temperature and the air temperature reduced the heat exchange performance, the cooling water inlet temperature change affected the heat exchange performance was the most significant, when the hot water temperature rise from 35°C to 39°C, the heat transfer performance improved 37.62%. The higher of the cooling medium temperature, the better performance of heat exchanger, and the influence on the heat exchange performance is more apparently, it shows that the heat exchanger is more suitable for high temperature medium; therefore, this cooler can be improved to an evaporative condenser. The above research results have laid a solid theoretical foundation for the development of the evaporative cooler which cooled by flank rotary spray water on both sides of the heat exchanger for the air conditioning system in subway station.

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References

[1] Parker R O, Treybal R E. The heat and mass transfer characteristics of evaporative cooler[J].Chemical Engineering and Processing Symposium Series, 1962, 57(32):138-147
[2] Bilal Ahmed Qureshi, Syed M. Zubair. Prediction of evaporation losses in evaporative fluid coolers[J].Applied Thermal Engineering,2007,(27):520-527
[3] Qureshi B A, Zubair S M. The impact of fouling on performance evaluation of evaporative coolers and ensers [J]. International Journal of Energy Research, 2015,29:1313 -1330
[4] LI Weijun, Dong Xiaoqiang, Yang Jun. Application and research progress of evaporative condensing/cooling technology[J]. Refrigeration and Air Conditioning, 2010, 10(1): 40-44.
[5] Ghannar N, Ghali K, Chakroun W. Evaporative cooler improves transient thermal comfort in chilled ceiling displacement ventilation conditioned space[J]. Energy and Buildings, 2013, 61:51-60.
[6] Heyns JA, Kroger DG. Experimental investigation into the thermal-flow performance characteristics of an evaporative cooler[J]. Applied Thermal Engineering, 2010, 30(5):492-498.
[7] Gomez EV, Martinez FJR, Gonzalez AT. Experimental characterisation of the operation and comparative study of two semi-indirect evaporative systems [J]. Applied Thermal Engineering, 2010, 30(11-12): 1447-1454.
[8] Xia ZZ, Chen CJ, Wang RZ. Numerical simulation of a closed wet cooling tower with novel design[J]. International Journal of Heat and Mass Transfer, 2015, 54(11-12):2367-2374.
[9] Facao J, Oliveira AC. Heat and mass transfer in an indirect contact cooling tower: CFD simulation and experiment[J]. Numerical Heat Transfer, Part A: Applications, 2008, 54(10): 933-944.
[10] Hasan A, Siren K. Theoretical and computational analysis of closed wet cooling towers and its applications in cooling buildings [J]. Energy and Buildings, 2002, 34(5):477-486
[11] LIU Nailing, SHAO Dongyue. Numerical calculation on the influence of tube evaporative cooler cooling performance[J]. Refrigeration, 2014, 28(3): 13-18.
[12] Leiden frost W, Korenic B. Evaporative cooling and

heat transfer augmentation related to reduced condenser temperatures[J]. Heat Transfer Engineering, 1982, 3(3-4): 38-59.

[13] HUANG Xiang, ZHOU Bin, YU xiangyang, et al. Experimental study on water distribution uniformity of tubular indirect evaporative coolers[J]. HV&AC, 2006,36(12): 48-52.

[14] He Yecong. Study on the Indirect Evaporative Cooler for Metro [D].Chong Qing: Chong Qing University, 2009.

[15] JIANG Bin, FU Xiangzhao, WANG Yong. Installation location of intact film plate evaporative cooler in underground railway stations[J]. HV&AC, 2014,41(6): 106-108.

[16] Tian Shengyuan. Experimental design and data processing [M].BEIJING： China architecture and building press，2000.

[17] Shen Jialong. Analysis and experimental research on heat and mass transfer theory of evaporative condenser [D],Guangzhou:South China University of technology,2005.