Design and Operation of Fan-Coil Units in Using River Water as Chilled Water

Aihua Jiang, Associate Professor; Huihe Chen, Master; Weiwu Ma, Doctor
School of Energy Science and Engineering, Central South University
Changsha, Hunan Province, China

Hanwen Zhu, Manager
Liyujiang Ltd., Hunan Huarun Electricity Power
Chenzhou, Hunan Province, China

jah65@163.com

Abstract: Based on the case research for China's first central air conditioning system utilizing natural cool river water as chilled water, this paper analyzes the technical design-and-innovation process and operating characteristics of Fan-Coil Units (FCUs) in the system. An approximate formula is proposed for computing the cooling capacity of FCUs when the temperature of water supply is a little higher than designed temperature. Finally, recommendations are given for the design of the FCUs to follow dry operating conditions in the air conditioning system that directly utilize natural cool resources.

Key words: natural cool resource; Fan-Coil Units (FCUs); temperature of water supply; dry operating condition

1. INTRODUCTION

As an indispensable terminal equipment in semi-concentrated air-conditioning system, the FCUs are mainly used to exchange cool or thermal energy with indoor air of rooms. The cooling or thermal capacity of FCUs is influenced by many factors such as the temperature and the flux of medium, the velocity of air passing FCU transversely and the properties of indoor-air, and so on. Especially, the temperature of inlet-water can not only make a strong impact on the capacity of the energy afforded by FCUs, but also affect the economic capability of the whole air-conditioning system directly.

As a rule, the designers of A/C systems pay more attention to the design of the inlet-water temperature of FCUs, and many correlative criteria have been established. Generally, considering the economic benefit of an air-conditioning system wholly, it is advisable that the inlet-water temperature of FCUs should not be higher than 7 , so the designing parameter of the inlet-water temperature provided by many air-conditioning manufactories is just 7 or not more than 10 . However, for these air-conditioning systems using natural river-water or well-water as cooling resource, the inlet-water temperature is often higher, even up to 15 , and the data provided by many air-conditioning manufactories do not suit the design of this kind of air conditioning systems. So, it is necessary to develop a suited and usable method to calculate and design such systems. The concentrated air-conditioning system, which came into use in 2000, in Liyujiang Power Plant, utilizes the discharged water of the Dongjiang reservoir as water supply of the FCUs directly, and the inlet-water temperature is about 14 . Testified by the successful operation of this A/C system, that the A/C systems direct-utilizing natural cool river-water as chilled water needn't refrigeration equipments and is not only a system with superexcellent economic benefit, but also a green and energy-saving air-conditioning system with environmental benefit, and is very worthy of extending. Therefore, for popularizing such an A/C system, energy-saving and protecting environment, it is of very significance to research the design approaches and operation performance of the FCUs with higher inlet-water temperature.

2. DESIGN OF FCUS IN A/C SYSTEMS DIRECT-USING COOL RIVER-WATER

2.1 Characteristics of Water Systems in the A/C System Direct-Using Natural Cool Resource

The air-conditioning system built in Liyujiang

Power Plant locates at the side of Liyujiang River in Chenzhou, Hunan Province, P. R. China. As the outflow coming from the bottom of Dongjiang reservoir, the river-water keeps its temperature varying in a limited area from 13 to 18 yearly, especially varying from 13 to 15 in summer. Therefore, the useable temperature difference of the river-water is more than 10 when the design temperature of the indoor air is 26 . To save energy and improve whole efficiency of their plant, the leaders of Liyujiang Power Plant decided to supply cool to the whole workplace and residential area by the concentrated air-conditioning system via utilizing the natural cool resource of the river-water directly, and as the first case in P. R. China. The concentrated A/C system utilizing natural cool resource of the river-water was built and put into service in 2000. The A/C system does not need any chiller, and the medium inlet-water provided to terminal equipment is just the low temperature river-water.

Facing the fact that the inlet-water temperature of the FCUs was about 14 , the designers had some problems with the designing and size-selecting of the FCUs, because the data of parameters related to the cooling capacity provided by most air-conditioning manufactories meant the designing parameters under the conditions of when dry-bulb temperature being 27 , wet-bulb temperature being 19.5 , and inlet-water temperature being 7 . Based on the method via combining the theoretical study and the usable experiment data, the designers selected a reasonable plan under dry operating condition, which kept the A/C system reaching the planed ideal goals.

2.2 Analysis of Influence on FCUs' Cooling Capacity by the Inlet-water Temperature

Based on the energy balance of FCUs exchanging heat with environment, at the same atmospheric pressure, air flow, and water flow, for the identical FCU, a cooling capacity formula is quoted by reference 3:

$$Q \propto (t_s - t_w) \cdot e^{0.02 t_s} \cdot e^{0.0167 t_w} \tag{1}$$

Where Q is the cooling capacity of a FCU; t_s is the wet-bulb temperature of inlet-air; t_w is the temperature of inlet-water [3].

As the wet-bulb temperature of inlet-air, that is t_s, is invariable, formula (1) turns to:

$$Q \propto (t_s - t_w) \cdot e^{0.0167 t_w} \tag{2}$$

So, when the inlet-water temperature is different, the ratio of the cooling capacity could be expressed by inlet-water temperature as following formula, that is:

$$\frac{Q_1}{Q_2} = \frac{(t_{s1} - t_{w1})}{(t_{s2} - t_{w2})} \cdot e^{0.0167(t_{w1} - t_{w2})} \tag{3}$$

Where Q_1 or Q_2 is the cooling capacity when the inlet-water temperature is t_{w1} or t_{w2}.

For the identical FCU, when the wet-bulb temperature of inlet-air is the same, but the temperature of inlet-water is different, the cooling capacity can be calculated and compared conveniently by formula (3).

For the A/C system utilizing natural cool resource of river-water mentioned above, the inlet-water temperature of the FCU is 14 , and the ratio of the cooling capacity could be educed by the formula (3), when the inlet-water temperature is 14 and 7 . The ratio is:

$$\frac{Q_1}{Q_2} = \frac{(t_{s1} - t_{w1})}{(t_{s2} - t_{w2})} \cdot e^{0.0167(t_{w1} - t_{w2})}$$

$$= \frac{(19.5 - 14)}{(19.5 - 7)} \cdot e^{0.0167(14-7)}$$

$$\approx 0.495$$

Indicated by the calculation and analysis as above, when the inlet-water temperature is 14 , the cooling capacity will be a half of that when the inlet-water temperature is 14 .

2.3 Experiment of Cooling Capacity of FCUs With Higher Temperature Inlet-water

For making sure the FCUs of the A/C system could reach the cooling capacity demanded by the air-conditioning rooms, the designer had done lots of experiments on the selected FCUs, which were produced by two manufacturers. The parameters of -

Tab.1 The parameter of some certain FCUs produced by two manufacturers

	FCU type	the parameter			experimental data	calculational data
		air volume $/m^3h^{-1}$	water volume $/kgh^{-1}$	cooling capacity of 7 $/W$	cooling capacity of14 $/W$	cooling capacity of14 $/W$
1	FP-10.0GM	1000	479	5500	2756	2723
	FP-600GMF	1020	950	5300	2602	2624
2	FP-8.0GM	800	479	4500	2247	2228
	FP-500GMF	850	700	4700	2597	2627
3	FP-6.3GM	630	479	3500	1771	1733
	FP-400GMF	680	700	3600	1825	1782
4	FP-5.0GM	510	479	2800	1365	1386
	FP-300GMF	510	480	2800	1415	1386

Note：the cooling capacity is tested when the inlet-water temperature is 7℃, the temperature difference between inlet-water and outlet-water is 5℃, the dry-bulb temperature of inlet-air is 27℃, the wet-bulb temperature is 19.5℃.

cooling capacity are given in table 1, in which: (a) the data at the inlet-water temperature of 7 is the designed cooling capacity supplied by the manufac -turers; (b) the data at the inlet-water temperature of 14 is the testing cooling capacity tested from experimental plot and; (c) the calculated data is computed by the formula (3). As it is shown in table 1, the calculated data and experimental data of the FCUs are greatly approximative, so the cooling capacity of FCUs can be calculated by the formula (3) when the practical operating condition of the FCUs is different from the usual ones.

3. DESIGN OF DRY OPERATING CONDITION ON FCUS IN A/C SYSTEMS DIRECT-USING COOL RIVER-WATER

3.1 Dry Operating Condition Analysis of FCUs

On the one hand, to avoid the condensate water, the inlet-water temperature need be higher when the FCU operates under the dry operating condition. On the other hand, for making adequately use of the cooling capacity, and reducing the size of FCU, the inlet-water temperature should not be too high. One of the main factors which influence the inlet-water temperature is the dew-point temperature of indoor air. In the usual range of temperature, the dew-point temperature of indoor air can be determined by the following formula which is quoted by reference 4:

$$t_l = 8.22 + 12.4\ln(\varphi p_{q,b}) + 1.9(\ln(\varphi p_{q,b}))^2 \qquad (4)$$

Where, t_l is the dew-point temperature of indoor air, φ is relative humidity of indoor air, $p_{q,b}$ is the partial pressure of saturated vapor at the dry-bulb temperature of indoor air[4].

As is indicated by the formula above, the dew-point temperature is one parameter which related to dry-bulb temperature and relative humidity of indoor air. At the standard atmospheric pressure, the different dew-point temperatures at different dry-bulb temperatures and relative humidity of air are listed in table 2. It is noticed from table 2, when dry-bulb temperature and relative humidity of indoor air increase, the dew-point temperature increases accordingly. Therefore, to avoid condensed water, the inlet-water temperature of the FCU under dry

Tab.2 The dew-point temperature of air t_l at different dry-bulb temperature t and relative humidity φ

φ（%）	t（ ）				
	20	22	24	26	28
40	6.09	7.85	9.62	11.39	13.17
50	9.31	11.13	12.96	14.80	16.63
60	12.02	13.90	15.78	17.66	19.55
70	14.38	16.30	18.22	20.14	22.08

operating condition in A/C system can't be a fixed value, and should be decided based on the dew-point temperature of air at the indoor design value.

Taking account of influence of heat transfer resistance, the inlet-water temperature should be a little lower than the dew-point temperature of air at the indoor design value when a FCU under dry operating condition is designed. As shown in the table 2, when dry-bulb temperature of indoor air is 26 , relative humidity is 50 percent, and the corresponding dew-point temperature is 14.8 . For the A/C system of Liyujiang power plant, the temperature of the inlet-water (water come from Liyujiang river) of the FCU is 14 (less than 14.8), so the FCUs' operation satisfies dry operating condition. Therefore, the designers were sure that all the FCUs can be contrived according to dry operating condition and the condensate water system needn't to be taken into account.

3.2 Analysis on the Operating Effect of the System

The A/C system came into use from the May, 2000 after the installation and test were finished at the end of the year 1999; the system's running performance in recent years has shown that all operating parameters had met the predicted value. Particularly, the FCUs are kept very clean and dry because of their dry operating condition, and at the same time, problems such as begriming, mildew and germ growing and so on, which often existing on wet operating condition, are avoided and the quality of indoor air is improved. Without the condensate water system, some of initial investment on equipment and installation cost of the project are saved, and destruction to the building and ornament caused by condensate water is prevented. Furthermore, in the A/C system, natural river-water is used directly instead of the chiller, so great economic and environmental benefit has been obtained because of saving much normal energy resource and decreasing polluting of environment.

4. CONCLUSIONS

(1) The paper's study on the design and operating characteristic of the A/C system of Liyujiang power plant has shown that the central air conditioning systems utilizing natural cool resource of river-water is green and energy saving, and should be popularized in some congeneric regions.

(2) Since the temperature of river-water or well-water is higher than that of inlet-water of general A/C systems with refrigeration equipment, it is suggested that the formula (3) educed by the paper can be used to compute cooling capacities of the FCUs when the A/C system utilizing these natural cool resources.

(3) When temperature of the inlet-water is 14 or over, it is considerable that the FCUs are designed under dry operating condition and the condensate water system can be omitted, so that the cost of the A/C system will decrease further.

REFERENCES

[1] Aihua Jiang, Chi Mei. Application of the energy of reservoir temperature difference to refrigerating and air conditioning[J]. HV&AC, 2004, vol.34(3):84-86 .(In Chinese)

[2] Aihua Jiang, Qiuxiong Hou. The river natural cool resource central air conditioning system and its economic analysis[J]. Refrigeration and Air-conditioning, 2003, vol.3(1):59-60.(In Chinese)

[3] Jialian Du, Wenqing Cai. Variational rule of the

cooling capacity of FCU with changes of the wet-bulb temperature of inlet-air and inlet-water temperature[J]. Fujian Construction Science & Technology, 1996,vol.4:21-22.(In Chinese)

[4] Jianwu Wan. Investigation of the cold water system in dry fan-coil unit[J]. Journal of Chongqing Jianzhu University, 2001,vol.23(4):63-66.(In Chinese)