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Performance of Energy-saving and Water-saving for Household Air Conditioner in Chongqing

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Abstract: A great deal of condensed water which contains a lot of cold energy is discharged from household air conditioners in hot summer and cold winter zones. To understand energy-saving and water-saving performance of air conditioners' condensed water in hot summer and cold winter zones, an experiment was conducted which was on condensed water of air conditioning with a cooling capacity of 7600 W installed in a typical office building in Chongqing. From the analysis of the measured data, it can be concluded that production capacities of condensed water by this type of air conditioner is 3100 mL h^{-1}. The relationship between condensed water and the cooling capacity is 0.4 mL/(w.h) with the temperature maintained at 10~15°C. Combined with the floor radiant cooling system and the district green Irrigation, some recommendations was made for comprehensive utilization of condensed water for residential districts.

Key words: Hot summer and cold winter zone, household air conditioner, condensed water, energy-saving, water-saving

INTRODUCTION

With the rapid development of social economy and the improvement of people's living standard, air conditioning, heating, hot water, electrical daily equipment have been increased and popularization. As a result, residents' energy and resource consumption intensity and requirements on quality of inhabited environment will be gradually improved. Figure 1 shows the ownership of air conditioners 100^{-1} urban households through 2000-2009 by hot summer zone (Anonymous, 2009).

However, condensed water is mostly drained out through the condensation pipe from a condensed water pond set under the air cooler. This treatment wastes plenty of water resource and the cold energy stored in it.

At the present stage, the utilization of condensed water focuses on two aspects. One is the utilization of the condensed water volume which means that the condensed water will be used as water resource (Liang, 2009; Ou Yang *et al*., 2006; Guz, 2005), such as the supplementary water for the cooling to the authorsrs, irrigation water for greening, water for drinking, etc. Another way is to use the cold energy stored in condensed water because of the low temperature which commonly ranges from 10 degree to 15 degree. Besides, the condensed water has huge latent heat of vaporization.

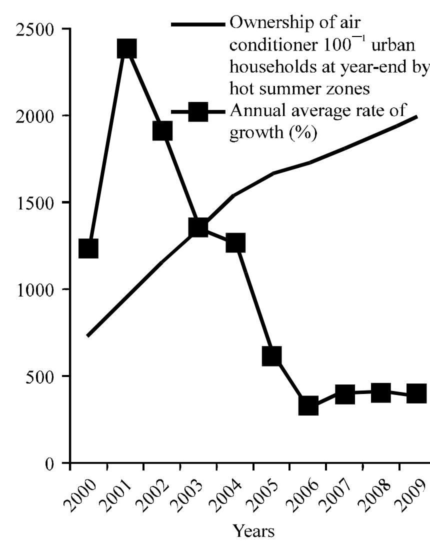

Fig. 1: Ownership of air conditioners 100^{-1} urban households through 2000-2009 by hot summer zone

Based on these aspects, it is necessary to do the study of the utilization of condensed water and do deep analysis on energy-saving and water-saving for household air conditioners.

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In order to carry out this study, condensed water situation in Chongqing-a typical city in China hot summer and cold winter zones was researched and a two-year test on air conditioners' condensed water was deployed in a typical office in Chongqing. Based on the measured data and a case study, the energy-saving and water-saving performance for household air conditioner in this kind of zones is proposed for further study.

METHODS

To understand exactly about the air conditions' condensed water condition, a two-year condensed water test was conducted in a typical office in Chongqing during 2009-2010. The office's area is 58 m^2, the floor height is 3 m and the rated refrigerating capacity of air conditioning used in the office is 7600 W. Test parameters mainly included outdoor air basic parameters, indoor air's basic parameters and the number of people indoor, the service condition and the number of devices, partial parameters of air conditioning, the temperature and volume of condensed water. Experimental instruments used in the test were temperature and humidity measuring device, mercury thermometer, ammeter and graduated container.

Test points were set both in the indoor side and outdoor side of the office. The outdoor measured points are far from the outdoor unit while these 5 indoor measuring points are set 1.5 m above the floor, the points setting pattern is showed in Fig. 2.

The working time of this office was from 8:30-18:00. According to the working time and the impact of air-condition load, the experiment time was decided as follows: every half an hour from 8:30-11:00, once an hour from 11:00-18:00 and all the parameters were measured at the ends of each experiment time period.

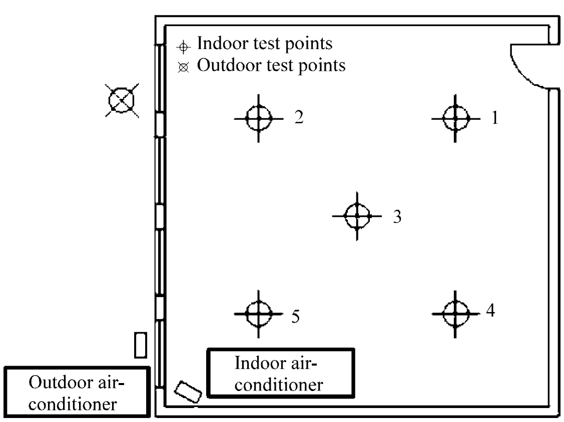

Fig. 2: Measured points both in the indoor side and outdoor

RESULTS AND DISCUSSION

Experimental results and analysis

Temperature of condensed water: According to the experiment, a result can be obtained that the temperature of condensed water maintained at 10~15°C, in most cases, it just ranged from 10-13 degree (Fig. 3). The production capacity of condensed water by a household air conditioner with a cooling capacity of 7600 W is 3100 mL h^{-1}.

Condensed water volume: The heat gain of the room consists of two parts, the sensible heat and the latent heat. When the latent heat is presented by the drained water in unit time, it is humidity load. There are many indoor humidity resources. While calculating the indoor humidity load theoretically, it mainly consists of moisture gain from occupant and the humidity load of the fresh air. The equation is listed below:

$$W = [G\,(d_W - d_N) + W_r] \times \Delta_t \qquad (1)$$

Where:

G = Fresh air volume, kg h^{-1}, calculated by the ventilation rate. the ventilation rate is n = 1.5, times/h which is based on design standard for energy efficiency of residential buildings in hot summer and cold winter zone and engineering experience

d_W = Moisture content of outdoor air in one moment (kg kg^{-1})

d_N = Moisture content of indoor air in one moment (kg kg^{-1})

Δ_t = Experiment time (h)

W_r = Moisture gain from occupant, kg h^{-1}. Moisture gain from occupant is affected by many factors and it is calculated as following equation:

$$W_r = n\,n'\,w \qquad (2)$$

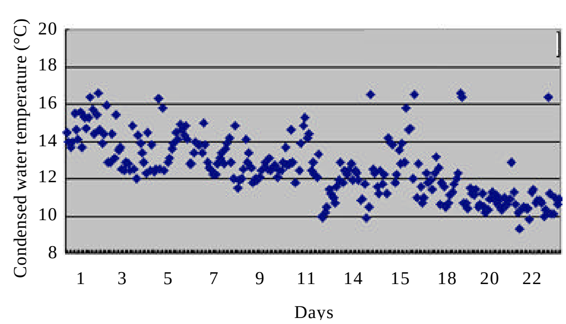

Fig. 3: Measured data of the condensed water temperature

Where:

w = Moisture gain from a male adult in different room temperature and different working conditions

n' = Clustering coefficient which considers the influence of the indoor people construction

Measured data is compared with the result of theoretical analysis (Fig. 4).

According to Fig. 4, they are not equal. The difference was made by the form of air conditioning system, moisture absorption (Xu and Hu, 2009) of envelop, indoor and outdoor environment change and so on.

Partial accidental error could be eliminated by taking a testing day into account. Then, the experimental results are compared with theoretical analysis again and the result is showed in Fig. 5.

To verify the test results, this study conducted the paired-samples T test. The two-tailed critical point was 2.06. If the significance level was 0.05, the experimental results could be accepted because of $P\ (T \le t_P\ (26)) = 1.706 < 2.06$. It implicates that the experimental results can be used as the index of condensed water discharged by a household air conditioner building in Chongqing.

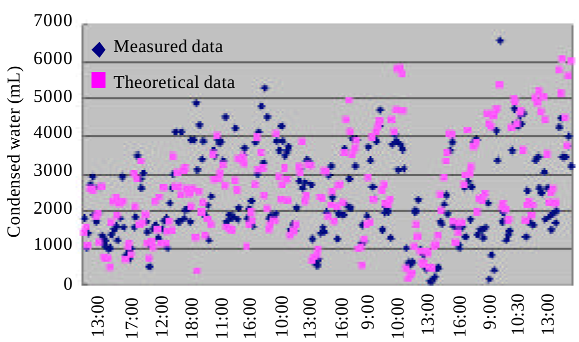

Fig. 4: Measured data and theoretical analysis on condensed water during 2009-2010

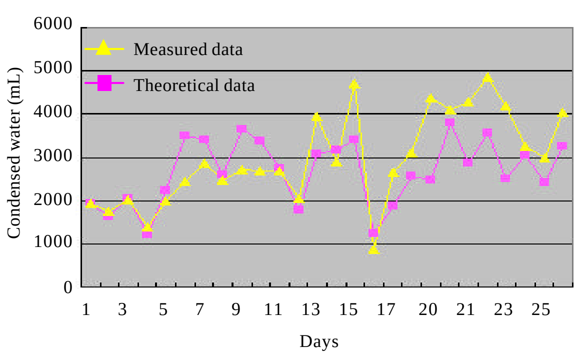

Fig. 5: Measured data and theoretical analysis on condensed water on each test day during 2009-2010

It can be concluded from the measured data and analysis above that the production capacities of condensed water by a household air conditioning with a cooling capacity for 7600 W is 3100 mL h^{-1}, the relation between condensed water and the cooling capacity is 0.4 mL/(w.h).

The cooling electric power consumption: The experimental results showed the relation between the cooling electric power consumption and amount of condensed water (Fig. 6).

While dealing with the data, fitting method will be used. The fitting curve was showed as the black one in the Fig. 5 and the equation was listed below:

$$y = 0.017\ x^{0.6076} \quad (3)$$

Where:

x = Condensed water volume

y = Cooling electric power consumption

The linear dependency was 0.79.

In order to justify this result, a series of theoretical analysis are deployed. The heat transfer performance of air cooler is influenced by a lot of factors. The following equation (He, 2008) is usually got according to the experiments:

$$K_s = \left[\frac{1}{Av_y^m \xi^p} + \frac{1}{Bw^n}\right]^{-1} \quad (4)$$

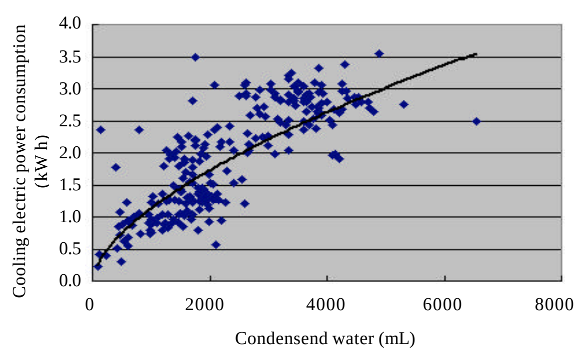

Fig. 6: The measured data of the condensed water volume and the cooling electric power consumption during the test time

Where:

v_y	=	Air face velocity (m sec^{-1})
W	=	Water velocity in a tube in heat transfer (m sec^{-1})
ξ	=	Dehumidifying coefficient
A, B, m, n, P	=	Some coefficients and indexes related the experiments

It can be learned from the experienced equation that heat transfer coefficient of an air cooler is not only related to air face velocity and water velocity but also to the dehumidifying coefficient. However, dehumidifying coefficient reflects the quantity of condensed water. It is obvious that heat transfer coefficient is proportional to the dehumidifying coefficient.

According to the Eq. 4, heat transfer coefficient of an air cooler will magnify while the amount of condensed water increases. Meanwhile, the superficial area of the heat exchange is unchanged and temperature difference between indoor circulating air and refrigerants increases which will bring about an augment of the amount of heat transfer. Above all, the cooling electric power consumption will increase as the refrigeration coefficient is certain without other factors taken into account. And it presents the power relation between the cooling electric power consumption and amount of condensed water.

Experimental results and theoretical analysis are identical with each other. As the amount of condensation water increases, the cooling electric power consumption will magnify. It presents the power relationship between the cooling electric power consumption and amount of condensed water.

Based on the test results and analysis above, the condensed water condition in Chongqing will be realized exactly.

DISCUSSION

The experimental results showed the huge energy-saving and water saving potentiality of condensed water. Taking the characteristics of condensed water into consideration, there are some methods to utilize it, such as combining the floor radiant cooling system.

It is obvious that the temperature of chilled water used in the floor radiant cooling system is higher than these in regular air conditioning systems. The condition is fit for utilizing natural cool source. Compared to the regular air conditioning system, energy consumption will be reduced by 28-40% (Feuste and Stetiu, 1995). Scholars around the world have done many researches on supply water temperature (Hawkes and Forster, 2002; De Carli and Olesen, 2002; Antonopoulos and Tzivanidis, 1997; Imanari *et al*., 1999; Wang, 2004) in the floor radiant cooling system. In summer, the authors can use the supply water the temperature of which maintains in 9-16° (Li *et al*., 2005) if the magnitude order of heat conduction coefficient of material of ground floor is about 10-1.

There are some successful cases about the application of the floor radiant cooling system (Zhao, 2010), such as the Bangkok Thailand International airport. In this case, construction area is about 550,000 m^2. It concludes 200,000 m^2, cooling floor. The indoor design temperature is 24°, the supply water temperature is 13° and the return water temperature is 19°. Floor surface temperature maintains at 20-23° and the design of coil spaces is between 150 and 200 mm. In this system, design cooling load is 97 W m^{-2}, it is assigned to the floor radiant cooling system with 70-80 W m^{-2} and the rest is to the fresh air replacement system. Radiative heat transfer is the dominant way of heat transmission in the floor radiant cooling system, for it has undertaken about 62% heat transfer. Anyway, the floor radiant cooling system is popular is France. China also has few cases, such as Fengshang International Apartment Project, Wukesong Indoor Stadium, China National Grand Theatre and so on. Taking the China National Grand Theatre as an example, the supply water temperature is 17.5° and the return water temperature is 20.5 (Zhou, 2007) degree in the floor radiant cooling system.

Based on these, a case study was conducted-collecting the whole residential district condensed water and using it as chilled water to the public regions which use the floor radiant cooling system, then, using it as the irrigation water to greening-for residential districts in Chongqing. The purpose is to quantify the condensed water's energy-saving and watering-saving performance.

There are 1500 tenements in the residential district. The latest survey shows that air conditioning units of per hundred urban households is 151.13. Therefore, there are about 2267 air conditioners in the residential district. Taking the use time into account, the simultaneity usage coefficient is considered as 0.5 related to the field practice.

Energy-saving performance: According to the measured data, It can be concluded that production capacities of condensed water by a household air conditioner building with a cooling capacity of 7600 W is 3100 mL h^{-1}. Taking this as a calculation standard, the amount of condensed water continuously supplied by the residential neighborhood mentioned in Part 3.2 is about 3514 L h^{-1}.

This study make recommendations for utilization of condensed water for residential districts: Collecting condensed water of the residential district together and delivering to air conditioning area. The water would be discharged after exchanging heat in the floor radiant cooling system. Because of the advantages of floor radiant cooling system, the cooling system can directly use the cold energy stored in the condensed water without the process making cool water by a chiller in regular air conditioning systems. The amount of condensed water continuously supplied by the residential neighborhood is about 3514 L h^{-1}. According to the successful cases mentioned before and taking the temperature rise during transportation process into account, the system's supply water temperature can be set at 15°C and return water temperature is 20°C. Based on these, the available cold energy supplied by this residential district's condensed water is 24500 W.

The cold energy supplied by condensed water can be used in the public places needing air conditioning of the residential neighborhood in summer, such as activity rooms, security rooms and content canal offices and so on.

Taking the activity room as an example, cooling load index of the activity room is 200 W m^2. Because the floor radiant cooling system just undertakes the indoor sensible heat load; it should be connected with air supply system. There is a feasible scheme distributing the air conditioning load (Lu, 2007). The floor radiant cooling system deals with the envelop load. If necessary, excess load can be assigned to the air supply system. On the other hand, both systems jointly handle indoor load. Furthermore, the mainly heat transfer way is radiation and accompanied by convection heat transfer. The study adopted the modified coefficient method to calculate the load undertaken by the floor radiant cooling system. The result is 70 W m^2 (envelop cooling load was accounted for 70% in the cooling load in addition to the cooling load from outdoor air, the cooling load from outdoor air was accounted for 50%, the modified coefficient was 0.9).

The analysis above indicates that the cold energy stored in condensed water of the residential district would meet the cooling demand for 350 sq. m area using the floor radiant cooling system.

Water-saving performance: To understand the water-saving performance, condensed water discharged by the floor radiant cooling system was collected and use for the district green irrigation. The water-saving benefit is obvious.

The latest survey shows that the number of the population in per household in Chongqing is 2.75. There are about 4125 people in the residential neighborhood. Public green land area for per capita mentioned in the Evaluation standard for green building should be 1 sq. m at least. Above this, the green land area in this district is about 4125 m^2.

The irrigation water to greening is 2 L m^2 day^{-1} correlated with Code for Design of Building Water Supply And Drainage. It could be calculated that 8250 L water would be used to irrigate per day. It just cost two and a half h cumulant of condensed water.

At the moment, architects always take the position of outdoor unit into account as the primary design begins. It is convenient for us to utilize condensed water. A signal pine connected with all the condensate pipes can be set to bring the water to the water storage tank. It will not damage building facades. Meanwhile, condensed water can be utilized fully.

CONCLUSION

This study has a big significance to understand the energy-saving and water-saving for air conditioners' condensed water. From the experiment and analysis, the results can be concluded as follows:

- There is a great deal of condensed water which contained a lot of cold energy discharged from household air conditioners in hot summer and cold winter zones. The production capacities of condensed water by a household air conditioner with a cooling capacity of 7600 W is 3100 mL h^{-1}, the relationship between condensed water and the cooling capacity is 0.4 mL/(w.h)
- The temperature of condensed water ranges from 10-15°, in most cases, it maintains at 10~13°. Low temperature condensed water is of great potential
- Green buildings propose the concept of land-saving, energy-saving, water-saving, material-saving and environmental protection. Combined with the floor radiant cooling system and the irrigation water to greening in residential districts, some recommendations are made for comprehensive utilization of condensed water

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