

Re-circulation Evaporative Cooling Technology and its Application in the Field of Air Conditioning

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Abstract: Applied to air conditioning, evaporative cooling technology has much effect on saving-energy, environmental protection and IAQ. Basing on the methods of direct evaporative cooling (DEC) and indirect evaporative cooling (IEC), this paper introduces the technology of re-circulation evaporative cooling, which uses a portion of supply air as secondary air to make cool water which is used to indirectly cool outside air through a heat exchanger. According to the technology, a set of apparatus is designed and tested, which indicates that it can get more dryer supply air than DEC, and get more cooler supply air than IEC. Then this paper analyses the applications of re-circulation evaporative cooling technology in the field of air conditioning. Finally concludes that this technology offers a new way of developing the equipments and systems of air conditioning, which can conserve energy and protect environment.

Keywords: re-circulation evaporative cooling, direct evaporative cooling, indirect evaporative cooling, saving-energy, application

NOMENCLATURE

DEC = Direct evaporative cooling
DBT =Dry-bulb temperature, °C
IEC = Indirect evaporative cooling
WBT =Wet-bulb temperature, °C
REC = Re-circulation evaporative cooling

1. INTRODUCTION

With the sustainable development of the economy in China, the use of air conditioners becomes more and more popular. However, it brings the serious lack of electrical power especially in summer. For example, there are nineteen provinces presenting the bad situation of switching off electrical power in the summer in 2003. Meanwhile, the popular use of conventional Freon refrigeration air conditioner is the main reason to destroy the atmospheric ozone layer. Therefore, energy-conservation and environmental protection have been paid more attention in the field of air conditioning. In order to look for new ways of air-conditioning system which can conserve energy and environment, the research of evaporative cooling technology has been attached importance to day by day since 1980s. Many foreign countries such as USA, Australia, India, Israel, have done a large amount of research work on the theory and application technology. Also many domestic scholars are engaged in researching in this respect^{[1]-[3]}.

Basing on the technology of direct and indirect evaporative cooling, a method of re-circulation evaporative cooling is put forward in this paper, and also analyse its application in air-conditioning system.

2. THE PRINCIPLE OF RE-CIRCULATION EVAPORATIVE COOLING

2.1 Direct evaporative cooling

In the course of DEC, air is brought into contact with water using either rigid or wetted media or spray nozzles. The evaporative media are pads made of different materials such as aspen wood fibres, specific paper, fibreglass, rigid cellulose. The air stream passes through a wetted porous medium fed with recirculated water(Fig.1). The evaporation of water makes the temperature of both air and water reduce. The sensible heat removed from the air stream to evaporate water results in a corresponding energy-equivalent increase in its moisture content. Through DEC, theoretically, the temperature of recirculated water and cooled air can come to the WBT of the entering air.

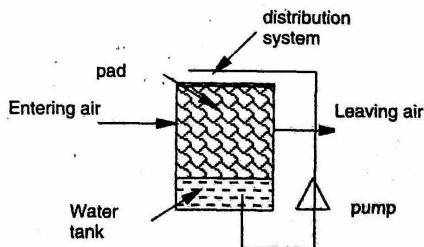


Fig.1 Schematic of a pad system

DEC can get good thermal comfort in hot, arid climates. However, when the humidity of outdoor air increases, the indoor humidity would become very high, which is uncomfortable. Furthermore, the range of lowering the temperature is limited.

2.2 Indirect evaporative cooling

To overcome the issue of high humidity after DEC, Pascod D first presented the method of IEC. IEC can cool entering air without adding moisture to the supply air stream. In fact, IEC use a heat exchanger to indirectly cool primary air that is supplied to the building by secondary air or water that has been cooled by water evaporation. There are two common methods to achieve IEC^[4]. One method makes use of a plate or tube type heat exchanger, where water is sprayed directly into secondary air in the wet passage while primary air in the dry passage is cooled(Fig.2). Another method involves a combination of DEC and air-to-air heat exchanger(Fig.3).

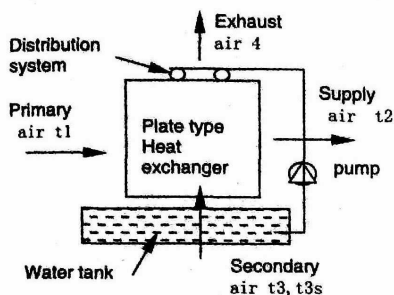


Fig.2 schematic of a type IEC

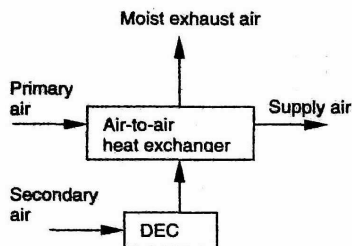


Fig.3 schematic of another type IEC

Without adding moisture to the supply air, IEC is more suitable for warm, arid climates than for hot, arid climates. There are two air flow streams in the IEC. The primary air flow passes through an heat exchanger and then into the room. The primary air dry-bulb temperature is lowered, but the humidity ratio remains constant. The secondary air flow enters from outdoors and passes through the wetted medium and then changes into moist exhaust air and then into the outdoor. The cooling performance of IEC is expressed as a performance factor. It also calls "effectiveness". It is a ratio of the primary air DBT drop to the difference between the entering air DBT and the entering secondary air WBT(Fig.2). It is written as:

$$E_i = (t_1 - t_2) / (t_1 - t_{3s}) \quad (1)$$

Where E_i is the effectiveness of IEC, t_1 the primary air DBT, t_2 the supply air DBT, t_{3s} the secondary air WBT.

2.3 Re-circulation evaporative cooling

In common, primary air and secondary air both are outdoor air. If improve the IEC as follow: utilize a portion of supply air as secondary air to make cool water by a pad DEC system, then employ the cool water to indirectly cool the primary air through a water-to-air heat exchanger. This method is re-circulation evaporative cooling (Fig.4).

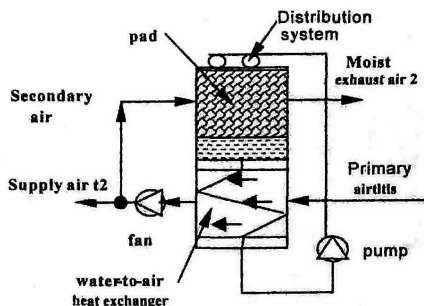


Fig.4 Schematic of a re-circulation evaporative cooling system

As showed in fig.4, when the primary air is cooled in the water-to-air heat exchanger without adding humidity, the WBT of supply air also falls. On account of using a portion of supply air as secondary air for DEC, the temperature of the cold water made by DEC may be less than the WBT of the primary air. Accordingly, the supply air of REC should be cooler than that of IEC. Following the definition of the IEC effectiveness, the REC effectiveness is written as(Fig.4):

$$E_r = (t_1 - t_2) / (t_1 - t_{1s}) \quad (2)$$

Where E_r is the effectiveness of REC, t_1 the primary air DBT, t_2 the supply air DBT, t_{1s} the primary air WBT.

3. THE STRUCTURE DESIGN AND TESTING RESULTS OF A REC APPARATUS

3.1 the main components

According to the principle of REC above-mentioned, an apparatus is designed. The apparatus mainly consists of an air handing unit, a box of DEC, a pump, a damper and ductwork. The air handing unit includes a centrifugal fan and an extended surface refrigerating coil. The DEC box contains water distribution tubes and rigid media pads made of special wettable cellulose in corrugated sheets bonded together. The pump keeps water re-circulating. The damper controls the portion of supply air as secondary air. In addition, an inverter is installed to change the volume of primary air. Here are two pictures of the REC apparatus (Fig5, Fig6).

The physical dimensions and models of the main components are listed in table 1.

Table 1: The physical dimensions and models of the main components.

Description	model	specification
air handing unit	YAH03	3000m ³ /hr
DEC box		400x400x600mm
rigid media pad	Celdek7090	400x400x150mm
inverter	HB280-3022	380V 5.5A



Fig7. view of model 2700 data acquisition system

When the velocity of air flow keep about 2m/s in the duct, the testing results are showed as table 2.

Table 2: The some testing results of REC.

DBT of primary air (°C)	WBT of primary air (°C)	DBT of supply air (°C)	the ratio of secondary air to primary air	Er
32.26	26.30	28.36	23%	0.65
31.44	26.10	27.80	33%	0.68
31.13	26.40	27.33	38%	0.80
32.77	25.76	27.16	51%	0.80
32.46	26.47	27.33	60%	0.86
32.73	26.22	26.98	71%	0.88
33.07	26.19	26.91	80%	0.89

As show in table 2, when the relative humidity of primary air is in the range 60%~65%, the effectiveness Er of REC become more and more higher with the increasing of the ratio of secondary air to primary air, and the primary air DBT is lowered about 3.5~6 °C while the humidity ratio remains constant. Compared with IEC mentioned in ref^[5], REC has more higher effectiveness. Of course, a portion of supply air is losing. In fact, one can see that about 40%ratio of secondary air to primary air is right.

• 4. APPLICATION

The characteristic of REC is to utilize part of supply air as secondary air for making cold water by direct evaporative cooling, then to indirectly cool the primary air by using the cold water. Compared with DEC, REC can get the almost same DBT of supply air without adding moisture to the supply air; Compared with IEC, REC can gain more lower DBT of supply air. Compared with traditional mechanical air-conditioning, REC needn't any compressor. It only needs blowers and pumps with consuming much less electric power, because REC utilizes natural energy that exist in unsaturated air, which is the vapour pressure difference between saturated air and unsaturated air. The more air is dryer, the more the natural energy can be used. Moreover, REC use water as refrigerant without employing any CFCS or HCFCs refrigerant. So REC don't destroy the atmospheric environment.



Fig 5. view of the REC apparatus

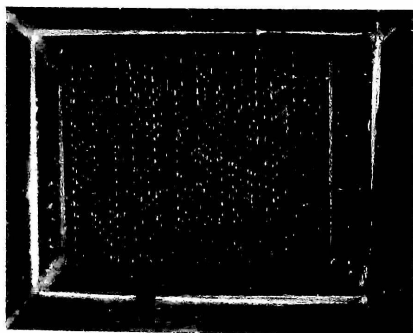


Fig 6. close-up of rigid media pad

3.2 Testing results

The DBT and WBT of air flow are measured trough T-type thermocouple. The temperature data are collected by model 2700 data acquisition system (Fig.7) manufactured by Keithley Corporation. The volume of air flow is measured trough the method of speed & area by Pitot tubes.

Because of the REC merits in the aspects of energy-conservation and environmental protection, it has an extensive range application in the field of air conditioning.

4.1 First, re-circulation evaporative coolers would be manufactured through REC technology. The coolers are applicable in the places where the relative humidity of outdoor air is less than 55%. Due to using whole fresh air, IAQ is improved greatly while keeping thermal comfort. Furthermore, the coolers are economical in the course of running because of energy-conservation. Hereby they have considerable advantage compared with conventional air-conditioner.

4.2 Second, the application of REC is to precool the incoming outdoor air as the first stage of an air-handling system in moderately humid locations. The second stage is a conventional air-handling unit. In this case, REC usually is not sufficient to meet cooling loads, but it can reduce both peak demand and total energy consumption in the cooling season.

4.3 Third, REC combined with liquid desiccant technology consists of liquid desiccant air conditioning system (LDAS). This system is very suitable in humid and moderately humid locations where dehumidification of entering outdoor air is usually necessary. LDAS has a lot of advantages. For example, it only uses a fraction of the electrical energy. Alternatively, it needs thermal energy for regeneration of the desiccant. This thermal energy can be of different kinds such as low-grade heat, waste heat, solar energy, natural gas etc. Most of the energy resources are green energy. In addition, in the LDAS the latent heat is removed from the entering air by liquid desiccant and the sensible heat by REC. Therefore, the temperature and humidity of supply air

can be controlled respectively to meet better thermal comfort.

5. CONCLUSIONS

5.1 By one stage of REC, the DBT of supply air can approach or lower to the WBT of primary air without adding moisture to the supply air. REC has more higher effectiveness than IEC.

5.2 REC technology offers a new way for developing air-conditioners and HVAC systems which have characteristics of saving-energy and environmental protection.

5.3 LDAS combined with REC technology is a very promising air conditioning system.

REFERENCES

- [1] P.L. Chen. Applications of the evaporative cooling techniques in moderate and humid climates[J]. Heating Ventilating & Air Conditioning, 1995,25(4):3-8
- [2] Xiang Huang, Jun-Mei Wu, Yong-Mei Xuan. An experiment study on the performance of two fill direct evaporative cooling air conditioners[J]. Journal of Refrigeration, 2001(3):33-40.
- [3] Xiang Huang. Integrating evaporative cooling outdoor air system [J]. Heating Ventilating & Air Conditioning, 2003,33(5): 13-16.
- [4] Pascal Stabat, Dominique Marchio, Matthieu Orphelin. 2001. Pre-design and design tools for evaporative cooling. ASHRAE Transaction: Symposia. Vol. 107 part1 501-510.
- [5] Wang zhongzheng, Guo Xiechuan etc. Investigation on indirect evaporative cooling system [J]. Journal of TianJin university. 1994,27(3):305-309