Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 143 (2017) 410–415

Energy Procedia

www.elsevier.com/locate/procedia

World Engineers Summit – Applied Energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference, WES-CUE 2017, 19–21 July 2017, Singapore

Free cooling technologies for data centers: energy saving mechanism and applications

Yin Zhang[a,b], Zhiyuan Wei[b], Mingshan Zhang[c*]

[a]*School of Architecture and Environment, Sichuan University, Chengdu 610065, China*
[b]*Department of Building Science, Tsinghua University, Beijing 100084, China*
[c]*Research Institute of Nationalities, Southwest Minzu University, Chengdu 610041, China*

Abstract

Air conditioning and cooling systems account for about 40 % of total electricity usage in data centers. Free cooling is a novel and promising technology that can decrease the load ratio of electrical chiller and save cooling energy consumption accordingly, through making full use of natural free cooling source. In this paper, four typical free cooling systems are analyzed and compared, to show their mechanisms, main features, energy saving effects and applicable situations respectively. (1) Direct fresh air cooling is of the highest free cooling potential. However, it is hard to meet indoor air quality demand due to the indoor-outdoor air mixing. (2) Rotating wheel heat exchanger can be used for indirect free cooling, since indoor and outdoor air flow in different paths for heat exchange. While its power usage effectiveness (PUE) increases inevitably under the same climatic conditions. (3) Heat pipe can be integrated with rack back plate to enhance heat transfer with free cooling sources. Its cooling efficiency can increase by 3-5 times compared to traditional heat exchangers. (4) In water-based free cooling system, a heat exchanger is installed in parallel with electrical chiller and the system can work under three modes according to different outdoor temperature. Increasing the load ratio of free cooling can decrease PUE and save electricity usage. In practical applications, the cooling system design for data centers depends on various factors, such as indoor air quality requirement, local climatic conditions, energy saving demands, room space, capital investment and operation costs.

Keywords: Data center; Refrigeration; Air conditioning; Free cooling; Energy efficiency

* Corresponding author. Tel.: +86-28-85522790; fax: +86-28-85524605.
E-mail address: swunzms@126.com

10.1016/j.egypro.2017.12.703

1. Introduction

During recent years, information communication and internet technologies are undergoing a dramatically fast development [1]. Thus the increasing demand for data processing caused a rapid growth in the data centers containing IT equipment, rack servers and related devices. It is reported that the total energy consumption in data centers doubled from 2005 to 2010 [2]. The IT devices are often of huge heat emissions and show high demands for temperature and humidity control in data centers, so that the cooling and air conditioning system is indispensable. According to a recent survey, the refrigeration and air conditioning system accounts for about 40 % of total electricity usage for data centers [3]. Therefore, in order to reduce the energy consumption of air conditioning is of great importance in energy efficiency for the whole data center.

There are many effective ways to save cooling energy usage in data centers, such as indoor air distribution optimization, heat transfer enhancement for rack servers, thermal performance improvement of chillers and so on [4]. Zimmermann [5] applied the hot water system to refrigeration system in IT rooms and established the energy model. Ebrahimi [6] introduced different cooling systems according to working conditions and found that energy efficiency could be increased substantially through low grade energy recovery. Marcinichen [7] proposed the two phase cooling technologies and put forward the method to evaluate heat recovery ratio. In addition, free cooling is a novel and promising technology that can decrease the load ratio of electrical chiller and save cooling energy consumption accordingly, through making full use of natural free cooling source [8]. Because of the high efficiency and low emissions, free cooling technologies utilized in data centers causes more and more attentions during recent years.

In this paper, four typical free cooling technologies and corresponding air conditioning systems are analyzed and compared, to show their mechanisms, main features, energy saving effects and applicable situations respectively. This work is of significance in guiding the design of refrigeration system with free cooling technologies for practical data centers.

2. Air Conditioning Systems in Data Center

IT devices always show high necessities in working conditions, especially the indoor temperature (22±2 ^{o}C) and humidity (50±5 %) control. Therefore, the air conditioning system is of great significance in space cooling for such data centers, considering the huge and consecutive heat emissions [9]. Fig. 1 shows the typical refrigeration system for data centers. The electrical chiller is used to produce low temperature water in its evaporator and then the chilled water is delivered to the terminal air handling units to take away the emission heat from racks. On the other hand, the condensation heat of the chiller is exhausted to the ambient through the cooling tower.

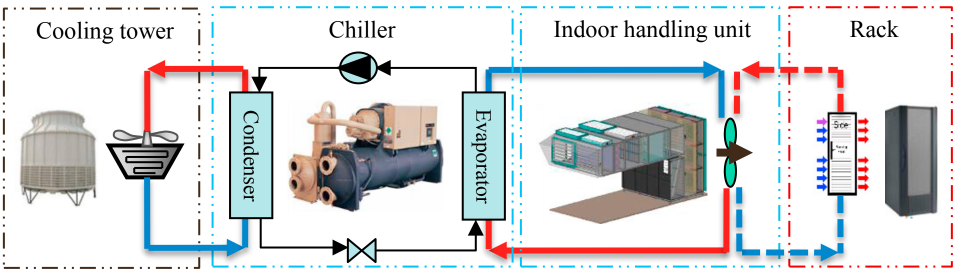

Fig. 1. Typical refrigeration system in data centers.

Such refrigeration system constitutes the dominant part of energy consumption in data centers, except for the IT devices themselves. Power usage effectiveness (PUE) is often used to evaluate the energy consumption level for data centers [4].

$$PUE = \frac{PU_{total}}{PU_{IT}} = \frac{PU_{IT} + PU_{AC} + PU_{else}}{PU_{IT}} \tag{1}$$

In Eq. (1), PU_{total} and PU_{IT} represent the power usage amounts of the overall data center and the IT equipment respectively. Therefore, a lower PUE value means that the data center is more energy saving. Hence, reducing energy consumption of air conditioning system (PU_{AC}) proves to be an effective way to decrease PUE and save power usage for the whole data center. Therein, free cooling technology is one of the most promising approaches.

3. Typical Free Cooling Technologies

3.1. Direct fresh air cooling

As Fig. 2 shows, when the outdoor temperature is low, the fresh air can be brought in directly through ventilation system for free cooling. Such a system can make most use of the ambient free cooling potentials without any extra refrigeration equipment. Nonetheless, due to the indoor-outdoor air mixing, it is hard to meet the indoor air quality (IAQ) requirement for direct fresh air cooling system. Thus such a ventilation system often work with other fresh air handling equipment, including dehumidification device, filters and air cleaners, to remove moistures, dusts and other pollutants, which will inevitably increase the primary and operation costs. As a result, Although of high energy efficiency and low PUE value, the direct fresh air cooling systems are merely applied in developed countries, such as Microsoft data center in Dublin and Hewlett-Packard data center in London, where direct fresh air cooling systems are installed with advanced indirect evaporation cooling equipment for air cleaning (PUE=1.08).

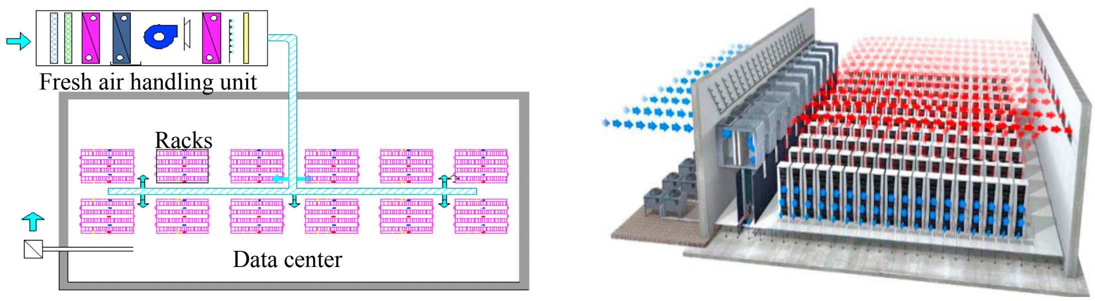

Fig. 2. Direct fresh air cooling system.

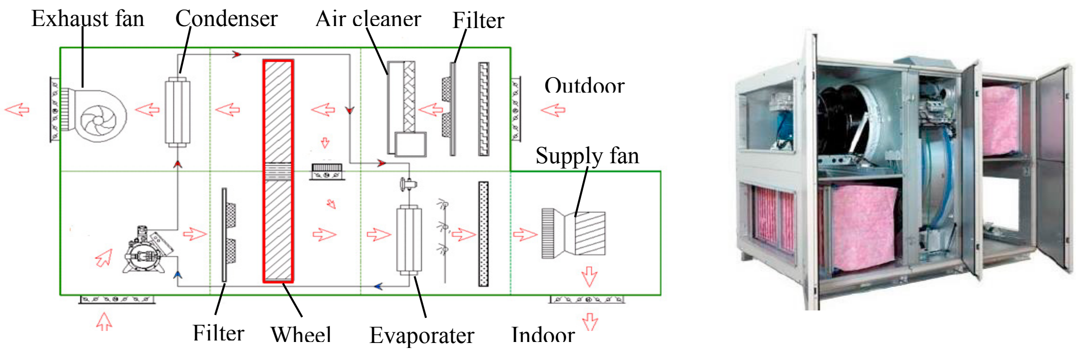

Fig. 3. Free cooling system based on rotating wheel heat exchanger.

3.2. Rotating wheel heat exchanger

To solve the indoor air quality problem of the aforementioned system, heat exchangers can be added between the indoor and outdoor airs. Therein, rotating wheels are widely used. Fig. 3 gives the schematic diagram of rotating wheel heat exchangers where the wheel keeps rotating at a speed of 10-12 r/min and the airs flows into different paths to avoid mixing [10]. Then the indoor air flows back to the data center for space cooling after heat exchange whereas the heated outdoor air is exhausted. Compared to the direct fresh air cooling, such a system based on the rotating wheel heat exchanger is in fact an indirect free cooling system, which can significantly improve the indoor environment. However, due to the extra medium heat exchange process, the free cooling effect of such an indirect free cooling system decreases inevitably under the same climatic conditions, increasing PUE value as a result. So in order to guarantee a reliable refrigeration system, electrical cooling equipment is often integrated with the rotating wheel heat exchanger. For instance, in data center of China Mobile Company at Harbin, only if outdoor temperature is lower than 23 ^{o}C, does the rotating wheel system work. Otherwise, the data center is refrigerated via electrical cooling. In addition, such a rotating wheel heat exchange system usually occupies a large space because of the relatively low air-air heat transfer efficiency, which also limits its applications.

3.3. Heat pipe back rack

Heat pipe is a kind of heat exchanger, where phase change materials are used to facilitate the high-efficient heat transfer. Integrating the heat pipe heat exchangers with racks is favorable for heat transfer enhancement between the high temperature racks and the free cooling sources. As Fig. 4 shows, multiple heat pipes are packed into a board installed at the rack back. Compared to traditional heat exchangers, the cooling efficiency of such heat pipe rack back can be increased by 3-5 times, which can decrease the PUE value dramatically. For example, the annual electricity usage amount of IT devices in China Mobile data center in Jiangsu province is 6.83×10^5 kWh. After heat pipe back racks taking place of traditional ones, the annual electricity consumption decreases considerably from 1.37×10^6 kWh to 1.07×10^6 kWh, making PUE decrease from 2.00 to 1.49 as a result.

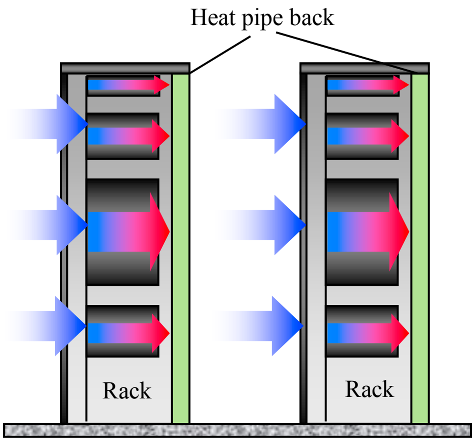

Fig. 4. Heat pipe back rack.

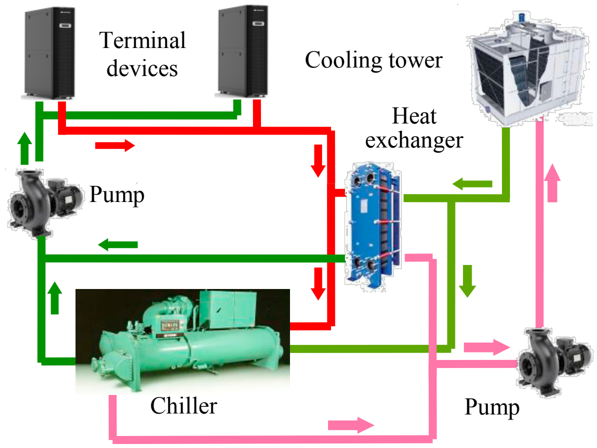

Fig. 5. Water-based free cooling system.

3.4. Water free cooling system

As Fig. 5 shows, the main difference between water-based free cooling system and traditional air conditioning system is that a heat exchanger is installed in parallel with electrical chiller to make full use of free cooling capacities from cooling tower. In other words, according to climatic conditions (especially the wet bulb temperature), the whole system can work under three different modes: (1) when the outdoor temperature is low (winter), the cooling water can be used to produce chilled water directly through the heat exchanger and the chiller can be turned off, so that the system works under "free cooling" mode; (2) when the outdoor temperature is high (summer), the chiller is activated instead while the cooling tower is only used to handle the condensation heat, so that the system works under "electrical cooling" mode; (3) when the outdoor temperature is moderate (spring and fall), the chiller and heat exchanger work together in parallel, so the system works under "free cooling + electrical cooling" mode.

Therefore, the working conditions of the water-based free cooling system are greatly impacted by the ambient temperature variation. Taking the HUAWEI dater center at Langfang (a northern city in China) as an example (Fig.

6), electrical cooling, free cooling, electrical cooling + free cooling account for 51%, 32%, 17% of time respectively in one year, resulting in that the annual average PUE value arrives at 1.35. Based on the previous analysis, the energy saving effect of such systems mainly derives from the free cooling. Hence, increasing the load ratio of free cooling can decrease PUE and save electricity usage.

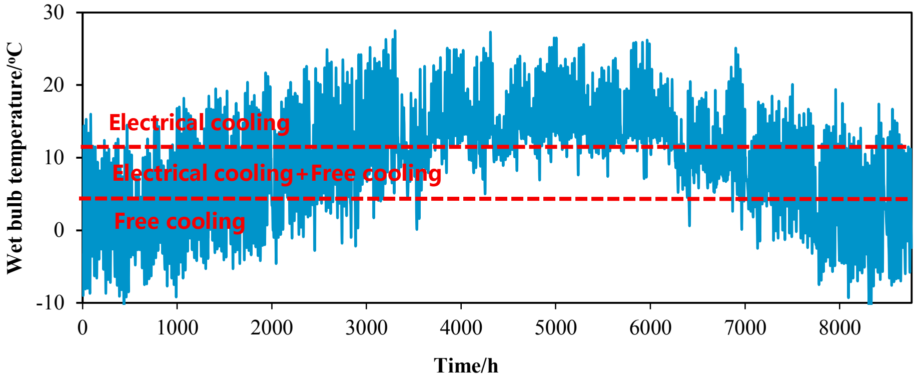

Fig. 6. Free cooling system based on rotating wheel heat exchanger.

Table 1. Comparison between typical free cooling systems in data centers.

	Direct fresh air cooling	Rotating wheel heat exchanger	Heat pipe back rack	Water-based free cooling
Air mixing	Yes	No	No	No
Air quality resuirement	High	Medium	Low	Low
Indoor humidity influence	High	Medium	Low	Low
Occupied room space	Small	Large	Large	Large
Electricity usage units	Fan	Fan	Fan	Pump
Power consumption	Low	High	Low	High
Primary investment	800 RMB/kW	1000 RMB/kW	1380RMB/kW	1250 RMB/kW
Maintenance	Filter, Fan	Fan	None	Heat exchanger
Key technologies	Air cleaning; Humidification	Humidity control; Heat exchanger;	Heat pipe; Anti-freezing	Temperature control Anti-freezing
Applicable situations	Low IAQ demand	High IAQ demand; Enough space; $T_{out}\leq 15$ °C	High IAQ demand; Limited space;	Large cooling load; $T_{out} \leq T_{chilled\ water} + 1$ °C

4. Conclusions

Decreasing the electricity usage of refrigeration system through free cooling technology is greatly important for energy saving in data centers. In this paper, four typical free cooling systems are introduced and analyzed, including direct fresh air cooling, rotating wheel heat exchanger, heat pipe back rack and water-based free cooling system. Furthermore, the comparison among these free cooling systems is conducted to show their mechanisms, main features, energy saving effects and applicable situations respectively (Table 1). In practical applications, the cooling system design for data centers depends on various factors, such as indoor air quality requirement, local climatic conditions, energy saving demands, room space, capital investment and operation costs. This work is of significance in guiding the design of refrigeration systems with free cooling technologies for practical data centers.

Acknowledgements

This research is financed by China Scholarship Council (201706245001), Sichuan Science and Technology Program (17YYJC0994) and Sichuan University Post Doctor Research Program (2017SCU12020).

References

[1] Santiago, I. and Sergio, N. (2016) "Scheduling energy efficient data centers using renewable energy." *Electronics*, 71.5 (2016): 1-16.

[2] Sharma, N., Barker, S., Irwin, D., et al. (2011) "Blink: managing server clusters on intermittent power." *ACM SIGARCH Computer Architecture News*, 39.1 (2011): 185-198.

[3] Almoli, A., Thompsion, A., Kapur, N., et al. (2012) "Computational fluid dynamic investigation of liquid rack cooling in data centres." *Applied Energy*, 89 (2012): 150-155.

[4] Alfonso, C. and Giulio, P. (2015) "Cooling systems in data centers: state of art and emerging technologies." *Energy Procedia*, 83 (2015): 484-493.

[5] Zimmermann, S., Meijer, I., Tiwari, M.K., et al. (2012) "Aquasar: A hot water cooled data center with direct energy reuse." *Energy*, 43.1 (2012): 237-245.

[6] Ebrahimi, K., Jones, G.F. and Fleischer, A.S. (2014) "A review of data center cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities." *Renewable and Sustainable Energy Review*, 31 (2014): 622-638.

[7] Marcinichen, J.B., Olivier, J.A. and Thome, J.R. (2012) "On-chip two-phase cooling of data centers: Cooling system and energy recovery evaluation." *Applied Thermal Engineering*, 41 (2012): 36-51.

[8] Behzad, N.K., Mohammd, B.M., Seyed, M.H., et al. (2016) "Performance assessment of cooling systems in data centers: methodology and application of a new thermal metric." *Case Studies in Thermal Engineering*, 8 (2016): 152-163.

[9] Cho, J., Yang, J. and Park, W. (2014) "Evaluation of air distribution system's air flow performance for cooling energy savings in high-density data centers." *Energy and Buildings*, 68 (2014): 270–279.

[10] Tu, R., Liu, X.H. and Jiang, Y. (2013) "Performance comparison between enthalpy recovery wheels and dehumidification wheels." *International Journal of Refrigeration*, 36 (2013): 2308-2322.