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Effect of climatic conditions on energy consumption in direct fresh-air container data centers

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ABSTRACT

To examine the use of fresh-air cooling to reduce energy consumption in container data centers (CDCs) regardless of location, a prototype fresh-air-cooled CDC was constructed in a Tokyo suburb, and a year-long operating test was conducted. Fresh-air cooling of information technology (IT) equipment does not require energy for air conditioning, and can be operated at reduced cost and energy usage. However, the characteristics of fresh-air change throughout the year, which would make it difficult to maintain inside temperature and humidity of a server room at the set points. Also, some geographic locations may be unsuitable for CDCs cooled directly by fresh-air. In addition to fresh-air cooling, CDCs at these locations have been equipped with supplemental air-conditioning units such as air conditioners to control the internal temperature and humidity. To reduce energy usage, it is desirable to use energy conservation methods such as evaporative cooling and waste heat from IT equipment as supplemental air-conditioning because they can be more feasible in compact facilities than conventional air conditioners. Although data centers (DCs) that supplement fresh-air cooling with these air-conditioning methods are currently in operation, it is not clear whether these methods can be applied in any location regardless of the climatic conditions. Depending on the application, in particular, it is necessary to set up CDCs in urban suburbs, because large access latency for users may be required. To examine these issues, a fresh-air-cooled CDC was set up and evaluated for one year in a Tokyo suburb, under different climate conditions of existing fresh-air-cooled DCs. The results confirmed that evaporative cooling and the use of waste heat from IT equipment were sufficient to support direct fresh-air cooling even when the characteristics of fresh-air were outside the range of acceptable server settings. Moreover, this CDC realized an annual energy savings of 20.8% compared with the centers that use conventional air conditioning. Furthermore, the power usage effectiveness of this CDC was found to be 1.058 from the energy usage and was compared with that of existing direct fresh-air-cooled DCs which is located in the urban suburbs. The CDC near Tokyo exhibited similar energy savings to other DCs.

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1. Introduction

The ongoing expansion of cloud services over the Internet is expected to dramatically increase the energy consumption of data centers (DCs)—infrastructure facilities that house computer systems and other components required for providing services [1,2]. As information technology (IT) equipment becomes increasingly consolidated in DCs, the total electrical power consumed by the equipment will, of course, increase, but so will the power consumed by building facilities such as computer-room air conditioning (CRAC) and chillers. The total energy consumption of a DC is the sum of the energy consumption of IT equipment and that of facilities such as CRAC, uninterrupted power supplies, and lighting. The amount of power consumed by the facilities in a typical DC has now reached approximately 52% of the total energy consumption, and nearly half of that power is used for maintenance of IT equipment [3]. Therefore, it is very important to reduce the energy consumption of not only IT equipment but also the facilities. Current energy saving measures in DCs include increasing of power-feeding efficiency, raising of cooling efficiency by using aisle capping to prevent the mixing of inlet and outlet air

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[4,5], harvesting of exhaust heat produced by servers for use in air conditioning [6,7], and introducing of natural heat dissipation methods.

DC CRAC generally consists of heat exchangers, compressors, and blowers. Waste heat from servers is transported to the outside of the server room. CRAC uses a large amount of energy to transport and radiate a large quantity of heat. Use of cold fresh-air is expected to reduce the energy required for cooling without consuming power. The following two methods are primarily used for fresh-air cooling:

- *Indirect fresh-air cooling*: waste heat from IT equipment is transported to the heat exchanger, and this heat is transferred to cold fresh-air. Indirect fresh-air cooling systems have an additional benefit of isolating fresh-air paths from one another and having a low risk of introducing corrosive gases and other contaminants.
- *Direct fresh-air cooling*: fresh-air is taken directly into the server room by fans, and internal IT equipment system is cooled. Fresh-air is often pass through a filter that to remove corrosive gases and other contaminants to prevent malfunctioning the IT equipment. This system does not require large facilities as CRAC does, and uses only facility fans that supply fresh-air into the server room. Therefore, the initial cost of such systems can be reduced, while achieving a high energy saving performance. Thus, greater energy savings are expected from direct fresh-air cooling than indirect fresh-air cooling.

Not only DC cooling, but DC structure is also designed for energy-saving. Container data centers (CDCs) have recently attracted much attention for their high efficiency. Because servers in containers are installed densely in narrow spaces, energy consumption for transporting cooling energy can be reduced and higher cooling efficiency can be obtained in CDCs than in conventional DCs. CDCs also have many other advantages such as multistage investment, quick deployment, and easy transportability. CDCs have already been commercialized by some DC vendors.

Measures to reduce the energy consumption in DCs have been implemented separately. However, it is important these measure need to be integrated and optimized totally to achieve even greater energy savings. Achieving energy saving DCs is an environmental concern from the perspective of combating global warming and preserving energy resources.

2. Motivation

In a conventional CDC using CRAC, the internal temperature and humidity need to be maintained within their respective set points. However, CDC cooled by direct fresh-air is always affected by the climatic conditions. Moreover, it is not clear that the limit of climate conditions which are feasible for a direct-fresh-air cooling without CRAC. In this paper, our goal was to develop a direct-fresh-air-cooled CDC that could regulate the changes in the temperature and humidity of fresh-air beyond the conditions set for the server room by using supplemental air conditioning that does not depend on CRAC, depending on the local climate. Here, a small-scale supplemental air-conditioning system was chosen to control the energy consumption of CDC as much as possible, and it was operated so that its period of service was minimized. Furthermore, we investigated the total energy consumption of this CDC during one year of operation period and the performance was compared with a conventional CDC with CRAC.

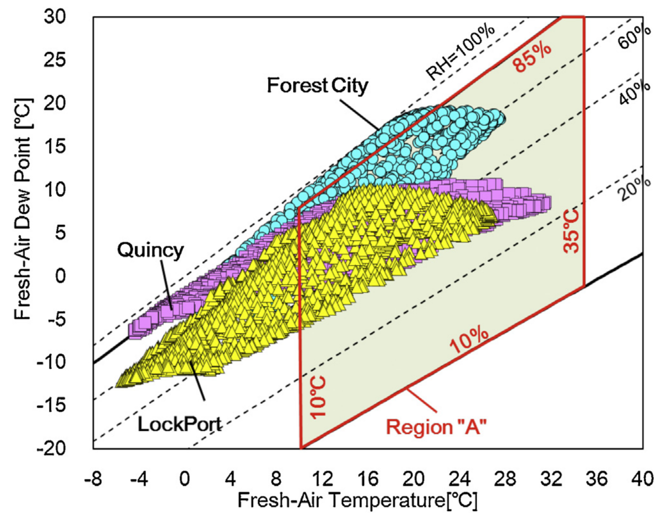

Fig. 1. Hourly climate data for 2010 observed at locations of direct fresh-air-cooled DCs.

2.1. Supplemental air conditioning

Air-conditioning methods that are expected to provide greater energy savings than conventional energy-intensive CRAC include the use of evaporative cooling and waste heat from IT equipment.

Evaporative cooling uses water evaporation to humidify fresh-air and evaporative latent heat of water to cool fresh-air. In an evaporative cooling system, fresh-air is passed through a high polymer seat called element, and the water in the seat is evaporated by fresh-air. The water absorbs heat from the fresh-air when it evaporates, decreasing the air temperature. In addition to the temperature decrease, fresh-air is also humidified by water evaporation, thus increasing the weight absolute humidity (SH) and relative humidity (RH) of fresh-air. Use of waste heat from IT equipment provides a warming system in which the fresh-air temperature rises when the exhausted waste heat is returned to the CDC. In addition, the RH of fresh-air decrease. This is very useful when the RH of the fresh-air is too high with respect to the desired server room conditions.

In this paper, direct fresh-air cooling was combined with evaporative cooling and circulation of waste heat produced by IT equipment to further reduce the energy consumption of CDCs compared with the conventional CDCs with CRACs.

2.2. CDC location

Direct-fresh-air-cooled CDCs that use above mentioned supplemental air-conditioning methods still have some problems due to the wider fluctuation of temperature and humidity of fresh air with respect to the location conditions, or in other words, the supplemental air conditioners cannot cope with the location conditions.

Fig. 1 shows an air diagram of the annual fresh-air temperature and humidity observed hourly in 2010 at three points in the United States (US) namely Lockport in New York, Quincy in Washington, and Forest City in North Carolina, where direct-fresh-air-cooled DCs, which use waste heat from IT equipment for heating and evaporative cooling, have been established [27–29]. The annual fresh-air temperature and humidity of some other places where CDCs have been set up are included within those observed at 3 areas. Typical server environmental conditions of temperature, humidity and maximum dew point (DP) are 10–35 °C, 10–85% (the region "A" in the figure) and 26 °C, respectively. The existing servers can withstand a maximum DP of 26 °C, a maximum RH of 90%, minimum RH of 10% and minimum temperature of 5 °C.

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