Study on Outside Air Cooling Systems Used in Data Processing Facilities

Iwao Yamaguchi¹, Makoto Koganei*², Tomonobu Goto³ and Masataka Tsushima⁴

¹ Graduate Student, Graduate School of Science and Engineering, Yamaguchi University, Japan
² Associate Professor, Graduate School of Science and Engineering, Yamaguchi University, Japan
³ Lecturer, Graduate School of Science and Engineering, Yamaguchi University, Japan
⁴ Student, Division of Perceptual Sciences and Design Engineering, Yamaguchi University, Japan

Abstract

It is currently estimated that with the increasing numbers of IT equipment, the amount of information data used by society will reach 200 times the present volume by 2025. Under such circumstances, there is an urgent requirement for cooling systems in server rooms with high density servers and compatibility with faster and larger servers along with high environmental efficiency. This survey carried out an experiment in which energy performance measurements with variance of outside air taken into the server room in a real size server room were taken. The results show that the cooling load of air conditioners could be approximately 90 percent less than that of the conventional air conditioning system for server rooms and that the overall energy consumption and COP are increased by 18 percent and 24 percent of the maximum respectively, compared to those of the conventional systems under maximum heat load conditions.

Keywords: energy saving; outside air cooling; data center; server

1. Introduction

Information Technology Data Processing Facilities such as data centers are playing more and more important roles in complying with such needs as the transmission and reception of a huge volume of data from the growing number of users such as ubiquitous computing service providers who have to cope with more sophisticated multifunctional personal digital assistants and their users. In addition, electronic power consumption and heat dissipation per floor area of buildings are also increasing year by year due to the increase in packaging density in IT equipment such as servers and storage devices that are installed in data centers, making data centers one of the large scale power consumers that cannot be overlooked as an insignificant constituent in society. In recent years, the numbers of IT equipment and information processing throughput have been progressively increasing and it is predicated1 that by 2025, it will be as large as 200 times the present throughout society as a whole. Under such a situation, it is urgently necessary for the air conditioning systems used in server rooms accommodating high-density servers to achieve systems with higher efficiency to help prevent global warming, in addition to supporting high-speed and large volume servers. An air recycling system was adopted in the present server room. This system supplies cool air into the room and air heated in the servers is cycled back into the air conditioner to cool the heated air and to supply the cooled air into the server room again. Thus, a lot of energy has to be consumed to cool the high temperature air. Since it is conceivable, for most days except hot mid-summer days, to use fresh air to cool the servers, systems that have the following mechanism can be used. In this system, fresh air is introduced into the server room, and only when the fresh air temperature is high, is the air cooled in the air conditioner, and the air heated in the server exhausted from the room to the outside without being cooled in the air conditioner. It is necessary to review this system with respect to such parameters as the cooling capacity of the system to cool fresh air and the optimum fresh air flow rate.

In this study, the energy saving performance of the system was investigated in experimental facilities that had the actual size of the outside air conditioning system of a server room.

2. Outline of Experiment

Fig.1. illustrates the flow of air in the system flow of the outdoor air cooling system that was investigated in this study. The heated air flowing out of the hot aisles, when returned to the Packaged Air Conditioner (referred to as the PAC hereinafter), is mixed with the fresh air to lower the temperature, allowing the PAC cooling load to be reduced.
The tops of the cold aisles are covered with ceilings (cold aisle capping). The system has a control function to maintain air balance between the air intake side and exhaust side while placing higher priority on the intake side.

Fig.2. shows the outline and layout of units in the server room used in the experiment. The actual servers were mounted on a part of the racks (i.e., one row of the rack) in place of the simulated load units.

Table 1. gives a list of the experimental conditions. One of the experiment parameters was the fresh air mixture ratio, and the experiment was carried out at the values of 25 percent (8 intake fans and 8 exhaust fans were operating), 12.5 percent (4 intake fans and 4 exhaust fans were operating), 6.3 percent (2 intake fans and 2 exhaust fans were operating), and 0 percent (no fans were operating).

The simulated heat dissipation (or simulated load) was another experiment parameter and the simulated load factors of 100 percent (600kW in terms of the simulated heat dissipation), 75 percent (450kW), and 50 percent (300kW) were used in the experiment. The temperature of air flowing out of the PAC was set at 18 degrees C. In order to calculate the energy saving achieved by the introduction of fresh air, the temperatures of air flowing in and out of the PAC as well as electric power consumption in the PAC and fan were measured. In addition, the temperature and humidity at various points in the server room shown in Fig.2. were measured to understand the thermal environment in the room. The air temperatures and humidities in each cold or hot aisle were measured at three heights (0.2, 1.0 and 1.9m) and five locations.

Temperature and humidity were measured with a small data logger (Hioki 3641 Data Logger) and electric power was measured with a clamp-on power tester (Hioki 3169-01 Clamp On Power HiTester). The experiment continued from November 3, 2009 to February 19, 2010.

The following 3 parameters were evaluated.

① PAC cooling load

Table 2. shows the theoretical design values of the PAC air inlet temperature and cooling load with no outside air intake. Table 3. gives the design outdoor air temperature. The PAC intake air temperature and blowout air temperature were measured, the PAC cooling load was calculated based on the PAC rated flow rate, and the measurements were compared with the theoretical design values.

② Total electric power consumption of the air cooling system

The total electric power consumption is a sum of the PAC compressor electric power consumption, electric power required for driving the PAC internal fans, and electric power required to drive the fresh air intake and exhaust fans.

③ System total COP

This is defined by the next equation: "(Cooling load of all the PACs + Sensible cooling rate by fresh air)/ (Power consumption of all the PACs + Power required to drive the fresh air intake and exhaust fans). The sensible cooling rate by fresh air was calculated from
the estimated exhaust temperature, the measured fresh air temperature, and the fresh air flow rate.

3. Experimental Results and Considerations

Fig.3. shows the changes in temperature and electric power consumption at different mixture ratios of fresh air. It was shown that when the fresh air mixture rate is 25 percent, the temperature remains less than the room temperature setting of 18 degrees C. The reason why is that, due to the low fresh air temperature, the intake temperature of the PAC located at the side of the room on which the air intake fans are installed is lower than the blowout temperature setting, and that the PAC is running in its blower mode operation. It is shown in the Figure that when the air mixture ratio was reduced to less than 25 percent, the system can control the temperature at around the temperature setting of 18 degrees C because the PAC intake temperature is higher than the blowout temperature setting and, that the electric power consumption is increased to drive the compressor. Compared with electric power consumption, it was confirmed that the consumption could be reduced even if the power consumption required driving air intake and exhausting fans because the PAC compressor was stopped or was inverter-controlled in its minimum operation mode.

Figs.4., 5. and 6. show the results of measurements at loads of 100%, 75% and 50% respectively.

Fig.4.(a) shows the relationships between PAC cooling load, outdoor air temperature and the volume of outdoor air intake of the entire system (a sum of the cooling load for 6 PACs at the air intake side, and that for 6 PACs at the air exhaust side).

Fig.4.(b) shows the relationships between electric power consumption, outdoor air temperature and the volume of outdoor air intake of the entire system (power consumption of all the PACs + power required to drive the air intake and exhaust fans).

Fig.4.(c) shows the relationships between system total COP, outdoor air temperature and volume of outdoor air intake.

Table 1. Experimental Conditions

| Volume of outdoor air intake [m³/h] (%) | 59,200 | 29,600 | 14,800 | 0 |
| Load [kW] (%) | (25) | (12.5) | (6.3) | (0) |
| Supply air temperature [°C] | 18 |

※ Ratio to total air volume of 12 units of PAC

Table 2. PAC Air Inlet Temperature and Cooling Load

| Load | Server heat dissipation | Temp. rise | PAC air inlet temp. | PAC cooling load *1 |
|------|-------------------------|------------|---------------------|---------------------|
| 100% | 6 kW x 100 unit 600 kW | 7.6        | 25.6               | 50.0               |
| 75%  | 6 kW x 75 unit 450 kW  | 5.7        | 23.7               | 37.5               |
| 50%  | 6 kW x 50 unit 300 kW  | 3.8        | 21.8               | 25.0               |

*Outdoor air intake = 0%
*Temperature rise =

Server heat generation rate (W)/(0.33 x 240,000 m³/h)

*PAC cooling load (W) =

0.33 x Temperature rise level x 20,000 m³/h

Table 3. Design Outdoor Air Temperature (PAC Cooling Load is Zero)

| Load | Outdoor air 25% | Outdoor air 12.5% | Outdoor air 6.3% |
|------|----------------|-------------------|-----------------|
| 100% | 10.4           | -4.7              | -35.1           |
| 75%  | 12.3           | 1.0               | -21.8           |
| 50%  | 14.2           | 6.6               | -8.5            |

Table 4. gives the energy saving at the "fresh air temperature when the PAC cooling load was based on the design values becoming zero" (under the maximum fresh air mixture ratio of 25 percent).

The values shown in this table indicate the maximum energy saving achieved in this system. When the load that could provide maximum energy saving was 100 percent, the PAC cooling load and consumption were reduced by approximately 90 percent and 18 percent, respectively. Also it is shown that the system total COP was increased by approximately 24 percent. The total electric power consumption of the air cooling system
(i.e., system electric power consumption in the table) was reduced by approximately 18 percent, 13 percent, and 6 percent relative to the power consumption when fresh air was not introduced when the load was 100 percent, 75 percent and 50 percent respectively.

Table 5. shows the mean relative humidity in col aisles in the server room during the experiment period. The relative humidity for the 9 days (8.2% of the total) were under the lowest level of the “allowable” range in the ASHRAE Guidelines \(^{3}\) (20 - 80%), and the relative humidity for the 77 days (70% of the total) were under the lowest level of the “recommended” range in the ASHRAE Guidelines (40% - 55%). Also, no impact

---

**Fig. 3.** Change in Temperature and Electric Power Consumption at Different Mixture Ratios of Fresh Air

**Fig. 4.(a)** Relation between PAC Cooling Load and Outdoor Air Temperature and Volume of Outdoor Air Intake (At a Load of 100 Percent)

**Fig. 4.(b)** Relation between Electric Power Consumption and Outdoor Air Temperature and Volume of Outdoor Air Intake (At a Load of 100 Percent)

**Fig. 4.(c)** Relation between System Total COP and Outdoor Air Temperature and Volume of Outdoor Air Intake (At a Load of 100 Percent)

**Fig. 5.(a)** Relation between PAC Cooling Load and Outdoor Air Temperature and Volume of Outdoor Air Intake (At a Load of 75 Percent)

**Fig. 5.(b)** Relation between Electric Power Consumption and Outdoor Air Temperature and Volume of Outdoor Air Intake (At a Load of 75 Percent)

**Fig. 5.(c)** Relation between System Total COP and Outdoor Air Temperature and Volume of Outdoor Air Intake (At a Load of 75 Percent)
caused by static electricity was observed in the actual servers during the experiment period.

4. Summary

The energy saving achieved by the fresh air cooling system used in server rooms with many high-density servers can be grasped in general from the experiment using the actual scale server room. In this study, fresh air was introduced from one side of the building and, if the air could be introduced from the opposite side, there would be further improvement in the energy saving. There were, during the experiment period, a considerable number of days when the humidity in the room became low, but no impact caused by static electricity was observed in the actual servers. However, it should be noted that this evaluation of dry conditions is based on the data obtained during a short experiment period, and thus it is prudent to investigate the relation between static electricity and lower humidity in the room due to fresh air cooling. The study to relax the humidity constraints for the data center is ongoing in ASHRAE, but as of now, the criteria for the constraints are still in a state of flux. The authors are planning to make a comprehensive assessment of the effectiveness of the fresh air-cooling system after studying the impact of the static electricity, quality of fresh air introduced, and other factors in detail.

References

1) Takeo Hoshino “New information age opened by green IT: For the realization of a sustainable IT society in harmony with environments” presented at the 22nd interactive meeting of the Executive Leaders Forum (2008) sponsored by the Research Institute of Information Technology and Management, Waseda University.

2) ASHRAE (2008): 2008 ASHRAE Environmental Guidelines for Datacom Equipment—Expanding the Recommended Environmental Envelope.