Indirect External Air Cooling Type Energy-Saving Hybrid Air Conditioner for Data Centers, "F-COOL NEO"

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ABSTRACT

To improve the energy efficiency of air conditioners in data centers, in which heat generation is dramatically increasing due to improved performance and higher-density of servers, systems that make use of outside air cold, which is natural energy, are being adopted. Fuji Electric has developed a hybrid air conditioner "F-COOL NEO" combining indirect external air cooling, which is less susceptible to the effect of dust and corrosive substances contained in external air, and vapor compression refrigeration cooling. F-COOL NEO automatically controls the operation ratio of the two types of cooling according to external air temperature and a cooling load. As a result of evaluation, it has been verified that high efficiency can be attained of the amount of power consumption throughout the year approximately 1/3 that of general air conditioners.

1. Introduction

In recent years, the amount of heat generated by servers used in data centers has increased dramatically as a result of the higher performance and higher density of the servers. The server-generated heat is typically cooled by air conditioning, and this creates a cooling burden throughout the year. In order to improve the energy efficiency of the air conditioning, the introduction of external air cooling using the cold energy of external air, which is natural energy, is being promoted. External air cooling is categorized as either a direct method in which the cold energy source of the external air is captured directly, or an indirect method in which the external air is passed through a heat exchanger to capture only the cold energy. Fuji Electric has developed the "F-COOL NEO" hybrid air conditioner that combines an indirect-type external air cooling (indirect external air cooling) system, which is less susceptible to moisture, dust and corrosive substances contained in the external air, with vapor compression-type refrigeration cooling.

The F-COOL NEO maximizes energy savings by automatically controlling the operating percentages of external air cooling and refrigeration cooling throughout the year according to the external air temperature that changes by season and by night and day, and according to the cooling burden, and is able to achieve high efficiency with an annual power consumption that is about one third of usual air conditioners.

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2. Features and Configuration

Table 1 shows the specifications of the F-COOL NEO. There are 2 models with rated cooling capacities of 25 kW and 40 kW.

Except for the time when starting up or when settings are changed, air can be supplied (blown) in the range of 18ºC to 35ºC with an accuracy of ±1 K with respect to the setting. Moreover, the air supply rate for the 25 kW model can be set in the range of 2,500 to 10,000 m^3/h and for the 40 kW model can be set in the range of 2,500 to 12,000 m^3/h. Additionally, the temperature control range can be controlled with greater accuracy than the previous ±2 K, and accordingly, if an upper limit value is defined and settings made so as not to exceed this value, then the temperature can be set to a higher value and energy can be conserved.

Figure 1 shows the configuration of the F-COOL NEO. The F-COOL NEO is an internal/external integrated unit that contains both an indirect external

Table 1 "F-COOL NEO" specifications

Item	Specification	
	FCA-25	FCA-40
Cooling method	Indirect external air cooling (antifreeze solution) + Compression refrigerator cooling (R410 A)	
Rated cooling capacity	25 kW	40 kW
Rated supply air flow	7,450 m^3/h (control range: 2,500 to 10,000)	8,500 m^3/h (control range: 2,500 to 12,000)
Supply air temperature setting	18 °C to 35 °C	
Supply air temperature accuracy	±1 K	
External dimensions	W1,200×D2,000×H2,500 (mm)	W1,200×D2,000×H2,700 (mm)

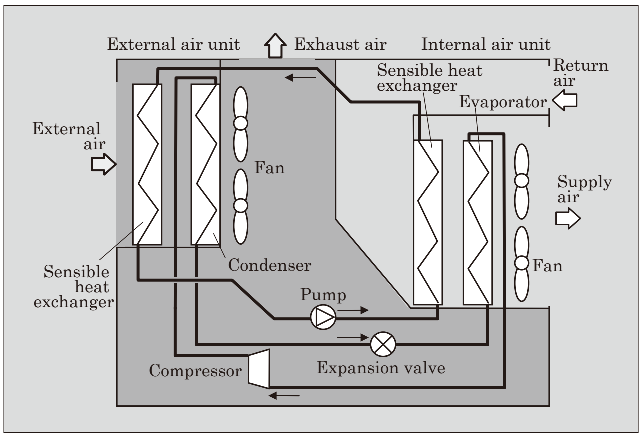

Fig.1 "F-COOL NEO" configuration

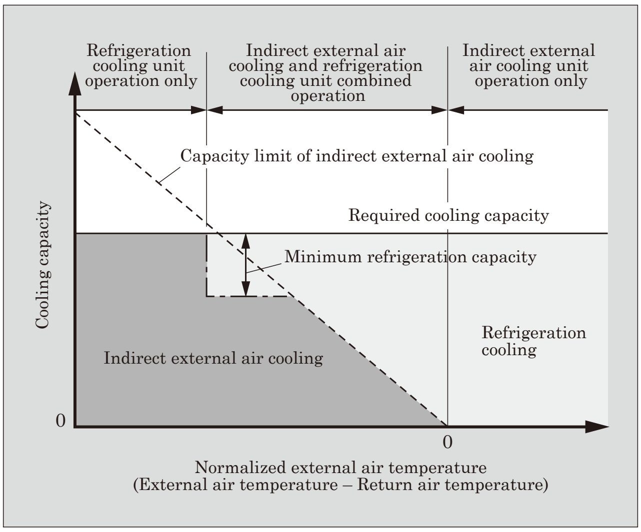

Fig.2 Schematic diagram of burden sharing for indirect external air cooling and refrigeration cooling

air cooling unit and a refrigeration cooling unit. The server-side air (internal air) and the cold energy source of air outdoors (external air) are separated inside the device, and there is no conduction of air. The indirect external air cooling unit provides both the internal air unit and the external air unit with a sensible heat exchanger, and brine coolant (antifreeze) is circulated by a pump to transport the external cold energy.

The refrigeration cooling unit operates to maintain the temperature of the supply air when the external air temperature is high and the capacity of the external air cooling is insufficient. The refrigeration cooling unit has an internal air unit that is provided with a vaporizer, and an external unit that is provided with a condenser, compressor and an expansion valve. Additionally, R410A is used as the refrigerant.

3. Operational Control to Realize Energy Savings

Indirect external air cooling has a high efficiency because it cools by the power of a pump and fan, without using a compressor. However, the cooling capacity is dependent on the external air temperature, and therefore the capacity decreases when the temperature of the external air increases. When the capacity of the indirect external air cooling unit is insufficient, the refrigeration cooling unit will operate to provide supplemental capacity, but the efficiency will decrease due to the operation of the compressor. Therefore, in order to realize energy saving operation with a minimal decrease in efficiency, automatic control is implemented to select an appropriate operating mode from among the multiple operating modes provided to support various operating conditions, and then the operation switches to the selected operating mode so as to maximally utilize external air cooling.

Figure 2 shows a schematic diagram of the burden sharing for indirect external air cooling and refrigeration cooling. The horizontal axis is the external air temperature normalized so that the external air cooling capacity becomes 0 when the temperature of the return air is the temperature of the external air. In other words, the capacity limit of external air cooling decreases as the temperature difference between return air and external air becomes smaller.

(1) Indirect external air cooling unit operation only mode

If the capacity of the indirect external air cooling unit is sufficient with regard to the cooling burden, the indirect external air cooling unit will operate by itself.

(2) Combined operating mode of the indirect external air cooling unit and the refrigeration cooling unit

If the capacity of the indirect external air cooling unit falls below the cooling burden, the refrigeration cooling unit compensates for the shortfall. However, because the refrigeration cooling unit of the F-COOL NEO does not have a mechanism for controlling the cooling capacity to the minimum capacity or less, the capacity of the indirect external air cooling unit is adjusted so as not to exceed the cooling burden.

(3) Refrigeration cooling unit operation only mode

Under the condition that the external air temperature is higher than the return air temperature and the cooling capacity cannot be provided by indirect external air, the refrigeration cooling unit will operate by itself.

One of the abovementioned operating modes (1), (2) and (3) will be selected automatically according to the cooling burden and the external air temperature, but the control of the devices will become discontinuous at the time when changing modes, and so that the temperature of the supply air does not fluctuate, multiple sub-modes with different control methods are provided within each operating mode.

4. Evaluation of Energy Savings

4.1 Test equipment

A characteristics evaluation of the F-COOL NEO was performed using the test equipment shown in

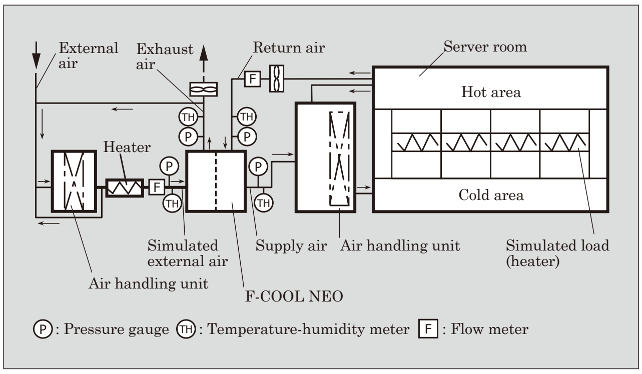

Fig.3 Test equipment

Figure 3.

At the internal air side, the amount of heat generated is controlled by a simulated load (heater) in a server rack installed in the server room, and the return air from the server room is fed to the F-COOL NEO and an air handling unit. A temperature-humidity meter and a pressure gauge are provided both before and after the F-COOL NEO. Additionally, a fan and a flow meter are provided upstream from the F-COOL NEO, and the external static pressure is maintained to be constant while the return air flow is controlled.

At the external air side, a simulated year-round external air condition is created by an air handling unit and a heater, and then fed to the F-COOL NEO. As in the case of the internal air side, a temperature-humidity meter and a pressure gauge are provided both before and after the F-COOL NEO. Additionally, a flow meter is provided upstream from the F-COOL NEO, and the flow rate of an air handling unit for external air is adjusted to maintain the external static pressure at a constant value, and to control the simulated external air flow rate.

Power consumption is measured by connecting a power meter to the power supply pin of the F-COOL NEO, and the cooling capacity is calculated from the air humidity and flow rate at the internal air side inlet and outlet.

4.2 Characteristics of external air cooling

Figure 4 shows the result of measurements of the cooling capacity of external air cooling by itself under the condition where the return air temperature, supply air flow rate and external air flow rate are all constant. The measurement results of a sensible heat exchanger alone in an equivalent evaluation apparatus are also shown in the figure.

Under the condition of constant return air temperature, the cooling capacity varies linearly with the external air temperature, and the cooling capacity drops as the external air temperature rises. Accordingly, when the external air temperature is high and the external air cooling capacity is low, the capacity must be supplemented by the refrigeration cooling unit in order to maintain the rated cooling capacity.

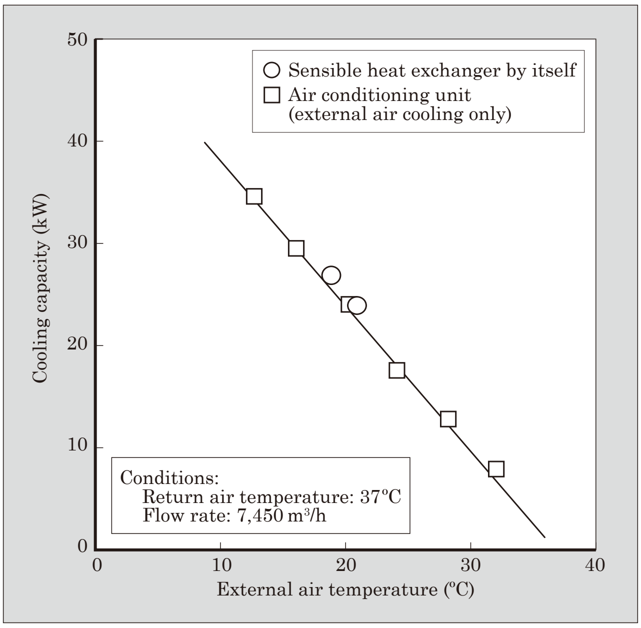

Fig.4 External air cooling characteristics

4.3 External air temperature dependence

Using simulated external air, the external air temperature was varied and characteristics were measured. While operating at the rated cooling capacity of 25 kW, the power consumption of all the equipment was measured, and coefficient of performance (COP) was computed from Equation (1).

$$\mathrm{COP} = \frac{\text{Cooling capacity}}{\text{Equipment power consumption}} \quad \cdots\cdots\cdots (1)$$

Cooling capacity: Computed from the inlet/outlet enthalpy difference at the internal air side

Equipment power consumption: 15 minute average value of the equipment power consumption

Figure 5 shows the power consumption and the COP calculation results and measurement results. At 19ºC or less, the indirect external air cooling unit operates alone, and the power consumption is about one fifth that of refrigeration cooling unit operation only at 37ºC or higher. In the intermediate temperature range, there is combined operation of the indirect external air cooling unit and the refrigeration cooling unit, and the power consumption is also in-between that of indirect external air cooling operation only and refrigeration cooling operation only, and the advantageous effect of external air cooling is obtained. Moreover, the power consumption and COP calculation results are nearly the same as the measured values.

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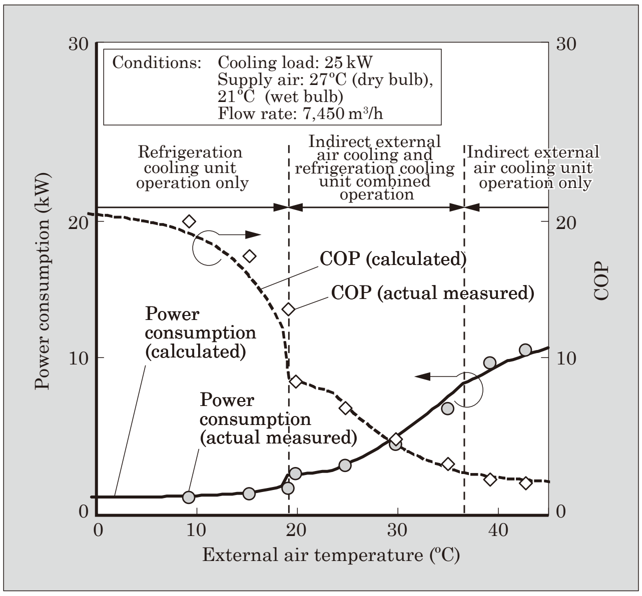

Fig.5 Power consumption, COP calculation results and measurement results (FCA-25)

5. Continuous operation evaluation at simulated data center

5.1 Evaluation equipment

As the evaluation equipment, a module-type simulated data center and the F-COOL NEO were installed in combination, and continuous operation was carried out in a semi-external environment (see Fig. 6). The heat source was controlled by a simulated load (heater) provided inside the simulated data center, and the total amount of heat was cooled with the F-COOL NEO.

5.2 Operating mode switching evaluation

When switching between indirect external air cooling unit operation only and combined operation of the indirect external air cooling and refrigeration cooling units, as shown in Fig. 2, the share of the cooling capacity becomes discontinuous, and therefore a submode that changes the method of device control is provided to smooth the capacity sharing. Figure 7 shows the transition from indirect external air cooling operation only to combined operation at a rated load. When the external temperature rises, establishing the condition for transitioning to the combined operation mode, the compressor starts operating, and at that time the cooling capacity is controlled by the rotating speed of the pump. The temperature of the supply air becomes slightly disturbed for about 15 minutes after transitioning, but the accuracy is maintained within 1K.

Figure 8 shows the transition from combined operation to indirect external air cooling operation only at a rated load. When the external air temperature

Fig.6 Evaluation equipment

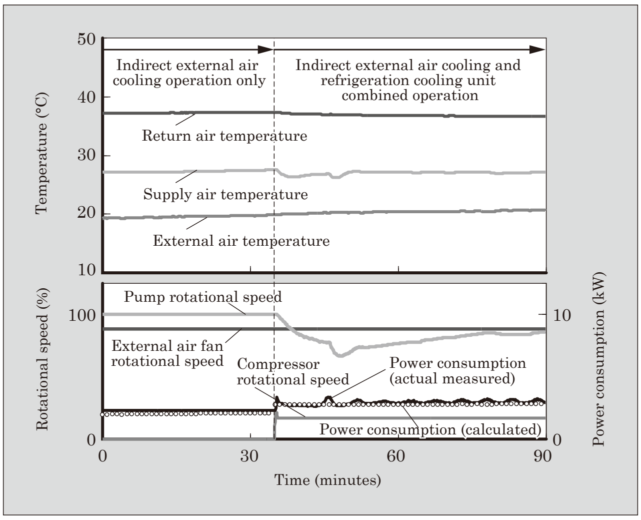

Fig.7 Operation mode switching (Indirect external air cooling unit operation only → Combined operation)

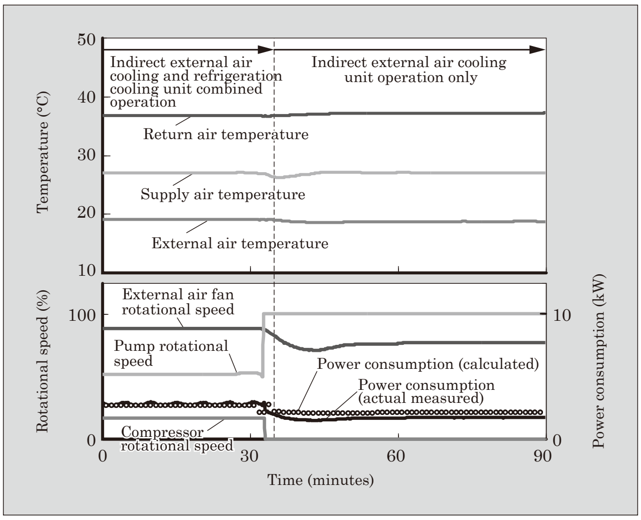

Fig.8 Operating mode switching (Combined operation → Indirect external air cooling unit operation only)

drops, establishing the condition for transitioning to the indirect external air cooling operation only mode, the rotating speed of the pump is controlled and then the compressor is stopped, and at that time the cooling capacity is controlled by the rotating speed of the external air fan.

The change in power consumption while transitioning operating modes and the values computed for each one-minute are shown in Figs. 7 and 8. The measured values are on close agreement with the calculated values, and the computation method is also considered to be effective for time-series variations.

6. Evaluation of annual efficiency

6.1 Measurement of power consumption

Figure 9 shows the changes in power consumption at rated load operation during a summer day in the simulated data center. The power consumption fluctuates with changes in the external temperature during the day, but the temperature of the supply air is maintained constant. In addition, the power consumption estimated from the hourly external air temperature matches the trend of the measurements. Table 2 compares the measured and estimated values of power consumptions. The measurement of the amount of power consumed in one day closely agrees with the estimated value.

6.2 Estimation of annual efficiency

Figure 10 shows the calculation results of annual energy consumption using 2009 hourly meteorological data from the Tokyo observatory of the Japan Meteorological Agency. Additionally, Table 2 shows the calculation results of the annual COP using Equation (2). The annual COP for the Tokyo region was 10.4.

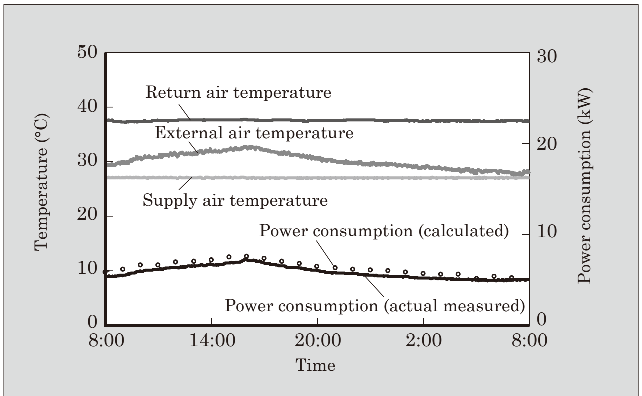

Fig.9 Power consumption during rated load operation for one summer day

Table 2 Power consumption and COP

		Thermal load (GJ)	Power consumption	COP
Daily operation (2009 summer, Tokyo)	Measured	2.20	117 (kWh/day)	5.2
	Calculated	2.16	126 (kWh/day)	4.8
Annual operation (2009 , Tokyo)	Calculated	788	21,009 (kWh/year)	10.4

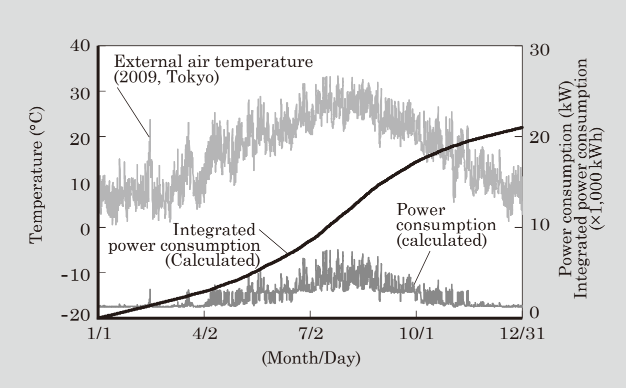

Fig.10 Power consumption during rated operation in 2009

$$\text{Annual COP} = \frac{\text{Annual amount of cold energy generated}}{\text{Annual power consumption}} \quad \cdots\cdots (2)$$

This value is significantly larger than the annual COP in the range of 3 to 4 of a package air conditioner for general computation use. By using the F-COOL NEO, it was confirmed that the amount of power consumption could be reduced to about one third.

7. Application to Modular data centers

When constructing a data center, the module concept is a key point in terms of minimizing the initial investment and achieving early operation, energy savings and scalability. In order to reduce the investment burden and shorten the construction period (3 months) through step-by-step construction with a standardized housing, air conditioning, power supply and the like, Fuji Electric has developed and commercialized a “built-in block system” modular data center. This module is configured from a server block, UPS block, power receiving block and an electricity self-generating block. Figure 11 shows the server block and the UPS block. The server block is configured from a server rack hous-

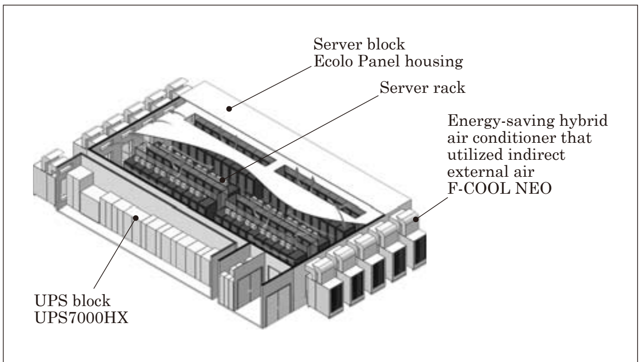

Fig.11 Modular data center

ing made from “Ecolo Panel” prefabric building material that Fuji Electric used in constructing convenience stores, electric power distribution equipment that distributes power to the server rack via a bus duct, and the F-COOL NEO that cools the server load. This basic block can house 80 server blocks and is provided with high thermal insulation and high earthquake resistance (980 Gal). The F-COOL NEO is installed in the outer periphery of the housing, and the cooling air supplied to the server rack is vented out from the interior walls of the housing, and air that has been warmed by the server rack is returned from above the ceiling to the F-COOL NEO. The UPS block use a Fuji Electric-made UPS “UPS7000HX” having an efficiency of 97% to boost the efficiency of the power supply equipment. Additionally, the monitoring and control of basic modules is performed by the data center energy management system “F-DMS,” and labor savings and remote operation are achieved. Investment can be optimized by gradually added equipment in response to the demand for these modules. Figure 12 shows a bird’s-eye view of a data center in which four sets of basic modules were installed.

Fig.12 Bird’s-eye view of data center site

8. Postscript

This paper has described the “F-COOL NEO” hybrid air conditioner that combines an indirect external air cooling unit which utilizes natural energy with a vapor compression-type refrigeration cooling unit. This air conditioner is not only for data centers and is also suitable for the precision machining field, and the food and pharmaceutical fields in which cooling air conditioning with clean air is needed throughout the year.

In the future, we intend to continue working to achieve energy savings through optimal operation control in response to fluctuations in the cooling load.

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