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Evaluation of Cooling Energy Consumption Varying Economizer Control and Heat Generation Rates from IT Equipment in Data Center

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Abstract A data center stores and manages internet data. The data center is mainly comprised of IT equipment, cooling systems, and other components. IT equipment is used for storing and processing internet data, generating heat during use. If the heat generated by IT equipment is not removed, it can cause malfunctions, and cooling systems are used to remove this heat. Cooling systems account for more than 40% of the total energy consumption and reducing cooling energy can reduce the overall energy consumption of the data center. Therefore, analyzing the cooling energy consumption according to heat generation changes caused by IT equipment in the data center is necessary. This study analyzed the impact of heat generation changes in IT equipment on cooling energy consumption. Additionally, three different economizer control methods were applied to select the optimal economizer control method. To achieve this, a data center model with economizer systems applied was developed using data measured from IT equipment and cooling systems. As a result, as the operation rates of IT equipment increased from minimum to maximum, the annual energy consumption for each case increased by approximately 11.7%. The economizer analysis showed that the energy savings were greatest when dry bulb temperature control was applied, but it did not meet the operation environment of the IT equipment. Therefore, it was determined that economizer control to meet the operation environment of IT equipment is required to be enthalpy-based.

Key words Data center, IT equipment, Cooling system, Cooling energy consumption, Economizer

1. INTRODUCTION

A data center, a facility equipped with telecommunications system, computers, and storage among other IT equipment, as well as cooling system, is tasked with the management of data storage, processing, and transmission. The recent growth in the AI market has led to an increase in internet data, causing the energy consumption of the data center to rise to 1,762 MW in 2022, with projections indicating it may reach 49,397 MW by 2029 [1]. This surge in energy consumption calls for more effective energy management strategies in the data center. The primary consumers of energy within these facilities are IT equipment and cooling system. 99% of the energy consumed by IT equipment is transformed into heat, which can cause operational issues in data center servers. As cooling system account for approximately 40% of total energy consumption in the data center, reducing cooling energy is essential [2]. Consequently, research is being conducted to reduce cooling energy in data center.

Kim et al. implemented an economizer cooling system that introduces outside air into the data center. They evaluated the system's performance based on various operation methods, including control of the outside air cooling system, setting supply air temperature, and design airflow changes [3]. Their results showed that cooling energy consumption decreased by up to 25% as the set supply air temperature increased, resulting in longer durations of outside air introduction. Additionally, a reduction in design airflow led to a decrease in fan energy consumption by approximately 15-25%. Kim et al. assessed the cooling energy consumption of the Water Side Economizer (WSE) system in the data center based on its chilled water piping configuration [4]. They analyzed the energy consumption and Free Cooling duration of the WSE system according to the local climate in Seoul, Busan, Daegwallyeong, and Chuncheon. Their analysis indicated that, compared to central cooling, the energy consumption of the WSE system decreased by 10.9-13.7%. Furthermore, the energy consumption of the WSE system decreased by up to 19.5% as the range of outside wet-bulb temperature decreased.

Previous research on data center cooling system has focused on reducing cooling energy through adjustments in supply air temperature, design airflow changes, and the application of outside air cooling. However, these studies did not consider the variations in heat output from IT equipment, often randomly setting the heat emission based on fixed and maximum heat outputs. Since the cooling load in the data center is significantly influenced by the heat output from IT equipment, it is imperative to consider this factor. Additionally, a review of prior studies revealed research that applied economizers to reduce cooling energy in the data center. This study aims to select the optimal economizer control method for implementing an economizer in the existing data center model. Therefore, this research utilized measured data from the A Institute data center in Daejeon to develop a model that reflects the variations in IT equipment heat output and categorized standard IT equipment operation rates into minimum, average, and maximum. Furthermore, the study combined an economizer system with the existing system to analyze the cooling energy consumption based on the operation rates of IT equipment.

2. METHODOLOGY

2.1 Overall research process

This study was conducted in four phases: development and verification of the simulation model, creation of IT equipment operation rates, application of economizers, and analysis of results (see Figure 1).

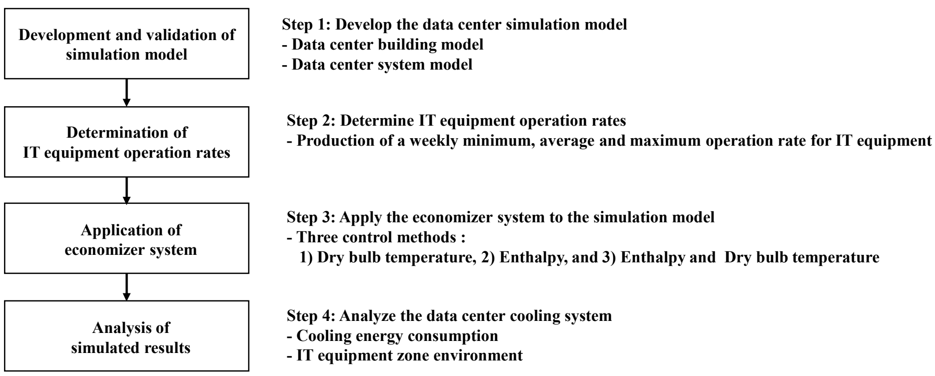


Figure 1. Overall research process

The first phase involved the development and verification of the simulation model. To create a building model similar to the actual data center located at A Institute, Sketch-Up and the simulation tool EnergyPlus were utilized [5]. The second phase, the creation of IT equipment operation rates, leveraged the characteristic that 99% of the energy consumption of IT equipment is converted into heat. The operation rates for IT equipment from April to July were normalized based on measured energy consumption and applied in the IT equipment operation rates field in EnergyPlus. For the annual simulation analysis, IT equipment energy consumption measured over four months was categorized into weekly minimum, average, and maximum to construct the rates. Three sets of operation rates were established for IT equipment: maximum, average, and minimum. The minimum operation rates ranged from 0.75 to 0.82, the average operation rates from 0.86 to 0.89, and the maximum operation rates from 0.93 to 1.

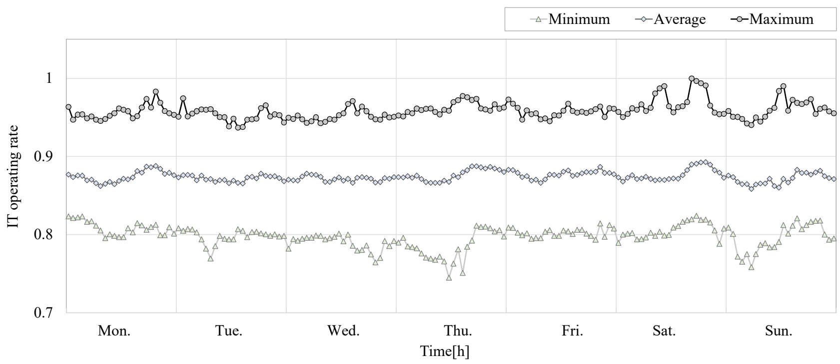


Figure 2. Minimum, average, maximum operation rates of IT system

In the third phase, economizer system were applied to the verified simulation model to reduce cooling energy. Three economizer control were implemented: dry bulb temperature control, enthalpy control, and a combined control of dry bulb temperature and enthalpy. The fourth phase involved analyzing the cooling energy consumption and the real environment conditions based on the economizer control methods and IT equipment operation rates. The real environment analysis evaluated whether the range of relative humidity entering the IT equipment servers, when economizer control methods were applied, met the standards provided by ASHRAE TC 9.9. Table 1 presents the operation environmental conditions for IT equipment according to the ASHRAE TC 9.9 environmental class. Class A1 represents a grade where environmental factors are strictly controlled, including computer storage facilities and enterprise servers. Class A2 to Class A4 allow for partial control over the operation environmental factors of IT equipment, including volume servers, computer storage facilities, personal computers, and workstations [6].

Table 1. Data center operation conditions according to environmental class

Class	Dry bulb temp. [°C]	Dew point temp. [°C]	Relative humidity [%]
Recommended			
A1 to A4	18 to 27	-9 to 15	50 or 70
Allowed			
A1	15 to 32	-12 to 17	8 to 80
A2	10 to 35	-12 to 21	8 to 80
A3	5 to 40	-12 to 24	8 to 85
A4	5 to 45	-12 to 24	8 to 95

2.2 Data center simulation modeling

The data center simulation model for this study was constructed based on data from A Institute, including insulation, real heat environment, and specifications. This model encompasses both the data center envelope and the internal layout. Figure 3 illustrate the concept diagram of the data center simulation model, and Table 2 presents the basic settings of the simulation model.

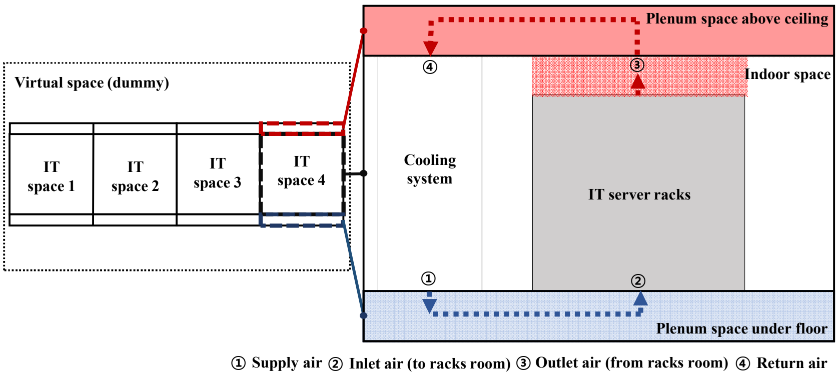


Figure 3. Schematic diagram for data center model

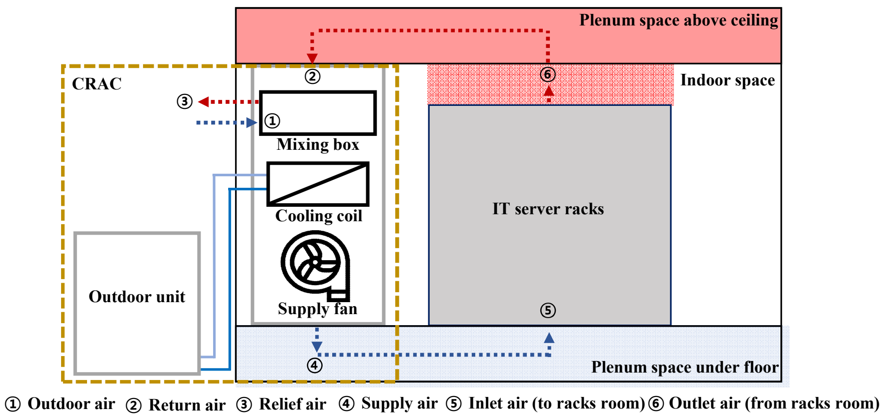


Figure 4. Schematic diagram for data center economizer simulation model

Table 2. Simulation modeling parameters

Input parameters				Values
Building	IT space	Type		Data center
		U-value	Wall	0.34 $W/m^2 \cdot K$
			Ceiling	0.21 $W/m^2 \cdot K$
			Floor	0.29 $W/m^2 \cdot K$
		Space set temp.		24 ± 1 ℃
	Virtual space	Space set temp.		20 ℃
	Location			Daejeon, South Korea
	Weather data for verification			KMA (Korea meteorological administration)
	Weather data for energy analysis			IWEC2 (International weather for energy calculations 2.0)
	Simulation run period for verification			4.16 ~ 7.30
	Simulation run period for analysis			One year
System	Cooling	Type		Air cooled type CRAC
		Fan efficiency		0.641
		Cooling coil capacity		30 RT
		Supply set temp.		14 ℃
	IT	Maximum IT load per space		75.5 kWh

The building model comprised four spaces housing IT equipment (IT spaces) and one surrounding space (Virtual space). The Virtual space, set to constantly maintain 20°C, reflected the actual environment of the IT spaces within the building. The cooling in IT spaces was implemented through a floor extraction method, using an air-cooled CRAC (Computer Room Air Conditioner). The CRAC, consisting of cooling coil and supply fan, was specified to match the real system. A single cooling system was installed in each IT space, with cooled air from the CRAC being distributed through the floor plenum (Supply air point) to server racks in IT equipment (Inlet air point), and circulating via the ceiling plenum (Outlet air point, Return air Point). The supply air temperature and the indoor temperature within IT spaces were set at 14°C and 24°C, respectively, mirroring the actual operation conditions at A Institute. The maximum heat emission from IT equipment located in one IT space is 75.5 kWh/space. The physical properties of the structural elements in IT spaces, such as ceilings, floors, internal, and external walls, were set identical to those at A Institute. The simulation verification period spanned from April 16 to July 30, the period for which actual measured data was available, and the simulation analysis period was set for one year. Meteorological data from the Daejeon regional Meteorological Administration was used for verification, and IWEC2 (International Weather for Energy Calculations 2.0) Daejeon weather data, produced by ASHRAE, was employed for simulation analysis. The validated model incorporated an economizer system, as depicted in Figure 4.

The air flow of the economizer cooling system involves mixing outdoor air (OA) with return air (RA), and the unmixed air is exhausted outside (Relief air). The mixed air passes through the cooling coil and blower, then is supplied to the floor plenum space (SA; Supply air), entering IT Space (Inlet air), passing IT equipment (Outlet air), and ventilated.

3. DATA CENTER MODEL VALIDATION

This study developed a data center simulation model for evaluating cooling energy consumption using economizer control methods and validated the model using measured IT equipment and cooling energy consumption. To enhance the accuracy of the simulation model, meteorological data measured at a point 1.3 km away from A Institute were utilized [7]. The legitimacy of the developed simulation model was confirmed through the ASHRAE Guideline 14 [8]. ASHRAE Guideline 14, Cv(RMSE) and NMBE, stipulate that hourly data should have a Cv(RMSE) less than 30%, and NMBE less than 10%, while monthly data should be less than 10% and 5%. The simulation model was validated using the ASHRAE Guideline 14. Hourly data for IT equipment indicated a Cv(RMSE) of 1.89×10^{-12}% and an NMBE of 3.5×10^{-9}%. The monthly data showed a Cv(RMSE) of 4.0×10^{-11} and an NMBE of 3.9×10^{-9}%, satisfying ASHRAE Guideline 14. The cooling system's hourly data showed a Cv(RMSE) of 13.1% and an NMBE of 0.2%, and the monthly data indicated 9.8% and 1.5%, respectively, meeting ASHRAE Guideline 14 (see Table 3). Therefore, the data center simulation model developed in this study showed energy consumption values for IT equipment and cooling system similar to actual measured data, confirming it as a validated model.

Table 3. Verification results of IT equipment and cooling system

System	Verification method	Hourly Verification result	ASHRAE Guideline 14	Monthly Verification result	ASHRAE Guideline 14
IT	Cv(RMSE)	1.9×10^{-12} %	< 30 %	4.0×10^{-11} %	< 10 %
	NMBE	3.5×10^{-9} %	< 10 %	3.9×10^{-9} %	< 5 %
Cooling	Cv(RMSE)	13.1 %	< 30 %	9.8 %	< 10 %
	NMBE	0.2 %	< 10 %	1.5 %	< 5%

4. APPLICATION OF ECONOMIZER

This section applied economizer control, which introduces outside air for cooling, to a data center simulation model reflecting IT equipment heat emission, for energy savings. The applied economizer in the developed model was controlled by the dry bulb temperature and enthalpy of outside air. The range for introducing outside air through economizer control based on dry bulb temperature is set from 1°C to 18°C, and for enthalpy-based control, it is set above 1°C and below 29 kJ/kg. The standards for the range of outside air introduction based on dry bulb temperature and enthalpy were set considering the cooling energy consumption and the relative humidity recommendations provided by ASHRAE TC 9.9, reflecting the enthalpy at 60% relative humidity (see Table 4).

Table 4. Simulation cases used for energy simulation

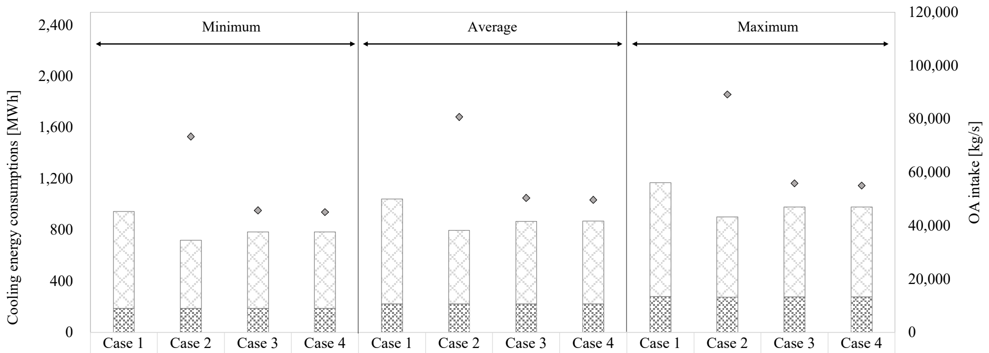
Case	Control method	OA inlet dry bulb temp. range	OA inlet enthalpy range
Case 1	Cooling system without economizer	-	-
Case 2	Cooling system with dry bulb temp. economizer	1-18 ℃	-
Case 3	Cooling system with enthalpy economizer	> 1 ℃	< 29 kJ/kg
Case 4	Cooling system with enthalpy and dry bulb temp. economizer	1-18 ℃	< 29 kJ/kg

5. RESULT ANALYSIS

5.1 Cooling energy consumption

5.1.1 Annual Energy consumption

This section presents the analysis results of annual cooling energy consumption in the data center, considering the operation rates of IT equipment (i.e., minimum, average, maximum operation rates) and different economizer control methods (i.e., Case 1 to Case 4) (see Figure 5).



	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Total	944	718	784	785	1,042	797	867	869	1,168	902	978	979
□ Coil	755	532	596	598	818	576	645	647	889	626	701	703
⊠ Fan	189	187	187	187	224	221	222	222	280	276	276	276
◇ OA intake	No intake	73,361	45,694	45,025	No intake	80,739	50,395	49,665	No intake	89,158	55,815	55,016

Figure 5. Annual cumulative cooling energy consumption

Initially, changes in the operation rates of IT equipment directly impacted the annual energy consumption of the data center. As shown in Figure 5, when the operation rates of IT equipment increased from minimum to average, and then to maximum, the annual energy consumption for each case increased by about 11.7%. This indicates that the increased heat emission due to higher operation rates of IT equipment influenced the energy consumption of the cooling system. Under the same operation rates conditions for IT equipment, the annual energy consumption was highest in Case 1. This suggests that applying economizer control can help reduce annual energy consumption. The cooling energy consumption saw over 99% energy savings in the coil due to the introduction of cold air through the economizer, and the fan energy consumption showed less than 1% difference from Case 1 to Case 4. Moreover, the cooling energy consumption in cases applying economizer control showed the lowest in Case 2 and the highest in Case 4. This is attributed to the fact that the amount of outside air introduced in Case 2, which controls only dry bulb temperature, was 37.6% more than in Case 3 and 38.5% more than in Case 4, thus reducing the operation time of cooling.

5.1.2 Seasonal cooling energy consumption

This section analyzed the cooling energy consumption and the amount of outside air introduced for each case, segmented by season. The seasons were divided into cooling season (summer), heating season (winter), and intermediate seasons (spring, autumn), with the heating season comprising January, February, March, and December; the cooling season comprising June, July, and August; and the intermediate seasons comprising April, May, September, October, and November.

Figure 6 shows a graph of the monthly distribution of outside dry bulb temperature and enthalpy based on IWEC2 weather data for the Daejeon. Figure 7 displays the seasonal cooling energy consumption and the amount of outdoor air intake.

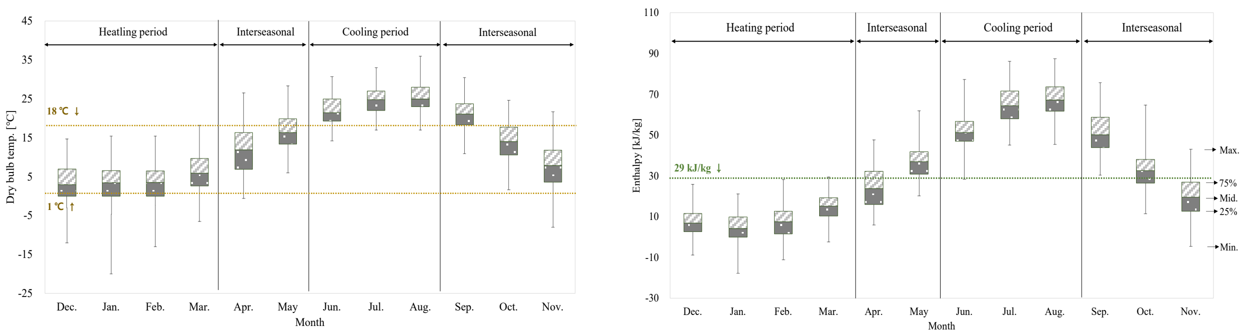


Figure 6. Monthly OA dry bulb temp. and enthalpy range

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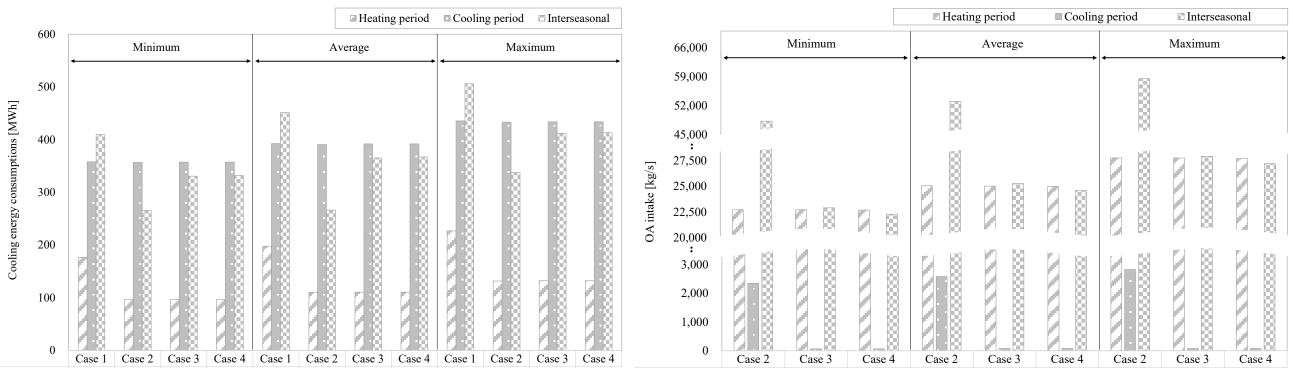


	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Heating period	177	96	96	96	198	110	110	111	227	132	132	132
Cooling period	358	357	357	357	392	391	392	392	435	433	434	434
Interseasonal	409	266	330	332	452	267	365	367	506	337	412	413

	Case 2	Case 3	Case 4	Case 2	Case 3	Case 4	Case 2	Case 3	Case 4
Heating period	22,729	22,728	22,679	25,051	25,049	24,997	27,787	27,785	27,726
Cooling period	2,353	66	66	2,590	72	72	2,837	78	78
Interseasonal	48,278	22,901	22,280	53,098	25,273	24,596	58,534	27,953	27,212

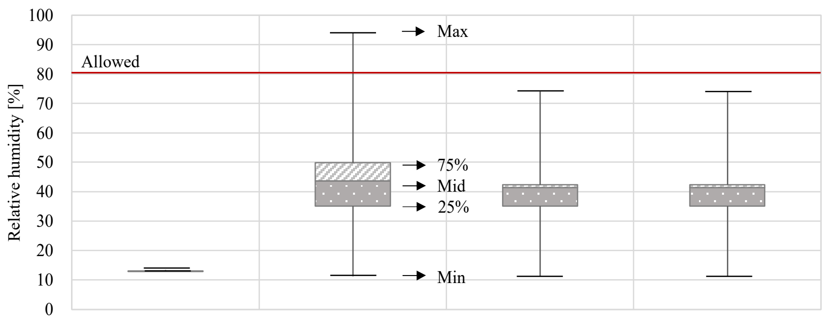
Figure 7. Cooling energy consumption and OA intake

During the heating season, there were no days when the outside dry bulb temperature exceeded the maximum indoor introduction standard of 18°C, but it was introduced indoors when it was above the minimum standard of 1°C. The enthalpy standard for possible outside air introduction, below 29 kJ/kg, was met for 4 hours in June, with enthalpy control being reflected for 4 hours over four months. Consequently, the amount of outside air introduced in Case 2, Case 3, and Case 4 showed less than a 1% difference, being 22,679 kg/s to 22,729 kg/s at the minimum operation rates, 24,997 kg/s to 25,051 kg/s at the average operation rates, and 27,726 kg/s to 27,787 kg/s at the maximum operation rates. With the difference in outside air introduction being less than 1%, the cooling energy consumption during the heating season showed a difference of less than 1 MWh, or the same values, being each 96

MWh, 110 MWh to 111 MWh, 132 MWh. Compared to Case 1, where outside air was not introduced, there was an energy reduction of 42% to 46%. During the cooling season, the outside dry bulb temperature ranged from 14°C to 35°C, and the time range for possible outside air introduction was 97 hours. The time when outside air enthalpy was below 29 kJ/kg was 2 hours in June, with no time for possible outside air introduction in July and August. The amount of outside air introduced in Case 2, which controls based on dry bulb temperature, was 2,353 kg/s to 2,837 kg/s, and for Case 3 and Case 4, which control based on enthalpy, it was 66 kg/s to 78 kg/s. Consequently, the cooling energy consumption showed less than a 1% difference compared to Case 1, where outside air was not introduced. During the intermediate seasons, the outside dry bulb temperature ranged from -8°C to 31°C. The time when the outside dry bulb temperature was suitable for indoor introduction, above 1°C and below 18°C, was 587 hours in April, 478 hours in May, 166 hours in September, 576 hours in October, and 606 hours in November. The time when outside air enthalpy was suitable for indoor introduction, below 29 kJ/kg, was 413 hours in April, 121 hours in May, 0 hours in September, 248 hours in October, and 483 hours in November. The time for outside air introduction based on monthly outside dry bulb temperature was at least 65 hours to a maximum of 357 hours more than the time for introduction based on outside air enthalpy. Therefore, the amount of outside air introduced in Case 2, which controls based on dry bulb temperature, was about 52% to 55% more than in Case 3 and Case Case 4, which control based on enthalpy. Additionally, the cooling energy savings rates in Case 2 was 33% to 41% compared to Case 1 and less than the energy consumption in Case 3 and Case 4.

5.2 Operation environment of IT equipment

This section evaluated the indoor environment of the data center when operation the cooling system. Data center IT equipment can cause short circuits or corrosion when exposed to high humidity. Therefore, ASHRAE TC 9.9 presents relative humidity standards for the operation environment of IT equipment (see Table 1). When analyzing the operation environment of IT equipment for each case, Case 1, which did not use an economizer, did not exceed the recommended range of relative humidity, and the maximum relative humidity in Case 2 was 93%, only satisfying the A4 allowance standard. The maximum relative humidity in Case 3 and Case 4 was 73%, differing by about 3% from the recommended relative humidity standard of 70%, but satisfying the allowance standards for A1 to A4 grades (see Figure 8). Therefore, in the analysis area of this study, using an economizer in data center cooling system did not satisfy the recommended values, but satisfied the allowance values when considering relative humidity.



	Case 1	Case 2	Case 3	Case 4
Maximum	13.2%	93.9%	73.3%	73.3%
75th percentile	12.9%	49.9%	41.7%	41.7%
Median	12.8%	43.6%	41.4%	41.4%
25th percentile	12.7%	35.1%	35.0%	35.1%
Minimum	12.5%	11.3%	11.3%	11.3%

Figure 8. Resultant relative humidity by simulated cases

6. CONCLUSION

This study developed a simulation model utilizing actual measured data to analyze the cooling energy consumption of the data center, considering the heat emission from IT equipment. Additionally, the verified simulation model applied an economizer to evaluate cooling energy consumption and the operation environment of IT equipment. The results of this study are as follows:

(1) The developed simulation model met the simulation model verification standards set by ASHRAE, with hourly data Cv(RMSE) less than 30%, NMBE less than 10%, and monthly data less than 10% and 5%.

(2) As the operation rates of IT equipment increased from minimum to average, and then to

maximum, the annual energy consumption for each case increased by about 11.7%. This indicates that the increased heat emission due to higher operation rates of IT equipment influenced the energy consumption of the cooling system.

(3) The analysis of cooling energy consumption by season showed that when introducing outside air, the cooling energy consumption decreased by up to 46% in the heating season, less than 1% in the cooling season, and 41% in the intermediate seasons, depending on the time and amount of outside air introduction.

(4) Economizer control based on dry bulb temperature showed the highest energy savings rates, but did not comply with the recommended relative humidity operation standards for A1 to A4 Class IT equipment set by ASHRAE, nor the allowance standards for A1 to A4 Class IT equipment. Control based on enthalpy did not meet the recommended range for A1 to A4 Class, but satisfied the allowance standards. Thus, it is determined that enthalpy control is effective for data center economizers, considering relative humidity.

This study evaluated economizer control methods satisfying cooling energy consumption and IT equipment operation rates in domestic the data center, considering the heat emission and operation rates of actual data center IT equipment. However, this study only considered dry bulb temperature and relative humidity; therefore, further research on economizer control methods considering factors other than dry bulb temperature and relative humidity is required.

ACKNOWLEGEMENTS

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