PERFORMANCE EVALUATION OF MULTIPLE AIR-CONDITIONING SYSTEMS PROVIDING SIMULTANEOUS COOLING AND HEATING FOR BUILDINGS

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Abstract: Multiple air conditioning systems for buildings have been widely installed in small, medium and large buildings. These systems are classified into the two types. The one type is the simultaneous system, and the other type is the changeover system. Generally, the former system is better than the latter system in flexibility, and worse in cost. But, in terms of actual energy efficiency, it is not clear whether the simultaneous system or the changeover system is better. The question noted above will be solved by this research.
For calculating the annual energy consumption, we used LCEM tool and the equipment performance characteristics which is experimentally obtained and we clearify the enegy consumption of noted above two systems under a given set of conditions of buildings.

Key Words: multiple air conditioning systems, energy conservation, air conditioning load

1 INTRODUCTION

In recent years, multiple air source/sink heat pump air conditioning systems have been widely installed in small, medium and large buildings due to their simple and straightforward system design and low initial installation cost. This system has been progressively improved in terms of performance and function.

In particular, the simultaneous cooling and heating system has been widely adopted because users like its capability to freely select both heating and cooling options with individual room units.

Although the simultaneous cooling and heating system (hereinafter referred to as the simultaneous system) is highly flexible in terms of repartitioning, the initial installation cost is higher than a heating and cooling mode operation changeover system (hereinafter referred to as the changeover system) in which the changeover of operational mode is made at each outdoor unit. Futher it is not clear which system is better in terms of actual energy efficiency within buildings.

Consequently, the energy performance of the simultaneous system was evaluated by means of simulated air conditioning loads, taking into account the actual operational conditions of existing buildings.

2 GENERAL DESCRIPTION OF SIMULATION

When computing the energy efficiency of an air conditioning system, it is vital to obtain precise air-conditioning load for the operations taking place in the building under actual, realistic conditions.In the actual building, different loads (cooling or heating) can occur in every air conditioning zone and cooling and heating loads can, therefore, both exist at the same time (hereinafter referred to as the mixed load condition)
Before conducting an energy evaluation and comparison between the simultaneous system and the changeover system it was, therefore, necessary to first determine the correct hourly air-conditioning load pattern. The peak load calculation was carried out using MICRO-PEAK-based simulation tools and the annual load was calculated using HASP/ACSS.
In order to compute energy efficiency, LCEM tools published by the Ministry of Land, Infrastructure, Transport and Tourism were employed. And when computing the energy efficiency of the simultaneous system, air conditioning unit performance data owned by Chubu Electric Power Co., Ltd., were used. (Reference (2))

3 COMPUTATION CONDITIONS

3.1 General Description of The Model Building

As previously stated, an existing building (Building A) with a multiple air conditioning system installed was selected as a model for computation use in this paper.
Building A is located in Tokyo and is a multi-purpose building containing offices and apartments. There are two floors in the basement and 15 floors above ground level (including offices up to the 9th floor and apartments above that level). The total floor area is 33,350.75 sq. m.

3.2 Air Conditioning Zoning

A typical floor plan within the building is shown in Fig. 1 and an outline of the air conditioning system installed is illustrated in Fig. 2.
The simultaneous system used has an air-to-air heat exchanger installed in each zone.
Four (4) room units, each connected to one outside unit, are installed in air conditioning zones A through F, respectively, as shown in Fig. 2.

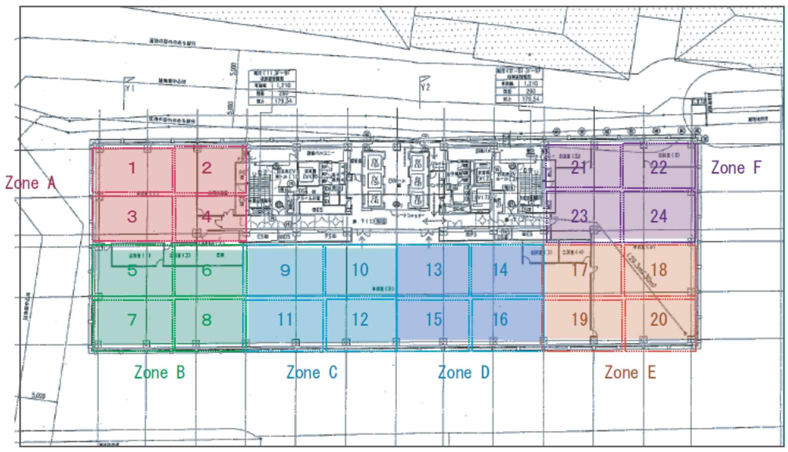

Figure 1: Typical Floor Plan

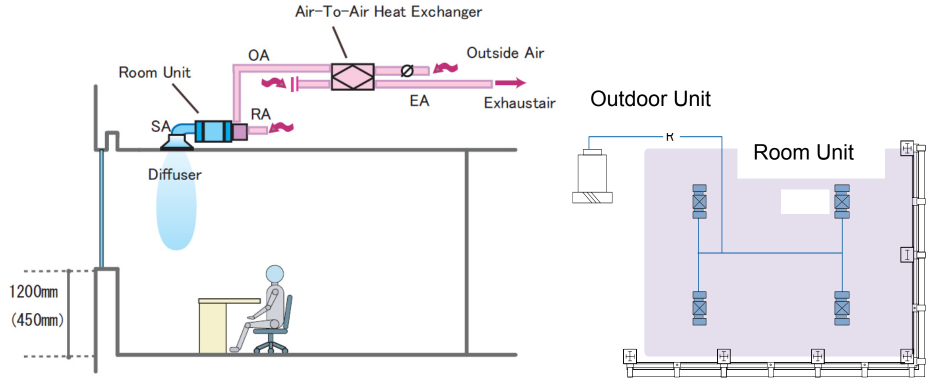

Figure 2: Outline of Air Conditioning System

3.3 Computation Conditions

An air conditioning load calculation was conducted on building A (the model building) using climate data for Nagoya. The conditions used for the load calculation are shown in Fig. 3.

The climate data employed were standard climate data obtained in Nagoya in the 1990s (temperature, humidity, direct solar radiation, sky solar radiation, nocturnal radiation, wind direction and wind velocity for 8760 hours, annually).

An infiltration rate of 0.3 times per hour was used for the areas facing windows.

The operational conditions of the air conditioning system were established as follows:

Operation hours: from 9:00 to 19:00 on weekdays, room conditions in summer: 26 deg. C DB/45% RH, in spring and autumn: 24 deg. C DB/45% RH, and in winter: 22 deg. C DB/40% RH.

The calculations of peak load and annual load were carried out using different internal heat emission schedules. For the annual load calculation, the actual net figures (excluding design margins) were employed.

The enthalpy exchange efficiency of the air-to-air heat exchangers, which reduced outside air load, was set at 65%

3.4 Case Studied

All studies were carried out on the model building described above, using a range of potentially realizable conditions such as different building orientations and various types of façade.

The main orientations of the façade compared were “South” and “East”, and two patterns of room conditions were established: “standard” conditions and “Cool Biz” design conditions (Cool Biz design conditions are based not only on the room design conditions but also take actual net internal heat emission data into consideration). Two types of window system (Low-E clear glass and 12mm float glass) were also compared.

Not only the type of window but also the height of the window is important when determining air conditioning loads. In low CO_2 emission buildings, it is expected that the window area ratio will become smaller in the future. In our simulation, two different window area ratios were selected: a high window area ratio with a 450mm-high spandrel wall and a low window area ratio with a 1200mm-high spandrel wall. Simulations were run for 16 cases in total.

The calculation conditions in each case are tabulated in Table-1.

Subject			概要
Climete Data			Nagoya (Standard Climate Data In 1995) Temperature,Humidity,Direct Solar Radiation, Sky Solar Radiation, Nocturnal Radiation, Wind Directions, Wind Velocity
Max Internal Heat Emission	Lighting		$20W/m^2$
	People		$0.15Persons/m^2$
	Office Appliances		$30W/m^2$
Infiltration			0.3times/h (Only For Perimeter Zone)
【Standard Design】 Air Conditioning Conditions	Operating Time		9:00～19:00
	Room Conditions	Summer	26deg. C DB, 50%RH
		Spring/Autumn	24deg. C DB, 45%RH
		Winter	22deg. C DB, 40%RH
【Cool-Biz Design】 Air Conditioning Conditions	Operating Time		9:00～19:00
	Room Conditions	Summer	28deg. C DB, 50%RH
		Spring/Autumn	24deg. C DB, 45%RH
		Winter	20deg. C DB, 40%RH

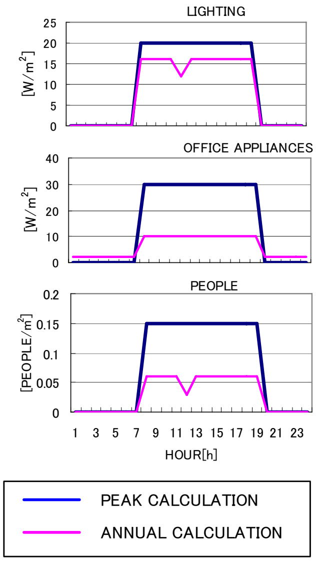

Figure 3: Computation Conditions

Table 1: Computation Conditions For Each Case Studied

Case(Studied)	Facade Orientation	Room Condition	Types of Windows	Spandrel Wall Height
CASE 1	South	Standard Design	LOW-E Clear Glass	450mm
CASE 2	South	Standard Design	Single Float Glass	450mm
CASE 3	South	Standard Design	LOW-E Clear Glass	1200mm
CASE 4	South	Standard Design	Single Float Glass	1200mm
CASE 5	South	Cool-Biz Design	LOW-E Clear Glass	450mm
CASE 6	South	Cool-Biz Design	Single Float Glass	450mm
CASE 7	South	Cool-Biz Design	LOW-E Clear Glass	1200mm
CASE 8	South	Cool-Biz Design	Single Float Glass	1200mm
CASE 9	East	Standard Design	LOW-E Clear Glass	450mm
CASE 10	East	Standard Design	Single Float Glass	450mm
CASE 11	East	Standard Design	LOW-E Clear Glass	1200mm
CASE 12	East	Standard Design	Single Float Glass	1200mm
CASE 13	East	Cool-Biz Design	LOW-E Clear Glass	450mm
CASE 14	East	Cool-Biz Design	Single Float Glass	450mm
CASE 15	East	Cool-Biz Design	LOW-E Clear Glass	1200mm
CASE 16	East	Cool-Biz Design	Single Float Glass	1200mm

3.5 Equipment Performance Characteristics

The performance characteristics of the air conditioning equipment tested were derived from experimentally obtained air conditioning unit performance data owned by Chubu Electric Power Co., Ltd., for the simultaneous system (Reference (2)) and, for the changeover system, power consumption data (Reference (3))calculated for different load factors and outside air temperatures were used.

4 COMPUTATION CONDITIONS

4.1 Peak Load Calculation

The hourly air conditioning loads were calculated in zones A through F, respectively, (as shown on the typical floor plan)

on the day in which the maximum load was recorded each month.
The results showed that the peak load appeared around 9 a.m. during the period of system start-up in summer and winter. The tendency for peak loads to appear in the morning was especially noticeable in winter (Reference (1)).

4.2 Annual Hourly Air Conditioning Load Pattern (Calculation Results in CASE 4)

The air conditioning load simulation was carried out for 24 hours over a period of 365 days. The calculated frequency distribution of load factors for cooling and heating loads (borne by the outdoor unit in each zone) was based on the status of the cooling and heating loads encountered in the four segmented areas within each zone.
We assumed that office building facades with low window area ratios would become more common in the future and computed the results for this eventuality in CASE 4, as shown. The total number of hours in the mixed load condition in CASE 4 was found to be equivalent to the average of the 16 cases studied in total and, therefore, could be considered representative of all the cases tested.
The frequency distribution of load factors for heat quantity (borne by each outdoor unit in zones A through F) was computed for both summer and winter, respectively.
The load factor was defined as the value of the calculated annual load divided by the capacity of the air conditioning unit. The capacity of the air conditioning unit was derived from the peak load calculation, as described earlier.
For zone A, the frequency distribution of cooling and heating load factors was compared in terms of the index of annual accumulated hours in the mixed load condition.
As shown in Fig. 4, 511 hours were spent in the mixed load condition, compared to 2810 hours of total annual operation. The total hours spent in the mixed load condition were, therefore, fairly large throughout the year (18% of the total).
Table 2 shows the numbers of hours of cooling and heating, broken down by every grade of load factor distribution. The load factors shown are low in terms of both cooling and heating (totaling less than 10% in most time zones). For zones B through F, the trend found was basically similar to that described for zone A.

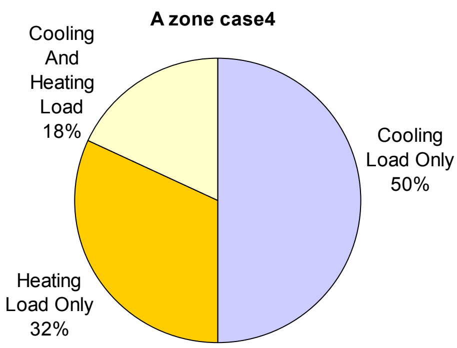

Figure 4: Cooling And Heating Load Ratio Encountered By Outdoor Units (Zone A, Case 4)

Table 2: Frequency Distribution Of Cooling And Heating Load Factors Encounterd By Outdoor Units (Zone A, Case 4)

		Cooling Load											
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Total
Heating Load	0%		322	586	429	64	2						1403
	10%	290	493										783
	20%	423	18										441
	30%	100											100
	40%	45											45
	50%	15											15
	60%	5											5
	70%	7											7
	80%	10											10
	90%	1											1
	100%												0
	Total	896	511	0	0	0	0	0	0	0	0	0	2810
A zone case4						Hours of Total Annual Operation						2810	2810

4.3 Energy Efficiency Evaluation (Computing Results in Case 4)

A comparison of energy efficiency was carried out between the simultaneous system and the changeover system, based on the results of the annual load calculation described above.

The LCEM tools published by the Ministry of Land, Infrastructure, Transport and Tourism were employed to calculate energy efficiency and the experimental data (Reference(2)) owned by Chubu Electric Power Co., Ltd., were used to establish the performance characteristics of the simultaneous system. For the changeover system, the experimental data shown in Reference (3) were used. Using this information, along with the load factors and outside air temperature, the power consumption was then computed.

The computation results from Case 4 were again found to be representative of all 16 cases studied.Total power consumption for the typical floor plan used is shown in Table 5 and the power consumption in each individual zone is shown in Table 6, classified by the status of cooling and heating load in each zone

The equivalent power consumption of residual load was defined as the amount of power consumed when residual loads were borne by the changeover system in the mixed load condition. The residual load was defined as the cooling load during the heating mode period (December and January through March) and the heating load during the cooling mode period (from April to November).

The residual load was converted into power consumption by making use of the performance characteristics of the air conditioning units which were installed in the zone where the residual load was encountered

The results obtained indicated that, in the mixed load condition, the power consumption by the changeover system was almost equal to that of the simultaneous system when the estimated power consumption for residual load was included.

However, the total power consumption by the simultaneous system was less than that of the changeover system, by about 6%.

Fig. 7 and Fig. 8 highlight the specific mixed load conditions from Fig. 5 and Fig. 6.

No significant difference was found between the changeover and the simultaneous system for the typical floor plan used, overall. However, in zones A, B and F, the power consumption calculated was less with the simultaneous system, while in zones C, D and E the opposite was found.

Comparing the performance characteristics of the equipment used (Reference (2) and (3)), it can be seen that, in general, the heating efficiency of the simultaneous system was higher than that of the changeover system. However, when load factor was low during cooling, its efficiency was less than that of the changeover system.

The rated COPs for the rated capacity of the simultaneous and changeover systems fluctuated substantially, depending on the equipment capacity and the [operating characteristics of the equipment used (varying between different manufacturer.

In this study, the air conditioning units in each zone were selected by the peak load.

There was a tendency for energy consumption to differ on a zone-by-zone basis due to the influence of the COPs of the specific air conditioning units selected. (Reference(1))

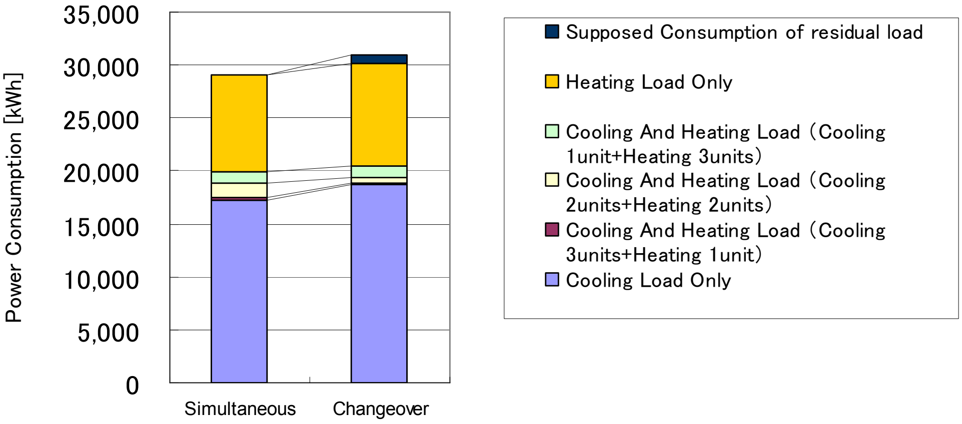

Figure 5: Typical Floor Total Power Consumption

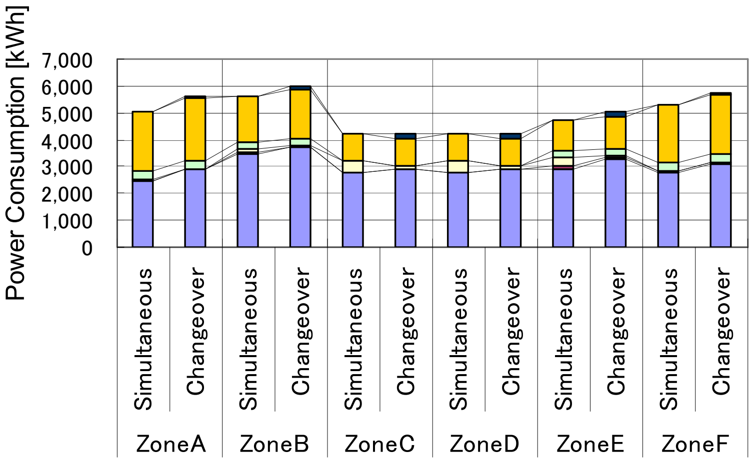

Figure 6: Power Cosumption in each individual zone

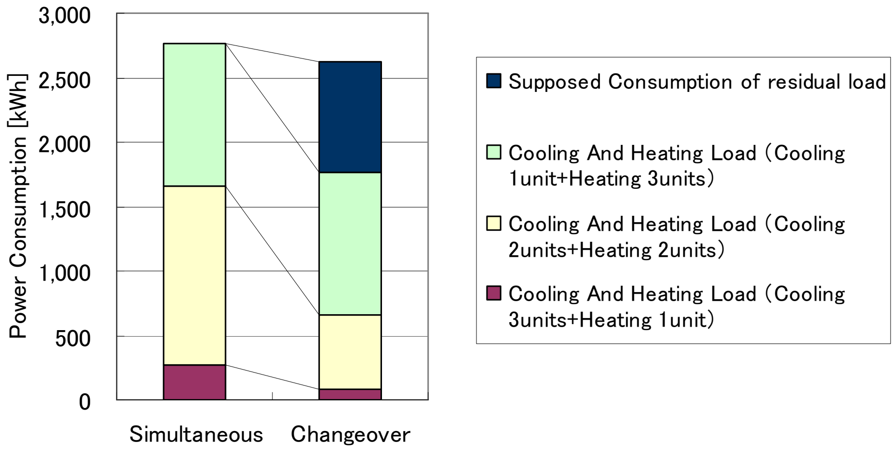

Figure 7: Typical Floor Total Power Consumption In the mixed load conditions

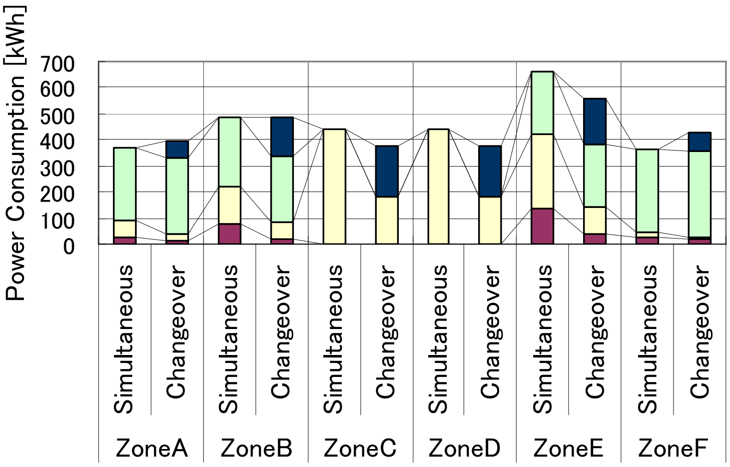

Figure 8: Power Cosumption in each individual zone
In the mixed load conditions

5 SUMMARY

In this paper, an existing building with a multiple air conditioning system (Building A) was selected for study. Various different operating conditions which were highly likely to be encountered in actual use were imposed on the building, and peak and annual load calculations were carried out to confirm the status of the load appearance.
An energy efficiency evaluation was then carried out, based on the equipment characteristics of the air conditioning systems used.
In terms of electric power consumption, it was found that the simultaneous system consumed less power, overall. The calculation formula derived from the experiments (Reference (2)) showed that the simultaneous system was highly efficient in terms of performance when the outside air temperature and the load factors were high.
However, the rated COPs for the rated cooling capacity of both the simultaneous and the changeover system varied substantially, depending on the [capacity][size] of the air conditioning units used.
This could have affected the results since the simultaneous systems selected for the zones compared all had high COPs.
For a typical floor plan, the simultaneous system produced a large overall reduction in energy consumption when a cooling or heating load existed, alone.
On the other hand, when operating in the mixed load condition, the changeover system consumed less energy.
However, if the residual load could be converted into energy consumption by the changeover system and the estimated amount of energy consumption required for residual loads was taken into consideration, then both systems were nearly identical in terms of energy consumption, overall.

6 REFERENCES

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