Optimizing AC Operation Using BEMS Data Analysis

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[Summary] As part of its sustainable business policy, Anritsu is targeting establishment of net zero energy buildings (ZEB) at its business sites. The air conditioning system in Anritsu's Global Head Office is controlled on each floor to optimize employees' comfort but needs to be even more efficient from the power consumption viewpoint. When examining measures to suppress power consumption, the Building Energy Management System (BEMS) integrating large amounts of data was used by the data analysis team to visualize collected temperature and humidity operation records and discover any issues with the AC management systems. In addition, discussions were held with the management team to discover AC operation improvement measures. At winter operation, the overall AC start times and temperature settings were reviewed to better control individual AC power on each floor, yielding a cut in peak power consumption of about 12% with no loss of employees' comfort.

1 Introduction

To celebrate the 120th anniversary of the company's founding, Anritsu opened its Global Head Office (GHO) in 2015. To provide a secure, stable, and comfortable work space as well as minimize CO_2 release and contribute to a sustainable society, the GHO aims to operate as a net zero energy building (ZEB). By the end of FY2015, the building energy consumption had been cut by 57.6% compared to FY2013. However, to become a ZEB in the future, it is essential to promote further energy saving measures.

More than half of the GHO energy consumption is used by the AC power. Consequently, considering the comfort of employees, fully understanding the AC usage and problems is important in switching the AC ON/OFF and changing temperature settings on each floor. To cut AC power consumption, it is necessary to investigate energy reduction measures by grasping the current situation based on temperature, humidity, and AC operational data for each floor.

2 Company GHO Air Conditioning (AC) System

2.1 AC System Configuration

Figure 1 shows the configuration of the GHO AC system.

The GHO AC system has individually controllable AC units on each floor plus Central HVAC (Heating, Ventilation, and Air Conditioning) system for controlling ventilation and humidification of the entire building with a chiller and heater supplying cold and hot water for the Central HVAC system, and a natural ventilation system that opens and closes automatically according to weather conditions.

The individual AC units on each floor can be controlled and can also be stopped remotely from a centralized monitoring station. In case someone forgets to switch off an individual AC unit, all units are switched off at 18:00 from the central monitoring station.

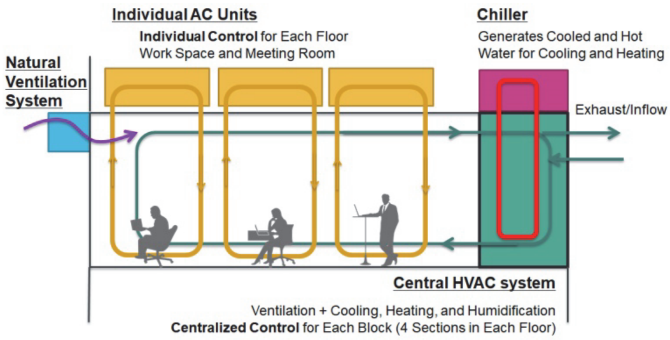


Figure 1 Air Conditioning System Configuration

2.2 BEMS System

A Building Energy Management System (BEMS) has been introduced to the GHO both for the purpose of managing the building overall power, including AC and lighting, as well as for collecting and saving data on AC and lighting, etc., ON/OFF switchings, etc., from more than 5000 locations.

2.3 Issues

The BEMS collects various data and the management section examines the data from a macro viewpoint to spot overall trends in building power and temperature changes.

Previously, the AC in all building rooms was managed centrally, requiring knowledge of how to analyze the accumulated big data and there was no understanding about the operation of individual machine units, which is probably why there has been no progress in use of these data. Not only were the functions inadequate for displaying BEMS data but also data for analysis required output from BEMS in comma-separated values (csv) format for processing with spreadsheet software, which was time-consuming and hindered data utilization.

3 AC Improvements using BEMS Data Analysis

3.1 Investigation Procedure

To solve the issues described previously, a joint investigation system was formed by the data analysis team and the infrastructure management team. The data analysis team with skills in statistical methods and software configuration took responsibility for analysis of BEMS data. Based on the data analysis and visualization by this team, the infrastructure management team with skills in AC operation and management held overlapping discussions to understand current issues and propose solutions.

3.2 Data Analysis Method

(1) Analyzed Data

Table 1 lists the analyzed data.

Table 1 Analyzed Data

Data Type	Units	Sample Points	Data Collection Interval
Room Temperature	°C	30	Hourly
Room Humidity	%	30	
Outside Temperature	°C	1	
Outside Humidity	%	1	
Individual AC Control	ON/OFF	116	—
Central HVAC system Control		20	—
Individual AC Total Power	kWh	97	Hourly
Central HVAC system Total Power		20	
Chiller Total Power		2	

* Data collection period: 2015/7 to 2017/1

* Target floors: 2F to 6F (7F is machine room)

* Data analysis performed after cleansing (outlier removal, missing data processing)

(2) Analysis Environment

Table 2 lists the data analysis tools.

Table 2 Analysis Tools

Software	Application
R version 3.4.2	Statistical Data Analysis Tool
RStudio Version 1.1.383	R Commands, UI, Results Display

3.3 Understanding Conditions using Data Visualization

The BEMS data was visualized from different viewpoints for analysis.

(1) AC Power Levels

Figure 2 shows the GHO overall power usage for each AC type.

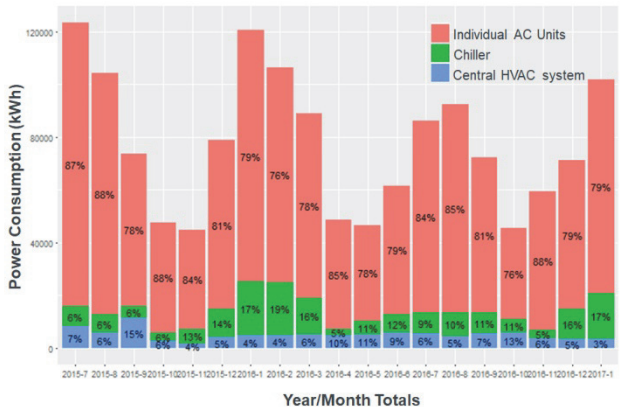


Figure 2 Power Usage by AC Type

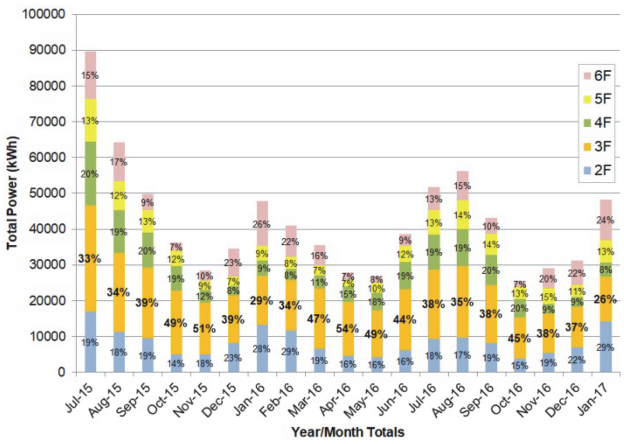
From Figure 2, it is clear that the individual AC units consume about 80% of the overall annual AC power. Additionally, the peak power consumption is in summer (July to August) and winter (January to February).

(2) AC Power Levels by Floor

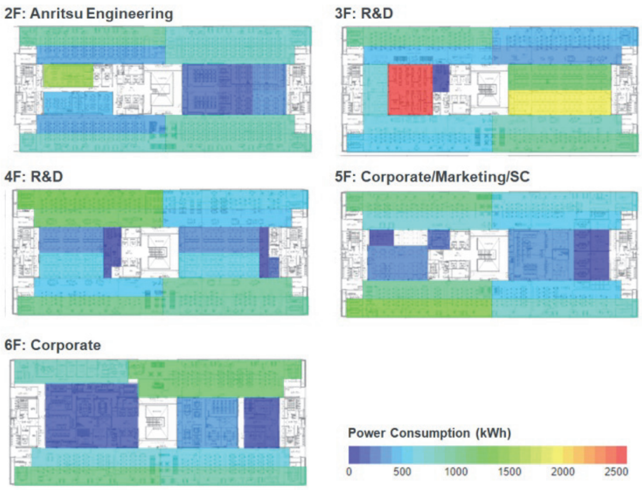
The data for the individual AC units consuming 80% of the AC power were analyzed to understand the conditions by floor and AC area. Floors 2 to 6 were used as data-analysis targets. The 1F where visitors arrive and the 7F with the machine rooms were excluded from the analysis.

Figure 3a shows the individual AC power totals by floor and Figure 3b shows the power usage maps by AC area.

From Figure 3a, there is clear seasonal change with the 3F consuming about 40% of the total power for all individual AC units. From Figure 3b, one area (the machine room with 24-hour AC operation) of the 3F has outstandingly higher power consumption. The trend for areas other than the machine room shows higher AC power at the window-side areas than the building central core.



a. Individual AC Power by Floor



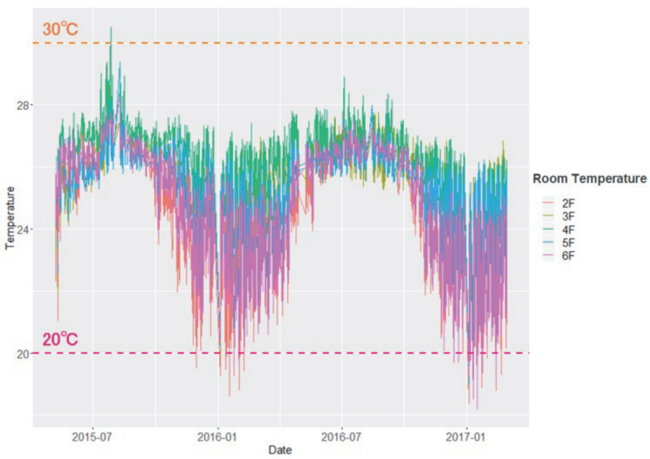
b. Floor Map of Individual AC Power

Figure 3 Visualization of Individual AC Power

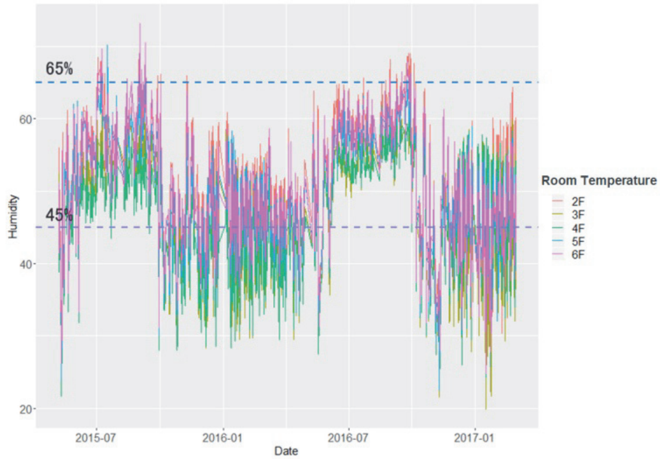
(3) Humidity by Floor

Figure 4 shows the temperature and humidity by floor.

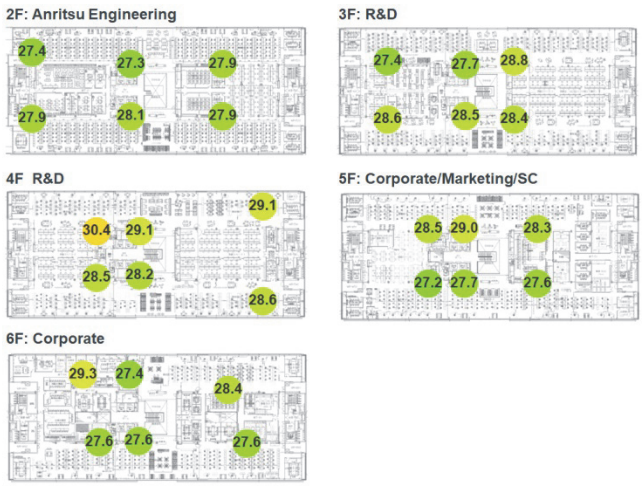
Figure 4a shows the trend in the mean room temperature by floor and Figure 4b shows the trend in mean room humidity by floor. Figures 4c and 4d show the position of the temperature sensors on maps of each floor.



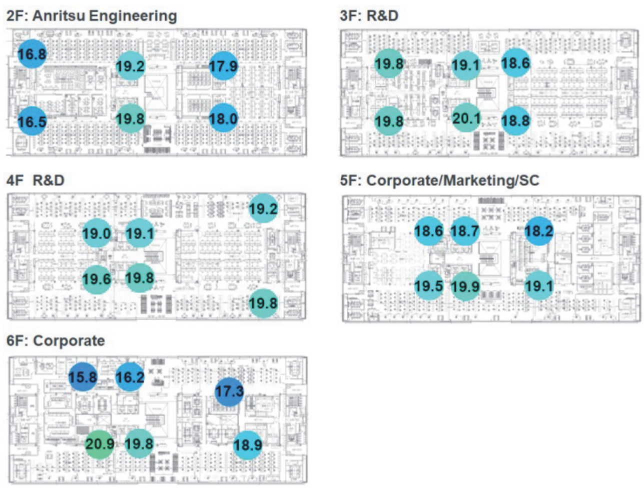
a. Change in Room Temperature by Floor (Weekday Work Hours)



b. Change in Humidity by Floor (Weekday Work Hours)



c. Floor Map (Maximum Room Temperature 2016/8)



d. Floor Map (Minimum Room Temperature 2017/1)

Figure 4 Visualization of Temperature and Humidity by Floor

From Figure 4a, the temperature on all floors is controlled within the range of 20° to 30°C.

From Figure 4b, humidity changes with season but is mostly controlled. In winter, the humidity sometimes drops to as low as 20%.

Looking at the temperature distribution using the floor maps, there is no large difference between floors for summer (Figure 4c) but in winter (Figure 4d), the west sides of 2F and 6F show a tendency to be cold. This is thought to occur because the colonnades on the 2F window side form pathways for rising heat, resulting in an effect from outside weather conditions; the ceiling of the 6F is thought to be affected easily by outside weather similarly.

In Figure 3b, the trend towards high power consumption at the window side is thought to be due to the hotter and colder conditions at that side but the trend could not be confirmed due to the central positioning of temperature sensors in the building core.

(4) Comfort Degree (Discomfort Index)

A discomfort index (DI) was used to measure the degree of comfort based on the following equation

$$DI = 0.81T + 0.01H\,(9.99T - 14.3) + 46.3$$

where, T = Dry Bulb Temperature (°C), and H = Humidity (%)

Table 3 lists the relationship between DI and people's actual body feeling.

Table 3 Degree of Discomfort and Body Feeling

Discomfort Degree	Body Feeling
85 to	Unbearably hot
80 to 85	Hot and sweaty
75 to 80	Quite hot
70 to 75	Not hot
65 to 70	Pleasant
60 to 65	Just OK
55 to 60	Chilly
to 55	Cold

In Table 3, a DI value of 60 to 75 covers the range where people feel comfortable.

Figure 5 shows the DI trend during weekday working hours by floor as a violin plot.

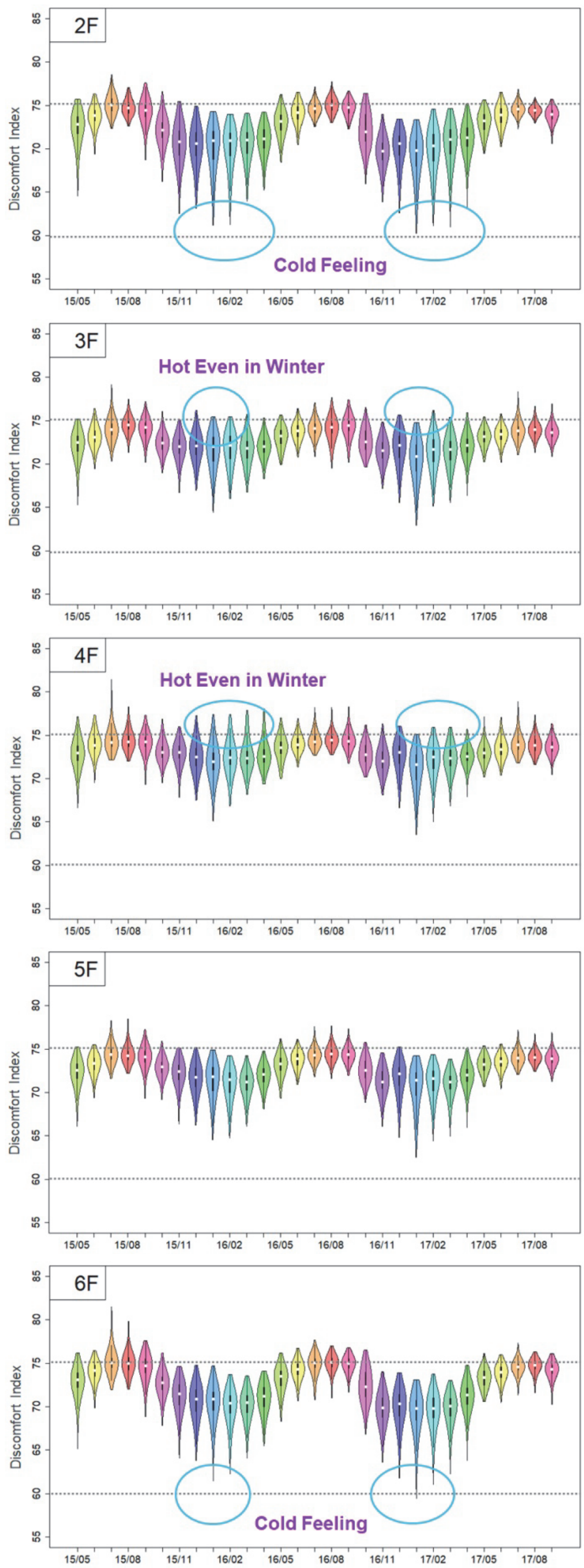


Figure 5 Visualization of Discomfort Index by Building Floor

From Figure 5, the median DI value throughout the year is 70 to 75, which is close to the range where people feel hot.

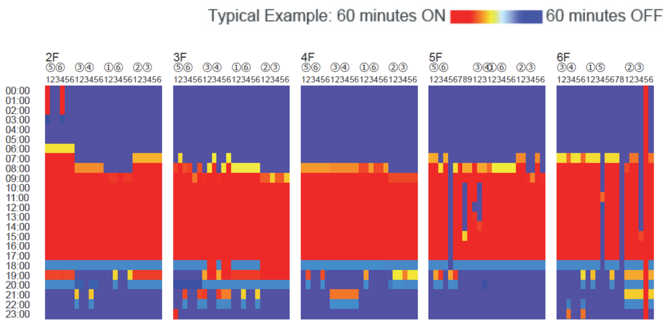
Looking at the trend for each season, the DI exceeds 75 on all floors in summer (July to September) and is in the range where most people feel quite hot. In winter (December to February), the DI tends to be close to 60 for the 2F and 6F but is above 75 (quite hot) for the 3F and 4F even in winter.

(5) AC Control

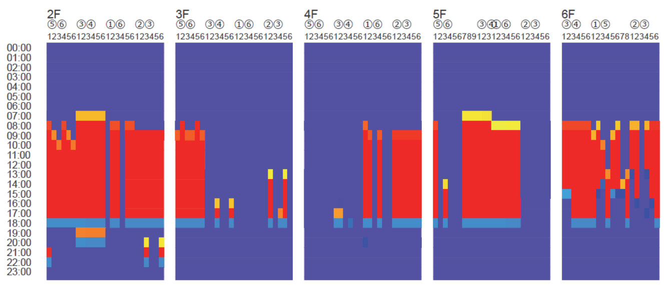
The AC start and stop times were visualized to understand the AC control status for each floor, and Figure 6 shows the AC block on the horizontal axis and time on the vertical axis with red indicating the ON time. From the results, in summer and winter there are few cases where AC is switched ON/OFF in response to the outside temperature; there are many instances where it is not controlled from arriving in the morning and switching ON until returning home in the evening or at automatic OFF at 18:00.

In winter, the AC on the 3F and 4F is not being switched on as expected. The building itself is well insulated and we guess that the temperature remains comfortable without operating the individual AC units due to heat rising from the lower floors via the colonnades.

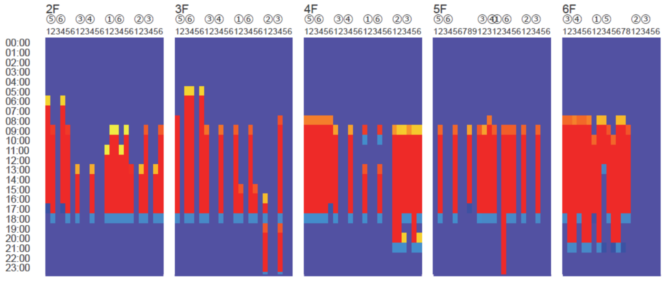
In the spring and fall, the operation differs between floors but there are many instances where the AC remains ON after having been switched ON once.



a. Summer Examples



b. Winter Examples

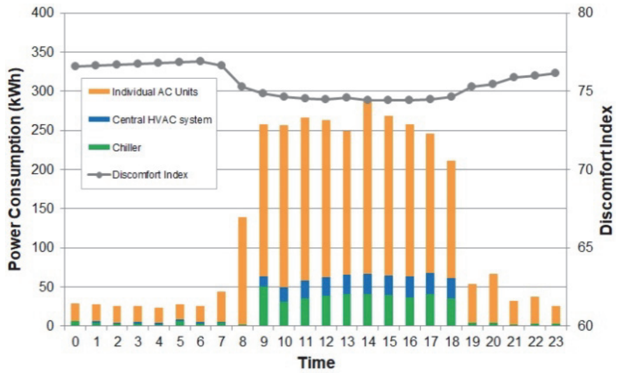


c. Spring/Fall Examples

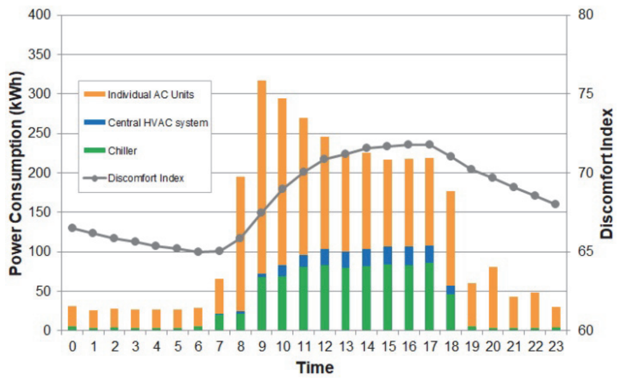
Figure 6 Visualization of Individual AC ON/OFF

(6) Time Variations in AC Power and Discomfort Index

We confirmed the time-related changes in AC power consumption and DI during summer and winter when power consumption is high.



a. Change in AC Power and Discomfort Index (2016/8)



b. Change in AC Power and Discomfort Index (2017/1)

Figure 7 Time Variation in AC Power and Discomfort Index

In winter (Figure 7a), observing the changes over time in power consumption and DI, power consumption is fairly stable during working hours and there are thought to be many instances where the AC continues running after arriving at the office until everyone leaves. However, since the DI shifts towards 75, we can guess that there are many employees feeling hot on occasion. On the other hand, in winter (Figure 7b), the morning AC power consumption is high after starting, with a falling trend in the afternoon. This is thought to occur because all floors are cold at the morning start so all the AC is run at once in the morning. The DI value is low at the start of work probably because many people feel cold but the DI exceeds 70 in the afternoon when people feel warm.

3.4 Problem Discovery

Discussions were held based on the data visualization results to discover problems from the viewpoints of AC power consumption and comfort.

(1) AC Power Viewpoints

- AC power consumption peaked in winter and summer. Power consumption is high in mid-morning when all the AC is running at once, especially in winter. Based on the power totals, improvements are required by emphasizing control of power consumption peaks.
- The Central HVAC system does not operate throughout the entire year. In particular, could it be run before people arrive at work to quickly increase floor temperatures to comfortable levels and cut the load on individual AC units?
- Individual AC units are rarely closely controlled on each floor. Some units run continuously even when conditions are comfortable. In addition to the automatic OFF setting at 18:00, could extra control be added after the 15:00 break?

(2) Comfort Viewpoints

- In summer, all floors tend to feel hot.
- During the afternoon time band in winter, there is a trend towards feeling slightly hot. In particular, the 4F feels uncomfortably hot even in winter. Would it be possible to control the temperature to a more comfortable level using cold air from the natural ventilation system?
- Based on the AC power consumption, the window-side areas seem to be easily impacted by outside weather but the trend is not captured because BEMS sensors are located in passageways.

To solve the above-described issues, we proceeded to investigate use of the Central HVAC system in summer and winter, as well use of the natural ventilation system in winter.

3.5 Additional Analyses

To confirm the effects of the Central HVAC system and natural ventilation system, we performed AC tests in the GHO 5F south side. Table 4 lists the setting changes in these AC tests.

Table 4 AC Tests

Case	Individual AC	Central HVAC system	Natural Ventilation System
1	OFF	ON (fan only)	OFF
2	OFF	ON (fan only)	ON (13:00 to 16:00)
3	OFF	OFF	OFF
4	OFF	OFF	ON (13:00 to 15:00)
5	OFF	ON (heating + humidification)	OFF
6	OFF	ON (heating + humidification)	ON (13:00 to 15:00)

In addition, simple temperature and humidity sensors were installed on the window side and in passageways (Figure 8) to confirm differences in temperature and humidity.

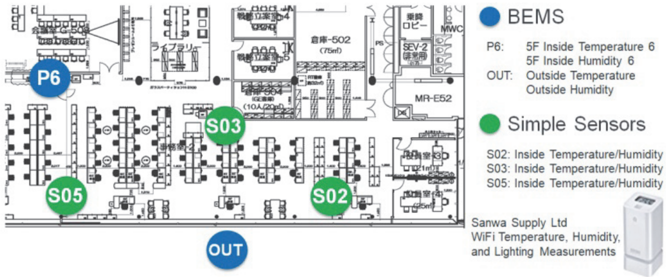


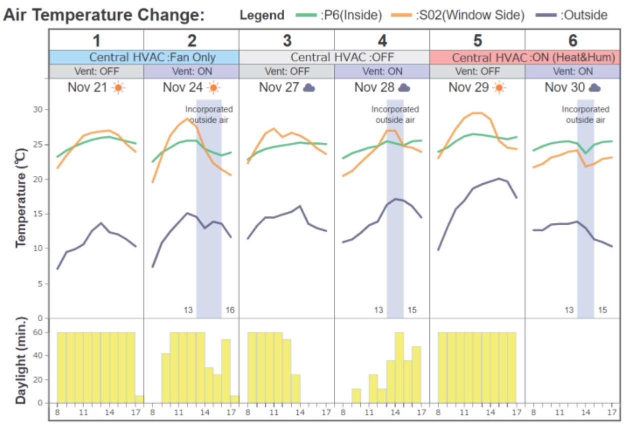
Figure 8 Locations of Simple Temperature and Humidity Sensors

Weather and daylight hours are thought to be factors influencing temperature and humidity at the window-side area. Data on weather and daylight hours was collected using search services of the Meteorological Agency for the weather station at Ebina closest to the Atsugi GHO.

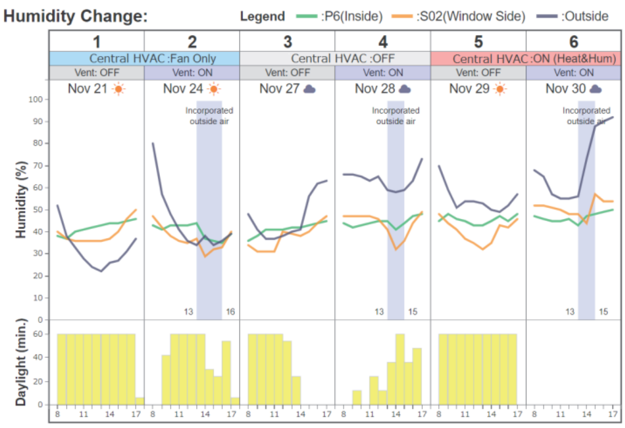
(1) Trends in Room Temperature, Humidity, and Discomfort Index During AC Test Period

Figure 9 shows the trends in the temperature, humidity, and DI in the passageways (inside) and window side during the test period.

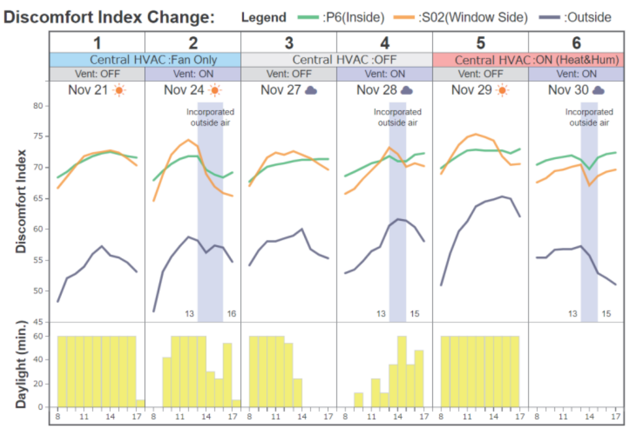
In the graph of room temperature trends (Figure 9a), the room temperature and humidity were stable at BEMS sensor P6 (inside), but a large effect was observed from outside temperature and daylight at the window-side sensor (S02). In particular, there was a large difference in room temperature on sunny days on November 21, 24, 27, and 29. When measuring floor comfort, use of data only from BEMS sensors was clearly inadequate.



a. Changes in Air Temperature



b. Changes in Humidity



c. Changes in DI

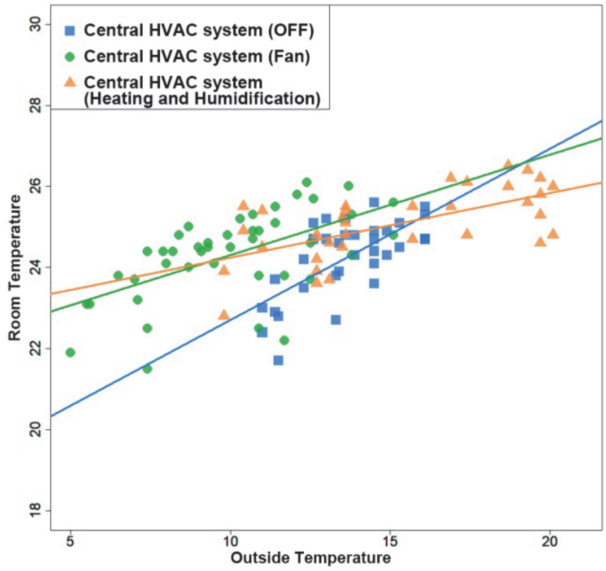
Figure 9 Changes in Temperature, Humidity, and Discomfort Index During Test Period

(2) Confirming Central HVAC system Heating Effect

To confirm the heating effect of the Central HVAC system, we performed a simple linear regression analysis on room temperature during the test period to explain the effect of the outside temperature variable on room temperature. Regression equations were found for three Central HVAC system operating conditions. Figure 10 shows the simple linear regression analysis results.

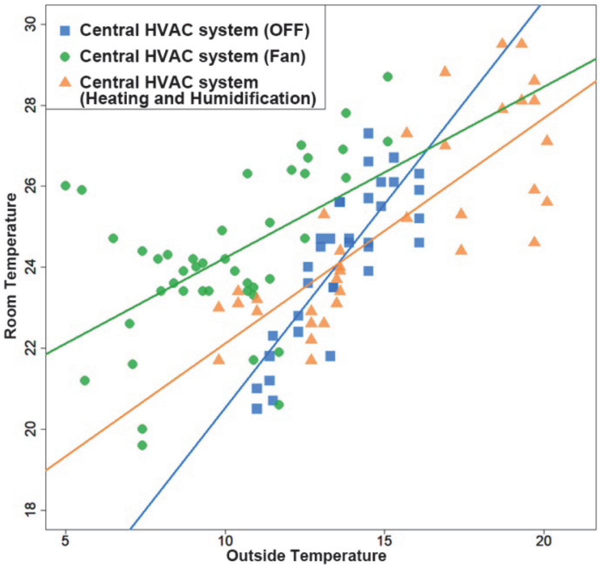
In Figure 10, the outside and room temperatures are plotted and regression lines are fitted to the plots by regression analysis. In addition, the slope of the regression line, the intercept, and coefficient of determination are described for each condition of the Central HVAC system.

When the AC effect is large, the correlation between the room and outside temperatures is low and the slope of the regression line is low. Conversely, when the AC effect is inadequate, the correlation between the room and outside temperatures is high and the slope of the regression line is high. In addition, the probability of the regression line is evaluated using the coefficient of determination. In Figure 10a, the slope of the regression line at P6 (inside) when the Central HVAC system is OFF is about 0.4 suggesting little impact from the Central HVAC system; the slope of the regression line becomes smaller when operating the Central HVAC system and is hardly affected by the outside temperature. Based on this observation, the effect of the heating + humidification operation is evaluated as adequate.



Central HVAC system	Slope	Intercept	Coefficient of Determination
OFF	0.422	18.485	0.446
Fan	0.247	21.837	0.319
Heating and Humidification	0.159	22.659	0.373

a. Correlation Between Outside Temperature and Room Temperature [P6 (inside)]



Central HVAC system	Slope	Intercept	Coefficient of Determination
OFF	1.007	10.453	0.684
Fan	0.422	20.014	0.258
Heating and Humidification	0.556	16.569	0.645

b. Correlation Between Outside and Room Temperatures [S02 (window side)]

Figure 10 Correlation Between Outside and Room Temperatures

Conversely, from Figure 10b, the slope of the regression line for S02 (window side) when the Central HVAC system is OFF is about 1, suggesting that changes in outside temperature have a direct impact on room temperature. The slope when the Central HVAC system is running is 0.4 for fan only, and 0.55 for heating + humidification, suggesting the impact of outside temperature is halved compared to when the Central HVAC system is OFF. The results also confirm the heating effect of the Central HVAC system even at the window side.

(3) Impact of Natural Ventilation System on Room Temperature

To examine the effect of the natural ventilation system on room temperature, Table 5 lists the change in room temperature with time at each of the measurement points.

Table 5 Outside Temperature and Room Temperature at Natural Ventilation System Operation

	Central HVAC system	13:00	14:00	15:00	16:00	Temp Diff	Temp Diff/h
P6 (Inside)	Fan	25.6	24.4	23.8	23.4	2.2	0.73
	OFF	25.5	25.2	24.9	—	0.6	0.30
	Heating + Humidification	25.2	23.7	25.0	—	0.2	0.10
S02 (Window side)	Fan	27.6	24.4	22.3	21.4	6.2	2.07
	OFF	27.0	27.0	24.8	—	2.2	1.10
	Heating + Humidification	24.1	21.8	22.2	—	1.9	0.95

In Table 5, the biggest drops in room temperature are achieved by running the natural ventilation system fans. At the window side, we confirmed a gentle drop in the room temperature of about 2°C per hour. Next, we looked at the effect with the Central HVAC system OFF; the room temperature fell slowly by about 1°C per hour, which is thought to be due to inadequate air circulation within the room. Moreover, when the Central HVAC system was set to heating operation, although the temperature dropped temporarily, it increased again after 2 hours. In other words, the heating effect of the Central HVAC system can be said to have adequate functionality.

Based on the above results, we confirmed the cooling effect of the natural ventilation system when the window-side area is too hot on winter days.

3.6 Investigation of Measures

Discussions were held based on the visualization results and the additional analysis results to propose some AC operation improvements listed in Table 6.

Table 6 AC Operation Improvement Measures

Item	Season	Measure
Central HVAC system	Summer	Review overall morning cooling settings (Change temperature settings before AC start time)
	Winter	Review overall morning heating settings (Increase temperature settings for 2F and 6F before AC operation start time and lower temperature settings for other floors)
	Summer /Winter	Late-night continuous operation (Set fixed room temperature for continuous operation to increase AC efficiency)

Item	Season	Measure
Individual AC Units	Spring /Autumn	Review all-at-once OFF operation (Change all-at-once OFF operation from 18:00 to 17:00 end of work time) Review all-at-once OFF operation at lunch break
	Winter	Review all-at-once OFF operation at lunch break
Natural Ventilation System Operation	Winter	Use planned natural ventilation system operation (Automatic opening from 13:00 to 14:00 in fine weather)

The building management section investigated how and when to implement the above measures.

4 Evaluation of AC Improvements

4.1 Measures for Evaluation

Changes to the operation times and settings for the Central HVAC system in winter were expected to cut power consumption.

Table 7 lists the settings before and after implementing the improvement measures.

Table 7 Central HVAC system Basic Setting Changes

Item	FY2016	FY2017
Set Temperature	All floors 20°C	2F, 6F: 26°C 3F to 5F: 23°C
Operation Start Time	07:30	06:30

* The above settings were for reference and actual operation were changed as necessary

4.2 Evaluation Method

In comparison to the previous year, many comparisons of total power consumption were made over fixed time periods but the large impact of outside temperature on power made testing of AC power control measures unsuitable. For example, when the mean outside temperature dropped during the severe 2017/2018 winter, power consumption increased accordingly. To evaluate the measures, it is necessary to compare under the same conditions for factors, such as weather conditions, affecting power consumption.

(1) Factors Affecting AC Power Consumption

Factors affecting AC power consumption were characterized to find days with the same conditions for comparing AC power consumption.

To characterize factors having an effect, we targeted variables assumed to change power consumption, such as outside temperature, room temperature, room temperature moving average, and room humidity, and used multiple regression analysis to explain the contribution of the variables. Evaluation of the combination of explanatory variables contributing most to the AC power consumption was performed using the adjusted coefficient of determination considering the number of explanatory variables. Table 8 lists the discovered combinations of explanatory variables where the adjusted coefficient of determination is maximum.

Table 8 Discovered Combinations of Explanatory Variables

Parameter	1	2	3	4
Outside Temperature	○	○	○	○*2
Room Temperature	○			
Room Temperature Moving Average*1		○	○	○*2
Room Humidity			○	
Adjusted R^2	0.714	0.743	0.747	0.758

*1 Room temperature moving average was calculated as the mean of the temperature 2 hours previously, 1 hour previously and at the current time.

*2 Items with interactive effect

Based on the above results, power reduction effects can be validly compared because the behavior of outside and room temperatures on similar days is being compared.

(2) Selection of Comparison Days

Days for comparison were selected as described above. Outside temperatures and room temperatures between the hours of 00:00 and 17:00 were compared for the evaluation period (January 1, 2018 to February 28, 2018) and the comparison period (January 1, 2017 to February 28, 2017) to find combinations of days with the smallest values for the [sum of squares of difference of outside temperature + sum of squares of difference of room temperature]. Table 9 lists the discovered combinations of days and Figure 11 shows the trend in outside and room temperatures for the compared target days.

Table 9 Selected Comparison Days

No	Test Date	Comparison Date	Calculated Value for Comparison*	Test Side		Comparison Side	
				Mean Outside Temp	Mean Room Temp	Mean Outside Temp	Mean Room Temp
1	2018/2/16	2017/2/2	7.09	5.7	23.7	5.7	23.4
2	2018/1/31	2017/1/25	22	4.1	22.7	4.1	23.0
3	2018/2/27	2017/1/31	25.5	7.4	23.4	7.4	23.4
4	2018/2/20	2017/2/7	28	7.1	23.4	7.1	23.3
5	2018/2/22	2017/1/20	28.8	3.7	23.5	3.7	23.2

* Sum of squares of difference of outside temperature + sum of squares of difference of room temperature (00:00 to 17:00)

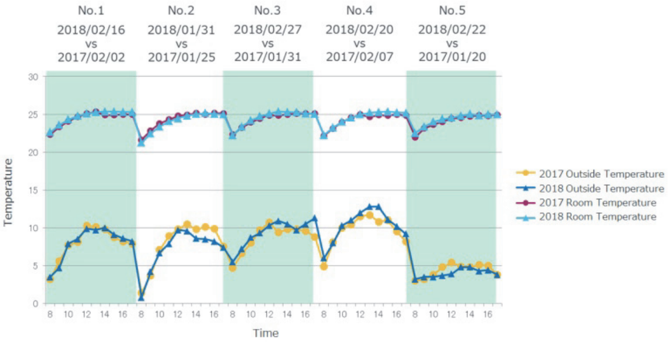


Figure 11 Trend in Outside Temperature and Room Temperature for Compared Target Days

There is no difference in the outside and room temperature trends for any combination of days and the conditions for comparing the effects of the AC measures can be evaluated satisfactorily.

4.3 Evaluation Results

The AC power consumption was confirmed for the comparison target days discovered as described above.

Table 10 lists the power consumption comparison data for each AC installation. In addition, the comparison day set used Item No. 5 with the lowest outside temperature.

Table 10 AC Power Usage Comparison

Item	FY2016 (2017/1/20)	FY2017 (2018/2/22)	Difference	Increase/ Decrease
Chiller	860 kWh	900 kWh	40 kWh	4.7%
Central HVAC system	154 kWh	174 kWh	20 kWh	13.0%
Individual AC	1,986 kWh	1,661 kWh	△325 kWh	△16.4%
AC Power Total	3,000 kWh	2,735 kWh	△265 kWh	△8.8%
Peak Power	335 kWh	295 kWh	△40 kWh	△11.9%

In the comparison of power consumption in day units, the chiller and Central HVAC system power consumption increased as the Central HVAC system operation time increased, but the power consumption of the individual AC units was suppressed and these units consumed 8.8% less power overall. In addition, peak power consumption fell by 11.9% for a saving of up to 300 kWh.

Figure 12 shows the trend over time in AC power consumption for FY2016 and FY2017.

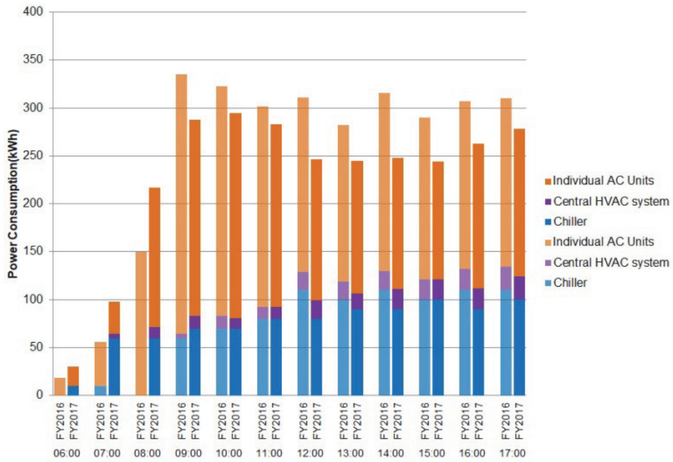


Figure 12 Changes in AC Power Consumption Over Time

In Figure 12, during the period when the improvement measures were applied, power consumption by the chiller and Central HVAC system increased between 06:00 and 08:00 because the Central HVAC system was starting earlier, but after 09:00, the power consumption of the individual AC units was clearly suppressed. In addition, the power peaks at 09:00 in 2016 were lower in the following year after application of the countermeasures.

5 Conclusions

To optimize AC operations at the GHO, we established an improvement process based on data analysis and drafted some effective measures. The improved winter AC operation cut peak power consumption by 11.9% compared to the previous year. Anritsu's target of achieving a ZEB rating for the GHO still requires continuing improvements and confirmation of achieved results. For the future, we will not only use BEMS data but will also establish measures using new methods such as optimized AC operation using machine learning (ML).

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