International Gas Union Research Conference 2011

Energy-Saving Design for Small and Mid-sized Buildings

– The Case of Y Building –

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ABSTRACT

Small and mid-sized office buildings account for most of the energy consumed by all office buildings in Japan. Energy saving in these buildings has not been sufficiently implemented in comparison with large office buildings; simple and practical energy-saving measures for such buildings should be promoted. The design of Y Building, completed in March 2009, was based on the following concepts: 1) optimum design of the air-conditioning capacity and system to reduce low-load operation and 2) occupancy and CO2 sensor control of office space lighting, air-conditioning and total heat exchanger on/off. The effects of these two concepts have been examined since 2009 summer. These efforts have produced two major results. First, low-load operation has been mostly replaced by intermediate-load operation due to optimization of the air-conditioning capacity and system, which has led to a significant improvement in efficiency. Second, lighting and air-conditioning power consumption has been reduced by employing occupancy sensors. In particular, lighting power consumption has been reduced by approximately 30% on a monthly basis, and the power consumption of CO2 sensor-controlled total heat exchangers has been reduced by approximately 55%. We will continue with the verification process on an annual basis to further increase energy-saving performance through improved operation.

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1. Introduction

Due to growing awareness in regard to global environmental problems, it is imperative that energy-saving measures be taken in office buildings. Small and mid-sized office buildings account for most of the energy consumed by all office buildings in Japan. It should be noted, however, that energy saving in these buildings has not been sufficiently implemented in comparison with large office buildings.

At Y Building (Table 1) located in Yodogawa-ku, Osaka City, we have taken energy-saving measures which are broadly applicable to small and mid-sized office buildings. This paper is intended to present an overview of our energy-saving design and verification results observed in Y Building.

Picture 1: Overview of Y Building

Structure/ number of floors	Steel construction/3 floors above ground	Total floor area	1,475 m^2
Building area	497 m^2	Users of this building	About 100 persons

Table 1: Outline of Y Building

2. Overview of energy-saving design

Figure 1 shows the schematic diagram of the energy-saving design for Y Building. There are two major factors involved in this design: (i) achieving highly efficient operation of heat source equipment (GHP) (i.e., reducing the capacity and optimizing the system of air-conditioning) and (ii) preventing unneeded operation of equipment (i.e., assisting energy-saving operation).

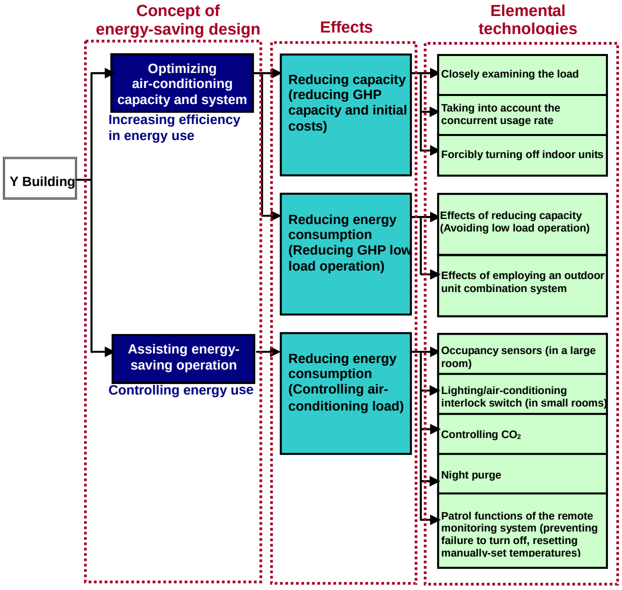

Figure 1: Schematic diagram of energy saving.

2.2 Design for reducing the capacity and optimizing the system of air-conditioning

Many buildings have excessive air-conditioning capacity in order to meet their ever-increasing peak loads. However, it is important to note that, because of this overcapacity, the equipment must be operated under low load for extended periods of time, which hinders energy-saving operation.

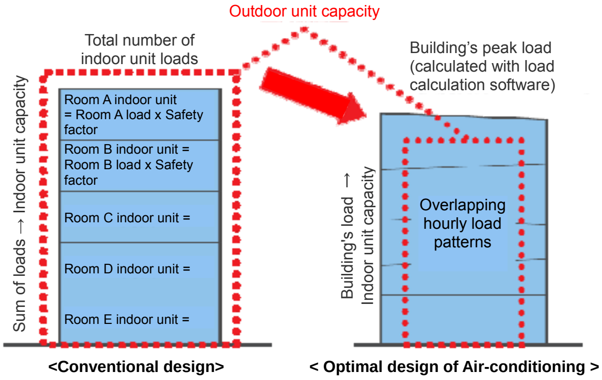

Figure 2: Reducing capacity of outdoor units.

As shown in Figure 2, we closely examined Y Building's overall air-conditioning peak loads in advance, and determined the outdoor unit capacity by taking into account the rate of concurrent use in the building. We also succeeded in reducing the capacity by 42% from 86 hp (initial design) to 50 hp (reduced capacity design with 25 hp x 2 units) by providing a backup function. In addition, an outdoor unit combination system (which enables air-conditioning with an optimal number of outdoor units in operation) was employed (optimum design) to increase efficiency during partial load operation.

2.3 Functions to assist energy-saving operation

It is desirable to stop equipment operation whenever rooms are not used. In reality, however, it is unrealistic to expect every single person to strictly observe this rule. It is even more difficult to introduce high-performance control systems in small and mid-sized buildings.

For this reason, we employed two types of simple automatic control devices in Y Building to ensure ease of energy-saving operation: occupancy sensors (for controlling lighting and air-conditioning) and CO2 sensors (for controlling ventilation).

3. Effects of energy-saving design

3.1 Effects of reducing capacity and optimizing system of air-conditioning

3.1.1 Verifying the building’s load (in summer)

Figure 3 shows Y Building’s air-conditioning load factor and daytime changes in outside temperature in summer (August 17, 2009). Here, the building’s air-conditioning load factor represents the percentage of the building’s overall air-conditioning load divided by the building’s overall air-conditioning equipment capacity.

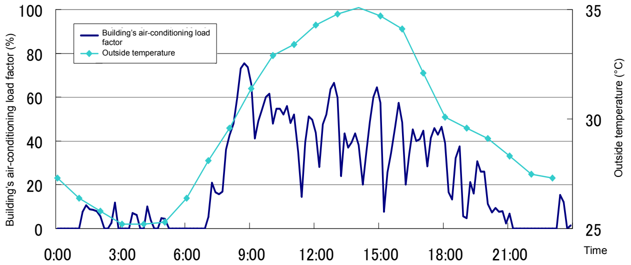

Figure 3: Typical daytime changes of the building’s air-conditioning load factors and temperatures in summer.

The building’s air-conditioning load factor peaks at the start of work in the morning, which matches well the hourly trend of the building’s overall load in air-conditioning optimum design. There are two probable factors behind this phenomenon. First, the office of Y Building is heated by sunlight in the morning because it has windows facing the east. Second, human body heat load peaks at the start of work when the number of users of this building is large; the number of users is smaller during the remaining business hours. It should also be noted that the load factor dips every hour because the temperature settings changed by users are reset to 28°C by means of Eneflex (a remote patrol system offered by Osaka Gas Co., Ltd.).

3.1.2 Effects of reducing and optimizing air-conditioning capacity

Here, the double effects of reducing air-conditioning capacity (reduction in capacity) and introducing the outdoor unit combination system (optimization) are evaluated by using the equipment load factor as an index. The equipment load factor is represented by the equation below and is distinguished from the building's air-conditioning load factor.

$$\text{Equipment load factor}(\%) = \frac{\text{Load handled by the equipment}(\text{hp})}{\text{Rated air - conditioning capactiy of the equipment}(\text{hp})} \times 100 \qquad (1)$$

The load handled by the equipment, which is a function of refrigerant flow rate and enthalpy difference, is based on the outdoor unit's internal data (engine speed, compressor pressure, temperature, etc.).

Figure 4 shows the frequency of equipment load factors in the initial design (86 hp), reduced capacity design (25 hp x 2 units), and optimum design (25 hp x 2 units) during summer (July–September), intermediate months (October and November), and winter (December–February), 2009.

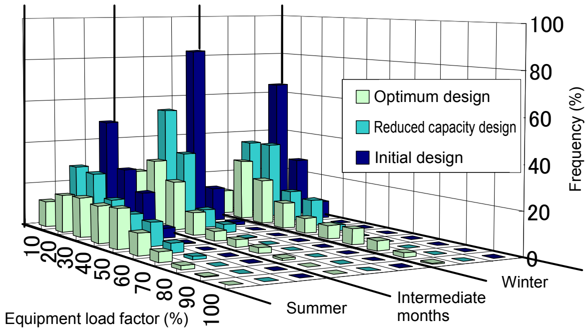

Figure 4: Frequency of equipment load factors (in summer, intermediate months, and winter).

As shown in Figure 4, low-load operation (capacity utilization: less than 30%) in optimum design has been reduced by 50% compared with that in the initial design for summer, leading to an increase in operation in the efficient, intermediate load range. Meanwhile, low-load operation (capacity utilization: less than 30%) in optimum design has been reduced by 32% compared with that in reduced capacity design, which verifies the fact that efficient, intermediate-load operation has increased by employing a mechanism which enables air-conditioning with an optimum number of outdoor units in operation, depending on the load. In the initial design, low-load operation (equipment load factor: less than 10%) accounts for over 80% of operation in intermediate months and over 60% in winter; in the optimum design, operation with equipment load factors of over 30% accounts for over 45% in intermediate months and over 60% in winter, which indicates that efficiency has been significantly improved.

3.1.3 Verifying amenity

High-efficiency operation of outdoor units has been achieved by optimizing the air-conditioning capacity and system. It is important to note, however, that amenity must not be sacrificed. In Y Building, ceiling fans are installed as a backup system to make up for capacity shortage. To meet severe capacity shortage, an indoor unit with forced turnoff function is installed just in case to stop the operation of indoor units in low-priority zones. During summer of 2009, air-conditioning was forcibly turned off in the common space for a very short period of time, but the impact was limited. Air-conditioning in high-priority zones (the office, etc.) was never stopped.

3.2 Effects of mechanisms for assisting energy-saving operation

Here, the effects of occupancy and CO2 sensors are discussed, among the mechanisms for assisting energy-saving operation shown in Figure 1.

3.2.1 Effects of occupancy sensor-controlled lighting and air- conditioning

Figures 5a and 5b show the daytime changes of total power (for lighting and air-conditioning) and gas consumption of the building in occupancy sensor-controlled and manual operations on weekdays and holidays.

As shown in Figures 5a and 5b, occupancy sensors significantly reduce lighting power consumption during the nighttime or on holidays when the building is used by only a small number of people. Power consumption is reduced by more than 70% during the nighttime on holidays. Meanwhile, the effectiveness of occupancy sensors in reducing air-conditioning power consumption is hard to recognize because the power consumption of indoor units is originally small (approximately 1/10 of that of lighting). The effectiveness of occupancy sensors in reducing gas consumption is also hard to recognize.

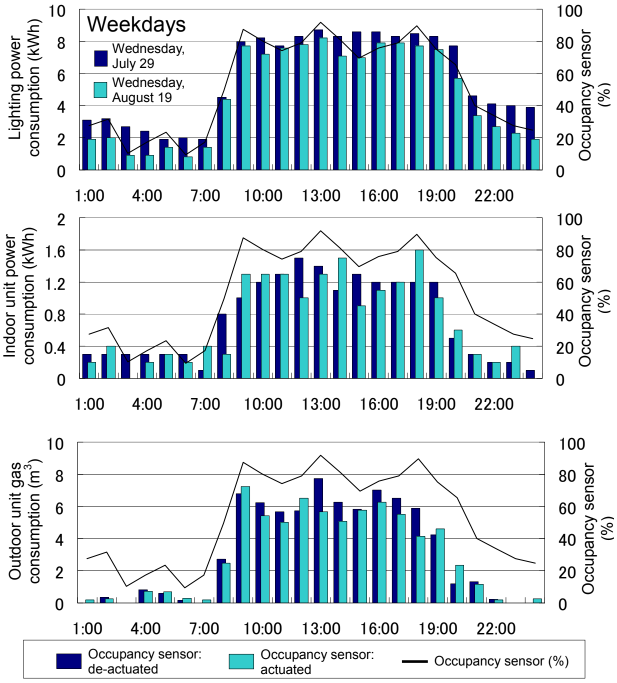

Figure 5a: Daytime changes of lighting power consumption (top)/indoor unit power consumption (middle)/outdoor unit gas consumption (bottom) and with occupancy sensor on weekdays.

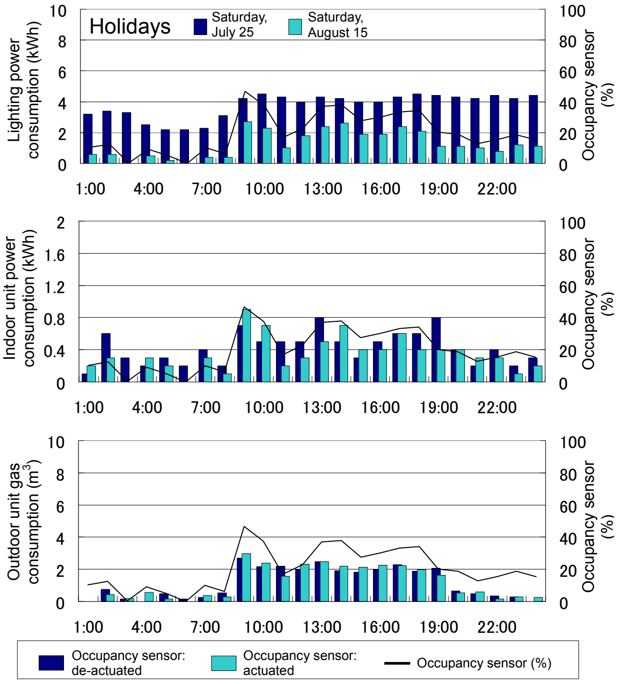

Figure 5b: Daytime changes of lighting power consumption (top)/indoor unit power consumption (middle)/outdoor unit gas consumption (bottom) and with occupancy sensor on holidays

Figure 6 shows the correlation between the occupancy sensor sensitivity, power (lighting and indoor units), and gas (outdoor units) consumption in summer, intermediate months, and winter.

In summer, there is a strong correlation between occupancy sensor sensitivity and lighting power consumption, air-conditioning power consumption, and gas consumption (which is hard to recognize in Figures. 5a and 5b). Thus, occupancy sensors are considered to be effective. Meanwhile, in intermediate months and in winter, the correlation between occupancy sensor sensitivity and outdoor unit gas consumption is weak, with little difference recognized when the sensor sensitivity is changed.

In other words, occupancy sensors are effective all day throughout the year in controlling lighting; occupancy sensors are also effective in summer (when the load increases) in controlling air-conditioning; and occupancy sensors may possibly trigger useless air- conditioning in other seasons (especially during the nighttime in other seasons).

Table 2 shows (i) the monthly lighting power consumption (which can be significantly reduced by occupancy sensors) with occupancy sensors actuated/de-actuated and (ii) the amount and rate of reduction attained by employing occupancy sensors. A reduction of approximately 30% can be observed throughout the period, with a power consumption of 1,000 kWh–1,800 kWh being saved on a monthly basis.

3.2.2 Effects of CO2 sensor-controlled ventilation

Finally, Table 3 shows the effects of CO2 sensors in reducing ventilation power consumption. CO2 sensor-controlled ventilation is as effective as occupancy sensor-controlled lighting in terms of reducing power consumption. Specifically, a power consumption of approximately 500 kWh–800 kWh (approximately 55%) is saved on a monthly basis throughout the period.

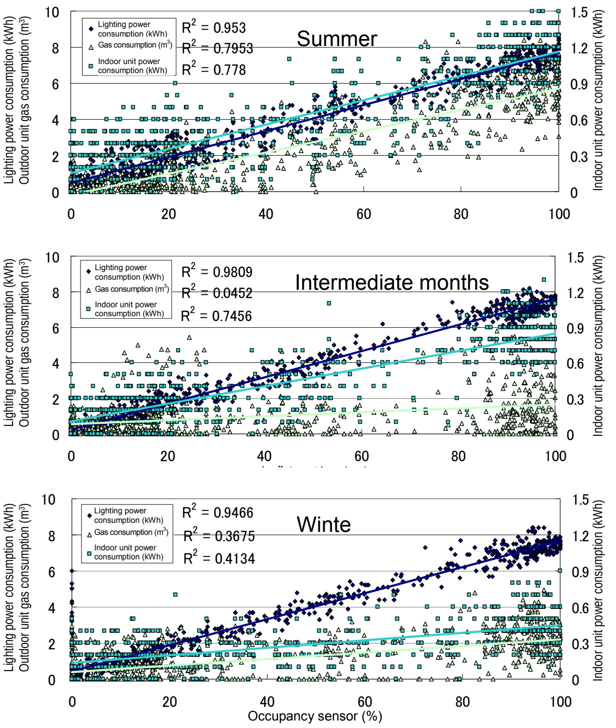

Figure 6: Correlation between lighting power consumption/indoor unit power consumption/outdoor unit gas consumption and occupancy sensors in summer (August), intermediate months (October), and winter

	Summer			Intermediate months		Winter		
	July	August	September	October	November	December	January	February
Occupancy sensor control	2516.2	2820.9	2479.5	2503.2	2783.4	2577.8	2175.5	2168.2
Manual control (kWh/month)	3843.1	3843.1	3719.1	4113.7	3981.0	3996.8	3996.8	3610.0
Reduction (kWh/month)	1326.9	1022.2	1239.6	1610.5	1197.6	1419.0	1821.2	1441.8
Reduction rate (%)	34.5	26.6	33.3	39.1	30.1	35.5	45.6	39.9

*: Power consumption data during periods when occupancy sensors are de-actuated for verification in each season is converted to monthly data. Power consumption data during periods when occupancy sensors are actuated is converted to monthly data by excluding power consumption data during periods when occupancy sensors are de-actuated for verification.

Table 2: Reduction in lighting power consumption by means of occupancy sensors

	Summer			Intermediate months		Winter		
	July	August	September	October	November	December	January	February
CO_2 sensor control (kWh/month)	591.8	697.0	703.1	666.2	534.2	590.1	715.8	669.6
Rated operation (kWh/month)	1399.4	1469.4	1422.0	1469.4	1422.0	1469.4	1469.4	1327.2
Reduction (kWh/month)	807.6	772.4	718.9	803.2	887.8	879.3	753.6	657.6
Reduction rate (%)	57.7	52.6	50.6	54.7	62.4	59.8	51.3	49.6

*: The rated operation is based on the assumption that (i) one unit/room is run under the rated operation conditions from 8:00 p.m. to 7:00 a.m. to mitigate the sick house syndrome; and (ii) all units are run under the rated operation conditions during the daytime.

Table 3: Reduction in ventilation power consumption by means of CO_2 sensors

4. Conclusion

In this paper, we discussed (i) an overview of our energy-saving design techniques (i.e., reducing the capacity and optimizing system of air-conditioning and energy-saving operation assisting functions), which are applicable to small and mid-sized office buildings, and (ii) the verification results of energy-saving effects. We will continue with the verification process on an annual basis to further increase energy-saving performance through improved operation.