Load Leveling and Energy-Saving Effects Evaluation of SOHO

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Abstract

“The California energy crisis of 2000,” like a bomb exploding in a crowd, alerted the world to issues surrounding safe and secure energy supply. Increasing energy demand calls for an expanding supply system in order to realize a stable supply of energy. On the other hand, environmental problems such as global warming, the heat island phenomenon, resource depletion, and so on, call for a more efficient and energy-saving supply system. With these as a background, load leveling, one of the effects of DSM (Demand Side Management), is considered to be an effective method.

In this paper, 24-hour investigations on SOHO (Small Office Home Office), residential buildings and offices were conducted in the central Tokyo area. Based on the results, the monthly and hourly energy consumption characteristics of SOHO were ascertained. In addition, the dimensionless parameters, load leveling ratio \( r_l \) and energy saving rate \( r_s \) were defined. Using \( r_l \), SOHO was proven to have profound effects on load leveling; and using \( r_s \), the energy saving potential was evaluated quantitatively.

Keywords: load leveling; energy-saving; DSM; energy efficiency; SOHO; multipurpose building

1. Introduction

“The California energy crisis of 2000,” like a bomb exploding in a crowd, alerted the world to issues surrounding safe and secure energy supply. Increasing energy demand calls for an expanding supply system in order to realize a stable supply of energy. On the other hand, environmental problems such as global warming, the heat island phenomenon, resource depletion, and so on, call for a more efficient and energy-saving supply system. With these as a background, load leveling, one of the effects of DSM (Demand Side Management), is considered to be an effective method.

DSM refers to a wide range of actions to reduce demand for energy (electricity, gas or others) and/or to shift demand from peak to off-peak times\(^1\). DSM is an important tool to help balance supply and demand in energy supply markets, to reduce price volatility, to increase system reliability and security, to rationalize investment in energy supply infrastructure and to reduce greenhouse gas emissions. Traditionally, DSM was driven by electricity businesses as a load and investment management tool, often within a “least-cost planning” framework. While this aspect continues in some countries, DSM is increasingly finding new applications as a market-based offer in liberalized energy markets. At the same time DSM is being used in emerging energy efficiency policy measures. Commonly, It is realized depending on DSM technologies or government implementation (for example, the price system).

Buildings are becoming large-scale and multipurpose. Multipurpose buildings consist of two types. First, there are those that comprise multipurpose functions, such as office space and restaurants, while the others are buildings of the same size with complex functions, such as SOHO (Small Office Home Office), use for living as well as working. In the case of the former, a separate energy supply system is often used for administrative convenience, while in the case of the latter; the building has a community energy supply system. Many countries are collaborating on research concerning DSM technologies, however, the load-leveling effects of multipurpose buildings have been neglected\(^2,3\).

In this paper, 24-hour investigations on SOHO, residential buildings and offices were conducted in the central Tokyo area. Based on the survey results, the load leveling effects caused by the building function compound are discussed. As one of the important methods of DSM, it meets the needs of lifestyle changes, while at the same time improving energy efficiency and assuring environmental and social sustainability. It is anticipated that the results of this paper will be used as reference in future urban development and renewal.

2. Method

2.1 Definition of SOHO

In Japan, the word “SOHO” (Small Office Home Office) was used for the first time in an article in the Nikkei industrial newspaper on June 13th, 1995. It was used for the first time in a governmental "communication white paper" of the old Ministry of Posts and Telecommunications in...
1998, which means that it had been publicly recognized by the government at last. After that, SOHO organizations and SOHO support enterprises appeared one after another. With the growing popularity of the Internet, according to the Japan SOHO Association, there are 5 million SOHO, in which about 15 million people are working all over the country. And there are more than 2.5 million people who would like to choose the working-style of SOHO in Tokyo.

SOHO has been defined variously by different organizations. In this research, we defined it as follows:

1. Dwelling units of multiple dwelling buildings;
2. At least one person lives there;
3. Carrying out tertiary industry activities by using computer and communications devices.

2.2 Drifting of Population Toward Urban Centers and Residential Preference

In Japan, during the asset-inflated late 1980s when land prices were sky-high, a demographic outflow continued and did not stop until 1996. Having suffered stagnation following the bubble economy for about 7 years, as shown in Fig. 1, the drifting of population toward urban centers started again from 1997 because of the fall in land prices. In order to make efficient use of land and meet the growing demand for living, super high-rise condominiums are now attracting a lot of attention.

With the spread of the computer and Internet, and the demand for SOHO, in the future, buildings using SOHO in urban centers are expected to rise further, too.

2.3 Outline of the Investigations

2.3.1 Outline of Investigation Objects

In these investigations, 4 SOHO, 34 offices and 43 residential buildings were selected. As shown in Table 1, SOHO A, B, and all of the residential buildings are equipped with floor-gas-heating systems and PACs (Packaged Air Conditioners) for heating and cooling. In SOHO C and D, PACs were used both for heating and cooling. In Buildings T and H, central air conditioning systems with turbo refrigerators and boilers being heat source equipment, FCU (Fan Coil Unit) in each room, was used for offices, while PACs were used concomitantly in some offices. Gas was used for hot water and kitchens in all of the investigated objects. Additionally, 11 offices with gross floor area ranging from 131.8m² to 982.5m² are located in Building T. The other 23 offices with gross floor area ranging from 39.3m² to 1661.7m² are located in Building H. The residences, which can be classified into 16 types according to floor plan, are located in the same super high-rise condominium. Also, fully equipped LAN connection environment in each household unit allows occupants to enjoy the Internet at home at any time. Figs. 2, 3 and 4 show the floor plan example of SOHO, office and residential space.

2.3.2 Investigation Areas and Periods

The investigations on SOHO and offices were conducted in the central Tokyo area from June 2003 to February 2004. Residential building investigations were conducted from June 2001 to February 2002. Measurement surveys of 24-hour energy consumption also were carried out. The periods are shown in Table 2.

2.3.3 Investigation Method and Items

In order to clarify the energy load level, we carried out 24-hour measurements of electricity, gas and oil consumption by recording the values of utility meters once every hour. Also, general information regarding buildings, equipment profiles, lifestyles of occupants and monthly energy consumption were investigated by questionnaires.

![Fig.1. Changes in Population and Number of Households in 23 Wards of Tokyo in the Last 20 Years](image)

Table 1. Outline of Investigation Objects

| Objects | Area(m²) | Be Used as Source of Energy | Space Heating | Space Cooling | Hot Water | Kitchen |
|---------|----------|----------------------------|--------------|--------------|-----------|---------|
| SOHO    |          | Electric/Gas               | Electric     | Gas          | Gas       | Gas     |
| A       | 69.2     | Electric/Gas               | Electric     | Gas          | Gas       | Gas     |
| B       | 73.2     | Electric/Gas               | Electric     | Gas          | Gas       | Gas     |
| C       | 211.2    | Electric                   | Electric     | Gas          | Gas       | Gas     |
| D       | 52.9     | Electric                   | Electric     | Gas          | Gas       | Gas     |
| Office  | Building T | 8997.7²*1                  | Electric/Oil | Gas          | Gas       | Gas     |
| Building H | 9242.7²*2   | Electric/Oil               | Electric     | Gas          | Gas       | Gas     |
| Residential House | 50.0-92.5²*3 *3 | Electric/Gas               | Electric     | Gas          | Gas       | Gas     |

Notes: *1. There are 11 offices with gross floor area ranging from 131.8m² to 982.5m² in Building T.
*2. There are 23 offices with gross floor area ranging from 39.3m² to 1661.7m² in Building H.
*3. The investigated 43 residential buildings with gross floor area ranging from 50.0m² to 92.5m² can be classified into 16 types.

Table 2. Schedule of Measurement Surveys

| Objects | Measurement Survey Days |
|---------|-------------------------|
|         | Summer | Autumn | Winter |
| SOHO    | Sep. 10, 2003 | Nov. 19, 2003 | - |
| B       | -      | -      | Feb. 11, 2004 |
| C       | Sep. 8, 2003 | Oct. 24, 2003 | - |
| D       | Sep. 12, 2003 | Oct. 31, 2003 | - |
| Office1 | Building T | Sep. 3, 2003 | Nov. 14, 2003 | Jan. 29, 2004 |
| Building H | Sep. 10, 2003 | Nov. 13, 2003 | Jan. 26, 2004 |
| Residential House | Aug. 28, 2001 | Oct. 10, 2001 | Jan. 16, 2002 |

Notes: *1. 34 offices in Buildings T and H were measured.
*2. 43 residential buildings were measured.
Where,
\( r_1 \) : Load leveling ratio, [%]
\( L_{\text{mea}} \) : The mean energy consumption value of 24 hours, [MJ/h]
\( L_{\text{max}} \) : The maximum value of energy consumption of 24 hours, [MJ/h]

Equation (1) can be used for evaluating equipment availability. And,
\[
\begin{align*}
    r_s &= \frac{L_{\text{office}} + L_{\text{house}} - L_{\text{SOHO}}}{L_{\text{office}} + L_{\text{house}}} \times 100 \\
    &= \left(1 - \frac{L_{\text{SOHO}}}{L_{\text{office}} + L_{\text{house}}} \right) \times 100 \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)
\end{align*}
\]

Where,
\( r_s \) : Energy-saving rate, [%]
\( L_{\text{office}} \) : Monthly or annual energy consumption basic unit of office, [MJ/(m$^2$•m)] or [MJ/(m$^2$•a)]
\( L_{\text{house}} \) : Monthly or annual energy consumption basic unit of residential buildings, [MJ/(m$^2$•m)] or [MJ/(m$^2$•a)]
\( L_{\text{SOHO}} \) : Monthly or annual energy consumption basic unit of SOHO, [MJ/(m$^2$•m)] or [MJ/(m$^2$•a)]

Equation (2) can be used for calculating monthly or annual energy-saving rate.

3.2 Fluctuation of Energy Consumption

In this paper, the thermal conversion factors for gas, electricity and oil are 46,055 [KJ/(m$^3$•N)], 10,258 [KJ/kWh] and 40,144 [KJ/l], respectively. In order to reduce the particularity of energy consumption linked to the individual action of users during the period of measurement, the mean hourly energy consumption values of investigation objects at a rate proportional to total energy consumption during a day were calculated. Using monthly energy consumption values, the average energy consumption per day of September, November and January were calculated. By the calculated proportion, Figs. 5, 6 and 7 show the hourly fluctuation of energy consumption in September (summer), November (autumn) and January (winter).

In Fig.5., the energy consumption of a residential building is more than that of an office during the evening hours and lower during the daytime. The reversals were at 0700 hours and 2100 hours. In contrast, the energy consumption value of SOHO between of office and residential building in most of time, and no significant differences were shown.

In Fig.6., the energy consumption peak value of a residential building was at 2000 hours, while that of an office maintained a high value from 0900 hours to 1500 hours and a low value during other times, especially from 2200 to 0700 hours. Against these characteristics, the energy consumption value of SOHO between office and residential building in most of time, and no significant differences were shown.

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3. Investigation Results

3.1 Definition of Load-leveling Ratio and Energy-saving Rate

To evaluate the load leveling effects, load leveling ratio and energy-saving rate resulting from synchronous load were defined as follows:
\[
r_1 = \frac{L_{\text{mea}}}{L_{\text{max}}} \times 100 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)
\]

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The energy consumption of 0100 hours is for hot bath water.

In Fig.7, SOHO energy consumption was a little more than a residential building but much lower than an office during the daytime. After 1800 hours, it showed a very similar pattern to a residential building but later than 2400 hours, it tended to be more than a residential building. That was because there was more automated office equipment in a SOHO than in a residential building, but less than in an office. The SOHO occupants were out on business in the daytime. Also, they never turn off their computers throughout the year. Those were the reasons why the energy consumption during the daytime hours was almost the same as that after 0300 hours. After returning home at night, the occupant worked till very late. That was the reason why energy consumption after midnight in a SOHO was higher than a residential building.

Notes: The numbers in ( ) are the number of sample objects.

3.3 Load Leveling Ratio \( r_l \)

Using equation (1), the load leveling ratios of SOHO, a residential building and office were calculated. According to Table 3, the load-leveling ratio of SOHO was higher than that of a residential building and office throughout the year. This means that the energy equipment availability of SOHO is higher than that of a residential building and office. In winter, though one sample object data was used, it showed a pretty high value. Here, the hourly mean value of the investigation objects was used.

3.4 Energy-saving Rate \( r_s \)

The energy-saving rate was calculated using the monthly mean energy consumption data of a SOHO, residential building and office. The results are shown in Table 4. The monthly energy-saving rate of SOHO indicated a fluctuation between 27.5% and 61.3%, with the lowest rate in November and the highest in September, while the annual energy saving was 44.1%. The results, as shown in Fig.8., show that SOHO has an energy consumption reduction effect, especially in the summer.

| Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Annual |
|------|------|------|------|------|------|------|------|------|------|------|------|--------|
| \( r_s(\%)\) | 35   | 39   | 33.2 | 36.4 | 47.2 | 55.9 | 59.7 | 60   | 61.3 | 42.5 | 27.5 | 30.6   | 44.1   |

Table 3. Load Leveling Ratio \( r_l \)

|            | Summer | Autumn | Winter |
|------------|--------|--------|--------|
| SOHO       | 63.7 (3) | 61.8 (3) | 55.8 (1) |
| Residential House | 56.5 (41) | 46.1 (43) | 49.5 (33) |
| Office     | 50.8 (34) | 46.9 (34) | 41.9 (34) |

Notes: The numbers in ( ) are the number of sample objects.
4. Discussions

This research is based on measurement surveys. Through investigations of SOHO, residential buildings and offices, the monthly, hourly energy consumption and lifestyle of users were ascertained. Also, the load-leveling ratio and energy-saving rate were defined. Using the investigation data, we discussed load-leveling effects and energy-saving effects of SOHO based on comparison with a residential building and office. Furthermore, the merits of SOHO are seen not only in load leveling and energy conservation, but also the convenience to people, the space that was saved by complex function, and the energy for transportation. Also, it saves time that can be used to communicate with occupants’ families. As mentioned above, there has been an increasing demand for living in urban centers recently. In order to optimize the use of small and expensive land in cities, both SOHO and the super high-rise condominium seem to be good choices. We hope that this study will serve as a useful reference for developers and policy makers.

Although the research is based on SOHO, the effects of other multipurpose buildings are expected and they should be further examined in the oncoming study.

5. Conclusions

This study aims to prove the load leveling and energy-saving effects of SOHO. To meet the growing housing demands, which were causing by the drift of populations toward urban centers, it is anticipated that the results will be used as reference in future urban development and renewal. For this purpose, investigations on SOHO, residential buildings and offices were conducted. This study has shown the following.

1) The reasonable usage structure or complex function of a building was proved to be very efficient in load leveling.
2) The rate proportion of total energy consumption during the day of SOHO compared to that of a residential building and office showed no significant difference.
3) The load-leveling ratio of SOHO was higher than that of a residential building and office. This means that the availability of energy equipment of SOHO is higher than that of a residential building and office, and that the load-leveling effect of SOHO was high.
4) The monthly energy-saving rate of SOHO indicated a fluctuation between 27.5% and 61.3%, with the lowest rate in November and the highest in September, while the annual energy saving was 44.1%. The results can be explained by the fact that SOHO has an energy consumption reduction effect, especially in summer.

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