Load Leveling and Energy-Saving Effects Evaluation of Multipurpose Building Based on Investigations on SOHO, Residential House and Small Office

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Abstract: - The California's energy crisis of 2000, like a bomb exploding in the crowd, alerted the world to the issues surrounding having a safe and secure energy supply. Increasing energy demand asks for a growing supply system in order to make stable energy supply realize. On the other hand, the environmental problems such as global warming issues, heat island phenomenon, resource depletion, and so on, ask for a more efficient and energy-saving supply system. With these backgrounds, 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 houses and small office were conducted in the central Tokyo area. Based on the results, multipurpose building was proven to have profound effects on load leveling and energy-saving.

Key-Words: - Load Leveling, DSM, Energy Efficiency, Sustainability, SOHO, Multipurpose Building

1 Introduction

The California's energy crisis of 2000, like a bomb exploding in the crowd, alerted the world to the issues of the safe and secure energy supply. The increasing energy demand asks for a growing supply system in order to secure of energy stable supplies. On the other hand, the environmental problems such as global warming issues, heat island phenomenon, resource depletion, and so on, ask for a more efficiency and energy-saving supply system. With these backgrounds, 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, price system).

Buildings are becoming large-scale and multipurpose. Multipurpose buildings have two types. The first is the building that has multipurpose parts, such as an office building with restaurants inside it. The other is the same space of the building with complex function, such as SOHO (Small Office Home Office), using for living, at the same time for working. In case of the former, the separate energy supply system is often used for administrative convenience. But in case of the latter, the building has the community of energy supply system. Many countries are collaborating on researches about the DSM technologies but load leveling effects of multipurpose building have been neglected [2,3].

In this paper, 24-hour investigations on SOHO, residential houses and small office were conducted in the central Tokyo area. Based on the survey results, the load leveling effects causing by the building function compound are discussed. As one of important methods of DSM, it meets the needs of lifestyle changes, as the same time improves the energy
efficiency, assures environmental and social sustainability. The results of this paper are expecting to be used as reference in future urban development and renewal.

2 Method

2.1 Definition of SOHO

In Japan, the word “SOHO” was used for the first time was on June 13th, 1995, in one of articles of Nikkei industrial newspaper. It was used in the governmental ”communication white paper” of the old Ministry of Posts and Telecommunications in 1998 for the first time, 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 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 was defined variously by different organization. In this research, we defined it as following:

- Dwelling unit of multiple dwelling houses;
- At least one person living there;
- Carrying on the tertiary industry activities by using a variety of 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 went sky-high, a demographic outflow continued and did not stop until 1996. Having suffered the stagnation after the bubble economy for about 7 years, as showing 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 demands for living, the super high-rise condominium attracts lots of attention. With the spread of computer and the Internet, and the demands for SOHO, in the future, the houses using for SOHO in urban center are expected to rise further, too.

2.3 Outline of the investigations

2.3.1 Outline of investigated objects

In these investigations, 4 SOHO, 43 residential houses and 10 small offices were selected. As showing in Table 1, SOHO A, B and residential houses are equipped with floor heating system for heating and PAC for heating and cooling. Others use PAC both for heating and cooling. Small offices use electric for hot water and kitchen. Others use gas. Additionally, the residential houses are located in the same super high-rise condominium. And they can be classified into 16 types according to the floor plans. Also, fully equipped LAN connection environment in each dwelling unit makes occupants can enjoy the Internet at home at any time they like. Fig. 2, 3 and 4 show the floor plan example of SOHO, residential house and small office.

Table 1 Investigation objects

<table>
<thead>
<tr>
<th>Objects</th>
<th>Type</th>
<th>AREA (m²)</th>
<th>Be Used as Source of Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOHO A</td>
<td>69.2</td>
<td>Electric / Gas</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>SOHO B</td>
<td>73.2</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>SOHO C</td>
<td>211.2</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>SOHO D</td>
<td>52.9</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>Small Office E</td>
<td>36.4</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>Small Office F</td>
<td>37.0</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>Small Office G</td>
<td>30.0</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>Small Office H</td>
<td>86.0</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>Small Office I</td>
<td>40.0</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>Small Office J</td>
<td>55.0</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>Small Office K</td>
<td>40.0</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>Small Office L</td>
<td>55.0</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>Small Office M</td>
<td>52.0</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>Small Office N</td>
<td>67.0</td>
<td>Electric</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
<tr>
<td>Residential house</td>
<td>50.0-92.5</td>
<td>Electric / Gas</td>
<td>Electric / Gas / Gas / Gas</td>
</tr>
</tbody>
</table>

Notes: Investigated 43 residential houses can be classified into 16 types and their gross floor area ranged from 50.0m² to 92.5m².

Fig.1 Changes in population and number of households in 23 wards of Tokyo in the last 20 years
2.3.2 Investigation areas and period
The investigations on SOHO and small offices were conducted in the central Tokyo area from June of 2003 to February 2004. Residential houses investigations were conducted from June of 2001 to February of 2002. Measurement surveys of energy consumption also were carried out. The periods are shown in Table 2.

2.3.3 Investigation items and method
In order to clarify the load leveling of energy, we carried out 24-hour measurements of electricity and gas consumption by recording the values of utilities meters once an hour. Also, the general information of architectures, equipments profile, the lifestyles of users, and monthly energy consumption were investigated.

### Table 2 Schedule of measurement surveys

<table>
<thead>
<tr>
<th>Objects</th>
<th>Type</th>
<th>Measurement Survey Day</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>A SOHO</td>
<td></td>
<td></td>
<td>Sep. 10</td>
<td>Nov. 19</td>
<td></td>
</tr>
<tr>
<td>B SOHO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C SOHO</td>
<td></td>
<td>Sep. 8</td>
<td></td>
<td>Oct. 24</td>
<td></td>
</tr>
<tr>
<td>D SOHO</td>
<td></td>
<td>Sep. 12</td>
<td></td>
<td>Oct. 31</td>
<td>Feb. 11</td>
</tr>
<tr>
<td>E Small Office</td>
<td></td>
<td>Sep. 5</td>
<td></td>
<td>Oct. 22</td>
<td>Jan. 23</td>
</tr>
<tr>
<td>F Small Office</td>
<td></td>
<td>Sep. 5</td>
<td></td>
<td>Oct. 22</td>
<td>Jan. 23</td>
</tr>
<tr>
<td>G Small Office</td>
<td></td>
<td>Sep. 18</td>
<td></td>
<td>Nov. 7</td>
<td>Jan. 26</td>
</tr>
<tr>
<td>H Small Office</td>
<td></td>
<td>Sep. 16</td>
<td></td>
<td>Oct. 30</td>
<td></td>
</tr>
<tr>
<td>I Small Office</td>
<td></td>
<td>Sep. 16</td>
<td></td>
<td>Oct. 30</td>
<td></td>
</tr>
<tr>
<td>J Small Office</td>
<td></td>
<td>Sep. 16</td>
<td></td>
<td>Oct. 30</td>
<td>Jan. 29</td>
</tr>
<tr>
<td>K Small Office</td>
<td></td>
<td>Sep. 16</td>
<td></td>
<td>Oct. 30</td>
<td></td>
</tr>
<tr>
<td>L Small Office</td>
<td></td>
<td>Sep. 16</td>
<td></td>
<td>Oct. 30</td>
<td>Jan. 29</td>
</tr>
<tr>
<td>M Small Office</td>
<td></td>
<td>Sep. 16</td>
<td></td>
<td>Oct. 30</td>
<td></td>
</tr>
<tr>
<td>N Small Office</td>
<td></td>
<td>Sep. 16</td>
<td></td>
<td>Oct. 30</td>
<td></td>
</tr>
<tr>
<td>Residential house</td>
<td></td>
<td>Aug. 28</td>
<td></td>
<td>Oct. 10</td>
<td>Jan. 16</td>
</tr>
</tbody>
</table>

Notes: 43 residential houses were measured.

### 3 Investigation results

#### 3.1 Definition of load leveling ratio and energy-saving rate
To evaluate the load leveling effects, load leveling ratio [4] and energy-saving rate because of synchronous load were defined as follows:

\[ R_i = \frac{L_{\text{mea}}}{L_{\text{max}}} \times 100 \]

Where,
- \( R_i \): 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,
\[ r_s = \frac{L_{\text{working}} + L_{\text{living}} - L_{\text{SOHO}}}{L_{\text{working}} + L_{\text{living}}} \times 100 \]
\[ = \left(1 - \frac{L_{\text{SOHO}}}{L_{\text{working}} + L_{\text{living}}} \right) \times 100 \] .................................(2)

Where,
\( r_s \): Energy-saving rate, [%]
\( L_{\text{working}} \): Monthly or annual energy consumption basic unit of small office, [MJ/(m\(^2\)-m)] or [MJ/(m\(^2\)-a)]
\( L_{\text{living}} \): Monthly or annual energy consumption basic unit of residential house, [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, thermal conversion factors for gas and electricity are 46055 [KJ/(m\(^3\)-N)] and 10258 [KJ/kWh], respectively. In order to reduce the particularity of energy consumption linking to the individual action of users during the period of measurement, the mean hourly energy consumption values at a rate proportion to total energy consumption during a day were used. Fig. 5-7 show the hourly fluctuation of energy consumption in summer, autumn and winter. In Fig. 5, the proportion of residential house is higher than that of small office during evening hours and lower during daytime. The reversals were at 9 o’clock and 20 o’clock. In contrast to it, the proportion of SOHO between them and no significant differences were shown. In Fig. 6, the proportion of residential house had two peak values, which were at 7 o’clock and 22 o’clock, while that of small office kept high value from 10 o’clock to 21 o’clock and low value during other time. Against those characteristics, the proportion of SOHO almost kept the same value except the period of 20 o’clock to 2 o’clock. In Fig. 7, the proportion of SOHO kept almost the same value as residential house and small office from 2 o’clock to 10 o’clock except 8. From 10 o’clock to 24 O’clock, it kept between residential house and small office by a small fluctuation in proportion.

3.3 Load leveling ratio \( r_l \)

Using equation (1), the load leveling ratio of SOHO,
though one sample was used, it showed a pretty high value. In the other hand, the value of small office is high, too. That’s because the employees in small office worked long time and refrigerator and electric pot were set up almost in each small office.

3.4 Energy-saving rate $r_s$
Using the mean monthly energy consumption of SOHO, residential house and small office, the energy-saving rate was calculated. The result was shown in Table 4. The monthly energy-saving rate of SOHO indicated a fluctuation between 22.1% and 59.8%, with the lowest rate in December and the highest in August. The annually energy-saving was 41.8%. The result can be explained that SOHO has energy consumption reduction effect, especially in summer.

<table>
<thead>
<tr>
<th>Table 3 Load leveling ratio $r_l$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Load leveling ratio $r_l$ (%)</strong></td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td>SOHO</td>
</tr>
<tr>
<td>Residential house</td>
</tr>
<tr>
<td>Small office</td>
</tr>
</tbody>
</table>

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

4 Discussion
This research is based on measurement surveys. Through the investigations on SOHO, residential house and small office, the monthly, hourly energy consumption and lifestyle of users were grasped. As mentioned above, all of them were similar in gross floor area. They all had the Internet environment and were equipped by refrigerator and electric pot. Also, load leveling ratio and energy-saving rate were defined. Using the investigation data, we discussed load leveling and energy-saving effects of multipurpose building based on the comparison of SOHO with residential house and small office. With growing of urban population, in order to use the expensive and rare inner-city land efficiently, more and more multipurpose buildings are supposed to be supplied. Appropriate uses of architectonics can implement the load leveling and energy-saving. It will further contribute to reducing the environmental burden and achieving sustainable development. Furthermore, the merits of multipurpose building not only are shown in load leveling and energy conservation, but also the convenience to people and space that is saved by complex function. In the case of SOHO, it also saves commuting energy and time, and its occupants have more time to communicate with their families than commuters, which is very helpful to resolve many kinds of social problems.

Although the research about multipurpose building is based on SOHO, the effects in an urban are expected and examined in further study.

5 Conclusions
This study aims to study the load leveling and energy-saving effects of multipurpose building. To meet the growing housing demands, which were caused by the drifting of population toward urban centers, the results are expecting to be used as reference in future urban development and renewal. For this purpose, investigations on SOHO, residential house and small office were conducted. Main results of this study are shown below.

1) The dimensionless parameters, load leveling ratio $r_l$ and energy saving rate $r_s$, were successfully defined, which were used to evaluate the energy saving potential in a quantitative way.

2) The rate proportion to total energy consumption during a day of SOHO between that of residential house and small office and no significant differences were shown.

3) The load leveling ratio of SOHO was higher than that of residential house and small office. This means that the energy equipment availability of SOHO is higher than that of residential house and small office. The load leveling effect of SOHO was also proved to be high.

4) The monthly energy-saving rate of SOHO indicated a fluctuation between 22.1% and 59.8%, with the lowest rate in December and the highest in August. The annually energy-saving was 41.8%. The result can be explained that SOHO has energy
consumption reduction effect, especially in summer.

5) Though this research is based on SOHO, residential house and small office, the basic idea is expected to apply to the other multipurpose buildings.

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