Reduction in Residential Energy Consumption Owing to Lifestyle Changes
—A Survey Research for Meguro Ward in Tokyo, Japan

Kazuhiro Yuasa*1, Mai Yata2, Yoichiro Nakano3 and Shuji Fujii4

1 Associate Professor, Department of Architecture and Building Engineering, Tokyo Institute of Technology, Japan
2 Doctoral Student, Department of Architecture and Building Engineering, Tokyo Institute of Technology, Japan
3 Student, Department of Music, Toho Gakuen College, Japan
4 Professor, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Japan

Abstract
Reducing energy consumption in the residential sector is crucial for addressing global warming. This study aims to evaluate the reduction in residential energy consumption owing to changes in residents' awareness and lifestyle. First, the power consumption of home electronics and the low-impact lifestyle recommended in 2010 were reviewed, and the annual reduction in electricity consumption by practicing low-impact lifestyle was defined as low-impact lifestyle point. Second, a questionnaire survey was conducted in Tokyo's Meguro Ward to investigate the relation between the residents' lifestyle and energy consumption. Results showed that the annual energy consumption decreased as the lifestyle points of the households increased. Finally, the effect of the Great East Japan Earthquake on residents' awareness regarding energy was examined. More than 85% of the respondents were found to have experienced a change in their awareness toward energy and the average reduction rate was found to be 13%.

Keywords: residence; energy consumption; lifestyle; questionnaire survey; the Great East Japan Earthquake

1. Introduction
To counteract global warming, urgent measures to reduce greenhouse gas emissions are required. Reducing energy consumption is one such measure. However, the energy consumption of the Japanese civilian sector has been steadily increasing with time. Therefore, the reduction of energy consumption in the residential sector, which accounts for more than 40% of the energy consumption in the civilian sector, is crucial for reducing greenhouse gas emissions.

Owing to the accident in the Fukushima nuclear power plant caused by the Great East Japan Earthquake in 2011, eastern Japan suffered serious electricity shortages. Rolling blackouts were implemented in the Greater Tokyo Area, and though not mandatory for the residential sector, various home energy-saving measures were encouraged by the government.

Residential energy consumption has been studied worldwide; for example, Uno et al. (2012) and Ekasiwi et al. (2013) conducted questionnaire surveys and field measurements in Surabaya, Indonesia, to examine the energy consumption of air conditioners. Ouyang et al. (2011) monitored the electricity consumption of several households in Hangzhou, China, and examined the change before and after the energy-saving measures were introduced.

Moreover, there have been numerous studies on energy consumption in the Japanese residential sector. A nationwide project was conducted by the Architecture Institute of Japan from 2001 to 2003, named the "Investigation on Energy Consumption of Residences all over Japan" (hereafter AIJ Investigation), and the results were reported in studies by Hasegawa et al. (2004), Murakami et al. (2006), Inoue et al. (2006), Yoshino et al. (2006a, 2006b), and Akabayashi et al. (2007). Moreover, Ishida (1997) and Miura (1998), among others, analyzed the energy consumption in terms of regional characteristics and family composition. Yamagishi et al. (2005), Mae et al. (2006), Hirayama et al. (2007), and Xie et al. (2007), among others, studied energy consumption by analyzing specific households in detail. However, residential energy consumption depends on not only regional characteristics, house structures, and family compositions, but also the lifestyle of the household members, which is one of the reasons why it is difficult to implement comprehensive energy conservation countermeasures in residences.

On the other hand, Mae et al. (2003), Niwa et al. (2004), Yamato et al. (2004), Mizutani et al. (2006),
2. Home Electronics and Low-Impact Lifestyle in 2010

2.1 Research Outline

To understand the current state of the residential sector in 2010, the authors examined the number of home electronics owned per household, the power consumption of home electronics, and the recommended low-impact lifestyle. The number of home electronics per household was obtained from the consumer confidence survey conducted by the Cabinet Office. The rated power consumption, or the annual power consumption, and the standby power consumption were obtained from the catalogs issued by the top five appliance manufacturers. As for the low-impact lifestyle, the energy-saving measures recommended by the Ministry of Economy, Trade and Industry (METI) and several institutions including gas and electric power companies were reviewed.

2.2 Research Results and Low-Impact Lifestyle Points

The number of home electronics and the corresponding power consumption in 2010 are shown in Table 1. As mentioned in Section 2.1, the number of home electronics was obtained from the Cabinet Office, and the power consumption was calculated using the average power consumption in the 2010 product catalogs. For comparison, the power consumption in 2000 in the study of Hasegawa et al. (2006) is also listed.

The power consumption of all appliances except irons and recorders has decreased since 2000. Television sets have shifted from cathode-ray tube (CRT) to liquid-crystal display (LCD), ray tube (CRT) to liquid-crystal display (LCD), and the power consumption in the 2010 product catalogs. For comparison, the power consumption in 2000 in the study of Hasegawa et al. (2006) is also listed.
and the operation power consumption and standby consumption decreased from 153 W to 39 W and from 14 W to 0.24 W, respectively. However, the number of televisions per household increased from one to two. In addition, the power consumption of personal computers decreased from 300 W to 55 W, whereas the standby consumption increased from 1.5 W to 2.1 W. Multimedia recorders are the only devices that showed an increase in power consumption, presumably because of the shift from VHS to DVD. Furthermore, there was an enhancement in the efficiency of air conditioning and lighting, which accounts for most of the household energy consumption. The coefficient of performance (COP) of air conditioning increased from 3.25 to 5.18 for heating and 2.67 to 4.37 for cooling, whereas the operation power consumption for lighting decreased from 131 W to 14 W to 0.24 W, respectively.

The recommended 2010 low-impact lifestyle list is shown in Table 2. The last research was conducted in 2000, and since then, 43 items have been quantitatively defined. In addition, new items have been added, such as rice cookers, air conditioning, and lighting. Most new items are seen in the lighting category, in which four out of six items have been added since 2000. The new items are the "choose Top Runner product" for rice cooker, "do not cover compressor unit" for air conditioning, "use dimmer," "turn off wall switch," "clean cover regularly," and "use LED" for lighting.

To consider the influence of each appliance and lifestyle on energy consumption, the annual reduction in electricity consumption is used as the coefficient and defined as the "low-impact lifestyle point" (hereafter lifestyle point). Table 3. lists the lifestyle points for air conditioning, refrigerators, television sets, washing machines, and lighting are lifestyle points from the viewpoint of the penetration of appliances. The maximum point of 61.72 is achieved when "control temperature settings" under the refrigerator category are practiced. The minimum point of 3.6 is the result of

| Appliances | Action | Settings | Lifestyle Point | Reference |
|------------|--------|----------|----------------|-----------|
| Air Conditioning | Decrease usage hours | Shorten usage hours by 1 hour per day (28°C setting) | 5.55 III | II |
| Refrigerator | Decrease brightness | Adjust brightness from maximum to middle | 2.46 I | |
| Washing Machine | Use less frequently | Comparison between 40% and 80% of rating capacity (6kg) | 5.88 I | |
| Lighting | Use dimmer | Use incandescent bulb at 60% brightness for 1 hour/day | 19.71 III | |

*1 See Table 2. for reference
*2 Converted at 22yen/kWh (Home Electronic Appliances Fair Trade Conference)
the "use dimmer" under the category of lighting. When all actions are considered, the total lifestyle points are approximately 445. The item "use with a fan" under the air conditioning category is omitted from the lifestyle points because it implies the use of fans and raising the temperature setting of air conditioning, which is similar to "control temperature setting."

3. Questionnaire Survey on Lifestyle and Energy Consumption in Meguro Ward, Tokyo

3.1 Survey Outline

A survey on lifestyle and energy consumption was conducted in Meguro Ward, Tokyo, in November 2011. One thousand detached houses relatively close to the Tokyo Institute of Technology, excluding dwellings with shops, were arbitrarily selected for the survey. The questionnaire was left in residential mailboxes with a self-addressed envelope. When the questionnaire was returned, prepaid cards were later sent to the respondents as a reward.

The survey items listed in Table 4. are the respondents' gender and age, number of residents, residents' gender and age, duration of use of home electronics, lighting types, the respondents' view on LED, the respondents' degree of practice of low-impact lifestyle, and the respondents' change in awareness concerning energy since the earthquake. Furthermore, the respondents were asked to fill in their gas and electricity consumption of the past 24 months, which could be obtained from their monthly bills, or from gas and electric company websites or call centers.

The response rate was 22.7% for the questionnaire and 8.1% for the energy consumption data. Analysis of energy consumption was performed on 49 households, which covered the entire 24-month data.

The respondents' gender and age is shown in Fig.1., and the number of residents vs. the number of responses is shown in Fig.2. The main respondents were male in their 60s and 70s, and females in their 70s, as well as 40s and 30s. Two-person households accounted for 40% of the households and the number of elderly households was relatively high.

3.2 Relation between Lifestyle and Energy Consumption

Fig.3. shows the types of lighting currently being used and the respondents' view on LEDs. In 2011, the typical types of lighting were incandescent and fluorescent lamps, and only 20% of the respondents were using LEDs. However, 80% of the respondents gave a positive response to switching to LED from incandescent and fluorescent lamps.

Fig.4. shows the duration of use of home electronics. Owing to the transition of the television-broadcasting format from analog to digital in 2011, the average...
duration of use of television sets was shorter compared to other devices. As a result, 80% of the respondents owned televisions that were less than five years old. As for the other home electronics, approximately 60% of the respondents owned appliances that were older than five years and approximately 20% owned appliances that were more than 10 years old.

Furthermore, 42% of the respondents answered that the Eco-Point System, implemented from May 2009 to March 2011, motivated them to replace their home electronics with more energy-efficient products.

Fig. 5. shows the respondents’ degree of practice of low-impact lifestyle. More than 75% of the respondents were practicing "decrease usage hours" under the lighting category and "control temperature settings" under air conditioning. Compared to lighting, where only one item was consistently practiced, most of the items under air conditioning were well practiced. The possible reason is that most of the lifestyle points under air conditioning are relatively high and may be widely recognized as energy saving measures by the residents. Forty-three percent of the respondents practiced "decrease brightness" under the refrigerator category, which has the highest lifestyle points (61.72 Points.) Only 16% of the respondents practiced "decrease brightness" under the television category; although it has a relatively high lifestyle point. However, "decrease usage hours" is an easier task than "decrease brightness," and 51% of the respondents selected this item. The effect of digitalization was seen in "shut off main power," where some respondents stated that they do not shut off the main power because digital televisions run automatic updates in standby mode.

Fig. 6. shows the relation between lifestyle points and electricity consumption. The averages of the lifestyle points and electricity consumption were 22.4 and 61 GJ, respectively. The average electricity consumption of single households was 22 GJ; however, no significant difference was seen in two-four-person households. In addition, five out of 49 households scored lifestyle points higher than 300. Overall, there was a tendency for annual electricity consumption to decrease as the lifestyle points increased.

3.3 Changes in Energy Consumption and Lifestyle before and after the Great East Japan Earthquake

Fig. 7. shows three examples of monthly energy reduction. Because the earthquake occurred in March 2011 and the survey was conducted in November, the energy consumption from April to September was compared with the period between 2010 and 2011.
The change in energy consumption before and after the Great East Japan Earthquake roughly falls into three categories. The ratio of Type A to B to C is 26 to 6 to 14. In many households, such as Type A shown in Fig.7., electricity consumption decreased after the earthquake in April and May, and then in August and September when air conditioning was often used. Gas consumption also decreased soon after the earthquake. However, it increased to the prequake level, or even exceeded the prequake level in several households. In Type B households shown in (2), the electricity and gas consumption decreased after the earthquake and then gradually increased to the prequake level. In Type C households shown in (3), the decrease in electricity consumption could not be seen right after the earthquake but the electricity consumption decreased in July, August, and September. Significant change in gas consumption could not be seen in Type C households.

More than 85% of the respondents answered that the Great East Japan Earthquake affected their attitude toward energy. Fig.8. shows the results of an open question on the low-impact lifestyle that respondents have adopted since the earthquake. The most common answer was "decrease usage hours" for lighting, which was relatively easy to practice. In addition, the "decrease usage hours" was another common answer for air conditioning, which may be the cause of reduced electricity consumption in August and September. Next to the "decrease usage hours" for lighting and air conditioning, the third most common answer was "be more aware of energy consumption in general." Several of the answers were not exclusive to the use of home electronics, and respondents reassessed their daily lives, e.g., "switch to eco-friendly equipment," "gather in one room to save electricity," "change electricity contract," "charge during the night," and "go to bed early."

Fig.9. shows the change in energy consumption before and after the earthquake. The average electricity consumption of two–four-person households were 25–28 GJ/6 months and did not show any significant difference, whereas the average electricity consumption of single households was 11 GJ/6 months, which was less than half of that in two–four person households. The reduction rate did not vary regardless of energy consumption before the earthquake, whereas the average reduction rate for electricity was 15–17% for the two–four-person households. The highest reduction rate was approximately 50%. Furthermore, with the exception of two-person households, the reduction rate in every household was on the positive side for electricity.

The average gas consumption for two–four-person households was approximately 80 MJ/6 months and the average reduction rate was lower than that of electricity, which remained at 5–8%. Whereas, the reduction rate in electricity consumption was positive for most households, the reduction rate in gas consumption was negative for 15 out of 50 households. Some respondents answered that they tried to use gas instead of electricity after the earthquake, which indicates that many residents were aware of their electricity consumption but not necessarily conscious of the reduction in gas consumption.

The average total energy consumption was 40 GJ/6 months and the reduction rate was 13%. Even though the gas consumption for some households increased after the earthquake, most of the households reduced their energy consumption, and as a result, the reduction rate was positive for most of the households.

4. Conclusions

In this study, the reduction in energy consumption owing to changes in the residents' awareness and lifestyle was investigated. The results are summarized as follows:

(1) To consider the effect of performance and usage of home electronics on energy consumption, the power consumption of home electronics and the recommended low-impact lifestyle in 2010 were reviewed. All appliances except irons and multimedia recorders show a decrease in power consumption since 2000. As for low-impact lifestyle, 43 items were quantitatively defined and six new items were added since 2000.

(2) A questionnaire survey on the residents' awareness, lifestyle, and energy consumption was conducted in Meguro Ward, Tokyo. The annual reduction in energy consumption by practicing a low-impact lifestyle was used as a coefficient and was defined as the "low-impact lifestyle point." It was found that as the lifestyle point increased, the annual energy consumption of the households decreased.

(3) The effect of the Great East Japan Earthquake on residents' awareness concerning energy was examined. Eighty-five percent of the respondents experienced a change in their awareness concerning energy after the earthquake. The most common answer on the low-impact lifestyle that respondents have adopted since the earthquake was "decrease usage hours" for lighting and air conditioning. The third most common answer was "be more aware of energy consumption in general." The overall average electricity consumption decreased by 15% after the earthquake, and with the exception of two households, the rate of electricity reduction for each household was positive. Although the gas consumption of some households increased after the earthquake, the average reduction rate of the total energy consumption was 13%, and most of the households decreased their energy consumption after the earthquake.
References
1) Akabayashi, S. et al. (2007) Study on the Energy Consumption of Various Electric Appliances for the 80 Houses in Japan. Journal of Environmental Engineering, No.619, 61-67. (in Japanese)
2) Ekasiwi, S. et al. (2013) Field Survey of Air Conditioner Temperature Settings in Hot, Humid Climates, Part 1: Questionnaire Results on Use of Air Conditioners in Houses During Sleep. Journal of Asian Architecture and Building Engineering, 12(1), pp.141-148.
3) Fong, W. et al. (2007) Influences of Indirect Lifestyle Aspects and Climate on Household Energy Consumption. Journal of Asian Architecture and Building Engineering, 6(2), pp.395-402.
4) Genjo, K. et al. (2012) Lifestyle and Energy Consumption of Student One-Person Households in Tohoku Area. Journal of Environmental Engineering, No.671, 11-18. (in Japanese)
5) Hasegawa, K. et al. (2006) Home Energy Saving by a Low Impact Life Style. Simulation Study Using a Standard Housing Model. Journal of Environmental Engineering, No.608, 97-104. (in Japanese)
6) Hasegawa, Y. et al. (2004) Energy Consumption in Housing on the Basis of National Scale Questionnaire. Study on Influence of Residential Characteristic and Dispersion of Energy Consumption Part 1. Journal of Environmental Engineering, No.583, 23-28. (in Japanese)
7) Hirayama, S. et al. (2007) Daily Fluctuation of Energy Consumption for Each Usage. Study on Energy Consumption in Houses in Kanto District. Journal of Environmental Engineering, No.613, 49-55. (in Japanese)
8) Inoue, T. et al. (2006) Energy Consumption in Housing on the Basis of National Scale Questionnaire. Journal of Environmental Engineering, No.606, 75-80. (in Japanese)
9) Ishida, K. (1997) Energy Consumption of Detached Houses. Journal of Architecture and Planning, No.501, 29-36. (in Japanese)
10) Mae, M. et al. (2006) Annual Sum and Monthly Fluctuation of Energy Consumption for Each Usage. Study on Energy Consumption in Houses in Kanto District. Journal of Environmental Engineering, No.610, 91-98. (in Japanese)
11) Mae, M. et al. (2003) The Study on Pattern Categorization of Time Schedule on Daily Life. Life Style and Energy Consumption of Residents on Urban Apartment Part 1. Journal of Environmental Engineering, No.573, 103-109. (in Japanese)
12) Miura, S. (1998) Study on the Regional Characteristics of Energy Consumption and its Uses of Housing All Over Japan. Journal of Architecture and Planning, No.510, 77-83. (in Japanese)
13) Mizutani, S. et al. (2006) Energy Consumption for Different Uses in Housing and Energy Usage. Analysis Based on National Scale Questionnaire. Journal of Environmental Engineering, No.609, 117-124. (in Japanese)
14) Murakami, S. et al. (2006) Detail Survey of Long-Term Energy Consumption for 80 Houses in Principal Cities of Japan. Description of the Houses and End Use Structure of Annual Energy Consumption. Journal of Environmental Engineering, No.603, 93-100. (in Japanese)
15) Niwa, Y. et al. (2004) Energy Consumption for Space Heating of Detached Houses in Nagano Prefecture, From Viewpoint of Residents’ Preconception and Heating Methods. Journal of Environmental Engineering, No.581, 73-79. (in Japanese)
16) Ouyang, J. et al. (2009) Effects of Improved Consumer Behavior on Energy Conservation in the Urban Residential Sector of Hangzhou, China. Journal of Asian Architecture and Building Engineering, 8(1), pp.243-249.
17) Uno, T. et al. (2012) Reduction of energy Consumption by AC due to Air Tightness and Ventilation Strategy in Residences in Hot and Humid Climates. Journal of Asian Architecture and Building Engineering, 11(2), pp.407-414.
18) Xie, J. et al. (2007) Detailed Analysis on Two-Years Energy Consumption and Thermal Environment. Journal of Environmental Engineering, No.618, 17-22. (in Japanese)
19) Yamagishi, A. et al. (2005) Energy Consumption by the Various Uses. A Study on the Energy Consumption in Houses in Niigata District Part 1. Journal of Environmental Engineering, No.593, 25-31. (in Japanese)
20) Yamato, Y. et al. (2004) Investigation on the Resident’s Consciousness, Life Style and Energy Consumption of Houses in and around Kyoto City. Journal of Environmental Engineering, No.586, 17-23. (in Japanese)
21) Yoshino, H. et al. (2006a) Survey of the Peak Electric in Residential Buildings, Analysis of the Data from Survey of Energy Consumption for 80 Houses in Japan. Journal of Environmental Engineering, No.610, 99-106. (in Japanese)
22) Yoshino, H. et al. (2006b) A Two Year Measurement of Energy Consumption and Indoor Temperature of 13 Houses in a Cold Climate Region of Japan. Journal of Asian Architecture and Building Engineering, 5(2), pp.361-368.
23) Yuasa, K. et al. (2009) Energy Saving Potential of Low-Impact Lifestyle in Residential Buildings. Journal of Environmental Engineering, No.642, 1019-1024. (in Japanese)