Installation of Residential Energy Systems: Local Conditions and Residents' Willingness

Kazuhiro Yuasa¹ and Mai Yata*²

¹ Associate Professor, Department of Architecture and Building Engineering, Tokyo Institute of Technology, Japan
² Researcher, Jyukankyo Research Institute Inc., Japan

Abstract
The feasibility of installing residential energy systems was investigated with respect to local conditions and residents' willingness toward installation. Visual surveys and questionnaires were conducted among 1,000 detached houses in Tokyo's Meguro Ward. The visual survey results showed that location had a greater impact on ground-level devices than on rooftop devices. The results of the questionnaire showed that more than 30% of people in all generational groups have considered photovoltaic installation, but less than 10% have considered solar water heater installation. The main reasons cited for not considering fuel cells and heat pump water heaters were the high initial cost and unfamiliarity with the product. When the questionnaire results were compared with those of the visual survey, it was found that more than 50% of suitable households were not interested in adding new systems to their homes. In particular, many respondents held a negative image of solar water heaters, which excluded them from consideration. Furthermore, elderly respondents cited their age as the main reason against installation.

Keywords: residential energy system; visual survey; questionnaire survey

1. Introduction
In recent years, taking countermeasures against climate change has become one of the world's most urgent tasks. The reduction of energy consumption in the residential sector plays a crucial role in reducing greenhouse gas emissions. Although the installation of residential energy systems (e.g., photovoltaics and high-efficiency water heaters) is a key approach to reducing residential energy consumption, widespread utilization of such systems is yet to be accomplished.

Numerous studies have been conducted on residential energy consumption in Japan. For example, a nationwide project was carried out between 2001 and 2003 by the Architectural Institute of Japan, and the results were reported by Hasegawa et al. (2004), Murakami et al. (2006), Inoue et al. (2006), Yoshino et al. (2006) and Akabayashi et al. (2007), among others.

The effectiveness of residential energy systems has been considered in many studies through simulations and empirical measurements; however, when dealing with the on-site installation of residential energy systems, there are limiting factors that need to be addressed in order to facilitate broader usage. Liu et al. (2006) evaluated the installation of photovoltaics, cogeneration, and all-electrified systems in detached houses in terms of energy saving, environmental impact, and economic effects. Kurosawa et al. (2010) analyzed user preference for adopting energy-saving facilities using conjoint analysis in terms of costs. Won et al. (2011) conducted market research on energy-efficient water heaters in order to analyze adoption rates and adoption obstacles.

Although on-site installation of residential energy systems is influenced by the condition of installation sites and residents' willingness toward installation, such systems have scarcely been studied. The aim of this study was to assess the feasibility of residential energy system installation from the viewpoint of local geography and residents' awareness toward installation through visual and questionnaire surveys.

2. Impact of Location on Feasibility of Residential Energy System Installation
2.1 Visual Survey Outline
In order to investigate the feasibility of residential energy system installation with respect to local conditions, visual surveys were conducted on 1,000 arbitrarily selected detached houses in Tokyo's Meguro Ward. The survey was conducted in November 2011 and dwellings with shops were excluded. In this study, photovoltaics, solar water heaters, home fuel cell cogeneration systems (hereinafter called fuel cells), and heat pump water heaters (hereinafter called HP
water heaters) were considered as residential energy systems.

The indices for the visual survey evaluation are shown in Table 1. To investigate the feasibility of photovoltaics and solar water heater installation, the authors visually investigated roof area, slope, aspect, and shading. Approximately 20 m² was used as an indication of the roof area, while roof slope was assessed on a scale of 0 to 3 (from flat to 45°). If the slope was greater than 45°, or if the roof was facing north, the house was considered unsuitable for installation. Shading was classified as: "No shading," meaning no obstacles nearby to cast shadow on the roof; "Shading from removable objects such as trees"; and "Shading from immovable objects such as adjacent buildings." For fuel cells and HP water heaters, premises were evaluated by using the required installation space for fuel cells as an approximate indicator and classified as: "Sufficient space," "Conditional," and "Insufficient."

Table 1. Visual Survey Evaluation Index

| Item          | Evaluation Index                                           |
|---------------|------------------------------------------------------------|
| Area          | Used 20m² as a rough indication of roof area               |
| Slope         | On a scale of 0 to 3                                       |
| Shading       | On a scale of 0 to 2                                       |
| Premises Area | Used 2.5m by 1m as a rough indication of installation area |

2.2 Grouping of Land Use Zones

Under the City Planning Law, urban areas of Japan are divided into 12 Land Use Zones, which can be summarized into residential, commercial, and industrial uses. Each Land Use Zone has specifications concerning the types of buildings that can be constructed. Prior to conducting the visual survey, Land Use Zones were categorized into four groups by usage, floor-area ratio, and building coverage ratio. Table 2. shows the groupings by Land Use Zone, including: Group I. low-rise residential zones; Group II. middle-high-rise residential zones; Group III. residential and industrial zones; and Group IV. commercial zones. Group I zones had the lowest floor-area ratios and building coverage ratios, while Group IV zones had the highest ratios and were primarily located near stations and downtown areas. Of 23 Wards in Tokyo, Meguro had the highest percentage of residential zones. The area ratio of Group I and Group II was 65% in Meguro Ward, while it was only 39% for Tokyo as a whole.

Table 2. Grouping of Land Use Zone

| Group | Constituent Zone                  | Representative Zone                  | Area Ratio | Building Coverage Ratio |
|-------|-----------------------------------|--------------------------------------|------------|-------------------------|
| I     | Land Use Zone                     | Category I & II exclusively low-rise residential | 20%        | 40%                     |
|       | Floor-Area Ratio                  | Building Coverage Ratio              |            |                         |
|       | I                                | Category I exclusively low-rise residential | 20%        | 40%                     |
| II    | Land Use Zone                     | Category I & II multi/high-rise oriented residential | 15%        | 25%                     |
|       | Floor-Area Ratio                  | Building Coverage Ratio              |            |                         |
|       | I                                | Category I high-rise oriented residential | 15%        | 25%                     |
|       | II                               | Category I exclusively high-rise residential | 20%        | 40%                     |
| III   | Land Use Zone                     | Category I & II residential Quasi-residential Quasi-industrial, Industrial | 40%        | 21%                     |
|       | Floor-Area Ratio                  | Building Coverage Ratio              |            |                         |
|       | I                                | Category I Quasi-industrial, Industrial | 40%        | 19%                     |
|       | II                               | Category I Residential Quasi-industrial | 40%        | 19%                     |
| IV    | Land Use Zone                     | Neighborhood Commercial                | 19%        | 13%                     |
|       | Floor-Area Ratio                  | Building Coverage Ratio              |            |                         |
|       | I                                | Neighborhood Commercial                | 19%        | 13%                     |

Fig. 1 shows the feasibility of photovoltaics and solar water heater installation. Group I had the highest feasibility, with 89% of the houses rated as suitable for installation. Although Group IV had the lowest number of suitable houses, it still maintained 73% feasibility, which showed the significant potential for solar energy utilization from a geographical standpoint.

Table 3. Requirements for "Conditional" Installation

- Downsizing vehicle
- Reducing the number of vehicles
- Removing compact sheds
- Reducing clutter in garages
- Moving flowerpots elsewhere
- Reducing the size of garden

Fig. 2 shows the feasibility of fuel cells and HP water heater installation. Compared with photovoltaics and solar water heaters, the differences between the groups were more prominent. More than 90% of the houses in Group I, and 45% of the houses in groups II and III were rated as having "Sufficient space." For Group IV, even including "Conditional," only 54% of the houses were rated suitable for installation.

Table 3. shows the requirements for "Conditional" installation for Fuel Cells and HP water heaters, which mostly concerned automobiles ("Downsizing vehicle" and "Reducing the number of vehicles"), personal items ("Removing compact sheds" and "Reducing clutter in garages"), and plants ("Moving flowerpots elsewhere" and "Reducing the size of garden").
3. Residents' Willingness toward Residential Energy System Installation

3.1 Questionnaire Survey Outline

While the visual survey was being conducted, a questionnaire was distributed to the corresponding houses in order to investigate residents' willingness toward energy system installation. The questionnaire was left in residential mailboxes with a self-addressed envelope. When a questionnaire was returned, a prepaid card was sent to the respondents as a reward. The survey items listed in Table 4. are the respondents' gender and age, house specification (e.g., structure, area, and age), degree of recognition and desirable payback time of the systems, willingness toward system installation, and reasons for/against installation. The response rate was 21.6% for Group I, 26.0% for Group II, 20.6% for Group III, and 22.7% for Group IV. The total response rate was 22.7%.

Table 4. Questionnaire Survey Items

1. Respondents' gender and age
2. House Specification
3. Degree of recognition of solar water heater, fuel cells, HP water heater and HEMS
4. Desirable payback time for photovoltaics, solar water heater, fuel cells and HP water heater
5. Willingness toward installation of following above devices and reasons for/against installation

3.2 Questionnaire Survey Results

3.2.1 Gender, Age, and Family Composition

The respondents' ages and gender are shown in Fig. 3., and the number of residents vs. the number of responses is shown in Fig. 4. Two-person households accounted for 37% of the responses. The ratio of elderly households (those consisting solely of residents over 70) was high in one-person and two-person households, being 75% and 39%, respectively.

Fig. 3. Respondents' Gender and Age

Fig. 4. Number of Residents vs. Number of Responses

3.2.2 Degree of Recognition and the Desirable Payback Time of the Systems

The degree of recognition for each device is shown in Fig. 5. Since photovoltaics are more widely recognized than other devices, they were omitted from the questionnaire and replaced by the Home Energy Management System (hereinafter called HEMS).

In order to compare the differences between generations, respondents' ages were divided into three groups: the younger generation (from 10–39 years), the middle-aged generation (from 40–69 years), and the elderly generation (>70 years). The recognition of solar water heaters was ~70% for the middle-aged and elderly generations. Solar water heaters have been commercialized for more than 30 years and were popular in the 1980s, which may have contributed to the higher degree of recognition among older respondents. The degree of recognition for fuel cells and HP water heaters among the elderly generation were around 30% and 40%, respectively. For the younger and middle-aged generations, the degree of recognition was 60% for fuel cells, and 70% for HP water heaters. HEMS was the newest technology considered and the degree of recognition was low in all generational group, with the highest degree of recognition only 16% (seen among the middle-aged generation).

Fig. 5. Degree of Recognition

Fig. 6. Average Desirable Payback Time

Fig. 6. shows the average desirable payback time. Regardless of device, the desirable payback time was generally longer for older generations. The average desirable payback time for photovoltaics was 6.0 years for the younger generation, 5.9 years for the middle-aged generations, and 6.7 years for the elderly generation. The present average payback time for photovoltaics is thought to be 10–20 years, significantly longer than the residents' preferences.

3.2.3 Residents' Willingness Toward Installation

The percentage of respondents who had considered installation is shown in Fig. 7. Although installation feasibility in terms of location was evaluated by the visual survey and found to be more favorable in Group I, the questionnaire survey results showed that the residents' willingness toward installation in Group I was not necessarily higher than in other groups. When compared by age, no significant differences were observed for photovoltaics and solar water heaters. However, for the newer technologies (i.e., fuel cells and HP water heaters), only 3% of the elderly generation considered system installation. However, 14% of the younger generation and 11% of the middle-
The reasons for considering photovoltaics, which had the highest percentage of respondents who were interested in system installation, are shown in Fig.8. As age advanced, more respondents chose "Environment-friendly," whereas the "Feed-in Tariff (FIT)" was more popular among younger generations. The percentages of "Environment-friendly" and "FIT" for the younger generation were both 28%, while 45% of the elderly generation chose "Environment-friendly," but only 6% chose "FIT."

The reasons against installation cited for photovoltaics, solar water heaters, fuel cells, and HP water heaters are shown in Fig.9. More than 50% of all generations chose "High initial costs" for photovoltaics, while 14% of the younger generation chose "Living in rented housing," and 23% of the elderly generation chose "Duration of stay in current house is unknown." For solar water heaters, 66% of the younger generation chose "High initial costs," regardless of the fact that solar water heaters are usually significantly cheaper than photovoltaics. For photovoltaics, 15% of the younger generation chose "Living in rented housing" and 24% of the elderly generation chose "Duration of stay in current house is unknown." Compared to other devices, solar water heaters had a higher ratio of "Others" among the older generations. "No need for reduction in utility costs" was cited by both the middle-aged and elderly generations for fuel cells and HP water heaters, but was not cited by the younger generation. Besides "High initial costs," "Unfamiliar with the equipment" had the highest response rate for the middle-aged and elderly generations for fuel cells and HP water heaters. Although over 60% of the younger and middle-aged generations, and more than 30% of elderly generation recognized fuel cells and HP water heaters, they did not feel familiar with these devices, which prevented them from considering installation.

4. Comparison between Visual and Questionnaire Surveys

Fig.10. shows the percentages of geographical reasons cited against installation. Approximately 15% of the respondents in Group IV, and less than 5% in other groups, chose "Not enough sunlight" for photovoltaics and solar water heaters. The majority of respondents' reasons against installation were found to be non-geographical. The visual survey showed that more than 70% of the houses in every group were suitable for photovoltaics and solar water heater installation; together with the results from the questionnaire, this shows that location was not the main objection to photovoltaics and solar water heater installation in Meguro Ward.
The percentage of respondents citing "Not enough space" for fuel cells and HP water heaters were similarly high in groups II and IV. Group IV had the least number of suitable houses in the visual survey results, which was consistent with the questionnaire results. The findings showed that location had relatively more impact on fuel cells and HP water heater installation than it did on photovoltaics and solar water heaters.

Furthermore, it was found that residents had more negative feeling toward solar heaters than they did toward other devices. The fact that solar water heaters have been available for more than 30 years and have caused problems in the past worked negatively against them. Many of those who answered "Do not feel the necessity" or "Performance is questionable" either had solar water heaters in the past and had not felt their effectiveness, or had heard someone else complain about the device. However, mistrust was seen not only in the performance of solar water heaters, but also in the vendors. Therefore, it is essential to improve the image of solar water heaters in order to popularize them again.

Table 5. Free Answers to the Reasons against Installation

| Installation Site: Roof | Visual Survey: Suitable / Questionnaire Survey: Willing | Visual Survey: Unsuitable / Questionnaire Survey: Unwilling |
|-------------------------|--------------------------------------------------------|----------------------------------------------------------|
| Photovoltaics           | Shading from adjacent building 6                       | Maintenance seems cumbersome 1                          |
|                        | The roof is facing North 4                             | Due to old age 3                                         |
| Solar Water Heater      | The shape of the roof is complex 2                     | Due to old age 2                                         |
| Fuel Cells              | Shading from adjacent building 1                       | Durability is questionable 3                            |
| HP Water Heater         | The shape of the roof is complex 1                     | The house is too old 2                                  |
|                        | Not enough space 4                                     | Planning home renovation 2                              |
|                        |                                                        | Maintenance seems cumbersome 1                          |
|                        |                                                        | Not enough space 2                                       |
|                        |                                                        | Using solar water heater 1                              |
|                        |                                                        | Relocating 1                                            |
|                        |                                                        | Planning home renovation 1                              |
|                        |                                                        | Total 25                                                 |
|                        |                                                        |                                                           |
|                        |                                                        |                                                           |

Fig. 11. shows the discrepancy between visual survey and questionnaire survey results. The percentage of households that were rated both unsuitable by the visual survey, and had residents unwilling to install, was 14% for photovoltaics and ~20% for the other devices. The table in Fig. 11. shows cases where the house was rated unsuitable for installation, yet the residents were willing to install the devices. More than 12 households showed interest in installing photovoltaics, but of these, 6 had shading from adjacent buildings, 4 had a north-facing roof, and 2 had a complex-shaped roof considered unsuited for installation.

The percentage of households that were rated suitable for installation (including "Conditional") by visual survey, but had residents unwilling to install, was 52% for photovoltaics, 76% for solar water heaters, 67% for fuel cells, and 65% for HP water heaters. The free text answers given by these households regarding their reasons against installation are listed in Table 5. The respondents who answered "The device is still premature" for photovoltaics felt that power generation efficiency was still too low to invest. Furthermore, since both photovoltaics and solar water heaters are installed on roofs and are highly visible, "It would compromise the exterior design" was a common reason cited for both devices.

"Satisfied with the existing water heater" was commonly cited against new solar water heaters, fuel cells, and HP water heaters. However, few respondents answered that they would consider installation when their existing water heater needed replacement. "Do not want to rely solely on electricity" was particularly cited for HP water heaters, and may reflect experiences with electricity shortages after the nuclear accidents caused by the Great East Japan Earthquake of 2011.

Finally, "Due to old age" was commonly cited against all four devices. Those respondents felt that either they had no money to invest since they were living on pensions, or that it was not worth installing since they might not live long. Since Japanese society is rapidly aging, efforts need to be made to make residential energy systems more accessible to the elderly.
5. Conclusions

In this study, the feasibility of residential energy system installation was investigated in terms of location and residents’ willingness toward installation. The results of the visual and questionnaire surveys can be summarized as follows:

1) The visual survey was conducted on 1,000 detached houses in Tokyo’s Meguro Ward. The results showed that more than 70% of the houses in every group were suitable for photovoltaics and solar water heaters. For fuel cells and HP water heaters, more than 90% of Group I had sufficient space to install, while only 54% of Group IV was considered suitable.

2) Questionnaires were distributed to the households used in the visual survey. It was found that more than 30% of all generations had considered photovoltaics installation, but less than 10% had considered solar water heater installation. The main reasons for not considering fuel cells and HP water heaters were high initial costs and unfamiliarity.

3) When the questionnaire outcomes were compared with the visual survey results, it was found that more than 50% of suitable households were not interested in installation. Negative images of solar water heaters prevented the residents from considering installation. Furthermore, elderly respondents cited their age as the main reason against installation.

This study illustrated the residents’ willingness toward residential energy system installation; however, the questionnaire methodology requires improvement before further study, in particular to increase the response rate.

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, pp.61-67 (in Japanese).

2) 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, pp.23-28 (in Japanese).

3) Kurosawa, T. et al. (2010) A Questionnaire-Type Survey on the User Preferences for Energy-Saving Facilities in Green House. Journal of Environmental Engineering, No. 651, pp.473-480 (in Japanese).

4) 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, pp.93-100 (in Japanese).

5) Liu, Q. et al. (2006) Evaluation Research on the Introduction Effect for Various Energy Supply Systems for Detached Houses. Journal of Asian Architecture and Building Engineering, 5(2), pp.391-398.

6) Yoshino, H. et al. (2006) 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.

7) Won, A. et al. (2011) An Analysis of the Adoption of Energy-Efficient Water Heaters in the Residential Sector. Journal of Environmental Engineering, No. 663, pp.529-538 (in Japanese).

8) Ministry of Land, Infrastructure and Transport, (2003) Urban Land Use Planning System in Japan [Online]. Available: http://www.mlit.go.jp/common/000234477.pdf [September 22, 2014].