# Evaluation of Subsidy Systems for Energy Retrofit of Existing Dwellings in Japan

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***ABSTRACT:*** One of the most important energy issues of residential sector in Japan is to reduce energy consumption of the more than 50 million existing dwellings. Hence, energy retrofit subsidies are currently being implemented throughout Japan. However, energy retrofits supported by subsidies have not yet become widely popular, because subsidies don't cover the total cost of the retrofit but cover only less than 20% of the costs. Homeowners typically must contribute a large portion of the retrofit costs. Therefore, estimations on both energy conservation and cost performance of energy retrofits supported by subsidies are needed. In this study, several energy retrofit subsidy systems offered by local governments in Japan are investigated. Using the results, subsidy systems are classified into retrofit techniques, number of subsidies for each technique and subsidy rates. Moreover, energy conservation performance of each retrofit technique is analysed using a computer program for calculating home primary energy consumption. The results of the combinations of energy retrofit techniques, such as ceiling insulation, LED and latent heat recovery gas water heaters, which are selected from the view point of both energy conservation performance and subsidy performance, are shown.

***KEYWORDS:*** existing dwelling, energy retrofit, subsidy system, energy conservation performance, cost performance, primary energy

## 1. INTRODUCTION

In 2013 in Japan, approximately 90% of greenhouse gases included carbon dioxide from energy sources according to an official Information (Ministry of the Environment, 2015). Therefore, reduction of $CO_2$ emissions is almost the same as reduction in primary energy consumption. Primary energy consumption from the household sector increased by 103.7%, while primary energy consumption from all sectors increased by just 26.0 % between 1973 and 2013 in Japan (Agency for Natural Resources and Energy, 2015).

In considering energy conservation within the household sector, the Energy Saving Standard for newly built dwellings is popular. On the other hand, approximately 70% of existing dwellings' insulation performance is not sufficient from the view point of not only indoor environments but also energy conservation. Results using an official calculation program given by the government show that the energy consumption of a typical 30 year-old house is 20% greater than a newly built house (Figure 1). These results indicate that energy conservation measures for existing dwellings, whose number is more than 50 times of the number of annual newly built dwellings, are also important.

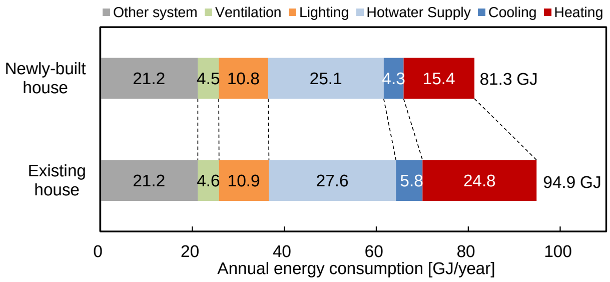


Figure 1. Primary energy consumption of newly built house and existing house (calculated result)

Recently, some local governments in Japan have started to provide subsidies for energy retrofit of dwellings. However, these kinds of subsidies have not been become widely popular, because these subsidies don't cover the total retrofit costs but only part of it. Therefore, subsidies' efficiency estimations of energy retrofits are needed especially with energy conservation and cost performance.

## 2. METHOD

### 2.1. Investigation of subsidy systems

In order to better understand the trend of subsidy systems provided by local governments, an investigation of subsidy systems of FY 2014 for energy retrofits was conducted. In this investigation, 235 municipalities that included the top five most populated municipalities in every prefecture were selected. The population of these 235 municipalities covers 55% of Japan's total population. Retrofit items, subsidy amounts, and subsidy rates were obtained by directly browsing the municipalities' application requirements for subsidy systems.

### 2.2. Estimation of primary energy reduction

Calculations for estimating primary energy reduction were computed by using a calculation program (Building Research Institute, 2015) (Figure 2), in order to show the effect of each retrofit item (Table 1). Moreover, the calculated results, utilising a base plan as a 30 year-old house before retrofit (Table 2) built in *zone 6*[i], were evaluated based on both initial and on running cost performance.

Insulation material conditions based on before and after the retrofits are shown in Table 4. Building envelope insulation performance of this base plan was set as the 1980 Energy Saving Standard of Japan

i. The Energy Saving Standard of Japan has 8 climate zones. The coldest climate is defined as the zone 1 and the hottest is as the zone 8. The zone 6 is mild climate zone and including most urban municipalities, like as Tokyo, and its population is the biggest among the zones.

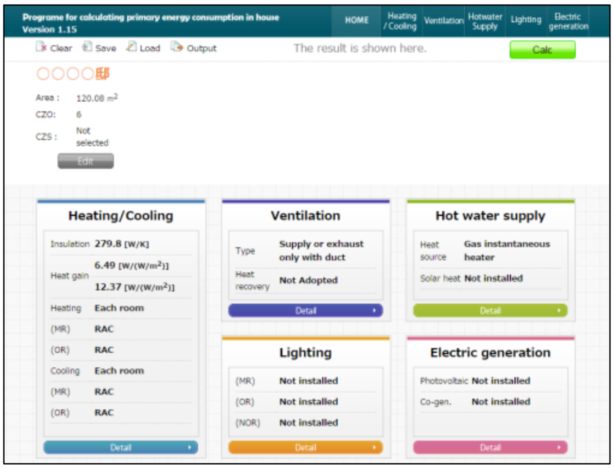


Figure 2. A screen of "*Programe for calculating primary energy consumption in house*" (Building Research Institute, 2015)

Table 1. Examples of major retrofit items obtained by the investigation

| | | |
|---|---|---|
| Insulation retrofit | | ・Ceiling<br>・Exterior wall<br>・Floor<br>・Window |
| Replacement of equipment | Hotwater supply | ・Electric heat pump water heater<br>・Latent heat recovery gas water heater<br>・Latent heat recovery oil water heater<br>・Solar water heater<br>・Photovoltaic system<br>・Highly insulated bathtub |
| | Electric generation | ・Photovoltaic power generation<br>・Fuel cell cogeneration system<br>・Gas turbine cogeneration system |
| | Heating & Cooling | ・Room air conditioner |
| | Lighting | ・LED |

Table 2. Setting conditions of the base plan

| | |
|---|---|
| Construction site region | ・Tokyo<br>・Climatic zone for Energy Saving Standard: Zone 6<br>・Climatic zone for annual solar radiation: A4 (Second largest radiation zone in Japan) |
| Building structure | ・2-story wooden house |
| Floor area | ・Total: 120.08 $m^2$<br>-First floor: 57.14 $m^2$<br>-Second floor: 62.93 $m^2$<br>-LDK: 29.81$m^2$<br>-Other habitable rooms: 51.34$m^2$ |
| Family structure | ・Husband and wife with two children |
| Age of building | ・Around 30 years old |
| Q value | ・4.69 $W/m^2K$ |
| Designed PEC | ・94.855 GJ/year |

(Q value[ii] $\leq$ 5.2 W/m$^2$K). Insulation materials to be used in the retrofit are set to meet the 2013 Energy Saving Standard of Japan (Q value $\leq$ 2.7 W/m$^2$K). Q value after the retrofits with all of the insulated parts of the house indicates 2.41 W/m$^2$K.

Setting conditions of equipment before and after the retrofits is shown in Table 5. Energy efficiency of the existing appliance on the market is used when calculating.

## 3. RESULTS AND DISCUSSION

### 3.1. Result of investigation on subsidy systems

192 of 235 observed municipalities provide 314 subsidy systems about energy retrofits. The retrofit items, shown in Figure 3, were classified into four categories: Insulation, equipment, electric generation/storage systems and other. Photovoltaic power generation is the most popular item. Fuel cell cogeneration system is also popular in the same category. Additionally, insulation retrofit and replacement of water heaters are also common.

The amount of subsidies and their subsidy rates, defined as the ratio of subsidies to total retrofit costs, of each item are shown in Figure 4. Ceiling insulation has the highest subsidy rates within the insulation category. Water heaters and LED, whose subsidies are comparatively small, have comparatively high subsidy rates in the replacement of equipment category. Electric generation systems were popular, however the estimated retrofit cost is so high that its subsidy rate is low (Figure 4, Table 3).

ii. Q value (Heat loss coefficient) refers to numerical indicator of housing insulation performance. The lower this value indicates, the higher the insulation performance is. Q value is obtained by calculating the amount of heat that escapes from exterior walls, ceilings, floors and other components of the house as well as the heat loss due to ventilation and air leakage and dividing the result by the total floor area of the house.

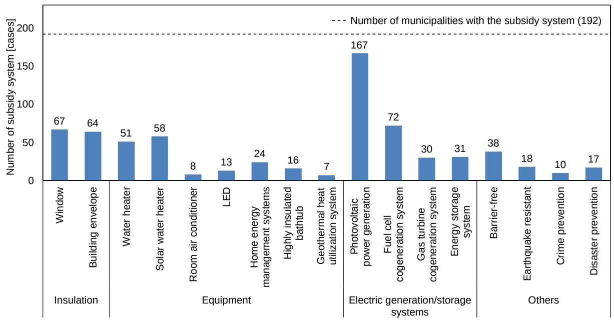


Figure 3. Number of retrofit items to be subsidised

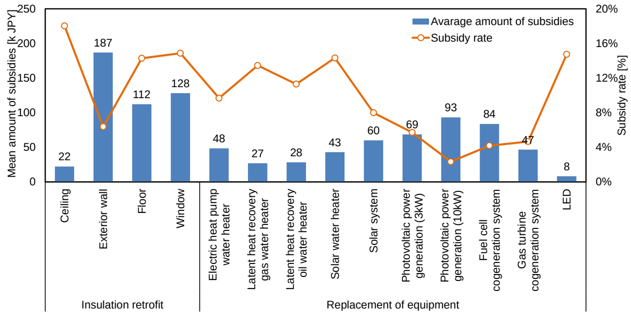


Figure 4. Mean amount of subsidies and their subsidy rates

Table 3. Retrofit cost and mean amount of subsidies and subsidy rate

| Retrofit items | Retrofit cost* [k JPY] | Mean amount of subsidies [k JPY] | S.D. [k JPY] | Subsidy rate |
|---|---|---|---|---|
| Ceiling | 123 | 22.2 | 10.6 | 18.0% |
| Exterior wall | 2,930 | 186.8 | 111.5 | 6.4% |
| Floor | 785 | 112.2 | 51.0 | 14.3% |
| Window | 862 | 128.2 | 64.6 | 14.9% |
| Electric heat pump water heater | 500 | 48.4 | 30.4 | 9.7% |
| Latent heat recovery gas water heater | 200 | 26.9 | 17.9 | 13.5% |
| Latent heat recovery oil water heater | 250 | 28.3 | 18.8 | 11.3% |
| Solar water heater | 300 | 43.0 | 29.9 | 14.3% |
| Solar system | 750 | 59.9 | 42.5 | 8.0% |
| Photovoltaic power generation 3kW | 1,200 | 68.6 | 37.1 | 5.7% |
| Photovoltaic power generation 10kW | 4,000 | 93.2 | 65.9 | 2.3% |
| Fuel cell cogeneration system | 2,000 | 83.7 | 55.3 | 4.2% |
| Gas turbine cogeneration system | 1,000 | 46.6 | 31.2 | 4.7% |
| LED | 55 | 8.1 | 2.6 | 14.7% |

* Retrofit costs of insulation items are excerpted from literature (IBEC 2010, Design Guidelines). Retrofit costs of equipment are set by referring to marketed products in Japan.

### 3.2. Calculated result of primary energy reduction

Calculated results of primary energy reductions by employing insulation retrofits and replacing equipment are summarised into Figure 5 and Figure 6. The cost-effectiveness, shown in Figure 5 and Figure 6, is defined as dividing the value of annual the primary energy reduction by the retrofit costs. Ceiling Insulation has the highest cost-effectiveness in the partial insulations and a combination of ceiling and floor insulation indicates high cost-effectiveness (Figure 5). In the equipment retrofit category, an LED installation is the most cost-effective (Figure 6). From a primary energy reduction view point, employing power generation equipment, such as photovoltaic power generation and fuel cell cogeneration system, have a high energy saving performance, but the cost- effectiveness is low. Moreover, smaller capacity power generation equipment, e.g. 3kW, has a higher cost-effectiveness than larger capacity equipment, e.g. 10kW.

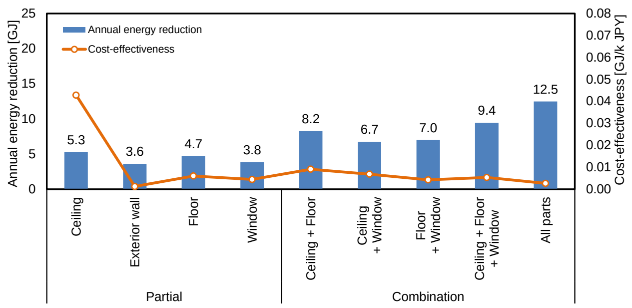


Figure 5. Annual primary energy reduction and cost-effectiveness by employing insulation retrofit

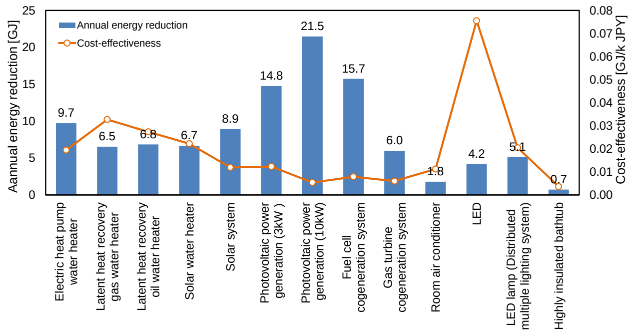


Figure 6. Annual primary energy reduction and cost-effectiveness by replacing equipment

Table 4. Setting conditions of insulation materials before and after the retrofits

| Insulation part (area of part) | Given conditions of insulation materials: Before the retrofits | Given conditions of insulation materials: After the retrofits insulation method (cost) |
|---|---|---|
| Ceiling ($67.92\ m^2$) | Glass wool 10K t=25mm | Glass wool 16K t=100mm<br>Attic insulation method ($21,000\ JPY/m^2$) |
| Exterior wall ($139.48\ m^2$) | Glass wool 10K t=25mm | A-XPS-B-3b t=50mm<br>Additional exterior insulation method ($21,000\ JPY/m^2$) |
| Floor ($65.41\ m^2$) | No insulation | Glass wool 32K t=80mm<br>Underfloor interior insulation method ($12,000\ JPY/m^2$) |
| Window ($28.71\ m^2$) | Metal Frame・Single glazing | Low-E double glazing (A6)<br>replacement glazing ($30,000\ JPY/m^2$) |
| Q value | $4.51\ W/m^2K$ | $2.23\ W/m^2K$ |

Table 5. Setting conditions of equipment before and after the retrofits

| Equipment | Given conditions of equipment: Before the retrofits | Given conditions of equipment: After the retrofits |
|---|---|---|
| Electric heat pump water heater | Gas hot water heater JIS (Japan Industrial Standard) labeled efficiency 70.4% | JIS labeled efficiency 3.3* |
| Latent heat recovery gas water heater | | JIS labeled efficiency 95%* |
| Latent heat recovery oil water heater | | JIS labeled efficiency 95%* |
| Solar water heater | | Total area of solar collector : $4.0\ m^2$ |
| Solar system | | Total area of solar collector : $4.0\ m^2$<br>Volume of hot water storage tank : 300 L |
| Highly insulated bathtub | Not installed | Installed |
| Photovoltaic power generation | Not installed | (1) System capacity 3kW<br>(2) System capacity 10kW |
| Fuel cell cogeneration system | Not installed | SOFC2 |
| Gas turbine cogeneration system | Not installed | GEC2 |
| Room air conditioner | Category of energy efficiency: Category B | Category of energy efficiency: Category A |
| LED | One or more incandescent lamp(s) is/are used | No incandescent lamp is used |

*These efficiency was referred to marketed product in Japan

### 3.3. Discussion of effective subsidies

The primary energy reduction effect of the subsidies, shown in Figure 7, is defined as a multiplied value of the cost-effectiveness and the subsidy rate. The results indicate that LED is the most effective retrofit item in utilising subsidies. Ceiling insulation is second highest and latent heat recovery gas water heaters placed third. Photovoltaic power's subsidies effect, which is provided by many municipalities, had one of lowest primary energy reduction subsidies effect, because of its high expenses and low subsidy rates.

Ceiling Insulation, LED and latent heat recovery gas water heaters were selected as the most effective retrofit techniques for energy conservation. Furthermore, considering the improvements of the indoor thermal environment, floor insulation was also selected since most 30 year-old dwellings have little or no floor insulation. After the retrofits of the four recommended retrofit techniques, the annual primary energy consumption of the base plan decreased from 94.9 GJ to 75.9 GJ (Figure7). The value after the retrofits fulfils the latest Energy Saving Standard on primary energy consumption of newly built dwellings. As for the insulation performance, the Q value after the retrofits improved to 3.23 $W/m^2K$, which fulfilled the insulation level equivalent to the intermediate of the 1992 and 2013 Energy Saving Standards (Q value $\leq$ 3.3 $W/m^2K$).

The life cycle cost of the base plan before and after the retrofits with the recommended menu, which is the combination of insulation retrofits (ceiling and floor) and equipment replacement (LED and latent heat gas water heater), is shown in Figure 9. The recommended retrofits, requiring approximately 1,000k JPY in actual costs, which is defined as a subtracted value from retrofit cost minus subsidies. The annual running costs are reduced by 55,800 JPY (from the base plan) and requiring approximately 18 years to recover the initial costs.

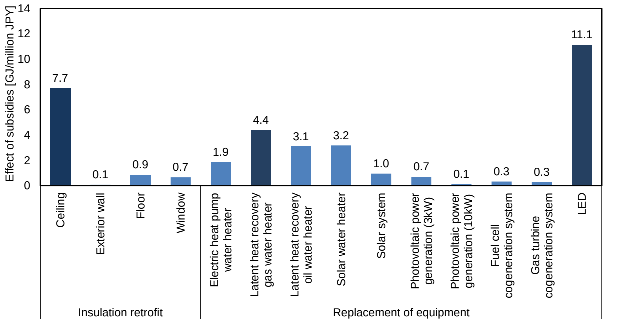


Figure 7. Primary energy reduction effect of subsidies

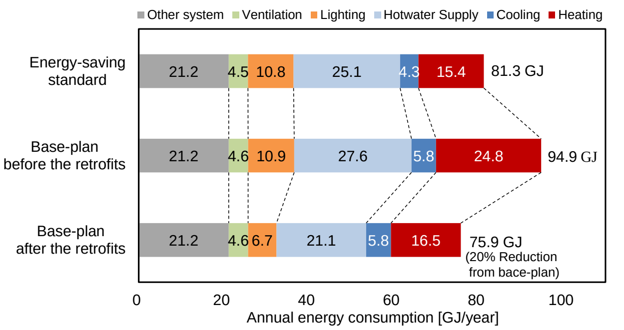


Figure 8. Annual primary energy consumption before and after the retrofits

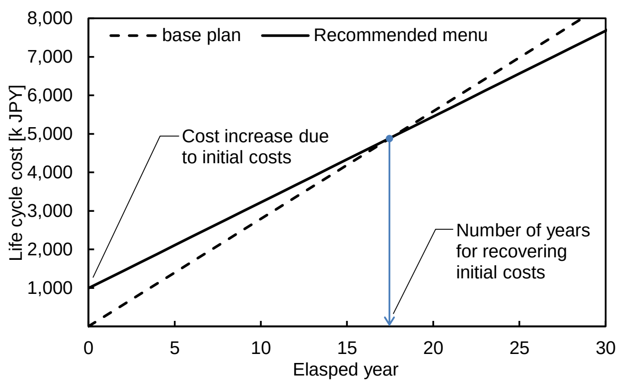


Figure 9. Life cycle cost calculation of the base plan before and after the retrofits with employing the recommended menu

Table 6. Reduction effect on energy cost by effective retrofit techniques

| Retrofit techniques | Actual cost (Retrofit cost - Subsidies) [k JPY] | Annual reduction amount of running cost [k JPY/year] | Pay-back period [year] |
|---|---|---|---|
| Ceiling & Floor | 781 (908 - 127) | 22.8 | 35 |
| Latent heat recovery gas water heater | 173 (200 - 27) | 21.5 | 9 |
| LED | 40 (55 - 15) | 11.5 | 4 |
| **Recommended menu** | **994** (1163 - 169) | **55.8** | **18** |

The service life of a latent heat recovery gas water heater is mentioned as approximately 20 years and the other items have even a longer expected lifespan. Therefore it is possible to recover all of the initial costs.

A diagram which indicates the typical retrofit items' cost performance is shown in figure 9. The line in this figure represents an exponential curve passing through the origin as a regression line of all plots. Retrofit items above the line have a relatively high effectiveness from the view point of energy saving and cost performance. Ceiling insulation or a combination of ceiling and floor insulation, water heaters such as latent heat recovery water heaters using gas or oil, solar water heaters and LED are evaluated as high effective retrofit items.

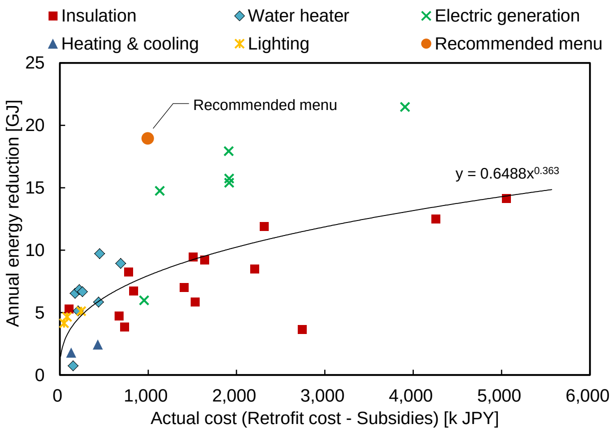


Figure 9. Annual energy reduction and actual cost of each retrofit items

## 4. CONCLUSION

Energy retrofit techniques for existing dwellings were evaluated using subsidy systems funded by local governments in Japan.

The Investigation on subsidy systems suggested that photovoltaic power generation is the most popular item to be subsidised. With regard to the amount of subsides, ceiling insulation has the highest subsidy rates in the insulation section. Water heaters and LED, whose subsidies are comparatively small, have comparatively high subsidy rates. Electric generation systems, which were offered in a large number of subsidy systems, have low subsidy rates since their retrofit costs were expensive.

The best combination of energy retrofits techniques, insulation for ceiling and floor, LED and latent heat recovery gas water heaters, were selected from the viewpoint of energy conservation and the effects of the subsidies. The calculated results of this study suggest that it is sufficiently possible to recover the initial cost of these three retrofit techniques over their life span by utilising the subsidy systems.

Energy conservation management based on the assessment of cost performance in respect to energy conservation is necessary in order to promote subsidy systems offered by local governments.

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