ECOLOGICAL HOUSE RENOVATION AND LOW-ENERGY LIFESTYLE

Keisuke HAMA[1]

[1]Research Institute for Culture, Energy and Life, Osaka Gas Co., Ltd. 3-6-14 Bingomachi, Chuo-ku, Osaka, 541-0051 Japan, k-hama@osakagas.co.jp
Visiting professor, Graduate School of Engineering, Osaka University

Keywords: eco-house, energy saving, lifestyle, renovation, regeneration, sustainability, thermal

Summary

For achieving sustainable building concept in housing, the renovation of existing into low-energy housing is the best way forward. The “Saisei Eco-House“ (regenerated eco-house) in Nara is a typical example that shows a possibility of achieving both material- and energy-saving. It is owned and lived by the author. This paper attempts to discuss how the house was renovated and how the family members have tried to reduce energy consumption.

The main aims of the renovation were 1) extending building lifespan, 2) improving thermal insulation, 3) utilising renewable energy and 4) greening the building.

In addition to technical improvements, energy-conscious lifestyle is essential to realise the objectives. A number of methods were tried to reduce energy consumption including, eliminating stand-by electricity and choosing energy-efficient goods, not using air-conditioner and not warming up unoccupied rooms.

As the result, electric production from photovoltaic exceeded the consumption. The solar heat gain for hot water has reduced the fossil fuel consumption to one third. The total consumption of conventional energy has become less than a half of the average.

It is vital to have positive environment awareness for achieving sustainable housing and living. Once people are enlightened to the importance of energy saving, every simple action becomes a daily custom.

1. Introduction

Longer lifespan and higher energy performance are strongly required for the Japanese housing stock. The average lifespan of the Japanese houses is reported to be 26 or 30 years. This fact is the starting point for the efforts to extend their durability. At the same time, the energy performance in terms of thermal insulation is not fully controlled by laws. The ratio of the energy consumed in housing is less than 20% of the total in Japan, but this is the sector where every person could make an effort to reduce resource consumption and contribute to prevent the global warming.

The renovation of existing into low-energy housing is the best way forward. The “Saisei Eco-House” (regenerated eco-house) in Nara is a typical example that shows the possibility of sustainable building achieving both material- and energy-reduction. This house was originally built in 1972 with reinforced concrete box frame structure. The author purchased it in 1999 and the renovation was a carried out a few months later. The floor area was extended from 143 to 153m2.

Besides good building and efficient equipment, an appropriate lifestyle is essential for achieving high-level energy saving. This paper attempts to discuss how the house was renovated and how the family members have lived since then from the viewpoints of energy saving and comforts.

Nara is located in the western half of Japan, approximately 30km east of Osaka and 35km south of Kyoto. Its climate is generally mild with inland features. The temperature sometimes drops below zero centigrade in winter, roughly a few degrees lower than that of Osaka, and rises to 35ºC in mid-summer.

Figure1 Building appearance before renovation, south facade

2. Renovation into an Eco-house

This project was not only a personal one. The author organised “Eco-house Study Group”. First, he proposed basic concepts for renovating the house in ecological ways, i.e., thermal insulation, reuse of dismantled materials, selection of healthy materials, utilisation of natural light and renewable energy, greening the building and so on. The members discussed the renovation project and gave a variety of ideas on how to implement the objectives. The following works were decided and undertaken.

2.1 Thermal Improvement

The house was originally poorly insulated. As the result, fungus was found under the wallpaper and in the built-in cupboards facing external walls. The thermal improvement of the walls, roofs and windows was therefore necessary not only to enhance energy performance but to assure the residents’ health and to improve living condition in winter.

Figure2 Enveloping with insulating material and an additional window sash

2.1.1 Converting the Light Court into Interior Space

There was a small light court in the middle of the house, which served for nothing but day lighting. From a thermal point of view, it was better to convert it into an interior space that still preserved natural daylight. The space was therefore covered by a glass roof. Consequently the upper part has become a kind of conservatory and the lower part an extension of living space. The total length of external wall diminished while the floor area increased. The ratio of the former to the latter has become 0.6 from 0.72m/m^2, which indicates that the thermal performance has been improved along with usability. On the top of the glassed roof, a small ventilation tower was built to allow indoor air to flow out. This has a manual dumper to control the ventilating capacity.

Figure3 Light court before renovation

Figure4 After converted into a nook of living space

2.1.2 External Walls and Floors

To make the best of thermal mass of concrete, the insulation material, 30mm (partly 60) expanded polystyrene, was placed on the outside of the wall. Including the void and wooden weatherboarding, the performance (by coefficient of overall heat transmission or K-value) has been improved from 3.6 to 0.72(W/m^2K).

The ground floor slabs directly lie on the earth without insulation. It was not possible practically to thermally improve the floor except inserting the panels for floor heating and new flooring.

2.1.3 Roofs and Ceilings

The roof was flat but there was a void between the roof slab and ceiling. The first step was to insert 50mm flax fibre in the void. The second step was to place 50mm expanded polystyrene on the roof slab and cover it with terracotta tiles. The K-value has been improved from 0.87 to 0.26(W/m^2K).

2.1.4 Windows

Three measures were taken; 1) Introducing high performance window sashes for the extended parts, 2) Placing an additional window sash outside the existing ones, and 3) Replacing the glass only from single glazing to double.

2.1.5 Roof Garden

There was a bare roof terrace upstairs covered with waterproofing material. Large-size plant boxes were installed around it for shrubs and flowers, and then the central area was covered with a wooden deck. A newly created space became a comfortable outdoor living space. This work was intended also to mitigate the temperature of the floor surface and that of the room below in summer.

2.2 Utilisation of Renewable Energies

To minimise the use of conventional energy, electricity from the grid, city gas and kerosene, renewable energy was used to the full. The most realistic source in housing is solar energy. In this case, the following facilities were installed and their performance has been monitored.

2.2.1 Photovoltaic (solar power generation)

The total capacity of PV modules is 2.672kW with an area of 19m2. As the average size of PV system in Japan is between 3kW and 4kW, this system is rather small. The orientation is almost south and the inclination is 20 and 27 degrees to the level.

2.2.2 Solar Collectors for hot water supply

A set of solar collectors was placed on the rooftop. The tube-type collectors also serve as storage tanks. They are covered by vacuum insulation to ensure heat gain and to prevent heat loss. They are automatically filled by city water pressure, as hot water goes out. The total capacity is 160litres.

2.2.3 Wood Stove for space heating

The carbon dioxide emitted from biomass is not considered as a green house gas. The carbon stored in wood is a part of CO2 or carbon circulation powered by solar energy. The most basic way to utilise biomass energy is to burn wood at home for heating. A wood stove was installed in the middle of the house, in a corner of the living room beneath the light well converted from a tiny court. The upward flow of the air is controlled by two traditional paper screens, which are normally placed horizontally and can be lifted up by rope to a vertical (open) position.

2.3 Renovation Cost

The total cost for this renovation was approximately 16millions yen. This cost includes 10 mill. for building, 2 mill. for sanitary equipment, 2 mill. for photovoltaic system, 0.5 mill. for solar collectors, 0.5 mill. for wood stove and 1 mill. for roof garden and others.

Excluding the cost for renewable energy utilisation and the roof garden, the renovation cost was 12 millions that corresponds roughly 40% of the construction cost of a new house of the comparable size and quality.

Figure5 Building appearance after renovation, south facade

3. Improvement Effects of Interior Thermal Condition

The thermal improvement is the basis for assuring comfort and reducing the energy demand for heating and cooling. The following studies were carried out.

3.1 Simulation Study and Observation in Winter

A simulation study was carried out to predict the thermal condition and the heat demand in the living room. The adopted software was “Solar Designer”. As the original thermal insulation was so poor the effects of thermal improvement was considerable, although the added insulation was at an ordinary level.

While the outdoor temperature varies from –3 to 9°C in winter, the indoor air temperature was estimated as between 5 and 14°C before renovation without heating. After the renovation, these figures was estimated to vary between 11 and 17°C. The heat demand, to keep 20°C all the time, was estimated as 68% less than that of the original condition.

In actuality, the indoor air temperature without heating varied from 13 to 20°C under the condition that the outdoor average temperature was 4°C higher than the simulation premise.

3.2 Thermal conditions in summer

To make sure the effects of improvement, the thermal condition of the living room on the ground floor was studied in mid-summer. Usually the windows are fully open during the night to cool the indoor space and are closed during the day. A Venetian blind is hung outside the eastern window. The main window facing the south has a balcony upstairs to prevent direct sunshine. However, it is not properly protected against the radiation from the terrace. Figure 6 shows the changes of the temperature of living room and other parts of the building in mid-summer.

The most remarkable feature is that the maximum indoor air temperature downstairs could remain around 28°C and that of the floor tile 26 °C while outdoor temperature reaches 35°C. In this condition, a breeze by electric fan is sufficient for assuring coolness. The air-conditioner is not in use.

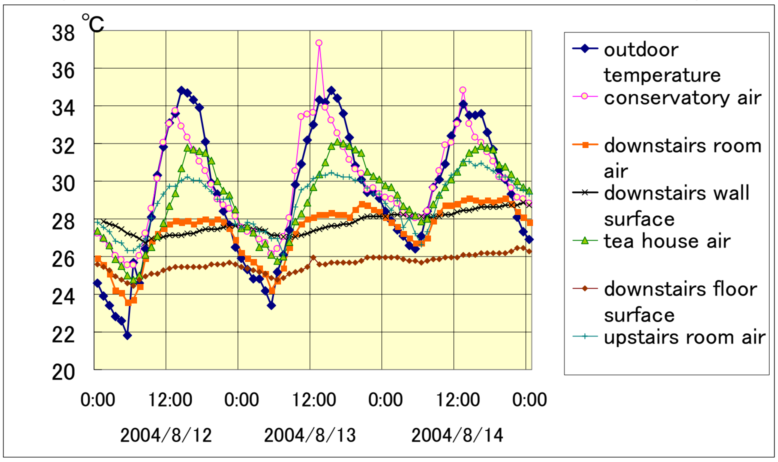
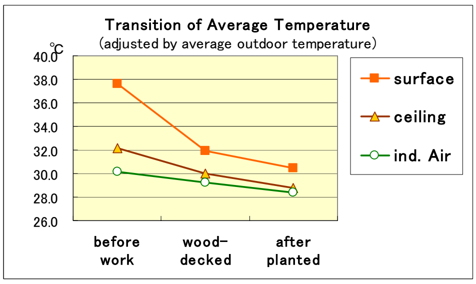


Figure6 Temperatures in and around living room in mid-summer

3.3 Effects of wood deck covering

Before the renovation, the maximum temperature of the bare floor surface reached 55°C in mid-summer. After the roof terrace was covered with a wood deck and earth filled plant boxes, it drastically dropped to 36°C. Figure 7 (right) shows the change of temperature before and after the renovation work. Figure 7 (left) shows the fall of average temperature according to the parts; slab surface, ceiling below the slab and indoor air of the room downstairs.



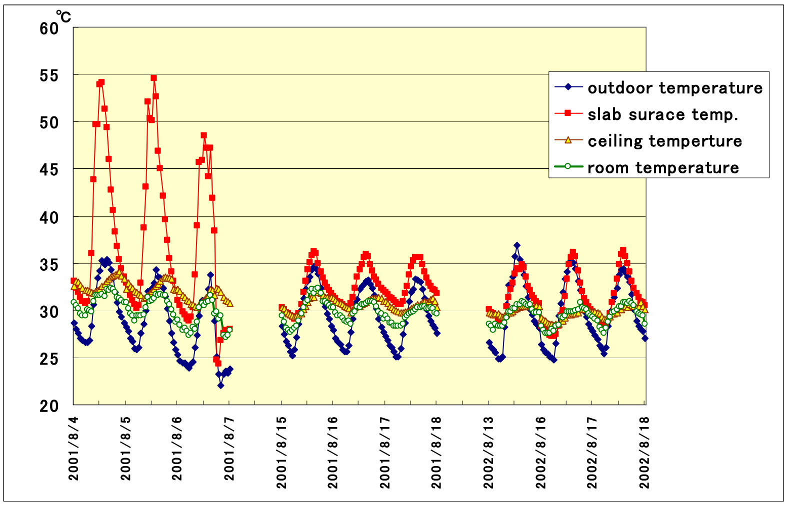


Figure7 Temperature related to roof terrace in mid-summer before renovation work, after wood-decked and after planted

4. Lifestyles to Reduce Energy Consumption

The daily lifestyle to reduce energy consumption is full of variety: the relationship between energy saving and lifestyle are featured as follows.

4.1 Space Heating

The house has large windows facing the south. This helps warm up the rooms when the sun is shining. As the shelter has still a limited level of thermal insulation, ordinary heating is needed. A combination of heating methods was installed; hot water floor heating system, hot water radiators, a wood stove, gas “fan heaters” and a kerosene heater. The basic way to minimise heating is to warm up only the occupied room. In addition, the temperature is kept to no higher than 17 °C. All the heating apparatus is turned off during sleep. Warm clothing and bedding can assure the acceptable level of comfort. The lowest temperature in a non-heated room could fall to below 10 °C in midwinter, which is still within the limit of endurance.

4.2 Space Cooling

No air conditioning has been used for cooling rooms. Instead there are several ways to keep the room temperature sufficiently low. In addition to the external thermal insulation, external Venetian blind and "sudare" (air-permeable screen made of bamboo or reed) are used to avoid heat penetration from the radiation of the sun. As it was described in the section 3.2, the action of opening and closing windows is necessary. The concrete wall and floor function as thermal mass. Since the highest temperature in the living room scarcely rise over 28 °C, the use of electric fans is enough to feel cool.

Another way to avoid excessive heat is to stay in a cooler area of the house. The rooms upstairs tend to be hotter than downstairs. Therefore the place to sleep changes its location according to the season. One room on the ground floor becomes the main bedroom during summer.

4.3 Hot Water Supply

Japanese are lovers of the hot bath. The majority take baths in a bathtub full of hot water every day. This case is different. Normally, they take baths four times a week through the autumn to spring and take only showers when the climate is hot. During summer, the temperature in the collectors sometimes rises up to 100 °C. As the demand for hot water is limited, it is often left unused in the collectors.

Dishwashing is usually done by hand and high temperature water is only necessary for greasy plates. For the rest and rinsing, low temperature is sufficient and hot water is not needed in many cases.

4.4 Lighting and Others (Use of Electricity)

The following efforts have been made to reduce electric consumption. The accumulation of each small saving together makes a considerable result.

4.4.1 Turn switches off

The most primitive way to reduce electric consumption is to turn switches off and avoid unnecessary light and use of equipment.

4.4.2 Eliminate stand-by electricity

The stand-by electricity is a small current to keep working the electronic functions including remote control switch, clock, preset memories etc. It is said that this covers more than 10% of total electricity consumption in a household. The elimination of stand-by electricity is implemented by installing taps with switches to be turned off when electric goods are not in use.

4.4.3 Choose efficient electric goods

Any electric goods have the limit of durability to be replaced. It is strongly recommended to do so with more efficient ones. The typical items are liquid -crystal TV, top-runner* refrigerator and bulb-type fluorescent lamps. More important is simply not to use heating apparatus for continuous use including hot-water server, electric carpet or electric space heater. (*Top Runner System obliges each manufacturer to ensure the future target level of energy-efficiency for their products to be higher than that of the most energy-efficient equipment in the same category currently available in the market.)

4.4.4 Make change in mind and lifestyle

Finally it is vital to change the attitude toward energy consumption and lifestyle. This includes, not to staying up late at night, not overusing air-conditioner for cooling, not warming up unoccupied rooms, wearing warm clothing in winter and so on.

4.5 Water Saving

Water is not exactly a kind of energy. However, it embodies electricity to prepare tap water by running it through aeration and pumping it up to the reservoirs.

A small rainwater tank was installed on the roof garden for watering the plants. The capacity is 200 litres only and the water saving effect seemed negligible. However, the consumption of tap water fell drastically. The residents realised that it is not always necessary to use drinkable water for many other purposes. The water consumption per person has become 4m2 per month, while the average figure is 6m2.

5. Results of Gain and Consumption of Energies

The efforts to reduce energy consumption can be proven by figures. They represent the combined results of technologies and lifestyle. The number of residents was three (3) till March 2004 and two (2) since then. The data, if not mentioned otherwise, are over 5 years from 2000 to 2004.

5.1 Electric Generation by PV and Consumption

The predicted electricity production per annum was 2700kWh from the photovoltaic system of 2.672kW. However, the result was that the system has generated 2855kWh/a, probably because of the favourable location not affected by shading. The surplus electricity sold back to the grid amounted to 2083kWh.

When there is not enough electricity, the shortage is supplied from the grid and the total electricity bought from electric power company was 1518kWh. The unit price for selling is equal to the middle-range buying price (monthly consumption over 120 to 300kWh, 23.2Yen/kWh as of 2004). There are two meters to count incoming and outgoing electricity respectively. The payment for buying and selling is done separately.

As for consumption, the average amount per annum was 2298kWh or 191kWh per month. Consequently, the amount of production exceeded the consumption by 24%. As the average consumption level per person is considered as 2090kWh/a* in Japan, this level is considerably low. (*data: Institute of Energy Economics, Japan 2002) The means of minimising the electric consumption were described in the precedent section 4.4. Watching the data of production and consumption, the family members were encouraged to seek for every possibility for reducing the consumption. It seemed that a passive consumer became a more active consumer. An owner of a photovoltaic system can be considered as a master of a micro power station.

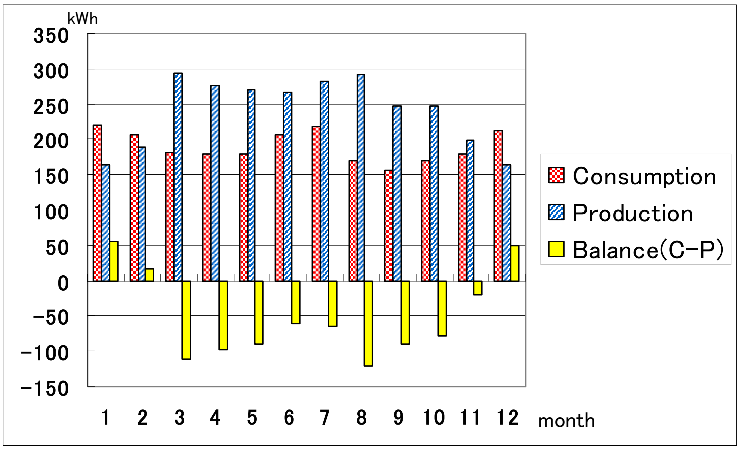


Figure8 Monthly electric generation and consumption (2002)

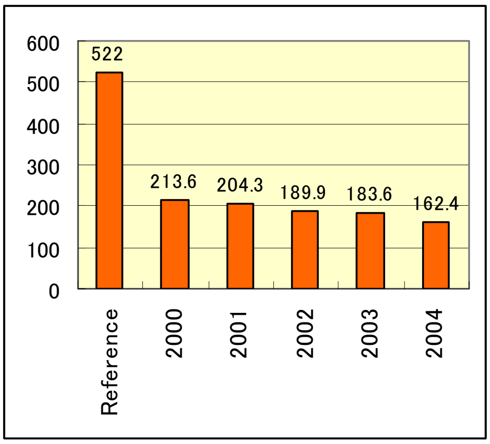


Fig9 Comparison of electric consumption by year (KWh per month, reference IEEJ)

5.2 Solar Heat Gain for Hot Water

The heat gain, both by solar system and by gas, was measured by calorie-meters, consisting of a water meter and two sensors measuring the difference of temperatures.

The average heat gain (from 2002 to 2004) was 4,302Mj/a. On the other hand, the heat given by the gas boiler was 2,295Mj/a (765Mj/capita.a). This means 65% of total hot running water was supplied by solar heat.

The above-mentioned results reflect the efforts to reduce hot water consumption. They include 1) taking bath before the temperature goes down, 2) lowering the hot water temperature for dish washing by hand, 3) not filling the bathtub during summer and 4) using up (not leaving) the hot water in the pipe.

As the reference figure for hot water demand is 13,800Mj/a (primary energy) in a detached home of 4 residents, consuming the gas boiler efficiency 80%, 2,760Mj/a is the average consumption per person. This shows that, in this case, the city gas consumption per person has been reduced to less than 30%.

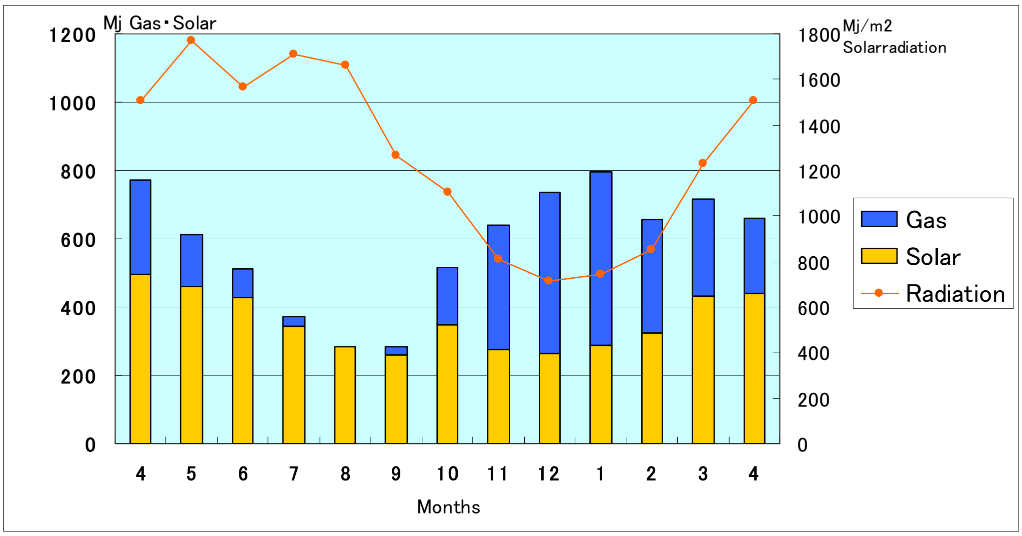


Figure10 Amount of Heat contributed from solar collectors and city gas boiler (2002-03)

5.3 Space Heating

The average amount of heating energy was estimated as 4.48MWh/a in 2003 for the used floor area of 100m2 (45kWh/m2 a year). They consist of city gas 2.49MWh, kerosene 4.45MWh and Firewood 1.55MWh. These figures could be diminished if the envelope insulation were improved more efficiently.

The amount of wood consumption varies between 300 and 400kg for 4 months per season and from15 to 20 evenings a month. The wood stove is not the main source for space heating but it consumes about 35% of space heating energy.

Wood stove heaters in the southern part of Japan are not as popular as elsewhere and there is practically no market of firewood. It is not simply a space heating equipment but an item to enrich the home. It is a pleasure to watch a wood fire and its psychological effects are highly appreciated.

5.4 Total Use and Evaluation

5.4.1 Energy Consumption by Use

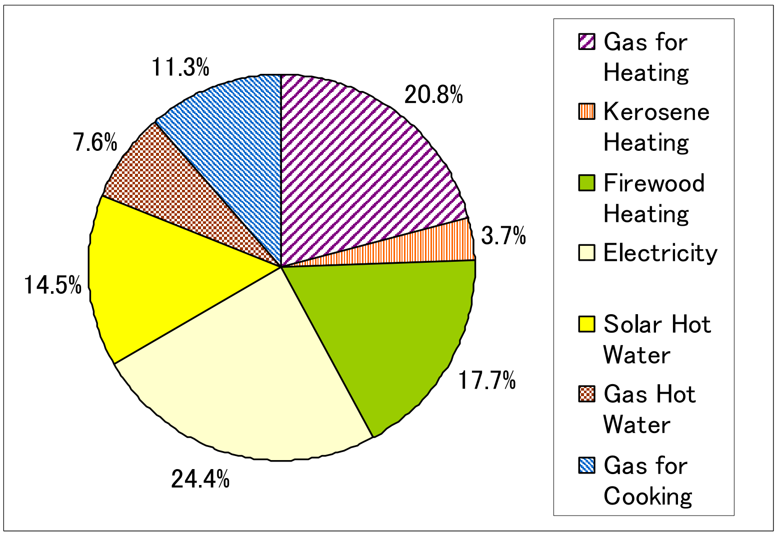
In total, the consumption and the gain of energy at home are summarised as follows taking the year of 2003. For taking account the electricity export, the figures for fossil fuel consumption are so adjusted that they are deducted proportionally by the net electricity export to the grid (534kWh) by primary energy equivalent. They also include estimation on the consumption of city gas for direct space heating (not through boiler).

The total amount used in this house was 8.7MkWh. They consist of 1) gas for space heating 1815kWh, 2) kerosene space heating 326kWh, 3) firewood space heating 1547kWh, 4) electricity for lighting and others 2129kWh, 5) solar heat for hot water 1261kWh, 6) gas for hot water 661kWh and gas for cooking 984kWh.

The most important use is space heating claiming 42%. The second is electricity for lighting and others 24% and the third hot water supply 22%.

If the electricity were converted to the primary energy at the power station, the total consumption could increase to 10.1MWh. Consequently the ratio of lighting and others greatly expands claiming 45%. Other uses decrease their proportions to 31% for space heating, 16% for hot water supply and 8% for cooking as shown in Fig12.

With respect of renewable energies, the total of firewood, photovoltaic and solar heat shares 57% in the former case and 68% in the latter case.



Figue11 Energy consumption by use, as of 2003

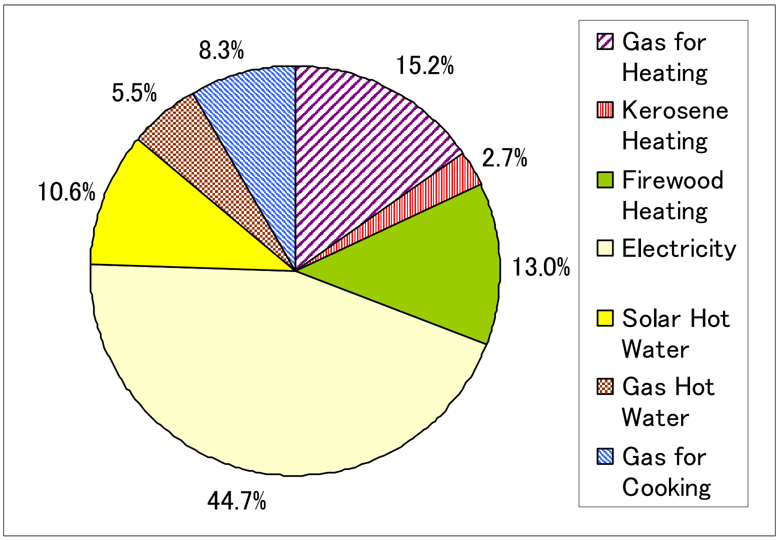


Figure12 Energy consumption by use, if electricity were converted into primary energy, as of 2003

These figures show three important facts; 1) the thermal insulation has a large room to be improved, 2) saving electricity consumption is particularly important and 3) the role of renewable energies is considerable for home use.

The electric power delivered to each house is only 40% of the primary energy consumed at power stations. (District heating system with CHP is negligibly rare in Japan) Besides emitting carbon dioxide causing global warming, the radioactive waste produced and accumulated at nuclear power stations is a more serious problem. It is a great risk for us and will be left to the future generations as a negative asset.

5.4.2 Estimation of Carbon Dioxide Emission

There are several alternative ways to estimate carbon dioxide emission through the living in this house. The main discussion is how to evaluate CO_2 emission by electricity. Here, the reverse current from photovoltaic to the gird is considered to reduce thermo-electric power generation, because it controls the balance of marginal demand and supply. Since the average consumption of city gas, kerosene and firewood per annum was 464m3, 51litres and 334kg, the emission of CO_2 as GHG by weight of carbon can be calculated 290kgC, 35kgC and 8kgC respectively. (City gas: 0.624kgC/m_3, kerosene: 0.6896kgC/litre, firewood: 0.023kgC/kg for road transport) The purchased electricity is counted at the total power source coefficient (0.098kgC/kWh to make 149kgC) and the reverse current at thermo-electric generation coefficient (0.184kgC/kWh to make minus 383kgC/kWh). Hence, the total emission can be estimated as 99kgC/a. This is approximately 1/9 of the average emission from a household in the area concerned.

5.4.3 Cost Saving Effects

The energy cost is not always proportionate to the amount of consumption and environmental impact, because there is a range of price menu and the resource characteristics. However, it is the commonest way for consumers to conceive it by monthly energy payment.

Table 1 indicates the transition of expenditure and revenue on energy of this house for the past five years according to energy types. In this case, the revenue is gained by selling electricity and shown in minus figure. The total energy cost is considerably small and is gradually decreasing. The efforts to reduce energy consumption are evident while the photovoltaic power generation is dependent on the weather or the solar radiation. The family members feel that this kind of table is one of the stimulants to encourage energy saving.

Table1 Transition of Expenditure and Revenue on Energy (Yen per month)

Year	Purchased (imported) Electricity	Sold (exported) Electricity	Balance of Electricity Payment	City Gas	Kerosene	Total Energy Cost
2000	3021	-4478	-1456	6882	123	5549
2001	2701	-4401	-1699	6321	183	4805
2002	2449	-4455	-2006	6053	177	4224
2003	2305	-3805	-1501	5316	220	4035
2004	1973	-4525	-2552	4023	140	1612

6. Conclusion

Energy conscious, ecological housing gives a pleasant stimulation to its residents. They take pleasure in reducing the environmental impact of energy use in particular. It is quite challenging to make a good living from a limited consumption of resources. Along with the empirical discussion so far, the key components for realising low-energy and comfortable living can be summarised as follows.

1) Properly thermal-insulated building compatible to heat and cold

2) Highly efficient equipment for energy conversion and consumption

3) Passive and active utilisation of renewable energy

4) Energy-conscious lifestyle including selection of primary energy sources and simple living

The interest in and the consciousness of energy saving can be developed through watching the data. To make invisible energy visible is an essential factor to encourage low-energy lifestyle.

Another important condition is the number of household members living together. A single or a family of two would have more difficulty to achieve energy saving per person than a larger household. At the same time, it is very important not to pursue the fulfilment of one's desire endlessly. Human happiness is based on how to learn to be contented.

To conclude, it is vital to have positive environment awareness for achieving sustainable housing and living. We must share the idea that energy saving is the undeniable necessity to prevent global warming and not to endanger our future generations. Once people are so enlightened, every simple action to avoid wasting energy becomes a daily custom. Finally we must not forget that the global issue is nothing but an enormous accumulation of small actions of each individual.