“ FACTOR4 DWELLING” IN THE NEXT21, EXPERIMENTAL HOUSING OF OSAKA GAS

Keisuke HAMA architect[1]
Yuichiro KODAMA Dr.Eng[2]

[1] Research Institute for Culture, Energy and Life, Osaka Gas Co., Ltd., Japan, k-hama@osakagas.co.jp
[2] School of Environmental Design, Kobe Design University, Kobe, Japan, y-kodama@kobe-du.ac.jp

Keywords: energy saving, house remodelling, heat insulation, factor4, renewable energy, SOFC

Summary

This paper outlines an experimental project for drastically reducing the environmental impact of home energy consumption whilst assuring a high level of living comfort. The project has been applied to an existing dwelling unit within NEXT21, which is the experimental apartment housing in Osaka, Japan owned and managed by the Osaka Gas Company.

The main approaches for achieving the objective of the project have been,

1) To remodel an existing dwelling unit,

2) To improve thermal insulation and shading,

3) To introduce efficient equipment for energy conversion and consumption,

4) To make possible the use of renewable energies and

5) To change the behaviour of the residents related to energy consumption.

The technical items include photovoltaic power generation, condensing gas boiler, hot water floor heating, home-size solid oxide fuel cell (SOFC) and semi-automatic shading / ventilation control system.

The simulation analysis gives figures, evaluated in terms of primary energy, for the expected effect. Compared to the reference model, the heating and cooling load will be lowered by 45% through architectural improvement. New efficient equipment will produce a further reduction of 15% and solar energy 13% of the original consumption. In total, the energy load may be lowered by 78%, including the efforts of residents to change part of their lifestyle.

1. Introduction

It is claimed that to prevent global warming greenhouse gases need to be reduced in the long term by 75 to 82%[1]. These figures might seem unrealistic in relationship to the pessimistic opinion that Japan could not meet the Kyoto Protocol promise to reduce greenhouse gases (GHG) by 6% in the year 2010 (average between 2008 and 2012, compared to 1990). However, the above-mentioned targets are essential to keep the average rise of atmosphere temperature to within 3.5/2.5 degrees Celsius respectively. Therefore, it is acceptable to consider them as the target for the advanced low- energy dwelling of today.

The majority of GHG is carbon dioxide (CO2) caused mainly by the consumption of conventional energies, not only fossil fuels but electricity. To find effective solutions in the field of urban housing, an experimental project was launched in June 2005, the target for which has been to reduce the energy-based environmental impact to a quarter of the original amount by remodelling an existing apartment dwelling and comparing it with a basic apartment. This could be realised through reducing energy consumption and wherever possible using sources of locally available renewable energy.

The project has taken place within Osaka Gas Company’s experimental housing, “NEXT21”, which was built in 1993 for the purpose of experimenting with gas equipment within a highly durable “open building” structure and flexible “infill”.

Dwelling no.301 was selected for the project. This dwelling unit was originally designed by architect Naomi Tachibana as a “Garden House”, which aimed at living in harmony with the natural environment. It enjoyed plenty of indoor / outdoor greenery, day-lighting and natural ventilation.

Many alternatives were examined from the available techniques. This paper describes the methods to remodel the dwelling to consume less energy as follows:

Figure.01 NEXT21 in Osaka

---

[1] Ministry of Environment Brochure based on IPCC 3rd Report

1) Improving the building envelope to reduce the heating and cooling load.

2) Introducing highly efficient equipment and new systems for energy conversion,

3) Incorporating renewable energy, namely solar energy and

4) Reviewing and changing the occupants' lifestyle in terms of energy consumption.

The estimated effect of these methods was examined through simulation analysis.

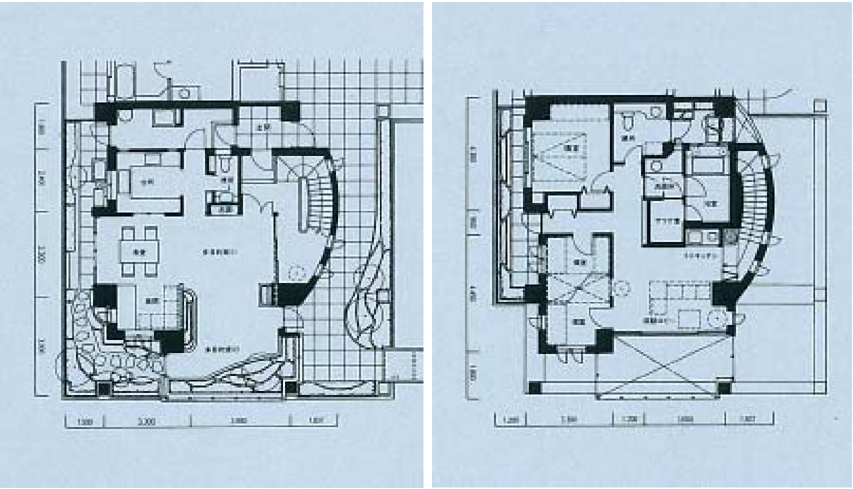
The target of reducing energy to a quarter of the original might appear over-ambitious but the intention of the project was to show people and the company that it was realistic for a household to achieve such an environmental impact. By early 2007 the remodelling work was complete and Unit 301 was given the name "Factor4 Dwelling", after the book "Factor Four, Doubling Wealth - Halving Resource Use" by Ernst von Weizsacker and others.

2. Improvement of Building Envelope

Unit No.301 is a maisonette apartment with external walls and openings on 3 sides, facing east, south and west. Its total floor area is approximately 150 sqm. The improvement of the building envelope has reduced the heating and cooling load. The unit had a relatively high ratio of external wall length to floor area. The total areas of windows were also considerable (Fig.-1). Therefore the heating and cooling load prior to remodelling was similar to that of an average detached house.

The first improvement to be made to the walls and floors was to add thermal insulation in the voids within the walls and the space under the lowest level flooring. In addition the total length of the external wall was reduced by enclosing the set-back porch and a balcony with additional doors / panels, which made these spaces internal. The second improvement was to add internal window sashes to change the glazing from double to triple. Shutters in the form of insulating panels were also provided to put over some small windows during winter. The third method was to reduce the heating load by maximising solar gain from the windows.

The original southern façade was a large area of glass, which created an interior space that had the feel of a conservatory but was effectively part of the living space. In addition the heat loss was greater than the solar gain from the glass so measures were taken to divide the space into separate living room and conservatory. This would prevent heat loss in the winter, and good shading would prevent heat penetration in summer. The actual remodelling method is discussed later. In the intermediate seasons, there would be little difficulty in controlling the indoor climate at the optimal level by closing and opening the windows and shading. The conservatory with internal planting would also be useful for cooling the atmosphere.



Figures.02, 03 Floor plans before renovation

Lower floor

Upper floor

Figures.04, 05 Floor plans after renovation

2.1 Thermal Insulation and Shading

The main objects and methods of insulation to the envelope were:

2.1.1 External walls: There was void between the external panels, backed up with foam polyurethane, and internal panels of gypsum board. It was totally filled with cellulose fibre made from recycled paper. The material was inserted though holes in the gypsum boards, which were finally covered with thin plywood and finished. Fortunately the void width was varied between 140 and 150mm, which enabled a good quantity of cellulose fibre to be inserted. These methods could reduce the heat loss, in terms of U-value, of a typical external wall from 0.62W/m2K to 0.20W/m2K.

2.1.2 Lower level floor: The space under the lower floor of the dwelling is a small auditorium, air-conditioned only occasionally when used. The floor was not insulated except where it was needed to prevent heat-bridging from outside. The former residents had complained about the cold floor. The void between floor slab and the flooring board was therefore filled with 190mm thick cellulose fibre, which was beneficial in terms of thermal insulation and energy saving and also for providing greater comfort.

2.1.3 Windows and doors (except conservatory): The following four methods were applied.

a) Internal sashes, wooden with single glazing, were added to the main windows. The glazing was converted from double to triple in total.

b) The small windows were fitted with insulated shutters to close them off during the winter seasons.

c) The windows in the stair well were fitted with interior Venetian blinds.

d) External Venetian blinds were installed on the western balcony.

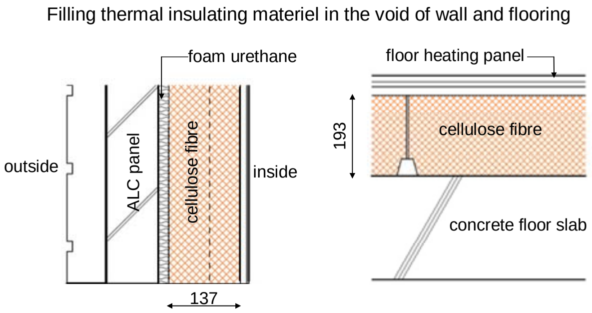


Figure.06 (left) Wall cross-section

Figure.07 (right) Under the floor (lower level) cross-section

2.2 Conservatory (Indoor Garden)

The southern part of the original living room was converted into the conservatory by dividing the space by new sliding doors. The conservatory will serve as the heat collecting space and buffer zone between the living area and the outside. This measure made it possible for the heating and cooling load to be drastically reduced because the conservatory is a semi-external space not part of the air-conditioned zone. The glazing planes separating exterior and interior space were designed so that heat gain, shading, ventilation and closing could be smoothly operated according to the seasons and other situations.

For shading, most of the glazing was covered with external roll-screens, which could be automatically closed and opened according to the strength of sunlight. The special swinging windows for ventilation “Swindows” were introduced for automatically controlling the ventilation. Four were fitted in the top and the bottom parts of the plane (8 sets in total). On sunny winter days, the screens are kept open for taking advantage of solar heat gain. The ceiling fan helps introduce warm air from the conservatory into the living space. The interior sliding doors are closed during the night. During the summer days, on the other hand, the shading screen and sliding doors are both closed and the “Swindows” open or closed dependent upon the indoor / outdoor temperature.

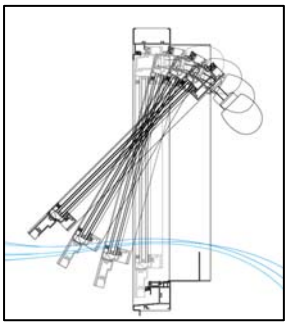


Figure.08 “Swindow” cross-section (product of Sankyo Tateyama Aluminium, Inc.)

The conservatory not only retained the original concept for the apartment to create an indoor green but also enhanced it by creating a secure intermediate space between outside and inside. The depth of conservatory could have been as little as 2m but to make the space a semi-external living area, it has become as large as the remaining living room.

Figure.09 Conservatory

Figure.10 Indoor Garden

The planting zones in the conservatory were filled with light soil and filled with greenery which was anticipated would lower the temperature in summer through water evaporation from soil and plants. The floor finish has been converted from wood to soil-ceramic tile suitable for semi-outdoor living. Eventually the conservatory area was named “Indoor Garden”.

The upper part of the high conservatory was difficult to clean and maintain. A new catwalk has been provided to solve this problem. A ceiling fan has also been installed to carry the warmed air into the lower level living space.

The shading screen can be controlled both by automatic and manual modes. It closes when the solar luminance or wind velocity exceeds a designated level. The “Swindows” can also be operated automatically and manually dependent upon controlling factors such as the combination of indoor and outdoor temperatures and high wind speeds.

2.3 Reducing external wall length

The entrance porch and the upper level service balcony had the shape of a (set back) bay. These were made into internal spaces by adding new doors, which reduced the total length of external wall and created smaller but thermally intermediate spaces. This lowered the heat load whilst the internal floor area increased. As this is effective only in winter, the doors can be left open in other seasons.

Comprising all the measures mentioned above, the Q-value (total heat loss per unit floor area) was to be improved to 2.52W/m2K after remodelling compared to 9.12W/m2K beforehand.

2.4 Greening

As unit no.301 had the name “Garden House”, greening the dwelling was the main design theme. The concept was characterised by interior plants. Besides conserving planting zones in the “Indoor Garden”, the western balconies are intended to have creeping plants for shading in summer using the existing metal trellis. Good maintenance and watering depend on resident participation.

2.5 Additional change in floor plan

2.5.1 Adding a bedroom

The dwelling had only 2 bedrooms although the floor area is more than150m2. The family size had been four throughout the early phases of the project and a regular complaint was that they needed an additional bedroom. This problem has been resolved by converting the upper level lounge into another bedroom. In addition, the kitchenette was abolished and converted into a closet for the newly created bedroom.

2.5.2 Change in staircase

The interior staircase is not within the heating / cooling zone. For preventing the heat transfer from the lower to upper level, however, the gaps between steps, which were intended to allow natural ventilation, have been closed. In this way, the energy saving concept has been given priority over the original design concept.

3. Improvement of Utility and Equipment

High efficiency is one of the most important considerations for saving energy in the home. Therefore the engineers have extra responsibility for equipment that the residents cannot change. The former air-conditioning system was no longer efficient. It has therefore been totally changed from a system serving the whole NEXT21 building to one for an individual dwelling. This has been made possible by the improvement in the quality of heat-pump for individual home use in the last 10 years. In addition, the energy systems have been chosen primarily for their efficiency and not necessarily their saving on the use of city gas.

3.1 Hot water supply and Combined Heat and Power

The solar heating to be installed still required an efficient boiler to cover the amount of heat needed to meet demand. On the other hand, a combined heat and power (CHP) system was to be tested in this experimental dwelling by introducing a developing fuel cell (FC) system. With two systems coexisting in one dwelling, I was possible to run them either separately or simultaneously. The comparison of these could be an interesting theme in terms of use practice and energy efficiency. (Solar heat utilisation will be discussed in the section of renewable energy. As of March 2008, the solar system was not yet installed.)

3.1.1 Condensing Gas Boiler

A condensing gas boiler has the function of absorbing exhaust heat by condensing the vapour into water to gain the latent heat. A latest condensing boiler has been installed. Its heat efficiency is 95% for hot water supply and 85% for floor heating (LHV[2]). This adds extra heat to the amount provided by solar collectors and fuel cell system. A mixing unit has been added to control the highest temperature of incoming hot water.

For the moment, only the hot water tank for fuel cell (FC) has been installed. There will be 2 tanks and the choice between them will be either automatic or manually done by the residents who can watch the temperature of each tank. When the temperature is high enough, they can use hot water directly from a tank instead of taking it through the boiler.

---

[2] Low Heat Value

3.1.2 Solid Oxide Fuel Cell (SOFC)

Among the developing fuel cell systems, solid oxide fuel cell (SOFC) is the most promising one for apartment houses or small households. The main reasons are the compactness and its high generating efficiency up to 45% (HHV[3]), which is higher than that of ordinary thermal power generation. The rate of usable exhaust heat from SOFC is relatively low up to 30% but it can be used for hot water supply. The dwelling unit No. 301 is one of the testing fields for improvement.

Figure.11 SOFC (Kyocera / Osaka Gas) right

3.2 Space Heating

The former heating/cooling system was a central VAV[4] air-conditioning. Hot water was generated from waste heat from the central CHP system and distributed to each dwelling. The efficiency was not high enough to meet the current target. The newly installed systems therefore include the following:

3.2.1 Floor heating by gas-heated hot water

One of the complaints from the past occupants was about the coldness of the floor at the lowest residential level, below which the space was non-residential and not sufficiently insulated. The heating efficiency of floor heating is lower than that of gas fan-heater and air-conditioning by electric heat pump. As for comfort and healthiness, however, floor heating is an ideal method. The level of comfort is higher because of the radiation from the floor and the direct touch of the feet on a warm surface. The vertical temperature distribution is almost even whilst air conditioning alone could only warm up upper part of the room.

The new system was aimed at lowering energy consumption compared with the existing system. Lower water temperature through larger pipes loses less heat during travel and reduces pumping power. Because of the sub-flooring system, however, there was no choice but to introduce a ready-made floor heating system in the remodelling.

3.2.2 Air conditioning

Air conditioning system for cooling can automatically be applied for space heating. There was no intention to introduce floor heating on the upper level. When the envelope heat loss has become very low, the excess heat at the lower level could warm the upper level. Hence a medium size air conditioning unit (2.8kW) seemed to be sufficient to keep the whole floor warm enough.

3.2.3 Gas cocks for eventual use

A newly installed heating facility does not require gas cocks but there could be a possibility of fault or insufficiency of heat distribution. Gas cocks in each room have been provided just for these cases.

3.3 Space Cooling

The former cooling system was also a central VAV air-conditioning. Cold water was prepared in a heat absorption chiller set in the basement of the building, transferred to dwellings, converted into cold air and finally distributed through duct to each room. The main shortcoming was high electricity consumption for the pump and fan.

However, the efficiency of electric air-conditioning units for home use has been remarkably improved in the last 10 years. Therefore it was decided to change the system from central to individual and adopt the highest performance model in the market. The coefficient of performance COP[5] exceeds 6.

The cooling load could be reduced by a half through the combination of high insulation and effective shading. Then only one system of 2.8kW in each level was estimated sufficient for keeping the room cool in summer.

3.4 Ventilation System

The use of a ventilation system conflicts with aspects of energy saving. For example, when increasing the volume of air ventilated, not only is lost but electricity consumption rises as a result of running the fan. In the remodelled apartment a heat exchanging ventilation system was installed on each level and the air ducts of the former VAV system re-used. In respect of seasonal operation, the compulsory ventilation level stipulated in the Building Standard Law, will be applied flexibly for energy saving. That is to say the mechanical ventilation system in the living space can be cut off during the non-cooling/heating seasons where a number of windows are usually kept open.

3.5 Lighting

---

[3] High Heat Value

[4] Variable Air Volume: an air-conditioning method manageable under partial load

[5] Coefficient Of Performance

Each light fitting was examined to decide how to improve it. A typical method of reducing electric consumption for lighting is to replace conventional bulbs with bulb-shaped fluorescent lamps, which use only one fifth of electricity to provide equal luminance. In addition, unnecessary lighting should be removed totally or just the bulbs taken out. Where sufficient luminance is achieved, the number of fluorescent lamps can be reduced.

In this way, unnecessary or surplus lamps and fixtures have been changed. The original condition was extravagant and far from the energy-saving concept. There were 49 lighting fixtures in total in the dwelling. The total capacity, according to the design document, reached 3.0kW when all were switched on. However, the length of time the lighting is switched on is unknown so the effect of energy saving is therefore difficult to determine.

3.6 Cooking

Energy saving in cooking could be improved through considering changing ways of daily life. In particular, it has direct effect to minimise the use of electricity for heating food and keeping it warm, because only 40% of the energy consumed in thermal power station reaches home. Although each action is small, there is a considerable room for reducing energy consumption in cooking. This might include the choice of cooking apparatus, developing methods of low energy cooking and other more ingenious cooking methods.

The only change made in the remodelled apartment was to introduce a modern gas cooking table, the heat efficiency of which reaches 56%, compared to 50% of a conventional model.

3.7 Other use of electricity

To stop using “stand-by mode” on equipment is one of the essential methods to reduce domestic electricity consumption. This can be realised with a small amount of investment or conscious efforts by the occupants. In the remodelled apartment, half a dozen electric sockets (taps) with switches have been provided. A small neon lamp indicates the main switch is not cut off and induces the users to cut the electricity from the socket to eliminate stand-by electricity.

4. Solar Energy Utilisation

However hard efforts are made to save energy, it is practically impossible to reduce domestic energy consumption to a quarter of the original amount. It is therefore paramount to take advantage of renewable sources of energy as a means of drastically reducing conventional energy consumption - which is the main cause of global warming. The typical renewable energy for home use is light and heat from solar energy.

4.1 Photovoltaic System

The photovoltaic (PV) system is most promising as a clean and quiet system for renewable power generation applicable to individual houses and low-rise blocks of housing. In the case of “NEXT21”, a PV module of 7.5kW has been set symbolically on the rooftop to generate electricity for use in common areas. One third of the existing PV module (2.5kW) has been switched exclusively to unit 301 for the experiment. A new power conditioner has also been installed.

The surplus electricity, i.e., the electricity that unit 301 does not consume, is transmitted to the electrical grid within the NEXT21 building. The 2.5kW is practically a maximum capacity for five-storey apartment block because the roof area per dwelling is limited to 20m2.

Figure.12 PV module, one third of it serves for the dwelling 301

4.2 Solar Hot Water Supply

If global warming is to be avoided, it is most important to use solar heat to cover a large part of the domestic hot water supply. In Japan, hot water constitutes about one third of the domestic energy consumption. Solar heating is classified into the following categories: 1) natural circulation type, 2) forced circulation type and 3) water storage type. The collector in this instance is a flat type set almost vertically within the concrete framework. The heat is collected in liquid medium then transferred to and stored in the hot water tank through heat exchanger.

5. Pre-evaluations

The effects of the various measures are evaluated through simulation both in terms of energy saving and gaining renewable energy. The first step is to establish the basic model against which the findings of the study will be compared. Standard energy use is calculated according to the energy use categories, which is based on standard data already available and actual data from the previous occupation.

All the energy use is converted into mega-joule (Mj) on a primary energy basis. As the electricity that has reached the users is roughly 40% of the energy consumed in thermal power plants, it is multiplied by 2.5 to give it a primary energy rating. Then, the reduction of each measure in each category is evaluated one by one, which is explained below. Finally, gain from renewable sources of energy, in this case PV for electric power and solar heat for hot water, is deducted from the total amount of energy required, on the premise that PV power and solar heat utilisation has negligible impact to the environment.

5.1 Basic Energy Consumption (Reference Data)

There are several sources of calculation to provide reference data. They are:

(1) Actual energy consumption during the early phases of occupation,

(2) Model data in Osaka from The Institute of Energy Economics Japan (IEEJ), and

(3) Simulation by SMASH[6] modelling for heating and cooling load only.

The adopted method consists of two of the above:

(1) Simulation by SMASH modelling for heating / cooling load, and

(2) Simple average of the actual consumption volume, using average data for a detached home. The Osaka average data from the IEEJ has been adjusted for the project to a household of four persons.

5.2 Effect of Energy Saving

The energy saving results listed below includes effects that have been verified through simulation analysis. Instead of solar heat gain for hot water, the waste heat from the SOFC system is included.

Assuming a basic level 100 (167.2Gj), the energy load has been calculated to be lowered through each measure as follows:

(1) Through architectural improvement (resulting better heating/cooling performance), the energy consumption will be reduced to 55% (92.1Gj),

(2) Through refurbishment or replacement of built-in facilities, to 48% (80.8Gj)

(3) Through replacement of home electrical appliances, to 44% (72.9Gj)

(4) Through expected change in lifestyle of the occupants, to 39% (64.7Gj)

(5) Through utilising the waste heat gained from the SOFC, to 35% (59.3Gj)

Finally, deducing the PV generated power from the residue of energy saving mentioned above, the total consumption was estimated to be 22% (36.8Gj, reduction rate of 78%). These figures represent the consumption level of conventional energy in terms of primary energy, which is comparable to the alleviation of the environmental impact.

Thus, although some presumptions are included, the target of “reducing energy load to a quarter of the original amount” seemed realisable when every measure was taken into account.

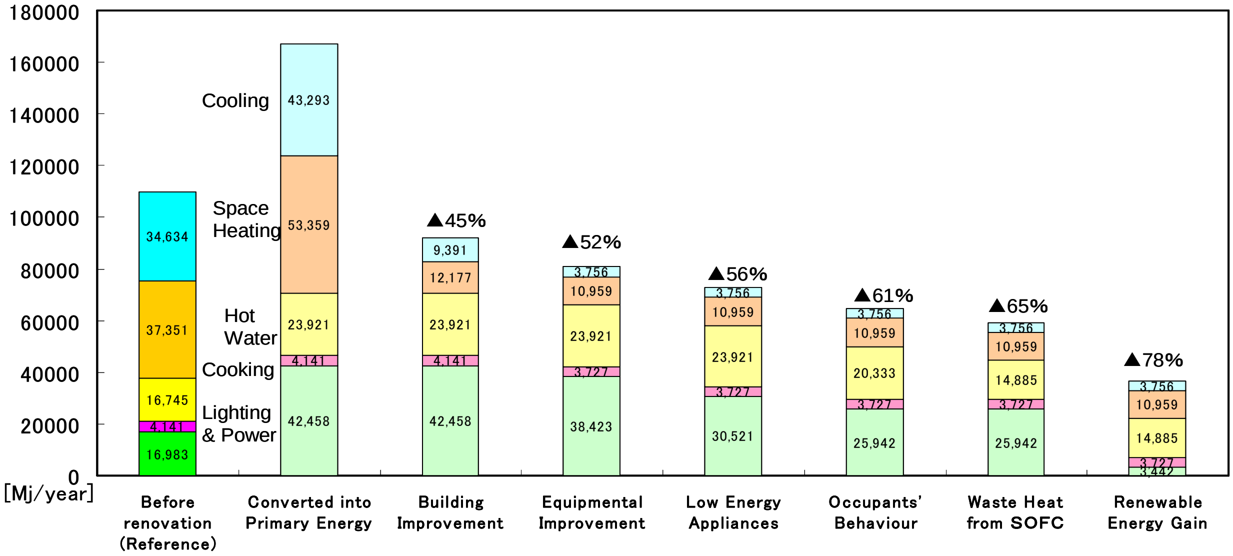


Figure.13 Expected process of Energy Impact Reduction (figures in Mj per year)

5.3 Effectiveness per Invested Cost

The energy reduction or gain of each measure, in term of Mj in primary energy per 1000 yen, was calculated to compare their effectiveness. After every measure, with its performance, had been assessed, the cost effectiveness was prioritised.

---

[6] Simplified Analysis System for Housing Air Conditioning, IBEC Japan

5.4 Data to be measured

Finally, it is necessary to compare the expected targets against actual data after occupation. This includes indoor/outdoor temperature, electric consumption, gas consumption, PV power generation and heat gain from either SOFC or solar collector. Sensors and meters were installed at suitable locations and the data have been transmitted to the logger installed in the basement of the building. They have been collected regularly and analysed.

6. Experiment through occupied condition

Once the energy saving/gaining measures were ready in April 2007, a family moved into the dwelling. The family consisted of a married couple with two daughters both in junior high school that year. Although the age of children is different, the family size is the same as the ones in previous phases (1st and 2nd).

A study group for “Experiment of Factor4 Dwelling Low Energy Living” has been set up. It has actively watched over the process, analysed the results and determined additional measures to fill the gap between the target and the outcome. This study is to continue for 5 years.

In the first fiscal year, April 2007 to March 2008, the family was not requested to make efforts to reduce energy consumption. The home electrical appliances remained as they had been brought in. The intention was to have basic data for comparison with the later energy saving behaviour.

The data from the first year has been collected sufficiently in spite of some errors and mistakes. At the same time, the weak points of remodelling have also been clarified. Following is a list of the main findings from the first year of occupation. The Fig.14 shows the energy consumption/gain results through the FY 2007 in comparison with the reference and the actual data in previous occupation.

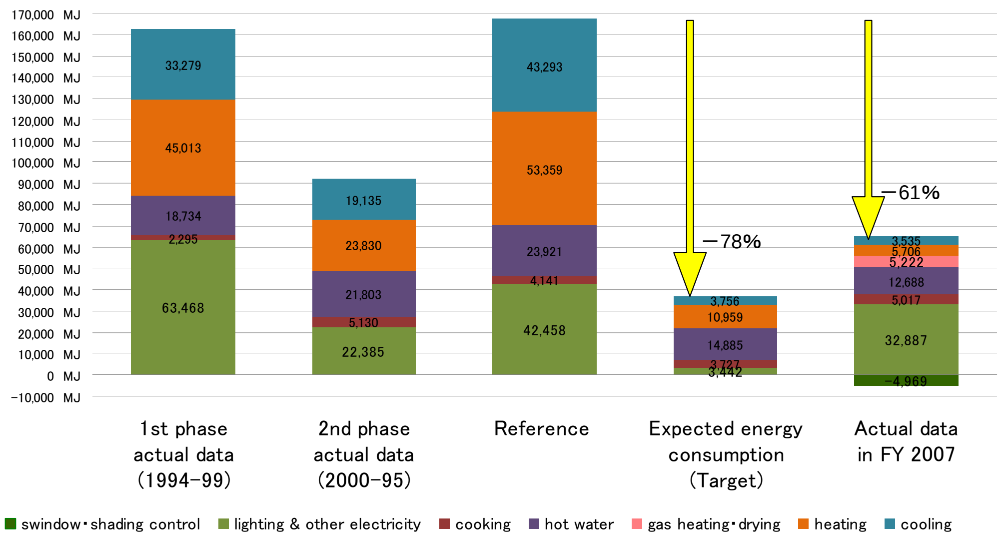


Figure.14 Results of energy consumption in comparison with target, reference and previous cases

Heating: The energy consumption for heating space was as low as expected. The effect of better insulation has been clearly proven.

Cooling: The cooling energy was 6% lower than expected but the way of using air-conditioner was intermittent which is not equal to the presumption.

Hot water supply: The waste heat from the fuel cell seems to have been well utilised. The energy use for this purpose was 16% lower than expected.

Cooking: The energy for cooking was 35% greater than expected but not as significant as other uses. The data during winter is estimated from the other seasons because it is only available for non-heating season.

Lighting and other electric use: This section has been the most difficult part of the project to analyse. The main reasons for the high-level consumption cannot be explained beyond the two old refrigerators in use. More detailed examination is required.

The total reduction rate for the first year was approximately 61%. That figure is still far behind the target of 78%. The electric consumption in particular has been much higher than expected. Patient watch, further improvement of equipment and good guidance to the occupants are required for attaining the target.