Experimental Home Targeting Zero Life-Cycle-Energy Balance

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ABSTRACT

Misawa Homes have developed a home aiming a zero annual energy balance, defined as the energy consumption over production by using solar energy, in 1997. According to our survey, energy balances of what we call Zero Energy Homes built in Tokyo or southern area of Japan were actually zero but it was not the case in those homes built in northern area [(1),(2)]. As one of the top housing distributors, we realize that it is our responsibility to develop and provide environmentally friendly homes to prevent global warming. When it comes to substantial effect on environmental impact, not only annual energy balance but the energy and resources consumed during manufacturing and construction periods, is important. In other words, life cycle energy (LCE) must be considered. We have now set a new goal to develop a home with zero annual-energy-balance no matter where you build it. Another goal is to develop technologies that realize zero LCE balance. An experimental Advanced Zero Energy Home was constructed in February 2008 in Asahikawa city, one of the coldest cities in Japan.

1. INTRODUCTION

As mentioned above, we define our Zero Energy Home as a home whose annual energy balance, defined as the difference between energy consumption and energy production can be reduced to zero. Energy consumption includes air conditioning, hot water supply, cooking, lighting and other electric appliances. In an attempt to bring the energy balance to zero, it is necessary to reduce the energy consumption of each usage without sacrificing comfort and convenience.

Minimized energy consumption can be balanced with the photo voltaic (PV) modules fully covering the roof. Building integrated PV modules enable durability and cost performance even though the modules on the north side of the roof generate less electricity per area.

No matter how a zero annual-energy-balance is effective in reducing environmental impact, it would make no sense if the energy required to realize it were comparatively high. The concept of Advanced Zero Energy Home is to further reduce the annual consumption so that the PV generation exceeds the consumption of the home. The remainder of the annual energy balance may be accumulated every year to compensate the energy required during the manufacturing and construction periods. In other words, life cycle energy balance may approach zero over time.

2. SPECIFICATIONS

2.1 Insulation and planning

Fundamental insulation spec of the experimental home is fortified at every part. The K value of the outer wall reaches 0.20W/(m^{2}K) by adding 100mm thick glass wool to the standard wooden panels. Ceiling is insulated by 300mm thick glass wool which enables K value to increase up to 0.13W/(m^{2}K). Foundation and basement floor is insulated by 100mm thick styrene-foam boards. Under-floor area is also air-tightened. Temperature under floor can be kept quite close to the indoor temperature. Windows are made of plastic sashes with double glazed low emissive glasses containing Krypton gas in-between them. Central ventilation system installs heat recovery unit with 70% recovery performance. The heat loss coefficient per floor area of the home is calculated as 0.80W/(m^{2}K) and is 1/2 of the highest performance indicated in the Performance Indication System prescribed in the Quality Assurance Law. Floor plan and elevation plan are shown in Figure 1. Total floor area, 139m^2, is about the average of newly built homes in Japan.

2.2 Equipments

Heating and cooling are provided by air-to-water heat pump system and panel radiators. Heated or cooled water is delivered from the heat pump unit to the radiators through poly-ethylene pipes coated with aluminum layer. Panels are installed in each room and are to be controlled individually with thermostats. Panel radiators, usually used only for heating, can be used for cooling in summer. They are combined with drain pans so that the condensed water created on the surface during cooling process can be drained out from the home. Newly introduced heat pump system shown in Table 1 is a system functionally guaranteed at -20°C (253K) outdoor condition.

Hot water is supplied by a newly improved CO_2 heat pump system aimed for cold regions. The system is functionally guaranteed at -25°C (248K) outdoor condition. The system utilizes inexpensive nighttime electricity to reserve hot water in a tank. The tank, having 460 litters capacity, reserves up to 90°C hot water in it. Monthly coefficient of performance (COP) of the system assuming outdoor condition at night time in Asahikawa city is shown in Table 2. In Japan, warm water is reserved in the bathtub for bathing every day. Since the water temperature in the bathtub is kept warm enough for long by reheating, the bathtub is now insulated for energy saving. Conventional bathtub loses 7 °C in 6 hours while the insulated tub only loses 2 °C in 6 hours. Furthermore, heat loss from the bathtub may be retrieved to heat the under-floor space to keep the floor surface temperature high and reduce heat load in winter.

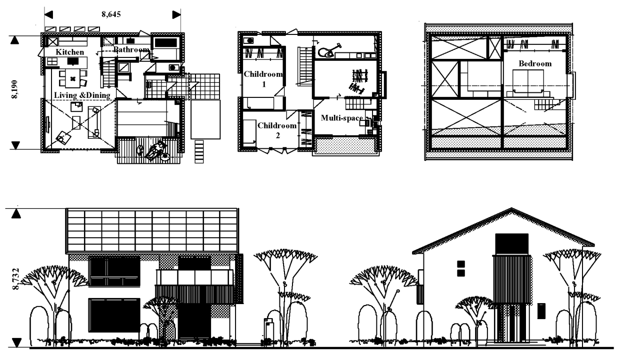


Figure 1 Floor plan and elevation plan of the home

Table 1 Performance of heating/cooling unit

Rated heating performance*1	11.5kW
Rated heating consumption*1	2.95kW
Rated heating COP*1	3.9
Rated cooling performance*2	7.0kW
Rated cooling consumption*2	2.8kW
Rated cooling COP*2	2.5

*1 Outdoor 7 °C, heating water 40 °C.

*2 Outdoor 35 °C, cooling water 7 °C.

Table 2 Monthly COP of heat pump hot water unit assuming the climate in Asahikawa

Jan	Feb	Mar	Apr	May	Jun
3.0	2.9	3.4	4.0	4.4	4.7
Jul	Aug	Sep	Oct	Nov	Dec
5.0	5.0	4.7	4.2	3.8	3.3

Conventional induction heating cooker is used for cooking while the exhaust air can be purified and returned to room resulting in ventilation heat load reduction. Air purifying system uses photo catalyst coated ceramic filter and ultraviolet lamp to resolve odor or oil. According to the calculation, heating load may be saved up to 15% due to ventilation reduction.

Light emitting diode (LED) devices are used for main lighting equipments in the home. Light emitting performance of LED is up to 7 times higher compared to that of a conventional bulb and 2 times higher of a fluorescent lamp. Another advantage is that the LED has high durability.

Since the equipments are all electrified, the time specific contract with local electric power company can be used. The contract offers discount rates at night.

2.3 Photo Voltaic system

The roof of the home is fully covered by building integrated PV modules. Mono-crystalline PV modules are designed to fit the entire roof area and the capacity is 5.16kW on the south side and 4.30kW on the north side. Generated electricity may be converted to alternative current to be used for any usage in the home. Since the system is connected to the grid, surplus electricity can be sold back to the power company. Buy-back price of the surplus electricity is the same with the day time electricity cost. On rainy days or at night time, when more electricity is required than generated, shortage may be compensated by the power company. Although it is not common to fix PV modules also on the north side of the roof, recent research indicates the life cycle cost advantage of the whole-side system when roof maintenance cost is included [3].

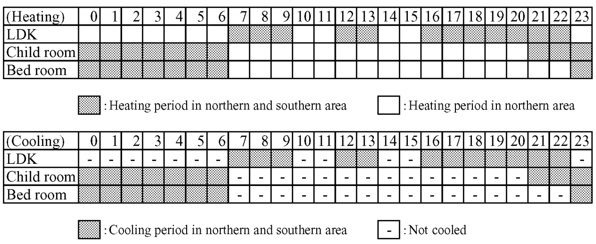
3. ENERGY BALANCE SIMULATION

The energy consumption of each usage was simulated assuming that the home was built at 5 different cities including Asahikawa where the experimental home was actually built. Simulative assumptions are noted as below.

3.1 Air conditioning

Heating and cooling load are simulated by conventional thermal network software SIM/HEAT[4]. The software simulates heat load and indoor thermal condition hour by hour depending on the local climate condition. Room temperature in winter is assumed to be controlled at 22 °C. Heating hour depends on the construction area. In northern area, in this case Asahikawa city, heating is provided throughout the home 24 hours a day. On the other hand, in southern area, heating is provided while occupant stays in the room. In summer, room temperature and humidity are controlled at 26°C and 50% when occupant stays in the room. Heating and cooling hour assumption is shown in Table 3. Monthly energy (electricity) consumption is obtained by the simulated heat load and seasonal COPs of the heat pump hot/cool water system.

Table 3 Heating and cooling hour assumption



3.2 Hot water

Heat load of hot water supply is referred to reference [5] that contains regional annual load data. Annual heat load data is divided into monthly data in accordance to the monthly water temperature difference. Monthly energy (electricity) consumption is obtained from the monthly load data and monthly COP of the system.

3.3 Cooking

Cooking load is also referred to reference [5]. Annual data is simply divided into 1/12 for monthly load. Monthly energy (electricity) consumption is obtained from reference data and the efficiency of the IH cooker. Vent air load during cooking period may be reduced in winter due to the air purifying circulation system.

3.4 Lighting and general electric appliances

Electric load for lighting and general appliances are also referred to reference [(5)]. According to recent research [(6)], the ratio of electricity load for lighting is 21% of the total load for lighting and general electric appliances. Electricity saving by LED for lighting may be calculated with the ratio and efficiency difference between conventional bulb and LED.

3.5 PV generation

Amount of PV generation can be calculated by parametric method. Parameters affecting the generation are module and converter efficiency, solar irradiation, temperature, and dust or snow accumulation. Simulated results meet well with the actual data [(7)].

3.6 Simulated results

Energy (electricity) consumption and PV generation of the Advanced Zero Energy home assuming Asahikawa and 4 other major cities are simulated. Energy consumptions of conventional home are also simulated. Specifications of thermal insulation or equipments related to the construction areas are shown in Table 4 and 5. “Northern area” in the figure stands for Asahikawa city and “southern area” in the figure stands for the rest of the cities. Heating and cooling load are simulated by the same software mentioned in 4.1. Energy load of hot water supply, cooking, lighting and general electric appliances are calculated for each city using the same assumptions and reference. PV generation is also simulated according to the local conditions. Simulated results are shown in figure 2.

Annual energy consumption of a conventional home in Asahikawa city is 21,240kWh. On the other hand, annual energy consumption and PV generation of Advanced Zero Energy Home in Asahikawa city may be 7,202kWh and 7,741kWh respectively. Annual energy consumption is 65% lesser, and as a result, PV generation exceeds the energy consumption by 539kWh/year. Annual energy balance rate, defined as energy generation by PV divided by energy consumption in the home is 107%. Annual energy balance rates also exceed 100% at rest of the cities ranging from 107% to 153% depending on the area.

Annual energy cost balance is also simulated concerning the local energy (electricity) price. According to our simulation, family living in our conventional home will cost 230,000 yen every year in Asahikawa city. On the other hand, the family will earn 77,000 yen every year by living in Advanced Zero Energy Home. The result, arranged in Figure 3, shows that the family will not only save the total energy cost but earn substantial surplus wherever they may live.

Table 4 Specification of thermal insulation

	Northern area	Southern area
Ceiling	GW 24 kg/m^3 300 mm	GW 24 kg/m^3 250 mm
	GW 24 kg/m^3 250 mm	RW 40 kg/m^3 200 mm
Wall	GW24kg/m^3 200 mm	GW24kg/m^3 150 mm
	GW24kg/m^3 100 mm	GW16kg/m^3 75 mm
Basement (Floor)	PSF B-3 100 mm	GW24kg/m^3 75 mm
	GW24kg/m^3 100 mm	GW16kg/m^3 75 mm
Window (Plastic sash)	Low-e double glazed window with Kr gas	Low-e double glazed window with Ar gas
	Low-e double glazed window with Ar gas	Double glazed window with dry air
Ventilation	HR central system (HR coefficient 70 %)	HR central system (HR coefficient 70 %)
	HR central system (HR coefficient 70 %)	HR central system (HR coefficient 70 %)

Specifications above broken lines are for Advanced Zero Energy Home. Those below broken lines are for conventional home.

GW: Fine fiber glass wool, PSF: Poly-Styrene foam, HR: Heat recovery

Table 5 Specification of equipments

	Northern area	Southern area
Heating	HP water system Rated COP = 3.9	HP air conditioner Seasonal COP = 5.0
	Thermal storage heater	HP air conditioner Seasonal COP = 3.5
Cooling	HP water system Rated COP = 2.5	HP air conditioner Seasonal COP = 4.0
	HP air conditioner Seasonal COP = 3.5	HP air conditioner Seasonal COP = 2.5
Hot water	CO_2 HP system Rated COP = 4.9	CO_2 HP system Rated COP = 4.9
	HP system Annual COP=1.1	HP system Annual COP=1.1
Cooking	Induction heater Efficiency =90 %	Induction heater Efficiency=90 %
	Induction heater Efficiency =80 %	Induction heater Efficiency =80 %
Lighting	LED	LED
	Conventional bulbs	Conventional bulbs

HP: Heat pump, COP: Coefficient of performance

Specifications above broken lines are for Advanced Zero Energy Home. Those below broken lines are for conventional home.

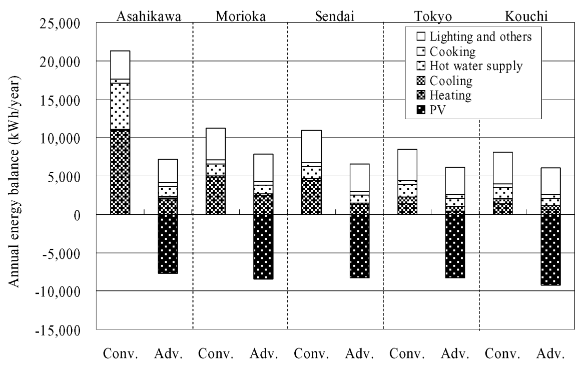


Figure 2 Energy balance of the home in each city

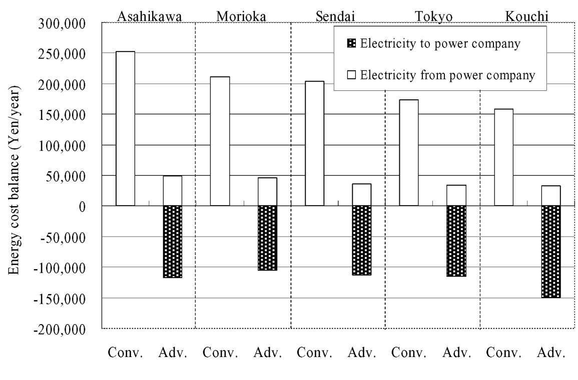


Figure 3 Energy cost balance of the home in each city

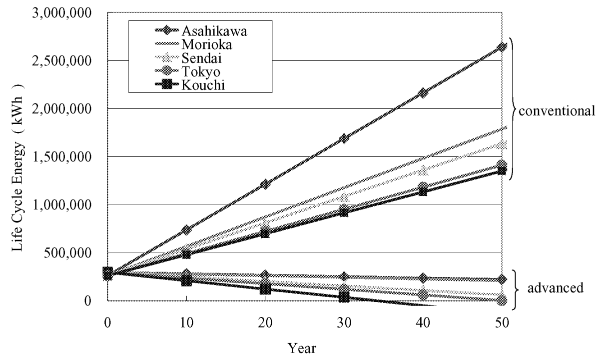


Figure 4 LCE balance of the home in each city

Advanced Zero Energy Home is not only a zero emission home but an "absorption" home. As mentioned above, the PV generation exceeds the energy consumption by 539kWh/year in electricity. It worth 300kg-CO_2 absorption every year[9].

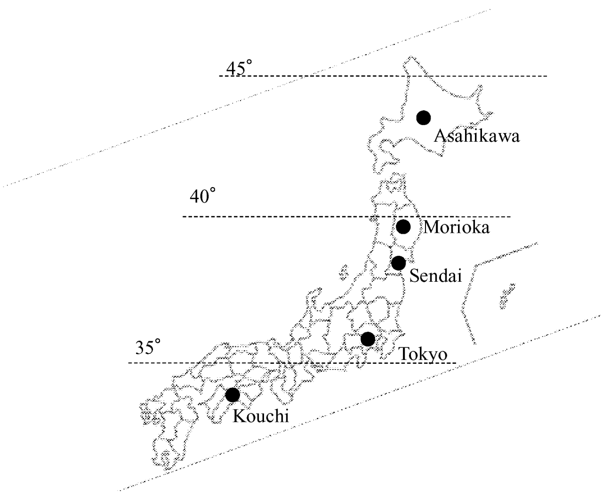


Figure 5 Location of the 5 cities

4. LIFE CYCLE ANALYSIS

Primary energy and resources of conventional home consumed during manufacturing and construction periods are calculated by life cycle energy analysis (LCA) software, BEAT [10], developed by Building Research Institute.

According to the calculation, a home shown in Figure 1 with conventional specification consumes 261,300kWh or 940GJ of primary energy during manufacturing and construction period. Since the software cannot calculate minute difference between conventional and Advanced Zero Energy specification, differences in structures and equipments are summed up on raw material and fuel base. The result is transformed into primary energy and added to the result obtained by the software. Minute difference between two specifications was 33,900kWh or 122GJ. Thus, Advanced Zero Energy Home in Figure 1 may consume 295,200kWh or 1,062GJ, during the manufacturing and construction periods. It implies a 12% increase in primary energy use [11].

Nevertheless, life cycle energy balance decreases every year since the annual energy balance is negative. Note that the secondary annual energy balance is transformed to primary one. Primary energy conversion rate for electricity is prescribed in the national law [12] as 9,760kJ/kWh. Consider the sample cities located in the southern part of Japan, for example Tokyo and Kouchi. The life cycle energy balance will reach zero within less than 50 years. For the sample cities located in northern part of Japan, for example Asahikawa, it may take longer years to reach LCE zero but the LCE will be saved more than 90% in 50 years.

5. SUMMARY AND FUTURE PLAN

Concept and simulated results of Advanced Zero Energy Home are shown. The home aims at realizing both zero annual-energy-balance and zero life-cycle-energy-balance at any region in Japan. Experiment home was built in Asahikawa city, one of the coldest cities in Japan, in February 2008 as shown in Figure 6. We are now taking actual data for further development.

Figure 6 Experiment home in Asahikawa city

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