Experimentation and Verification of the “Perfect Recycle House”

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Abstract
This paper proposes two typical environmentally symbiotic residences and verifies their validity. These residences are designed on the theme “resource circulation and reduction of environmental impact”. One of them is a wooden house based on the Japanese traditional timber frame house, and the other an industrial residence using modern technology and materials. The following results were obtained by the design of these two experimental residences (the Perfect Recycle House), through construction and verification.

1. Introduction
During the period of great economic growth in Japan, “mass production, mass consumption, and mass disposal” were basic to the diverse industrial activities, social system, and our lifestyle and were seen as our wealth. But, the activities based on this policy have changed the global environment and are threatening our very existence. Under such conditions, it is demanded of both urban planning and architecture to develop hardware and software technology which can reduce the load on the global environment.

In respect of CO2 discharge reduction measures in the construction industry, residential facilities, and especially detached houses, are lagging behind the commercial facilities¹. Therefore, as through reuse and recycling are in great demand, it is essential that building components be standardized, components reused as much as possible and the rest recycled. However, at the moment problems arise from the fact that neither the standardization of simple building nor consideration for recycling is practiced. This must be solved before pursuing a standardized social structure. In this research, a construction method premised on the reuse of components and thorough use of recyclable materials was carried out. "Reuse" means the use of building components as they are, while "recycle" means the use as a raw material for building.

Experimentation regarding the “Perfect Recycle House” has been made, which aims to reuse or recycle more than 80% of its components and to establish a system of facilities and lifestyle which can reduce the environmental load related to our living such as energy, water and waste etc. This model house consists of two types of different material and method. One is the reuse type of W-PRH, which is based on the Traditional Timber Frame House and the lifestyle that fuses well with the natural ecosystem, located in Oyama Town, Toyama prefecture. The other is the recycle type of S-PRH, which is an industrial house of steel structure, and all of its components are designed to be circulated within the industrial chain system, located in Kitakyushu City, Fukuoka prefecture.

This paper explains the concept, design method and experimentation system of these model houses, and inspects and reports the results of the experiment.

2. The Concept of the Perfect Recycle House and the Method of Evaluation
2-1 The Concept of the Perfect Recycle House
In this research, the schedule has been made on the
assumption that it pursues a vision of the detached house in 21st century and fulfills the goal of; “Reducing the CO2 emission of newly built houses by 30% and extends the durable years by three times.” which is the COP3 proposal presented by the Architectural Institute of Japan in October 1997. Therefore, the following ideas of recycling from a viewpoint of lifecycle has been introduced for both “building” which is related to the construction and disposal and “facility and living” which are related to management.

1) Recycling of Buildings

The recent average durable years of houses is 20 – 30 years2), and most of their components are disposed of as construction waste when they are demolished. There are two causes for this short lifetime; the use of components with insufficient durability assuming certain cycle of scrap & build, and the difficulty of separating waste at the demolition site because too much adhesive is used in order to minimize the construction period and cost3). To improve this and form a circulatory system for buildings themselves, it is necessary to practice the following;

#1 Use of components with high durability and the capability of being reused or recycled.

#2 Adoption and development of methods that can provide easy demolition.

2) Recycling of Facility

Recent houses depend on urban supply for their water and energy, and on treatment plants to dispose of wastewater and other waste. Because of this package supply and treatment method, no circulatory system has been formed in small or medium areas or building sites, and as a result the utilization of resources and energy is not being carried out. To improve this, it is necessary to practice the following:

#1 Provide the function of supply and treatment within building sites as much as possible and increase recycle rate in the site.

#2 Establish a recycling system for building components and waste and increase the recycle rate in a wide area.

3) Presentation of two Types of Reuse / Recycle House

Present detached houses are roughly divided into two types by building method; one is the conventional timber frame house derived from the traditional timber frame house, and the other is the industrial house which rapidly developed after the war. This research, under the concept of the recycling of buildings and facilities as stated above, presents two contrasting models; the W-PRH: continuing the reuse performance of traditional wooden houses, and S-PRH: a new type of industrial steel house which takes into consideration separation and recycling not only during production but also at dismantling. The explanation by secular change of the stock of the detached houses is shown in Fig.1: industrial houses of the flow type will change to two types of PRH.

2-2 Concept of the Reuse-Type House: W-PRH

Traditional Japanese houses are well maintained and lived in for a long time and are carefully dismantled and rebuilt in another location with a lot of reusing of components. W-PRH is a model house which follows Japanese traditional building methods, consists of only natural materials and applies joint attachments to simplify dismantling and reuse. In the living stage, cedar #4 ture,
cedar woods and soil at the site as a part of facility system and utilizing energy of nature, it aims to circulate them within the site. Fig. 2 shows the resource circulation concept of W-PRH which utilizes the natural ecosystem.

2-3 Concept of the Recycle-Type House: S-PRH

A lot of industrial houses, which are very popular today, on the one hand, pursue rationalization when they are built, but, their life is short at only 20-30 years and most of their components are disposed of as mixed waste through dismantling with construction Equipment “Called mince dismantling”. The S-PRH, a model house designed with consideration given to dismantling and separation, is built only with materials that are capable of being recycled into the same building, and apply the dry construction method without using adhesives. These materials are circulated through a recycling plant covering a wide area, and during its lifetime by adopting high tech facilities, aims to carry out as many of the supply and treatment processes within the house as possible. Fig.3 shows the resource circulation concept of S-PRH which is included in the industrial chain system.

2-4 Evaluation Method through PRH Value

The formula of PRH value is shown in Fig.4. The PRH value is an evaluation method of Life Cycle Mass and was originally selected as a way to measure resource circulation for this research. This value is calculated as follows: divide the amount of consumed material during construction by the total amount of waste during 100 years, and multiply by 100. This will equal the amount of time it takes for material consumed at construction to become waste.

3. Experimentation and Verification of the Wooden Perfect Recycle House: W-PRH

3-1 Design

The W-PRH was built based on the above concept. The location is Oyama Town, Kamisinkawa County in Toyama prefecture. It is designed to be a detached house located in a mountainous area with rich resources in the forest. The external appearance is shown in Fig.5, building specifications are in Table 1 and finishing specifications of each part are in Table 2. After completion of the construction, actual life experiments were carried out for about one and a half years, and it was then dismantled and reconstructed.

The features of each part of the W-PRH are as follows...

#1 Structure: Using wood with large section for longevity, utilizing the traditional joint attachment method to simplify dismantling and separation and to increase the reuse rate.

#2 Material: Only natural materials were applied: wood, roof tiles, natural stone, soil and plaster were used, while persimmon juice and Bengal have been used for paint and rice chaff for insulation.

#3 Exterior: To simplify dismantling and rebuilding, wall panels with chaff insulation and soil walls and plaster to increase durability were used.

#4 Interior: Like the external walls the internal walls were panelized. Thanks to the large section structure, internal wall panels can be removed, and it is easy to change the plan. Floor panels and roof panels are finished with naked finishing to make
them durable and easy to maintain.

5 Plan and Greenhouse: Plans of each floor are shown in Fig. 6. One couple, two children and one aged person are assumed to live here. In order to secure insulation and ventilation in a north-south direction the house has a long east-west plan atrium “Greenhouse” on the south side as a buffer space. The section of this Greenhouse is shown in Fig. 7. In summer, heat is extracted through an exhaust opening, and in winter, solar radiation is accumulated from a large aperture to reduce the heating load. In the middle season it also has the function to maintain ventilation in the house.

6 PRH Value of W-PRH: Under the conditions above, PRH value for W-PRH is calculated to be 170: as large as five times the normal conventional timber frame house. (Fig. 20 )

3-2 Facility Design
1) Air Conditioning and Hot Water Supply System by Solar Heat and Incineration Heat
The system diagram is shown in Fig. 8. This system accumulates solar heat and incineration heat from construction scrap, fire wood and combustibles in the thermal storage tank and utilizes it for hot water and heating. Heating is provided by a panel heater and warm air circulator, while air-conditioning is provided by a cold-water chiller.

2) The Solar Generator and System Interconnection System
A 5kW solar cell on the roof generates electricity, and buys the deficit and sells the surplus by adverse current.

3) Utilization of Rain Water and Sewerage System
Water from the rainwater pipe is filtrated to store in a 2,000 litre storage tank, and utilized for flush water and sprinkling etc. Drain water is collected into a soil and waste treatment tank, and after additional processing in a third treatment tank, disposed of into the ground.

4) Waste Separation and Weighing System
After through separation, wastes are weighed and controlled, garbage is processed in compost, combustible wastes are brought to the firewood boiler as fuel and recyclable wastes are separately collected. This increases the recycling rate in the site and is expected to increase the residents’ environmental awareness.

3-3 Dismantling and Rebuilding Experiment
A dismantling and re-building experiment was carried out on the W-PRH house, which is designed to pursue the maximum reuse of components, and the reuse rate estimated and evaluated.

1) Definition of Reuse Rate
Reused material is, in this research, defined as material which is reapplied for the same purpose in the same place, in a building which has been re-built in the same form as the original. Therefore the formula for the reuse rate is calculated as follows: (material amount used in the same part at re-building / material amount in new building) * 100 (%)
3-2 Insulation performance does not fulfill the 1992 standard of energy conservation because it is made of traditional timber frame and plaster walls, and the heat conductivity of rice chaff used as insulation is not so small: 0.064 (W/mK), but extension of the structure’s longevity and merit for healthiness are chosen rather than the 1999 standard of energy conservation. And at the new construction and rebuilding, airtightness and the concentration of formaldehyde were measured (Table 3). From the results of re-building; after airtightness has been improved by the new construction method, airtightness of the traditional building method can raise the performance very close to that of the conventional method. The concentration of formaldehyde was so low that it can be disregarded, and its performance in terms of healthiness turned out to be especially high.

3-5 Actual Life Experiment

Through the one and a half year life experiment, the following facts were found:
- Actual survey in summer has confirmed that the Greenhouse has high utility value as a living room in the daytime owing to good ventilation and contributes to a reduction in the air-conditioning load, while increasing comfort.
- Energy: Hot-water supply load has been covered by 60% solar and incineration heat in winter and almost 100% throughout the rest of the year. However the heating load was not sufficiently covered. This is because of the traditional building method in terms of low air-tightness and abolishment of adhesives. At the rebuilding, joints and gaps have been largely improved and the use of solar and incineration heat was changed to hot-water supply only.
- Water: Utilization of rain water has reduced the consumption of city water by a monthly average of 22%, and the total water system has reduced its CO2 discharge by 16% compared to the conventional house. It is also found that, in winter, the snow on the roof has the function to reserve water.
- 59% of domestic wastes have been reused at the site, which was more than twice that expected.

3-6 Reuse and Recycle Center for W-PRH

In order to circulate reuse type houses like W-PRH, stockyards for dismantled materials and a new logistics system for old materials are necessary. Therefore, sug-
gesting the Reuse / Recycle Center as shown in Fig.11, collected materials should be appropriately handled; according to each material's state and sorting, they will be reused, thermally-recycled etc. This system leads to reduced construction-originated waste.

4. Experimentation and Verification of the Steel Structure Perfect Recycle House: S-PRH

4-1 Design

The S-PRH was built based on the above concept. The location is Wakamatsu ward in Kitakyushu City, Fukuoka prefecture. It is designed to be a detached house located in a suburban area. The external appearance is shown in Fig. 12, building specifications are in Table 4 and finishing specifications of each part of the building are shown in Table 5. One month after the performance examination following completion, dismantling and re-building were carried out and the life experiment was started in April 2001.

Features of each part of the S-PRH are as follows…

#1 Structure: Longevity extension has been attempted by thick, heavy steel frame and construction of vibration isolation, while simplification of dismantling and separation, and increase of reuse-recycle rate have been attempted by the dry construction method using the modular designed and factory made system-frame.

#2 Materials: Selecting artificial materials capable of being perfectly recycled within the industrial chain, the body is made of steel frame, with an exterior of aluminum and glass, and interior using resin materials such as plastics.

#3 Exterior: In order to simplify dismantling and rebuilding, the dry construction panelization method has been implemented. Covering the entire house with glass increases durability and weather resistance, which recycled PET bottle fiber has been installed as insulation.

#4 Interior: Screws and double-sided adhesive tape, substituted for adhesives which were not used. Because the free-plan was adopted; internal walls and panels can be set anywhere on the 900 by 900 mm square lattice ceiling runner.

#5 Plan and Double-skin Space: Plans of each floor are shown in Fig.13 and section is shown in Fig.14. The first residents are assumed to be a young couple. In order to secure ventilation in a north-south direction and solar radiation in the winter, the S-PRH has a large aperture on the south side and an atrium with double glazing (Double-skin Space) as buffer space between the outside and inside. This Double-skin Space has a role like that of a perimeter corridor in a private house, in the summer it not only functions as eaves along with blinds but also has a ventilation effect that takes air from under the floor and vents hot air from the air outlet. In winter the direct gain coming through the large aperture is accumulated into gravel and reduces the heating load. In the middle season, by putting plants in this space, an evaporative cooling effect during ventilation is also expected.

#6 The PRH Value of S-PRH: Under the conditions above, the PRH value of S-PRH is calculated to be 402: about ten times the normal steel frame house. (Fig. 20)

4-2 Facility Design

1) The Stratification Air-conditioning System By Ice Thermal Storage

The system diagram is shown in Fig.15. The heat source is a heat pump, and direct heat exchange is made between the air and thermal-storage; ice in summer and hot water in winter, after that, temperature and humidity are controlled and finally the air is brought to each room by fans. Room ventilation is
carried out by the stratification air-conditioning system which covers only the residential zone by blowing air from the lower part and the air intake at the top.

2) Multipurpose and Advances Purification System for Rain Water

In order to increase the capacity factor compared to the conventional rainwater system used for flush water in the toilet and sprinkling etc., this system has advanced purification and pasteurization and can multipurposely utilize rainwater for the washing machine or bathroom.

3) Garbage Disposal System

Installing a system that shreds garbage by disposer and discharges it into the drain after purifying it in the exclusive septic tank, increases hygiene and reduces the frequency of waste collection.

4) Digital Facility Control System

This system controls all the house facilities through a network, and enables remote control and data access via Internet.

4-3 Dismantling and Rebuilding Experiment

Regarding the S-PRH, the design of which aims to achieve the perfect reuse-recycle of components, dismantling and rebuilding, an experiment was carried out and the reuse rate (separation rate) estimated and evaluated. The recycle rate can be calculated from the separation rate and recycle performance value of each material.

1) Definition of Reuse Rate (Separation Rate)

This is basically the same as the reuse rate in the W-PRH, however in the S-PRH, considering the ultimate recycling of each material, the reuse rate is equivalent to the separation rate.

2) Research on The Amount of Waste during Dismantling and Rebuilding

Fig.16 shows the weight of each material used in the S-PRH, and the percentage of steel and concrete is large. Fig.17 shows the amount of waste at the dismantling of each material. A large amount is steel such as high-strength bolts and nuts which cannot be reused and polypropylene plate for floor finish which has been partly damaged during dismantling, however, the rest are consumables for attachment such as double-sided adhesive tape and adhesive nets.

3) Calculation of Reuse Rate

As shown in Fig.18, the rest of the consumables for attachment have a reuse rate of more than 90%. The reuse rate of the total turned out to be about 98%, and high separation performance of S-PRH has been proven.

4-4 Building Performances

Owing to the high heat conductivity of recycled PET insulation, as with glass wool: 0.038 (W/mK), the insulation performance is between the 1999 and 1992 energy standards.

Airtightness and the concentration of formaldehyde were measured at the original and rebuilding stages (Table 6). From the result, the equivalent thickness was found to be approximately 3.00 (cm²/m²) and fulfilled the standard regarding airtight houses. Because of furniture and equipment the concentration of formaldehyde varies slightly from the original construction to rebuilding, however, compared to the standard, the concentration is at a sufficiently low level, so it is found that, properly selecting materials and construction methods, even industrial materials can produce a very healthy environment.

4-5 Actual Life Experiment

The following facts have been found through the actual life experiment begun in April 2001.

- The actual survey of Double-skin Space has confirmed that it contributes to an increase in comfort and exten
sion of the middle season, an increase in comfort and reduction of the air-conditioning load in summer.
- Energy: The realization of stratification air-conditioning through the suggested system is confirmed.
- Water: It is confirmed that the advanced purification system for rainwater produces water of so high a quality that it is suitable for use in the bath.
- Garbage: is processed by the disposer and the exclusive septic tank without any problem.
- Control: Used to monitor measurements on the web.

4-6 Recycling Center for the S-PRH
In order to operate the S-PRH houses on a circulatory system, as in the automobile industry, it is necessary to establish a system in which building materials are circulated within the industrial chain system. Therefore a system is suggested to build a recycle center in a landfill in Hibiki-nada district where Kitakyushu City is now promoting the Ecotown enterprise, separating the collected materials there and thoroughly recycling them. Through cooperation between S-PRH houses and the recycling center, building materials can be circulated within the industrial chain system. Fig.19 shows the site plan for the recycling center located in Hibiki-nada.

5. Conclusion
This research has presented the concept of the “Perfect Recycle House,” described the design method and experiment system for two types of model houses and verified the result. A summary of the result of this research is as follows…

#1 The following PRH concept was presented: in order to realize the perfect recycling of houses, it is necessary to establish the “recycling of buildings” and “recycling of facilities.” “Recycling of buildings” means the use of materials which are durable and capable of being recycled and adoption of dismantling-friendly building methods and “recycling of facilities” which aim to establish a circulatory system from the level of the site to the wider area.

#2 Based on the PRH concept, two types of model houses were presented by thoroughly pursuing reuse and recycling; the reuse type of W-PRH based on the traditional wooden house method and the recycle type of S-PRH made of steel frame.

#3 To evaluate the circulation of resources in this research, a “PRH Value” was suggested as one of the evaluation methods for the Life-Cycle Mass.

#4 Comparing the W-PRH and S-PRH with conventional houses (wooden houses and light gauge steel frame houses) by PRH value, as shown in Fig.20, the PRH’s were very good; W-PRH shows a PRH value of 170 and S-PRH value of 402. The PRH values for conventional houses were estimated as predicted value assuming maximum dismantling and separation and using LCA calculation model house data provided by the Japan Institute of Construction Engineering9). (Table 7).

#5 From the result of an actual building performance survey, both perfect recycling houses which applied materials capable of recycling and methods which did not use adhesives, showed good airtight performance and extremely low air contamination; they are found to produce a very healthy environment.

#6 Both the Greenhouse in W-PRH and the Double-skin Space in S-PRH showed an increase of comfort and reduction of air-conditioning load, which confirms their validity.

#7 The actual life experiment is still under way both in W-PRH and S-PRH, however, the result is almost as expected in each system; energy, water and waste. The effect of improvement at rebuilding will be clarified in future research.

The perfect recycle houses are presented here only under the condition that both the site level and wider area level circulatory systems are established which are capable of perfect recycling, including building and living systems. It is hoped that detached houses like these models as well as the various reuse/recycling centers can be realized.

Acknowledgment
This study was carried out as a project of the Research for the Future Program, “Sociological Experiment for Low Environmental Impact and Resource Circulation Habitation System” (JSPS-RFTF97100501) by the Japan Society for the Promotion of Science.

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