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The efforts to develop longer life housing with adaptability in Japan

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Abstract

In the past, the average life of housing in Japan had been around 30 years vs. 77 years in the UK. In the late 1970's, the Japanese government and private sector started research and development projects to design and build longer life housing that is adaptable with time, such as the Kodan Experimental Housing Project (KEP) and the Century Housing Project (CHS). We have been researching the outcomes of those experimental projects to determine whether the attempted adaptability has worked or not over the thirty plus years that people have been living in them. We found that the housing with adaptable infill has been able to adjust to changes in family size and lifestyles in the KEP and CHS projects and have reported on it at several CIB conferences.

The Japanese government enacted the Long Life Housing Law in 2009 to extend the life of Japanese housing and increase its adaptability over time. The law's technical guidelines require that continuous efforts be made to improve adaptability to extend the life of housing, and the amount of housing built based on these guidelines has been increasing.

In the near future, Japan will have a shortage of construction workers. Therefore, an infill system that can be installed by unskilled labor needs to be developed. We need to compensate for the coming labor shortage in the construction sector by improving its relatively low productivity. We think it is becoming more important to design and construct buildings which require less skilled labor. At the same time, the infill of those buildings needs to be simple like furniture, easy to install on site, and easy to replace by residents and users. The concept of Open Building will play an important role in Japan's future.

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Keywords: Houging; Longer Life; Adaptability; Infill; Open Building; Japan

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1. A Post-Occupancy Evaluation of Layout Changes made to KEP (Kodan experimental housing project) Adaptable Housing built in 1982

1.1. Research purposes

The author investigated the "Tsurumaki -3" housing estate of Tama New Town, a suburb of Tokyo. It was the first undertaking of the KEP (Kodan Experimental-housing Project) which the Japanese Housing Corporation started in 1973 in order to research and develop flexibility and adaptability for housing. Since the 1970's, multifamily housing in Japan has been focusing on quality more than quantity. The most important object of our research is to investigate how residents have adopted the design concepts to suit their individual needs and how they have adapted their living environments to changes in their lifestyles over time by remodeling rooms and changing the position of partitions, especially that of KEP movable partitioning system (Figure 1,2). In the Tsurumaki -3 estate, there are 192 units in four-story flats and 29 units in two-story terrace houses to own. This paper reports on the survey of the four-story flats that was implemented in 2005 and 2014.

1.2. Research methods

First, we developed a questionnaire survey for the residents. We took pictures of the interior layouts of units when we were allowed to do so. We asked the residents if they had altered the room arrangement by changing the position of the KEP movable partitioning system or by using a conventional partitioning system. Similar investigations were performed in 1982 (just after the completion of the estate) and in 1995 [1, 2]. We analyzed the transformation of the room layout of each unit through more than 30 years by comparing the results of the studies made in 1982, 1995, 2005 and 2014.

1.3. Results of the survey

There are three main types of plans for units in the estate: A, B and C. Type A can be subdivided into types A1 - A3, Type B into types B1 - B5 and Type C into types C1 - C4, for a total of 12 types of units. Type C units are not equipped with the KEP movable partitioning system. Figure 1 shows the plan and the location of the movable partitioning system in each type of unit.

Residents have been aging and families maturing in the estate. Residents' interest in permanent occupancy was changing during the survey period. The residents seem to have become more willing to live in their units as long as possible as they aged. As they have aged, their interest in permanent occupancy has increased to the point where 67% of the residents in 2014 wish to live in their units permanently.

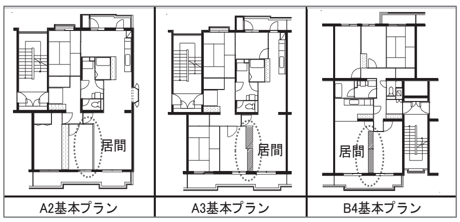

Fig. 1. Basic Plans of A2, A3, B4 Types (Dotted circles show the Movable Partitioning Walls and Storage Units)

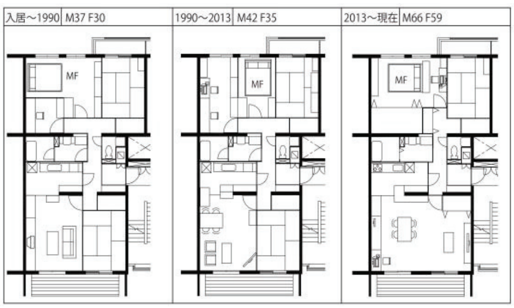

Fig. 2. Layout Changes in a B Type Unit of KEP housing by Moving the positions of Movable Partitioning Walls and /or Movable Storage Units

1.4. Changes in the room arrangement

Both the KEP movable partitioning system and a conventional remodeling system were used to make changes in the room arrangement. Residents of 51% (33 /65) of Type A units and 59% (19 /32) of Type B units have made at least some room layout changes. On the other hand, only 8% (6/72) of residents of Type C units (which do not have the movable partitioning system of the A and B units), have made room layout changes. In most cases, the room layout has been changed in order to make the living room or private room larger and it has been residents whose children have left home who have made the layout changes. By 2005, the children of many households in the estate had already moved out. The KEP system, which allows a living room or a private room to be enlarged by moving the partitioning wall and/or partitioning storage walls separating two rooms, has been adapted well to the changing needs of residents.

As children grew, and when they left home, many families used the KEP partitioning system to adjust the room arrangements to fit the changes in their lifestyles. The KEP system appears to have worked the way it was planned to more than thirty years ago. Some of the residents told us that some of the mechanical parts of the movable partitioning system had become rusted and did not work well enough for them to move and/or reinstall by themselves. There were also residents who thought the sound insulation performance of the movable partitions was not good enough because of the joints between the partitions. They did not think it would be worthwhile to sacrifice the sound insulation performance of the partitions for the sake of movable partitions that would likely be used only once in 10 years. The residents’ experiences and comments suggest important topics for us to research further.

Figure 4 shows a history of renovation works in each dwelling unit from 1982 to 2014 entered by year period. Each row shows the dwelling unit renovation history of one household. The white part shows residency period, and the black part shows the periods when the surveyed household did not occupy the complex. In years indicated by the symbol "◆", renovation work was done, and the letters of the alphabet in the table indicates the contents of renovation works.

2. Long-Term Occupancy Records and Infill Renovation of Housing Designed Based on the Century Housing System

2.1. Research purposes

In the 1970s, the total number of dwelling units in Japan began to exceed the number of households, changing the aim of research and development from supplying a large number of homes to improving their quality and meeting diverse residential needs. At the time, many dwellings did not fully satisfy residential and daily life needs due to the change of the family structure and lifestyles. The durability of interior finishing and equipment (fit-outs) were shorter than the durability of the base buildings, and the failure to perform appropriate maintenance became social problems. To overcome these challenges, the Ministry of Construction started the Century Housing System (below, "CHS") as a certification system in 1986 following the research and development of KEP.

The Century Housing System Guidebook [3] stipulated the following guidelines as basic standards for CHS certification.

[1] Base buildings have long-term durability.
[2] To maintain them after construction, inspections are easy to carry out.
[3] The floor plan, interior finishing and equipment (fit-outs) are replaceable.
[4] The interior finishing and walls of the dwelling can be repaired, renewed, replaced, or moved easily without impacting other parts.
[5] Building drawings are provided to appropriately inform residents of the characteristics of CHS housing.
[6] The above can be done for a long period of time.

This research is aimed to obtain knowledge that will contribute to prolonging the lifetime of multi-family dwelling units by surveying changes in lifestyles in multi-family dwelling units constructed based on the concept of CHS and the state of infill renovations and by analyzing the changeability and renewability etc. of interior finishing and equipment intended to be achieved by CHS.

2.2. Research methods

2.2.1 Investigation method

Few ongoing investigations of long-term occupation have been done [4,5,6], because while their importance has been pointed out, it is difficult to continuously investigate the object of the investigation for several decades. This research attempts to investigate and analyze change of lifestyle of each household that is an object of the investigation from the start of occupation until the present time using questionnaires or by conducting interviews. Because these methods do not permit investigation of households that have moved out and rely upon the memories of respondents, it is necessary to take great care to ensure the accuracy of the investigation results, but this approach was adopted assuming it is one realistic investigation method for clarifying long-term occupation.

During this investigation, the questionnaire survey was done by distributing multiple dwelling unit floor plan diagrams to occupants, and asking them to enter the present lifestyle and past ways they occupied the interior of their dwelling unit. The dwelling unit floor plans were used to investigate the changing history of occupation accompanying change of the composition of the family, their evaluations of their living environment, history of infill renovations, plans for future renovations, and their awareness of CHS. Also, based on responses to the questionnaires interview survey was conducted of households which agreed to be interviewed.

The questionnaire survey was conducted from September 21, 2013 until October 5, 2013. The questionnaires were placed in the residents' mailboxes. They were distributed to 228 of 234 homes, and responses were received from 58 homes. This is a response rate of 25.4%. Six homes did not receive questionnaires because of the long-term absence of the household head. The interviews were conducted from September 28, 2013 until November 16, 2013 in 14 homes.

Investigations of the Management Association Board of Directors, residents' association, and the management association members were accompanied by interviews with the management company. Other interviews were conducted at the companies that designed and constructed the multi-family dwelling units, and their related companies which are in charge of renovation work of the said dwelling units. The companies that designed and constructed the housing provided design drawings and documents etc. concerning CHS. The results of the survey were reported to the technologists who had initially been in charge of designing the building and equipment, and views concerning the evaluation of CHS were exchanged with these technologists.

2.2.2 Objects of the Investigation

The objects of the investigation are Complex E, Building A in a private condominium complex in Chiba Prefecture. Complex E consists of seven residential buildings, but CHS was adopted only in Building A. Complex E is close to a JR (Japan Railways) station, educational and medical facilities, and public facilities, and access to the center of Tokyo by train is convenient, making it an extremely convenient location.

2.2.3 Characteristics of CHS in Building A of Complex E

The following are characteristics of CHS in Building A of Complex E that was investigated (partially corrected based on the CHS planning document [7,8] prepared by the designer).

- The base building protection to deal with the deterioration and its thermal insulation are improved to ensure its physical durability.
- Columns and beams protrude outside (out-frame).
- The interior dimension of the building frame uses 300mm single grid modules.

・It adopted a highly changeable interior finishing wood-working system.
・Interior partition, ceiling, and floor fittings are ceiling- and floor-propense. Mounting walls are all double walls.
・Ceilings are all double ceilings. In principle all are ceiling-propense.
・Pipe shafts are installed facing to common corridors. These are repaired and renewed from outside.
・Pipes (drainage pipes, cold water pipes, hot water pipes, and gas pipes) are installed in the light courts.
(They are not installed in some dwelling units.)
・Wet areas are placed on the common corridor sides of dwelling units.
・Cold and hot water supply, gas, and drainage pipes are installed in the double floors of the corridors, washstand rooms, and toilets.
・Ducts, heating use hot water pipes, and electric cables are installed between the double ceilings.
・In principle, switches and electric power plugs are not installed in movable partitions.
・Inspection ports are installed according to purpose in concealed parts of exclusive use areas.
・Basic repair plans are enacted for each component of the private use area according to their service lifetimes. (30 year cycles)
・Annual repair plans are enacted for common use areas.

The multi-family housing that is the object of the investigation was built by applying the CHS concept to an SRC structure condominium apartment building with which the company that designed and constructed it had previous experience. Not all features that were the goals of CHS at that time were realized. The company in charge of its design and execution had, until then, not installed equipment pipes in the building frame, and had installed equipment inspection ports based on floor planning that concentrated wet parts, and used conventional general purpose methods of equipment work which it had used in the past.

According to design documents for Building A of Complex E, the floor height and ceiling height etc. were as follows. The floors of the corridors, toilets, and washstand rooms are double floors to accommodate under-floor pipes. The floors of the corridors are 70mm and the floors of toilets and washstand rooms are 170mm higher than in other habitable rooms. In multi-family dwellings designed in recent years, generally the frame slabs of wet areas are lowered to form double floors where the under-floor pipes are installed to meet the barrier-free requirements, but when the multi-family building that was investigated was designed, concern for barrier free was not widespread, so only the wet areas and corridors where pipes are installed have double floors, forming floor level differences at the boundaries between the wet areas and corridors, and other habitable rooms.

・Floor height of standard floors: 2,850mm Floor slab thickness of ordinary parts: 200mm
・LDK, western rooms, and Japanese rooms ceiling height: 2,550mm
Depth of ceiling of the above habitable rooms: 100mm
(Including finishing thickness, and substrate thickness)
・Ceiling height of corridors: 2,330mm
Double floor height of corridors: 70mm
・Ceiling height of toilets and washstand rooms: 2,230mm
Double-floor height of toilets and washstand rooms: 170mm

2.3. Attributes of residents

As the attributes of the 58 households that answered the questionnaire, most household heads were in their 60s at 27.6% (16 out of 58). Households led by household heads 60 years of age or older accounted for 60.3% of all households (35/58 households). The average age of household heads is 62.8 years. The youngest household head was 32 and the oldest was 92.

Males led 54 of the total of 58 households. White color workers and other working people were heads of 31 of the 58 households. Percentages of all residents in age cohorts were 17.1% in their sixties (28/164), followed by

15.9% in their fifties (26/164). The most common number of household members was two, accounting for about 40%.

Half of the questionnaire respondents were 29 households who had occupied their unit for 20 or more years. Most households had occupied their units for 25 years or more, at 37.9% (23/58). The average number of years of occupancy of households surveyed was 17.5 years.

2.4. Changing lifestyle

"Changing lifestyle" refers to change of the lifestyle of the residents themselves and actions they take to satisfy new residential demands in response to changes of the family's life stages or the family's circumstances. For example, changing a room formerly used as children's bedroom into a storeroom after the children become independent.

Of the surveyed households, 16/58 (25.9%) changed their lifestyle. The average number of times these households changed their lifestyle was 1.94 times. The household that changed most often changed its lifestyle 4 times in 27 years.

Most of the changes of lifestyle were done because of "the children's independence": 16 out of 31 times (51.6%). Because of "children maturing" was the reason in 6 cases, "birth of a child" in 3 cases, "sharing by families" in 2 cases, and "death in the family" in 1 case. The background to these trends is the fact that in Complex E, many households moved in after their children were born and grown up to a certain extent.

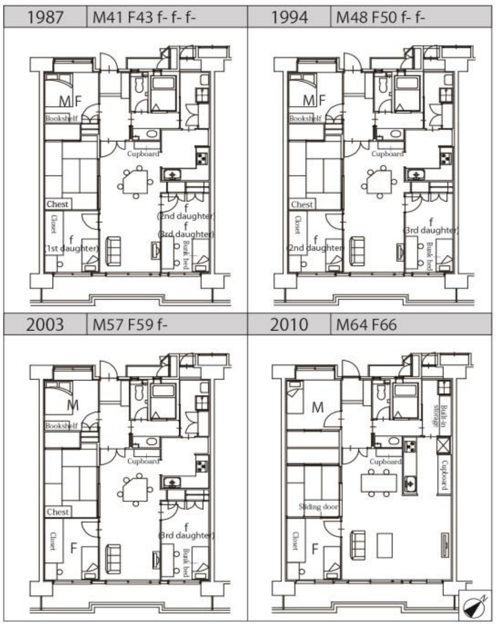

Fig. 3. Layout Changes of CHS housing unit

2.5. Renovation of the dwelling units

2.5.*1 State of performance of dwelling unit renovation*

"Dwelling unit renovation" means doing renovations to deal with the deterioration of interior finishing or equipment inside a dwelling unit, and to do partial renovation of space inside a dwelling unit to meet new habitation needs.

Of the 58 households surveyed, 47 households (82.8%) had experienced the renovations of their dwelling units. The average number of times these households renovated their dwelling units was 1.75 times. But the renovation of multiple places at the same time was counted as one renovation.

Wet area renovation was the commonest type of dwelling unit renovation at 55 cases among 128 cases (43.0%), mainly because of deterioration over time. Renovation work also included 19 toilet and washstand room renovations, 11 kitchen renovations, and 22 bath room renovations. As dwelling unit renovations related to changeability of the floor plan, which is a feature of CHS, "floor plan change" and "complete renovation" were done 23 times, and "increasing or decreasing storage space" was done 9 times.

2.5.2 Using habitable rooms after changing the floor plan during dwelling unit renovation

Changing the floor plan during dwelling unit renovation is categorized as three kinds: "removing a partition wall", "adding a new partition wall", and "moving a partition wall." Partition walls were removed 10 times, moved 7 times, but only added 2 times.

The renovation, "removing a partition wall", was done 8 times by removing the partition wall between habitable rooms and living rooms in order to widen living rooms. The renovation, "adding a new partition wall", was done 2 times by adding a partition wall in a relatively wide habitable room inside the dwelling unit in order to obtain a bedroom. The renovation, "moving a partition wall", was done 5 times, by reducing the size of an infrequently used room in order to expand a bedroom or private room. In such cases, Japanese rooms were often made smaller, and used as a western-style room or as a walk-in closet. This was done twice in each case.

2.5.3 History of renovation of dwelling units

Figure 5 shows a history of renovation works in each dwelling unit from 1987 to 2013 entered by year period. Each row shows the dwelling unit renovation history of one household. The white part shows residency period, and the black part shows the periods when the surveyed household did not occupy the complex. In 1999 and 2013, large-scale repairs of common areas were carried out, and in 2006, water supply pipe renewal work was done in common areas. In years indicated by the symbol "◆", renovation work was done, and the letters of the alphabet in the table indicates the contents of renovation works.

Figure 5 shows that renovation work can be broadly categorized into two trends. One is renovation works done when a household moved into a used dwelling unit. As reasons for renovation works, many answered that the reason was deterioration over time, or to adapt their dwelling units to match their own taste. One more is renovation work done in response to deterioration of equipment and machinery or change of lifestyles by households that have lived in the dwelling unit for a relatively long period of time, often done in recent 10 years. This renovation work included renovation of bath rooms, toilets, kitchens, etc. and other wet areas done mainly because of deterioration over time. Type 15 [note 2)] components (estimated service lifetimes of 12 to 25 years) in Building A are

1) kitchen cabinets that are kitchen components,
2) walls and ceilings of bath units (but floors are Type 30 and bath tubs are Type 8), and

3) wash stands,
4) air exhaust ducts, and
5) heating system terminal equipment and radiators.

Figure 5 shows that from the 12th year after occupancy in 1998 to the 25th year after occupancy in 2011, many renovations of kitchens, bath units, washstand rooms, toilets, and other dwelling equipment and machinery were carried out.

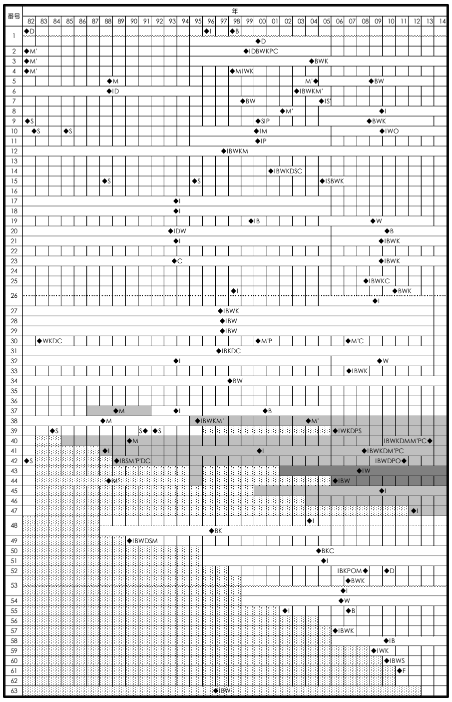

Fig. 4. Infill Renovation at KEP housing

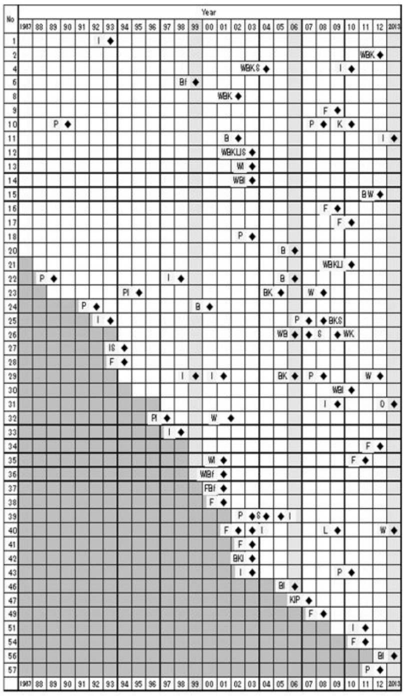

Fig.5. Infill Renovation at CHS housing

W: Toilet, Wash room B: Bath K: Kitchen L: Piping S: More storage, Less storage
I: Replacing flooring, Replacing tatami, Repapering sliding door, Windows, Recovering wall, Ceiling, Interior finishing
Bf: Removing level difference, P: Removing partition, Installing partition, Removing Japanese room
F: Comprehensive renovation of exclusive use areas O: Water heater

3. The Act for Promotion of Long-Life Quality Housing

3.1. Introduction

Because the average life span of newly-built houses in Japan has been very short compared with those of European countries and the United States, the new law called " The Act for Promotion of Long-Life Quality Housing", which promotes the longer life of housing in Japan was implemented from June 4th, 2009. We build high quality houses and take scrupulous care of them to preserve them for longer periods of time. The lengthening of the life of a house must be useful to reduce the consumption of natural resources, the economic burden of housing expenses for families and should help solve the global environmental problems and waste problems in the future. The technical guidelines consisting of nine chapters explain the technical details required for extending the life span of housing. The client can apply for tax reductions and can receive subsidies by designing and building a house which complies with the new law and technical guidelines. The total number of units of Long-Life Quality Housing approved in Japan since its establishment in June, 2009 is 696,516 at the end of March, 2016. Most of them are detached houses. Only 17,396 units were condominiums. In spite of the difficult requirements, we can find some condominium apartments actually built based on the act and technical guidelines.

3.2. Technical guidelines of the new law

The technical guidelines explain the technical details required for extending the life span of housing. There are nine chapters in the technical guidelines, and an appendix as;

Chapter 1. Durability of the material; Deterioration measures;

House structures should be able to be used for several generations. They should be designed so that the period their structure can be used continually under maintenance conditions considered normal is at least 100 years. It should be counted on to be usable for between 150 and 200 years under appropriate maintenance.

Example:

In the case of reinforced concrete (RC) construction, one of the following types of design should be taken.

・Water cement ratio of 45% or lower.

・Water cement ratio of 50% or lower and covering thickness (of concrete) increased by 1 cm.

Chapter 2. Structural design; Earthquake resistance

Make it easier to repair damage caused by an extremely uncommon earthquake to ensure the continuous use of the house by reducing the level of damage caused by earthquakes.

Either build it as a base-isolated building or take measures to reduce deformation caused by large earthquake force at or below a specified level.

Example:

The ratio of the safety limit deformation of each above-ground story to its height should be 1/100 or less (in the case of wooden construction, 1/40 or less) during a large-scale earthquake.

Chapter 3. Ease of maintenance and renewal

Measures necessary so that the maintenance (cleaning, inspection, repair and update) of the interior finishing and facilities which have shorter life spans than the building structures can be carried out easily should be taken.

・The building should be designed so that private piping and common piping are easily maintained.

・The building should be designed so that common drainage pipes are easily maintained. It shall be possible to maintain common piping of condominium apartments without entering private parts of dwellings.

Chapter 4. Adaptability

Measures should be taken which permit the modification of room layouts according to changes in the lifestyle of the occupants. Ceiling height of the building frame must be adequate for piping and wiring according to modification of the original room layouts.

Example:

A specified building frame ceiling height or higher (2,650mm or higher) must be ensured.

Chapter 5. Universal design for the elderly and handicapped

Necessary space in common halls and corridors must be maintained so that it is possible to perform renewal work to make a home barrier free in the future.

Example:

The width etc. of common halls and corridors must be designed to ensure necessary space.

Chapter 6. Energy efficiency; Energy conservation
The performance of the insulation etc. must ensure energy conservation.

Chapter 7. Floor space for each unit
Sufficient space must be secured to ensure the occupants have reasonable levels of living standards.

Chapter 8. Living environment
The maintenance and the improvement of the living environment and the landscape in the surrounding area.

Chapter 9. Long-term maintenance planning
1) Elements necessary for structural resistance,
2) Parts which prevent the infiltration of rainwater, and
3) Water supply and water drainage systems.
The inspection details and periods for the above items must be contained in the maintenance plans.
Inspections must be performed at least once every 10 years

Appendix: documentation and house records

3.3. Incentive for longer life housing

The client can apply for tax reductions and can receive subsidies by designing and building a house which complies with the new law and technical guidelines. Specific incentive measures have been implemented. 1) When a person has purchased or constructed and occupied long-life-span superior housing, the person is exempt from income tax up to a maximum value of 5 million yen over a ten year period according to the balance of the person's housing loan at the end of each year. 2) When a person has purchased or constructed and occupied long-life-span superior housing, the person receives an income tax exemption equal to 10% of the construction cost which exceeds that of ordinary housing (limited to 6.5 million yen). 3) The fixed asset tax on long-life-span superior housing is reduced by 1/2 for two years longer than in the case of ordinary housing.

4. Recent developments of Infill system of Japanese Housing

Three companies, Nomura Real Estate, one of the largest developers in Japan, Haseko, which has designed and built more than one-quarter of all new condominiums in Metropolitan Tokyo, and Bridgestone, a large chemical company, have developed a zero-slope drainage system for kitchens of condominium units. The Architectural Institute of Japan has established technical guidelines for zero-slope drainage systems for engineers to promote the widespread use of this system [9]. These three companies are continuing research and development that will allow bathrooms and laundry appliances to be positioned freely. The zero-slope drainage piping system provides more freedom both in the planning of new condominium units and in the refurbishment of existing housing.

Mitsui Real Estate has begun to sell condominiums in which infill can be installed and moved freely in each unit like furniture. The bathroom units and toilet are fixed but the other spaces can be planned freely by residents. The first apartment building in Akabane-nishi developed by Mitsui Real Estate constructed by Haseko Corporation did not meet the technical guidelines of the Act for Promotion of Long-Life Quality Housing. The apartments are located in quiet middle-class residential areas in the north of Tokyo and most of the units are under 80 square meters in order to make them affordable for many people. To qualify as long life housing, the price of each unit must be higher. The developer, Mitsui Real Estate, which is well aware of the law, seems to have decided not to invest too much to give this housing longer durability than what is expected by its owners. Instead, it provided economical housing for families with average incomes.

The kitchen can be located in seven different places. There are three conduits on the floor to connect piping and wiring. There is also an exhaust system which ventilates the gases from cooking and returns clean air to the room. However, professional engineers must be called in to change the position of the kitchen, not because of legal requirements or the necessity of technical work, but to prevent improper and incomplete connecting of piping by the residents. There is also a mechanical lever system for movable cabinets which is similar to systems like those installed at the KEP Tsurumaki-3 Estate in 1982 and at the Flex Court Yoshida in Osaka in 1996.

5. Conclusions

Because Japan will be experiencing a shortage of construction workers in the future, an infill system that can be installed by unskilled labor must be developed. Haseko Corporation is starting to use a prefabricated toilet unit for its new apartments to reduce the amount of on-site work. The Urban Renaissance Agency (UR), which owns more than 700 thousand rental condominiums, needs to refurbish its old units and is conducting many experiments to renovate its housing stock. Last year, UR worked with IKEA to refurbish some of its units in the Tachikawa Saiwaicho housing estate. These and other attempts to invite new residents to older housing units are a topic of great interest in Japan.

Japan needs to compensate for the coming labor shortage in its construction sector by improving its relatively low productivity. The author thinks it is becoming more important to design and construct buildings which require less skilled labor. The configuration of structural elements must be simple. It is not easy to develop robots that can work at construction sites, so simple structures which robots can work with would be welcome. At the same time, the infill of those buildings needs to be simple like furniture, easy to install on site, and easy to replace by residents and users.

The infill system for housing must be adaptable to changing lifestyles of residents and must be easily fitted and removed. It may be used not only for condominiums but also for detached houses, which is a larger market in Japan. The author will carefully examine the characteristics of the future infill market in Japan to find the most attractive infill for residents as well as for the housing industry based on post-occupancy evaluations of housing projects like KEP and CHS. The concept of Open Building, which focuses on adaptability with time, will play an important role in Japan’s future.

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Notes

1) This paper is based and modified on the “LONG-TERM OCCUPANCY RECORDS AND INFILL RENOVATION OF HOUSING DESIGNED BASED ON THE CENTURY HOUSING SYSTEM” published and presented by the author at the Future of Open Building Conference 2015, ETH Zurich.
2) Service lifetimes were set for each component and the mutual impacts were studied to set anticipated lifetimes: Type 04: 3 to 6 years, Type 08: 6 to 12 years, Type 15: 12 to 25 years, Type 30: 25 to 50 years, and Type 60: 50 to 100 years.

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