

FIRE PERFORMANCE REQUIREMENTS OF BUILDINGS FROM AN ENVIRONMENTAL POINT OF VIEW

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ABSTRACT

Fire accidents have been a burden to the global environment because (1) they generate a great amount of debris (2) they consume other new materials and energy for reconstruction activities (3) they disperse many toxic and/or harmful substances to surrounding areas. Earthquake fires have been a threat to the sustainability of many societies, with many buildings and houses being burned down, including heritage buildings. All societies need to inherit sustainable facilities based on environmental features linked to cultural issues. In Japan, almost all houses, historical shrines and temples, have been constructed of wood with no design features to guard against fire. These practices allow traditional succession to easily vanish in a fire. This paper is mainly aimed at clarifying both the requirements of fire protection performance, and the amount of burnt down debris including CO₂, from an environmental point of view.

Keywords: Fire damage, environmental burden, CO₂ generation, Kobe quake-fire, long-life building, quality management.

INTRODUCTION

Recent global situations have encouraged the design and construction of long-life buildings built from durable materials, increasing the demand for further renovated design methods. The aim is to limit the extent of fire damage, causing further adaptations of environmental and risk management systems to be necessary for construction of sustainable buildings. This paper deals with requisite items for fire protection and resistive performance for the reduction of environmental burdens. A survey of basic data on live or dead loads for calculating burnt debris including CO₂, and several results of calculation in cases of residential or earthquake fires are also given.

BUILDING FIRE PROTECTION AS ENVIRONMENTAL SUBJECTS

Fire has a great influence on surrounding areas. Much burnt debris includes more or less asbestos, toxic or harmful substances such as halogenated organic materials, HCl, acrolein etc., Many of these substances are hard to transfer to recycling processes. The generation of CO₂ has a significant impact to the earth, because of its global warming effect¹. Fire also shortens the life of buildings and houses. Reconstruction activities after fires lead to increased consumption of building materials and equipment. The disposal of fire retardant products at refuse incineration plants is problematic as they are liable to produce some harmful substances such as dioxin (polychlorinated dibenzo-p-dioxin, polychlorinated dibenzofurans), fleon (CFCl₂, C₂FCl₃) and so on. Moreover, fire sometimes burns down precious cultural heritages or traditional buildings, which are indispensable to sustain human society through their environmental status. The important environmental issues relating to fire damages are shown in Figure 1.

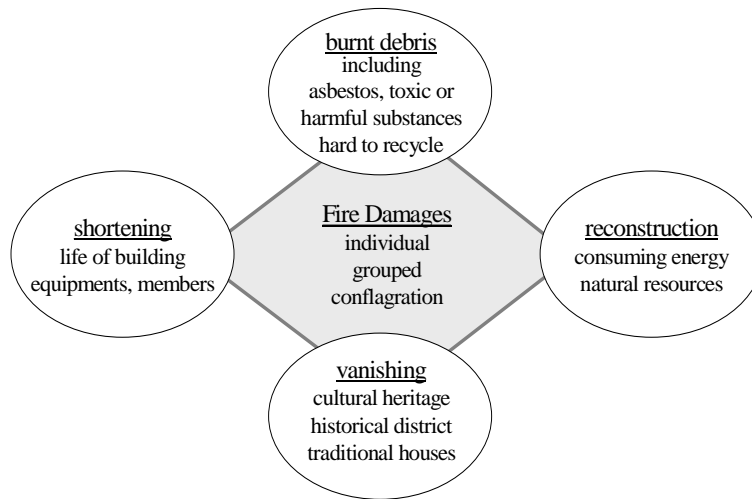


Figure 1: Relationship between fire damage and environmental issues.

Fire also disperses corrosive substances such as HCl and H₂S which may interrupt the function of social and environmental network systems by corroding their wiring circuits. In order to escape these destructive features, it is important to reduce various causes of fire occurrences. Occurrences such as urban quake-fires and a wild fires produce huge amounts of CO₂. The former generates great amounts of waste, together with consumption of building materials and energy for their reconstruction. For instance, the 1995 Kobe earthquake destroyed 67,421 buildings and partly collapsed 55,145 buildings, with almost all classified as houses². A destroyed house generates 120 m³ of debris³. According to this data, if these damaged houses were all removed, the amount of debris reaches 14.7 million m³ in the former case and 7 million m³ in the latter case. The volume of the former case is equal to 11.9 times the volume of the Tokyo Dome (baseball stadium in Tokyo, 1.24 million m³), which is enough to fill in a valley of 200 m depth x 200 m width x 350 m length. The latter would be estimated to be about half the former, because an average house of 105.2 m² generates 60 m³ combustible debris and 55 m³ noncombustible debris. Figure 2 shows the stock of houses by structural types, based on the data of the national scale investigation⁴.

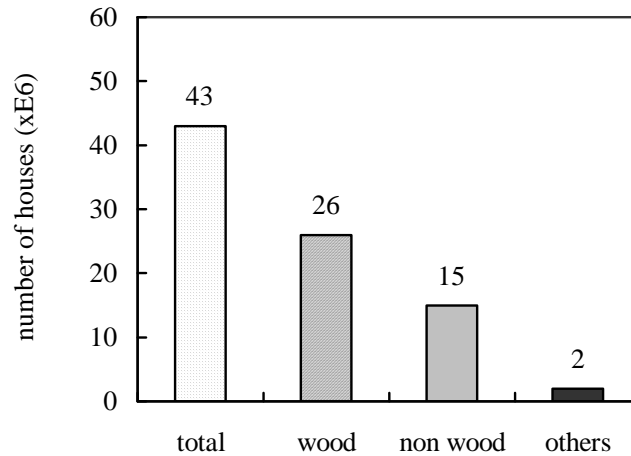


Figure 2: The stock of Japanese houses by structural type in 1999.

Figure 3 also shows the number of house-fire occurrences and average damaged floor areas by structural type, based on the white paper by the National Fire Defense Agency⁵.

Figures 2 and 3 indicate that wooden houses represent about 62.2% of all structural types, represent 51.9% of fire outbreaks and the amount of fire damaged areas are twice that of protective or quasi-resistive houses and 7.6 times that of other structural types. The life span of Japanese houses is short compared with those of the UK or the USA as shown in Figure 4. This indicates that Japanese houses may be weak in fire features⁶, identifying some defects in the social systems for evaluating real estate. This causes the renewal period of housing stocks and the average life of houses to be quite short, reflecting that Japan is a country that consumes a great amount of building materials and energy. However, reinforced concrete and steel houses have interior combustible materials that produce CO₂ and many types of toxic and harmful substances in a fire, similar to a wooden house. Table 1 shows various kinds of combustible materials existing in a house by structural type presumed from the reports of several house industries and the Japanese Renovation Center, which is a witness of these fire characteristics^{7,8}. According to Table 1, a wooden house of floor area 125.1 m² generates 11.5 t (55 m³) of combustible and 23.4 t noncombustible debris during demolition activities.

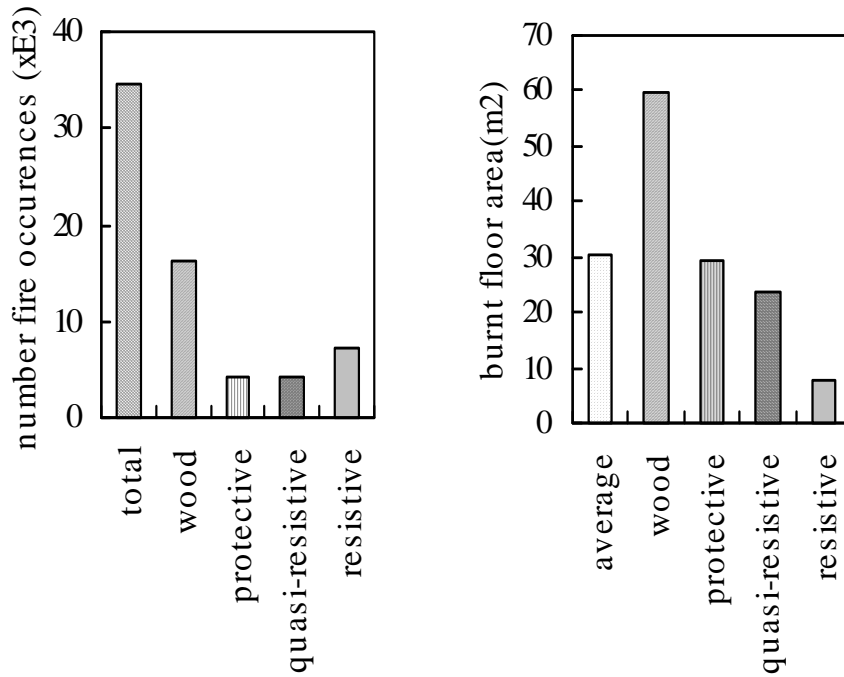


Figure 3: The number of house-fire occurrences and burnt floor areas by structural type in 1999.

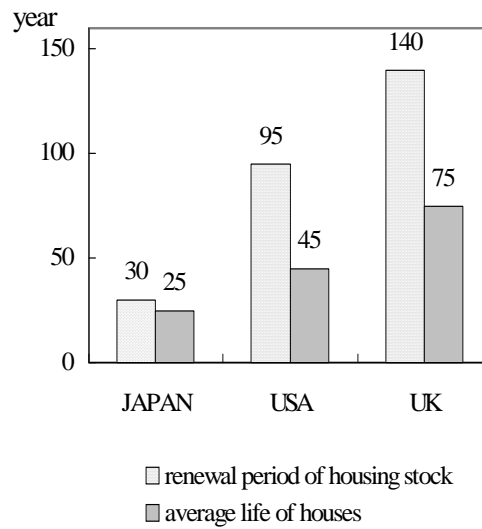


Figure 4: International comparison of the general life span of a house.

Table 1: Weight and percentage of materials generated in construction or demolition.

materials	wood plywood paper	plastics	mortar concrete	glass ceramics	metal	total
life stage	construction demolition	construction demolition	construction demolition	construction demolition	construction demolition	construction demolition
weight t' kg/m ² (%)	t' (%)	t' (%)	t' (%)	t' (%)	t' (%)	t' (%)
wood Structure (125m ²)	97.3 (20.6) 88.1 (31.7)	6.8 (1.4) 3.5 (1.3)	260.4 (55.2) 135.3 (48.6)	96.2 (20.4) 3.5 (12.4)	11.0 (2.3) 16.9 (6.0)	471.6 (99.9) 278.3 (100)
RC Structure (85m ²)	17.3 (0.9) 9.4 (0.5)	9.2 (0.5) 8.1 (0.5)	1726.6(91.2) 1640.4(91.3)	2.8 (0.2) 4.6 (0.3)	89.3 (4.7) 89.3 (5.0)	1893.2(97.5) 1797.4(97.6)

The amount of stocked or fire-generated CO₂

A great number of full-scale fire experiments for detached houses or flats have been carried out^{9,10,11} whose results indicate that the concentration of CO₂ in the gas phase during a fire is around 1% at an early stage and around 10 to 20% at a fully developed stage as shown in Figure 5. This can be summarized at about 12.5% after 30 min of burning. These houses were comparatively well contained by fire resistive compartments, and their fire characteristics at a fully developed stage would be similar in type to ventilation- controlled fires.

The volume of gases emerged from the openings of a fire room have been estimated at about $5.5A\sqrt{H}$ (kg/min), where A is the opening area (m²) and H is the opening height (m). The actual values are about 100 kg/min, when the opening area of Japanese houses is estimated at around 15 m² derived from legal limitations. That is "opening area should be more than 1/7th of room floor area". The statistical value of average floor area is 105 m², which is derived from the average floor areas of both 125.1 m² for wood houses and 85.2 m² for reinforced concrete flats. Then, if the average height of openings is set at 1.5 m at a room temperature of 700⁰C the emerging flux of gases would be 101 m³/min. Then, the total volume of CO₂ would be 1,000 m³ (550kg), that is 5.5 kg/m² for a house or dwelling fire. According to Japanese fire statistics, average fire damaged floor area is about 50 m² per dwelling per year, which means that 275 kg of CO₂ is dispersed at a dwelling fire, and fire statistics note that approximately 17,500 dwelling fires occur in a year, causing about 4,810 t of CO₂ to be dispersed yearly into the environment. On the other hand, the basic stock of carbon in wood is 0.25 t-C/m³ and a wooden house has 0.2 m³ of wood per unit floor area (m²)⁽¹²⁾, where t-C/m³ means the weight of stocked carbon (ton) per 1 m³ of materials. A wooden house generally stocks 0.2 m³ wooden materials per unit floor area (m²), which indicates that one wooden house constitutes about 23 t CO₂. Figure 6 shows the results of calculated CO₂ for Japanese houses based on¹² and Table 1. In Figure 6, each item on the x-axis refers to the generated weight (kg) of CO₂ by each material on its process of production per unit floor area (m²) of its stocked structural type of

housing.

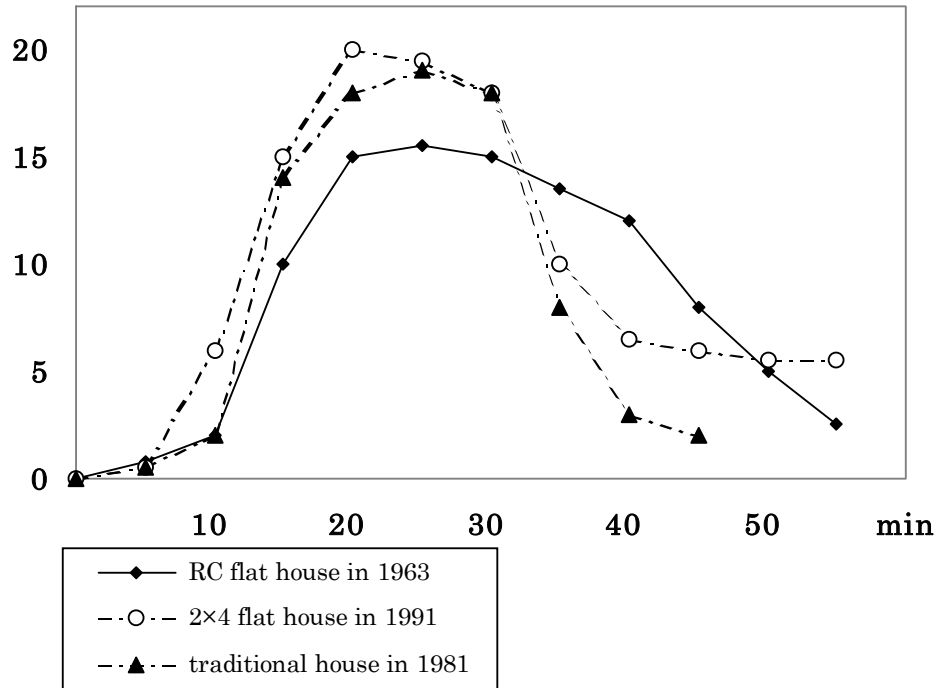


Figure 5: CO₂ concentration obtained by full-scale experiments.

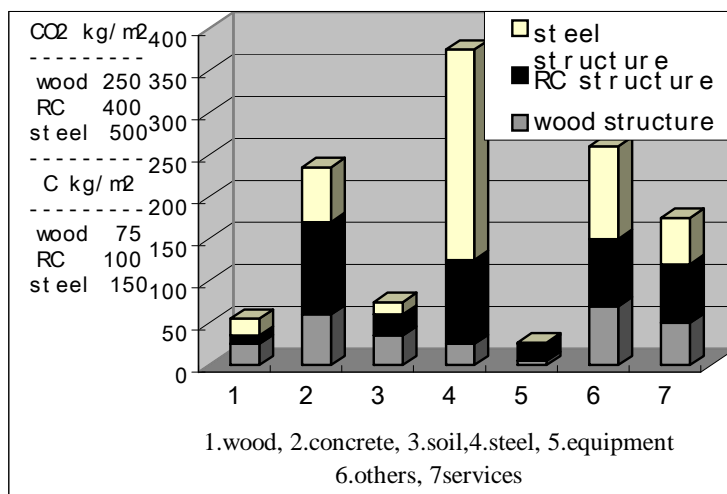


Figure 6: Calculated CO₂ and kg-C/m² for Japanese houses.

The chemical composition of wood is generally expressed as C₈H₁₀O₇⁽¹³⁾ and an average wood house is

made of 25 m³ (= 0.2 x 125.1 m³) of wood. Then, if the density of wood is 0.4 t/m³ and the water content is 13%, the equivalent amount of CO₂ reaches 14.5 t under ideal combustion. The 1995 Kobe-quake completely burnt out around 7,000 houses and partly about 350 houses, which indicates the quake fire generated roughly 105 x10³ t of CO₂, a value that results from the following calculation: 0.275 + 14.5(7000 + 350/2). These results of calculations indicate that the increase of fire-protected wood constructions is quite effective in reducing CO₂ production and the area of damaged. In contrast, the existence of great numbers of decayed houses presents a global warming potential threat.

Flame retardant agents and other substances

Flame retardant treatment for interior furnishings, upholstery, and clothing should be one of the most important countermeasures for building fire protection. However, some of these materials are prone to generate harmful substances during a fire. Notably, polychlorinated agents are liable to emit dioxin under 800^oC burning condition¹⁴, which means that as the fire temperature in a compartment generally exists around 700 to 800^oC at a fully developed stage, the generation of dioxin would be a threat to human life (fire fighting personnel). Polybromo-diphenylethel or hexabromocyclododecan are used for flame retardant treatment, and the latter emits little dioxin compared with the former, which is popular for authorized products¹⁵. Figure 7 shows the number of certified products during 1999 to 2000 in Japan based on the evaluation policy of the Fire Retardant Association.

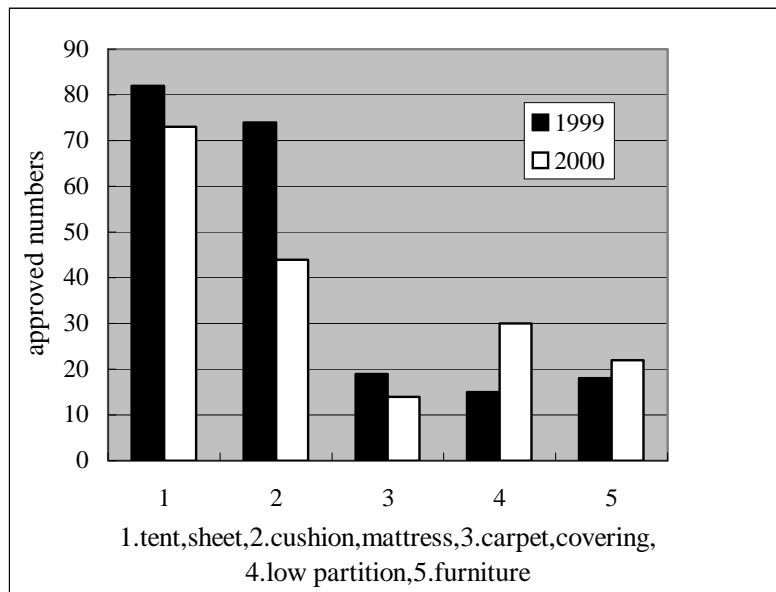


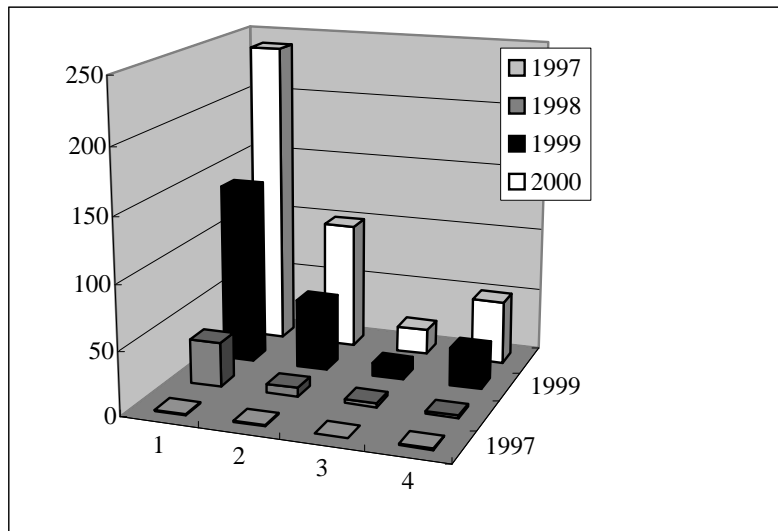
Figure 7: Approved number of flame retardant products.

There also exist great numbers of building related materials used for upholstery, household appliances, electric apparatus, interior furnishings and so on, which could emit various sorts of substances contributing to global warming or destruction of the ozone layer during fire conditions. Some of these emissions are also toxic or harmful to human health. Moreover, it is expected that the use of HFC's and PFC's for the next generation of fire extinguishing or semiconductor cleaning agents will be prohibited, because of their high values of GWP (global warming potential), despite their lower values of

ODP(ozone destructing potential).

Building fire protection aimed at environmental break through

In order to secure the sustainability of society, the life-span of any building or house should be elongated by reliable life cycle design and site works. There should be efforts in the reduction of the use of materials and energy, together with the exclusion of toxic or harmful substances, and avoidance of emissions that are harmful to the function of electronic circuits. From an architectural point of view, large structural spaces would be preferable for this purpose, because these structures are flexible for occupancy and building use. This concept is applicable to a housing design with the use of various sorts of partitions. However, such spacious compartments would allow easy spread of fire, reducing the predicted life of buildings or houses. This indicates the importance of fire protection of buildings, through securing fire resistance or durability of materials and/or components. Other indispensable requirements for assuring fire safety are to keep coherent management systems based on ISO 9000s, 14000s and OHSAS 18000s which might contribute to inducement of performance-based design concepts to both site works and maintenance procedures of buildings. Recently, the numbers of acquisitions have been increasing in the Japanese building field. The number of ISO 9000s acquisitions was about 7,000, while those of ISO 14000s were about 230 during 2000¹⁶. The break-up of the acquisition of 14000s in each field were: general contractors occupy 60%; building manufacturers 23.5%; sub-contractors 12%; and architect offices 5%¹⁷ as shown in Figure 8. Each standard should be unified with the others, aimed at integration of knowledge concerning the relationship between construction works and their management systems for securing sustainability of buildings. Fire safety engineering that could be realized by the establishment of a performance-oriented fire scenario needs adopting, with further knowledge gained on management-related standards for their indispensable contribution to the reduction of environmental burdens.



x-axis: 1.general contractor, 2.material maker, 3.architect, 4.sub-contractor.

y-axis: number of acquisitions of certification.

Figure 8: Increase of acquisition numbers of ISO 14000s in Japan.

Table 2: Building fire protection as for environmental breakthrough.

environmental subjects	fire protection counter measures
elongation of building life · reduce the amount of materials · reuse used materials · recycle used materials	eco-fire performance design for: · huge or long-span space; availability of occupancy and use · fire protection of building members and jointing parts; durability of materials · saving of energy, zero-emission
check of harmful substances CO ₂ , HCl, dioxin, CO, HCN, acrolein, asbestos, flon, etc.	estimation of generating harmful substances earthquake fire, wild fire, room fire fire retardant agents
check of final disposition place, incineration	estimation of refuse volume and disposal requirements on retardant agents for burning
check of eco-construction process	Acquisition of ISO 9000s,14000s,OHSAS 18000s

Table 2 shows some checkpoints, indispensable in securing fire protection performance of buildings from the environmental point of view, which must be continuously adopted during building construction phases.

CONCLUSIONS

Fire protection design of buildings should be linked to environmental issues because fire generates a great amount of debris, CO₂, toxic and/or harmful substances, and shortens the lives of buildings. Fires are also responsible for the consumption of materials and energy for reconstruction. Some types of flame retardant agents emit toxic and harmful substances creating a serious burden on the environment. Fire performance requirements for breaking through environmental subjects are suggested here. Investigations on the recent status of basic data such as the stock of houses, average floor areas by structural type, and international situations on availability and durability of houses were carried out. It was shown that the average life-span of Japanese houses is 1/3 that of the USA and 1/5 that of the UK. Also, the number of burnt down houses, the amount of combustible debris generated during 1995 Kobe earthquake, the concentration of CO₂ obtained by full-scale fire experiments and CO₂ stocks of houses were investigated, in order to calculate the volume of CO₂ related to fire conditions. The results of these calculations helped clarify the effectiveness of building fire protection through several estimated values of CO₂ which were about 5.5 kg/m² for a dwelling fire, 120.0 kg/m² for a completely burned down wooden house, and 100,000 t at the Kobe earthquake site. The authors would finally like to describe the importance of securing fire protection performance through keeping appropriate site works and maintenance processes under international management standards.

REFERENCES

1. Hansen: Geophysical Research Letters,1988.
2. Calculated based on the report on material damages by Kobe-quake published by the City of Kobe, 1996.
3. Building Safety Division:A guideline for demolition works, Prefecture of Hyougo, 1995.
4. National Statistics Bureau: House and land survey in 1998, Ministry of General Affairs,1999.
5. Fire Prevention Division: White Paper, National Fire Defense Agency, 1997 made out by investigating the 1993 Annual Bulletin of Housing and Building for Europe, American Housing Survey during from 1987 to 1993 and Housing Statistics Survey during from 1988 to 1993.
6. Information Division: Digest Report, Misawa Home Ltd., from 1997 to 2000.
7. Publication Division: Annual Report on Housing Renovation, Center for Housing and Dispute Settlement Support,1999.
8. Fire Experiment Committee: A full scale fire experiment at Akabanedai flat house, p39-49,Japan Housing Corporation, 1962.
9. Fire Research Committee for prefabricated houses: A full scale fire experiment for a prefabricated wood tenement house, p99-103,Prefabricated Building Association, 1992.
10. Housing Fire Committee: A full scale fire experiment for a traditional house, p19 – 21,Center for Wood and Timber Engineering, 1986.
11. Task group for environmental issues: Architectural strategy for realizing a sustainable society, p74-84,AIJ, 1999.
12. N. I. Nikitin : The Chemistry of Cellulose and Wood, Daniel Davey, 1966.
13. Shinichi Sakai: A story of dioxin, p69-73,Daily Industries Newspaper Ltd., 1998.
14. Publication Division: Flame retardant products as recycling issues, p138 – 157, Flame Retardant Association of Japan, 1999.
15. Shinichi Sugahara, Haru Uchida: Recent trends on management systems in Japanese building field, p129 – 130,CIB World Building Congress, Wellington, 2000.
17. Shinichi Sugahara, Haru Uchida: Recent trends concerning the building field management systems in Japan, ISO/TAG 8 Document N268, Berlin, 2000.