SIMULATION OF FIRE PROPAGATION IN A WOOD FRAME HOUSE

by
Ichirou HAGIWARA
and
Isao TSUKAGOSHI

Building Research Institute
Ministry of Construction
1 Tatehara, Tsukuba-city, Ibaraki-ken, 305 JAPAN

ABSTRACT

Fire safety of residential wood buildings were discussed on the basis of fire incident statistics. Finishing and lining materials used in newly built houses are surveyed. Using these data, a computer simulation was tried for predicting the average burned area in a standard wood frame house.

1. INTRODUCTION

As Japan has frequently encountered city fires of extremely large scale, it has become a common sense that wood frame building is the most hazardous construction type. Recently large scale city fire scarcely happens and the combustibility of major structure does not seem to be related to the problem of casualties in fire. So it is considerable that the worse reputation for wood frame house is due to its inferiority in preventing property loss.

It is a fact that the average burned floor area for wood construction is larger than that for other constructions as shown in Fig.1.[*1] Attention should be paid to that the statistic data includes the fire loss for old houses constructed 20 or 30 years ago and the proportion of such old houses in wood construction category is greater than in other categories. Fig.2 shows the average burned floor area by completion year of houses and by construction method.[*2] The loss for newly built house of wood or fire protected wood construction is apparently small, while fire resistant construction does not make much difference.

According to the analysis of statistic data, it can be assumed that the recent construction method of wood frame house is different from the old one and has the better fire protective characteristics. However, this should be validated or enforced by other methods because statistics give us very little information on the causes of facts.

The purpose of this paper is to look over the fire risk of wood frame buildings for dwelling occupancy in view of the property loss. The present state of construction method was surveyed by an inquiry to house builders and using the results of the survey, a computer simulation of fire propagation was done in order to know the average property loss.

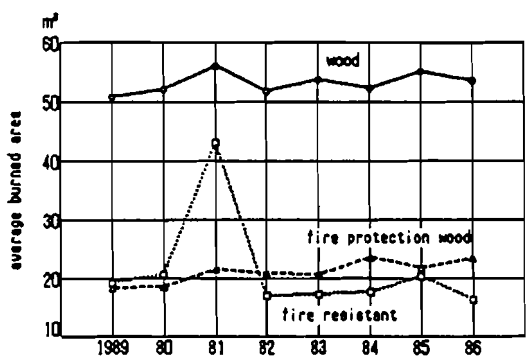

Fig.1 Average burned area by construction category

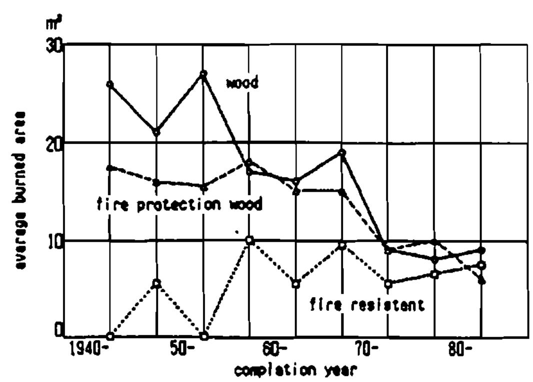

Fig.2 Average burned area by completion year

2. SURVEY FOR CONSTRUCTION METHOD

The objective of this survey is limited to wooden detached houses constructed in 1987 FY by the subsidy of the Housing Loan Corporation(HLC); this is the most popular type of housing in Japan. In addition to the information on finishing materials which were already surveyed by HLC, the information on lining or underlayer materials are indispensable to determine the fire resistance of separations such as ceiling, wall and floor. Therefore, we decided to conduct the secondary survey.

Inquiry format was sent to about 100 house builders through the Wooden Home Builders Association of Japan and have got 31 answers which cover 15358 houses constructed in 1987 FY. By means of this survey and the HLC survey, we can know how frequently what materials are used for the assemblies of ceiling, wall and floor in four types of room such as living room, bedroom, kitchen and japanese room.

It was found that similar materials are selected for the types other than Japanese room and the most popular assemblies are wall paper on 9mm gypsum board for ceiling, wall paper on 12mm gypsum board for wall and flooring plywood or plank with no underlayer for floor. The frequencies in use of these representative assemblies are 55-80%, different by element and type of room. In Japanese room, the tendency of material selection is different from in other rooms: 94.6% of ceiling is covered by 3-4mm finished plywood with no underlayer: 59.6% of wall finish is "Sen-i-kabe"(daubed pulp) on 7mm plaster board: 87.1% of floor is "Tatami-mat" made of straw and others made of foamed plastic, with underlayer of 12-15mm plywood or plank.

Every combination of finishing material and underlayer material was evaluated in respect of fire resistance on the basis of existing test data and finally classified into four grades. The frequencies of these grades are shown on Tab.1 by three kinds of element and four types of room.

Tab.1 Frequency of interior assemblies by fire resistance (%)

grade fire resistance (min.)		1 (15)	2 (10)	3 (5)	4 (2.5)
ceiling	living room	14.00	73.96	5.04	6.98
	bedroom	13.65	75.82	3.88	6.66
	kitchen	9.60	80.04	9.41	0.96
	Japanese room	1.25	3.69	0.44	94.62
wall	living room	60.96	29.14	9.86	--
	bedroom	58.64	34.26	7.08	--
	kitchen	65.83	33.86	0.30	--
	Japanese room	39.86	59.60	0.55	--
grade fire resistance (min.)		1 (15)	2 (10)	3 (7)	4 (5)
floor	living room	9.83	20.51	69.65	--
	bedroom	18.81	20.53	60.65	--
	kitchen	1.39	42.00	56.59	--
	Japanese room	39.89	53.17	6.94	--

3.SIMULATION OF FIRE PROPAGATION

1) CONCEPT

It is not easy to describe the transition of burning area among multi-rooms by means of complete physical model. But, generally speaking, as every room in a wooden house has relatively large windows and they are not fire protected, an initiated fire would grow up in short time into an active fire and it is considerable that the early state of fire is not so important for the prediction of burned area in a whole house. In addition to this, there is another problem that numerous repetitions of calculation are required according to the combination of initial conditions and building materials for each element of each room. And therefore, we have finally chosen a very simplified model which is only based on fire resistance of building assemblies between rooms.

The house in Fig.3 was presented by the HLC as the japanese standard detached house whose characteristics such as the total floor area, the number of story, the number and the sorts of room, etc. are the average of surveyed data. We have decided to apply our simulation model of fire loss prediction to this specific house.

This house can be simplified to a network model with nodes and links; it is possible to assign: a node to a room, a space behind ceiling or an exterior space, a link to a fire spread route with a fire resistance.

Providing that all the separations between rooms are made of the ideal fire resistant construction (we call this type of house as fire resistant house), we need not consider a fire spread route through floor and ceiling, wall, ceiling spaces nor exterior space. Fire would spread only by way of interior doors. In this case the network model is very simplified as shown in Fig.4 and the fire spread time for each room could be given by hand calculation.

On the other hand, if a house is a wood construction, there are many fire spread routes between two rooms. The fastest fire spread time is determined by comparing the fire resistance of the routes.

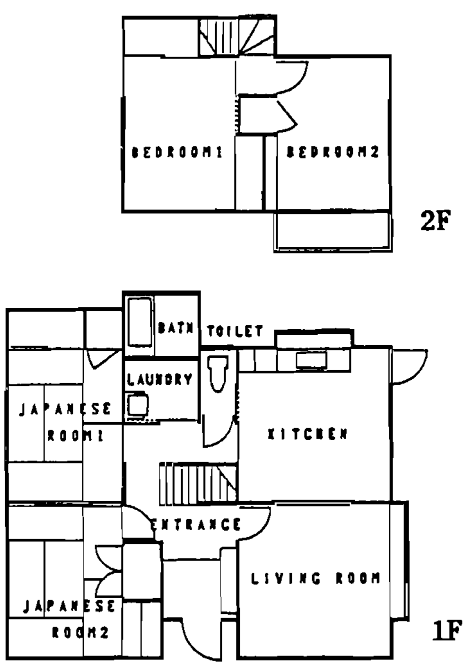

Fig.3 Model house

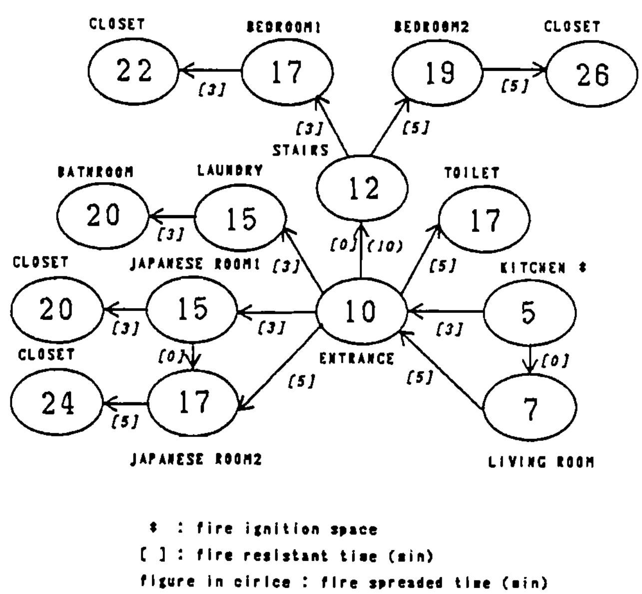

Fig.4 Example of network space model
(a fire resistant house)

2) ASSUMPTION IN SIMULATION

This simulation is based on the following assumptions :

(1) A fire breaks out in one of the 9 rooms in the model house with the probability corresponding to fire statistics.

(2) A fire ignition room needs 5 min. to be burned out, other spaces 2 min.

(3) The fire resistant time and the frequency in use for each fire grade of building element are given by Tab.1. The fire resistant time of openings (doors, windows) is

a door (3mm plywood flush door) : 5 min.
a sliding door (Japanese "Fusuma", or glass door): 3 min.

(4) The test data of horizontal separation with the upper surface exposed could not be obtained and the fire fire resistance for such case is assumed to be one half times of the normal case.

All the openings are also assumed to be closed, because the comparison of fire loss between wood frame construction and fire resistant one is one of the objectives of our work and this assumption would expands the difference of them.

3) ALGORITHM OF PROPAGATION

To determine the fire spread time of each room the following algorithm is adopted. If there is any fire spread route between the node i and j on the network space model, the fastest spread time Lij can be determined as multiple value of time unit(dt) which is sufficiently small to be accepted as the allowance of calculation. On Fig.5, if the node j starts to burn at time t, the fire has had to come from one of the adjacent nodes which was already in fire at time t-dt. Thus the node j is burned by the fire from i or n, not from k, because k is not in fire at time t-dt.

Which node is the spread source depends on fire resistant time of link and fire spread time of adjacent node. There are 3 possible cases.

i) if $t = Ti + Lij$ & $t < Tn + Lnj$ then from node i
ii) if $t < Ti + Lij$ & $t = Tn + Lnj$ then from node n
iii) if $t = Ti + Lij$ & $t = Tn + Lnj$ then from both

if t does not fit to any of these cases, the node j has not get been in fire at t. As this procedure is repeated at every dt and for every node not get in fire, fire spread times of all the nodes can be determined.

4) CALCULATE BURNED AREA

One case of simulation, corresponding to a location of initial fire and a combination of all the related materials, makes one burned area-time curve. This

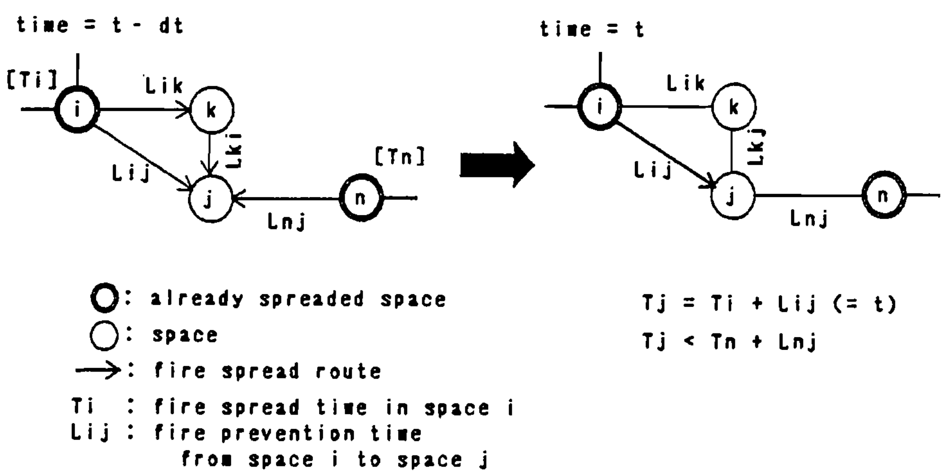

Fig.5 How to determine the fire spread time

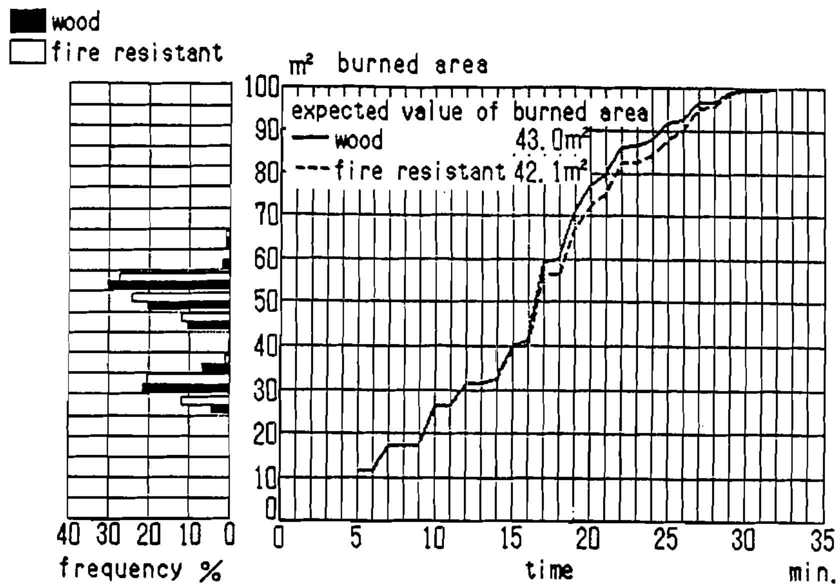

Fig.6 Burned area-time curve
and frequency of expected burned area

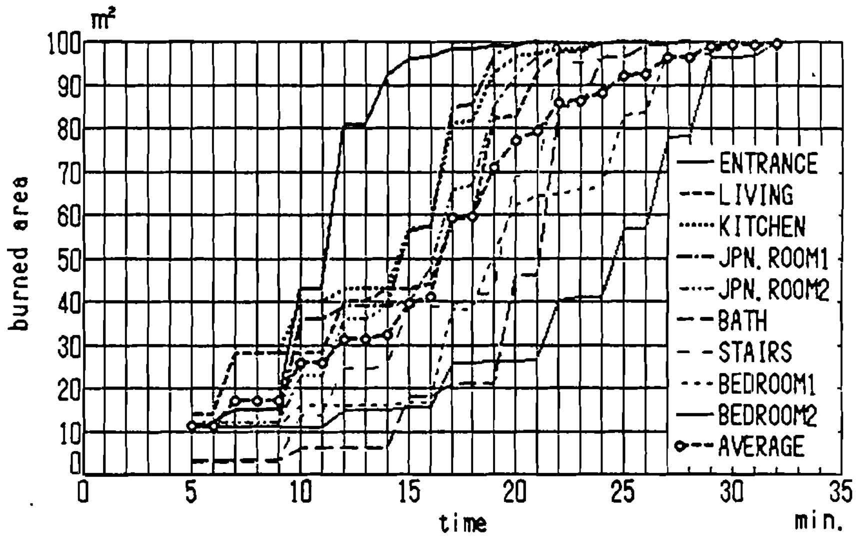

Fig.7 Burned area-time curve by fire ignition room

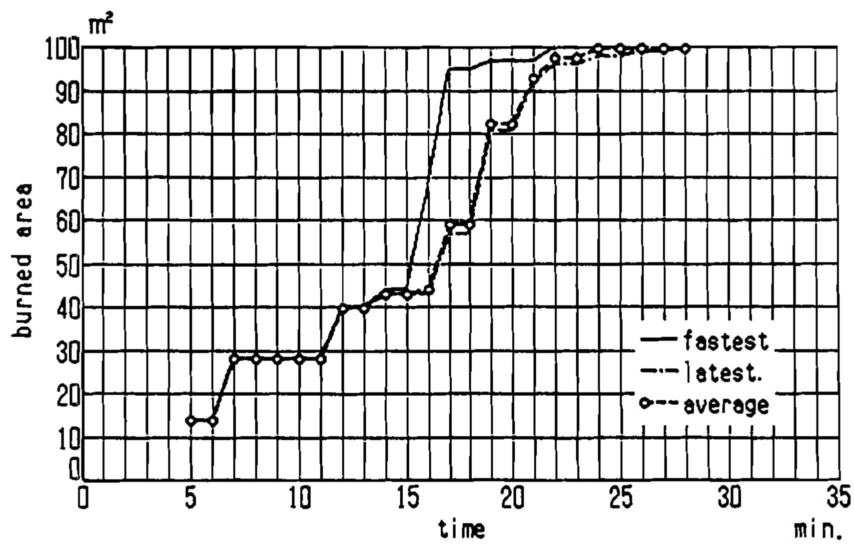

Fig.8 A case of living room fire

curve shows the burned area at each time under the condition without fire fighting. So, to calculate the expected value of burned area, the curve should be multiplied by the probability of fire extinguishment at each time and summed up for all the cases. After all, the plan in Fig.3 needed about 15 millions cases of simulation.

5) RESULT

As shown in Fig.7, a burned area-time curve mainly depends on the location of fire ignition. A fire starting in the entrance hall(1F) spreads out fastest of all the ignition. The latest case is for a fire from the bedroom2(2F).

Fig.8 shows the burned area-time curve for the living room fire, indicating the difference by assembly materials. In the fastest case, all the separations are made of the 4th or 3rd fire resistant grade.

The latest case referring to the first grade separations is corresponding to the case of a fire resistant case, because a fire does not penetrate through the first grade separations and spread out only by way of openings. And the average curve for a wood frame house is almost same as the curve for a fire resistant house.

The solid line curves in Fig.6 is the average of all the curves in Fig.7 and represents the fire growth curve for japanese newly built wood frame house and the dotted line is the result of the summation of the cases corresponding to a fire resistant house. The two curves have almost no difference. The expected value of burned floor area for a wood frame house is 43.0 m^2 and for a fire resistant house 42.1 m^2.

4. CONCLUDING REMARKS

The analysis of fire statistics and the result of simulation study indicate following remarks:

1) In a recent wood frame house in Japan, noncombustible materials like gypsum board are used in large quantities as linings or underlayers. They are replaced to plywoods or planks in conventional construction.

2) This has improved the fire resistance of assemblies of ceiling, wall and floor and it serves to keep a fire in a room relatively long time. Consequently, the burned area growth curve given by the computer simulation is resembles to that for a fire resistant house.

3) It is important in the background of the simulation that doors separating two rooms have only 3-5min. of fire resistance and make the major route of fire propagation. The situation for a fire resistant house is all the same as that for a wood frame house. Therefore, the improvement of quality of doors would provide a better result of property loss but, at the same time, a greater difference between wood frame construction and fire resistant construction.

4) For future studies with a more plausible model, we need a sub-model which gives fire spread time in a room with the specific conditions of combustibles and openings. After an adequate improvement of the model, combined with smoke development model and human behavior model, we believe that it can be evolved to a comprehensive model to evaluate the fire risk in a small house.

REFERENCE

*1 Fire statistics data by the Fire Defense Agency, Ministry of Home Affair
*2 H.Kakegawa, T.Nagaoka, M.Tsujimoto "Estimation of Fire Risk Using Data Base, No.2 Fire Risk in Residential Buildings in Tokyo" Proceedings of 1989 Annual Meeting of the Japanese Association of Fire Science and Engineering, 1989.5.17