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NATIONAL BUREAU OF STANDARDS REPORT

10 534

STUDY ON SMOKE AND GASES GENERATED FROM FIRES AND FIELD FIRE EXPERIMENTS FOR INTERIOR FINISH MATERIALS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
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STUDY ON SMOKE AND GASES GENERATED FROM FIRES

by F. Saito and T. Wakamatsu

FIELD FIRE EXPERIMENTS FOR INTERIOR FINISH MATERIALS

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NBS

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Translation by
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PREFACE

This report is a translation of papers prepared by F. Saito and T. Wakamatsu describing research performed at the Building Research Institute of Japan.

The translation has been prepared to disseminate useful information to interested fire research personnel on a need-to-know basis and is not original work generated at the Building Research Division.

We express our appreciation to the authors for providing their original manuscript for translation and for their assistance in making this information available.

STUDY ON SMOKE AND GASES GENERATED FROM FIRES

Investigation of the Effect of Ventilation Openings
in a Compartment on Smoke Generation and Smoke Movement

1.1 OPENING CONDITIONS OF FIRE ROOM AND SMOKE GENERATION

by

F. Saito

In spite of using the same internal linings, the smoke generation from compartment fires will be different if opening conditions are not the same. Since the temperature and the burning rate in a fire room depend upon ventilation conditions, the rate of smoke generation should be considered along with the course of fire growth. Suppose a fire breaks out and ignites the wall materials first and then the ceiling to reach flashover. In this case, the rate of smoke production from room fires at time t can be expressed in terms of internal lining areas of wall materials, A_1, A_2, etc., at the corresponding temperatures of T_1, T_2, etc., as

$$\frac{dc}{dt} = \frac{dc_1}{dt} A_1 + \frac{dc_2}{dt} A_2 + \text{etc.} \qquad (1)$$

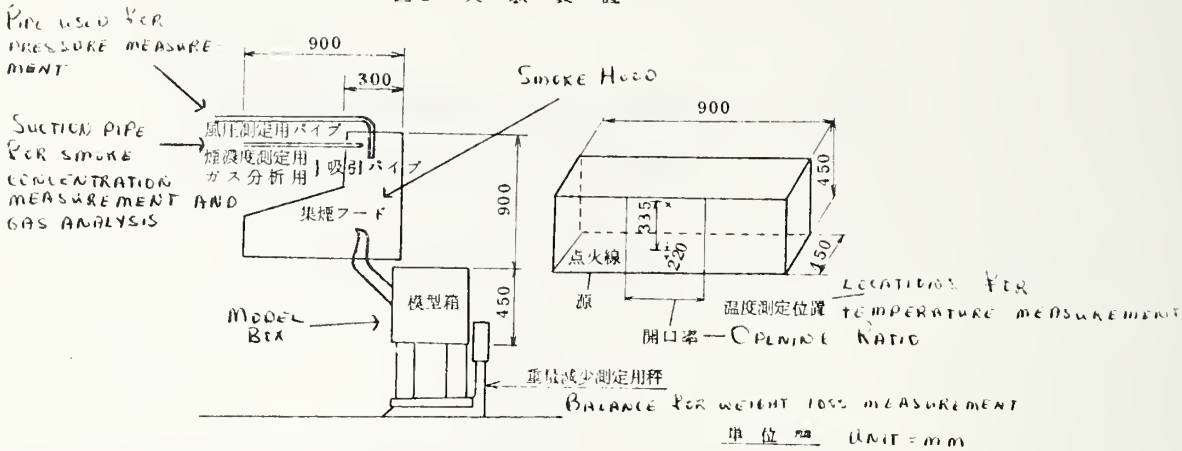
Most materials have such smoke characteristics that the maximum smoke generation occurs at about 400 to 500°C. A small amount of smoke is produced at the initial stage of room fires since at such low room temperatures the burning area and the burning rate are small in spite of high rate of smoke generation per unit area. However, the amount of smoke generation increases rapidly at or after flashover because the area of active burning enlarges to cover the whole fire room through a steep rise in the room temperature. Consequently, the former commonly can be ignored campared to the latter.

In order to measure the quantity of smoke discharged from the fire room, it requires to determine the flow rate of hot gases leaving the opening and the history of smoke concentration.

Smoke generation from a fire room as described before has a close relation with flashover. A model box as shown in Figure 1 was used to simplify the geometry of a compartment and the smoke was gathered and measured at a hood hanging over the box.

FIGURE 1 Experimental Apparatus

図1 実験装置



The rate of smoke generation is given by

$$\frac{dc}{dt} = C_s v \tag{2}$$

The total amount of smoke production thus can be expressed as

$$C = \int_0^t C_s A v dt \tag{3}$$

where C_s is the light attenuation coefficient of smoke in m^{-1}, A is the cross-sectional area of the hood in m^2, v is the mean velocity of hot gases in M/sec.

The volume of the discharged gases in which the smoke particles are dispersed is considered here regardless of the concentration of smoke particles, and this volume is dependent on chemical composition of the material involved.

If W Kg of wood-like material is burned in α percent of excess air, the volume of smoke produced has the following form:

$$V = (0.72 + 3.97\ \alpha)\ W \tag{4}$$

and the rate of smoke generation after flashover can be written in terms of the burning rate R as

$$\frac{dc}{dt} = (0.72 + 3.97\ \alpha)\ R \tag{5}$$

1. Experimental

The amount of smoke produced from compartment fires depends upon the amount of fire load, types of interior finish materials, size of the compartment (available internal lining area) and the rate of burning (the ventilation conditions).

According to the studies made by Kawagoe and Sekine, and Thomas, an approximate value for the burning rate of a fully developed fire can be obtained from the area A (m^2) and the height H (m) of a ventilation opening through the equation: $R= 5.5\ A\sqrt{H}$. In similar way, the present model experiment was constructed to determine the rate of burning, the smoke generating coefficient and the rate of smoke generation for various geometries of the openings. Three different sizes of model boxes of 1 m x 2 m x 1 m (H) (large scale), 0.5 m x 1.0 x 0.5 m (H) (medium scale) and 0.5 m x 0.5 m x 1.0 m (small scale model) were used, and the interior finish materials employed mainly were plywood in the present study.

(a) Fire Source

There is a certain relation among flashover, e.g. the flashover time (FOT), size of the fire source and the ratio of the combustible lining area (A_s) to the surface area of wood crib exposed to air (A_c). (See Table 1) Lattice-type wood cribs which were constructed from spruce sticks of 2 cm x 2 cm in cross-section by either 25 cm (large scale) or 12 cm (small scale) in length, and piled up 5 layers (total 30 pieces) for large scale or 4 layers (total 12 pieces) for small scale were used as fire sources. The cribs were ignited from the bottom row by a stick dipped in alcohol.

表 1. 模型の大きさと火源

TABLE 1. THE SIZES OF MODELS AND FIRE SOURCE

	As (m²)	As / Ac
大型模型 LARGE SCALE MODEL	4.9 ～ 6.7	10.6 ～ 20.4
小型模型（横型） SMALL SCALE MODEL	1.56	15.2 ～ 17.3
小型模型（縦型） MEDIUM SCALE MODEL	2.06	17.4 ～ 19.3

TABLE 2 THE SIZES OF THE OPENINGS

表 2. 開口部の大きさ（cm）

開口率 OPENING RATIO	$A\sqrt{H}$	下り壁の深さ DEPTH OF SLIDING WALL	開口高 HEIGHT	開口巾 WIDTH
		0	48	49
1/2	0.163	8	42	60
		16	36	75
		0	48	24.5
1/4	0.081	8	42	30
		16	36	37.5
		0	48	12.2
1/8	0.041	8	42	15
		16	36	19
		0	48	6.1
1/16	0.020	8	42	7.5
		16	36	9.5

(b) Ventilation Opening

Various opening ratios which is defined as the ratio of the opening area to total area of the front wall, can be obtained by varying the width of the opening with a constant height. The opening ratio in the present study respectively were 1/3, 1/4, and 1/8 for large scale and 1/2, 1/4, 1/8, and 1/16 for small scale models. (See Table 2)

2. Discussion of Experimental Results

The rate of smoke generation from a material depends on the product of the smoke generating coefficient and the burning rate. For a given opening condition, the rate of smoke production similar to the average temperature in a fire room can be expected to reach a certain value at flashover. However, from general observation, the internal materials were not burned with a constant rate in horizontal direction into their thickness, but part of them fell out and burned locally. These phenomena present some difficulties in determining the correct value among the measured ones.

(i) Burning rate

Figures 2 and 3 show typical weight loss curves. As indicated in the figures, these curves deviate noticeably from the linearity after flashover because of intermittent falling out of the internal lining materials. From the figures, the rate of burning was determined from the slope between two points in which the burning was at a steady state. The rate of burning is decreased with decreasing the opening ratio since the amount of air inflow is depressed. Yet, this burning rate is not further increased and shows almost constant when the opening ratio exceeds a certain region. Figure 4 indicates such relations. The dash lines in Figure 4 are the results reported by D. Gross on the burning velocity of cribs made from cellulose-base fiberboards. Under the same opening condition, the present work shows higher rate of burning. This is attributed to the differences in materials (plywood and fiberboard), and in stick geometry.

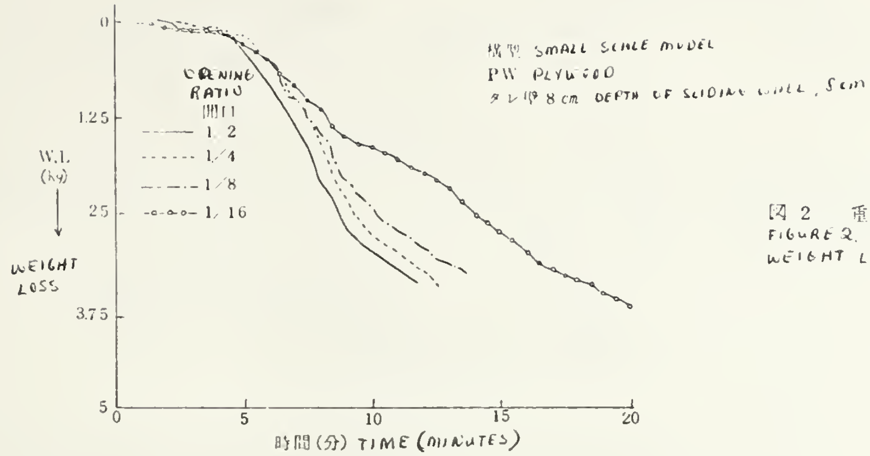


図 2 重量減少曲線
FIGURE 2.
WEIGHT LOSS CURVE

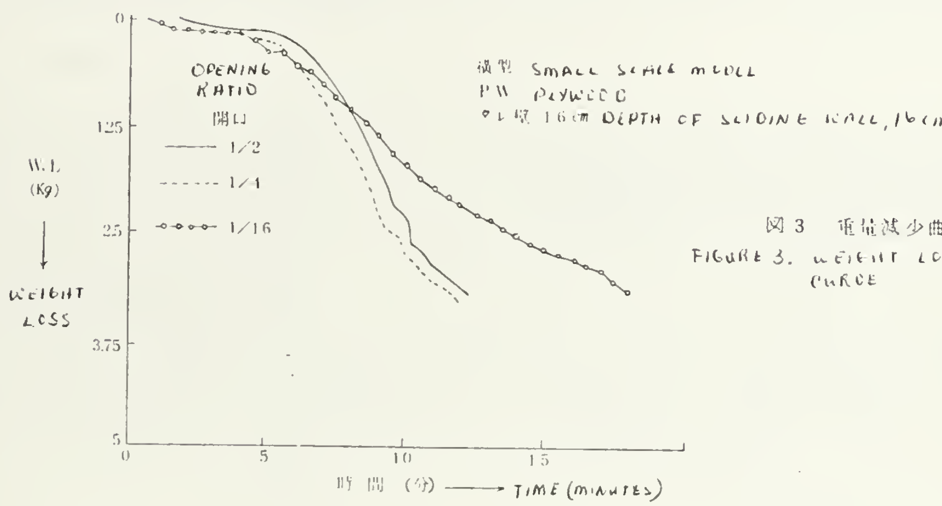


図 3 重量減少曲線
FIGURE 3. WEIGHT LOSS CURVE

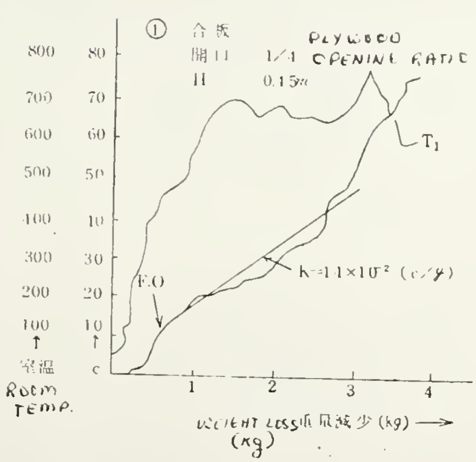
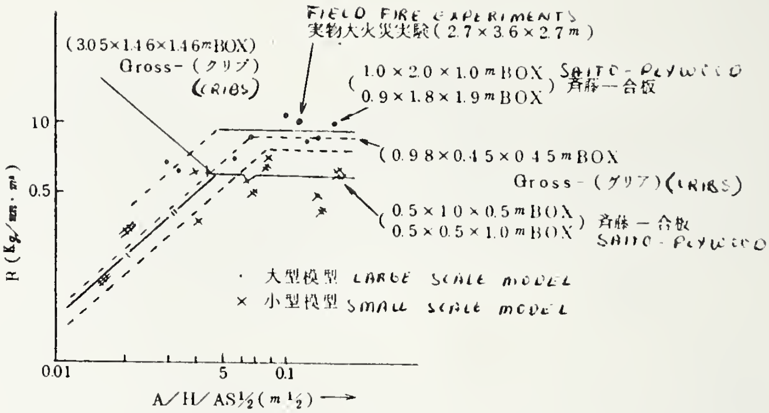


図 4　燃焼速度と開口条件
FIGURE 4. THE BURNING RATE AND THE OPENING CONDITIONS



(ii) Smoke Generating Coefficient

Smoke generating coefficient K is defined as the amount of smoke generated per unit weight of the fuel consumed and can be estimated from the slope of weight loss versus total amount of smoke production curve. Figure 5 shows a typical example.

FIGURE 5. – RELATION BETWEEN WEIGHT LOSS AND THE AMOUNT OF SMOKE GENERATION
図 5　重量減少と発煙量の関係

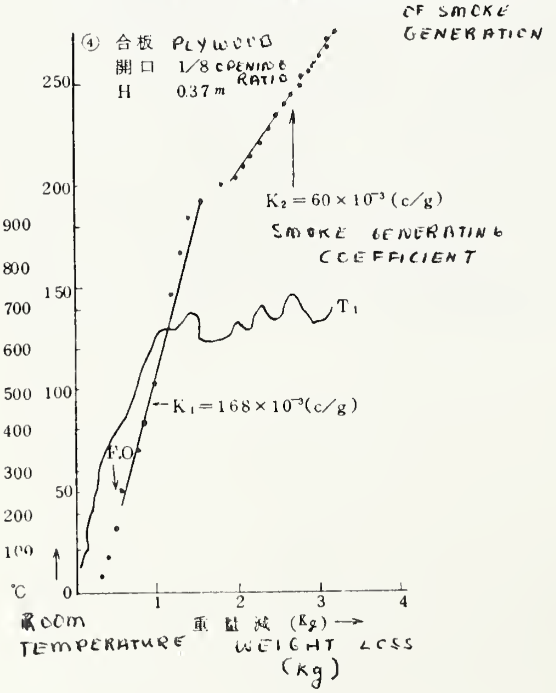
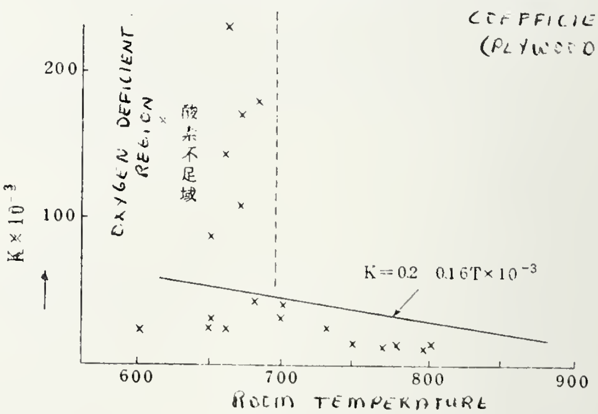


FIGURE 6. ROOM TEMPERATURE AND SMOKE GENERATING COEFFICIENT (PLYWOOD)
図 6　室内温度と発煙係数（合板）



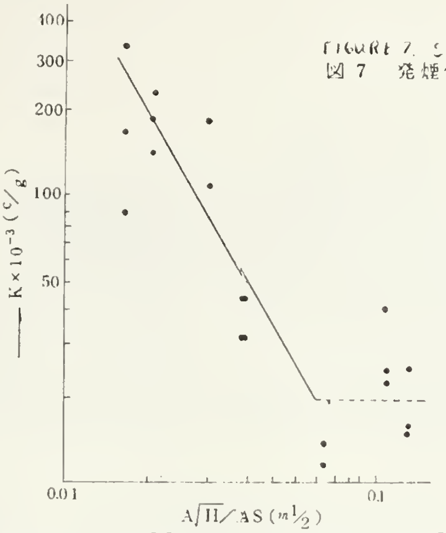


図 7 発煙係数と開口条件 FIGURE 7. SMOKE GENERATING COEFFICIENT AND THE OPENING CONDITIONS

The smoke generating coefficient is large for small opening and decreases with an increase in the opening ratio. Figure 6 presents a relationship between the room temperature and the smoke generating coefficient. As shown in Figure 7, at the value of $A\sqrt{H}/A_s$ smaller than about 0.04, the smoke generating coefficient increases rapidly because of the smoldering burning caused by the shortage of oxygen.

(iii) Rate of Smoke Generation

The rate of smoke production is determined by the product of burning rate and the smoke generating coefficient of the material, and as discussed before the opening condition is then an important controlling factor. Figures 4 and 7 indicate a relation that the smoke generating coefficient is inversely proportional to the rate of burning.

As shown in Figure 8, the rate of smoke generation decreases with an increase in the ventilation opening and tends to converge to a certain value. In the same figure, there is an estimated value which is calculated from the results of field experiment along with the consideration of friction effect due to a 30 m long passage between fire room and air entrance.

図 8 発煙速度と開口条件（合板） FIGURE 8. THE RATE OF SMOKE GENERATION AND THE OPENING CONDITIONS

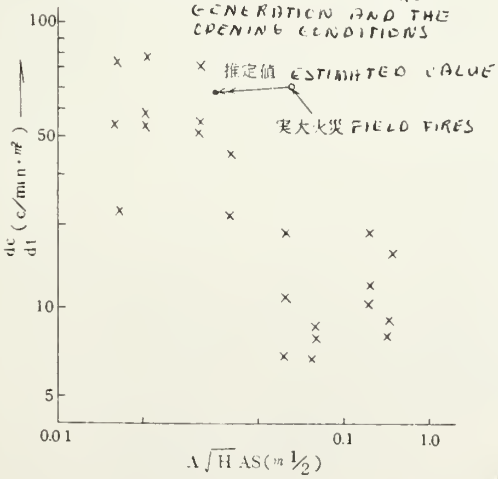
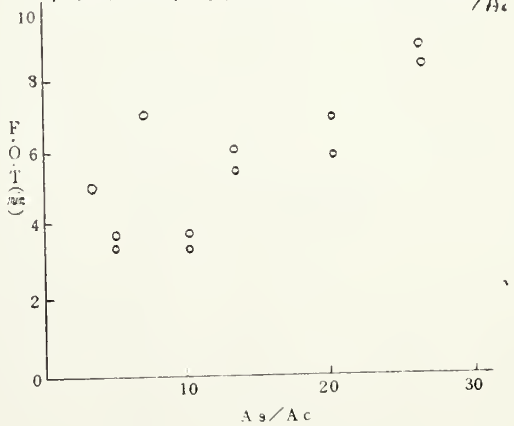


図 9 フラッシュオーバー時間と As/Ac FIGURE 9. FLASHOVER TIME AND As/Ac



(iv) Flashover Time and Fire Source

Flashover starts when the concentration of combustible gases in the fire room gets into a certain range. Consequently, the time taken from ignition up to flashover depends upon the opening condition and size of the fire source. For a given opening condition, flashover is determined by the rate of heating acting on the materials (size of fire source). Figure 9 shows a plot flashover time against A_s/A_c for plywood. For the case of cribs experiment, it requires the correction for the time taken to active burning of the fire source. An empirical equation for plywood at the opening ratio of 1/4 is obtained as follows:

$$F.O.T. = [2.6 + 0.3 (\frac{A_s}{A_c})] - D$$

Here D is the time taken to develop into a certain degree of fire.

TABLE 3 EXPERIMENTAL RESULTS

表 3. 実 験 結 果

模型箱の大きさ (m) / SIZE OF MODEL BOX (m)	開口率 / OPENING RATIO	$A\sqrt{H}/A_s$ (m1/2)	タレ壁の深さ (m) / DEPTH OF SIDING WALL	燃焼速度 (Kg/min/m²) / BURNING RATE	発煙速度 C/min/m² (c分)×10³ / RATE OF SMOKE GENERATION	発煙係数(1)* / SMOKE GENERATING COEFFICIENT	発煙係数(2)** (c分)×10⁻³	実測室温 (°C) / ROOM TEMP	フラッシュオーバー時間 / FLASH OVER TIME	A_s/A_c	材料名 / MATERIAL	板厚 (mm) / THICKNESS (mm)	備考 / NOTES
1 × 2 × 1	1/2	0.142	0	0.97	–	–	–	800	8′ 00″	18.9	合板 (PLYWOOD)	5.5	
	1/3	0.110	0	0.82	–	–	–	865	7′ 30″	19.8	〃	〃	
	1/4	0.065	0	0.87	–	–	–	895	8′ 20″	20.4	〃	〃	
	〃	〃	0	0.69	–	–	–	900	8′ 30″	12.3	〃	〃	
	1/8	0.032	0	0.66	–	–	–	740	10′ 30″	21.1	〃	〃	
	1/4	0.065	0	1.02	–	–	–	870	6′ 40″	12.3	難燃合板	〃	TREATED PLYWOOD
	〃	〃	0	1.00	–	–	–	885	9′ 40″	20.1	〃	〃	含水率15.2% MOISTURE CONTENT
09×18×09	1/3	0.090	0	1.01	286	17	283	850	7′ 45″	10.6	合板	5.5	
	1/4	0.065	0	0.88	25.7	25	282	830	6′ 50″	10.9	PLYWOOD 〃	〃	
	1/8	0.031	0	0.69	12.7	16	184	700	6′ 25″	11.3	〃	〃	
	1/3	0.090	0	0.88	37.0	44	4205	650	10′ 00″	10.6	〃	9.0	
	1/4	0.065	0	0.75	488	66	651	870	8′ 00″	10.9	〃	〃	
	1/8	0.031	0	0.55	462	37	840	800	7′ 00″	11.3	〃	〃	
	1/3	0.090	0	0.79	220	36	2785	850	7′ 40″	10.6	〃	12.0	
	1/4	0.065	0	0.81	267	35	330	900	7′ 25″	10.9	〃	〃	
	1/8	0.031	0	0.71	175	25	2465	860	6′ 30″	11.3	〃	〃	TREATED PLYWOOD
	1/3	0.090	0	0.66	246	36	373	720	11′ 40″	10.6	難燃合板	5.5	注入処理 INJECTION TREATMENT
	1/4	0.065	0	0.69	358	79	519	650	11′ 15″	10.9	〃	〃	
	1/8	0.031	0	0.66	295	68	447	600	10′ 00″	11.3	〃	〃	
	1/4	0.065	0	0.78	865	135	1109	750	8′ 35″	10.9	〃	〃	同上+PVC樹脂 SAME ABOVE & PVC RESIN
	1/8	0.031	0	0.56	1122	210	198.5	700	9′ 00″	11.3	〃	〃	
	1/3	0.090	0	0.65	398	63	6125	720	12′ 40″	10.6	〃	〃	
	1/4	0.065	0	0.71	46.0	65	6409	800	11′ 45″	10.9	〃	〃	同上+ベンゾグアナミン樹脂 SAME AS ABOVE
	1/8	0.031	0	0.34	–	–	–	650	10′ 40″	11.3	〃	〃	
0.5×1.0×0.5	1/2	0.127	0	0.47	1008	–	225	600	6′ 30″	15.2	合板 (PLYWOOD)	5.5	
	〃	〃	8	0.51	1248	–	244	650	5′ 30″	〃	〃	〃	
	〃	〃	16	0.48	1920	–	40.0	730	6′ 47″	〃	〃	〃	
	1/4	0.063	0	0.52	1056	34	204	670	6′ 30″	16.3	〃	〃	
	〃	〃	8	0.52	624	13	–	680	6′ 27″	〃	〃	〃	
	〃	〃	16	0.57	1728	50	303	650	6′ 30″	〃	〃	〃	
	1/8	0.031	0	0.41	7390	110	1800	680	6′ 15″	17.0	〃	〃	
	〃	〃	8	0.42	4240	113	106.0	670	–	〃	〃	〃	
	〃	〃	16	–	42.72	–	–	690	–	〃	〃	〃	
	1/16	0.016	0	0.23	7344	–	3140	600	–	17.3	〃	〃	
	〃	〃	8	0.27	4464	–	1652	615	–	〃	〃	〃	
	〃	〃	16	0.26	23.04	–	889	650	–	〃	〃	〃	
0.5×0.5×1.0	1/2	0.150	0	0.63	1620	–	256	730	4′ 15″	17.4	〃	〃	
	〃	〃	15	0.61	8.20	–	145	800	5′ 40″	〃	〃	〃	
	〃	〃	30	0.61	9.27	–	152	780	6′ 50″	〃	〃	〃	
	1/4	0.079	0	0.65	6.08	13	10.7	800	6′ 05″	18.6	〃	〃	
	〃	〃	15	0.74	6.89	20	10.7	770	6′ 35″	〃	〃	〃	
	〃	〃	30	0.67	9.32	19	13.9	750	6′ 00″	〃	〃	〃	
	1/8	0.040	0	0.80	35.64	53	447	680	7′ 25″	19.3	〃	〃	
	〃	〃	15	0.63	21.87	20	308	700	–	〃	〃	〃	
	〃	〃	30	0.41	–	–	–	570	–	〃	〃	〃	
	1/16	0.020	0	0.27	46.58	–	1712	580	–	19.5	〃	〃	
	〃	〃	15	0.34	48.20	–	141.7	560	–	〃	〃	〃	
	〃	〃	30	0.34	80.60	–	237.0	560	–	〃	〃	〃	
	1/2	0.150	0	0.32	55.8	–	174.0	330	–	5.2	難燃合板	5.5	TREATED PLYWOOD
	〃	〃	15	0.51	55.8	–	1095	650	8′ 40″	〃	〃	〃	
	〃	〃	30	0.51	68.8	–	135.0	700	10′ 40″	〃	〃	〃	
	1/4	0.079	0	0.61	55.8	–	91.7	760	7′ 50″	5.5	〃	〃	
	〃	〃	15	0.49	61.2	–	124.8	8[illegible]	7′ 35″	〃	〃	〃	
	〃	〃	30	0.54	84.3	–	1565	770	7′ 45″	〃	〃	〃	
	1/8	0.040	0	0.[illegible]9	112.8	–	1912	700	–	5.8	〃	〃	
	〃	〃	15	0.54	55.8	–	1032	680	–	〃	〃	〃	
	〃	〃	30	0.17	68.8	–	146.5	610	–	〃	〃	〃	

* 実測値 ** 計算値

* EXPERIMENTAL VALUE

** PREDICTED VALUE

1.2 EXPERIMENTS ON SMOKE MOVEMENT IN BUILDINGS

by

T. Wakamatsu

1. Study Objectives

The present experiment aims to determine the minimum amount of required air supply to prevent smoke entering the stair room for various opening conditions, and using the experimental results to compare with theoretical calculation (1).

2. Experimental Installations

Air supply and smoke discharge passages, the stair rooms and the living rooms were installed on first to fifth floor of a five-story building. The fire room (the living room on the third floor served as the fire room in the present experiment) and air conditioning unit (whose supply capacity of 5 m^3/sec and conditioning capability ranging from -10°C to 20°C with respect to the outside air) were set up on the first floor and the instrument room on the second floor. The air supply passage was connected to a blower through a duct, and a natural draft smoke opening and a suction fan (capacity 2.5 m^3/sec) were installed at the roof portion of the smoke discharge passage. In order to make the position and the area of the openings adjustable, two ventilation openings which connected the living room to supply and discharge passages were divided into six portions in vertical direction, and installed with six pieces of 1 m wide x 40 cm high door.

3. Experimental Procedure

Alcohol contained in a pan with a cross-sectional area of 0.35 m^2 was burned in the living room on the third floor and smoke was produced through a smoke generating cylinder. The tests were performed for 14 opening conditions in which doors D1, D2, and D3 on the first floor and door DF and window W1 of the fire room were always opened, and door DR of the stair room and window W2 of the fire room were either shut or opened. The size of each opening is presented in Table 1.

表 1. TABLE 1.

SIZE OF THE OPENING (WIDTH & HEIGHT)(m)
開口寸法〔巾×高さ〕（m）

D_1	D_2, D_3, DF	DR	W_1, W_2	AIR INLET 給気口
1.64×1.8	0.82×1.8	0.82×1.0	0.56×0.9	0.5×0.5

W1，W2の窓下端までの高さは床上1 m
THE DISTANCES BETWEEN THE BOTTOMS OF WINDOWS W1, W2 AND THE FLOOR ARE 1 m SEPARATELY.

The amount of air supply was determined by hot wire anemometers placed at the center of each air entrance. In this case, the discharge coefficient for each opening was assumed to be 0.85.

The experiment was started by running the blower at full capacity of about 5 m^3/sec, and setting fire to produce smoke in the fire room. In this stage, most smoke would discharge out from the windows of the fire room. The mimimum amount of required air supply to the stair room was obtained by gradual reduction of air supply until the smoke started to move into the stair room. Repeated tests were made in duplicate or triplicate for each opening condition and a total of 31 runs was performed.

4. Experimental Results and Observations (Comparison with the Calculated Values)

Table 2 illustrates the average temperatures of air in the outdoor, the stair room and the fire room, the direction and the speed of the outside air measured at the instrument room, and the predicted and experimental values for minimum amount of required air supply. The predicted values were calculated based on the equations derived in Reference 1 along with the data obtained from the present experiment. In general, the predicted values are in reasonably good agreement with the experimental values.

References

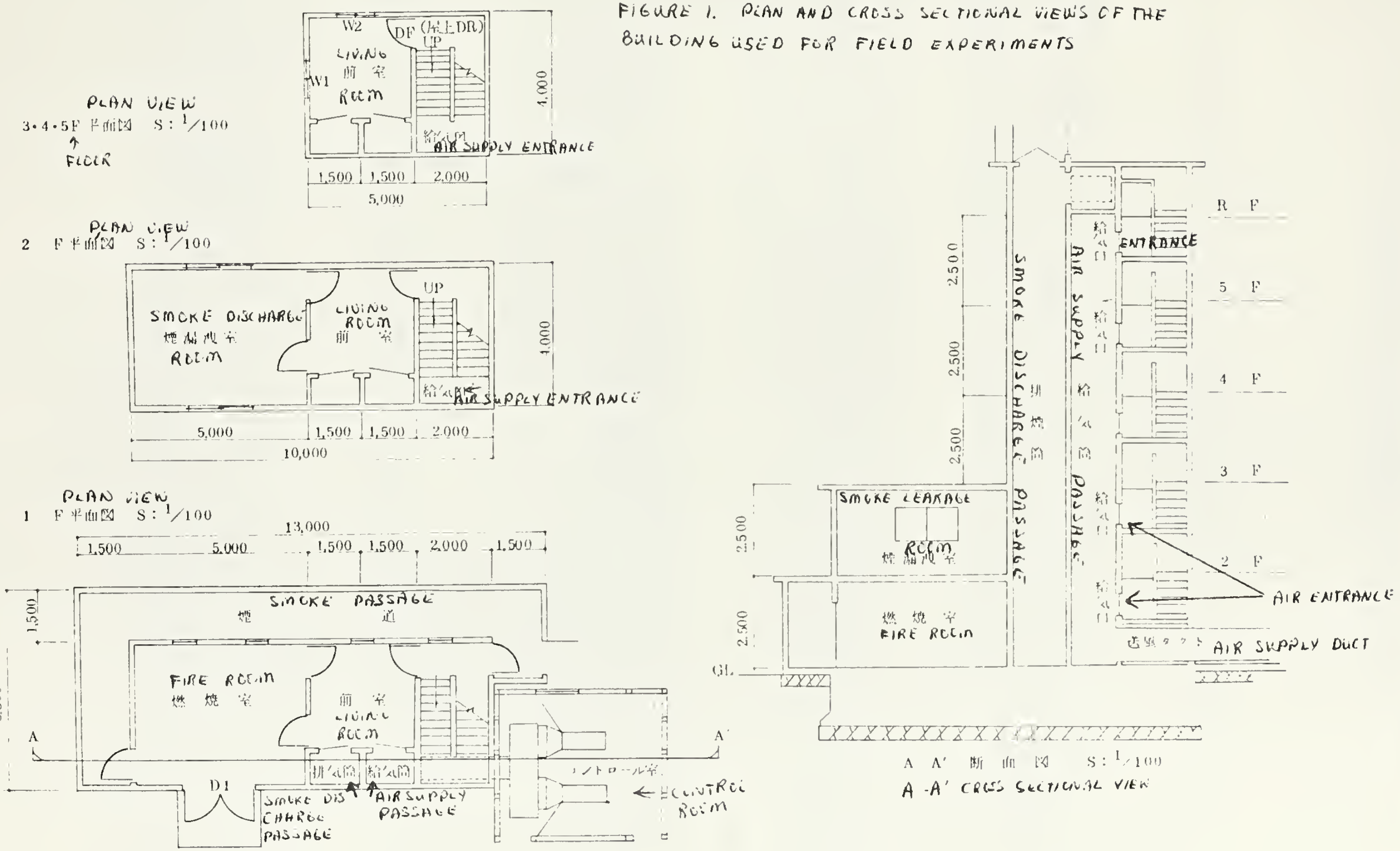
[1] Wakamatsu, T., "Calculation of Smoke Movement in Building," BRI Research Paper No. 34, (1968).

TABLE 2. EXPERIMENTAL AND PREDICTED VALUES OF MINIMUM AMOUNT OF AIR SUPPLY REQUIRED TO PREVENT SMOKE ENTERING

表2. 遮煙に必要な最小給気量の実験値と計算値

SERIES シリーズ NO.	OPENING CONDITION 開口条件 ROOF WINDOW	○：開放 OPEN －：閉鎖 CLOSED		TEMPERATURE 温度 (C)			WEATHER 気象(m)	MINIMUM AMOUNT OF AIR SUPPLY REQUIRED 最小給気量(m³/sec)	
	屋上窓 DR	排煙窓 W2 SMOKE ROOM WINDOW	給気口(各階)	OUTSIDE AIR 外気	STAIR ROOM 階段室	FIRE ROOM 火災室	WIND DIRECTION + WIND SPEED 風向風速	EXPECTED VALUE 実験値	CALCULATED VALUE 計算値
1－1	－		5	18.0	18.0	50.0	0	1.2	1.3
				19.0	19.0	57.0	0	1.2	
1－2	－	－	1	21.0	21.0	45.0	S 0.2	1.5	1.2
				18.0	18.0	55.0	0	1.4	
1－3	－	－	2, 4	19.0	19.0	50.0	S 2.0	1.3	1.3
				21.0	21.0	59.0	NW 0.2	1.6	
				19.0	20.0	55.0	E 1.2	1.5	
1－4	－	－	1～5	20.0	20.0	61.0	E 1.5	1.6	1.6
				17.0	17.0	55.0	E 1.2	1.6	
2－1	－	○	5	18.0	18.0	53.0	SW 1.2	0.8	1.2
				16.0	16.0	62.0	E 0.2	1.1	
				17.0	18.0	50.0	E 0.5	1.3	
2－2	－	○	1	17.0	17.0	46.0	SW 1.0	1.1	1.0
				16.0	16.0	45.0	E 1.0	1.3	
2－3	－	○	2, 4	20.0	20.0	52.0	W 2.0	1.2	1.2
				20.0	20.0	52.0	0	1.3	
				20.0	20.0	50.0	E 0.2	1.1	
2－4	－	○	1～5	16.0	16.0	54.0	E 0.3	1.0	1.3
				15.0	15.0	45.0	SSW 1.5	1.0	
3－1	○	－	1	16.0	16.0	47.0	E 1.0	2.5	2.0
				18.0	18.0	52.0	E 1.5	2.5	
3－2	○	－	2, 4	19.0	19.0	46.0	W 2.0	2.2	2.2
				18.0	18.0	53.0	0	2.2	
3－3	○	－	1～5	15.0	15.0	58.0	E 0.2	2.1	2.5
				15.0	15.0	52.0	E 0.1	2.6	
4－1	○	○	1	18.0	18.0	39.0	E 2.0	1.7	
				18.0	18.0	47.0	E 1.5	1.7	1.2
4－2	○	○	2, 4	19.0	19.0	47.0	W 2.0	1.8	1.1
				19.0	19.0	43.0	N 0.8	1.7	
4－3	○	○	1～5	18.0	19.0	63.0	SW 2.0	1.4	
				18.0	18.0	60.0	SW 1.2	2.2	1.9

図1　実大火災実験用建物平面図および断面図
FIGURE 1. PLAN AND CROSS SECTIONAL VIEWS OF THE BUILDING USED FOR FIELD EXPERIMENTS



FIELD FIRE EXPERIMENTS FOR INTERIOR FINISH MATERIALS

by

F. Saito

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Introduction

In spite of a building constructed entirely from non-combustible materials, it still possesses a high degree of the potential of fire hazard because of the combustibilities of furniture and goods within the building. Several fire experiments were sponsored by the Building Research Institute in which the following four experiments were related to interior finish materials.

Experimental Procedure

The accuracy and the repeatability of the experiments on field fires are decreased with an increase in size of the building. However, the experimental procedure and the ignition method were carried out in the same manner for each run.

1. Ignition Method

Wood cribs, which were constructed of 12 pieces of 2 cm x 2 cm x 60 cm spruce sticks per layer, were placed at the corner of a compartment and were ignited by inserting an alcohol soaked stick (1 cm x 1 cm x 60 cm) at the bottom layer. Wood cribs which were piled up to 10 layers and located near the center of the room were used as the fire source to simulate office fires in the fire experiments made in May 1967, and cribs piled up to 31 layers were employed for the experiments in April 1968.

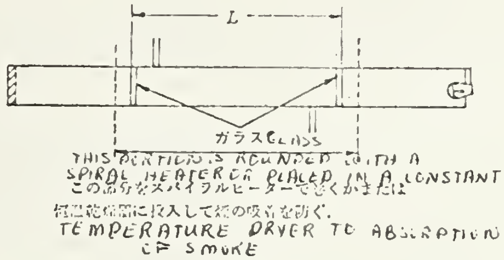
2. Temperature Measurements

Temperature measurement was made with CA thermocouples (Class 0.65) connected to the electronic type self-balancing temperature recorders.

3. Smoke Concentration

The attenuation coefficient is used in the present experiment for the indication of smoke density. The conventional way to measure the smoke concentration is direct measurement of the intensity of light attenuated by the smoke between the light source and the receiver, but this method has limitations due to the temperature compensation of the cell and the effect of flame present in the smoke in some cases.

A temperature compensation type sucking smoke meter was employed for measuring smoke concentration。 (See sketch)



4。 Gas Analysis

In gas analysis, CO_2 and O_2 were separately determined for the experiments in 1964, CO gas in 1965, and CO, CO_2 and O_2 gases were analyzed in the 1967 experiments。

Kinds of Interior Finish Materials and Flashover

Flame spread, the temperature and duration of fire depend on the kinds and amount of combustible loads such as the materials used as walls and ceilings, and air ventilation conditions. Table 1 shows several field experiments in which actual building materials were employed and some of the observations are added as follows:

TABLE 1. FIELD EXPERIMENTS ON INTERNAL LINING MATERIALS
表1 内装材料を対象とした火災実験

DATE 実験年月	NAME OF EXPERIMENT 実験名	PURPOSE 実験目的	BUILDING STRUCTURE 建物構造	SIMULATION 想定条件	EXPT. NO. 実験回	INTERNAL LINING MATERIALS 内装材料	COMBUSTIBLE LOAD (WOOD CRIB) & DESK, ETC 収容可燃物量 (kg/cm²)
SEPT 1964 昭和39年9月	1964 横浜大建ビル火災実験 FIRE EXPTS	INTERNAL LINING MATERIALS 内装材料とフラッシュオーバー FLASH OVER	STEEL BEAMS AND CONCRETE 鉄筋コンクリート造		1	天井：杉板(3mm)，カベ：プラスター 床：タタミ (CEILING - SPRUCE (3mm), WALL - PLASTER)	0
					2	天井・カベ：難燃合板(5.5mm)，床：タタミ (CEILING & WALL: TREATED PLYWOOD (5mm), FLR.- TATAMEE)	0
					3	天井・カベ：石膏ボード(9mm)，床：タタミ (GYPSUM BOARD (9mm), FLOOR TATAMEE)	0
					4	天井・カベ：合板(9mm)，床：タタミ	0
MAY 1965 昭和40年5月	1965 1965年5月火災実験 FIRE EXPTS	SAME AS ABOVE 内装材料とフラッシュオーバー	WOOD 木造平家建	住宅火災 DWELLING FIRES	1	天井・カベ：合板(3mm)，床：タタミ (CEILING & WALL — PLYWOOD)	27.0
				〃	2	天井・カベ：石膏ボード(9mm)，床：タタミ (GYPSUM BOARD (9mm))	23.4
			BRICK 耐火造階建	〃	3	天井・カベ：石膏ボード	23.2
				〃	4	天井・カベ：塗装合板(3mm)，床：タタミ	23.9
MAY 1967 昭和42年5月	1967 1967年5月火災実験 FIRE EXPTS	INTERNAL LINING MATERIAL AND SMOKE GENERATION 内装材料と発煙性	WOODEN HOUSE COVERED WITH ALUMINUM SHEETS 木造平家外部亜鉛鉄板張り	OFFICE FIRES 事務室火災	1	天井・カベ：合板(4mm)，床：塩ビタイル	17.0
					2	天井・カベ：石膏ボード(9mm)，床：塩ビタイル (FLOOR - PVC TILE)	17.0
APRIL 1968 昭和43年4月	1968 1968年4月火災実験 FIRE EXPTS	INTERNAL LINING MATERIALS AND SMOKE GENERATION AND SMOKE DIFFUSION 内装材料と発煙性および煙拡散	鉄筋コンクリート造		1	天井・カベ：合板(5mm) (CEILING & WALL = PLYWOOD)	
					2	天井・カベ：塩ビフィルム(0.3mm)張 (PVC FILM (0.3mm) SHEET)	
					3	カベ：塩ビシート(2mm)張	
					4	天井・カベ：塗装合板(3mm) (PAINTED PLYWOOD (3mm))	
					5	天井・カベ：特殊難燃合板(12.0mm)	

TATAMEE = JAPANESE MATTRESS MADE FROM STRAWS

1. Combustibility of Internal Lining Material

As shown in Table 1, the experiments were carried out under such conditions that with the exception of one room, the remaining three rooms were lined with the same sort of materials for walls and ceilings.

In this case, the materials used have the following relation with the classification of building materials designated by the regulation:

Partially non-combustible material: gypsum board
Hardly combustible material: treated plywood
Combustible material: plywood

The material which is classified above the hardly combustible material is considered as a fire resistant material. Figure 1 shows that the difference in the time taken to flashover between plywood and treated plywood was about 1.5 minutes. However, this deviation in flashover time is dependent upon the size of fire source and the compartment size.

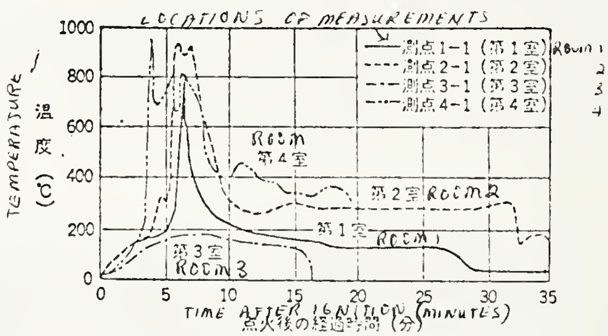


図 1 アパート部火災における各室代表点での火災温度曲線
FIGURE 1. TEMPERATURE CURVES OF EACH ROOM IN AN APARTMENT FIRE

The interior finish material used in the third room was a partially non-combustible material and only burned the paper coated on the surface of gypsum board located around the fire source. The walls of the first room were internally finished respectively with non-combustible materials and Japanese cedar, and the fire source was located in the vicinity of cabinets within the compartment.

The rate of smoke generation at flashover and the flashover time for several interior finish materials used in model and field experiments are summarized in Table 2. The flashover time as described before is dependent upon the ratio of the size of fire source (the rate of heat release) and the exposed surface area inside the compartment and the comparison is not possible as the ratio is not fixed. However, the rate of smoke generation which depends on the smoke generating coefficient, the rate of thermal decomposition and the temperature can be used for comparison purpose.

表 2 TABLE 2.

材料名 MATERIAL	小型模型 SMALL SCALE MODEL (0.45×0.9×0.45m) 厚さ THICKNESS	開口 OPEN RATIO	FOT	発煙速度	大型模型 LARGE SCALE MODEL (1.0×2.0×1.0m) 厚さ THICKNESS	開口 OPEN RATIO	FOT	発煙速度	実大実験 FIELD EXPT. (5.0×5.0×3.3m) 厚さ THICKNESS	開口 OPEN RATIO	FOT	発煙速度 RATE OF SMOKE GENERATION
合板 PLYWOOD	5.5	1/3 1/4 1/8	— 5'00" 3'30"	— 0.405 0.1	5.5	1/3 1/4 1/8	7'45" 6'50" 6'25"	0.322 0.299 0.237	5.0	1/4	4'30"	1.1
難燃合板 TREATED	5.5	1/4	5'40"	0.37	5.5	1/3 1/4 1/8	11'40" 11'15" 10'00"	0.284 0.414 0.344	12.0	1/4	8'30"	0.64
塩ビ合板 CHLORINATED PLYWOOD					5.5	1/4 1/8		1.00 1.31	3.0	1/4	5'30"	1.57
塩ビフィルム張り CHLORINATED FILM ON FLEXIBLE BOARD フレキシブルボード+0.3mm PVC フィルム張り 0.3mm PVC FILM										1/4	3'30"	
内装材使用量 INTERNAL LINING MATERIALS USED	≒1.0m²				≒7.5m²				≒72m²			

The experimental values obtained in model studies are less than those in the field experiment. This may be attributed to the low temperature and smoldering occurred in the field fires because through such a distance of about 40 to 50 m between outside air and the fire room, air supply for combustion is insufficient。

有機質材料の燃焼と火災 ＜

TABLE 3. COMBUSTIBLE LOADS (kg)
表 3 収納可燃物量 (kg)

	木造平家建 WOODEN FLAT HOUSE 内装・合板 INTERNAL PLYWOOD	内装・石膏ボード GYPSUM BOARD	防火造2階建 BRICK 2 STORY BUILDING 内装・石膏ボード INTERNAL LINING GYPSUM BOARD 1階	2階	内装・合板 PLYWOOD 1階 1ST FLOOR	2階 2ND FLOOR
たんす等 FURNITURES	94.8kg	91.7kg	134.7	80.0	140.7	114.2
家具類 雑誌・衣料 MAGAZINES CLOTHES	146.2kg	117.0kg	133.3	83.5	143.5	46.8
小計			268.0	163.5	284.2	161.7
総計 TOTAL	241.0kg	208.7kg	431.5		445.9	
kg/m²	27	23.41	27.6	18.4	29.2	18.2
			23.2		23.9	

TABLE 4 表 4 建物構成材料 BUILDING MATERIALS

	内装・普通合板 INTERNAL LINING PLYWOOD	内装・石膏ボード INTERNAL GYPSUM BOARD
屋根 ROOF	7mmラワン合板下地 着色亜鉛鉄板 かわら棒	12mm防水石膏ボード下地 着色亜鉛鉄板 かわら棒
外壁 EXTERNAL WALLS	7mmラワン合板下地 着色亜鉛鉄板	12mm防水石膏ボード下地 着色亜鉛鉄板
内壁 INT WALLS	4mmラワン ベニヤ タイプII類	12mm石膏ボード張
内壁 両住戸に面する内壁	7mmラスボード下地・石膏プラスター15mm仕上	同 左
天井 CEILINGS	4mmベニヤ張	12mm石膏ボード張
床 FLOORS	[illegible] 5.5mm ラワンベニヤタイプ1下地ビニルタイル張	同 左

TABLE 5. 表 5 可燃物の種類と量 (kg)
KINDS AND AMOUNTS OF COMBUSTIBLE LOADS (kg)

可燃物の種類 KINDS OF COMBUSTIBLE LOADS	石膏ボード内装 GYPSUM BOARD	木質系内装 WOOD LIKE MATERIALS
構造材 STRUCTURAL MATERIALS	364.5	364.5
積載可燃物 OCCUPIED COMBUSTIBLES	169.3	174.5
合板 PLYWOOD		84.2
外壁下地 EXTERNAL WALLS		181.2
プラスター壁 PLASTER WALLS	94.5	94.5
石膏ボード(内外装) GYPSUM BOARD	756.0	
総計 TOTAL	1,404.3	898.9
可燃物計 TOTAL COMBUSTIBLE LOADS	533.8	623.2

2. For the Case of Combustible Loads Present in the Compartment

Flashover is also dependent upon the amount of combustible loads present in the compartment. Especially for the case of dwellings, a large amount of various shapes of combustible materials in general scatters inside the compartment. The progress of fire is controlled by its intensity when the fire spreads over the surfaces of combustible loads such as furnitures. Thus, the time taken to flashover is dependent on the quantity of combustible load and types of construction materials used. The combustibilities of the materials employed greatly affect flashover and as shown in Figures 2 and 3, the degree of deflection for various building materials exposed to fires is noticeably different.

The experiments conducted to simulate office fires in May 1967 aimed to study the relation between smoke generation and internal lining materials. The size of the office used in these experiments was about 10 m^2 and the fires were started by burning wood cribs placed near to a desk and a chair. A remarkable difference in gas composition and concentration of the smoke discharged from the openings of the building was observed as shown in Figures 4 to 6 for using various interior finish materials in spite of insignificant difference in their flashover times (see Figure 7).

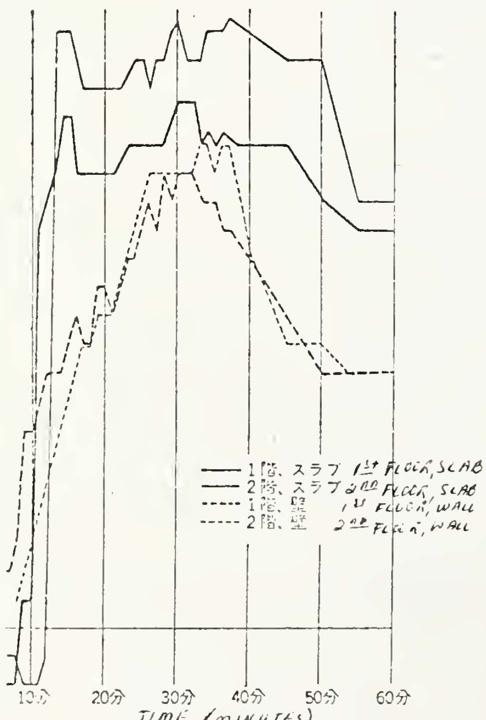


図 2 トランシットによる変形量の測定（第4回実験 内装・合板）
FIGURE 2. DEFLECTIONS MEASURED BY TRANSITS (TEST NO. 4 INTERNAL LININGS, PLYWOOD)

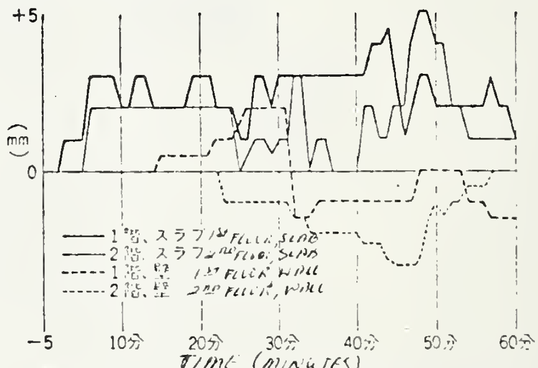


図 3 トランシットによる変形量の測定（第3回実験 内装・石膏ボード）
FIGURE 3. DEFLECTIONS MEASURED BY TRANSITERS (TEST #3, INTERNAL LININGS, GYPSUM BOARD)

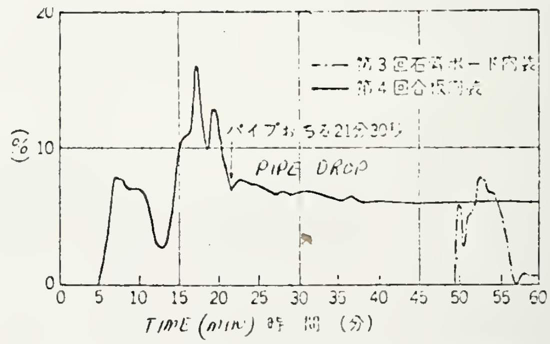


図 4 2階（北側中央床上 150 cm）での CO 濃度
FIGURE 4. C.O. CONCENTRATION IN THE SECOND FLOOR (NORTH SIDE AT THE CENTER WITH 150 cm ABOVE THE FLOOR)

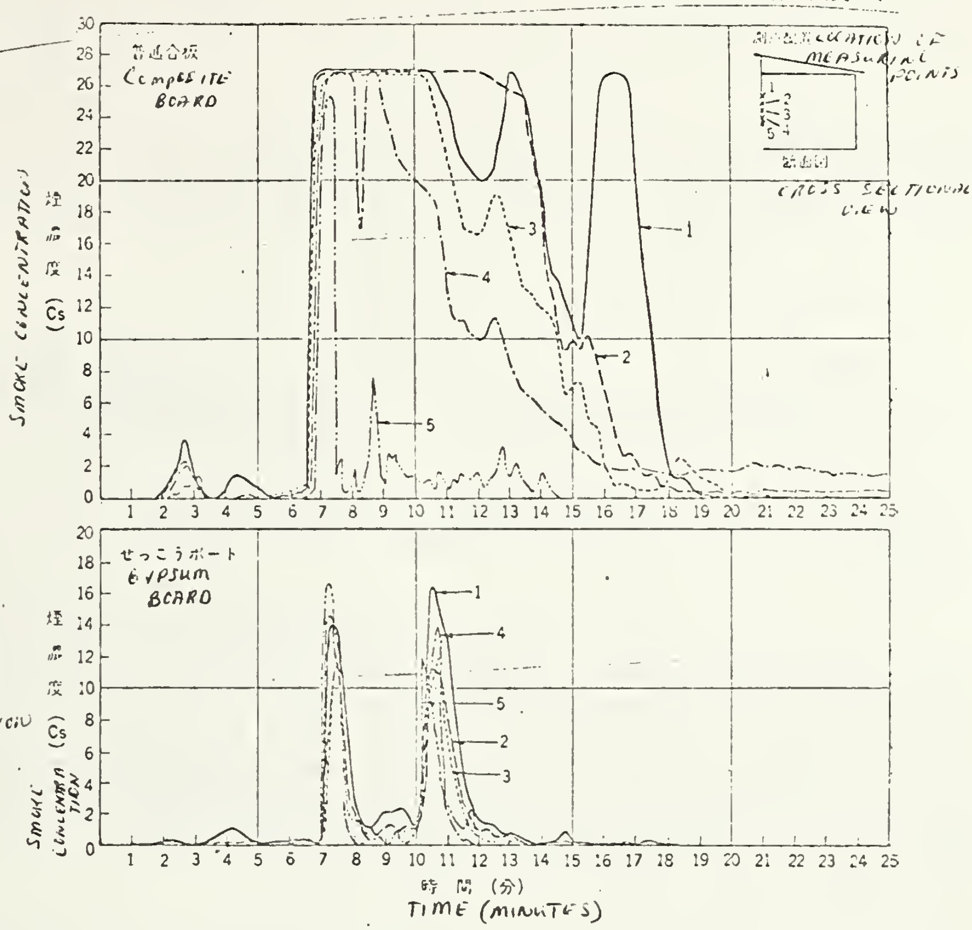


FIGURE 5

図5
煙濃度
SMOKE CONCENTRATION

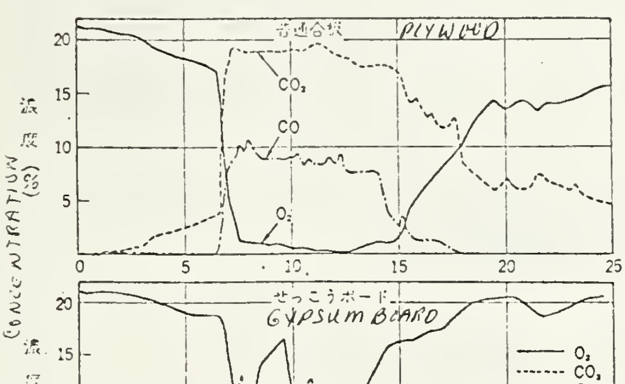


図6 ガス分析
FIGURE 6. GAS ANALYSIS

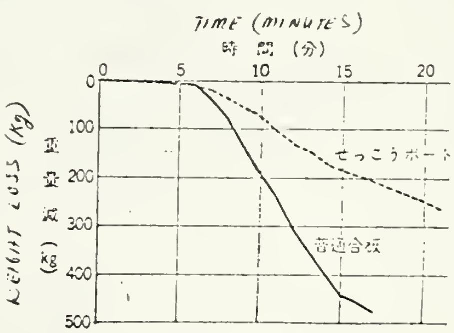


図7 重量変化
FIGURE 7. WEIGHT LOSS CHANGE

Fire Experiments and Internal Lining Materials

From the experiments performed, it can be concluded that free burning fires and combustibility of the material have the following relations:

1. No Combustible Materials in the Fire Room

The flashover time for the case of internal lining materials only existing in the fire room depends upon the combustibility of the material involved, and the ratio of the burning rate of fire source to the exposed surface area of the interior finish materials. According to the classification of fire resistant materials, the material classified above as the partially non-combustible material shows almost no flashover, and a hardly combustible material simply prolongs the flashover time compared with the combustible material.

In the 1968 experiments, the smoke was discharged to the corridor from one side of the compartment, and these discharge rates and diffusion rates inside the building were determined. Figures 8 to 17 show details of the experiments and the rate of smoke generation for various kinds of materials. In the second experiment a PVC flexible board, the total amount of smoke produced tended to be flat when the fire became intensive as shown in Figure 17. Plywood and treated plywood used in No.'s 1 and 4 experiments were completely burned out within 4 to 5 minutes after flashover.

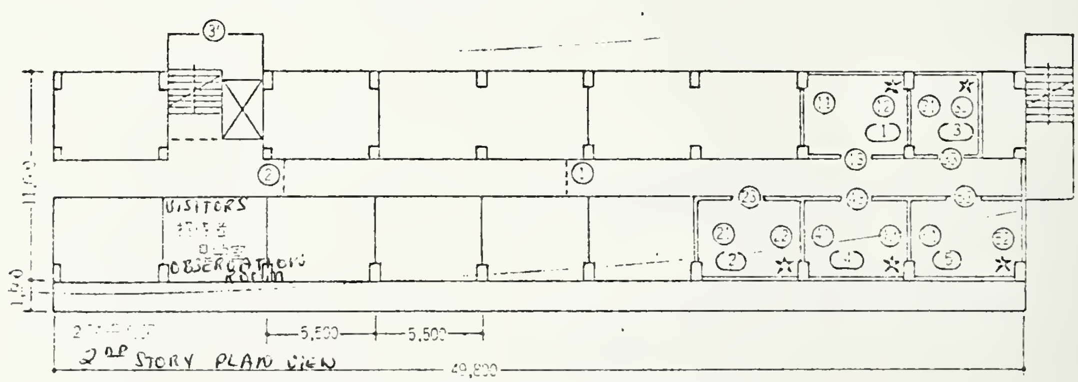


FIGURE 8 図8 実験建物平面図および測定点配置図
PLAN VIEW OF FIELD EXPERIMENT BLDG

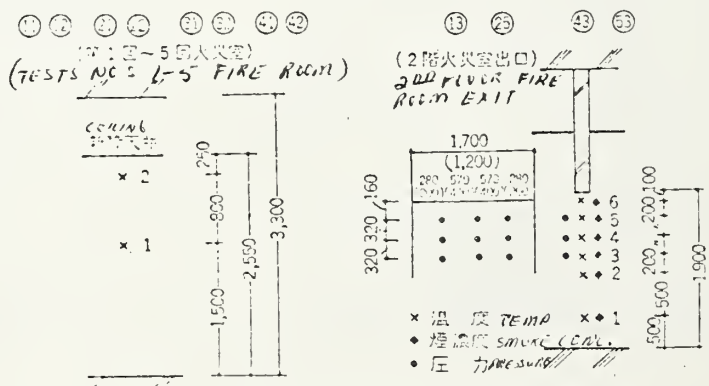


FIGURE 9 LOCATION OF MEASURING POINTS
図9 各測定点位置

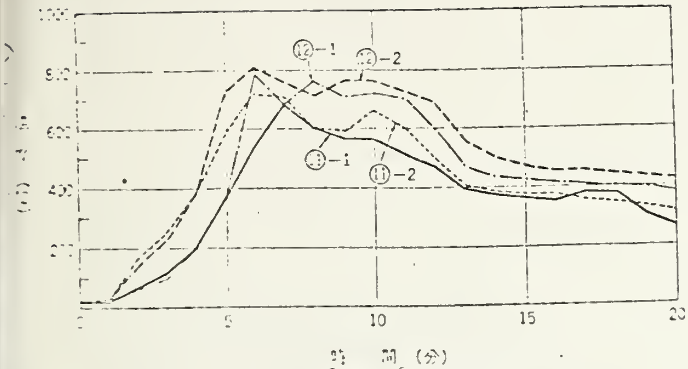


図 10　第1回・火災室・温度（測定点⑪⑫）
FIGURE 10　TEST NO. 1　THE TEMPERATURE IN THE FIRE ROOM. (MEASURING POINTS ⑪ ⑫)

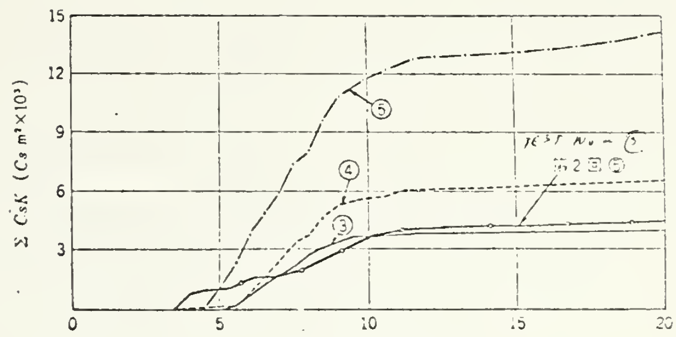


図 14　第1回および第2回実験・高さ別発煙速度
FIG. 14　TEST NO'S 1 and 2, RATES OF SMOKE GENERATION AT DIFFERENT HEIGHTS

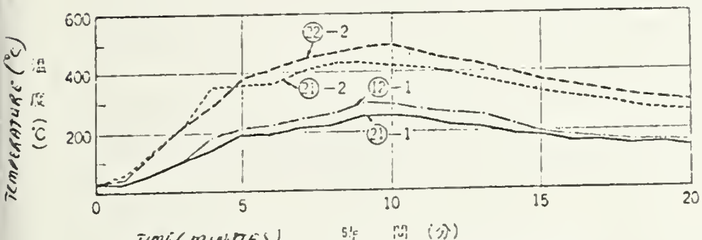


図 11　第2回・火災室・温度（測定点㉑㉒）
FIG. 11　TEST NO. 2　FIRE ROOM TEMPERATURE (MEASURING POINTS ㉑ ㉒)

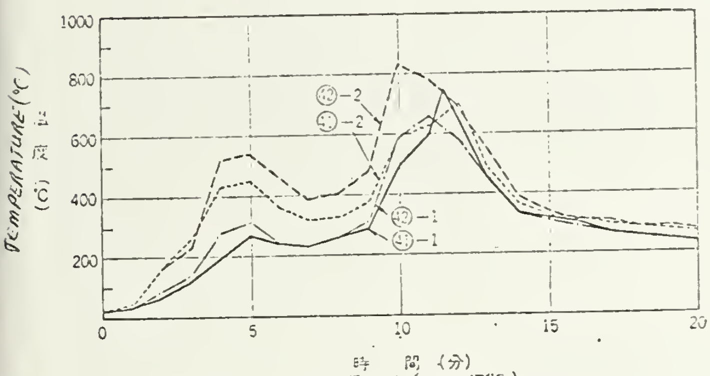


図 12　第4回・火災室・温度（測定点㊶㊷）
FIG. 12.　TEST NO. 4　FIRE ROOM TEMP. (MEASURING POINTS ㊶ & ㊺)

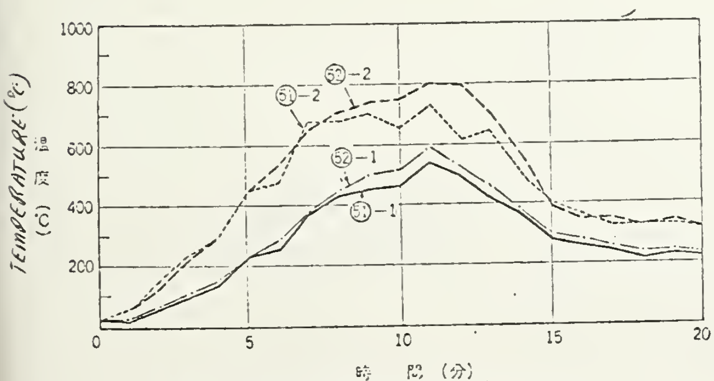


図 13　第5回・火災室・温度（測定点㊿㊾）
FIG. 13　TEST NO. 5　FIRE ROOM TEMP. (MEASURING POINTS 51 & 52)

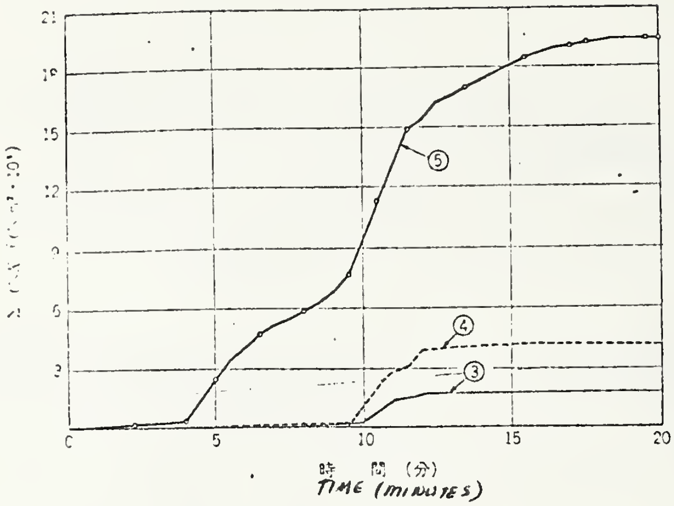
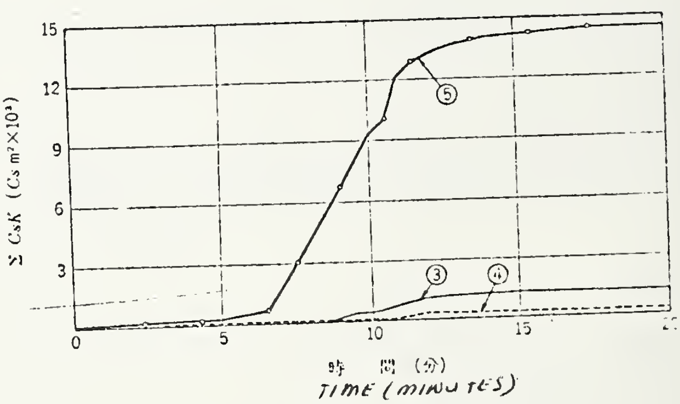


図 15 第4回実験・高さ別発煙速度
FIG. 15 TEST NO. 4, RATE OF SMOKE GENERATION AT DIFFERENT HEIGHTS

図 16 第5回実験・高さ別発煙速度
FIG. 16. - TEST NO. 5, RATE OF SMOKE GENERATION AT DIFFERENT HEIGHTS



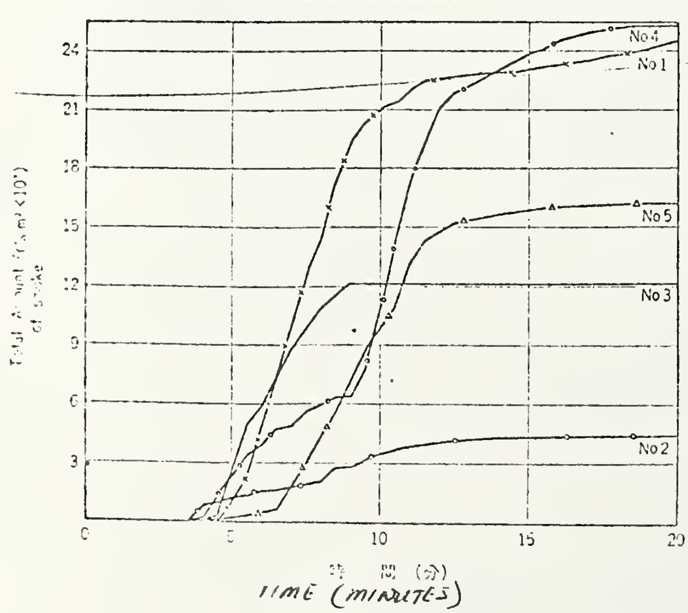


図 17 総 発 煙 量
FIG. 17 TOTAL AMOUNT OF SMOKE GENERATION

2. A Large Amount of Combustible Loads in the Fire Room

The fire experiments in 1965 were conducted on dwellings and the fire was initiated in front of the cabinets. In 1967, the experiments were directed towards the study of office fires and the fire started at the side of a desk. Under both conditions, the time taken to flashover was independent of the position of initiation of the fire and the properties of the materials used since the combustible materials were completely burned out beforehand. Consequently, the internal lining materials which are non-combustible can be expected to have the same results.

The interior finish materials which act as fuels in fires have a tremendous effect on the deflection of the building components. In the present experiment, fire was initiated in the neighborhood of the cabinet where the combustibilities of the materials were difficult to compare. If the fires start at the opposite corner where the comparison of material characteristics is possible, a phenomena of no combustible loads in the fire room can be expected to be present. It can be concluded that the experiments on office fires in 1967 are similar to this case.