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6th Asia-Oceania Symposium on Fire Science and Technology
17-20, March, 2004, Daegu, Korea

A STUDY ON DESIGN FIRES FOR OCCUPANT SAFETY IN OFFICE SURROUNDINGS

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Abstract

The purpose of this study is to grasp the fire load contributed in the initial phase and the fully developed phase of fires and estimate the heat release rates of composite combustibles. In this study, the investigation was conducted covering 6 buildings, 36 sections (total area of 8753.4m^2). In addition, a combustion test was applied to desk unit as a composite combustible, and to the single component composing the desk unit. The results showed that the difference in the mass of combustibles per desk unit is the difference of documents and books, the volume and layout of plastic combustibles provide more effect than that given by the volume of wooden combustibles in the fire growth phase.

1. Introduction

Because of the popularized use of computers and the enhanced employment of regenerative plastic fixtures to reduce environmental load in recent office buildings, the office furniture and the status of combustibles surrounding desks are differing from that of the past investigation into office buildings [1]. However, the characteristics of combustibles in the recent office spaces have not been clarified yet.

Meantime, in performance-based fire safety design of buildings for means of egress, design fires are used for input data in predicting fire hazard. Generally, the design fires for means of egress are often used models based on results of past fire load surveys for the fully developed fire phase about the time series of heat release rates

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accompanied by growing combustion. However, the fire spreading of combustibles at the initial phase is closely related to the type, layout and volume of the combustibles. Therefore, use of the fire load for fully developed fire phase at the initial phase of fires may lead to superfluous evaluation in the fire growth estimation. Especially in the case where composite combustibles like furniture is located in plural numbers, the combustion will accordingly be complicated. To obtain the heat release rates in such case, therefore, it is required to conduct a combustion test by using the actual combustibles in each case. However, a full-scale combustion experiment using combustibles in actual layout will practically be very difficult due to limitation on the expense and experimental device. Under the circumstances, it will be very useful if the burning behavior of composite combustibles can be estimated by using the combustion data of an individual combustible.

In order to grasp the combustibles contributed in the initial phase of fires and estimate the heat release rates of composite combustibles, a combustion test was applied to a desk unit as a composite combustible, and to the single component composing the desk unit. This report outlines the result of fact-finding research on combustibles in office buildings, introduces the combustion test of the desk unit in the working room, estimates the heat release rates of the desk unit and explains the combustion test of single component composing the desk unit. This study was performed as a part of the cooperative study [2][3][4] conducted by Taisei Corporation, Kajima Corporation and Shimizu Corporation to establish the design fires of offices for evacuation safety.

2. Fire Load Surveys in Office Buildings

The purpose of this investigation was to grasp the actual status of the combustibles that contribute in burning at the initial and fully developed phases of fires. The types, dimensions, weight, layouts of typical room application in office buildings were investigated.

2.1 Object of investigation

The investigation was conducted covering 6 buildings, 36 sections (total area of 8753.4m^2) in Tokyo in July ~ Sept., 1999. The application of objective rooms for the investigation was that typically found in office buildings including working rooms, meeting rooms, lunchrooms and libraries.

For the working room, it was estimated that the status of combustibles might differ depending on the working style. Under the circumstances, we divided them into two types for the investigation. One is that to use documents and materials stored in common shelves like in accounting and general affair sections (working room type A), and another is that to use documents by storing them personally like in design and research & development sections (working room type B). As a result, the working room type A counted for 16 sections and the working room type B for 13 sections.

2.2 Calculation method of combustible mass

The degree of contribution to burning differs depending on the storing method of combustibles at the initial phase of fires. In this investigation, it was assumed that the combustibles stored by the steel shelf did not burn at initial phase of fire. For this reason, the combustible mass contributing in burning at the initial and fully developed phases of fires was calculated for each storing status of combustibles respectively. As the plastic combustibles such as personal computers, chairs and the like are of the product mixed with incombustible materials, the weight of combustible part was calculated as 1/2 of the total weight. The fire load density was arranged by two methods shown below.

(1) Fire load density 1: W_1 [kg/m^2]

W_1 is the fire load density without considering the materials of combustibles. W_1 can be calculated by the following equation.

$$W_1 = \sum a_i w / A \qquad (1)$$

where, a_i: Constant corresponding to the storing status of combustible, w: Weight of combustible (kg), A: Sectional floor area (m^2)

(2) Fire load density 2: W_2 [kg/m^2]

The value obtained by converting the weight of plastic combustibles into that of wooden combustibles according to the heat release per unit weight. W_2 can be calculated by the following equation.

$$W_2 = \left(\sum a_i w_w H_w + \sum a_i w_p H_p\right) / AH_w \quad (2)$$

where, H: Heat of combustion (kJ/kg), Subscript w: Wooden combustibles, p: Plastic combustible. Here, H_w was defined as 18.9 (kJ/kg), and H_p as 37.8(kJ/kg), twice of H_w.

2.3 Result of fire load survey

Table 1 shows the fire load density (W_1, W_2) contributing in burning at the initial and fully developed phases of fires per working room.

A difference in the fire load density at the initial and fully developed phases of fires counted for 10kg/m^2 approximately regardless of the form of working styles. This may be caused by the difference of the combustible mass stored in steel furniture.

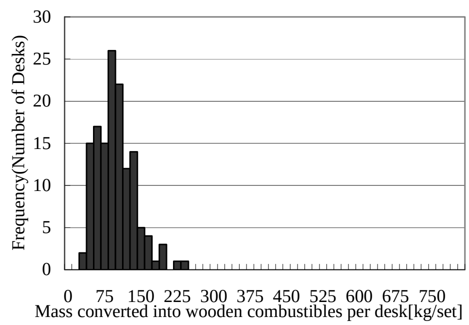
In respect of the difference of working forms, the fire load density of the working room type B is higher than that of the working room type A by about 20kg/m^2.

Table 1. Fire load density (W_1 and W_2)

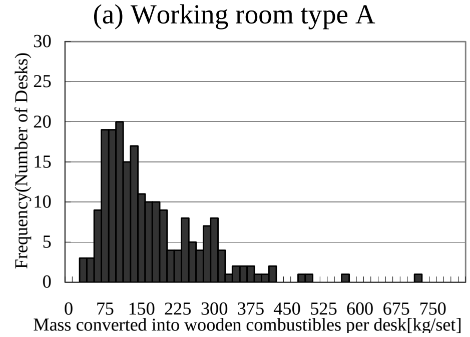
Desk type \ Fire phase		Initial fire (kg/m^2)	Fully developed fire (kg/m^2)	
			This survey	BRI1982[1]
Working room type A	W_1	4.2-18.3 (10.0)	4.4-24.7 (20.0)	-
	W_2	5.7-27.5 (14.0)	6.0-31.3 (24.1)	9.9-18.8 (14.0)
Working room type B	W_1	13.8-49.0 (30.0)	22.7-54.2 (39.0)	-
	W_2	20.2-54.1 (36.0)	28.8-59.6 (45.7)	17.0-30.1 (22.3)

The figure in parenthesis indicates the mean value.

Figure 1 shows a histogram of the weight of combustibles contributing in burning at the fully developed phase of fires. The mass of combustibles represents that converted into wooden combustibles. The mean weight of combustibles per desk unit counted for 90.7kg/set in the working room type A, while for 163.8kg/set in the working room type B.



(a) Working room type A



(b) Working room type B

Figure 1. Weight of combustibles contributing in fully developed phase of fire per desk unit

The standard deviation marked 39.7kg/set for the working room type A, while 104.8kg/set for the working room type B. In the working room type A, the combustible weight per desk unit was less than that in the working room type B and the scattering was also less. Meantime, the area occupied by one set of the desk was $3m^2$. As result of investigation, the desk, the chair, the personal computer, the telephone, etc. were existed respectively in each desk. This means the difference in the mass of combustibles per desk unit was caused by the amount of documents and the books.

Table 2 shows a ratio of plastic combustible to all combustibles in the investigated sections, and that of OA equipment (Computer unit, monitor and peripheral equipment) to the plastic combustible. Among the plastic combustible, OA equipment occupied more than 40% indicating a large portion.

Table 2. Ratio of plastic combustibles in working rooms

Desk type \ Fire phase		Initial fire (%)	Fully developed fire (%)
Working room type A	R_1	42.0	21.0
	R_2	41.0	41.7
Working room type B	R_1	29.1	17.3
	R_2	57.1	52.1

R1: A ratio of plastic combustibles to total mass of combustibles
R2: A ratio of OA occupying in plastic combustibles

Table 1 shows the result of survey on office fire load conducted by Building Research Institute of Ministry of Construction. (Hereafter called BRI1982. [1])

Compared to BRI1982 survey, the fire load has increased in the present survey. The reason of this may be as follows. The BRI1982 survey reported that a ratio of plastic combustible to the total combustibles counts for about 5% even at most. As observed from Table 2, however, plastic combustible has increased recently due to the popularization of OA equipment allowing a person to own a computer, and plastic made office furniture are used frequently in addition.

When the fire load is summed up by the conventional calculation method of combustibles [1], the survey result of this time indicates an increasing trend due to the popularization of OA equipment. However, it will be difficult to consider that the increased fire load directly causes a risk to generate fires. Under the circumstances, the authors wish to evaluate the degree of contribution in burning by conducting combustion tests of typical combustibles inside working spaces.

3. Burning behavior of typical offic e furniture

In order to grasp the burning behavior of combustibles in office working spaces at the initial phase of fires, combustion tests were applied to the working desk unit consisting of a desk, chair, computer, and documents (hereinafter called the composite combustion test). To examine the possible estimation of burning behaviors in addition, combustion tests were applied to the single combustible component composing the desk unit (hereinafter called the single combustion test).

3.1 Description of experiments

3.1.1 Test facility

The combustion tests were conducted by using the combustion test facility as shown in Figure 2.

The hood to measure heat release rates by the method of oxygen consumption calorimetry was of a square shape with a side of 3.0m approximately, and a 0.9m deep drop wall was installed below the hood to prevent combustion products from flowing out at the test. To measure the mass loss of combustibles, a load cell was installed at the 4 corners of the test table.

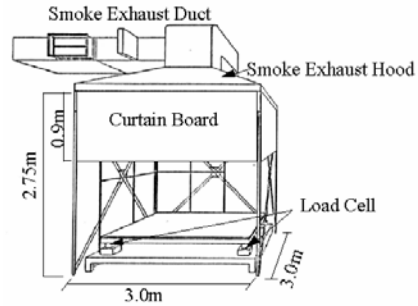


Figure 2. Test facility

3.1.2 Instrumentation

With a purpose to measure the heat release rates by the method of oxygen consumption calorimetry, the concentration of oxygen, carbon dioxide CO_2, and carbon monoxide CO inside the duct were measured. For the air temperature inside the duct, 3 points were measured in vertical direction by thermocouples, and the averaged value of 3 points was employed for the temperature inside the duct. The air velocity inside the duct was measured with a micro-manometer through a bi-directional pilot tube. The mass loss rate was also measured with the load cell. For the measurement of radiation from the fire source, 4 sets of radiometer were used. The installation position of the radiometer was changed for each combustible material.

3.1.3 Condition of Specimen

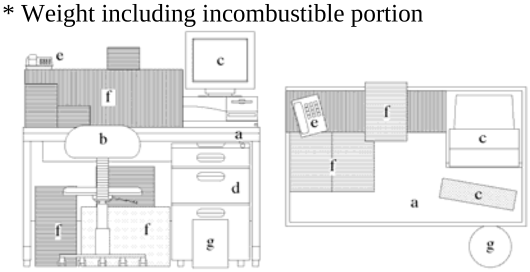
The specimen used in the composite combustion test is shown in Table 3 and Figure 3 respectively. The configuration of the composite combustion test was set according to the investigation of combustibles described in the former chapter. The Desk unit A shown here represents the type with much combustibles of the working room type B, and the Desk unit B represents the type with a few combustibles of the working room type B. The main difference between two types of desk units was the quantity of papers (Desk unit A:140kg, Desk unit B:55kg), the chair and the CRT. The specimen applied with the single combustion test is shown in Table 4.

Meantime, the specimen with same specifications was used for both composite and single combustion tests in principle.

Table 3. Items of combustible materials in a Desk unit

Kind of Items			Weight* (kg) Desk unit A	Weight* (kg) Desk unit B
a	Desk		34.4	34.4
b	Low back chair without armrest 2		7	-
	Low back chair with armrest		-	15.2
c	Computer and CRT	CRT (15 inch)	20.4	-
		CRT (17 inch)	-	34.4
d	Desk wagon		22.9	22.9
e	Telephone		0.7	1.2
f	Paper of files		140	55
g	Trash basket		0.5	0.5
Total weight (kg)			225.9	163.6

* Weight including incombustible portion



(a) Elevation view (b) Plan view

Figure 3. Layout of Desk unit A

Table 4. Condition of specimens for a single combustion test

Combustible Materials	Weight[1] (kg)	Size (m) Wide	Size (m) Long	Size (m) Height	Main materials	Location of fire ignition
Low back chair without armrest 1	11.1	0.45	0.4[2]	0.73	Polyurethane foam padded, Synthetic Resin-frame	Under a chair
Low back chair without armrest 2	7.0	0.4	0.38[2]	Out of data	Polyurethane foam padded, Synthetic Resin-frame	Under a chair
Low back chair with armrest	15.7	0.45	0.4[2]	0.75	Polyurethane foam padded, Synthetic Resin-frame	Under a chair
Desk	34.4	1.2	0.7	0.7	Metal-frame, melamine resin overlaid board ABS and PVC used in part	Under a desk
Computer	9.9	0.36	0.43	0.13	Synthetic Resin Covering	Side of a Computer
CRT (15inch)	13.5	0.37	0.38	0.39	Synthetic Resin Covering	Side of a CRT
Desk wagon	22.9	0.4	0.58	0.63	Metal-frame covered in ABS	Front of a desk wagon

1) Weight including incombustible portion
2) Length of seat surface

3.1.4 Test procedure

(1) Fire ignition

Referring to the cause of fires in recent offices listed on the fire statistics, the trash basket fire caused by a disposed cigarette, showing a high ratio of fires next to incendiary fires, was estimated. The trash basket was of polypropylene made (capacity of 7.4 litter), and ignited by putting a piece of methanol solid fuel of 7.5g. For the filling inside the trash basket, corrugated cardboard of 0.2kg was set by referring to the survey result of the office being investigated for combustibles. In the past full-scale test [5], a gas burner (50kW- for 200 seconds) was used as an ignition source. This gas burner was so modeled that to supply heat for the same degree when the trash basket is burnt.

The peak heat release rate of the trash basket used as the ignition source this time counted for about 50kW, and the total heat release for about 11.0 MJ. These values have no significant difference with that shown in the existing studies. In the single combustion test, the trash basket was installed at the position shown in Table 4. While in the composite combustion test, the trash basket of the ignition source was installed in front of the desk wagon.

(2) External radiation

In order to grasp the difference of the burning behavior when the radiation heat is applied from other combustibles, the single combustion test with the external radiation was conducted also. For the external radiation, about 2kW/m^2 was applied to the specimen by assuming a substance with a large heat amount existing in offices frequently (i.e. low back chair without armrest 1). To apply a constant heat to the specimen in the test, two pieces of ceramic board damped with kerosene are inserted into three steel vessels (0.32m x 0.32m, 0.15m deep) respectively and are burnt outside of the hood. The combustion of kerosene reached steady-state within 1 minute after igniting, and continued combustion for about 8 - 9 minutes.

3.2 Results of experiments

3.2.1 Composite combustion tests

Table 5 shows the visual observation record of burning status for Desk unit A and B. Figure 4 shows time series of the heat release rate for Desk unit A and B.

Under the present configuration of desk units, the route of fire spreading was in the order of the trash basket, the wagon, the chair and the computer, for both Desk units A and B, spreading to the combustibles using plastic material. Fire spreading to the documents was observed at the peak combustion of the Desk unit after the burning of the computer. The heat release rate decreased when the surface area in vertical direction was reduced after the breaking down of combustibles. At both Desk units A and B, the surrounding of documents was burnt but the internal portion remained being not burnt. Since the fire was watered and extinguished, the mass of the documents after the experiment of Desk unit A and B has not been measured.

Table 5. Fire spreading process visually observed

Time from ignition	Desk unit A
300 sec	Desk wagon front surface burnt. [Flame height 0.6m approx.]
320 sec	Fire spread to key board
330 sec	Fire spread to chair seat side
450 sec	Fire spread from desk wagon rear surface to PC body
510 sec	Chair fallen down, fire spread to CRT, documents on desks
598 sec	Entire Desk Unit burnt with the maximum heat release rate of 919kW [Flame height over 2.5m]
Time from ignition	**Desk unit B**
300 sec	Desk wagon front surface burnt [Flame height 0.8m approx.]
350 sec	Fire spread to chair leg
390 sec	Fire spread to chair seat surface, keyboard
450 sec	Fire spread to CRT
556 sec	Entire Desk Unit burnt with the maximum heat release rate of 2117kW [Flame height over 2.5m]
566 sec	Chair back dropped

The peak heat release rate of Desk unit A counted for 919kW, while Desk unit B for 2117kW. The Desk unit B had less documents than that of Desk unit A but owned much plastic materials of chairs and the CRT with a larger surface area. From this, it can be found that the effect of plastic materials is larger than that of documents locating on desks in the initial phase of fires.

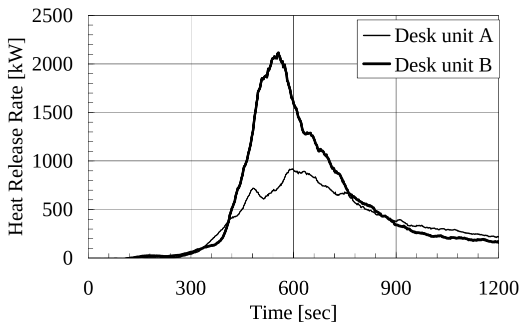


Figure 4. Heat release rate for Desk unit A and B

3.2.2 Single combustion tests

Figures 5 - 10 show the time series of heat release rates in the tests for a low back chair without armrest, that with armrest, a desk wagon, a desk, a computer and 15' CRT. In Figures 5 - 10, note that a point of the time inserting a piece of methanol solid fuel into the trash basket is representing 0 second. Table 6 shows the lag time to ignite each specimen from the ignition source t_0, maximum heat release rate Q_{max} and its time required t_{max}

(1) Chair (Figures 5, 6)

With the chair, the plastic material of the legs and seat rear surface was burnt firstly and the entire seat surface was enveloped in flames. After then, the flame spread abruptly along the back, leading to the combustion of the entire chair. The peak heat release rate was recorded at the time when the entire chair was burnt, and after then, the heat release rate reduced promptly upon falling down of the back and leg of the chair. The low back chair with armrest showed about 800kW for the peak heat release rate, which is 2.6 times that of the low back chair without armrest 2. This may be caused by the difference of the volume and surface area of used plastic material. The flame height of the low back chair with armrest marked the maximum reaching the ceiling of the experimental facility when the back of the chair was existed. Compared with other furniture surrounding the working desk, the time required to ignite is shorter, the peak heat release rate is higher and the time reaching the peak heat release rate is shorter in the case of the chair stuffed with polyurethane foam padded, plastic material frame. Therefore it can be judged as a combustible material giving the most serious effect in spreading fires among the combustibles surrounding working desks.

(2) Desk wagon and Desk (Figures 7, 8)

The desk wagon was regarded as incombustible material under the investigation. Although the fire growth rate is small compared with that of the chairs, it was burnt under the heat release rate of about 350kW. The plastic material coated on the wagon surface was firstly ignited and then the front part of wagon was burnt. Then the combustible ceiling plate at the desk wagon upper surface (about 1kg) was burnt, recording the most high heat release rate. The height of the flame marked over 2m. As same as the desk wagon, a combustible material is used for the ceiling plate of desks, however, the enlargement of combustion was not caused with the fire source of the trash basket.

(3) Computer and CRT (Figures 9, 10)

The ignition of computers and CRTs required a considerable time. For the computer, a contacting portion was only melted by the ignition source of the trash basket. For the CRT, the circumference composed with plastic material was burnt for about 2.0kg but the peak heat release rate was low.

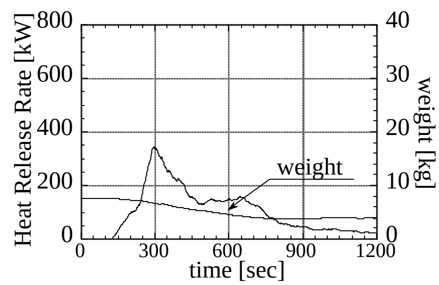


Figure 5. Low back chair without armrest 2

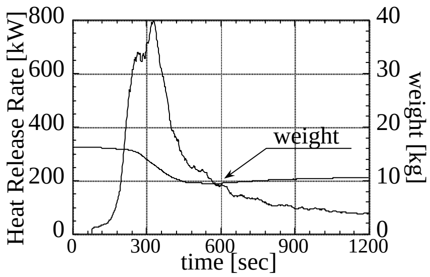


Figure 6. Low back chair with armrest

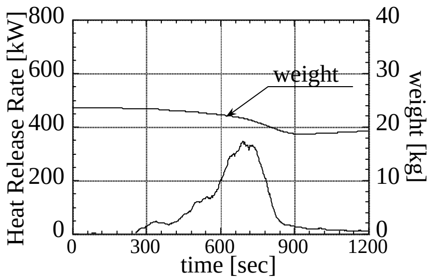


Figure 7. Desk wagon

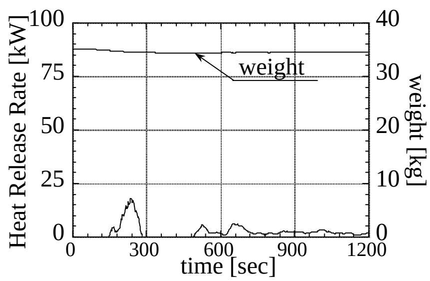


Figure 8. Desk

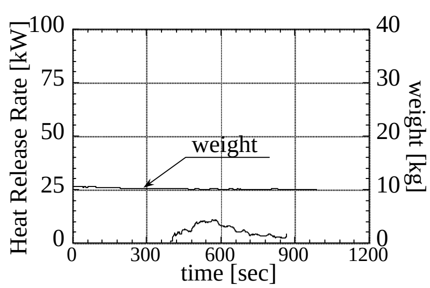


Figure 9. Computer

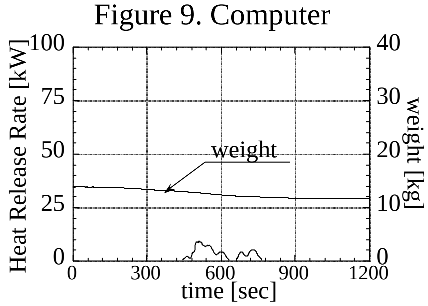


Figure 10. CRT (15inch)

Table 6. t_0, Q_{max} and t_{max} in single combustion test

Combustible Materials		t_0 (sec)	Q_{max} (kW)	t_{max} (sec)
Low back chair without armrest 1	Without external radiation	130	540	356
	With external radiation	90	758	342
Low back chair without armrest 2		120	310	296
Low back chair with armrest		76	797	326
Desk		144	18	236
Computer		396	11	564
CRT (15inch)		444	9	510
Desk wagon		254	349	688

(4) Comparison of heat release rate with external radiation and without

Figure 11 shows the difference of heat release rate of the low back without armrest 1 caused by the presence of external radiation. With the external radiation, the time reaching the peak heat release rate counted for 342 seconds, while without external radiation, it counted for 356 seconds, somewhat earlier. The difference of the peak heat release rates was 176kW (about 1.3 times). The combustion up to about 360 seconds was accelerated by external radiation until the chair is deformed.

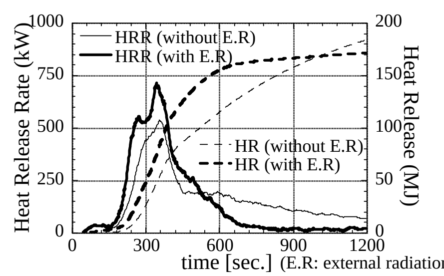


Figure 11. Difference of heat release rate of the low back chair without armrest 1 caused by external radiation

3.3 Discussion

3.3.1 Study on estimated burning behavior of desk unit

The estimation of the heat release rate of composite combustibles was studied by using the heat release rate obtained by burning single combustible components. The study was conducted on both Desk units A and B in this report.

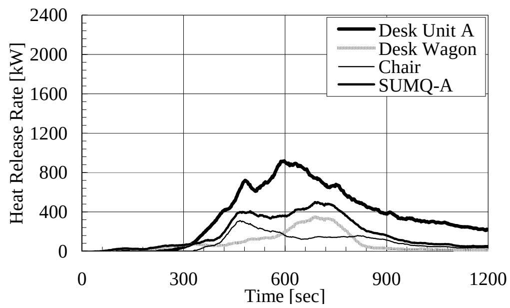
As shown in Equation (3), the heat release rate of single combustible components was integrated by considering the ignition time delay for each combustible component here. (Hereinafter, this integrated value is called SUMQ.) For the ignition time to each combustible component, the time read from the photo in each test was employed. In the integration of the heat release rates for prediction of fire behavior at initial fire phase, we decided to use the plastic combustibles of influence greatly at an early fire. However, the heat release rates of the desk, the computer, the CRT and the telephone set not mostly burnt were excluded from this calculation. On the other hand, what is considered not to contribute to initial fire phase, such as documents, decided not to include. The result is shown in Figure 12.

$$Q(t) = \sum Q_i (t - t_{i0}) \qquad (3)$$

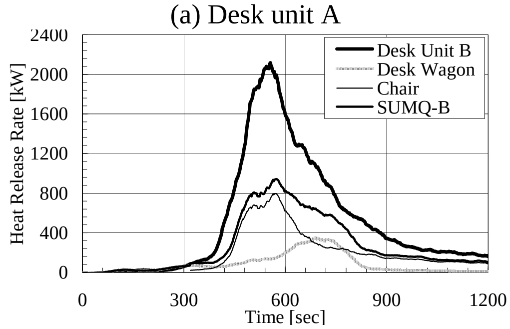
where Q: Heat release rate (kW)、t: Time elapsed after ignition(sec), t_{i0}: Time of ignition to combustibles i(sec)

When plural combustibles are located, other combustible materials than that firstly ignited are burnt due to the radiation heat received. In the composite combustion test, it is presumed that the heat release rate becomes large due to the radiation heat from plural combustible materials and the stay of the heat resulting from an arrangement situation. In the composite combustion test, the peak heat release rate of Desk unit A showed 919kW (598 sec), while SUMQ-A 499kW (696 sec) and Desk unit B showed 2117kW (556 sec), while SUMQ-B 1091kW (574 sec). The peak heat release rate obtained from the composite combustion test doubled the integrated value of the heat release rate of the single combustion test approximately. The total heat release showed a difference exceeding the value doubled.

In the composite combustion test, it was presumed that the total heat release increased as compared with SUMQ because of the computer, the desk and documents burnt completely, but were not almost burnt in single combustion test. In order to predict the fire growth of the composite combustibles with more sufficient accuracy, it will be required to carry out by the experiments repeatedly in consideration of conditions, such as a source of ignition and the external radiation, and to fix the combustion data of the single combustible components.



(a) Desk unit A



(b) Desk unit B

Figure 12. Heat release rates for the Desk units and SUMQ

4. Conclusion

Through the fire load surveys in the office buildings and the combustion tests on the typical office furniture in working spaces, the following items were clarified.

1) The volume of plastic combustibles in working rooms has increased from that investigated similarly in 1982 due to the popularized use of OA equipments.

2) The great portion of wooden combustibles, such as documents, burned and remained. In the initial phase of fires, the volume and layout of plastic combustibles provide more effective than that given by the volume of wooden

combustibles. Therefore, estimating the burning behavior in the initial phase of fires only based on the volume of wooden combustibles may lead to over estimation.

3) To estimate the burning behavior of combustibles placed in composite locations by using the combustion data of the each composing element, it is required to grasp the acceleration of burning by the radiation and obtain the data of the heat release of the computers and the like that were not burnt in the present test.

The further research will be needed to obtain the experimental data of which the conditions such as source of ignition and the external radiation will be changed gradually as well as the maintenance of the combustibles combustion data in order to predict the burning behavior of composite combustibles.

ACKNOWLEDGMENT

The authors wish to express our thanks to Professor T. Wakamatsu, Professor O. Sugawa, Lecturer K. Matsuyama, and Graduate student at the time of testing, N. Nakamura, of Tokyo University of Science for their support and assistance.

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