Design Fires for Means of Egress in Office Buildings based on Full-scale Fire Experiments

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ABSTRACT

In performance-based fire safety design for means of egress, t-squared heat release rates have been used as design fires. In order to estimate fire growth rates in office rooms, eleven full-scale fire experiments were conducted for typical office arrangements. They included cases with and without suppression. Typical office arrangements were modeled based on fuel load surveys in contemporary office buildings. The results of experiments clarified that: 1) fire growth in office rooms largely depends on the combustion of plastic materials, which are commonly used in office fuel packages; and 2) In the case of quick response sprinkler operation, HRRs continued to be approximately 200 kW during suppression.

We estimated fire growth rates for all experimental cases by modeling the t-squared fires and examined the effects of parameters on fire growth rates. We compared the results of experiments with several design fires in the engineering design guidelines and discussed design fires for office buildings. Fire growth rates for office desk units range from 0.007 to 0.017 kW/s^2, that are close to the 'medium' fire growth in NFPA 92B. Heat release rate curves with suppression are almost included within the design fire that was proposed by Lougheed, even if only one sprinkler head was activated.

KEY WORDS: design fire, fire growth rate, office building, full-scale experiments, heat release rate

INTRODUCTION

Recent changes in office furniture and equipment have raised concerns about fuel loads in office rooms, mainly caused by the spread of computer networks in office buildings. In performance-based fire safety design of buildings, t-squared design fires for fire growth have been often used (for example, [1], [2], [3]). Design fires are used as input data in predicting fire hazards, and play an important role in checking sufficiency of means of egress and/or smoke management systems.

Fire growth rates largely depend on the spread of fire among combustibles and are closely related with the amount, quality, and arrangements of combustibles. For performance-based fire safety design of buildings, it is very important to examine fire growth rates in accordance with the geometry and occupancies of buildings.

Requirements for design fires are established in several engineering design guidelines, for example, NFPA 92B [1], British Standard Institution (BSI) DD240 [2], and Ministry of Construction in Japan (MOC) [3]. Fire growth rates in design fires are mainly based on full-scale fire experiments of various commodities. In order to examine the fire behavior of office combustibles, Madrzykowski [4,5] conducted full-scale fire experiments for a single work station in an office. These studies were intended to predict the peak heat release rate of an office work station with cone calorimeter data, and to develop a fire suppression algorithm. Lougheed [6] also conducted full-scale fire experiments of work stations in open plan offices and proposed a design fire for sprinklered office buildings in the design of smoke management systems.

The main purpose of this paper is to investigate fire behavior during the fire growth phase in contemporary office workplaces and to discuss design fires for office buildings in designing means of egress. To accomplish this goal, eleven full-scale fire experiments were conducted for typical office combustible arrangements. We estimated fire growth rates for all experimental cases by fitting the t-squared fires and examined the effects of experimental parameters on fire growth rates. Furthermore, we compared fire growth rates obtained from the experiments with several design fires in the engineering design guidelines.

DESCRIPTION OF EXPERIMENTS

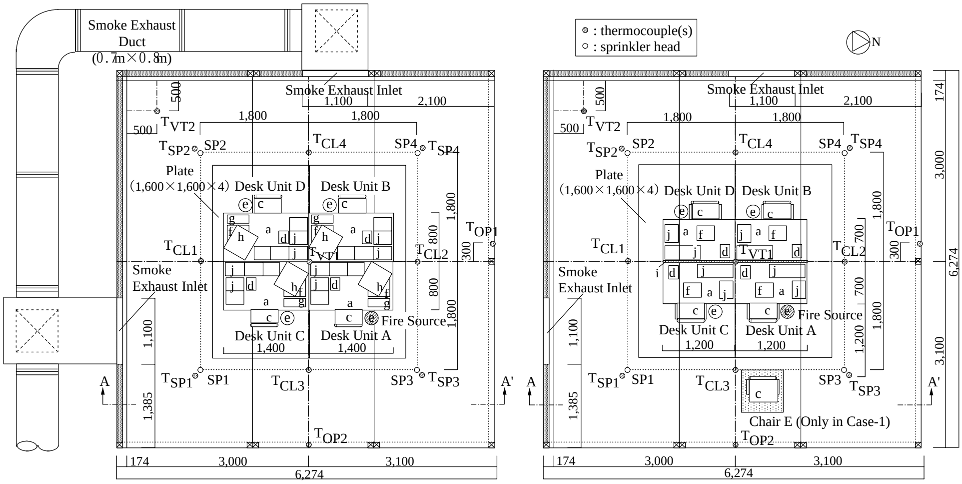
Test Facility

Figures 1 and 2 illustrate schematics of a test facility, which is located at a large-scale test facility in National Research Institute of Fire and Disaster (NRIFD). The compartment had a square floor area of 36 m^2 and the average ceiling height was approximately 2.3 m. The floor was shielded by steel panels and sloped toward the west wall at an angle of 2 degrees so that water would be collected by the drain ditch, which was installed at the bottom of the west wall. The south and west sides of the facility had composite walls which consisted of steel panels, mineral fiber insulation and stainless steel panels. In order to provide air for ventilation, the north and east sides of the facility had openings 1.4 m high from the floor level and stainless steel curtain boards of 0.9 m below the ceiling. A mechanical exhaust system was connected to the compartment with a duct. Two exhaust inlets (1.1 m wide, 0.6 m high) were installed at the south and west sides of the walls below the ceiling.

Four quick response sprinkler heads were installed under the ceiling of the compartment. Nominal operation temperature of a sprinkler head is 72^{o}C and the response time index (RTI) is approximately $33m^{1/2}s^{1/2}$. The locations of the sprinklers are shown in Figures 1 and 2. Water discharge was set at the pressure of 100 kPa. Water flow rate per a sprinkler head was adjusted to 80 L/min to meet the requirements of the Fire Service Law of Japan.

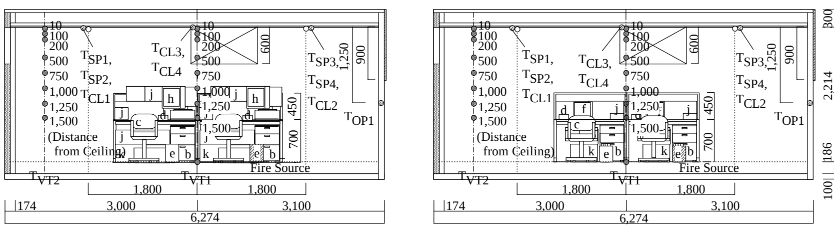
Instrumentation

In order to estimate heat release rates by the method of oxygen consumption calorimetry, a gas-sampling tube for measuring CO, CO_2 and O_2 concentrations was installed in the duct, which was located at approximately 8 m from the nearest exhaust inlet. A thermocouple and a hygrometer were installed in the duct near the gas sampling tube. Air flow velocity in the duct was measured by a Pitot velocity probe.



(a) Engineering Desk Units (b) Clerical Desk Units

Figure 1. Plan View of the Test Facility



(a) Engineering Desk Units (b) Clerical Desk Units

Figure 2. Section View of the Test Facility（A-A’ Section in Fig.1）

The exhaust fan was operated at 30,000m^3/h. The lag time for sampling gases and for analyzing gas concentration by gas analyzer was corrected in estimating the heat release rate. The lag time was determined to be 70 seconds from the results of the operation test of the gas analyzer and the calibration test of free-burn of normal-heptanes, which were conducted before the experiments.

Two thermocouple trees, with eight or nine thermocouples each were located at the center and the south-west corner of the compartment (Figures 1 and 2). Four thermocouples were located at the ceiling near the four sprinkler heads. All data were recorded in a computer every second via a data recorder.

Fuel Packages

Fuel load surveys for six office buildings (8,758 m^2 in total) were conducted to quantify the amounts of combustibles in office workplaces [7]. Typical fuel packages for desk units were identified from the results. Typical desk units were classified into two types: the 'engineering desk unit' and the 'clerical desk unit'. In this paper, the 'engineering desk unit' means one that is used for design or R&D, whereas the 'clerical desk unit' means one that is used for general affairs or finance.

Table 1 describes items for each type of desk unit. The differences of items between the two types of desk units were: (1) armrests of chairs, (2) types of computer (desktop or laptop), and (3) amounts of papers. Office furniture, such as desks and chairs, consists of mainly plastic materials that are commonly used in contemporary office workplaces. In order to examine the effect of desk materials on fire behavior, a steel composite desk, which was joined with the desk wagon, was used in one of the cases. The amounts of paper were determined based on the fuel load surveys [7] and they correspond to approximately mean $+2\sigma$ values for each type of desk unit. A fuel load density of paper files was 46.2 kg per file meter of A4 sheets on average.

The existence of the desk partitions was considered as one of the experimental parameters. Desk partitions, 0.45 m high, were installed on the desk. They consisted of metal-framed honeycomb corrugated paper with wooden panel and acrylic fabric.

Table 1. Items of Combustible Materials in Single Desk Unit

Kinds of Items			Size in meters			Engineering Desk Unit		Clerical Desk Unit	
			Wide	Long	Height	Num.	Weight in kg	Num.	Weight in kg
a	Desk with metal-frame, melamine resin overlaid board ABS and PVC used in part		1.4	0.8	0.7	1	42.1	---	---
			1.2	0.7	0.7	---	---	1	35.4
a’	Desk with metal-frame (in Case-14)		1.06	0.635	0.74	(1) [c]	(41.0) [c]	---	---
b	Desk wagon with metal-frame [a]		0.4	0.6	0.62	1	23.9	1	23.9
c	Low back chair with polyurethane foam padding covered with acrylic fabric [b]	Without armrests	0.45	0.54	0.75	1	11.1	---	---
		With armrests				---	---	1	13.9
d	Telephone		0.22	0.16	0.085	1	0.7	1	0.7
e	Polypropylene trash basket (8.0L) with 13 pieces of corrugated paper		0.214ϕ		0.275	1	0.6	1	0.6
f	Computer	Desktop type	0.4	0.4	0.15	1	11.0	---	---
		Laptop type	0.3	0.23	0.05	---	---	1	3.0
g	Keyboard		0.45	0.16	0.03	1	1.2	---	---
h	CRT（17 inch）		0.45	0.4	0.4	1	18.0	---	---
i	Desk partition with metal-frame, honeycomb corrugated paper covered with wooden panel and fire-retarded acrylic fabric		---	---	0.45	1	8.0	---	---
						---	---	1	7.0
j	Paper for files	On the desk	---	---	---	---	55	---	25
		Under the desk	---	---	---	---	55	---	10
		In the wagon	---	---	---	---	15	---	15
k	Corrugated paper box with papers (under the desk)		0.45	0.32	0.3	2	30	1	15
Total weight (in kg)			Without desk partition			---	263.6 (262.5) [c]	---	142.5
			With desk partition			---	271.6	---	149.3
Exposed surface area of combustibles (in m^2) (plastic / cellulose materials) [d]			Without desk partition			3.80/ 4.23 (2.78/ 4.23) [c]		2.57/ 2.39	
			With desk partition			4.77/ 3.94		3.52/ 2.26	

a. Top panel of a wagon is made of polystyrene. Front panels of drawers are made of ABS resin.
b. Legs of a chair are made of nylon resin. Armrests are made of polypropylene resin.
c. Numbers in parentheses express values in Case-14.
d. Plastic materials indicate items from ‘a’ to ‘i’, and cellulose materials indicate items ‘j’ and ‘k’.

Full-scale fire experiments were conducted for eleven cases. Table 2 shows the test conditions for the experimental parameters: types of desk unit, and numbers of desk units, desk partitions and sprinkler suppression. Figures 1 and 2 show examples of combustible arrangements for four engineering and clerical desk units. In the cases of four desk units, the units were set facing each other in accordance with typical office arrangements in Japan. Four desk units were located at the center of the four sprinklers. In the cases of a single desk unit, the unit was set at the place of desk unit A in Figure 1. Only in Case-1, an additional chair was set at the back of the chair of desk unit A to examine the spread of fire to the back of the desk unit from a fire source.

Test Procedure

A polypropylene trash basket was used as the fire source, because approximately thirty percent of fires in office rooms start in paper trash or paper materials according to Japanese fire statistics [8]. The trash basket was set in front of the desk wagon at a distance of 0.1m (Figure 1). In the trash basket, thirteen pieces of corrugated paper (0.1m wide, 0.3m long) with a total weight of 0.2kg were placed, because amount of paper trash from office buildings was found to be almost 0.2kg/day/person on average from the results of fuel load surveys in office buildings [7]. A piece of methanol solid fuel of 7.5g, having a combustion duration of approximately five minutes, was used as the ignition source of the trash basket. At the start of the experiments, a piece of ignited solid fuel was placed in the trash basket of desk unit A. The peak heat release rate of the polypropylene trash basket by itself was approximately 50 to 60kW

In the case of sprinkler operation, only sprinkler head No.3, the nearest to desk unit A, was operated automatically due to the temperature rise of the sprinkler head. Operation of the other heads was prohibited by shutting off the valves to simulate more dangerous situation. Water was supplied for twenty minutes after sprinkler activation according to the requirement of the Fire Service Law of Japan. Average water flow density was 2.53 L/min/m^2 on the desk of desk unit A, which was measured prior to the experiments.

Table 2. Condition and Results of Experiments

Case No.	Experiments Condition				Results of Experiments [c]				
	Type of Desk unit [a]	Num. of Desk Unit	Partition	Sprinkler Activation	Q_{max} (kW)	t_{max} (sec)	Q_{SP} (kW)	t_{SP} (sec)	T_{SP} (°C)
1	C	4 [b]	---	---	3,035	508	---	---	---
2	C	4	O	---	2,476	616	---	---	---
3	E	4	---	---	2,957	793	---	---	---
4	E	4	O	---	2,271	732	---	---	---
5	C	4	---	O	771	500	470	255	101.5
6	C	4	O	O	408	286	390	281	97.9
7	E	4	---	O	281	255	260	250	95.9
8	E	4	O	O	378	271	290	259	90.1
11	E	1	---	---	1,602	441	---	---	---
12	E	1	O	---	1,870	412	---	---	---
14	E	1	---	---	1,219	601	---	---	---

a. Type of Desk Unit: 'E' expresses engineering desk unit. 'C' expresses clerical desk unit.

b. Only in case-1, an additional chair E (see Fig.-1) was arranged.

c. Q_{max} : Maximum HRR (kW), t_{max} : Time to reach maximum HRR (sec.)

Q_{SP} : HRR at sprinkler activation (kW), t_{SP} : Time at sprinkler activation (sec.)

T_{SP} : Temperature below the ceiling at the nearest point of sprinkler head No.3 (^{o}C)

RESULT OF EXPERIMENTS

Fire Behavior in Free-burn Experiments

Table 3 shows how the fire spread for the engineering desk unit (Case-3), which was obtained by visual observation. In Table 3, heat release rates were derived from data by oxygen consumption calorimetry. From visual observation, the desk wagon started to burn two minutes after ignition, then flames spread to the keyboard, the chair, and the CRT monitor. In all cases, the chair in desk unit A caught the fire from 180 to 255 seconds after ignition. Once the chair caught fire, the heat release rate increased rapidly. The process by which fire spread from the trash basket to the other combustibles was almost the same in all the cases except Case-14, which used steel composite desk units. It seemed that the location of the trash basket affected the fire spread process. The heat release rate when the desk wagon started to burn was approximately 200kW. When desk unit C caught fire, the heat release rate became almost 1000kW.

Table 3. Fire spread process in the free-burn experiment (Case-3)

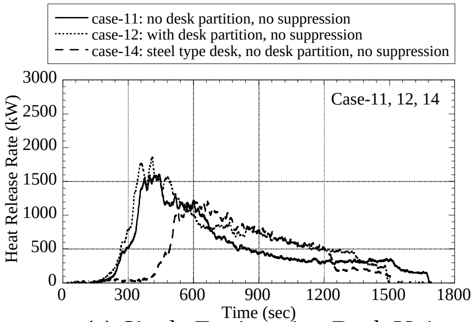
Time from ignition (sec)	Fire spread process	Burning desk units	HRR (kW)
0	Ignition (solid fuel thrown into the trash basket)	Desk Unit A	0
30	Flame from the trash basket		5
50	Flame height reaches the top of the desk		10
90	Trash basket melting		30
120	Flame spread to the desk wagon		30
170	Flame spread to the keyboard		105
210	Flame spread to the chair		184
240	Ignition to the computer and the monitor		224
300	Chair covered with flame		395
450	Flame spread to the desk wagon of desk unit C	Desk Unit A & C	1040
610	Flame spread to the monitor of desk unit C		1650
810	Flame spread to the computer of desk unit B	Desk Unit A, C & B	2670
880	Experiment over (fire extinguished by standpipe)		2025

Figures 3 and 4 show time series of heat release rates and temperature of smoke layer at T_{VT2} for a single engineering desk unit, four engineering and clerical desk units. As shown in Figure 4, temperatures of smoke layer reach approximately 150 to 300^{o}C. At that time, smoke layer thickness almost reaches at the bottom of curtain board. From these results, it is assumed that burning rates were enhanced by the thermal feedback from smoke layer to combustibles even if the test facility was mechanically ventilated.

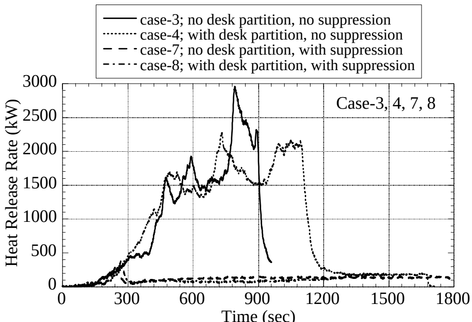
The effects of experimental parameters on the fire behavior are outlined below.

(1) Types of Desk Units

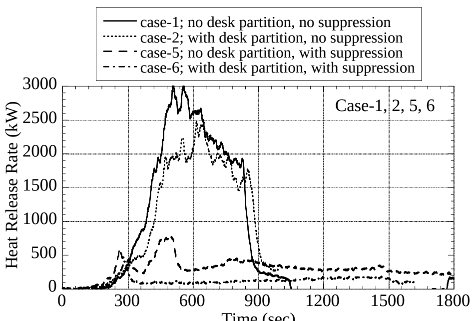
As shown in Figure 3, fire growth did not depend on the type of desk unit. In Case-1, the peak heat release rate during the fire growth phase was higher than in the other cases. This was because the flames spread to the additional chair E at 420 seconds after ignition, and desk unit A and chair E caught fire at the same time. On the contrary, the duration of the steady state burning for the engineering desk units were longer than that for the clerical desk units. During the steady state burning, the engineering desk units periodically reaches the peak heat release rates and were consistent with the ignition time of the plastic items, such as desktop type computers or chairs. Desktop type computers would be one of the most important factors affecting the duration of the peak heat release rates in the engineering desk units.



(a) Single Engineering Desk Unit

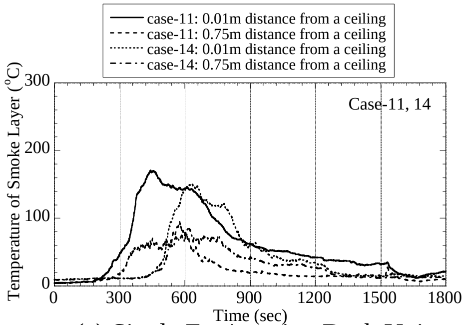


(b) Four Engineering Desk Units

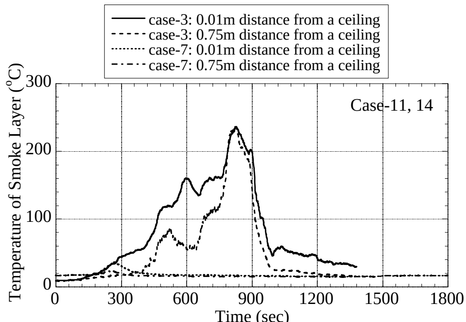


(c) Four Clerical Desk Units

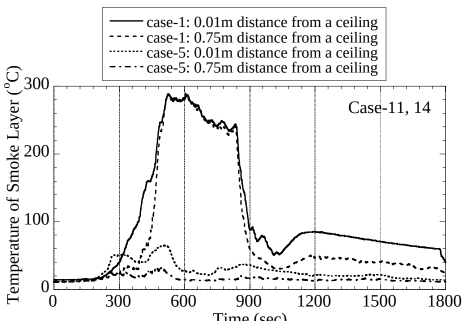
Figure 3. Time Histories of Heat Release Rates



(a) Single Engineering Desk Unit



(b) Four Engineering Desk Units



(c) Four Clerical Desk Units

Figure 4. Time Histories of Temperature of Smoke Layer at T_{VT2}

Based on our observations, most of the paper files remained unburned after the experiments, which matches the results that masses of cellulose materials, such as files of papers, do not affect the heat release rate during the fire growth phase.

In the case of the steel composite desk unit, ignition of the desk wagon was delayed and flames spread to the chair before the desk wagon. It is because most of a front panel of the desk wagon is made of steel and it is difficult to spread a fire to the desk wagon. Arrangement of plastic materials near the ignition source would affect initial fire growth.

(2) Number of Desk Units

By comparing the results of Case-11 and Case-3, the peak heat release rate increased about twice as much in the case of four desk units. The duration of the peak heat release rate continued for almost 10 minutes. As shown in Table 4, it took about 7 to 14 minutes for the fire to spread from the fire-originated desk unit to the adjacent one. The peak heat release rate of the fire-originated desk unit passed at the time the fire spread to the adjacent desk unit. In the case of a single desk unit, the peak heat release rate corresponded to the time when the chair reached the maximum combustion. In the case of four desk units, the peak heat release rates corresponded to the time when two desk units were on fire.

(3) Desk Partitions

Figure 3 shows that the tendencies of fire growth did not depend on desk partitions. Thus, the existence of desk partitions had little effect on the heat release rate during the fire growth phase. On the contrary, if the types of desk units are the same, fuel packages without desk partitions (Cases 1 and 3) had higher peak heat release rates than those with desk partitions (Cases 2 and 4). These results can be explained by the fact that flames could spread faster from the fire source to desk unit B via computer equipment in the cases without desk partitions. From our observation, the process of fire spreading to the adjacent desk unit seemed not to be related to the existence of desk partitions but to the arrangement of plastic materials on the desk unit.

Table 4. Flame Spread Time to Desk Units from Visual Observation

Case No.	Desk Unit A		Desk Unit B		Desk Unit C		Desk Unit D	
	Components	t_A (sec)	Components	t_B (sec)	Components	t_C (sec)	Components	t_D (sec)
1	Wagon Chair	140 230	Paper	436	Wagon Chair	420 420	---	---
2	Wagon Chair	120 210	Partition	720	Paper Wagon	390 420	---	---
3	Wagon Chair	90 210	Computer	810	Wagon Chair	450 621	---	---
4	Wagon Chair	120 255	Monitor Paper	540 1050	Monitor Wagon Chair	375 450 524	Paper	860
5	Wagon Chair	90 190	Paper	840	Wagon	570	---	---
6	Wagon Chair	120 195	---	---	---	---	---	---
7	Wagon Chair	120 198	---	---	---	---	---	---
8	Wagon Chair	120 180	---	---	---	---	---	---
11	Wagon Chair	80 240						
12	Wagon Chair	90 220						
14	Chair Wagon	210 240						

In Case-1, flame spread to Chair E (at the back of the Desk Unit A) at 420 seconds after ignition.

Fire Behavior in Sprinkler Suppression Experiments

In the cases of sprinkler operation, sprinklers were activated when smoke layer temperature T_{SP3} at the ceiling near sprinkler head No.3 reached in the range of 90 to 100°C. Sprinklers were activated after 250 to 281 seconds and there was little difference between these cases. The heat release rates while the sprinklers operated ranged from 260 to 470 kW. Visual observation indicated that the sprinklers were activated when the chair of desk unit A caught fire.

Comparing peak heat release rates in sprinkler operation cases with those in free-burn cases, peak heat release rates were limited to 1/4 to 1/10 after sprinkler was activated. These results indicate that sprinklers can control the fire. It must be noted that the sprinklers were unable to stop the fire completely, the fire continued in the area where water did not reach directly, such as paper files under the desk, the top of the desk wagon, and the beneath the seat of the chair. Even after the sprinkler was activated, heat release rates continued to be approximately 200 kW.

In Case-5, the heat release rate at sprinkler activation was greater than in the other cases of sprinkler suppression, because the fire spread to the chair earlier than in the other cases. In Case-5, a part of the chair, such as the bottom of the seat, continued to burn after sprinkler activation. The effectiveness of sprinkler control is likely to be more related to the burning objects when the sprinklers are activated than the initial amounts of combustibles.

Table 4 indicates that it took at least 375 seconds for the fire to spread to the adjacent desk unit in the free-burn experiments. Accordingly, the fire did not spread so fast between the desk units during the fire growth phase. For the desk arrangements of this study, sprinkler operation could contain the fire to the desk unit where the fire was originated.

In this study, heat release rates are measured by the oxygen consumption calorimetry based on O_2 depletion. We should note that some errors could have existed under the suppression condition in measuring heat release rates. Separately, we have conducted some crib suppression experiments in the same test facility. From the results of these experiments, errors in measuring heat release rates are estimated as approximately 200kW under the suppression conditions in the test facility. It is necessary to examine this point in the future.

DISCUSSION

Fire Growth Rates for Office Arrangements

This paper discusses t-squared design fires for means of egress in office buildings. In the experiments, there was a time lag until ignition of the desk or the chair from the fire source, because the trash basket was used as the ignition source. Usually, the time lag until a fire started to grow depends on the arrangement of combustibles around the fire origin, in other words, fire scenarios of the experiments. Fire scenarios have wide varieties and the ignition time lags could deeply depend on the fire scenarios. On the other hand, fire growth rates eliminating the ignition time lag are usually greater than those obtained when fire ignites at the first ignition source. Judging from the above, it seems reasonable that the fire growth rate without ignition time lag should be used in design fires for designing means of egress for the worst case.

For these reasons, heat release rate during the fire growth phase is expressed as follows:

$$Q(t) = \alpha(t - t_0)^2 \qquad (1)$$

where t is elapsed time from ignition of the trash basket, Q(t) is the heat release rate at time t, a is fire growth rate, and t_0 is the time lag until ignition of adjacent combustibles from the trash basket.

Figure 5 shows relationship between the lag times and fire growth rates derived from the experimental data. The fire growth rates were estimated by the method of least squares with nonlinear regression analysis. As only one fire scenario of the ignition is used for all cases in this study, the time lags were determined for each case by visual observation as shown in Table 4. The regression range by the method of least squares was determined from 100 kW to the peak heat release rate, considering the spread of flames to the wagon or the chair, because the heat release rate of the trash basket by itself is approximately 50 to 60 kW.

The estimated fire growth rates had little variation between all cases and ranged from 0.007 to 0.017 kW/s^2. Initial time lags to ignition of the desk or the chair were considerably different between the plastic composite desk and steel composite desk; they were approximately 80 to 140 seconds for the plastic composite desk and 210 seconds for the steel composite desk. Conversely, the estimated fire growth rates were almost the same between the plastic composite desk and the steel composite desk. It seems that the chair or the computer affected the fire development after the ignition of the desk. In this study, the fire growth rates may have been estimated smaller than those in real fires in an office room, because the air in the compartment was ventilated mechanically.

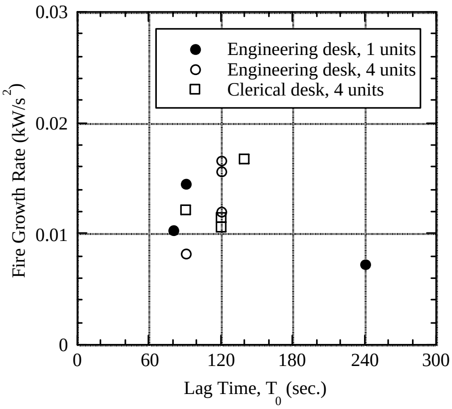


Figure 5. Relationship between Lag Times and Estimated Fire Growth Rates for All Experimental Cases

Comparison with the Design Fires in Engineering Design Guidelines

Design fires for means of egress have been established in the engineering design guidelines, such as NFPA 92B [1], BSI DD240 [2] and MOC [3]. These design fires are modeled as t-squared fires for initial fire growth. For performance-based fire safety design of buildings, it is very important to examine fire growth rates in accordance with the types and occupancies of buildings. Recommended fire growth rates for office occupancies vary somewhat between these guidelines, for example, 0.012 kW/s^2 in BSI DD240, and 0.05 kW/s^2 in MOC. In these design guidelines, a typical piece of furniture is usually expected to be a fuel package of fire origin. For example, ‘medium’ fire in NFPA 92B corresponds to cotton/polyester inter-spring mattress. It was confirmed that fire growth rates estimated in this study could be compared with NFPA 92B as 'medium' (0.012 kW/s^2) on average and as 'fast' (0.049kW/s^2) at the upper limit. Fire growth rates obtained from this study seem to be more realistic arrangements of fuel packages in office workplace than several design guidelines. Full-scale fire experiments conducted by Madrzykowski [4] also indicated that the fire growth rate of a three-sided work station was representative of 'medium.' Judging from the above, it seems reasonable that the fire growth rate in office design fires for means of egress is supposed to be 'medium' (0.012 kW/s^2), even if we consider that a fire spreads beyond the adjacent desk units.

Lougheed [6] proposed a design fire for sprinklered office buildings based on some full-scale fire experiments. Figure 6 shows the comparison of heat release rate curves between the experimental results with suppression of our study and design fire proposed by Lougheed [6]. In the Lougheed's design fire, the fire growth rate and the maximum heat release rate were determined to be 0.049 kW/s^2 (Fast) and 1000 kW, respectively. In Figure 6, time lags in experimental data are corrected and times to ignition of the desk wagon were set at time zero. Figure 6 confirms that the design fire proposed by Lougheed provides conservative estimate of the heat release rates that were measured in the experiments. In Lougheed's study, some conditions of sprinkler installation are different from our study, for example, distance between sprinkler heads is set at 4.6m and ceiling height is 2.74m [6]. We should note that in our study, desk units were located at the center of the four sprinklers to take the distance from every sprinkler head and only one sprinkler head was operated for more dangerous situation. The arrangements of combustibles and the location of sprinkler heads would affect the heat release rate curve, especially peak heat release rate. In order to establish a proper design fire with sprinkler operation, it seems reasonable to consider these design parameters.

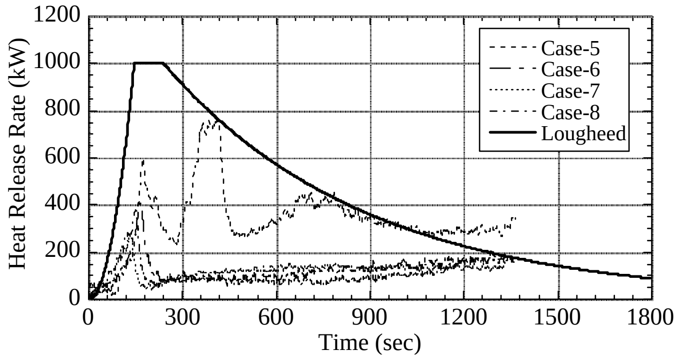


Figure 6. Comparison of Heat Release Rate Data with Design Fire for Sprinklered Office Buildings Proposed by Lougheed (1997) [6]

Initial ignition time, before the fire starts to develop, depends on the ignition scenarios or the arrangements of the ignition source and combustibles. It is difficult to determine the initial ignition time in advance even if the arrangement of combustibles is fixed. Therefore, initial ignition times were eliminated in estimating fire growth rates as the design fire for means of egress. On the other hand, during the initial ignition phase, smoke will be produced by smoldering combustion. If we use design fires in predicting the operation time of detectors, we have to establish an another design fire, which considers several ignition scenarios.

CONCLUSION

Eleven full-scale fire experiments were conducted for several types of office arrangements. The findings of the experiments are summarized as follows.

1. Fire growth for office desk units largely depended on combustion of plastic materials, which were commonly used in office furniture or computer equipment. The amounts of cellulose materials, such as masses of paper files, had little effect on the heat release rates during the fire growth phase.

2. Fire growth rates for contemporary office desk units, which are made of mainly plastic materials, range from 0.007 to 0.017 kW/s^2, that are close to the 'medium' fire in NFPA 92B on average.

3. In the cases where sprinkler was operated, the combustion of office fuel packages was controlled. Heat release rates were approximately 500 kW at sprinkler activation, and 200 kW during suppression.

4. Heat release rate curves with suppression are almost included within the design fire that was proposed by Lougheed [6], even if only one sprinkler head was activated.

In this study, experimental parameters such as the arrangement of desk units or the location of an ignition source were restricted. These parameters may affect fire behavior during the fire growth phase. Future studies should focus on these points, and suitable design fires with sprinkler operation should be examined.

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