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MEASUREMENTS OF FIRE LOADS AND CALCULATIONS OF FIRE SEVERITY[1]

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ABSTRACT

Types of furnishings, interior finish, and occupancy trends have changed considerably over the last several decades, so new fire load surveys for various occupancies are being conducted in various countries, using modern surveying techniques. These new data can be used to calculate fire growth curves, considering modern lightweight methods of construction using large window areas and mechanical ventilation. Computer models are designed to evaluate fire growth as a dynamic process, using such factors as heats of combustion, changing temperature levels, combustion enthalpy per unit mass of air, thermal conductivities and radiation, furniture arrangements and collapse during fires, etc. As these computational methods become more refined, changes in fire endurance testing can be made to produce more realistic results, which may represent fire exposures and potential fire severities different than those we are familiar with.

Keywords: Fire load, fuel load, fire growth, heat release, combustion, computer models, fire severity, fire endurance.

INTRODUCTION

Fire load is the starting point for estimating the potential size and severity of a fire, and thus, the endurance required of walls, floor-ceiling assemblies, columns, doors, and other parts of the enclosing compartment. This applies also to loadbearing beams and columns, doors, and windows, and in fact, all situations where containment of a building fire is both desirable and necessary. Earlier publications have summarized the relationship between fire load, resultant fire severity, and use of standard furnace tests to measure the ability of structural components to withstand effects of severe fire (Robertson and Gross 1970; Sup. Doc. 1942). This paper is intended to provide two types of information: an update on the measurement of fire loads, particularly in office and residential occupancies, and a brief survey of the application of computer solutions for heat balances in compartments in order to utilize fire load data in predicting fire growth and fire severity.

FIRE LOADS

Fire load, or more accurately fire load density, is defined as the weight of combustible contents per unit floor area. It is commonly divided into two categories: (1) movable contents fire load consisting of combustible furniture, equipment, goods, and supplies brought in for the use of the occupant; and (2) interior finish fire load consisting of exposed combustible materials permanently affixed to walls, ceilings, or floors plus doors, trim, and built-in fixtures. Fire load is sometimes called fuel load. Typically, all weights are converted to equivalent weights of combustibles having a calorific value of 4,700 Kcal/kg (8,000 BTU/lb).

During the period 1928 to 1940, surveys were conducted of fire loads in residences, offices, schools, medical buildings, and a few mercantile buildings (Sup. Doc. 1942). In 1947, an enlarged survey was made of the combustible contents of mercantile and manufacturing buildings (Ingberg et al. 1957). These surveys involved the actual

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TABLE 1. *Weights of combustible contents [based on survey data reported in BMS 92 and BMS 149 (from Robertson and Gross)]*

Type of Occupancy		Number Surveyed	Floor Area sq ft	Combustible Contents: Average psf	Combustible Contents: Range of Maximum Values for Single Occupied Room psf	Combustible Contents: Maximum for Any Area psf
Residence		13	8 165	8.8	8 to 14	49 (linen closet)
Hospital		1	143 780	2.8	3 to 22	19 (service store) 23 (laundry, clothes storage)
School		6	72 385	15.7	7 to 39	228 (textbook storeroom)
Mercantile (department store)		2	1 105 032	10.3	...	47 (paint department)
Manufacturing	Furniture Factory	2	549 784	15.3	...	117 (veneer storage) 104 (paint shop) 167 (paper storage)
	Mattress Factory	2	155 791	16.4		
	Clothing Factory	2	91 701	10.7		
	Printing Plant	2	191 755	34.0		
Warehouse	General	4	518 193	25.0	...	256
	Printing	1	135 055	174.4		
Office		82	89 075	18.4 (10.6 excluding heavy files)	7 to 43	86 (heavy files)

weighing of all movable combustible contents of the buildings studied. In cases where furnishings were fixed in place, estimates of weight were made on the basis of dimensions. In addition, weights were estimated for combustible flooring and exposed woodwork other than flooring. These fixed, interior finish items were reported separately as well as combined with movable fire load to show the total fire load present. Results of these surveys are summarized in Table 1 and have been used (Sup. Doc. 1942) as a basis of defining fire endurance performance requirements for fire-resistive buildings in building codes.

Recognizing that types of furnishings, interior finish, and occupancy trends have changed over the last several decades, new fire load surveys have been conducted in various countries and occupancies (Nilsson 1970; Bonetti et al. 1975; CECM 1974; Baldwin et al. 1970; Berggren and Erikson 1970; Witteveen 1966; Forsberg and Thor 1971; Magnusson and Pettersson 1972). Many of these surveys have been summarized by Babrauskas (1976). Improvements in weighing and in surveying techniques have also been made (Bryson and Gross 1975).

Probably the most extensive single survey involved over 2,200 office rooms in 23 buildings in various regions of the United States (Culver 1976; Culver and Kushner 1975) (also see Table 2). This recent survey involved an inventory system usng classification of furnishings and visual measurements recorded on a computer-sorted survey sheet rather than actual weighing of contents. The conversion from size to weight was made from frequency distribution curves and transfer functions for as large a range of classified furnishings as could be obtained from manufacturer's catalogs and sales and shipping information (Fig. 1). Although this visual survey based on population distributions by type is not as accurate as direct weighing, this procedure permitted a much larger sampling to be accomplished on a limited budget.

Principal results of the above survey are as follows:

1. There did not appear to be any significant difference between loads in government and private office buildings (Fig. 2).
2. Measurement error associated with the inventory technique was estimated to be approximately 10%. Variability in loads from room to room was significantly greater.
3. Magnitude of loads in office buildings was not significantly affected by geographic location, building height, or building age.
4. Variation of load with occupancy duration was not clearly established and requires further study.
5. Magnitude of room fire loads and live loads was related to the use of the room. Libraries, file rooms, and storage rooms were the most heavily loaded.
6. In general, mean room load decreased as area of the room increased, although room use and room area may be correlated. Further study is required to establish the influence of area on load magnitude.
7. There was a definite tendency for loads in offices to be concentrated around the perimeter of the room. The majority of furniture items were within 2 feet of the walls.
8. In the majority of offices surveyed, between 20 and 40% of the floor area was occupied by furniture and equipment.
9. Overall mean total fire load was 36 kg/m^2 (7.3 psf), consisting of 28 kg/m^2 (5.7 psf) movable contents and 8 kg/m^2 (1.6 psf) interior finish.
10. Paper and books accounted for approximately 40% of the total fire load.

TABLE 2. *Office building characteristics (from Culver 1976)*

Bldg. No.	Occupancy Type	Location: Region	Location: State	Height (No. of Stories)	Age (Years)
1	Private		PA	5	13
2	"	North-	NY	7	58
3	"	East	PA	21	68
5	"		PA	25	23
7	"		IA	5	16
8	"	North-	IL	5	2
9	"	Central	WI	20	10
10	"		IL	23	16
11	"		OK	2	8
12	"	South	GA	10	73
13	"		GA	10	5
14	"		OK	22	25
17	"		WA	9	11
18	"	West	AZ	17	13
19	"		WA	49	5
20	"		CA	5	63
21	Government	North-	PA	3	47
22	"	East	NY	44	7
23	"	North-Central	IL	2	7
24	"	South	MD	12	11
25	"		GA	4	6
26	"	West	CO	2	3
27	"		CA	18	6

Cumulative frequency distributions of total fire load from this survey are shown in Fig. 3. Approximate cumulative frequency distributions based on fire load surveys in various countries are approximately as given in Table 3. Several European investigators have suggested that the 80% cumulative frequency fire load level is suitable for design (Witteveen 1966; Forsberg and Thor 1971).

A similar type of inventory survey was recently conducted by the National Bureau of Standards (NBS) on single family residences in the Washington, D.C. area. Data are currently being key-punched, sorted, and analyzed by computer. However, a partial, manual survey was made of fire loads in basement recreation rooms of private homes. Transfer functions for typical furnishings were again used to convert visual estimates into average weights. Of a total 270 residences surveyed, a partial sampling of 70 residences with basements yielded 39 basement recreation rooms. The fire load, consisting of both combustible

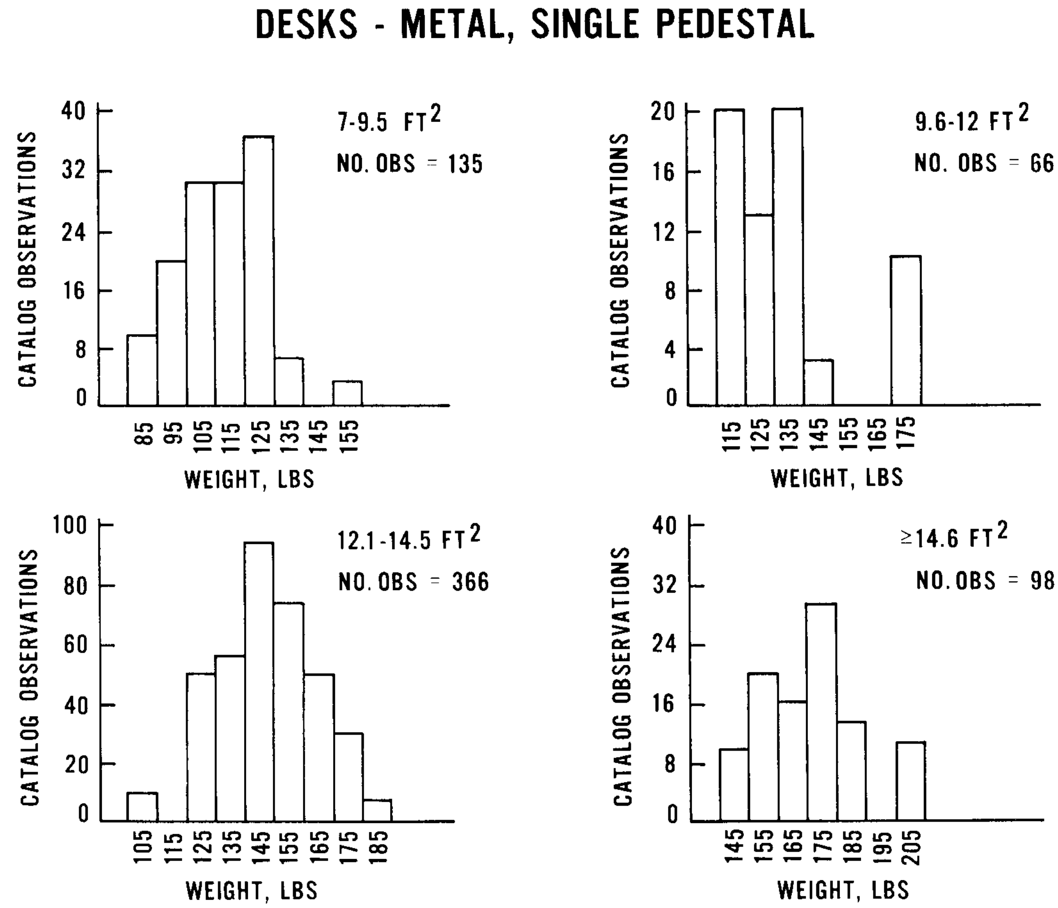

FIG. 1. Catalog frequency distributions of metal desks (from Culver and Kushner 1975).

contents and combustible interior finish, ranged from 5 to 54 kg/m² (1 to 11 psf). The overall median value of fire load (weight of combustibles per unit floor area) was 27 kg/m² (5.5 psf). Combustible contents accounted for 80% of the total and the walls and ceiling 20%.

Thus, movable combustible contents in these recreation rooms represent about 22 kg/m² (4.4 psf) and interior finish about 5 kg/m² (1.1 psf). The movable contents portion may be compared with the results of a survey conducted 40 years ago in which movable contents averaged 17 kg/m² (3.4 psf) for 13 entire apartments and residences and 24 kg/m² (5.0 psf) for bedrooms and closets. However, the interior finish portion is considerably below the average 26 kg/m² (5.4 psf) previously assigned to entire residences based on 12.7 kg/m² (2.6 psf) of wooden floor and 13.7 kg/m² (2.8 psf) of other exposed woodwork. The results represent only a partial hand-computed sampling, and hopefully, complete analyzed data will be available in report form later this year.

FIRE GROWTH CALCULATIONS

To calculate fire history, a computer program is a practical necessity. Input quantities typically include fuel burning rate, ventilation conditions, and thermal properties of enclosing surfaces. From basic mass

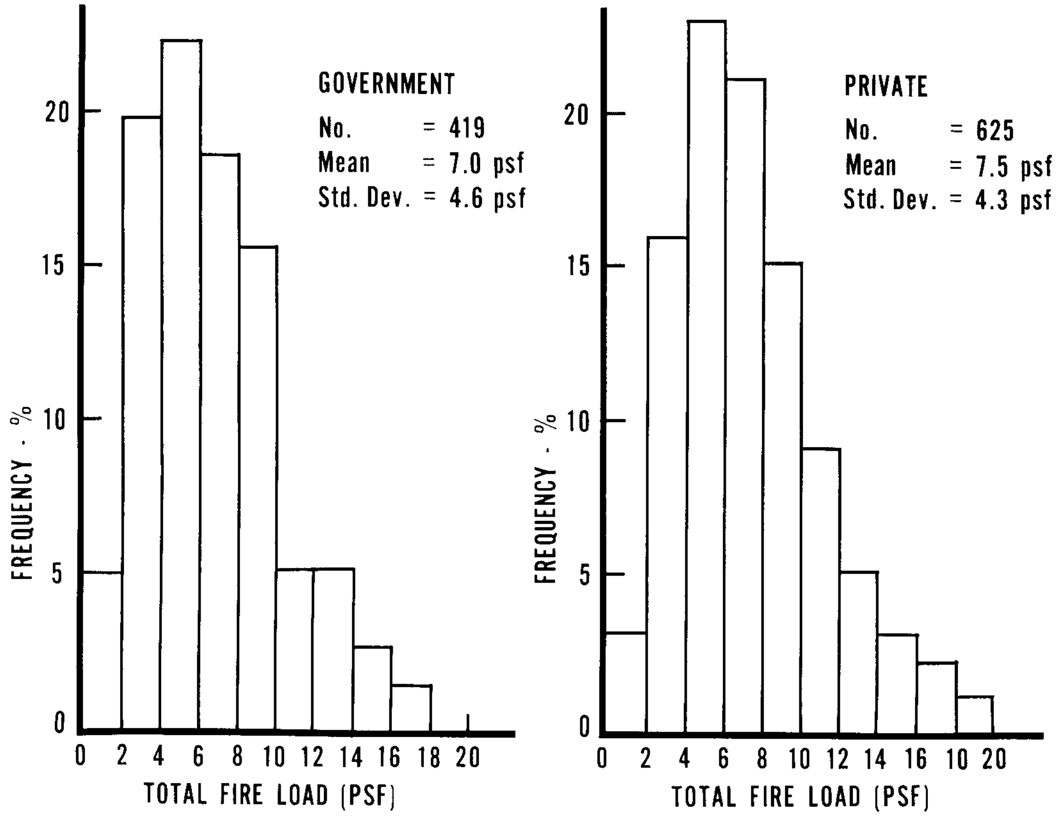

FIG. 2. Frequency distributions of room fire loads (from Culver 1976).

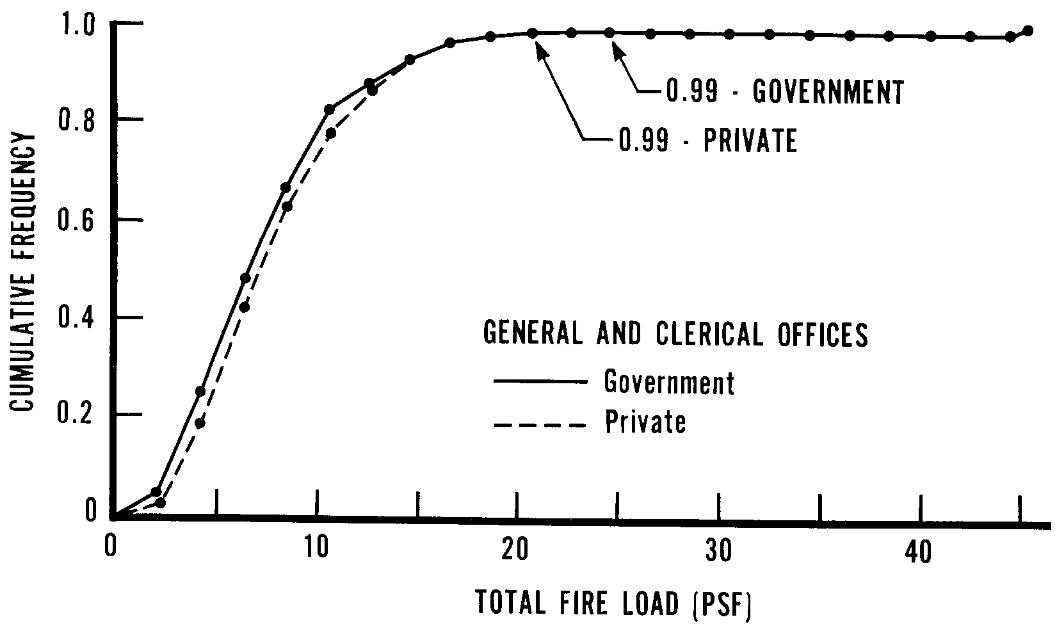

FIG. 3. Cumulative frequency distribution for room fire load (from Culver 1976).

TABLE 3. *Cumulative frequency (probability) of fire loads (from Babrauskas 1976)*

Cumulative Probability Percent	FIRE LOAD (in kg wood equivalent/m^2 floor area)				
	OFFICES				
	U.S.A. (Culver 1976)	W. Germany (CECM 1974)	Sweden (Berggren & Erikson 1976)	Holland (Witteveen 1966)	England (Baldwin et al. 1970)
25	20	25	24	5	5
50	35	43	28	10	20
80	50	60	38	24	32
99	100	130	70	46	110
	RESIDENCES	OTHERS (SWEDEN)			
	Sweden (Nilsson 1970)	Schools (Forsberg & Thor 1971)	Hotels (Forsberg & Thor 1971)	Hospitals (Magnusson & Pettersson 1970)	
25	37	17	15	30	
50	40	22	18	33	
80	45	26	22	35	
99	53	43	34	71	

and heat balances, rate of combustion and composition and temperature of combustion products may be computed as a function of time.

One of the earliest analyses of the burning process in rooms was provided by the Japanese researcher Kawagoe in 1958. He provided an enthalpy balance of a room fully involved in fire based on: (a) the combustion of wood, (b) buoyancy-induced ventilation, and (c) heat losses to enclosing walls and ceiling. In succeeding reports, he added improvements and established a workable computational tool for fire growth (Kawagoe and Sekine 1963; Kawagoe 1967). The importance of ventilation in terms of the height, h, and area, A_w, of the window in controlling burning rate was a substantially simplifying approach and subsequently was used by others. Under these conditions, details on the geometrical nature of the fire load could be ignored. Kawagoe established the mass flow rate of air as $\dot{m}_{air} = 1880\ A_w \sqrt{h}$ kg/hr based on air at 20 C and an assumed discharge coefficient of 0.7. The mass burning rate of (wood) fuel was $\dot{m}_{fuel} = 330\ A_w \sqrt{h}$ kg/hr ($5.5\ A_w \sqrt{h}$ kg/min). To account for incomplete burning and loss of pyrolysis products, Kawagoe took the effective heat of combustion ΔH_c as 2575 Kcal/kg (4640 BTU/lb). The net or effective heat release from burning contents currently remains an important research subject.

In 1963, Odeen published a thesis which provided a means for performing heat balance calculations where heat release rate was an independent variable, unrelated to window opening. More recent contributions have been made by Magnusson and Thelandersson (1970), Tsuchiya and Sumi (1971), Babrauskas and Williamson (1975), and Babrauskas (1976). Typical curves shown in Fig. 4. For fire-resistance design of buildings, Lie in 1974 sought to establish a temperature-time curve whose effect, with reasonable probability, will not be exceeded during the use of the building. Since ventilation-controlled fires are generally more severe and have a substantial probability of occurrence, Lie computed characteristic fire curves for several levels of fire load ventilation and thermal properties.

Obviously, many assumptions are made in such analytical models regarding chemical reactions, air flow and entrainment, completeness of combustion, temperature gradients, and heat loss relationships. In some cases, simple assumptions are reasonable and proper, and errors introduced are slight; in other cases, results depend very strongly on one or more factors that are not sufficiently known. For example, one

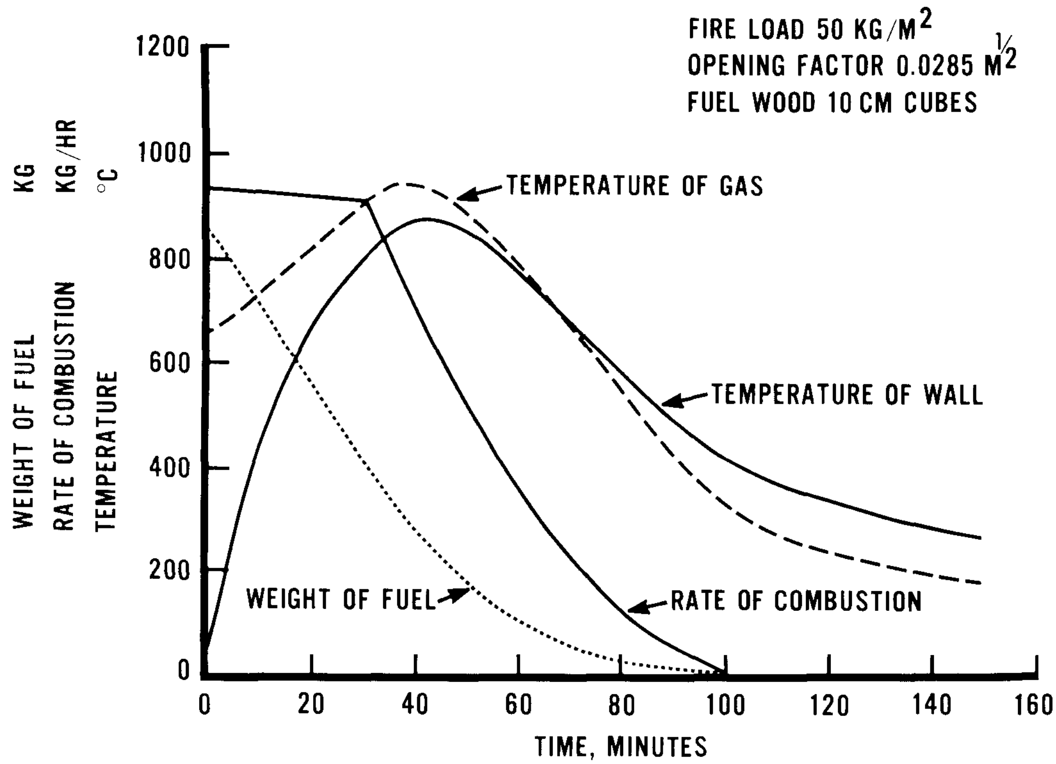

FIG. 4. Behavior of fire (from Tsuchiya and Sumi 1971).

simplification that may be made is based on the fact that the combustion enthalpy per unit mass of air is nearly the same for many fuels, even though their calorific values per unit mass vary considerably.

To calculate the highest or most consistent temperature in some computer programs, comparisons are made either between computed and assumed fuel burning rates or between alternately calculated temperatures in the ventilation and fuel-controlled modes. Computer calculations can be made to agree fairly well with experimental data, although large-scale compartment experiments normally have considerable scatter. A comparison of calculations by Babrauskas (1976) and experimental data for wood cribs burning in compartments are shown in Fig. 5. In this case, measured weight loss data was used, so this is not a complete predictive calculation.

Computer calculations are particularly valuable for sensitivity studies, such as examining effects of major variables on heat balance within a compartment containing burning combustibles. In general, on the basis of analytical and experimental considerations, the overall effect of scale has been considered to be slight. However, larger compartments can generate higher temperatures, increased radiation, and higher burning rates; and quantitative generalizations from small scale models should be made with caution.

The effects of different thermal conductivities of enclosing walls on gas temperature are significant (Fig. 6). During the early stages where radiation is dominant, thermal inertia, kρc, is most important, while in the later stages where heat conduction losses predominate, thermal conductivity is most important.

The discussion on computer calculation has so far ignored factors that determine

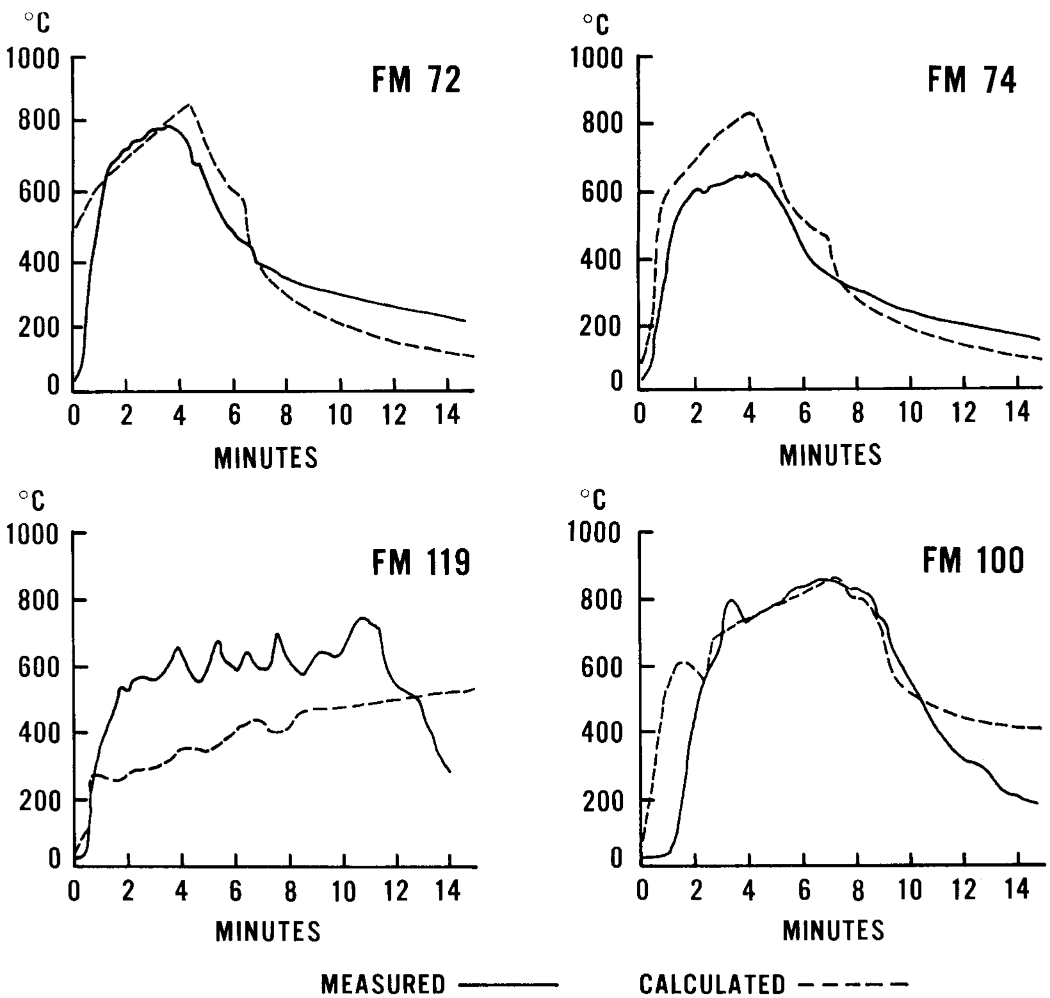

FIG. 5. Comparisons of measured and computed temperatures (from Babrauskas 1976).

the early or pre-flashover stages of fire growth. This is considerably more complex and as previously stated can be largely disregarded if ventilation-controlled burning is assumed. In models of early fire growth, however, important parameters include the amount, surface area, and arrangement of combustible contents; the collapse and rearrangement of furniture during a fire; the formation of openings in walls, ceilings or doors; and local zones of hot gases. There is now a movement in the direction of models that consider the progressive development of a fire in space as well as in time.

In general, these next generation computer models attempt to solve the basic mass, energy, and momentum equations either on a strictly mathematical basis or alternately in terms of simplified modules, in which the energy transfer phenomena are considered individually. The former approach, which is more exact and difficult, may take years to formulate and solve. The latter is capable of solution now and is being actively pursued by a number of researchers.

The IITRI model of Pape and Waterman, for example, incorporates a volatilization rate with an assigned probability for a

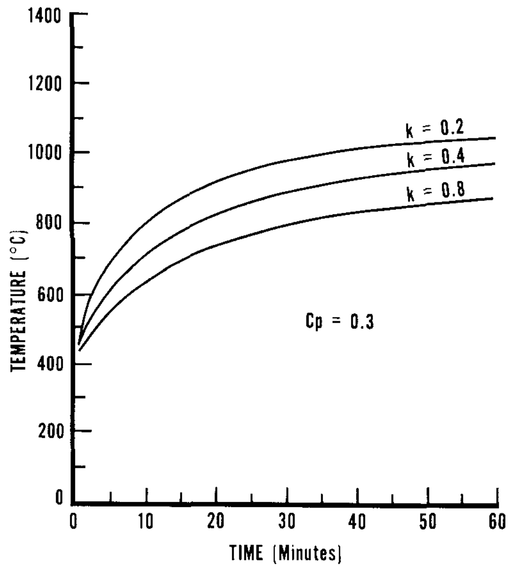

FIG. 6. Effect of thermal conductivity of wall (from Babrauskas 1976).

burning item of furniture (Pape et al. 1976). It is possible to perform repetitive computations with different room geometries, ignition locations, and volatilization rates for the major burning item, and to develop a series of curves of probability of occurrence.

Other computer programs have been or are being developed to account for special factors and situations, such as an aircraft cabin (Reeves and MacArthur 1976), a multi-room building (Emmons 1977), and a complete industrial building (Rockett 1969). In general, these models incorporate layers or 2-zone discontinuities to provide more accurate representations of heat buildup in the upper part of the room, which is particularly important for measuring early fire growth. They may also include the effects of plumes, radiation interchange, the formation and reaction of

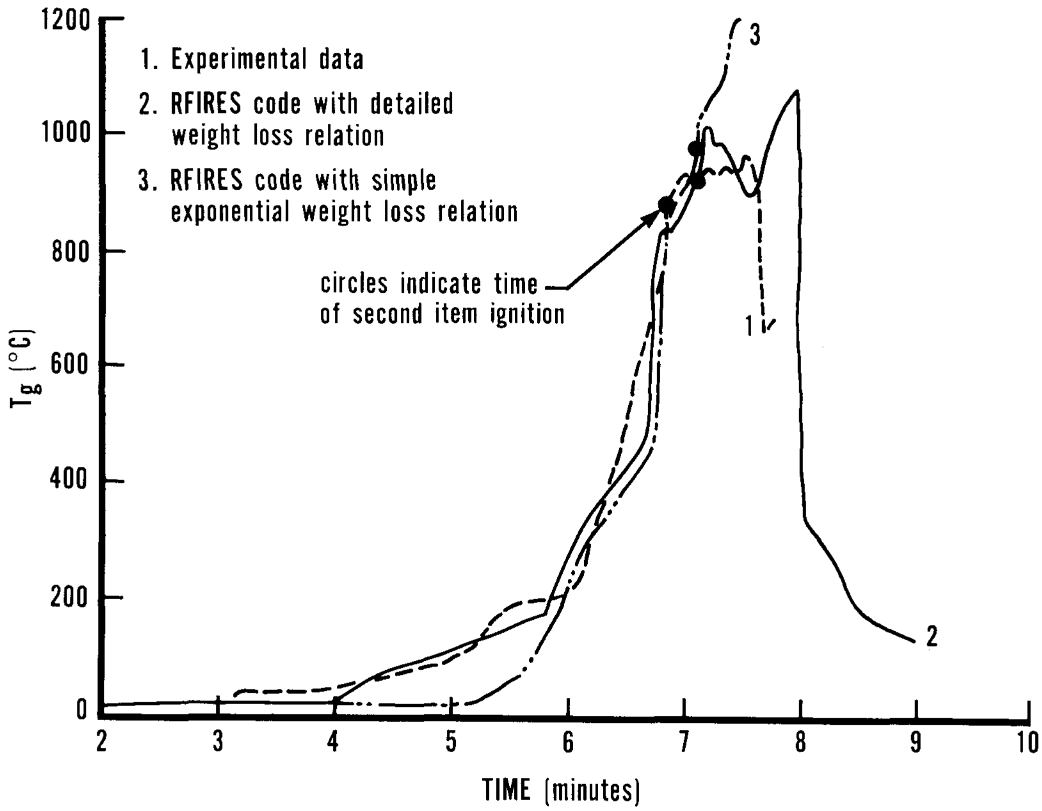

FIG. 7. Hot gas layer temperature (from Pape et al. 1976).

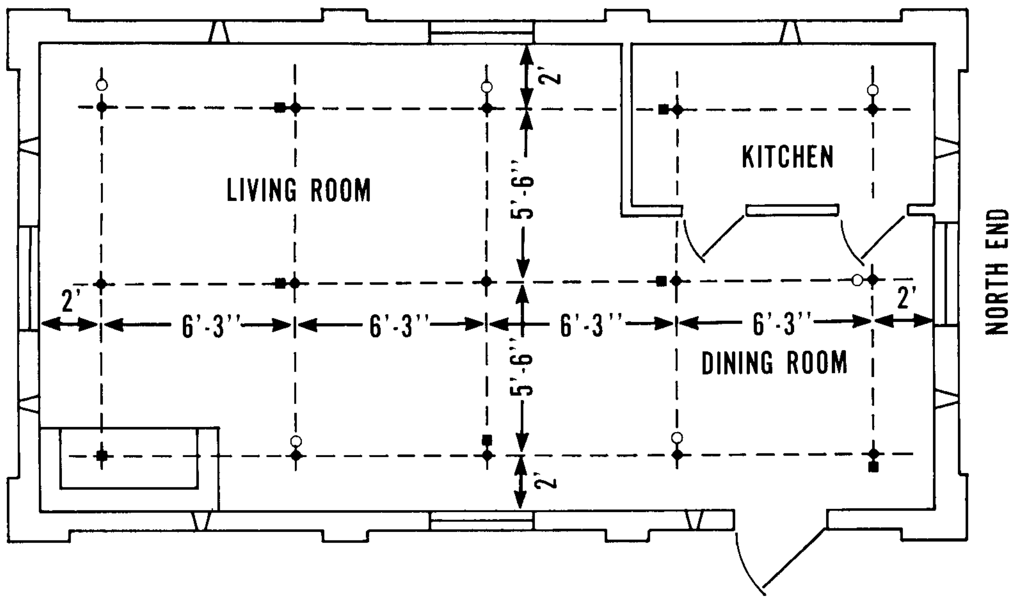

FIG. 8. Plan of building and thermocouple placement (from Rodak and Ingberg 1967).

gaseous combustion or pyrolysis products, the formation of char, and the presence of smoke.

The model developed by IITRI (Pape et al. 1976) has been exercised to provide a comparison between the analytical prediction and a full-scale fire test (Croce 1975) (Fig. 7). As these computer models become more sophisticated, they will be able to examine more, but probably never all, of the complex chemical, fluid mechanical, and heat transfer factors involved in an uncontrolled fire.

TABLE 4. *Summary of tests—residential burnout tests of 1939 (from Rodak and Ingberg 1967)*

Test	Occupancy	Finish Floor	Fire[a] Load lb/ft²	Equivalent Fire Duration: 150 C Base min	Equivalent Fire Duration: 300 C Base min
A	Residential	Concrete	5.2	NOT TABULATED	
B	Residential	Concrete	5.3 (14% books)	29	20
C	Residential	Concrete	7.9 (38% books)	33	22
D	Residential	Wood	8.5 (16% books)	45	34
E	Furniture Storage	Concrete	12	54	52

[a] Gross combustible weight divided by total floor area (427 ft²)

There have been a number of experimental investigations involving instrumented full-scale test rooms and buildings. For example, in 1939, a series of 5 full-scale fire tests were performed to measure fire development in a building arranged to represent a three-room residential occupancy (Rodak and Ingberg 1967) (Fig. 8). Information was obtained on the duration and intensity of fires from burning a similar furniture arrangement, but with the addition of paper, books, and foodstuffs to provide total fire loadings ranging from 25 to 59 kg/m² (5.2 to 12 psf) (Table 4). Just as in 1939, orientation of combustible contents with respect to fire origin are important. In general, average spatial temperatures in individual rooms were lower than the standard ASTM E 119 time-temperature curve. However, for total fire

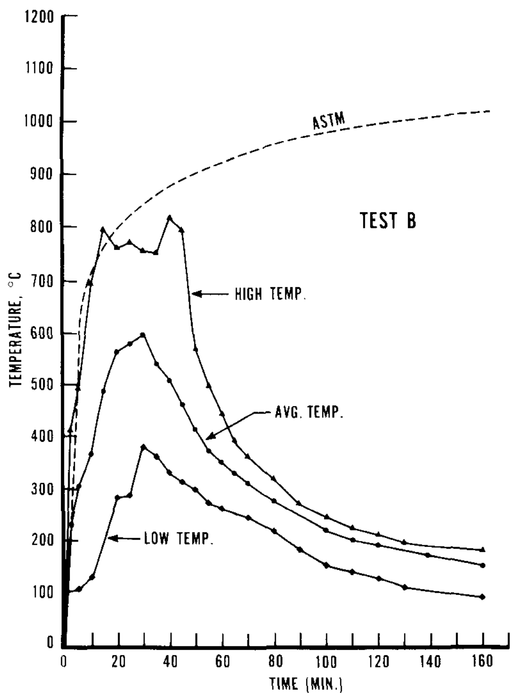

FIG. 9. Test B, for all rooms tested (from Rodak and Ingberg 1967).

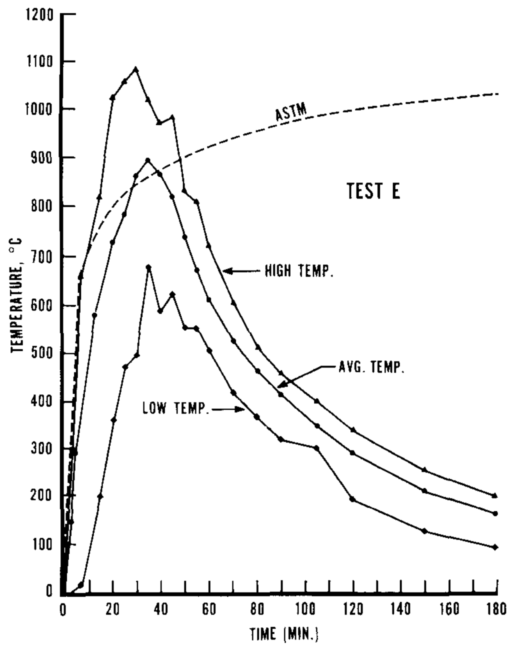

FIG. 10. Test E, for all rooms tested (from Rodak and Ingberg 1967).

loads of 42 to 59 kg/m² (8.5 and 12 psf), average spatial temperatures of the living room, dining room, and ceiling exceeded the standard curve for periods up to 22 minutes (Figs. 9 and 10).

FIRE SEVERITY

Fire severity is defined as the intensity and duration of a fire. To some extent, fire severity also expresses the concept of the potential for a fire to damage a structure or its contents. In common practice, fire severity is considered in terms of the equivalent duration test. The actual assessment of severity in any specific building fire situation is largely a subjective matter and to a certain extent depends upon the physical and thermal properties of the enclosing structure itself and the degree of ventilation involved. Thus, temperatures reached and the duration of burning in a compartment depend upon whether the walls and ceiling are good conductors or insulators and how much thermal energy is exhausted outside the burning room.

The most common method of applying the concept of fire severity involves use of the area under the fire exposure temperature-time curve above an arbitrary level (Ingberg 1928). In proposing this approach, Ingberg recognized that high temperatures for short durations and low temperatures for long durations were technically not equivalent. When originally proposed, it applied fairly well to heavy masonry buildings with small windows and fire durations up to at least 4 hours. In the current context of lightweight and combustible construction, large window areas and mechanical ventilation, the equal area severity concept is open to considerable question.

The major application of this concept has been in comparing experimental burnout fires with laboratory fire endurance tests according to ASTM Standard E 119. The original test data were summarized by Ingberg in terms of areas above two reference temperatures: 150 C, represent-

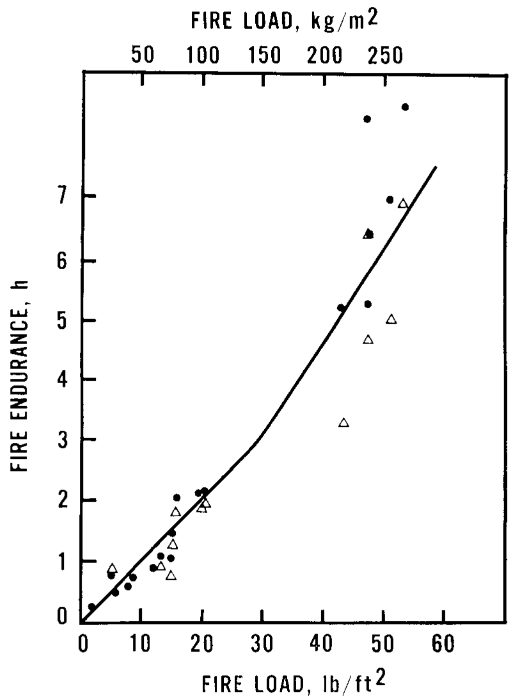

FIG. 11. Laboratory fire endurance test period corresponding to experimental temperature-time results from 15 burn-out experiments performed by Ingberg. Points marked ∆ and · correspond to a match of areas above base temperatures of 300 and 150 C, respectively. The solid line passes through points recommended by Ingberg (1928).

ing the temperature at which thin partitions would be damaged; and 300 C, representing the temperature at which thicker partitions or walls would be damaged. The relationship between fire load and equivalent fire endurance period is firmly established and seems to hold fairly well for the limited ventilation situation (Fig. 11). The relationship is less valid for short duration fires, where increased ventilation permits considerable flaming and heat release to occur outside the burning compartment. In such cases, higher short duration peak temperatures but lower average compartment temperatures will generally yield lower equivalent fire endurance periods. A closer approach to reality in some fire endurance testing may involve a considerably different fire exposure than the one we are most familiar with.

Law (1971) used a simplified approach in analyzing the severity of a fire in a compartment and showed that:

$$t_f = (KL)\ (A_w A_T)^{-1/2},$$

where t_f is a measure of the fire severity in a compartment (min)
L is the total fire load (kg)
A_w is the window area (m^2)
A_T is the sum of the wall and ceiling areas (m^2)
and K is a factor found to lie between 0.7 and 1.5.

Coward (1975) estimated the statistical distribution of t_f for office rooms by performing a parameter sampling study using Monte Carlo simulation. Based on some approximations and assumptions, Coward estimated that about 7% of office rooms would have a fire severity exceeding one hour, and that the distribution could be approximated by an exponential relation of the form:

$$p = e^{-0.04R},$$

where p = proportion of rooms with fire severity greater than R and R, determined in minutes, is expressed as:

$$L\ (A_w A_T)^{-1/2}.$$

If fire growth differs significantly from the standard temperature-time curve, it should not present too much of a problem to program a fire endurance furnace to a different temperature-time history, or even to a prescribed heat input schedule. Actually, fire endurance furnaces are not standardized, and the fractions of input energy which are lost through the exhaust stack and into the refractory surfaces are generally unknown. A start in this direction has recently been made by the addition of a recommendation in ASTM E 119 for recording the amount of fuel flow to the furnace burners. This information may be useful for performing a furnace heat balance analysis, measuring the effect of changes in the furnace or control settings, comparing assemblies of different properties, and programming heat input rates representing a wider and more realistic range of fire exposures and potential fire severity.

CONCLUSION

Various surveys on measurements of fire loads have been made with emphasis on office and residential occupancies. Fire load density, or the weight of combustible contents per unit floor area, can be divided into two categories: movable contents fire load and interior finish fire load. Modern analytical and statistical approaches in predicting both fire growth and fire severity may lead to considerably different fire exposures than those we are familiar with. Fire endurance tests according to ASTM Standard E 119 may be changed to program the fire endurance furnaces with different temperature-time histories or prescribed heat input schedules to reflect the new data on fire load, growth and severity.

REFERENCES

BABRAUSKAS, V. 1976. Fire endurance in buildings. UCB FRG 76-16. Univ. Calif., Berkeley.

———, AND R. B. WILLIAMSON. 1975. Post-flashover compartment fires. UCB FRG 75-1. Univ. Calif., Berkeley.

BALDWIN, R., M. LAW, G. ALLEN, AND L. G. GRIFFITHS. 1970. Survey of fire-loads in modern office buildings—some preliminary results. FR Note 808. Fire Research Station. Borehamwood, Herts, England.

BERGGREN, K., AND U. ERIKSON. 1970. Brandbelastning i Kontorhus Statistisk Inventering och Utvardering. Rapport 18:1. Stalbyggnadsinstitutet. Stockholm.

BONETTI, M., P. KREE, AND J. KRUPPA. 1975. Estimation des Charges Modiliere d'Incendie dans les Immeubles a Usage de Bureaux. Construction Metallique. No. 3.

BRYSON, J. O., AND D. GROSS. 1975. Techniques for the survey and evaluation of live floor loads and fire loads in modern office buildings. BSS 16. Nat. Bur. Stand. Washington, D.C.

CONVENTION EUROPEENE DE LA CONSTRUCTION METALLIQUE. 1974. Fire safety in constructional steelwork. Report CECM III-74-2E.

COWARD, S. K. D. 1975. A stimulation method for estimating the distribution of fire severities in office rooms. Build. Res. Estab. Current Paper CP 31/75.

CROCE, P. A. 1975. A study of room fire development: the second full-scale bedroom fire test of the home fire project. FMRC Serial 21011.4, RC 75-T-31. Factory Mutual Research Corp. Norwood, MA.

CULVER, C. G. 1976. Survey results for fire loads and live loads in office buildings. BSS 85. Nat. Bur. Stand. Washington, D.C.

———, AND J. KUSHNER. 1975. A program for survey of fire loads and live loads in office buildings. Tech. Note 858. Nat. Bur. Stand. Washington, D.C.

EMMONS, H. W. 1977. Computer fire code (II). Home Fire Project Tech. Rep. 20. Harvard Univ. Cambridge, MA.

FORSBERG, U., AND J. THOR. 1971. Brandbelastningsstatstik for Skolar och Hotell. Rapport 44:1. Stalbyggnadsinstitutet. Stockholm.

INGBERG, S. H. 1928. Tests of the severity of building fires. Quarterly Rep. Nat. Fire Prot. Assoc. 22:43–61.

———, J. W. DUNHAM, AND J. P. THOMPSON. 1957. Combustible contents in buildings. Report BMS 149. Nat. Bur. Stand. Washington, D.C.

KAWAGOE, K. 1958. Fire behavior in rooms. Report 27. Build. Res. Inst. Tokyo.

———. 1967. Estimation of fire temperature-time curve in rooms. Research Paper 29. Build. Res. Inst. Tokyo.

———, AND T. SEKINE. 1963. Estimation of fire temperature-time curve in rooms. BRI Occasional Report 11. Build. Res. Inst. Tokyo.

LAW, M. 1971. A relationship between fire gradings and building design and contents. Joint Fire Res. Org. Fire Res. Note 877.

LIE, T. T. 1974. Characteristic temperature curves for various fire severities. Fire Tech. 10(4):315–326.

MAGNUSSON, S-E., AND O. PETTERSSON. 1972. Brandteknisk Dimensionering av Stalkonstruktioner. Chapt. 8 *in* Norrbottens Jarnverks AB Stalhandbook. Lulea.

———, AND S. THELANDERSSON. 1970. Temperature-time curves of complete process of fire development, Theoretical study of wood fuel fires in enclosed spaces. Acta polytechnia Scandanavia Civil Eng. Const. Ser. 65.

NILSSON, L. 1970. Fire loads in flats. Report R34. Statens Institut for Byggnadsforskning. Stockholm.

ODEEN, K. 1963. Theoretical study of fire characteristics in enclosed spaces. Bulletin 10. Division of Building Construction. Royal Inst. Tech. Stockholm.

PAPE, R., J. MAVEC, D. KALKBRENNER, AND T. WATERMAN. 1976. RFIRES program documentation and users guide—semistochastic approach to predicting the development of a fire in a room from ignition to flashover. Report to Nat. Bur. Stand. ITT Res. Inst.

REEVES, J. B., AND C. D. MACARTHUR. 1976.

Dayton aircraft cabin fire model. FAA-RD-76-120. Univ. Dayton Res. Inst.

ROBERTSON, A. F., AND D. GROSS. 1970. Fire load, fire severity, and fire endurance. ASTM Special Tech. Pub. 464:3–29.

ROCKETT, J. A. 1969. Objectives and pitfalls in the simulation of building fires with a computer. Fire Tech. 5:311–322.

RODAK, S., AND S. H. INGBERG. 1967. Full-scale residential occupancy fire tests of 1939. Unpubl. Rep. Nat. Bur. Stand. Washington, D.C.

SUPERINTENDENT OF DOCUMENTS. 1942. Fire resistance classifications of building constructions. Building Mater. Struct. Rep. 92. Washington, D.C.

TSUCHIYA, Y., AND K. SUMI. 1971. Computation of the behavior of fire in an enclosure. Combustion and Flame 16:131–139.

WITTEVEEN, J. 1966. Brandveiligheid Staalconstructies. Centrum Bouwen in Staal. Rotterdam.