UPHOLSTERED FURNITURE HEAT RELEASE RATES: MEASUREMENTS AND ESTIMATION

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ABSTRACT

A new instrument, termed a furniture calorimeter, has been constructed and placed into operation for measuring furniture heat release rates based on oxygen consumption. Using the furniture calorimeter, burning rate information has been obtained on a series of 13 chairs, loveseats, and sofas, most of them specially built to permit direct comparisons of construction features. A quantitative assessment is made of the effect of fabric types, padding types (cotton batting, ordinary polyurethane foam, and California-requirements foam), and frame types. The advantages of furniture calorimeter testing over normal room fire testing are discussed. Based on these measurements, a rule is presented for estimating the heat release rate based on design factors. Finally, implications for achieving both good flame resistance and good cigarette ignition resistance are discussed.

Key words: burning rate; chairs; flammability tests; furniture; heat release rate; plastics flammability; textile flammability; upholstered furniture.

INTRODUCTION

FURNITURE FIRES ACCOUNT FOR ROUGHLY HALF OF ALL THE FIRE deaths in the United States. These are primarily divided into upholstered furniture fires and bed fires, with about half the losses in each category. Thus, efforts in reducing upholstered furniture fire losses can have a significant effect on the over-all fire problem.

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Because of many unifying characteristics, it is convenient to divide furniture fires according to the ignition mode. Smoldering fires are those started typically by a discarded cigarette, but occasionally by electric cords, fireplace embers, etc. Flaming fires are those started by matches, cooking flames, or other flaming objects. Statistical analyses indicate that for all type of residential occupancies smoldering ignitions predominate; however, analysis of individual large fires and catastrophes more often points to flaming ignitions. It is commonly considered that there is no connection between good flaming ignition performance of upholstered furniture and good cigarette ignition resistance qualities; we shall, however, re-examine this point.

A test was developed at the National Bureau of Standards nearly a decade ago for quantifying furniture resistance to cigarette ignition. This has been documented [1] and presented to the U.S. Consumer Product Safety Commission (CPSC), which has the relevant regulatory authority.

In the present work we address the initial issues associated with developing appropriate test procedures for determining the behavior of upholstered furniture specimens under flaming ignition conditions. The long-range goal of this effort is the development of bench-scale test procedures which can be used to predict, to an adequate degree, the performance of interior furnishings in full-scale in a room. Here we report the first set of findings: heat release rates for a variety of upholstered furniture, along with an initial release rate estimating rule.

SOURCES OF FLAMING IGNITION

There is a considerable amount of confusion concerning the definition of "the first item to ignite." This first item in the great majority of flaming fires is a match. This definition is not sufficiently informative. We can envision a sequence where the match ignites the match book, which is dropped into a pile of newspapers, which ignites a sofa. This suggests that for "first item to ignite" we should infer "first large item to ignite," and define its "ignition source" as the one previous step in this chain. Thus, in this study we will assume that an upholstered chair is a typical first (large) item to ignite under study.

It is possible to ignite many, but not all typical upholstered chairs with a single match. It is possible to ignite all, except the especially fire-hardened, with a small plastic wastebasket aflame with some refuse [2]. In some places, e.g., England [3], this type of observation prompted the development of a graded ignition series, where a specimen is subjected to an ignition source of increasing size. This appears to protect against children playing with matches (and bunsen burners) but not against those who drop their matches on a newspaper pile, into a wastebasket, or who try to hide their fire under a pillow. While the best-performing specimens may, in fact, fail to ignite at all when subjected to a moderate source, the more common situation is where a well-performing specimen may ignite, burn briefly, and die out, releasing negligible heat [2]. Further, data are available [2] showing that furniture items of very similar ignition potential can have widely varying burning rates. These observations suggest that of primary importance is the rate of heat release of a fire once ignited, and that a realistically large but not excessive ignition source should be chosen. A small plastic wastebasket, filled with trash can be such a source. In the present study, a gas burner simulating the performance of a wastebasket was adopted. Its characteristics are described in a later section.

In the U.S. a test for behavior of upholstered furniture subjected to flaming ignition has been promulgated by the state of California [4]. This comprises separate, bunsen-burner type tests for upholstery fabrics and for padding materials. The padding materials are not covered by fabric in the tests. One objective of this study has been to assess the useability of results from this test as a measure for describing the burning rate of full-sized upholstered furniture pieces.

RATIONALE FOR MEASUREMENTS

Full-scale evaluations of furniture burning characteristics have generally been done by conducting room fire tests (e.g., [5,6]). Room fire tests are difficult to conduct due to cost and complexity and also due to problems of reproducibility. More important, in recent years it has become possible to calculate and predict [7,8] room fires behavior *if* the heat release rate(s) of the burning object(s) and other parameters are known. Thus, it becomes feasible to separate the problem: heat release data can be obtained on test objects burning under approximate free-ambient conditions, while the effects of the enclosing room can be computed numerically. With the room fire approach, a new test may be required if a different condition, such as a change in window opening size, is prescribed. With the open testing/mathematical calculation approach, only a new computer run is required. This type of separation, it should be added, does not hold after flashover (gas temperatures $> 600\,^{\circ}C$ near the ceiling, floor level radiant fluxes > 20 kW/m^2) is reached in the room. The burning rates after flashover is reached are, in fact, not simply related to the free-burn rate.

In the crudest sense, the burning rates of furniture items could be determined by burning them in the open on a weighing platform, calculating mass loss rates, and multiplying by an average heat of combustion. This is not ideal, both because numeric differentiation is required and because the effective heats of combustion may be difficult to determine and may vary during the course of the fire.

A test could be made where it is attempted to capture and measure all the heat released, both convective and radiative. This is difficult to do on any scale and would be especially difficult for full-size furniture.

Instead, the attractive features of the oxygen-consumption principle were used to design a simple test apparatus.

THE OXYGEN-CONSUMPTION BASED FURNITURE CALORIMETER

It has been known for some decades that most organic combustibles, when burned, release a nearly fixed quantity of heat *per unit oxygen consumed.* Heats of combustion per unit fuel mass vary by more than a factor of 2 for common combustibles [9]. However, the heat released per kg oxygen consumed is, to within about ± 5 percent, equal to 13.1×10^3 kJ/kg for all common combustibles. Huggett [10] has tabulated and discussed this constancy in detail.

It now becomes possible to consider a simple instrument for determining the heat release rates: all that is required is to measure oxygen concentration changes, which is easy, rather than trying to capture all the sensible heat, which is difficult. Figure 1 shows the instrument developed to take advantage of this measurement principle for upholstered furniture items. A weighing platform is included in order to document approximate heats of combustion. Heat release rates in the calorimeter are determined according to the equations developed by Parker [11]. The basic equation is

$$\dot{Q} = \frac{\Delta h_c}{r_o}\left(\dot{m}_{O_2,\infty} - \dot{m}_{O_2}\right)$$

where $\dot{Q}$ is the heat release rate (kW), $\Delta h_c/r_o$ is the constant 13.1×10^3 kJ/kg, $\dot{m}_{O_2}$ is the oxygen flow in the exhaust system during combustion (kg/s), and $\dot{m}_{O_2,\infty}$ is the oxygen flow without combustion. Additional theoretical considerations and operational details are reported in [12].

Specimens releasing more than ~2000 kW were tested under similar conditions in a large rig with a capacity of over 6000 kW, with lower resolution but similar in principle to the one depicted in Figure 1.

Ignition of test specimens was accomplished with a gas burner simulating a wastebasket fire placed adjacent to the left chair arm (Fig. 2). Earlier testing [2] had determined the wastebasket burning rate. For the present tests this was approximated as 50 kW for 200s (Fig. 3). A flux map of this burner is shown in Figure 4.

For characterizing the ignition potential for other fuel items, a single point target irradiance measurement was provided. This was made with a Gardon gage facing the fire 0.5 m in front of the specimen and at a height of 0.5 m.

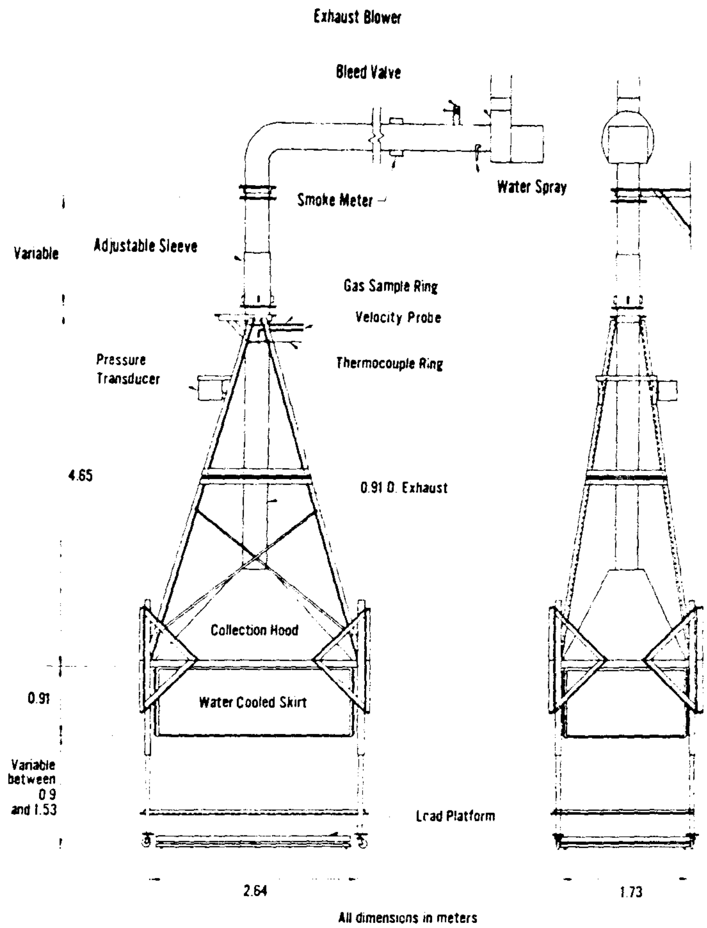


Figure 1. View of calorimeter

TEST SPECIMENS

One objective of the present tests was to be able to isolate the influence of different furniture materials. For this reason, the majority of the specimens were custom-made. These specimens (F21 through F26 and F29 through F32) were made by a furniture maker using normal construction practices, but varying one feature at a time: padding, fabric, frame, or total size. Table 1 gives details of the test pieces. Both ordinary and "California" (sold as meeting California state requirements—this was checked using the specified test method [4]) foams were procured from normal commercial wholesale channels. Figures 5 through 8 show some of the test specimens, along with views during peak burning.

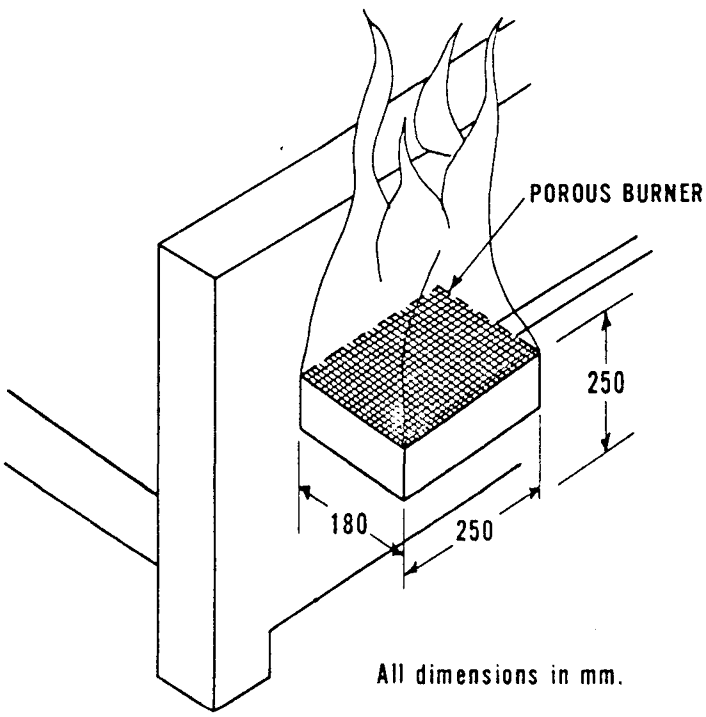


Figure 2. Wastebasket simulation burner used as the ignition source

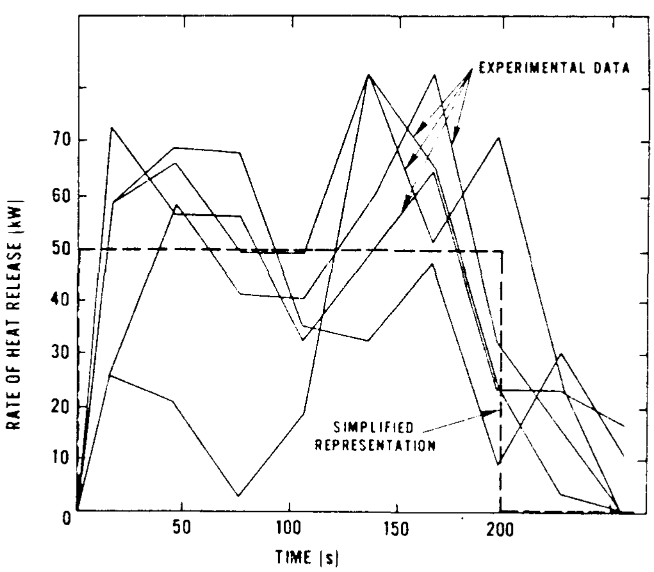


Figure 3. Measured wastebasket heat release rates, along with adopted simplified representation

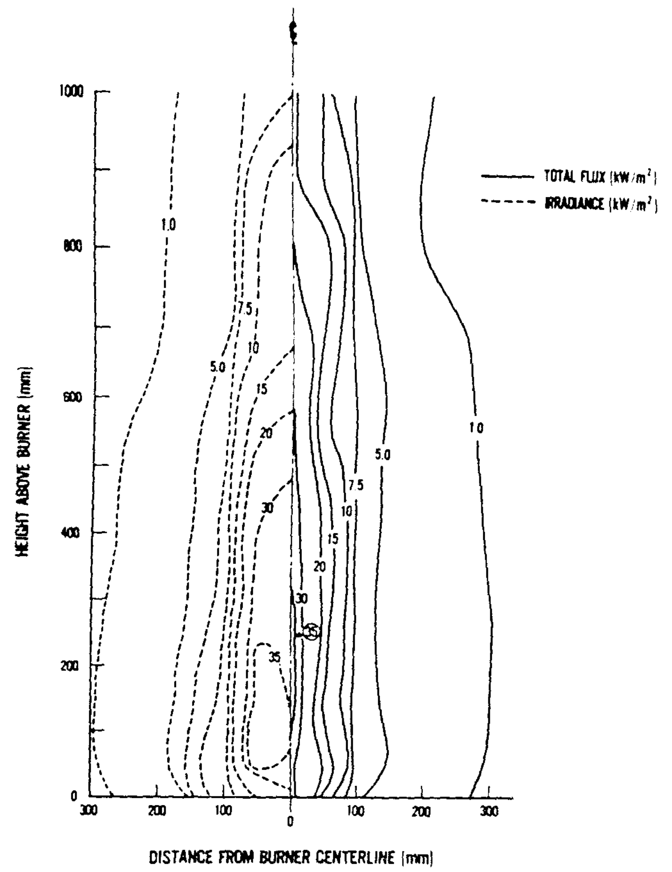
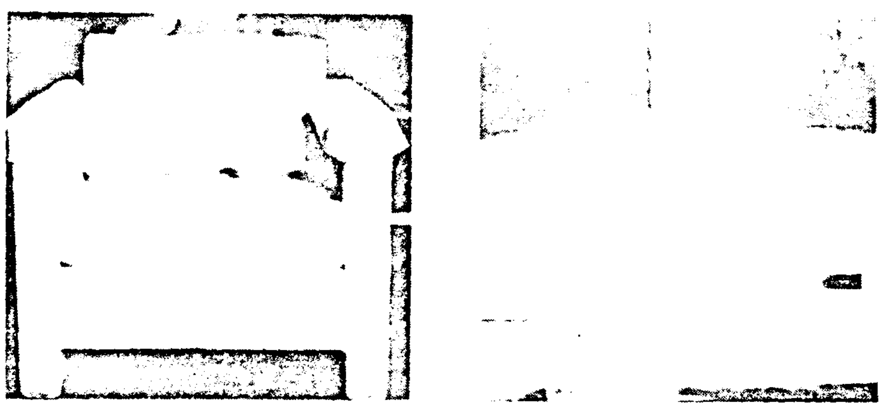
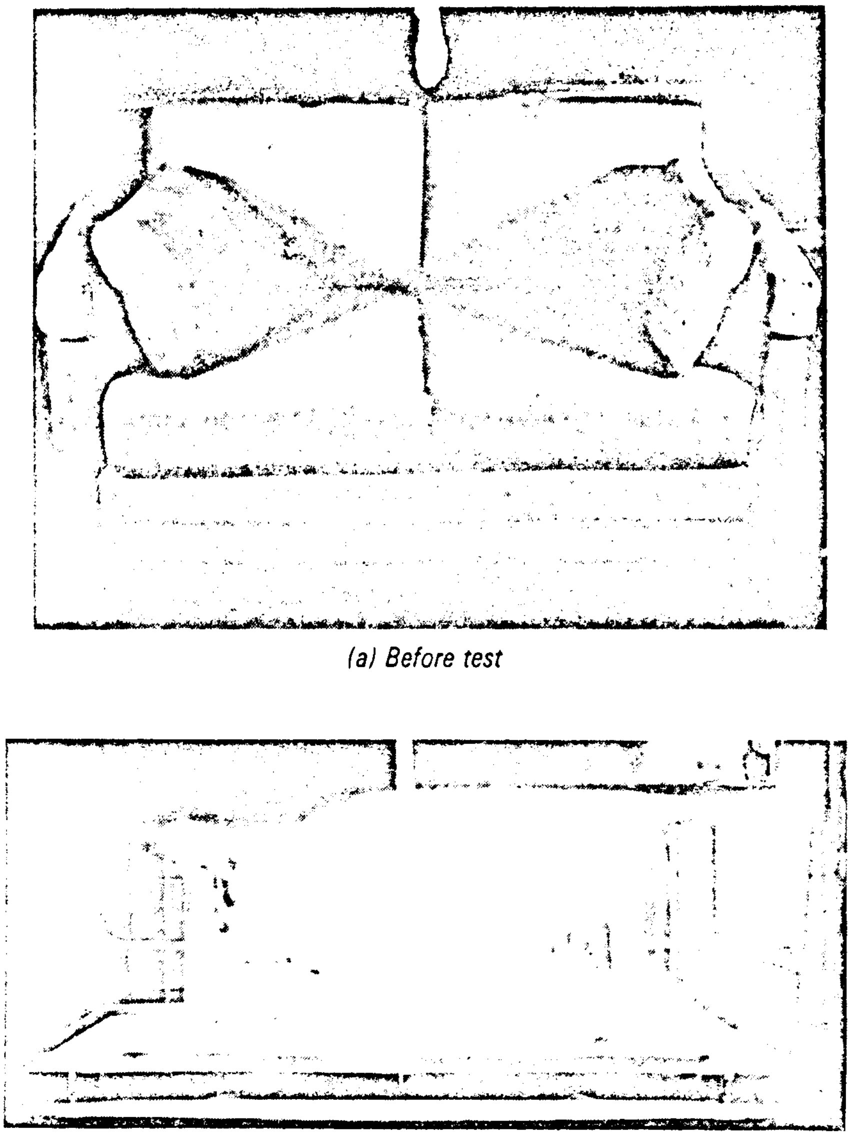


Figure 4. Fluxes measured at the wastebasket simulation burner (in a vertical plane adjacent to the 250 mm burner edge, which is against a non-combustible wall)



(a) Before test *(b) near peak burning time*

Figure 5. Chair F21



(a) Before test

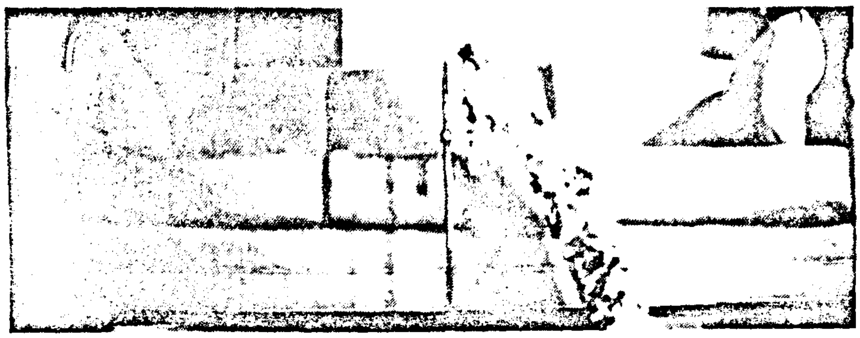
(b) Near peak burning time

Figure 6. Chair F31

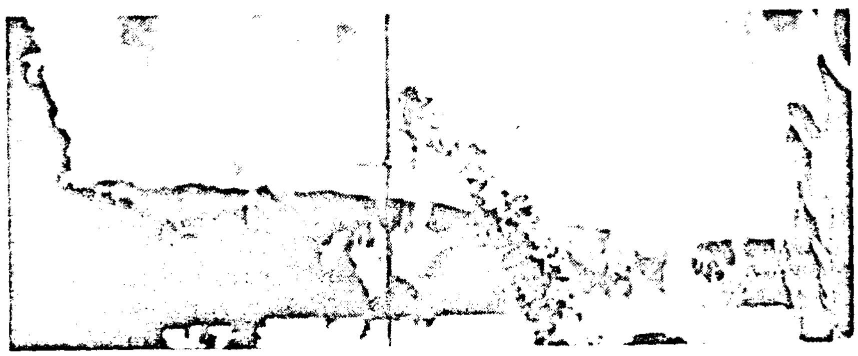
None of the test specimens included fire hardened constructions since such are not readily available on the commercial market.

TEST OBSERVATIONS

The ignition source burner successfully ignited all test specimens. Ignition times were short—on the order of 15 s for thermoplastic fab-

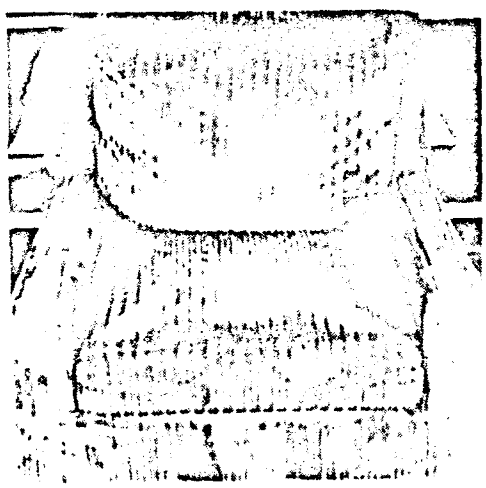


(a) Before test

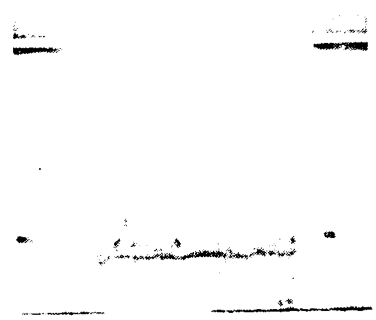


(b) Near peak burning time

Figure 7. Chair F32



(a) Before test



(b) Near peak burning time

Figure 8. Chair F28

Table 1. Test specimens

Chair	Tests	Mass (kg)	Padding Material	Fabric	Frame
F21	T19,T45	28.3	Calif. Foam	Polyolefin	Wood
F22	T24	31.9	FR Cotton Batting	Cotton	Wood
F23	T23	31.2	FR Cotton Batting	Polyolefin	Wood
F24	T22	28.3	Calif. Foam	Cotton	Wood
F25	T29	27.8	Non-Calif. Foam	Polyolefin	Wood
F26	T25	19.2	Calif. Foam	Polyolefin	Wood (Min. Weight)
F27	T26	29.0	Foam, Cotton, Polyester	Cotton	Wood
F28	T28	29.2	Foam, Cotton, Polyester	Cotton	Wood
F29	T27	14.0	Non-Calif. Foam	Polyolefin	Polypropylene
F30	T30	25.2	Non-Calif. Foam	Polyolefin	Polyurethane
F31	T31,T37	40.0	Calif. Foam	Polyolefin	Wood (Loveseat)
F32	T38	51.5	Calif. Foam	Polyolefin	Wood (Sofa)
F33	T18	39.2	Foam, Cotton	Cotton	Wood (Loveseat)

rics—and somewhat longer for cellulosic ones. Exact times were not recorded because of the difficulty of observing ignition obscured by the burner flame. As a measure of the time scale, the time to peak rate of heat release is considered much more important, as discussed below. The left (occupant's view) side arm, being adjacent to the burner, was the first to burn. From there flaming usually progressed to the outside back of the chair. A little later flames would start across the seat cushion and the inside back. The upholstery, on the right side arm melted in about 80-120 s for the case of thermoplastic fabrics. This allowed rapid fire involvement of the foam underneath. In the case of cellulosic fabrics, the spread was much slower; the right side arm typically ignited not from radiation at a distance, but at the time when continuous flame spread reached it, at about 250 s. The front of the chair was the last to get involved in all cases.

Most specimens showed some pool burning underneath the chair since even the cotton batting units had a polyolefin dust cover underneath the seat deck which melted in the fire. Some California foam specimens showed spurting of burning liquified polyurethane foam in small streams at the side. Neither this phenomenon nor the pool burning was judged to provide any significant increase in other item ignition potential, beyond that due to high radiant heat fluxes. The active burning period normally did not last beyond about 1800 s, since in that time the majority of foam and fabric would be consumed. The total burning time is very difficult to define since the last bit of smoldering may not be extinguished for several hours. Generally by about 1800 s the heat release rate was very small, about 50 to 100 kW; at 3600 s it was around 25 kW. For wood frames, total collapse had occurred by about 1500 s. For the polyurethane frame specimen, F30, collapse had occurred by 1200 s, while for the polypropylene frame specimen, F29, collapse was at around 900 s. This difference could be anticipated since the F29 frame melted during the burning and, in fact, contributed to the fire at the peak burning time, while the F30 frame was not thermoplastic and tended instead to char.

Tests were stopped and data gathering discontinued when all flaming had ceased. Most items slowly smoldered for several more hours, producing little heat.

RESULTS OF MEASUREMENTS

A summary of the data is presented in Table 2. Included are two repeat tests, which show agreement to better than 10%. Detailed performance is illustrated for specimen F21 in Figures 9 and 10. For purposes of this preliminary analysis, it was considered that there are two primary variables of interest—the peak rate of heat release and the time to reach the peak. The peak intensity values are needed to determine the worst room fire behavior. The time to reach the peak is also considered important because in many fires detection may be feasible at or very shortly after ignition. Thus, time for occupant escape can be partly controlled by the fire growth rate.

Table 2. Summary of test data

Chair	Test	Mass (kg)	Time to Peak (s)	Maximum $\dot{m}$ (g/s)	Maximum $\dot{Q}$ (kW)	Total Q (MJ)	Δh_c Near Peak (MJ/kg)	Δh_c Average (MJ/kg)	Peak Target Irradiance (kW/m²)
F21	T19	28.2	280	N.A.	1970	440	N.A.	18.1	49.
	T45*	28.3	260	83	2130	443	26.4	18.4	42.
F22	T24	31.9	910	25	370	425	14.8	14.9	3.7
F23	T23	31.2	450	42	700	461	16.8	16.1	14.
F24	T22	28.3	650	46	700	369	15.1	14.6	19.
F25	T29	27.8	260	80	1990	419	24.8	17.0	46.
F26	T25	19.2	240	61	810	300	13.2	18.0	32.
F27	T26	29.0	570	58	920	519	15.7	20.3	24.
F28	T28	29.2	420	42	730	369	17.2	14.9	12.
F29	T27	14.0	220	72	1950	446	27.1	35.1	39.
F30	T30	25.2	235	41	1060	363	26.0	20.9	17.
F31	T31	39.6	N.A.	N.A.	>2500	N.A.	N.A.	N.A.	>35.
	T37*	40.4	230	130	2890	614	22.2	17.5	99.
F32	T38*	51.5	250	145	3120	714	21.5	18.9	N.A.
F33	T18	39.2	560	75	940	453	11.9	13.9	N.A.

N.A. – Not Available

* – Test conducted in large test rig

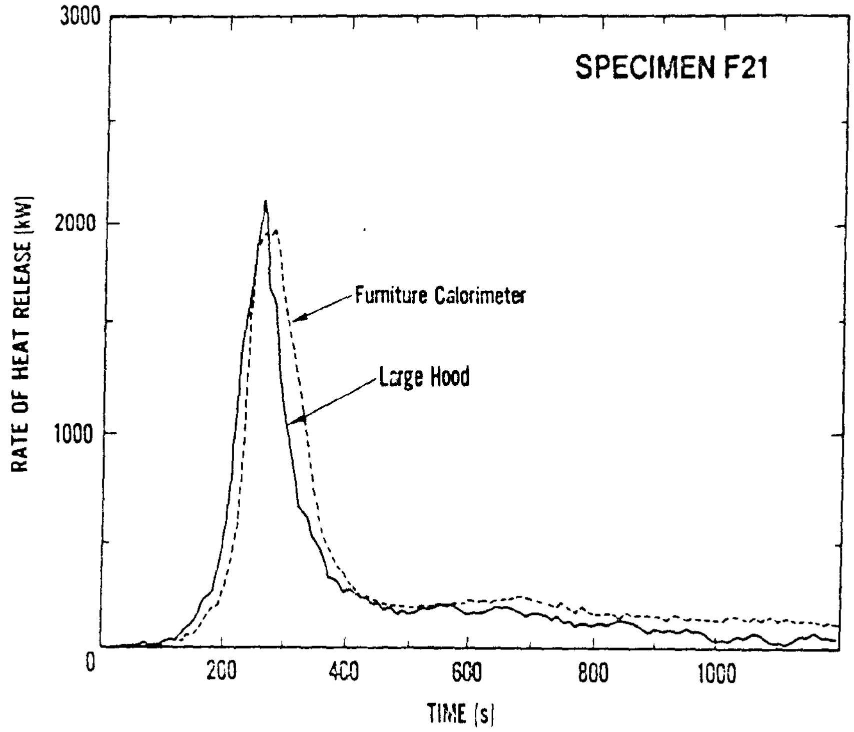


Figure 9. Rate of heat release for specimen F21

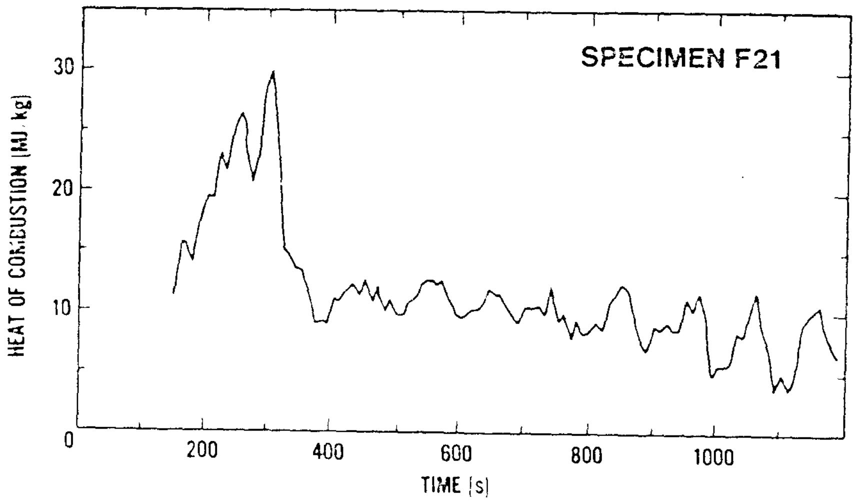


Figure 10. Effective heat of combustion for specimen F21

Table 3 shows the ranked peak times. Three distinct groups of results appear. Specimen F22, while showing flaming combustion from about 100 s to 1200 s, did not show a substantial rate of heat release peak (Fig. 11). The highest numerical value was registered at 910 s. Specimens F24, F27, F33, F33, F23, and F28 showed peak times in the range of 420-650 s. Finally, specimens F21, F25, F32, F30, F31, and F29 burned rapidly and showed peaks in the range of 220-280 s. The relative ranking within each of these groups is not considered significant. The constitution of each of these groups is striking, however. Clearly the slowest fire development occurred with an all-cellulosic construction. The fastest fire buildup happened with polyurethane foam padding combined with thermoplastic fabric upholstery. Constructions using cellulosic fabrics with polyurethane foam padding or, conversely thermoplastic fabrics with cotton batting showed a similar, intermediate buildup time. Mixed type fillings (e.g., both foam and batting in one chair) also fall into this category. It can be noted that foam type, i.e., whether ordinary or "California" type, had no effect on time to peak.

Peak rates of heat release are ranked in Table 4. Again, three distinct levels of performance can be seen. The all-cellulosic specimen, F22, performed the best, releasing only 370 kW at peak. Next came a large number of specimens clustered in an intermediate heat release range, 700 to 1060 kW. Finally came a group showing rates 2 to 4 times again as large as the previous, with the values ranging from 1950 kW to 3120 kW. With two exceptions, the members of the best, intermediate, and

Table 3. Ranked Peak Times

Specimen	Time to Peak (s)	Padding	Fabric
F22	910	Cotton	Cotton
F24	650	PU Foam, C*	Cotton
F27	570	Mixed	Cotton
F33	560	Mixed	Cotton
F23	450	Cotton	Polyolefin
F28	420	Mixed	Cotton
F21	280	PU Foam, C	Polyolefin
F25	260	PU Foam, NC	Polyolefin
F32	250	PU Foam, C	Polyolefin
F26	240	PU Foam, C	Polyolefin
F30	235	PU Foam, NC	Polyolefin
F31	230	PU Foam, C	Polyolefin
F29	220	PU Foam, NC	Polyolefin

*PU = Polyurethane; C = California Foam;
NC = Not California Foam

Table 4. Ranked peak heat release values

Specimen	Peak $\dot{Q}$ (kW)	Padding	Fabric
F22	370	Cotton	Cotton
F24	700	PU Foam, C*	Cotton
F23	700	Cotton	Polyolefin
F28	730	Mixed	Cotton
F26	810	PU Foam, C	Polyolefin
F27	920	Mixed	Cotton
F33	940	Mixed	Cotton
F30	1060	PU Foam, NC	Polyolefin
F29	1950	PU Foam, NC	Polyolefin
F21	1970	PU Foam, C	Polyolefin
F25	1990	PU Foam, NC	Polyolefin
F31	2890	PU Foam, C	Polyolefin
F32	3120	PU Foam, C	Polyolefin

*PU = Polyurethane; C = California Foam;
NC = Not California Foam

lowest groups were the same for both the time to reach the peak and for the peak burning rate itself. The differing ones were F26 and F30. Both of these have thermoplastic upholstery and polyurethane foam padding. Chair F26 was a "minimum weight" specimen, so while it reached its peak burning rate quickly it did not have as much fuel to burn as other specimens. Chair F30 had the rigid polyurethane foam frame. The results indicate that while replacing cotton batting padding with flexible polyurethane foam normally acts to increase the burning rate significantly, replacing the wood frame with a comparable polyurethane one not only did not increase the heat release rate but in this case actually decreased it. This is striking but perhaps not unexpected since the rigid polyurethane frame predominantly charred rather than melted.

A detailed comparison of the effects of construction features is presented in Figures 11 and 12 and in Tables 5 through 8. Table 5 shows the effect of different padding types, for a given fabric. Type of foam ("California", or ordinary) is seen to have no effect. For a given fabric type, however, cotton batting construction produces less than half the rate of heat release as polyurethane foam or mixed types. Mixed type constructions can be of various sorts but—within a fairly wide amount of scatter—show heat release similar to the all-foam and not to the all-cotton batting types.

The effect of fabric types is explored in Table 6. For a given filling material type, the cellulosic (cotton) fabric specimens had a rate of heat release of less than half that of the thermoplastic (polyolefin) fabric specimens.

Within a given construction type, total specimen mass can be expected to be a major factor. The relationship is shown for polyurethane foam types in Table 7. An approximately linear dependence on specimen mass is seen on the heat release rate, with no effect on time to peak.

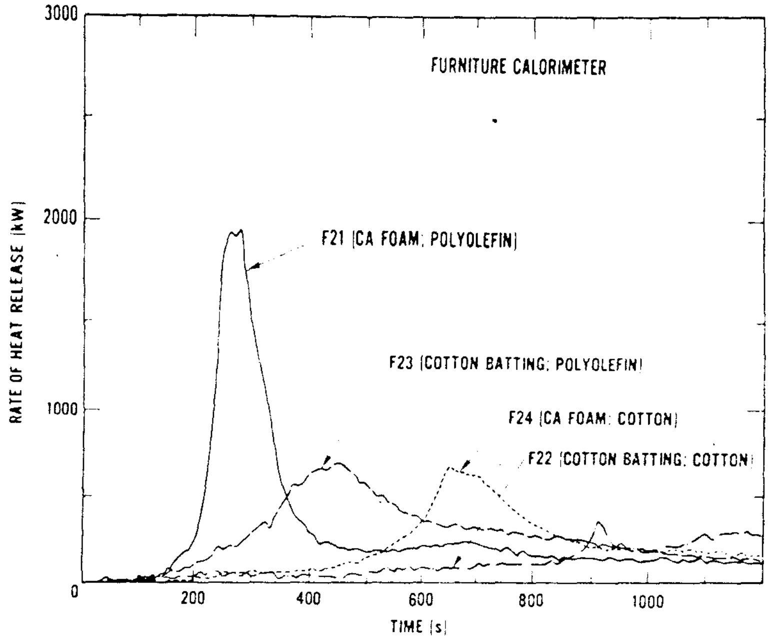


Figure 11. Effect of specimen padding and fabric on rate of heat release

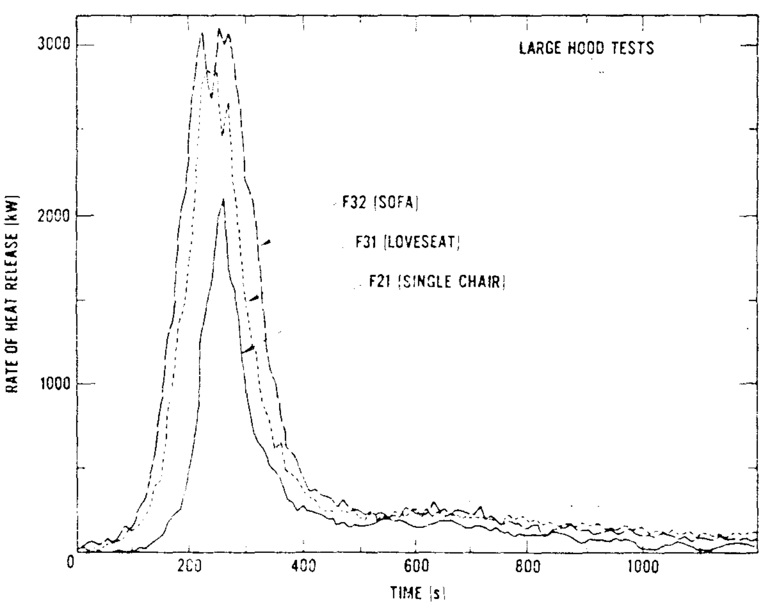


Figure 12. Effect of specimen mass on rate of heat release

Table 5. Effect of padding type for specimens with similar fabrics

Specimen	Peak $\dot{Q}$ (kW)	Time to Peak (s)	Padding	Fabric
F21	1970	280	California Foam	Polyolefin
F25	1990	260	Non-California Foam	Polyolefin
F21	1970	280	California Foam	Polyolefin
F23	700	450	Cotton	Polyolefin
F24	700	650	California Foam	Cotton
F22	370	910	Cotton	Cotton
F27	920	570	Mixed	Cotton (not identical to above)
F28	730	420	Mixed	Cotton (not identical to above)

Table 6. Effect of fabric type for specimens of similar construction and padding

Specimen	Peak $\dot{Q}$ (kW)	Time to Peak (s)	Fabric	Padding
F24	700	650	Cotton	California Foam
F21	1970	280	Polyolefin	California Foam
F22	370	910	Cotton	Cotton
F23	700	450	Polyolefin	Cotton

Table 7. Effect of specimen mass on polyurethane foam padded specimens of similar construction

Specimen	Peak $\dot{Q}$ (kW)	Time to Peak (s)	Mass (kg)	Comments
F26	810	240	19.2	Minimum Weight Chair
F21	1970	280	28.2	Standard Chair
F31	2890	230	40.0	Loveseat
F32	3120	250	51.5	Sofa

Table 8. Effect of frame type for specimens with similar padding and fabrics

Specimen	Mass (kg)	Peak $\dot{Q}$ (kW)	Peak $\dot{Q}$ ÷ Mass	Time to Peak (s)	Frame	Foam	Fabric
F25	27.8	1990	72	260	Wood	Non-Calif.	Polyolefin
F30	25.2	1060	42	235	Polyurethane	Non-Calif.	Polyolefin
F29	14.0	1950	139	220	Polypropylene	Non-Calif.	Polyolefin

Finally, frame type is seen to have a significant effect on the peak rate of heat release, though not on the time to reach the peak (Table 8). Traditional wood framing is shown to exhibit an intermediate behavior. Structural plastic foam chair frames are available in two types—thermoplastic (polypropylene and polystyrene) and thermosetting (rigid polyurethane). Polystyrene frames were not tested because they are used only in specialized applications and are not readily available. The chair with the polypropylene frame, F29, showed a rate of heat release almost identical to the comparable wood frame unit, F25. It, however, had only half the mass of F25. Thus, on a mass basis it would have to be considered twice as fast burning. (Component weight breakdowns are not available, but Table 7 suggests that for specimens using wood or plastic frames it is not unreasonable to approximate rates of heat release on the basis of total mass.) The polyurethane frame specimen, F30, showed considerably slower burning, for a roughly similar specimen mass. Apparently this frame is not only slow to contribute to the fire itself, but also by maintaining its integrity it can help reduce the role of fuel contribution from the uncovering of fresh fuel. Wood frames, by contrast, tend to fail in a fire at metal connection points.

TARGET IRRADIANCE

Peak target irradiance values are also given in Table 2. In [2] a simplification was established by dividing target fuels into three groups. The "especially easily ignitable" ones could ignite at an irradiance of 10 kW/m^2. "Normal" ignitability level was taken as 20 kW/m^2, while "difficult to ignite" objects corresponded to 40 kW/m^2. The furnishings examined in [2] were primarily slow-burning institutional and office furniture, as contrasted to the residential type items used in the present series. A comparison between the maximum radiant flux values observed during the course of the present tests and those recorded in the previous test series is shown in Figure 13. The fluxes, for a given peak mass loss rate, were substantially lower in the present series. This is partly explained by the fact that the relationship derived from the earlier tests was taken on a worst case basis. In those tests there was a substantial difference between worst case and average or typical performance. In the present case there is little deviation from a single relationship, as shown by the close fit of points in Figure 13. Additional study of the relationship between an item's mass loss rate and the target irradiance values seems warranted.

EFFECTIVE HEATS OF COMBUSTION

For modeling room fires, for estimating fuel loads and for other purposes, it is often desirable to know approximate heats of combustion for furniture. The effective heat of combustion is defined here as the heat release rate divided by the mass loss rate. A typical computed effective heat of combustion curve is shown in Figure 10 for specimen F21. Results for all the specimens are shown in Table 2, computed both for the whole period of active burning and for the time near the peak. In Table 9, a summary is given, grouped according to type of construction. Differences in padding and fabric do make some difference, but for wood-framed specimens most effective heat of combustion values are concentrated in the narrow range of 15 to 18 MJ/kg. Polypropylene framed construction, however, results in a significantly higher value, due to the high value of the net heat of combustion for polypropylene—43.2 MJ/kg [9]. The average effective value for specimen F29 was 35 MJ/kg, approximately double that for the others. Most specimens showed a behavior similar to F21—higher initial values of the heat of combustion were followed by lower values for charring frame combustion.

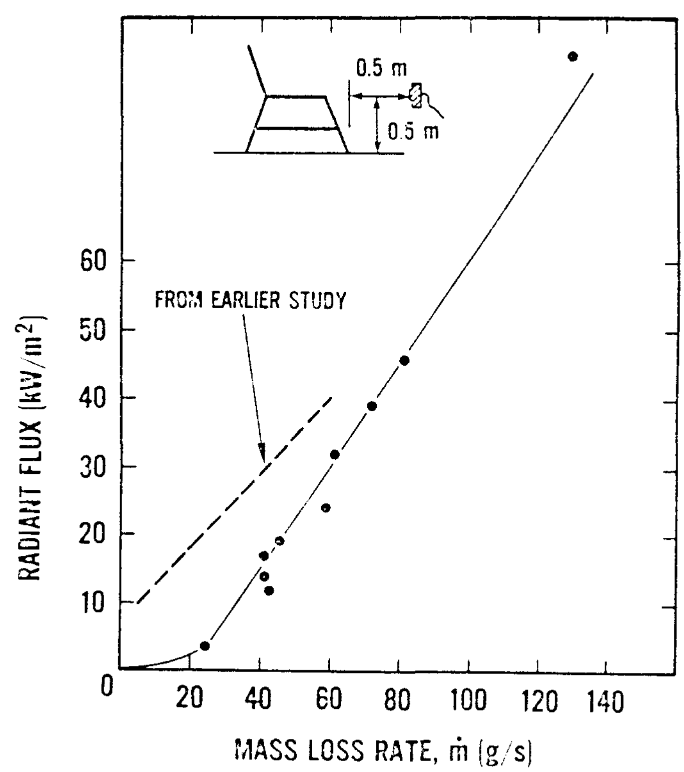


Figure 13. Relationship between mass loss rate and target irradiance

Table 9. Effect heats of combustion (averaged over entire test period)

Construction				
Padding	Fabric	Frame	Specimens	Average Effective Heat of Combustion (MJ/kg)
PU Foam	Polyolefin	Wood	F21, F25, F26, F31, F32	17.9
PU Foam	Cotton	Wood	F24	14.6
Mixed	Cotton	Wood	F27, F28, F33	13.9-20.3
Cotton	Polyolefin	Wood	F23	16.1
Cotton	Cotton	Wood	F22	14.9
PU Foam	Polyolefin	Polyurethane	F30	20.9
PU Foam	Polyolefin	Polypropylene	F29	35.1

ANALYSIS FOR ESTIMATION

The eventual goal of the present investigations is to develop a bench-scale test protocol whereby samples are cut from upholstered chairs and tested for rate of heat release and other properties. Testing full-sized specimens would then not be required. This procedure is not yet available. Furthermore, in some cases, say for fire hazards surveying of existing buildings and occupancies, this may never be appropriate. Thus, at this time, based on the existing test data, it was found that a useful rule can be constructed. The rule states that the peak heat release rate, $\dot{Q}_{peak}$, in kilowatts, can be approximated by a series of factors:

$$\dot{Q}_{peak} = (\text{mass factor}) \times (\text{frame factor}) \times (\text{style factor}) \times (\text{padding factor}) \times (\text{fabric factor})$$

The factors are computed as follows:

$$\text{Mass Factor} = 64. \times (\text{total mass, kg})$$

$$\text{Frame Factor} = \begin{cases} 1.0 \text{ for wood} \\ 0.6 \text{ for (rigid) polyurethane foam} \\ 2.0 \text{ for (thermoplastic) polypropylene foam} \end{cases}$$

$$\text{Style Factor} = \begin{cases} 1.0 \text{ for plain, primarily rectilinear construction} \\ 1.5 \text{ for ornate, convoluted shapes, with} \\ \text{intermediate values for intermediate shapes} \end{cases}$$

$$\text{Padding Factor} = \begin{cases} 1.0 \text{ for polyurethane foam, ordinary or California} \\ 0.4 \text{ for cotton batting} \\ 1.0 \text{ for mixed materials filling} \\ 0.4 \text{ for polychloroprene foam*} \end{cases}$$

Fabric Factor = { 1.0 for thermoplastic fabrics (fabrics which melt prior to burning)
0.4 for cellulosic fabrics (cotton; also rayon, line, etc.)
0.25 for PVC/PU type coverings** }

The above rule is useful only for estimating the behavior of pieces generically similar to the ones included in the testing program. Thus single-piece molded chairs, bean bag chairs, built-in furniture and other specialty items are not included. A few of these types were included in an earlier [5] study, where some observations on details of burning are recorded.

A comparison between actual heat release values and ones estimated by the above rule is given in Figure 14. It is not appropriate to quantify the goodness-of-fit of this relationship, since predictive value is expected to vary according to how close the construction resembles these chosen as "typical." The chosen frame and style factors are very general. Additional studies of a wider range of specimens could produce more detailed factor variables and ranges.

Minimum time to peak can be estimated as

≅ 250 s for thermoplastic fabrics over polyurethane foam
≅ 900 s for cellulosic fabrics over cotton batting
≅ 550 s for all others.

based on the selected scenario of a wastebasket fire ignition. These times would be significantly greater if a smaller ignition source were used. The peak release *value*, however, can be considered independent of ignition source type, provided specimen ignition is achieved.

ON ACHIEVING BOTH CIGARETTE IGNITION RESISTANCE AND GOOD FLAMING BEHAVIOR

From furniture cigarette ignitability tests, it is seen that cellulosic fabrics perform generally less well than thermoplastic ones and that polyurethane foams might be preferred because, unlike cotton batting, they do not have to be specially treated to achieve cigarette ignition resistance [1]. Thus, while at first glance cigarette resistance and good

*Estimate based on extrapolation from earlier work [13]. This value would also be applicable to the best available highly retardant treated polyurethane foams but in practice this distinction cannot be made without detailed testing.
**This is an extension based on recent unpublished work. Into this group of coverings are placed those which have a thick layer of polyvinylchloride (PVC) or polyurethane (PU) material supported on a fabric scrim. The construction is often found in washable waiting room chairs and in imitation leather chairs.

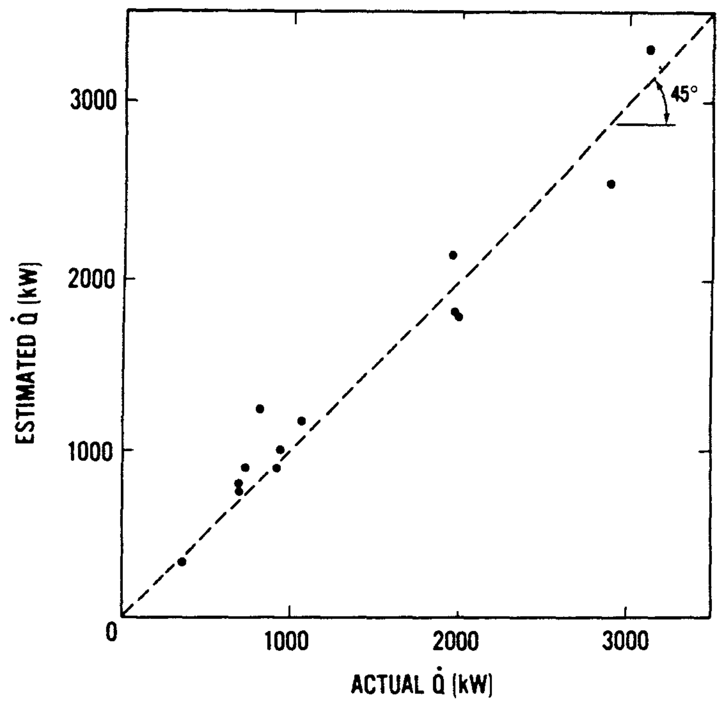


Figure 14. Relationship between actual and estimated peak values of rate of heat release

flaming behavior might seem antagonistic goals, this need not be the case. Some readily available materials are known to perform well in both cases—wool fabric and polychloroprene foams are such examples. Both of these have the drawback of being relatively costly. Other possibilities are the PVC/PU type coverings mentioned earlier. These tend to show good behavior in both cases, but may not be acceptable from the point of view of comfort.

It is, however, likely that comfortable designs can be worked out which combine materials of modest cost in such a way as to achieve good overall performance for both cigarette ignition and flaming situations. Polyurethane foams are, for various manufacturing reasons, much preferred in the furniture industry. It has been seen [13] that it is possible to produce highly fire retardant polyurethane foams that have performance similar to polychloroprene. Unfortunately, costs and foam density are also comparable. A more fruitful approach may be to protect polyurethane foams with an interliner. Polychloroprene interliners intended for this use have recently come on the market. While this does not reduce the fuel load, it can delay fire development and reduce peak burning rates. When a heavy cellulosic fabric is used on polyurethane foam, it burns slowly when subjected to flames and does not expose the foam itself to flames for some time; however, it is difficult to achieve cigarette ignition resistance with a heavy cellulosic fabric. On the other hand, it was seen in the present test series that common thermoplastic fabrics tend to melt quickly when exposed to heating. Thus, they expose the foam to rapid heating from flames and from radiation early in the fire. An interliner may only provide a modest additional benefit when used under a cellulosic fabric but can be of significant benefit under a thermoplastic one. The use of some early polychloroprene-based interliners has been studied [5,13]. An extensive testing program in Great Britain resulted in recommendation for the use of cotton cambric as an interliner [14]. Additional cigarette resistance and durability can be imparted to such a cambric by bonded aluminized and thermoplastic layers, as has been done in experimental systems.

For the choice of fabrics, additional investigation is likely to show modestly priced types beyond the PVC/PU films that can have both smolder resistance and good resistance to rapid flame propagation. Since poor flaming condition behavior is largely attributed to the fabric melting away and opening up quickly, charring fiber materials, such as modacrylics and matrix fabrics, should be investigated.

SUMMARY

The advantages of open—as opposed to room—fire testing have motivated the construction of an oxygen consumption based furniture calorimeter. The primary effort described here generated comparative burning rate data on a set of upholstered furniture pieces where only one construction feature was varied at a time. The findings showed that for the range of constructions examined:

(a) Furniture using polyurethane foams with retardants added to meet California state requirements did not show any reduction in rate of heat release compared to ordinary polyurethane foams.

(b) For foam-paded chairs, the rate of heat release was proportional to specimen mass, i.e., for comparable specimens, those that weighed more showed higher rates of heat release. This indicates that any realistic testing or evaluation procedure must include both testing of bench-scale specimens and consideration of object total mass.

(c) Furniture using padding materials made of cotton batting showed lower rates of heat release and slower fire buildup than those using polyurethane foams or battings of mixed fibers.

(d) Furniture using cellulosic fabrics showed lower rates of heat release and slower fire buildup than those using thermoplastic fabrics. Cellulosic/thermoplastic blends were not investigated.

(e) Structural foam frames showed widely differing behaviors. A frame of a charring plastic was seen to give a better lower heat

release rate than a wood frame, while a melting, thermoplastic frame material led to a substantially greater heat release.

(f) A very approximate set of rules was suggested for estimating the rate of heat release of upholstered furniture based only on known weights and construction. This can be useful in hazards surveying work.

Finally, it is emphasized that limited heat release behavior during flaming exposure and good cigarette ignition resistance are not necessarily mutually exclusive and that reasonable designs can enhance both. Flexibility of choice in the marketplace thereby may be traded off against enhanced fire safety performance.

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