Chair Burns in the TB133 Room, the ASTM Room, the Furniture Calorimeter and the Cone Calorimeter

WILLIAM PARKER and KING-MON TU
Building and Fire Research Laboratory
National Institute of Standards and Technology, USA

SAID NURBAKHSH and GORDON DAMANT
Bureau of Home Furnishings and Thermal Insulation
State of California Department of Consumer Affairs, USA

ABSTRACT

Ten sets of upholstered chairs were tested in the California Technical Bulletin 133 (TB133) room, in the proposed ASTM room and in the NIST furniture calorimeter. The chairs varied only in the type of fabric, type of foam, and whether or not there was a fiberglass interliner present. The rooms were instrumented to measure the total heat release rate of the chairs. A relationship was established between the peak heat release rate in the rooms and the temperature rise 25 mm below the ceiling above the chair. The combinations of fabric, fiberglass interliner and foam were also tested in the Cone calorimeter. A correlation of the full scale and bench scale results for this set of chairs was obtained. Calculations were made of the upper layer temperature in the room, using Hazard I and the measured heat release rates.

KEYWORDS: Furniture, Furniture Calorimeters, Cone Calorimeters, Room Burns, Heat Release Rate, Computer Models.

INTRODUCTION

The California Technical Bulletin 133 test (TB133) [1], developed at the California Bureau of Home Furnishings (CBHF) in Sacramento, is a flammability test procedure for seating furniture for use in public occupancies (hotels, prisons, nursing homes, etc). The Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST), in collaboration with CBHF, recently undertook a study of this test and its procedures with a view toward possible improvements [2].

The TB133 test is conducted in a 3.0 m by 3.7 m (10 by 12 ft.) room with a ceiling height of 2.4 m (8 ft) and a 1.0 m by 2.1 m (38 by 81 inch) open doorway in one corner. The walls and ceiling are lined with gypsum board. The furniture is located on a weighing platform in the rear corner farthest from the doorway. The ignition source (prior to the 1991 edition) was five double sheets of loosely wadded newspaper placed at the back of the seat and confined by a chicken wire cage. Temperatures, CO concentration, smoke opacity, and mass loss are measured during the test. One of the requirements for passing the TB133 is that the temperature rise measured 25 mm below the ceiling directly over the chair must not exceed 111°C (200°F). An analysis by Quintiere [3] identified the heat release rate as the principal hazard of upholstered furniture.

Three major issues of concern were (1) the reproducibility of the newspaper ignition source, (2) the need to run the test in a room with these particular dimensions rather than in the 2.4 m by 3.7 m ASTM room which many of the testing laboratories already have for evaluating interior finish materials, and (3) the development of a relationship between the peak temperature rise in the room and the peak heat release rate of the chairs. Such a relationship could be used to define an equivalent heat release rate criterion so that the test might be run in the furniture calorimeter. As part of this project, Ohlemiller and Villa [4] proposed a gas burner as an alternative ignition source. This burner has now replaced the newspaper ignition source. The other issues which involve temperature and heat release rate are discussed in this paper.

The ASTM room refers to the proposed ASTM room fire test for interior finish materials [5]. This room is 2.4 by 3.7 m (8 by 12 ft.) with a 2.4 m (8 ft.) ceiling and a 0.76 by 2.0 m (30 by 80 in.) doorway at the center of one of the 2.4 m (8 ft.) walls. The chair to be tested was located in one of the rear corners and was ignited with the standard TB133 newspaper ignition source. For this project the ASTM room which was located at NIST was lined with ceramic fiberboard and instrumented identically to that of the TB133 room at CBHF.

EXPERIMENTS

Instrumentation was added to the exhaust duct of the TB133 room in order to measure the rate of heat release by oxygen consumption. A 0.13 mm (0.005 in.) type K thermocouple was added 100 mm down from the center of the ceiling. The tests were run in accordance with TB133.

Ten sets of upholstered chairs were tested in the ASTM room and in the furniture calorimeter [6] at NIST. Chairs from each of the six sets having the lowest flammability were tested in the TB 133 room at CBHF. The chairs in the different sets varied only in the type of fabric, type of foam, and whether or not there was a fiberglass interliner present. The combinations of fabric, fiberglass interliner and foam were tested in the Cone calorimeter [7] in order to examine the correlation between the full scale and bench scale results. The tests in the Cone calorimeter were run in the horizontal orientation at an external radiant heat flux of 35 kW/m^2. This is the heat flux specified in the proposed NFPA 246A standard for the use of the Cone calorimeter for upholstered furniture [8]. The three minute average heat release rate and heat of combustion of the fabric, interliner and foam combinations for all of the chairs in the test series were measured in the Cone calorimeter. The averaging period began with the time of ignition. Calculations were made of the upper layer temperature in the room, using HAZARD I [9] with the measured heat release rates in the room as input data.

MATERIALS

The material combinations tested in the full-scale upholstered furniture tests were based upon the use of two foam types, a fiberglass interliner, and four fabrics. The foams investigated were melamine-treated polyurethane foam and a less fire-retarded polyurethane foam that had simply passed the California Technical Bulletin 117 test (TB117) [10]. The four fabrics were nylon, polyolefin, a fire retardant polyvinylchloride, and wool. The combinations are listed in Table 1.

TABLE 1. Combinations of Materials Used in the Full Scale Tests.

Chair Code	Material Description	Chair Code	Material Description
A	Wool Fabric TB117 Foam	B	Wool Fabric Interliner TB117 Foam
C	Nylon Fabric Melamine Foam	D	Nylon Fabric Interliner Melamine Foam
E	Nylon Fabric TB117 Foam	F	Nylon Fabric Interliner TB117 Foam
G	PVC Vinyl Fabric TB117 Foam	H	PVC Vinyl Fabric Melamine Foam
I	Polyolefin Fabric Interliner TB117 Foam	J	Polyolefin Fabric TB117 Foam

The chairs were of plain rectilinear construction with side arms and wood frames. This geometry was selected to provide a worst case scenario, in as much as the side arms, if they ignite, would irradiate the seat and chair back, helping to sustain flaming. Experience has shown that chairs with upholstered or closed arms exhibit a greater probability of failing the TB 133 test. A single manufacturer was selected to construct the chairs to assure that they were all identical in so far as possible. The chairs were 915 mm wide, 880 mm deep, and 775 mm high, with a seat height of 460 mm.

RESULTS

The general shape of the heat release rate curve for upholstered chairs consists of two peaks. The first is associated principally with the fabric and the second with the foam. However, this curve degenerated to a single peak in the case of Chairs B, D and H because there was little or no involvement of the foam. For chairs A, C, E and J the involvement of the foam was so rapid that the two peaks merged. Hence it was only chairs F, G and I that exhibited two distinct peaks. One of the complexities in the burning of these upholstered chairs is the transition from smoldering to flaming combustion. For chairs F, G and I there was a significant heat release rate at some time during the first few minutes associated with the burning of the fabric. Then the flame was reduced to a very low level or died out completely. The chairs continued to smolder for some time before the foam burst into flame with a much larger heat release rate. Only chairs B and D satisfied the temperature criterion of less than 111°C rise for the thermocouple just below the ceiling above the chair.

TABLE 2. Maximum Temperature Rises and Maximum Heat Release Rates During Fabric Peaks in the ASTM and TB133 Rooms.

CHAIR	TEMPERATURE RISE (°C)		HEAT RELEASE RATE (kW)	
CODE	ASTM	TB133	ASTM	TB133
B	54	61, 48	25	31*, 16
D	107	109, 70	64	70*, 43
H	120	141, 143	80	130*, 68
G	165	163, 171	101	125, 119
I	184	170, 225	152	102*, 141
F	215	38, 204	211	123, 172

* Calculated from rate of mass loss.

Table 2 compares the maximum temperature rises and the maximum heat release rates in the ASTM and TB133 rooms for the fabric peaks of those chairs for which the fabric and foam peaks were distinct. The first tests conducted in the TB133 room were done before the heat release rate instrumentation was installed. The heat release rates for these tests were calculated from the mass loss rate during the test and the heat of combustion measured in the Cone calorimeter. Within the limitations of the small number of chairs tested and scatter of the data the results of the tests in the two rooms are similar.

The maximum temperatures measured 25 mm below the ceiling above the chair in all of the tests conducted in the TB133 and ASTM rooms are plotted against the maximum heat release rate in Fig. 1. The depression of the temperature at 2.8 MW is probably real. The fire has become ventilation limited so that any increase in the rate of pyrolysis simply leads to more burning outside the room without contributing to any increase in the interior temperature. Indeed the unburned pyrolysis products in the room actually lower the room temperature slightly due to dilution. This curve makes it possible to predict the temperature rise in either the TB133 room or the ASTM room from the heat release rate measured in the furniture calorimeter provided that the interaction with the room does not have a significant impact on the total heat release rate of the chair. This interaction would be due to heat feed back and ventilation restrictions. When the lower region of the curve in Fig. 1 was expanded and additional data were included, it was found that the criterion of 111°C temperature rise was equivalent to a peak heat release rate of 65 kW.

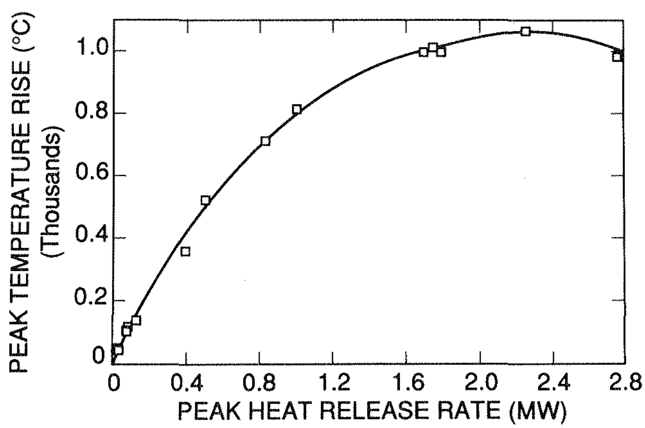

FIGURE 1. Temperature Rise vs. Heat release Rate for TB133 and ASTM Rooms

The peak heat release rates measured in the TB133 and ASTM rooms are plotted against the peak heat release rate in the furniture calorimeter in Fig. 2. The lower solid line in the plot is the equality line. Except for one outlier, chair F, the peak heat release rate in the room is similar to that in the furniture calorimeter for heat release rates under 600 kW. Beyond that point the heat feedback from the hot upper layer and room surfaces enhances the burning rate significantly as seen from the upper line in Fig. 2.

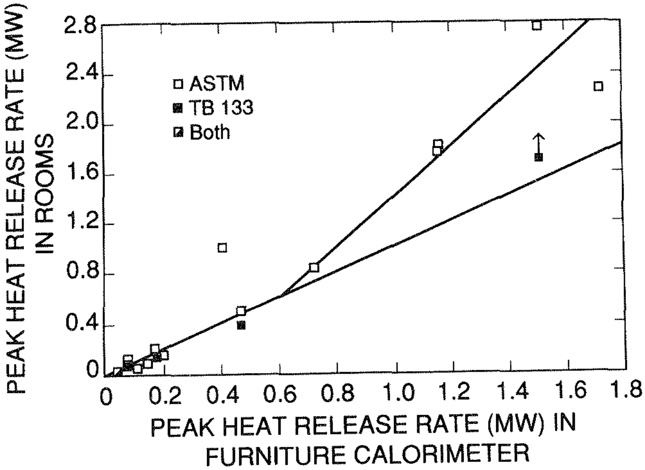

FIGURE 2. Heat Release Rates in Rooms and Furniture Calorimeter

The heat release rates measured as a function of time in the ASTM room were used in HAZARD I to calculate the temperature histories of the upper layer for all ten chairs. In Fig. 3 the peak calculated values are compared with the peak measured values 100 mm below the ceiling at the center of the room. Except for Chair E, the points fall close to the equality line. Chair E had a considerably higher heat release rate than any of the other chairs but a significant fraction of the burning took place outside of the room. The calculations performed with HAZARD I assumed all of the heat was released inside of the room.

Fig. 4 compares the temperature above the chair 25 mm below the ceiling with the upper layer temperature as defined by the thermocouple 100 mm down from the center of the ceiling. At the lower heat release rates where the flames do not impact the thermocouple above the chair directly, the temperature there is in fairly close agreement with the upper layer temperature. Thus the temperature above the chair could also be calculated reasonably well with Hazard I for those chairs which pass or nearly pass TB133.

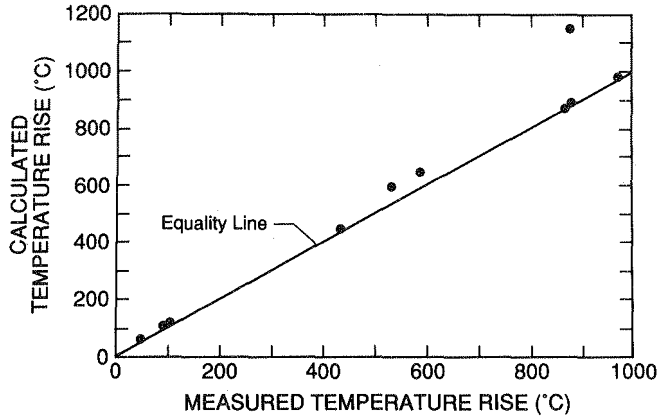

FIGURE 3. Calculated Temperature Rise Using Hazard I

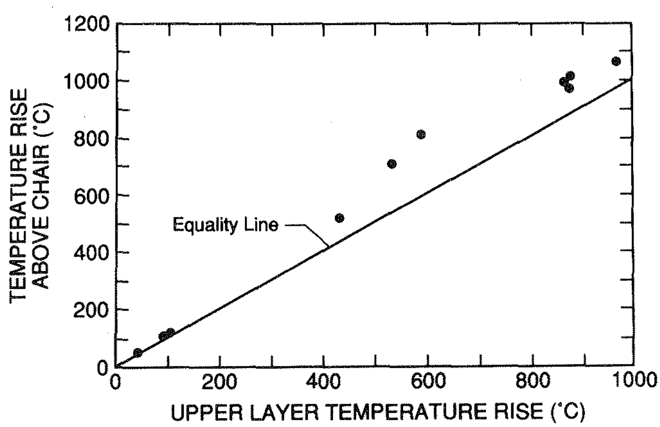

FIGURE 4. Temperature Above Chair vs. Upper Layer Temperature

The peak heat release rates in the furniture calorimeter are plotted against the three minute average heat release rates per unit area in the Cone calorimeter in Fig. 5. The points labeled B, D, H, I', F' and G' are the peaks associated with the fabric burning while the points labeled I, F, G, A, C, E, and J represent the peaks associated with the burning foam or the foam and fabric burning together. The fabric peaks fall along one line while the foam peaks fall along another. It is noted that point I lies along the extension of the foam line while point F falls well below it. Chair F was also the outlier in Fig. 2. Both of these discrepancies are due to its low foam peak measured in the furniture calorimeter. No explanation for this low value has been found. With the exception of Chair I, all of the material combinations which had heat release rates less than 180 kW/m^2 in the Cone calorimeter did not exhibit significant involvement of the foam in the furniture calorimeter. The fabric fire for these chairs was either limited to the neighborhood of the ignition source or it spread very slowly over the remainder of the chair. The foam peak for Chair I occurred after 25 minutes due to a transition of smoldering to flaming ignition long after the flames had died out on the fabric.

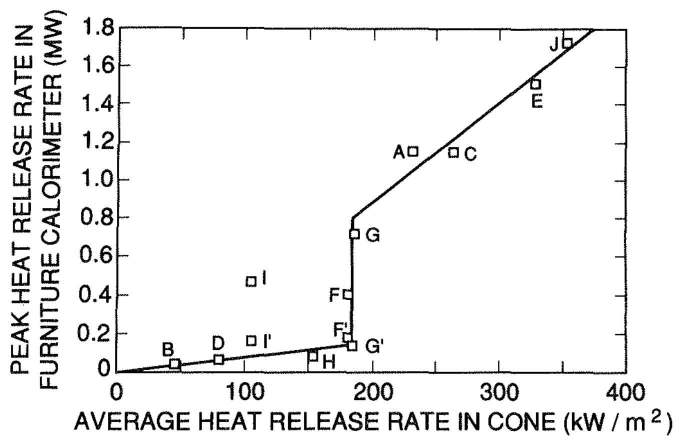

FIGURE 5. Correlation between the Cone and Furniture Calorimeters.

The combinations of materials used in the chairs that pass the TB133 test have three minute average heat release rates in the Cone calorimeter of less than 180 kW/m^2. In fact it can be seen from the curve in Fig. 5 that the total heat release rate restriction of 65 kW derived from the 111°C temperature rise criterion of TB133, is equivalent to a three minute average heat release rate in the Cone calorimeter of approximately 87 kW/m^2. Only Chairs B and D, which passed the upper temperature criterion in TB133, have heat release rates in the Cone calorimeter below 87 kW/m^2. It is important to recognize that this particular correlation can be assumed to be valid only for this particular style and size of chair. More work needs to be done to generalize the application of such a correlation.

CONCLUSIONS

The following conclusions apply to the burning of the upholstered chairs tested on this project:

(1) The TB133 test could be conducted in an ASTM room with similar results.

(2) A temperature rise of 111°C (200°F) in the TB133 room test is equivalent to a heat release rate of approximately 65 kW in the furniture calorimeter.

(3) Below a peak heat release rate of 600 kW there is no significant interaction between the chair and the room so that the heat release rates in the room would be the same as those in the furniture calorimeter. This is true for the ASTM and TB133 rooms and rooms of larger size. However, for rooms with low thermal conductivity lining materials and smaller size rooms the interaction would be expected to occur at lower peak heat release rates.

(4) Given the heat release rate in the room, the temperature of the upper layer can be calculated using HAZARD I. The upper layer temperature is defined here as the temperature measured 100 mm down from the center of the ceiling. After flashover a significant portion of the burning usually takes place outside of the room so that the measured heat release rate will be higher than the actual heat release rate in the room.

(5) For a chair with a sufficiently low heat release rate to pass the TB133 test, the temperature measured above the chair is reasonably representative of the upper layer temperature and thus might be calculated by Hazard I.

(6) A correlation was obtained between the total heat release rate of the full scale chairs tested on this project and the three minute average heat release rates of the material combinations measured in the Cone calorimeter at an external radiant flux of 35 kW/m^2. For these chairs the total heat release rate of 65 kW in the furniture calorimeter is equivalent to a 3 minute average heat release rate of 87 kW/m^2 in the Cone calorimeter. A generalized correlation would hold out the prospect of an economical means to test numerous fabric-cushion combinations for a given chair style using bench scale tests.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the help of Kay Villa, Tom Ohlemiller, Jim Quintiere, Vyto Babrauskas, John Krasny, Dick Zile, Roy McLane, Gary Roadarmel, and Bill Twilley on various phases of this project.

REFERENCES

1. Technical Bulletin 133, State of California, Department of Consumer Affairs, Bureau of Home Furnishings and Thermal Insulation, 3485 Orange Grove Avenue, North Highlands, California 95660-5595, 1991.

2. Parker, W.J., Tu, K., Nurbakhsh, S. and Damant, G.H., "Furniture Flammability: An Investigation of the California Technical Bulletin 133 Test. Part III: Full Scale Chair Burns", NISTIR 4375, U.S. Natl. Inst. Stands. and Tech., 1990.

3. Quintiere, J., "Furniture Flammability: An Investigation of the California Technical Bulletin 133 Test. Part I: Measuring the Hazards of Furniture Fires", NISTIR 4360, U.S. Natl. Inst. Stands. and Tech., 1990.

4. Ohlemiller, T. and Villa, K., "Furniture Flammability: An Investigation of the California Technical Bulletin 133 Test. Part II: Characterization of Ignition Source and Comparable Gas Burner," NISTIR 4348, U.S. Natl. Inst. Stands. and Tech., 1990.

5. Proposed Method for Room Fire Test of Wall and Ceiling Materials and Assemblies, 1982 Annual Book of ASTM Standards, Part 18, p 1618, 1982.

6. Babrauskas, V., Lawson, J.R., Walton, W.D., and Twilley, W.H., "Upholstered Furniture Heat Release Rates Measured with a Furniture Calorimeter," NBSIR 82-2604, U.S. Natl. Bur. Stands., 1982.

7. Babrauskas, V., "Development of the Cone Calorimeter - A Bench Scale Heat Release Rate Apparatus Based on Oxygen Consumption,", Fire and Materials, 8:, 81-95, 1984

8. Babrauskas, V., "Flammability of Upholstered Furniture with Flaming Ignition Sources," Cellular Plastics, 8:, 198-224, 1989.

9. Bukowski, R.W., Peacock, R.D., Jones, W.W., and Forney, C. L., "HAZARD I Assessment Method--Software Users Guide, and Example Cases," NIST Handbook 146, NIST, 1989.

10. Technical Bulletin 117, State of California, Department of Consumer Affairs, Bureau of Home Furnishings and Thermal Insulation, 3485 Orange Grove Avenue, North Highlands, California 95660-5595, 1991.