Björn E. Sundström

Furniture Reaction to Fire: Test Methods and Models

Reprint from EUCOFF '92 -3rd European
Conference on Furniture Flammability,
November 1992 Brussels
Published by InterScience Communications
Limited, London

SP
Swedish National Testing and Research Institute
Fire Technology
SP REPORT 1993:10

Björn E. Sundström

Furniture Reaction to Fire: Test Methods and Models

Reprint from EUCOFF '92 -3rd European
Conference on Furniture Flammability,
November 1992 Brussels
Published by InterScience Communications
Limited, London

SP
Swedish National Testing and Research Institute
Fire Technology
SP REPORT 1993:10

Abstract

Furniture Reaction to Fire: Test Methods and Models

Reaction to fire test methods for upholstered furniture burning behaviour is discussed. A philosophy employing small and large scale testing to predict the fire conditions in a design scenario is presented. The fire calorimeters are the only tests that produces data directly useful for prediction of fire conditions. The furniture calorimeter gives quantitative data of heat release rate, smoke and toxic gas species for a full sized furniture directly useful for model input. However, being large scale it is a relatively expensive test. The cone calorimeter is a bench scale test and thus cheaper. The cone data has to be interpreted into the burning behaviour of full sized items. Various models for that purpose are discussed. An important problem is to predict the influence of furniture design. More work is needed on prediction of smoke and toxic gas species.

Key words: fire, furniture, furniture calorimeter, cone calorimeter, fire testing, fire modelling.

SP
SP Rapport 1993:10
ISBN 91-7848-393-X
ISSN 0284-5172
Borås 1993

Swedish National Testing and Research Institute
SP Report 1993:10

Postal address:
Box 857, S-501 15 BORÅS,
Sweden
Telephone + 46 33 16 50 00
Telex 36252 Testing S
Telefax + 46 33 13 55 02

FURNITURE REACTION TO FIRE: TEST METHODS AND MODELS

Björn E. Sundström
SP Swedish National Testing and Research Institute, Borås, Sweden

ABSTRACT

Reaction to fire test methods for upholstered furniture burning behaviour is discussed. A philosophy employing small and large scale testing to predict the fire conditions in a design scenario is presented. The fire calorimeters are the only tests that produces data directly useful for prediction of fire conditions. The furniture calorimeter gives quantitative data of heat release rate, smoke and toxic gas species for a full sized furniture directly useful for model input. However, being large scale it is a relatively expensive test. The cone calorimeter is a bench scale test and thus cheaper. The cone data has to be interpreted into the burning behaviour of full sized items. Various models for that purpose are discussed. An important problem is to predict the influence of furniture design. More work is needed on prediction of smoke and toxic gas species.

A FIRE IN A ROOM

Assume a fire starting in a room of a domestic size. It may for example be a curtain that is ignited by a candle. The burning curtain then falls onto an upholstered sofa which in turn is ignited. The fire in the sofa grows and from being small at the beginning it accelerates to become large in only a few minutes. The wall behind the sofa and nearby objects are ignited. At the same time the hot gases from the fire fills the room and escapes through the open door. The hot layer come down to about one meter in the room. This layer becomes quickly several hundred degrees hot and contains black smoke that is highly toxic and impossible to see through. When the hot layer temperature reaches 500-600 °C the thermal radiation from it ignites items on the floor and suddenly everything in the room burns; flash-over has occurred. Much more pyrolysis gases are formed than there is oxygen available for combustion in the room. Large amounts of unburnt or partly burnt black, toxic gases leave the burn room. Some of these gases ignites when meeting fresh air outside the burn room. A huge flame is shooting out and the rest of the building starts to burn. At the moment of flash-over nobody can survive the fire in the burn room. After flash-over the fire, the flames and a large amount of smoke moves into the rest of the building. It is natural to assume that post flash-over fires are more dangerous, causing more victims, than the fires that stay in the room of origin. This is supported by fire statistics[1], see table 1.

Table 1 Fires and deaths in dwellings and apartments, as related to the extent of fire (NFIRS data for 1985)[1].

Extent of fire	**Number of fires**	**Number of deaths**	**Number of deaths per 1 000 incidents**
Confined to object	95 558	68	0.71
Confined to part of room	36 297	108	2.98
Confined to room	28 974	179	6.18
Confined to compartment	1 699	30	17.66
Confined to floor	8 325	162	19.46
Confined to structure	35 659	1 006	28.21
Extending beyond structure	5 712	212	37.11
Undetermined/not reported	61 421	67	1.09
Total	273 645	1 832	

When the fire is confined to an object only, for example a chair or a curtain, the number of deaths per 1 000 incidents is less than one. However, the room content may ignite, spread flames and release heat to the point of flashover. At flashover when the fire is no longer confined to the room the number of deaths increases to about 18. Thus, the fire should be kept in the room of origin. The occurrence of large fires are rare compared to a fire in a single object like a piece of furniture. However, when occurring the bench-mark of hazard is the flashover.

If, however, the objective is to protect people in the room of fire origin, then attention must be paid to the room atmosphere prior to the flash-over. Already a rather small fire can be a threat to peoples safety. At flash-over the heat release rate, HRR, is typically 1000 kW, while a dangerous atmosphere in the burn room may occur already at one or two hundred kW of fire size. In fact, investigations on the California TB 133 fire test room showed that the acceptance levels used for that test corresponded to a HRR of less than 100 kW.

In estimating hazard from the general discussion above it is clear that we must know maximum fire size to estimate flash-over potential and, for inside room risk assessment, we must know the fire size as a function of time. The HRR from the fire must be known. The rate of production of smoke and toxic gas species must also be known.

The characteristics of the fire can be found out by testing. However, test data today does not allow a prediction of all the possible fires in real life. There are numerous possible combinations of products and rooms that all will behave differently in a real fire. The state of the art does not allow modelling of all types of fires. Testing of each room situation can of course be done, but this is completely unpractical unless for very special cases. Instead one has to define design fire scenarios which are sufficiently precise for hazard assessment by testing and calculation.

A DESIGN FIRE SCENARIO

A design fire scenario could be defined as a room in which the upholstered furniture alone is on fire. The interaction with the room structure and content is neglected or modelled. This assumption is valid until the fire has a certain size rather close to the flash-over energy rate. Under these circumstances it is possible to use data from modern test methods combined with fire model calculations to predict various aspects of fires in the fire scenario.

MODELLING THE FIRE SCENARIO

For a defined fire it is possible to predict the atmosphere in the burn room as a function of the room construction materials, geometry, ventilation situation etc. Unless there are very complicated geometry's so called zone models can do a good job, see figure 1.

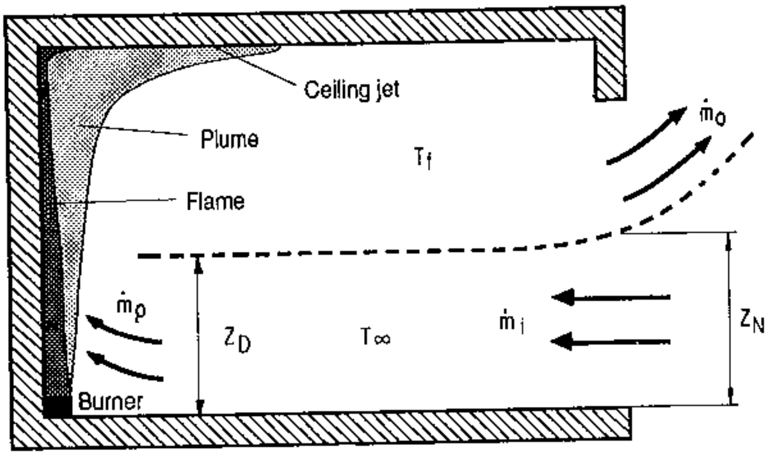

Figure 1. Principal of a zone model. Cold air goes into the room through the lower portion of the opening and is entrained in the fire plume. The hot upper gas layer is at uniform temperature. It consists of air, combustion gases and smoke particles. The thermal discontinuity Z_D moves down when HRR increases. When the hot layer temperature is at about 500-600 °C there is a flash over.

FAST is a computer code developed at NIST in USA. It is a zone model used for fire engineering purposes. Input data is the fire itself, room structure, ventilation etc. Output are for example upper layer gas temperature and height of thermal discontinuity. These are the quantities needed for estimating hazard; in fact FAST is a part of the HAZARD package which includes hazard assessments. Recently a furniture fire model, FFM, by Dietenberger[2] is being incorporated into FAST. This allows for an input of fire parameters from small scale testing. FFM then calculates the full scale furniture fire which is the input to FAST.

THE FURNITURE CALORIMETER GIVES REAL FIRE DATA

For predicting the conditions in a fire scenario HRR as well as rates of production of smoke and toxic gases from the burning item is required. The furniture calorimeter[3] can provide such data, see figure 2.

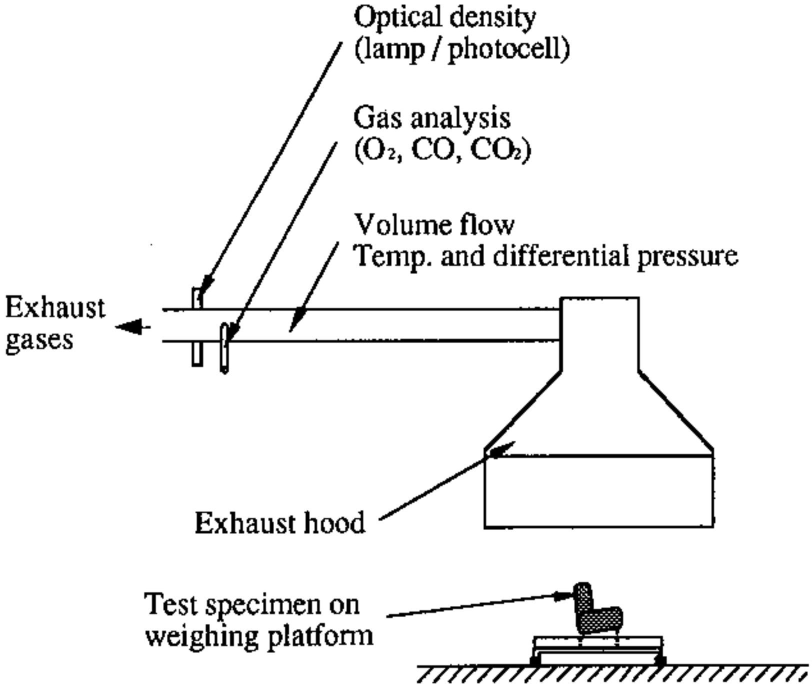

Figure 2. The furniture calorimeter as defined by NORDTEST; NT FIRE 032. Front and side view. A full size piece of furniture is placed on a scale under a hood. A specified ignition source starts the fire test. Rates of heat release, smoke production, gas species and mass loss is measured continuously.

The furniture calorimeter comprises a weighing platform on which the test specimen is placed, a combustion gas extraction system and provisions for measurements of volume flow rate, smoke density and gas species.

The test specimen is a full size item of upholstered furniture as it appears in reality. If comparative testing of only cushion material (filling covered with fabric) is required then a three seat sofa mock-up is used.

The test specimen is ignited with a wooden crib according to BS 5852: part 2: crib no 7. For special situations other ignition sources are allowed for. As the wooden crib is not sufficiently reproducible it should be replaced by a gas ignition source, possibly constructed as in the California TB 133 test.

The test specimen burns freely without any restriction of air supply. The combustion gases from the product is extracted into a hood 3 m x 3 m in opening area. In the exhaust duct, measurements of gas species, gas flow rate and smoke optical density are performed at a location far enough from the hood to ensure perfect mixing and a fully developed flow profile.

By measuring the oxygen consumed by the fire it is possible to calculate the heat release rate, the so called oxygen consumption calorimetry. The heat release rate, HRR, from the fire is a measure of the fire size and the growth with time. HRR is thus the most important fire parameter.

Mass burning rate is continuously measured during a test. Combined with the HRR the effective heat of combustion could be calculated. Many PU-foam fabric combinations have an effective heat of combustion of about 20 MJ/kg. Thus for control purposes or studying various designs it may be possible to determine HRR from mass loss rate measurements only which would give a low cost test version.

Toxic gas species can also be measured, the most common being carbon monoxide which can be continuously registered throughout the fire test. A new technique to measure a large variety of toxic gas species is being introduced, the so called FTIR (Fourier Transform InfraRed). This is an instrument employing infrared measurements simultaneously over the whole spectrum. Thus many gas species can be measured, especially halogen compounds like HCN, HCL, HBr, HF are suitable to analyse.

Smoke optical density is measured with a white light system having a detector with the same spectral responsively as the human eye. The results are expressed as the volume of smoke of a certain optical density that is produced per unit time; RSP rate of smoke production. As the mass loss rate from the sample is measured simultaneously yield data of smoke can also be given.

For illustration HRR data of testing upholstered chairs is given in figure 3.

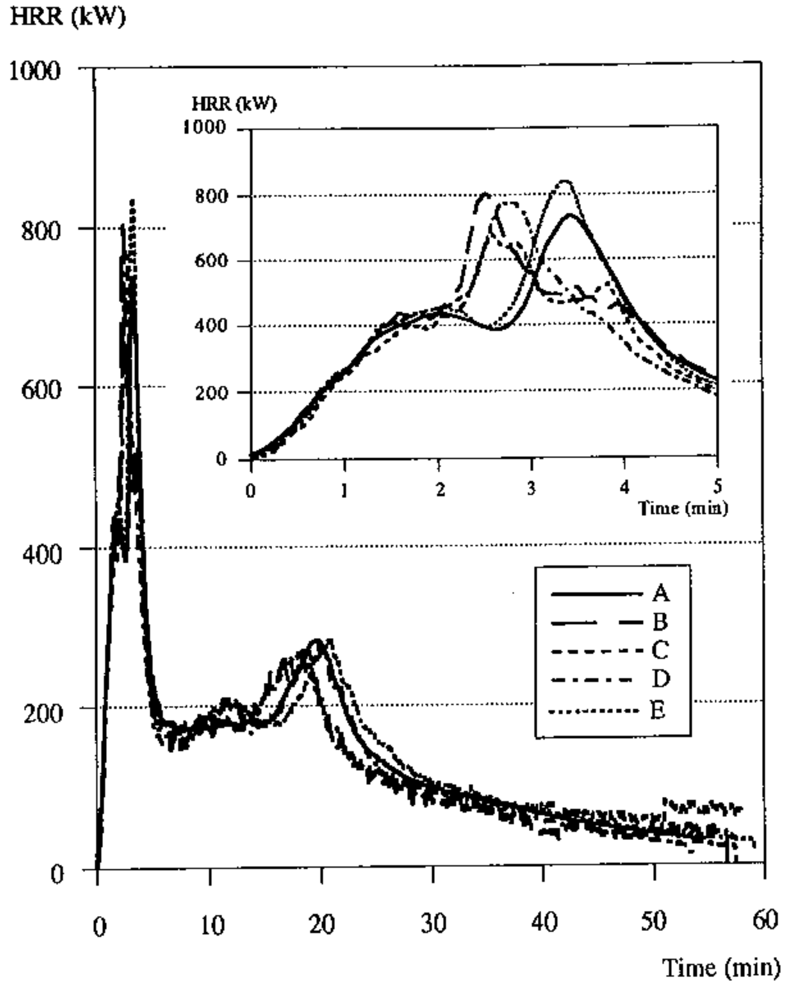

Figure 3. Furniture calorimeter data from tests of an upholstered chair at 5 different laboratories. The peak HRR is about 800 kW. A bedroom reaches flash-over at about 1000 kW. A dangerous atmosphere in a bedroom is reached at HRR levels below 800 kW.

The furniture calorimeter would be sufficient to produce indata for modelling. However, it is expensive to always test full size furniture. Thus a bench scale test would be advantageous. A candidate is the cone calorimeter.

THE CONE CALORIMETER FOR UPHOLSTERED FURNITURE

The cone calorimeter, ISO 5660, is a bench scale test method that measures all the fire parameters as the furniture calorimeter does but on samples that are only 10 by 10 cm. If one could translate HHR, smoke and toxic gases into what a full size burning furniture would give off then the link to the fire scenario is established. The logic's given in figure 4 apply.

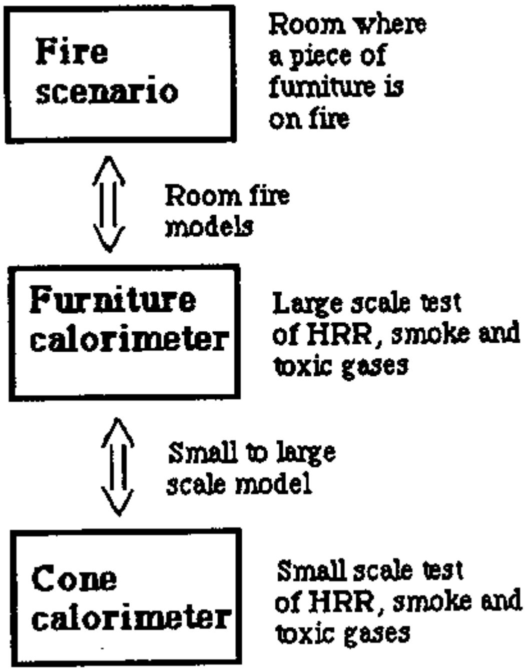

Figure 4. Validation of small and large scale calorimeters for a fire scenario. The calorimeters measure heat release rate, HRR, and rates of production of smoke and toxic gases. The cone calorimeter data are translated into the burning behaviour of a piece of upholstered furniture by a model; small to large scale. The furniture calorimeter data from a full sized furniture is translated into the fire scenario, the room conditions, by a fire model.

Computer codes like FAST takes care of the fire modelling between the furniture calorimeter and the fire scenario as discussed earlier. However, the modelling between small and large scale is not clear although there are some work available.

Dietenberger has developed a deterministic model, FFM, that predicts the furniture calorimeter HRR based on data from the cone calorimeter and the LIFT apparatus, ISO CD 5658 part 2. The LIFT test is a spread of flame test measuring for example ignition temperature and a flame spread constant. Work at NIST in USA is currently under progress to integrate FFM into the FAST code; FAST/FFM[4].

Babrauskas[5] has developed a correlation between cone calorimeter and furniture calorimeter data. The HRR curve for the furniture calorimeter is approximated as a triangle. Further correlation work has been done by Parker[6].

Kokkala[7] has developed a method of calculating an index that reflects the HRR of a full sized fire. This was done for surface linings in the EUREFIC research programme, but with some modifications this approach also applies for furniture.

It is essential that the models can handle the effect of furniture design. Furniture constructed of similar materials may burn quite differently due to differences in design only.

The mentioned models deals only with prediction of heat release rate. However, reduced sight length due to smoke and toxicity due to combustion gases need to be predicted as well. This is an area for research. One approach might be to use the measured yields of smoke and gas species. The product of mass burning rate and yield then gives the amount of smoke and gas. The mass burning rate than differs from the HRR only by a constant, the effective heat of combustion. The HRR is predicted by the model. In that way the smoke and toxic gases could be predicted. In addition, when a fire approaches flash-over the supply of air for combustion is not enough, the combustion becomes less complete and more toxic gases are formed. This ventilation effect has to be accounted for when predicting smoke opacity and gas species.

SIMPLIFIED TESTING

Cone calorimeter testing of the furniture composite i. e. the fabric, any intermediate layer and the foam is apart from design factors very close to end use conditions. Therefore, one assumes that the measured fire parameters are representative of the actual burning behaviour of the furniture. However, it may be more practical to test the components only. Then the fire parameters of the fabric, the intermediate layers and the foam have to be combined into an end use burning behaviour of the composite. As earlier discussed the furniture fire models and the room fire models would predict the room scenario conditions. A big advantage is of course that the effect of combining different materials could be predicted. The amount of practical testing could be reduced substantially. However, this is a new field of research and very little, if any, work has been done so far.

Another possible way to simplification could be to use a simplified version of the cone calorimeter. The HRR could be estimated by measuring the rate of mass loss only. they differ only by the effective heat of combustion. A very simple test apparatus is needed. Only the conical heating source and a load cell is required. However, much information is lost. Especially the hazard of smoke and toxic gases can not be estimated based on individual test data. This is also a new field for investigations.

CONCLUSIONS

To predict the fire conditions in a scenario, for example a room, where a piece of furniture is on fire so called fire calorimeters are required. The reason is that they give quantitative data of heat release rate and rates of production smoke and toxic gases. These data can be used in fire modelling. The furniture calorimeter and the cone calorimeter are two useful calorimeters. In the furniture calorimeter full sized furniture is tested and data can be used directly in fire models. The cone calorimeter is a bench scale test for small samples and is therefore quite practical. However, the testing protocol needs to be investigated at some points and improved. Further cone data must be able to predict the burning behaviour of real furniture. Already much work has been performed and three approaches are specially interesting. These are the deterministic furniture fire model, FFM, that is also to be used in the FAST fire model FAST/FFM, correlation formulas and the use of weighted fire indexes.

REFERENCES

1 Takeda, H., Yung, d,. "Fire Types and Probabilities in Residential Buildings", IRC Fire Research News, National Research Council, Canada, No 61.

2 Dietenberger, M., "Upholstered Furniture: Detailed Model," Chapter 14, p. 479, Heat Release in Fires, edited by Babrauskas. V. and Grayson, S.J., Elsevier Science Publishers, Ltd, London, 1992.

3 "Upholstered Furniture: Burning Behaviour - Full Scale Test", Nordtest method NT FIRE 032, Helsinki.

4 Dietenberger, M:A:, Technical Reference and User's Guide for FAST/FFM (Version 3)," NIST-GCR-91-589, 1991.

5 Babrauskas, V., Krasny, J., "Fire Behaviour of Upholstered Furniture", NBS Monograph 173, National Bureau of Standards.

6 Parker, W.J., Tu, K.M., Damant, G.H. and Nurbakhsh, S.,"Furniture Flammability: An Investigation of the California Technical Bulletin 133 Test. Part III: Full Scale Chair Burns," NISTIR 4375, NIST, 1990.

7 Kokkala, M.,"Two Classification Indices Based on the Cone Calorimeter," Pre-print, Eurefic Seminar, Copenhagen, 11-12 1991.

SP
Swedish National Testing and Research Institute
Box 857, S-501 15 BORÅS, Sweden
Telephone: 033 - 16 50 00, Telefax: 033 - 13 55 02

SP REPORT 1993:10
ISBN 91-7848-393-X
ISSN 0284-5172