AN OVERVIEW OF THE FINDINGS OF THE Combustion Behaviour of Upholstered Furniture PROJECT

Stephen J Grayson
Interscience Communications Limited, UK

Björn Sundström and Patrick Van Hees
SP-Fire Technology, Sweden

ABSTRACT

This paper gives an overview of the CBUF project. The work described is the collective effort of 11 CBUF partners, laboratories, universities, industries, in 8 countries. It became possible to do this research thanks to the European Commission interest in the burning behaviour of upholstered furniture and their willingness to sponsor this large effort. The opportunity to work with the many of the most prominent fire researchers and furniture experts have been extremely rewarding. All the expertise of these scientists have resulted in a lot of research results that are presented. The article only gives the main findings and conclusions of the project, namely the presentation of the fire safety design procedure of the CBUF project. Other articles will deal with specific modelling topics and an extensive description of the project can be found in the final CBUF report EUR 16477 EN.

INTRODUCTION

A small flame in an upholstered chair can develop into a disastrous fire in only a few minutes. There are very few, if any, items in a home that have this potential for fire development. Surveys of European statistics show that a major cause of fire fatalities is associated with burning of upholstered furniture[1]. In private dwellings they were found to cause 49% of all fatal casualties and in public buildings 15 %. Ignitions by smokers' materials is a common event (42% of reported cases) that can start a fire. After a period of smouldering or "hidden burning" visible flaming appears. Once the furniture is burning, the growth rate of the fire may be so large that people are not given sufficient time to escape.

Our test results reveal that a considerable portion of the European marketplace furniture burns rapidly and produces large amounts of heat and smoke. The fire statistics mentioned above may be seen to be supported by the burning behaviour that we find. However, there are also items that burn very slowly. Between these extremes all variants exist. Obviously there is a need for an assessment technique that allows quantitative evaluation of the hazard.

The UK regulations address the combustion behaviour of upholstered furniture. When they came into force they introduced a major change of acceptance level in the UK. However, the component and the furniture industries demonstrated a high capability to make furniture of high fire performance standards. The UK regulations had to be adopted hastily. Therefore validations and precision studies are lacking. The European Commission facing the same issue, however, had the opportunity to ask for a general study of the combustion behaviour of upholstered furniture.

In preparation for a furniture directive, the Commission wanted to express performance criteria as safe escape from a room involved in a furniture fire. CBUF, Combustion Behaviour of Upholstered Furniture, was created to develop the appropriate assessment tool.

CBUF has applied proven technology to furniture fire problems. The test methods used, the Cone Calorimeter (ISO 5660), the Room/Corner test (ISO 9705), and the Furniture Calorimeter

(NT FIRE 032), are all well established. Their precision has already been verified in earlier studies. The small scale test, ISO 5660, is widely used and available in about 60 European laboratories. The main issue was therefore to develop quality assured test protocols suitable and robust enough for routine testing of upholstered furniture. The mathematical fire modelling in CBUF also largely builds on earlier work. The predictive models rest on established fire physics developed for application to building materials, yet the specific application is for furniture. Nonetheless, a large portion of the modelling is innovative. Especially the composite model is a completely new tool that proved to be very successful.

To the user, the CBUF fire safety design procedure can be viewed as in Figure 1.

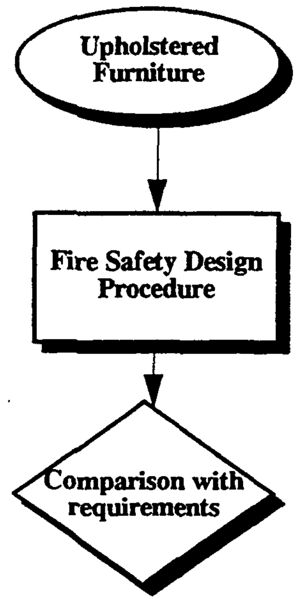

Figure 1. CBUF procedure used for fire safety design

THE CBUF FIRE SAFETY DESIGN PROCEDURE

The CBUF fire safety design procedure is the use of the collection of test methods, modelling and correlation formulae to determine whether an item of upholstered furniture meets certain requirements of fire safety.

The requirements of fire safety are selected by those responsible for regulation taking account of the level of performance required, harmonisation and the cost/benefit. The selection of performance level is based on tenability limits in room scenarios for a piece of burning furniture. The tenability limits can then be translated into fire parameters of the full size furniture burning behaviour measurable in the CBUF tests.

The test data may be derived from Cone Calorimeter measurements on composite or individual components or alternatively a full scale test using the Furniture Calorimeter. When Cone Calorimeter data is used a mathematical model fire model is applied to estimate the full size furniture burning behaviour.

Four models have been developed for this purpose. They are shown to work very well for the CBUF database. However, it is noted that modelling, and especially the correlations, *rely on the*

basic test data. Therefore care should be taken if the models are considered for use on products very different in design from those covered by the CBUF database and modelling principles.
The collection of test methods, models, and correlations formulae can be viewed as a tool-kit. The user can select different components of this tool-kit according to his preferences. The potential exists for this tool-kit to be incorporated into a computer program with a user friendly interface which could be run on a standard PC.

Such a computer software could be operated by a furniture manufacturer. He could select the appropriate style from a database, input additional design parameters and also the performance details for the composites or the components. The program would then give an assessment as whether the appropriate design would pass or fail the required criteria.

Alternatively it would be possible for the program to classify the fire performance of the furniture into different categories, perhaps into a Euroclass type classification similar to that proposed for construction products.

The concept shown in Figure 1 will be evolved in detail below and the CBUF tool-kit will be explained and discussed.

CBUF - COMBUSTION BEHAVIOUR OF UPHOLSTERED FURNITURE

The CBUF (Combustion Behaviour of Upholstered Furniture) research programme on the fire safety of upholstered furniture was started at the beginning of 1993 in support to a draft directive on the fire safety of upholstered furniture (and related articles including mattresses). The draft directive was prepared by the services of the European Commission but was not presented to the Council of Ministers of the European Union.

The draft directive had two main "Essential Requirements". The first of these was that upholstered furniture and related articles should not ignite when exposed to certain ignition sources, the size of which depends upon the intended use of the furniture (smokers' materials, for example, in the case of domestic furniture). However, in view of the danger of upholstered furniture fires, particularly in domestic dwellings, it did not appear sufficient to merely control the ignitability of upholstered furniture. The Second Essential Requirement therefore aimed to control the hazards linked to the "burning behaviour" of the upholstered furniture - that is to say, the phenomena which occur after ignition has taken place. It was the second essential requirement which was addressed by the CBUF research programme. The objective was to provide scientific and technical support for performance requirements on safe escape from the room of fire origin.

The aim of the research programme was to provide a sound basis, within a period of two years, for the development of the test methods for measuring the burning behaviour of upholstered furniture that would be needed either for the implementation of possible European Union or national legislation or for European standardisation.
The CBUF work programme, see Figure 2, was directed towards the development of fire test procedures and fire models in support of a system going from the large-scale room fire to small-scale simple tests and assessment procedures.

Performance criteria relate to a room scenario. Measured room fire conditions were interpreted by analyzing fire hazards and identifying tenability limits and associated times.
The conditions occurring in the room scenario (ISO 9705 and larger rooms) due to the burning of a piece of furniture were predicted based on the results of large scale testing in the Furniture Calorimeter (NT FIRE 032). A so-called zone model (CFAST) and a field model (JASMINE) were used for fire modelling the room scenario.

Furniture Calorimeter results were in turn predicted based on the data from bench scale tests, ISO 5660, on composites consisting of various layers of fabrics, interliner and padding used in the construction of the furniture. These relationships are based on engineering furniture fire models and correlation models.

A special model for the Cone Calorimeter (ISO 5660) test data on composites was developed. Data on component materials, i.e. fabric, interliner and padding, can be combined to predict the

composite fire data as expected from the Cone Calorimeter model.
The project was performed by the following institutes:

- -Dansk Brandteknish Institut, Denmark
- -Furniture Industry Research Association, United Kingdom
- -Fire Research Station, United Kingdom
- -Forschungs- und Materialsprüfungsanstalt Baden-Württemberg, Germany
- -Laboratorio di Studi e Ricerche sul Fuoco srl, Italy
- -Laboratoire National d'Essais, France
- -Interscience Communications Ltd., United Kingdom
- -Valtion teknillinen tukimuskeskus, Finland
- -Sveriges Provnings- och Forskningsinstitut, Sweden
- -FMC Corporation Ltd, United Kingdom
- -Universiteit Gent, Belgium

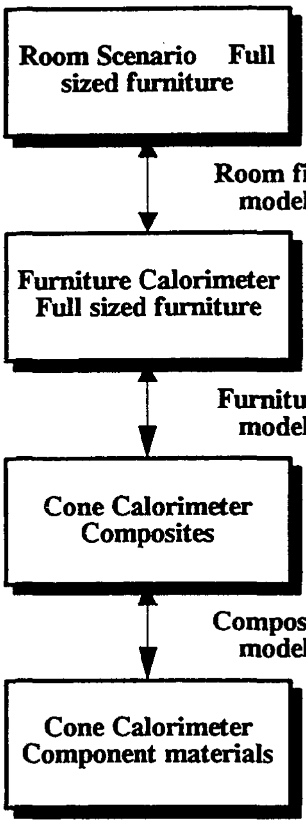

Figure 2 The CBUF programme structure

THE FURNITURE ITEMS TESTED

Much care was taken to select the furniture that was tested in CBUF. CBUF deals only with upholstered furniture. Non-upholstered plastic chairs, row chairs etc. are not included. The intention of the CBUF project was not classify a large number of products according to their burning behaviour but to develop a useful design procedure for hazard assessment based on a limited number of typical items. Building a product database for classification could easily be done in a second step as the analysis tool-kit is now available.

There were five series of test furniture in the programme:

- series 1, the European marketplace series, consists of real furniture items purchased in UK, Eire, France, Germany, Spain and Sweden. Domestic and contract type seating furniture as well as mattresses and bed bases were included.
- series 2, 3, 4 and 5 were "custom made" furniture designed for study of the effect of materials, types of construction, ventilation conditions, etc. and to allow mathematical fire modelling.

The CBUF database contains over 1500 tests of various types such as room tests (ISO 9705, large room and limited air supply), furniture calorimeter tests, cone calorimeter tests on composites and on components and LIFT tests.

THE HAZARD FROM A BURNING ITEM OF UPHOLSTERED FURNITURE

We first consider the fire hazard in a room. Assume a furniture item which starts to burn. A hazardous situation in the room can now gradually develop. People in the room have to escape before the fire grows beyond a certain critical size. The available time is from discovery of the fire until untenable conditions are reached, i.e. tenability limits.

In the fire laboratory we express the fire size as the heat release, HRR, in kW. When the fire reaches about 1000 kW in a small room, flashover occurs. At flashover the entire room is involved in flames and the temperature reaches the order of 800-1000 deg.C. Flames shoot out through openings and spread rapidly to other spaces. People in the fire room may be dead before flashover. Hazard analysis deals with the fire development prior to flashover. The time-resolved heat release rate curve gives us a good measure of this process. Therefore, if we measure and analyze the HRR from a burning furniture item much of the history of the hazard is captured. Figure 3 shows the heat release rate histories during testing of a representative selection of upholstered furniture and mattresses that are available on the European market, CBUF series 1. Details cannot be seen in the figure but at least four types can be identified from this selections:

- quick development, high peak HRR.
- delayed development, moderate peak HRR.
- slow development, low peak HRR.
- very limited burning.

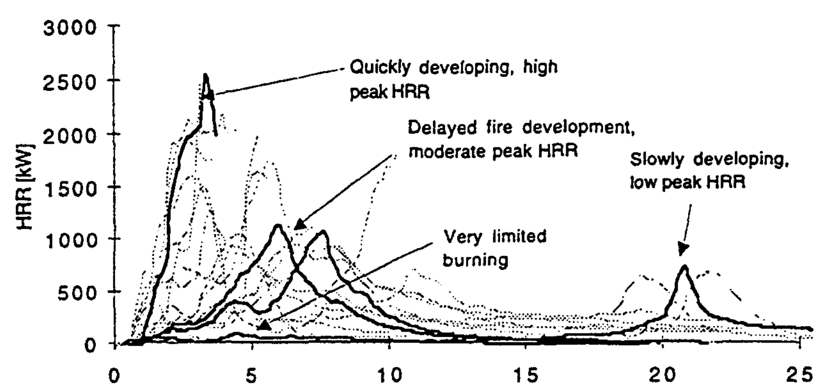

Figure 3 Heat release rate, as a function of time for a representative selection of European upholstered furniture and mattresses.

The very limited burning items will almost always be safe while the quickly developing high peak HRR will create dangerous fires shortly after ignition. We see that typical times for development of a large fire varies from a few minutes to more than 20 minutes.

Now consider the possibility to escape as a function of the fire size. Figure 4 shows typical HRR curves of furniture items.

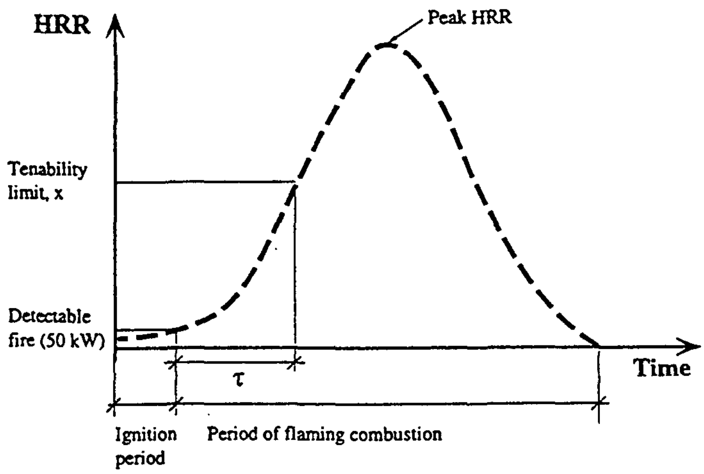

Figure 4 HRR versus time for typical burning behaviour of an upholstered furniture item

The tenability limit is assumed to be at a HRR level of X. The time τ elapsed after the item is on fire is then the available escape time. The point of "being on fire" is assumed to have occurred when the fire reaches 50 kW. This includes the ignition period up to detectable fire size. Young and alert people may take advantage of delays in the fire development resulting from better fire performance of the furniture. However, even capable individuals receiving early warning of fire may fail to escape. This usually happens when they perceive the fire size as "not threatening". Often they attempt to investigate, rescue other, fight the fire, etc. When a while later the fire develops rapidly, they are trapped and become casualties.

If the HRR curve stays below the tenability limit, then furniture is safe in a well ventilated room. Safe furniture is an ideal situation. This is particulary true of high risk situations where people cannot escape by themselves. For very old and very young persons, disabled and people taken in custody the furniture must be safe or a rescue team must organise the escape in time.

Within the CBUF project different room scenario's were studied. We will limit ourselves by listing them:

- rooms with ventilation openings
- completely closed large rooms
- completely closed small rooms

More information about the detailed hazard analysis for these particular situations can be found in the final report describing the complete project[2].

THE HAZARD OF REDUCED VISIBILITY AND TOXIC GASES

So far we have discussed the fire hazard in a room as a function of the fire size or the heat release rate, HRR. But what is the hazard due to reduced visibility and toxic gases?

The gases in a room will at the early stages of the fire separate into two distinct zones: the upper hot layer and the lower cold layer. The upper layer contains the hot combustion gases that might be highly toxic and dense with smoke. These combustion gases are mixed with entrained air which does not undergo combustion but serves to lower the upper layer temperature and reduce the concentration of the toxic gases and smoke. The lower layer consists mostly of fresh air that is entering from the compartment openings. The interface between the layers is sharp: the temperature and the concentration of smoke and toxic gases change dramatically over a narrow band when going from one layer to the other. It is the difference between being in the middle of a fire or just outside it.

The CBUF work resulted in the following findings:

- the upper layer contains several toxic gases species.
- the interface height is a measure of tenability.
- the height of the interface can be predicted from the heat release rate.
- in a small closed room only a few hundred grams of pyrolysed material is sufficient to reach untenability.

CONCLUSIONS HAZARD ASSESSMENT: FIRE SAFETY DESIGN PROCEDURE

The hazard assessments based on the ISO Room would be safe on the safe side when applied to rooms of larger size. Therefore, since the ISO room corresponds to approximately the smallest size of habitable room in real fire, we use the ISO room example throughout the analysis of hazard and modelling.

The hazard analysis shows that we need only to predict the time histories of the heat release rate for the upholstered furniture. No actual room tests are needed. The possible testing procedure required then become:

1. large scale testing of the actual furniture item with the Furniture Calorimeter, or
2. small scale testing of composite samples 10 cm by 10 cm with the Cone Calorimeter, or
3. small scale testing of component materials (fabric, foam and other separately) with the Cone Calorimeter.

Any testing procedure under points 1-3 will be sufficient. However points 2 and 3 require special testing protocols and furniture fire models that can predict the real burning behaviour of the furniture item and which were examined by the CBUF project.

The first route is testing the actual furniture item in the Furniture Calorimeter. Fire hazard assessment becomes straightforward. The full size furniture burning behaviour is determined and the HRR curve is compared to the required limit values.

A second route is testing the composite in the Cone Calorimeter. With the Cone Calorimeter testing it is now necessary to predict the burning behaviour of the full scale furniture. For this purpose three different furniture prediction models have been developed in CBUF. The models will be explained in another article of this symposium[3]. We will only list them in this article:

1. Model I is a factor based model, i.e. a series of statistically-correlated factors are used to predict the HRR of the burning item.
2. Model II is based on an area-convolution technique. In it, empirically-justified expressions of burning area versus time are sought for various furniture types.
3. Model III is based on some novel extension to the thermal fire spread theory.

The third route of investigating the hazard of the furniture item is the use of the composite model. With this model the composite burning behaviour is predicted form the individual components of fabric, foam and any intermediate layer. Also this model is explained in detail within the scope of another article of this symposium[4]. The overall view of the fire safety design procedure is given in figure 5.

The hazard analysis leads us to at least three things we want to know about the burning behaviour of the furniture. First of course, will it ignite? However, ignition testing is treated

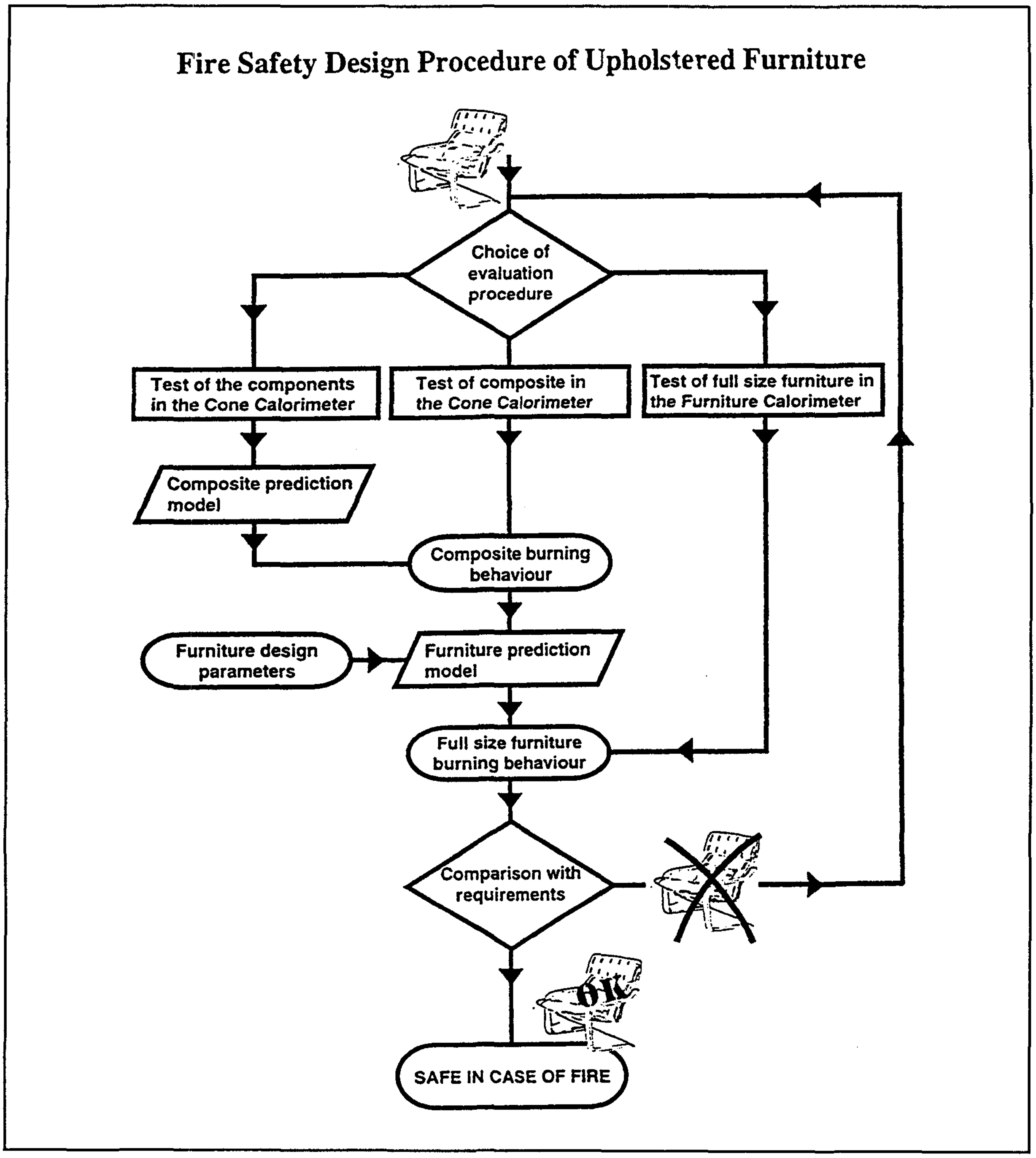

Figure 5 Procedure for fire safety design of upholstered furniture

elsewhere. So we move to the next three points. After ignition will the fire propagate beyond the point of ignition? If it does not, we are safe. However, if the fire grows, will it be so large that untenable conditions appear? If the fire remains small compared with the room we are safe. If not, if the fire continues to grow, what is the time available for safe escape?

The first question is " will the fire propagate beyond the point of ignition?". The answer is no if the heat release rate of the furniture composite as we measure it in the cone calorimeter is less than 65 kW/m^2. This a concrete and simple result from CBUF correlation work. For the highest level of safety, the testing and assessment is very simple.

The second question is "will the fire produce untenable conditions?". To answer this we must

know the maximum burning rate of the fire i.e. we must know the peak heat release rate.
The prediction of peak heat release rate is based on correlation's from the cone calorimeter (figure 6). Input is heat release data and a design factor of the actual furniture. We see that the results are good and that predictions that are less accurate will be on the safe side. We can use a relation like this to investigate whether untenable conditions will occur or not. In the latter case the fire will never be so large that it is dangerous.

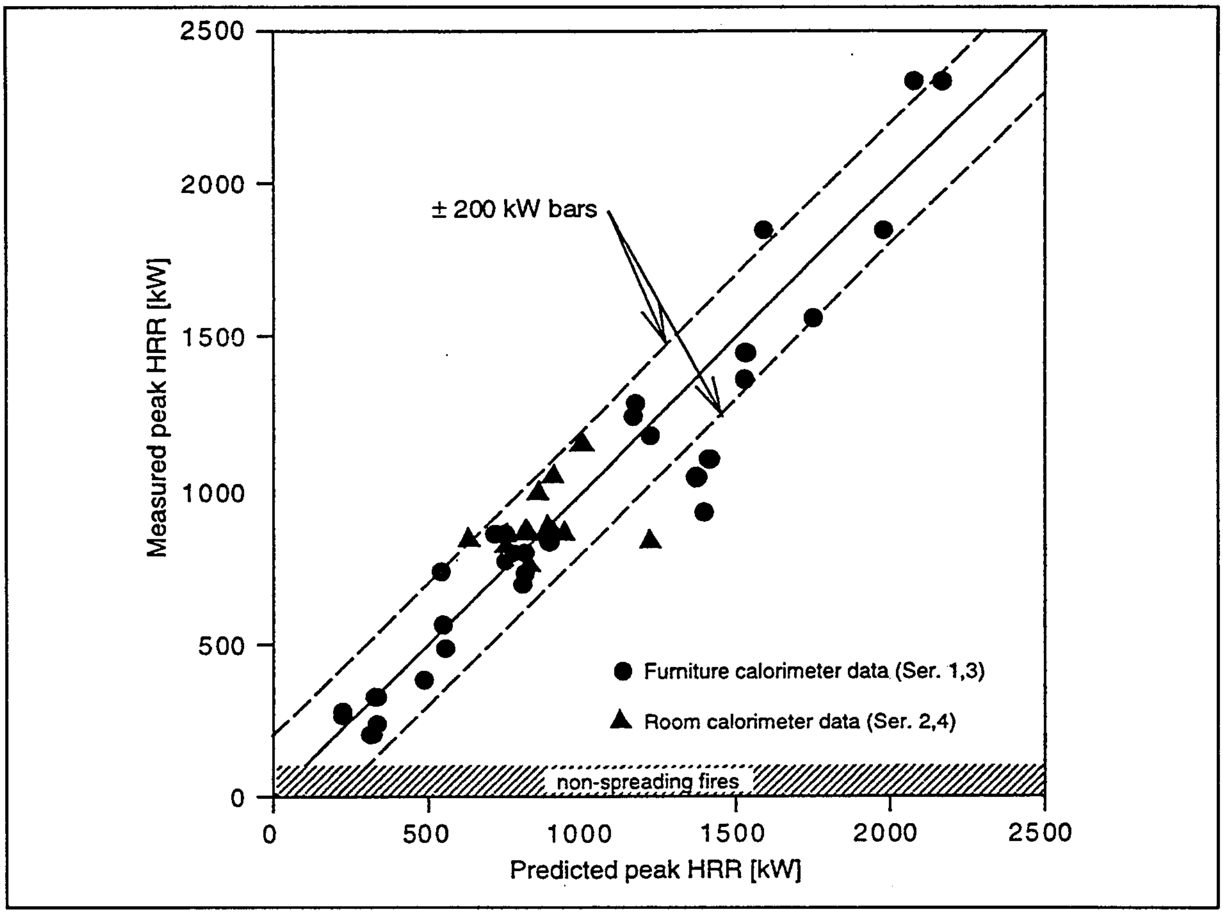

Figure 6 Prediction of peak HRR using model I

The third question is "what is the time available for safe escape?". This is crucial to know when we have a fire that will be dangerous at some point in time. Observe that this case requires action to be safe in contrast to the earlier cases when the fire never became so large that it was dangerous. Action means that you run out from the room yourselves or a rescue team is saving you.
As an example we assume that you can escape under a smoke layer that comes down to 1.2 m and that you are in the small ISO room with an open door. Figure 7 shows the predicted versus measured time available for escape in this example. Again the prediction is good. It is based on the Cone Calorimeter. The input is heat release rate and a design factor of the actual furniture. We can use this relation to determine how many minutes a person has to run away from the fire.

MAKING FIRE SAFE FURNITURE

The choice of material, material combinations and the design of the furniture are factors that can influence the burning behaviour. It can be a matter of delaying the fire development or of avoiding a propagating fire in its entirety.
It is of interest to furniture manufacturers to know how the different variables can influence the

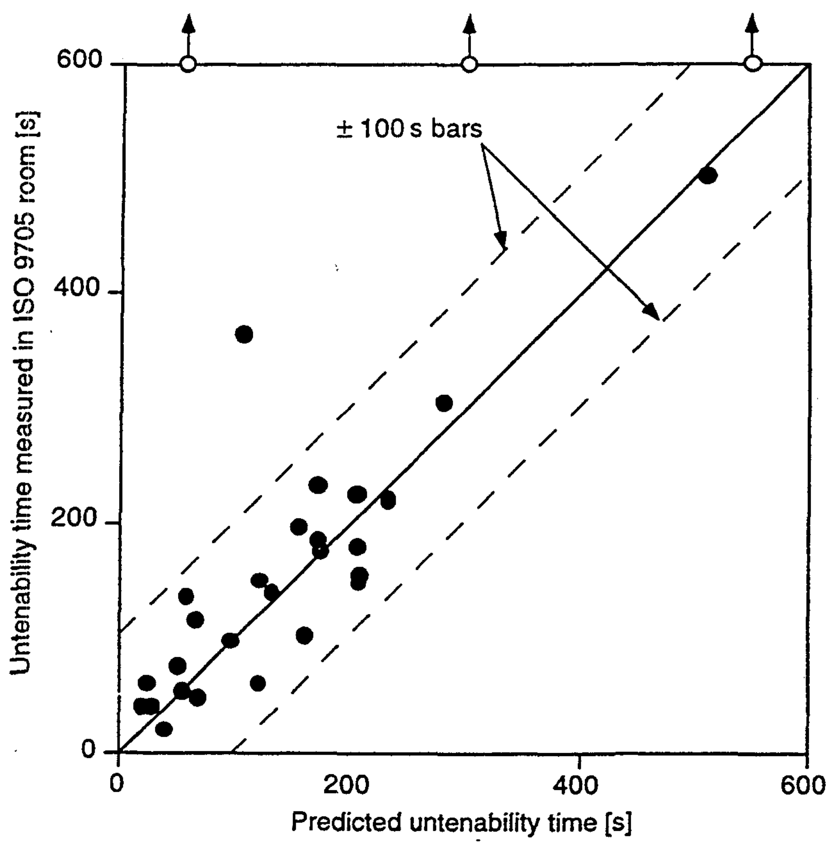

Figure 7 Prediction of the untenability time

burning behaviour. For that reason a special analysis was made where improvements possible in each area of furniture construction were examined. Full details can be found in the final report of the project but the following items were investigated:

- influence of fabrics
- influence of foams
- influence of interliners
- influence of furniture design
- presence or absence of armrests
- support and layout influence
- influence of high or low back, gaps between major cushion areas and button tufting
- influence of frames
- the effect of innersprings in mattresses
- the effect of weight and size

All these findings can be used to identify strategies for improved burning behaviour by adequate material selection and design.

CONCLUSIONS

1. A fire safety design procedure for upholstered furniture is presented. The user can specify the safety criteria in terms of escape under the smoke layer interface. The test data can be taken from:

- The Furniture Calorimeter for full scale data, or

- The Cone Calorimeter, for small scale composite data, or

- The Cone Calorimeter, for small scale component data

2. In a small closed room with no ventilation only a few hundred grams of material is enough to cause untenability. Ignition control and a mass loss criterion in addition to requirements of burning behaviour could be used for safety assessment.

3. Test protocols for the Furniture Calorimeter and the Cone Calorimeter as well as a measurement technique for toxic gas species (FTIR and Ion Chromatography) were developed. The validity, the precision and the versatility were all sufficient for the purposes of routine testing.

4. There is a data base on HRR, temperature, heat flux, smoke density and toxic gas species like CO, CO_2, HCN, HCl, NO_x, HBr from more than 1500 tests on furniture items and materials.

5. The test samples were selected to represent a large spectrum of burning behaviour from representative European upholstered furniture.

Furniture items with very rapid fire development as well as those that did not burn at all were found.
Ways of improving the fire performance by material selection and design of furniture were identified.
Combinations of high performance foams like the CMHR and interliners and good fabrics were found to be very successful in terms of controlling burning behaviour.

REFERENCES

1.de Boer, J.A., "Fire and Furnishing in Building and Transport, Statistical data on the Existing Situation in Europe", Fire and Furnishing in Buildings and Transport Conference proceedings, Luxembourg, pp1-14, 6-8 November 1990.

2.CBUF consortium, Fire safety of Upholstered Furniture - the final report, European Commission Measurement and Testing Report EUR 16477 EN edited by B. Sundström, Borås 1995.

3.V. Babrauskas, The cone calorimeter used for predictions of the full scale burning behaviour of upholstered furniture, Fire and Materials '95, Crystal City, VA, USA, October 1995.

4.W. Parker, A model to predict the burning behaviour of upholstered furniture based on test data from foam and fabric separately, Fire and Materials '95, Crystal City, VA, USA, October 1995