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Reducing life hazards due to fire A govermental investigation

By S E Magnusson

REDAKTÖREN

Sommaren 1976 gav bostadsministern i uppdrag åt Statens planverk och Konsumentverket att i samråd med Bostadsstyrelsen och Statens brandnämnd utreda brandriskerna i landets byggnadsbestånd. Utredningen — kallad Brandriskutredningen (SOU 1978:30) — fick som främsta uppdrag att kartlägga förekomsten av brandfarliga material och produkter i den dagliga miljön samt att uppskatta konsekvenserna av en övergång till mindre brandfarliga material och produkter.

Brandriskutredningen konstaterar att man för ett flertal inredningskomponenter nu uppnått en sådan risknivå, att åtgärder blivit nödvändiga från myndigheternas sida. Åtgärder kan vidtas med stöd av marknadsföringslagen och brandlagen. Vad gäller den fasta inredningen och byggnadsdelarna, föreslår Statens planverk skärpta krav i flera avseenden. Något generellt förbud mot användning av vissa material med toxiska sönderdelningsprodukter föreslås dock ej. Brandriskutredningen pekar också på behovet av ökad forskning och mer nyanserade provningsmetoder. Endast härigenom kan man undvika onödigt hårda krav på material och produkter.

Artikeln har skrivits för FoU-brand av tekn dr Sven-Erik Magnusson vid Lunds Tekniska Högskola. Dr Magnusson har varit brandteknisk expert i utredningen och sammanställt ett omfattande material baserat på statistiska uppgifter och tillgängligt forskningsunderlag.

EDITORIAL

For years, increasing concern has been attributed to fire hazards created by new materials, primarely plastics. Cellular plastics in particular, have been blamed for a number of nasty fires. However, it is normally quite difficult to relate a certain fire course to the fire behaviour of one specific material present. Thus opinions of the severity of the problem have differed considerably between experts.

In the Spring of 1976, the Swedish Ministry of Housing ordered an extensive survey of fire hazards in buildings. The survey was conducted as an inter-agency investigation involving four Government agencies under supervision of the National Board of Physical Planning and Building. The aims of the survey were to identify the nature, frequency and severety of product-related fire injuries and to investigate alternative remidial strategies, i.e. mandatory safety rules, voluntary product standards, information and education.

This article was prepared for FoU-BRAND by Dr Sven-Erik Magnusson at the Lund Institute of Technology, University of Lund. Dr Magnusson has been a fire expert on the survey team and prepared an extensive material based upon statistics and research available in Sweden and abroad.

1. THE DIRECTIVE

In April 1976 the Swedish government (Department of Housing) ordered four governmental agencies (the National Swedish Board of Physical Planning and Building, The National Board for Consumer Policies, the National Board of Rescue and Fire Service, the National Housing Board) to

- identify those materials used in bulding structures and in fixed furnishings, which are to be regarded as fire hazardous and as exceptionally fire hazardous, respectively
- investigate the composition of materials which constitute the majority of products used as moveable furnishings in building
- identify materials in moveable furnishings which are to be regarded as fire hazardous and as exceptionally fire hazardous, respectively
- estimate the economic consequences if, by governmental decree, these materials were replaced with those of a less fire hazardous nature.

2. BACKGROUND

The background to these directives is well-known and universal. A number of industrialized nations has during the last few years sensed a new "fire consciousness" regarding the accelerating use of plastic materials and products. Materials used for interior finishings as well as furniture and other fixed and moveable furnishings have drastically changed during the period since the 1950-ies. In general terms, traditional materials of well-known and accepted fire hazards such as massive wood, cushioning materials of wool and cotton, have increasingly been replaced with petroleum-based synthetic polymers with fire characteristics varying within a much expanded range. For the individual product, the change from a fire-safety point of view may be vanishingly small but the total effect of virtually hundreds of such changes has proved to be substantial and of public concern. Consequently, on many levels of society, from manufacturers and building code officials to the common consumer, there is a pervading uncertainty with regard to fire performance characteristics of new mateials. A considerable part of this concern relates to the capability of existing testing methods to discriminate between safe and unsafe materials.

3. SCOPE AND OBJECTIVE OF INVESTIGATION

The directive mentioned materials in the building structure and in the building contents. The committee interpreted this to exclude electrical applicances, clothing, toys, hobby equipment from the investigation. Some of the more important general questions that the committee had to consider were:

- To what degree are human fire losses material related or material dependent
- Specific environments (dwellings, hotels, hospitals etc) require different levels of fire-safety, i.e. the tolerable probability that a fire of a certain size will occur differs. What are the requirements on the fire performance characteristics of single products in order to achieve the overall level of safety?
- The fire hazard associated with a product is defined by a number of fire characteristics—ignitability, burning intensity, smoke optical density, etc. Can existing data help us to identify the predominant risk component for individual products and end-uses?
- Material related fire hazards are invariably measured by product performance in fire tests. What is the relation between performance in test and actual end-use?

This paper summarizes some of the material that evolved during the committee's work. To the specialist it will contain nothing new, all facts have been published before. To the more uninitiated, it may give a feeling of the basic unachievability of the task and of the limits of technological intervention.

4. LEGISLATIVE FRAMEWORK

Efforts to improve the firesafety by expanding existing legislation must be made with a view to the possibilities offered within the existing regulatory framework. Current Swedish legislation of relevance may be divided into three main parts: the Swedish Building Standards (SBN 1975), the Swedish Fire Law and the Marketing Practices Act.

The Building Standards follow the uniform pattern of building codes, its firesafety section regulating in a detailed manner fire-resistance and firespread requirements. Until the 1975 edition, one- and two-family houses had virtually no fire-safety requirements. In that edition the development that had occurred in the building materials' market had as consequence the inclusion of the following general or blanket clause, applicable to all buildings and building components (§ 37:31).

The current version of the Fire Law was issued in 1962 and regulates among other aspects the responsibilities of the local authorities to maintain an effective fire brigade.It is the obligation of the fire brigade to conduct supervisory fire inspections of all public and other buildings where unwanted fires constitute a life hazard for more than a few people. The wording of the paragraphs is such that the inspection may comprise control of the fire performance of furnishings, such as textiles, furniture, carpeting, etc. The Fire Service Board informed that inspections of this kind are very rare in practice, due to the fact that there are no adequate testings standards or performance criteria available.

The Marketing Practicies Act was enacted on July 1, 1976. The act is intended to protect the consumer's interests in connection with the marketing of goods and services. The act contains three so called general or blanket clauses (§ 2, 3 and 4):

- (it is required that) statements, claims, promises or commitments made in marketing must not be misleading. All information must be verifiable. In cases of malpractice a report is filed by the Consumer Ombudsman to the Swedish Market Court, who issues an injunction
- paragraph 3 states that manufacturers have the obligation to include in their marketing information of special importance to the consumer ("special importance" implies merely that the need must not be neglible)
- paragraph 4 states the authority of the Market Court to prohibit the marketing of consumer goods which, due to their properties, represent unreasonable risks for human injury. (Prohibition may also apply to products manifestly unsuitable for their main intended function).

The application of the Marketing practices act is at the moment unknown and untested in the consumer firesafety area. The opinion of the committee was that use of § 4 would pose no problem for products where field experience had revealed manifestly unreasonable fire hazards. Application of § 3 is another matter. To be operable, § 3 requires knowledge on the part of the manufacturer on what kind of information on product characteristics which is of special importance to the consumer, how to measure these characteristics and acceptance criteria. To this end, the National Board for Consumer Policies issues so called product guidelines or product standards. Evidently, the formulation of these guidelines will be decisive for product fire performance.

5. FIRE RISK DATA COLLECTION AND ANALYSIS

To identify those products and materials where the fire hazard is unacceptable, an examination is needed of existing field experience and statistical studies. The field experience may help us reveal those materials which are not very frequently involved in unwanted fire processes but, if an involvement occurs, may cause an extremely rapid fire growth or generate exceptionally harmful combustion products. Clearly these products should be eliminated from the market in accordance with § 4 of the Marketing Practices Act. Statistical data may help to identify highfrequency chains of events and uses of products, leading to human fire injuries. Even a rather small improvement in the flammability characteristics of these products may lead to significant decreases in human fire losses. This section summarizes some of the findings on the relevance of available statistical data to the committee's task.

National Data

Fire accident data collected in Sweden are fragmentic and often difficult to interpret. The most reliable data concerns fire deaths. Data are obtained both by the Central Bureau of Statistics, as a part of the bureau's death certificate statistics, and by the Swedish Fire Protection Association. The latter organization collects their data by a survey of daily newspapers, and the data comprises a listing of fire death causes. **Fig. 1** gives the number of fire deaths during the period 1961—1976 from the two sources. It may be noted that in some years there is a difference in the order of 20%. The data on fire causes do not indicate any direct or clear trends. In an ordinary year, very roughly one third of the deaths are caused by smokers materials and one third are categorized as "unknown causes".

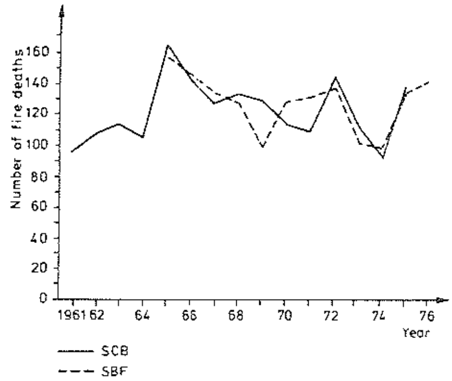


Figure 1. Number of fire deaths in Sweden. Two sources: Central Bureau of Statistics (SCB) and Swedish Fire Protection Association (SBF).

Table 2. Numbers of fatal casualties: Cause of death related to location of fatality [1].

Location of fatality	TOTAL	Burns	Toxic fumes*	Other and unknown
TOTAL	270	47	213	10
At seat of fire**	203	39	156	8
In room of origin, but away from seat of fire	26	2	24	—
Away froom room of origin	29	5	24	—
Unknown	12	1	9	2
Percentage at seat or in room	85	87	85	80

* Overcome by smoke or toxic gases
** eg sitting in ignited chair, in bed

The Swedish fire injury statistics could thus provide little or no information on either medical causes of fire death (burns, inhalation of toxic gases, etc) or on consumer product involvement. As a consequence it became necessary to review statistical and other information from countries outside Sweden.

Non-Swedish Data Analysis

The committee decided to concentrate on fire injury data produced in U.K. and U.S., well aware of the fact that differences in social and cultural environment as well as in data-collecting techniques may make the relevance of some of the data to Swedish conditions questionable.

Of available data sources, the fire statistics from U.K. have since long been considered the most reliable. A paper by Baldwin et al [1] gives an example of how the statistics can be utilized. It describes the circumstances surrounding fires involving furniture and furnishings in U.K. 1970. Furniture fires accounts for only 23 per cent of fires in dwellings but over 40 per cent of the deaths, **table 1.** A closer analysis of the 270 deaths from furnishing fires is found in [1], where number of fires, number of fatalities and cost is related to type of furniture, cause of fire, room of origin. **Table 2** describes for the 270 fatalities cause of death and location. Bowes [2] and Chandler [3] in other studies considered the long term trends in causes of human fire injuries and in general characteristics of domestic furniture fires.

Some of the conclusions:

- there is an increase in numbers of non-fatal and fatal casualties who are overcome by smoke and toxic gases. Whereas deaths due to burns were constant since 1955 at 300-400 a year, deaths due to being overcome by gas or smoke had increased six-fold in the same period
- the proportion of non-fatal casualties among those overcome by smoke or toxic gases is approximately constant at 60 per cent during the period, indicating no significant change in the toxicity of the fire gases
- possible reasons for the fact that more people are being overcome by smoke and toxic gases include a more rapid build-up of trapping smoke-layers, increased total amounts of generated combustion products and, perhaps, an increase in the irritating and panic-inducing properties of these products
- during the period 1962-1972, furniture (bedding and upholstery) fires were on approximately constant portion of all domestic fires. However, the likelihood of a furniture fire leading to deaths increased, both in day-time and night-time fires. The sharpest increase in risk to life occurred in fires resulting from the ignition of upholstery.

Table 1. Numbers of fires and deaths in dwellings, 1970 [1]

Type of fire	No. of fires	No. of deaths
TOTAL	45305	627
Furniture	10530	270
Other	34775	357

In U.S., during the last few years or the last decade, a number of authorities have organized data collecting system. Examples are NFPA (Fire Incident Data Organization, FIDO), Consumer Product Safety Commission (National Electronic Inquiry Surveillance System, NEISS), National Bureau of Standards (Flammable Fabrics Accident Case and Testing System, FFACTS) National Fire Data Center (National Fire Incident Reporting System, NFIRS).

For the committee's purpose, the data supplied by FFACTS was of special significance. The primary source of the accident data incorporated in the FFACTS data base was in-depth investigation reports on flammable fabrics accidents collected by NBS. Whenever possible, the investigation comprised flammability testing of fabrics involved in the actual fire process. As of June 30, 1975 the FFACTS data base contained 3347 case histories. Statistics are broken down in a number of ways, indicating e.g. age and sex of persons involved, first fabric item to ignite, ignition sources, human activity leading to fabric ignition, time of incident, location, severity of injury [4]. A number of conclusions can be drawn. Garment items were the first to ignite in over three-fourths of the injury cases. Eighty per cent of the "no-injury" cases involved person in the 11—64 age range. As could be expected data thus indicated that fabric-related burn injuries occur relatively more often to the young and elderly. The "no-injury" cases involved primarily interior furnishings and beddings as first-to-ignite items. Data will only be examplified by **table 3** from [5], indicating deaths associated with first-to-ignite fabric products.

The figures in table 3 may seem to indicate that the committee, by not consid-

Table 3. Deaths Associated with First-to-Ignite Flammable Fabric Products (3687 Cases) [5]

Fabric Product Type	Number of Deaths
Robes, Housecoats	43
Upholstered Furniture	41
Nightgowns	27
Pyjamas	26
Dresses	22
Shirts/Blouses	15
Pants/Slacks	15
Mattresses	14
Sheets	7
Blankets	6
Sweaters	6
Bedspreads/Quilts	5
Drapes/Curtains	5
Aprons	4
Carpets, Rugs	2
Coats	2
Jackets	2
Scarfs	2
Skirts	1
Gowns	1
Undercoats	1
Pillow Cases	1
Tents	1
Convertible	1

ering clothing, ommitted the group of consumer products creating the largest fire hazard. It must be remembered, however, that the figures in table 3 exclusively concern fires associated with flammable fabrics. A more complete description of the overall situation is given by the investigation of Carke and Ottosson [6]. The aim of the investigation was to identify the most frequent chain of events or circumstances leading to a fire loss. Each such scenario was described by four factors: type of loss—type of occupancy—ignition source—first item ignited or agents of fire spread. By using complementary data from four data bases, the 14 top fire death scenarios were identified. The data confirm the information given by the U.K. statistics, indicating that the residential fires caused by ignition of furnishings are by far the most frequent single cause of fire fatalities.

Fire Toxicity and Autopsy Studies

The problems of clarifying the effect of combustion products on the human organism is of deterring complexity. The difficulty of deriving cause effect relations refers both to the combustion products generation system and the reaction of the biological system. Major causes of death or incapacition are [9]

- heat
  direct burns
  thermal shock
- presence of carbon monoxide
- deficiency of oxygen
- presence of other thermal decomposition gases
- presence of smoke
- panic, emotional shock, trauma.

Regarding the fire toxicity, a number of intoxication syndromes are possible, e.g.

- CO-induced anoxia, resulting from displacement of oxygen from hemoglobin with carbon monoxid and measured by increased blood levels of carboxy-hemoglobin (COHb)
- the complicated interference of HCN with specific enzymatic reactions and with brain electrical activity,
- the neurotoxiticity of certain organophosphates, in some cases leading to an abnormal excitability of the central nervous system and the death of the test animals.

Examples of recent reviews on fire toxicity are to be found in [7], [10], [11].

The cited U.K. statistics gave causes of death only as inhalation of smoke and toxic gases without qualification. To find out details and to corroborate laboratory test with actual fire death causes, a number of autopsy studies have been performed over the years. A summary is given in a review by Birky[7]. Perhaps most widely known is the study of fire fatalities in the state of Maryland during 1972-1973 [8]. Detailed autopsies were performed in 129 cases, combined with biochemical analysis.

The autopsy studies indicated that carbon monoxide was the primary cause of death in 50 per cent of all cases; CO in combination with pre-existing heart diseases, alcohol consumption and burn injuries were causes of 30% of the deaths. Burns accounted for approximately 10 per cent and in the remaining 10 per cent the cause could not be established. The studies showed that fire victims in addition to toxic gases had inhaled quantities of smoke. It is well known that smoke particles may carry adsorbed irritants such as organic acids, aldehyds and alcohols. In the Maryland study, soots ingested by fire casualties showed a surprisingly frequent presence of metals, such as lead, copper, cadmium.

As a conclusion of these and similar studies the following emerges: Carbon monoxide remains the dominant, final cause of fire deaths. The role of HCN remains unknown, partially through lack of a reliable method to measure hydrogen cyanide in human blood. Particulate matter or smoke may play a much more diversified role than is implied by it light-attenuating properties. As published studies mostly concerns fires where the involvement of new synthetic materials have been small, no conclusions can be drawn of the relative toxicity of these materials.

6. THE FIRE PROCESS, FIRE TESTS AND FIRE HAZARD CLASSIFICATION

Factors affecting fire growth and spread

The committee's task was to identify fire hazardous materials. In doing so it had to remember that the fire hazard associated with specific indoor environment is a function of a number of factors. Some of these are of random nature and outside the control of authorities, examples are ventilation conditions, locating of furniture. Examples of factors at least partially controllable are time to fire detection (smoke detectors) and human behaviour (public information and education). Building design and organization of fire brigades are examples of factors traditionally under authorites' control. The final hazard level is a complex function of all these components. Regulations, aimed at reducing fire hazards by new material and product standard, have to be based on a realistic assessment on the relative proportion of fire injuries influenced by improved material selection. Hard numbers in this area are not obtainable, 'America Burning' mentions an unsubstantiated figure of ten per cent.

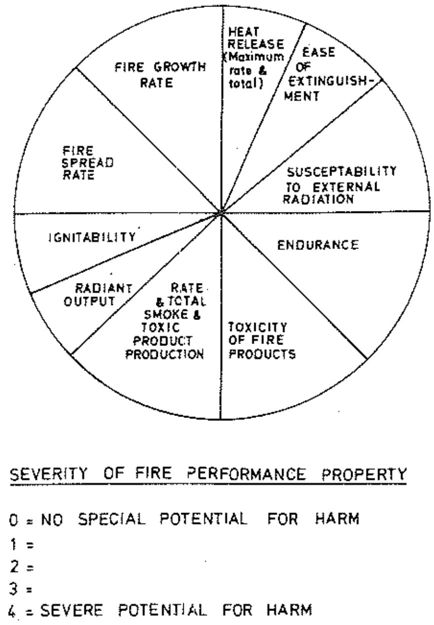


Figure 2. Classification scheme for fire performance of products and systems (ASTM).

As examplified in section 5 present data bases indicate the importance of only one of the more important material flammability characteristics, the ignition resistance. With the new and extended data collecting techniques now being planned or in operation this may hopefully change and useful data merge on materials and products determining fire growth and spread [12]. As long as these data are missing, we must rely on laboratory tests to determine the relative proportion of the fire hazard which is material- or product-related and thus may be reduced by material modification.

The entire process of ignition, fire spread and growth, flash-over and extinguishment is controlled by a number of material and environmental parameters. Here we can mention merely a few, fragmentary characteristics, directly coupled to material performance. For a more complete description, reference is made to the reviews of Friedman [13], Quintiere [14], Thomas [15].

Time of ignition of an externally heated object is dependent on surface heating rate, which very roughly speaking is inversely proportional to the product of specific heat, thermal conductivity and bulk density. The products of these three material properties is commonly called thermal inertia. As flame spread may be considered a continuous series of ignition events, thermal inertia should be an important influencing factor. For downward and horizontal spread this has been analytically and experimentally verified. The theoretical modeling of the more rapid and important process of upward spread is still in its infancy, but experiments indicate the dominant influence of flame radiative properties.

One of the most decisive phenomena in the fire growth process concerns the flash-over event, which is produced by specific combinations of compartment mass burning rate and ventilation conditions [16], [14]. Flash-over is the semi-explosive ignition of pyrolysis products from all parts of a room when, at a critical temperature threshold, it suddenly becomes engulfed in flames.

An ASTM-committee give the following classification scheme for products and system, see Fig. 2. The classification is quite general and no quantitative estimates are made for specified fire environments.

Flammability testing

For the foreseeable future, laboratory tests will provide the available means of product fire hazard assessment. Thus the limitations of the existing set of testing methods is the final factor determining the relevance and efficiency of proposed, extended regulations. As rather few data are available on the Nordtest methods and their correlation to real fire situation, a review had to be made of the experience gathered by investigations of international laboratory tests. A number of these small-scale methods have been developed to determine the ignitability, fire growth and smoke production characteristics of wood and wooden-based materials. Applied to new materials, with an expanded range of fire responses, these methods have often proved to give directly misleading data for assessing the behaviour under real fire conditions. Examples are plentiful. The classical illustration is the ranking of 24 wall covering materials by six national flammability test methods. Surface material 18 was ranked most hazardous in one country and least in another. **Table 4** taken from [18], gives the numerical ratings of a fire-retardant treated polyurethane foam tested according to ASTM E 84 (Sterner tunnel), ASTM E 162 (Radiant panel) and ASTM D 1692 (Bunsen burner). Red oak is used as calibrating material and given the rating of 100 (the higher the more flammable). Benjamin [19] gives the following **table 5**, correlating flame spread rating in the tunnel test with time-to-flash-over in corner and room tests.

As a consequence, ASTM requires that the following caveat is attached to the use of laboratory fire methods for marketing purposes.

The possibility that laboratory tests may give misleading fire performance data have been recognized for a long time as well the underlying causes. The basic deficiency in present testing methodology lies in the fact that the various national tests operate without flexibility in a fixed environment. A rational characterization of the flammability of materials requires the measurement of a number of basic materials fire parameters (heat of gasification, flame radiative properties, convective and radiative rate of heat release, rates of generation of combustion products) over the range of environmental conditions met with in a real fires. Examples of important environmental parameters are level of thermal exposure, degree of ventilation, type of combustion (flaming, smouldering). **Figures 3a, b and 4** clearly indicate the variability of material response with changing environment. Figure 3 illustrates the practical consequences of disregarding this variability.

Mostly for traditional materials, a number of national tests have been correlated quantitatively with full-scale experiments. Examples are the radiant panel and the tunnel test in Canada and U.S., "l'epiradiateur"-test in France, the British fire propagation test. Commonly, for the same material, the numerical index or indices of the laboratory test is compared with event of time to flash-over in the full-scale con-

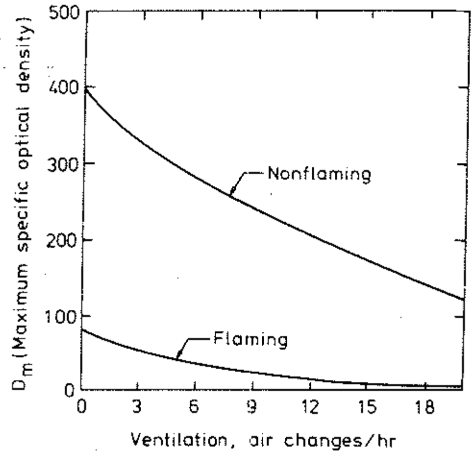


Figure 3 a. Effect of ventilation on maximum smoke density of red oak /20/.

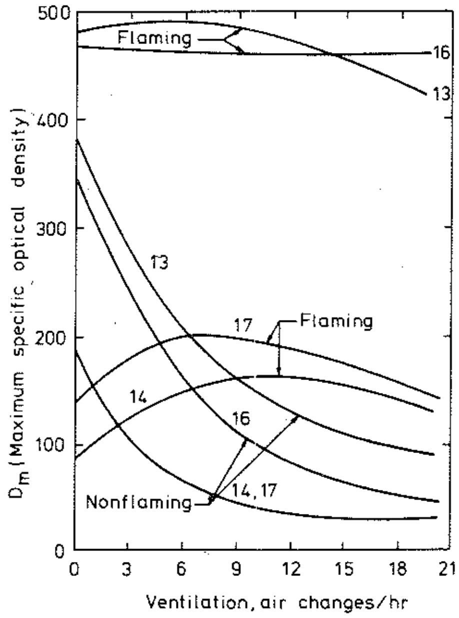


Figure 3 b. Effect of ventilation on maximum smoke density of three acrylics (13, 14, 17) and one polystyrene (16) /20/.

Table 4. Test ratings for red oak and polyurethane foam /18/.

ASTM-test	Red oak	Urethane foam
E-84 Steiner Tunnel	100	40
E-162 Radiant panel	100	880
D-1692 Bunsen burner	Self Extinguishing	Self Extinguishing

Table 5. Time to full ceiling involvement (with 20-lb crib). [19]

Sample	Flame Spread Classification	Time	Material
CORNER TESTS			
J	54	10:10	untreated fiberboard
Q	59	1:22	foam plastic
AD	75	0:40	foam plastic
AE	100	8:45	red oak
ROOM TESTS			
S	22	1:20	foam plastic
A	23	1:40	foam plastic
G	23	N*	treated plywood

*Not reached in 20 min.

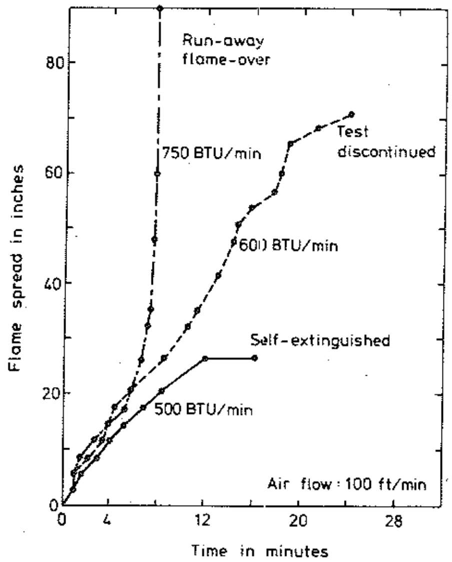
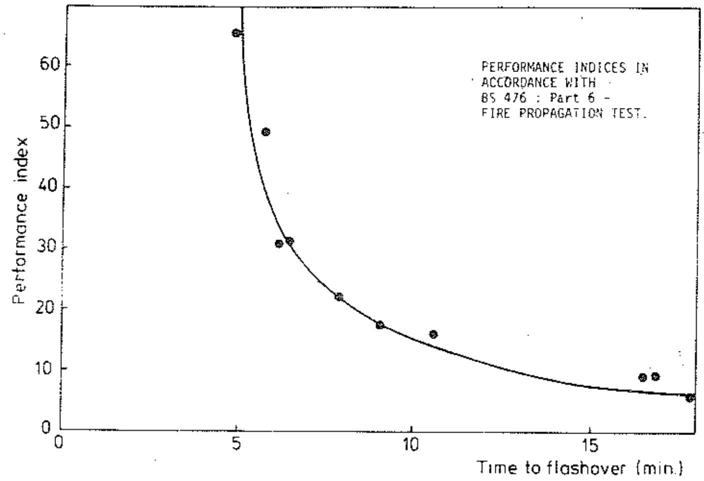


Figure 4. Flame spread results for a nylon carpet with underlay. Model corridor study. Three levels of heat input 500, 600 and 750 BTU/min /21/.



◀ **Figure 5. Relationship between flashover time and performance indices for 11 materials.**

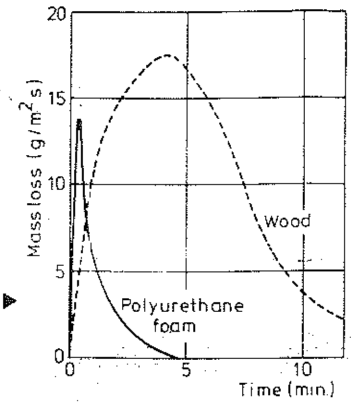


Figure 7 a. Weight loss of wood and PUR-foam samples heated by a radiant flux of 27 kN/m² /26/. ▶

figuration. The British fire propagation test is an enclosed compartment test of principally the same design as the Nordic 'hot box' test. **Figure 5** gives the correlation of flash-over time with performance index for 11 materials.

As the Swedish box test has some design features at least principally similar to the British test, it can be hoped that a good correlation between test results and time to flashover also exists for the Swedish test. When being developed in the 1950's, the hot box test results were compared with full-scale experiments studying the spread of a fire from one room to another, e.g. a corridor. No correlation has been made in full-scale regarding the growth and flashover process of the typical domestic, one-room fire.

Extensive and intensive efforts are at the moment being made to develop material flammability tests, which are more rational in the sense that they are designed to measure a relevant, firmly defined fire performance characteristic. These tests may measure basic material fire parameters, such as heat of gasification, flame radiative properties [22], more complex material parameters such as ignitability, surface spread of flame, rate of heat release (ISO-tests) or the fire hazard of a specific situation ('flooring radiant panel test'). [23]. An essential feature is that they all can be at least crudely mathematically modelled and that the test results should be usable in an analytical study of the full-scale situation.

Tests for the measurement of the hazards of combustion products

Traditionally, the testing methods in this area have been divided into 'smoke' tests and 'toxicity' tests, with the smoke test measuring the light attenuation properties of the aerosol and the particulate fraction at the combustion products. The toxicity hazard has historically been assessed by chemical analysis of selected gases in small scale laboratory tests. As illustrated by the autopsy studies, the relevance of the ligth-transmitting properties of smoke to the life hazard posed is highly questionable, the burning and irritating effects of the smoke having probably at least the same influence as the decreased visibility. Further illustration is given by **Fig. 6, [24]**. In addition, the particulate matter often serves as carriers of toxic products **[8]**. Regarding toxicity, a rational analysis of two vastly complex systems, combustion product generation and the pathological effects of these products on the human organism and on human behaviour, requires a combination of analytical chemistry and biological assessment. A number of animal testing procedures have been developed. Hilado **[25]** gives the relative toxicity data from fourteen different test methods. As for the flammability test, results are shown to vary widely with test method design; in this case mode of combustion (flaming, smouldering), temperature, air flow, material concentration, animal species.

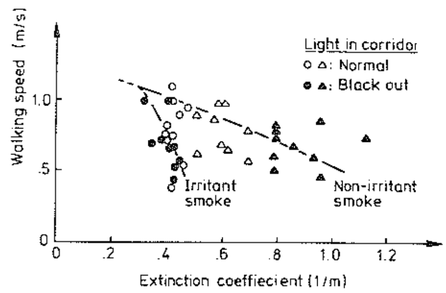


Figure 6. Effects of smoke density and irritation on walking speed /24/.

Difference in gross fire characteristics of natural-synthetic polymers

A few fragmentary illustrations to the difference that may exist in fire response parameters of natural and synthetic polymers: **Figures 7a and b** taken from [26] illustrate firstly that the difference in thermal inertia means that polyurethane foam and solid wood react on a fundamentally different time scale to thermal exposure and, secondly, that material fire response varies with e.g. exposure level and that

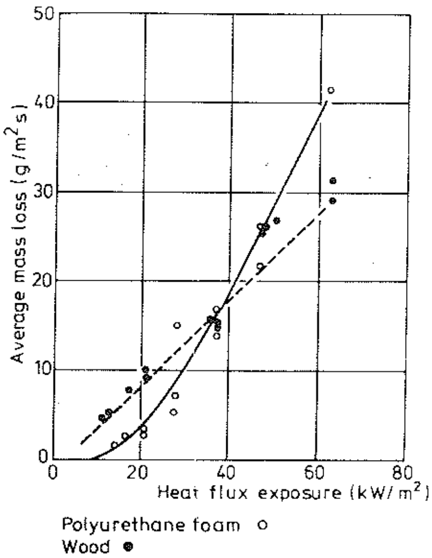


Figure 7 b. Average rate of weight loss for different incident heat fluxes.

ranking of two materials is relative to that level.

A fundamental fire parameter for e.g. furniture material is the mass burning rate, which determines the rate of combustion products and the probability of room flashover. **Table 6 [22]** shows mass burning rates of different synthetic and natural polymers at simulated full scale condition, demonstrating the influence of heat of gasification and flame radiative properties.

The difference in smoke-producing characteristics of wood and some synthetic polymers is illustrated by figures 3a and b. The NBS smoke density chamber, normally operating as a closed box, was changed to permit ventilation. Light attenuation of the smoke inside the box was measured as a function of degree of ventilation.

7. STRUCTURAL COMPONENTS AND INTERIOR FINISHING MATERIALS

With the general data in sections 2-6 as a base, the committee had to turn to specific products. For building components the

Table 6. Mass burning rate m'', apparent heat of gasification L_g, and heat flux from the flame to the surface q'' for samples of selected materials [22]

Sample	M'' (gm/m²sec)	L_g (Joules/gm)	q'' (W/cm²)
Flexible polyurethane foam	54	1.343	7.25
Rigid polyurethane foam	50	1.523	7.69
Ethyl alcohol	44	975	4.29
Polystyrene	39	1.757	8.30
FR rigid polyisocyanurate foam	37	1.523	5.64
Methyl alcohol	36	1.197	4.31
FR rigid polyurethane foam	29	1.188	3.45
FR rigid polystyrene foam	28	1.356	5.25
Polycarbonate	28	2.071	5.80
Polymethylmethacrylate	27	1.611	5.41
Glass fiber reinforced polyester	20	1.393	2.79
FR glass fiber reinforced polyester	19	1.753	3.33
Polyoxymethylene	18	2.427	5.03
Polypropylene	16	2.029	5.06
Phenolic	14	1.640	2.30
Wood (Douglas fir)	14	1.820	2.55
FR rigid phenolic foam	12	3.736	4.48
FR Plywood	11	950	1.05
FR glass fiber rigid polyisocyanurate foam	10	3.669	3.67

primary task of the committee was to quantify the requirements of § 37:31 of the 1975 Swedish Building Standards, see section 4, i.e. to set minimum standards on products not otherwise regulated. Examples of such products are doors, doorframes, door-cases, window-frames, wall cabinets, builts-in cupboards, wardrobes, decorative beams and all other surface areas of fixed, non-moveable furnishings. Excluded are only products of a very limited surface area such as mouldings and doorsills.

It was obious to the committee that the set of 'reaction to fire tests' under development within ISO would not be ready for practical use for some years to come. Employment of these tests hopefully will mean that a much more rational and differentiated design methodology can be developed. As regulatory base remained the existing hot box method, NT 004 (NT = Nord Test).

Up till now, the classification system of surface finishings in Sweden had consisted of two classes, class I and II, coupled to different limit curves of the gastemperature-time curves when materials were testen in NT 004, see **Fig. 8.** The Nordic Committee for Building Regulations has recently proposed the employment of a limit curve III to be applicable for the unregulated surface finishings of walls and ceilings in one and two-family houses. Limit curve III corresponds to the flammability characteristics of massive wood. In short, the committee concluded that limit curve III of NT 004 could be used to quantify paragraph 37:31.

We have previously touched upon the flammability characteristics of cellular plastics. The committee was influenced by the Federal Trade Commission—decision

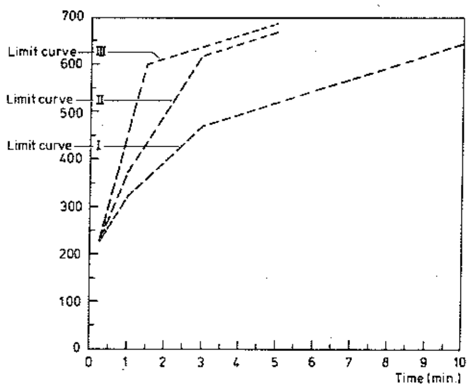


Figure 8. Limit curves for materials of class I, II and III respectively when tested according to Nordtest 004 ('hot box').

[29] on these products, creating strict guidelines on allowable markering procedures. FTC expressed the opinion that cellular plastics, "once ignited", had the following characteristics:

"1. The flame spread is more rapid than 'more conventional materials' such as wood, glass or cotton;
2. Extreme heat is quickly generated;
3. Great amounts of dense smoke are produced;
4. Toxic of flammable gases or chemicals are quickly released at various stages of the combustion process;
5. Polystyrene and its copolymers tend to melt or drip in the presence of fire, which can contribute materially to the spread of a blaze;
6. Certain types of cellular polyurethane may self-ignite if improperty formulated or applied."

The Federal Trade Commission's order to the industry can be summarized as follows:

— Stop using descriptive names that could mislead the users; as to the performance of their products under actual fire conditions (i.e. slow burning, self-extinguishing).
— Take steps to inform the users of the fire hazards of the plastic products. This includes the use of warning placards in trade and other publications and informing interested parties (including underwriters).
— Establish and implement a $5 million dollar research program to study the flammability of the products and the ways to minimize them.

8. FURNISHINGS

In contrast to building components, furniture and other furnishings often play a decisive role in the fire growth process and the generation of a life hazardous environment. More extensive laboratory work has been done only during the last decade and available results are as a consequence far from final and difficult to survey. The committee decided to divide the material into five main groups: upholstered furniture, bedding, curtains, rugs, furniture and furniture parts of rigid plastics. For each group of consumer products, the committee tried to survey the materia changes taken place over the last decades, the fire hazard pattern of the product, experimental work performed, available standards and, to a limited degree socio-economic consequences of remedial actions. A few fragmentary conclusions will be shown concerning the product group upholstered furniture only.

Upholstered furniture

Over the past thirty years, foamed materials have largely replaced other padding and cushioning materials. The padding materials once used in combination with springs included animal hair, cotton or wool flocks, kapok, sisal fibre, rubberised hair. Initially rubber latex foams were used instead, but these have to a large extent been substituted by flexible polyurethanes. Framing of a piece of furniture is nowadays often made of expanded, rigid polystyrene. Regarding the covering fabric, there is now, in addition to the traditional cotton, rayon and wool fabrics, a variety of new materials: polyesters, polyamiders, acrylies, olefins, modacrylics, PVC (imitation leathers).

The modern types of furniture can in some cases be ignited by the flame from a match, burn rapidly with high localized temperatures and with the generation of large quantities of smoke. The widespread concern these circumstances have created have had as a consequence a number of investigations. The scale of the experimental work has varied from studying the ignition resistance of small test samples to burn-out test of fully furnished rooms.

As for other product categories, the general problem is to define the fire hazard pattern associated with the product and to find the optimal remedial action. Main questions are here

- which are the most frequent ignition sources?
- to which degree will the fire hazard level of the environment decrease by increasing the ignition resistance of the specific product?
- which is the importance of fire growth characteristics (flame spread, mass burning rate)?
- will smoke and toxic gas hazard increase if the product is made more flame resistant by treatment with chemical additives?

Ignitability

The US Consumer Product Safety Commission has prepared a massive briefing package on the flammability of upholstered furniture [**30**]. It is concluded that the primary hazard component is defined by ignition of the furniture by a burning cigarette, generated smouldering combustion and production of toxic gases.

Burning intensity

The experience from a number of countries show that dwelling fires have a more rapid and intense development if the burning furniture is of the modern kind. As a very rough estimate, the time to flashover from start of ignition may decrease to 5-10 minutes from the 15-20 minutes in case of traditional furnishings. This is a very significant change taking into account prescribed arrival time of the fire brigade, 10 minutes in inner parts of cities, 20 minutes in the suburbs.

Experimental data

Laboratories in a number of countries have performed investigations on single components of the furniture, on model-scale, mock-up systems, on full size furniture and on fully-furnished rooms. As an example, the introduction of furniture flammability regulations in California was preceded by a survey of 'a vast cross-section of materials used in the construction of consumer upholstered furniture' [**31**]. The ignitions studies could be counted in thousands.

Pioneering work to improve firesafety characteristics was carried out in Great Britain at RAPRA (funded by the Home Office), see e.g. [**32**]. The final phase comprised a sequence of sitting/dining-room fires. The results showed that traditional furniture was relatively difficult to ignite with a small flame. On the other hand, traditional furniture is much more likely to sustain cigarette—induced smouldering combustion than modern furniture. This is a general conclusion with many exceptions in practice. After ignition of the traditional furniture, further growth and spread of fire was slow and no flashover occured. Modern furniture could be ignited by small flaming sources. Once ignited it initially burned rapidly evolving considerable quantities of smoke. A light obscuration to 50 and 100 per cent was obtained after a few minutes, while this time period for the traditional furniture could be an order of magnitude longer. The same difference in escape time apply to the 300 °C room temperature level. Main toxicity hazard in all experiments was CO. In on fire with modern furniture, chemical analysis indicated that the toxicity from generation of HCN was of the same order as that from CO. It was also demonstrated that the flammability of modern upholstered furniture could be considerably reduced by use of improved covering and filling materials and by modifying the design to include a flame-retardant interlining between foam and the upholstered fabric.

Socio-economic consequences

To estimate the socio-economic impact of mandatory or voluntary standards to reduce the flammability of consumer products is no precise exercise. The U.S. Consumer Product Safety Commission has for a number of years worked on a proposed mandatory standard to increase the cigarette ignition resistance of upholstered furniture [**30**]. Estimates on the reduction in yearly casualties as a result of the proposed standard vary from 460 (including 97 deaths) to 6200 (including 1650 deaths), depending on choice of data evaluation bases. The impact on the economic costs would vary from 16-28 per cent for small firms to 9-21 per cent for large firms, bases on furniture retail prices.

In a recent paper from the British Furniture Industry Research Association [**33**] it was shown that at least 90% of domestic furniture in current production should be regarded as potentially ignitable by a match or cigarette. Only furniture with covering fabrics of PVC or wholly wool could be expected to pass an ignition test with these two heat sources. Such a drastic reduction in consumer choice seems unrealistic. The alternative is an interliner, costing 50-100 £ per three-piece suite. According to table 2, the prevention of upholstered furniture ignitions by smokers' materials would reduce the yearly number of fatalities in U.K. with 46 persons or 17 per cent, based on dwelling fire deaths.

Fire retardant additives and combustion products hazard

To impose stricter flammability requirements on consumer products means an expanded use of flame retardant additives. The substances most commonly employed include halogens and organic phosphorus compounds.

Some of these are known or suspected to create environmental and health hazards at even normal temperature use. Examples comprise chlorinated biphenyls and tris (2, 3-dibromopropyl) phosphate. Concern over the use of these and other additives has been growing and was not lessened when in 1975 a research group at the University of Utah reported that a rigid polyurethane foam, based on a low molecular trimethylalpropane (TMP)-polyol and treated with a phosphorus compound generated combustion products containing highly toxic phosphate ester with abnormal neurological effect on the test animals.

However, it is not ascertained that this experience is indicative of a general trend. Toxicity screening tests with animals both at the University of Utah [**7**] and San Fransisco [**25**] indicate that the addition of fire retardants had either no significant effect or resulted in a reduction in relative toxicity. The latter was the case with cushioning and upholstery materials treated to comply with the California furniture flammability regulations.

Regarding smoke generation, studies with the standard version of NBS smoke density chamber indicate that generalized statements to the effect that fire retardant treated plastics produce more smoke than the nontreated materials, are not valid [**34**]. On the other hand, here is substantiation that the majority of "first generation" fire retardant treatments did increase smoke generation. The additives and treatments included in the "second generation" evolution are increasingly designed to limit visible smoke as well as ignitability and flame spread [**35**].

9. PROPOSAL OF COMMITTEE

Briefly summarized, the committee's recommendations to the Department of Housing include the following proposals:

Structural components and built in furnishings

Paragraph 37:31 (see section 4) of the Building Standards is of comprehensive validity and is thus applicable to all building components and fixtures not otherwise regulated. The committee proposed that § 37:31 be quantified with the aid of limit curve III of the Nordtest method 004 (see Fig. 8). Nt 004 measures the contribution of surface materials to the fire growth and flashover process. Qualitatively the reference to limit curve III implies that the fire response of the products in question must at least be equal to that of massive wood. Products involved by the proposed regulation include internal and external lining material of one- and two-family houses, external lining on certain other buildings, all interior trimming materials. Exceptions are only made for products of negligibly surface areas, door-sills, etc.

For smoke density measurements the committee recommended a change to the NBS smoke density chamber as soon as the problem with thermoplastic materials has been solved.

The committee recommended that cellular plastic material must not be used as interior or exterior surface finish material. The only exceptions are products of limited surface area, door frames, window frames, moldings, decorative beams, etc. Naturally, the requirement of limit curve III still stands. When cellular plastics is used as insulating material, the fire-resistive or thermal barrier qualities of the covering materials must as a rule be increased from what is prescribed for other materials.

When tested in accordance with Nordtest 003, the temperature rise on the unexposed side of the thermal barrier should not exceed 150 °C during the first 15 minutes of testing. Corresponding figures for conventional materials are 250 °C and 10 minutes.

Furniture and other furnishings in dwellings

The Marketing Practices Act must be the instrument to use for decreasing the fire hazard level in dwellings. With this act as a base, the National Board for Consumer Policies has the means and obligations to formulate guidelines for a) marketing practices b) design of consumer products with respect to potential for human injury hazard.

The National Board has actively started the work to draw up product standards or guidelines. The work is a cooperative effort involving authorities, manufacturers and researchers. Ongoing or planned standards work includes upholstered furniture, bedding materials, rugs, curtains and surface finishing materials. For the last category, requirements must necessarily be congruent with the requirements issued by the National Board of Physical Planning for the same products. Fire safety characteristics should not differ for materials built into a new house and the materials bought to refit the same house.

Regarding the other product categories, indications point to the fact that primary requirements will be on ignition resistance. As a base for selection of test methods and choice of acceptance criteria, experimental investigations are in different stages of development.

Furniture and furnishings in public buildings, etc

The same kind of work as has been started for private consumer use must be initiated for the contents of offices, restaurants, schools, hospitals and other buildings. The Commission considers it a matter of urgency that regulations are drawn up as soon as possible. The commission proposes that the National Board of Rescue and Fire Service is given powers to issue the required regulations, in which connection the guide-lines drawn up the National Board for Consumer Policies for individual products may form a basis. It must be the duty of the person responsible for certain premises to show that applicable fire protection requirements have been complied with. As the technological base regarding test acceptance criteria, etc. emerges a successively built up inspection and control system should come into force. Requirements levels must be higher than for dwellings, involving limitations on mass burning rate and toxicity of combustion gases.

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