Flammability of building materials and fire growth
Mehaffey, J. R.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20329951
Designing for fire safety: the science and its application to building codes: [proceedings of] Building Science Insight '87, pp. 21-33, 1987-11

Flammability of Building Materials and Fire Growth

J.R. Mehaffey, Ph.D.

Introduction

Despite efforts to restrict the use of combustible material in buildings and to prevent ignition, fires will continue to start. Whether these fires grow and how quickly, depends to a large extent on the basic flammability of building materials and contents, as well as on the building design. The more quickly a fire develops, the less time occupants of the building have to escape.

To provide building occupants with sufficient time to escape, building codes and other regulations restrict the flammability of building materials and contents. Controlling the fuel in this manner may impede the rate of fire growth significantly. Generally, the extent to which flammability is restricted by the codes depends on the building size, the hazards it contains, the mobility and level of awareness of its occupants,and whether it is sprinklered. The control of fuel, as it relates to the objectives in the Fire Safety Concepts Tree, is shown in Figure 1.

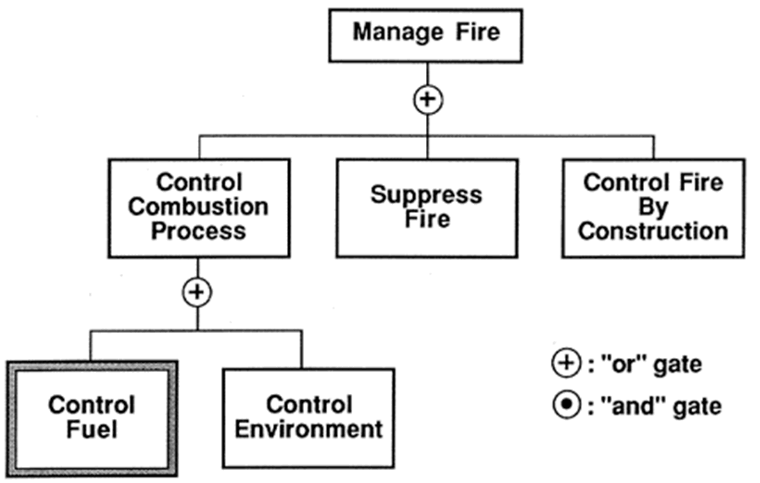

Figure I Control of Fuel, in the Manage Fire sub-branch of fire safety tree

In this paper the relationship between product flammability and fire growth is explored. The nature and status of regulations based on existing test methods are outlined. The potential impact of computer models for fire growth on material selection and building design are discussed.

Room - Fire Growth

When an object in a room starts to burn (such as the armchair in Figure 2), for some time after ignition, it burns in much the same way as it would in the open. After a short period of time, however, confinement begins to influence fire development. The smoke produced by the burning object rises to form a hot gas layer below the ceiling; this layer heats the ceiling and upper walls of the room. Thermal radiation from the hot layer, ceiling, and upper walls begins to heat all objects in the lower part of the room and may augment both the rate of burning of the original object and the rate of flame spread over its surface.

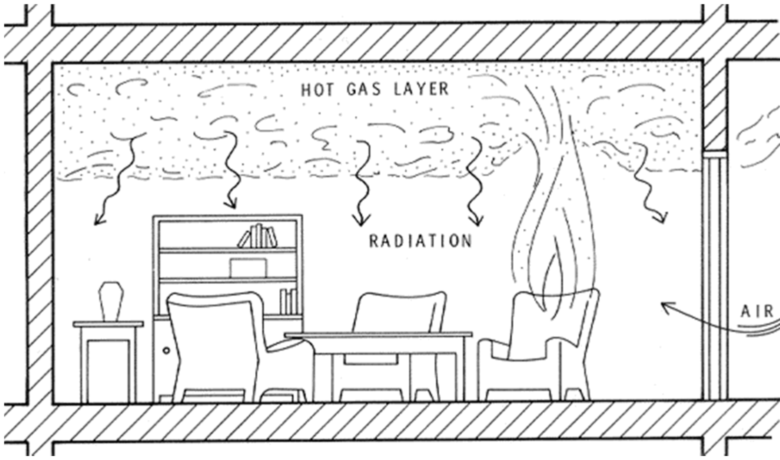

Figure 2 Fire growth in a confined space

At this point, the fire may go out if, for example,the first object burns completely before others start, or if sufficient oxygen cannot get into the room to keep the object burning. Sometimes, however, the heating of the other combustibles in the room continues to the point where they reach their ignition temperatures more or less simultaneously. If this occurs, flames suddenly sweep across the room, involving most combustibles in the fire. This transition from the burning of one or two objects to full room involvement is referred to as 'flashover'.

Usually at the time of flashover, windows in the room will break, allowing for the entry of fresh air. The fire burns vigorously for some time until the combustibles are mostly consumed. Flaming eventually ceases, leaving a mass of glowing embers.

The course of a compartment fire can be expressed in terms of the average gas temperature in the room. Figure 3 illustrates three stages of such a fire:

1. the growth or preflashover stage, in which the average temperature is low and the fire is localized in the vicinity of its origin;
2. the fully developed or post-flashover fire,during which all combustible items in the compartment are involved and flames appear to fill the entire volume; and
3. the decay or cooling period.

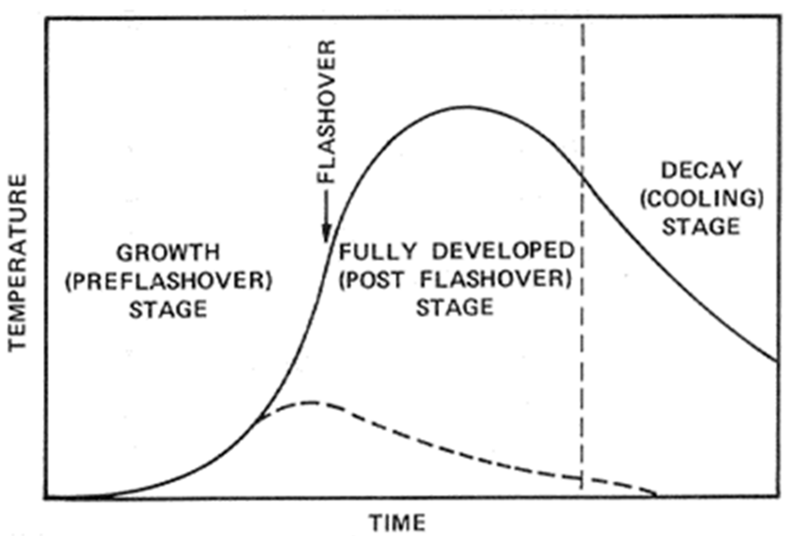

Figure 3 Upper layer temperature during a room fire

The dashed line represents the scenario in which the first item burns completely before flashover. In one- and two-storey apartment buildings, only 22% of fires proceed to flashover (from an analysis of U.S. data obtained from the National Fire Incident Reporting System). The preflashover period lasts from 5 to 20 minutes, the fully-developed fire period lasts 20 to 40 minutes, and the decay period, more than an hour.

The description of preflashover fire growth outlined above would apply even where the walls or ceiling were noncombustible. In a different scenario, the final major item ignited is a wall or perhaps a ceiling. Suppose, for example, a fire starts in a wastepaper basket situated in a corner of a room lined with a combustible wallcovering. If the wall is sufficiently flammable, it will catch fire and, depending on its flame-spreading propensity, flames will begin to grow vertically along the corner. If flames reach the ceiling and spread along the upper wall,flashover is likely to occur. What is important in determining the contribution of a wall to fire growth is its flame-spread propensity.

Whether the initial item ignited is a piece of furniture or a wall, flashover is imminent should the temperature of the hot upper layer in the room reach 500 to 600 ° C.[1] Clearly, under such conditions, occupants of the room will have perished if they have not escaped.

Historical Background

Historical fire incidents reveal that both furniture and combustible wall linings can contribute significantly to the growth of fires. Until recently, means to regulate furniture materials were not in place. However, some time ago, code-writing bodies (which can regulate only materials used in building construction) saw the opportunity to use such regulations to increase control over fire losses (including deaths).

During the 1940's several fire disasters in the United States highlighted the need to regulate interior finishes in buildings.[2,3] In the Cocoanut Grove Night Club fire in 1942, 492 people were killed when flames moved quickly across a cotton cloth which covered the ceiling of the lounge. Other significant fires of the time include the Winecoff Hotel, LaSalle Hotel, and Canfield Hotel fires in 1946, and the St. Anthony Hospital fire in 1949. The magnitude of loss in all these fires was directly related to the rapidity of flame spread on the interior finish. The extensive loss of lives was attributed to asphyxiation as well. It became clear that it was necessary to test and classify materials with regard to three essential properties: flame spread, fuel contributed and smoke developed. In this paper it is the flame spread which is of immediate interest.

The Tunnel Test

In response to these needs, the tunnel test was developed by A. Steiner at Underwriters Laboratories Inc. in the United States.[3] This test has been employed in Canada since 1960 to test materials for compliance with requirements in the National Building Code.[4]

The test equipment consists of a horizontal tunnel 7.6 m long, 450 mm wide, and 300 mm deep (Figure 4). The roof is removable and lined with a low density material of mineral composition. The walls and floor are constructed of refractory fire brick. One wall has observation windows along its length.

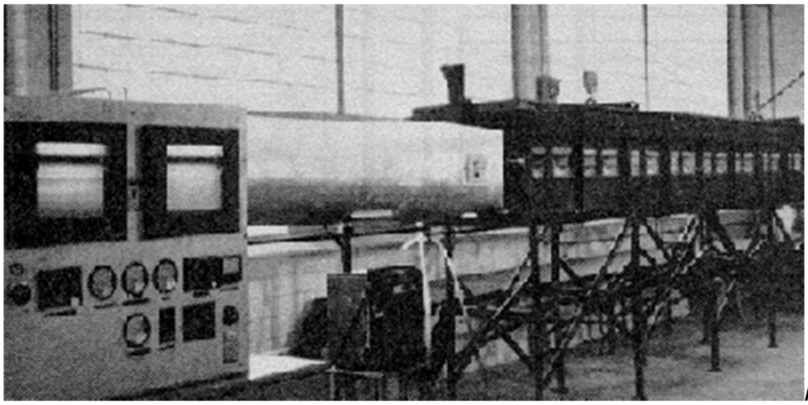

Figure 4 The tunnel test apparatus

Flames from two burners at one end are forced down the tunnel by a steady draught of air at 1.2 m/s. These burner flames are about 1.37 m long, release heat at a steady rate of about 90 kW, and impinge directly on the test specimen, which is mounted either on the floor or on the ceiling of the tunnel. This exposure is similar in intensity to what occurs when a small piece of furniture leaning against a wall is set on fire. The tunnel is calibrated by adjusting the rate of heat release of the burners so that it takes about five and a half minutes for flames to reach the exhaust end of the tunnel when the specimen is 18 mm select-grade red oak. In the exhaust duct at the end of the tunnel are a light source and detector for measuring smoke and a thermocouple for determining heat released.

Before testing, specimens are conditioned at a temperature of 23 + 3 ° C and at a relative humidity of 50 + 5 % until their mass reaches a stable value. This may take a few days to several weeks, depending on the type of product and its initial moisture content.

In Canada, building materials to be tested are mounted on and form either the ceiling or the floor of the tunnel. If the material can support itself in position, or can be supported, it is mounted on the ceiling and tested in accordance with the National Standard of Canada CAN4S102-M83, Standard Method of Test for Surface Burning Characteristics of Building Materials and Assemblies.[6] If, however, the material is to be the finished surface or covering of a floor, or cannot be tested when mounted on the ceiling because it melts and drips or otherwise cannot support its own weight, it is tested on the floor in accordance with CAN4-S102.2-M83, Standard Method of Test for Surface-Burning Characteristics of Flooring, Floor Covering, and Miscellaneous Materials and Assemblies.[6] American versions of the tunnel test do not allow for the testing of floor-mounted samples. (There are a few other minor operational differences between the Canadian and American tests).

Flame Spread Classifications of Building Products

To determine the Flame Spread Classification (FSC) of a material, the burners are ignited and the advance of the flame front along the test specimen is recorded for ten minutes. The detailed methods for computing the FSC are included as an Appendix. The calculation methods are designed so that the FSC of a noncombustible inorganic board is zero, and that of red oak is 100. The values for all other products are determined in comparison with these materials.

The flame front position-versus-time curves for red oak and 6 mm Douglas fir plywood are shown in Figure 5, the curve for 12.7 mm gypsum wallboard in Figure 6, for a loose-fill cellulose insulation in Figure 7, and for a polyurethane foam insulation in Figure 8. There are clearly significant differences in the performance of these materials during the test. The methods for determining FSC have been carefully designed to account for these differences. Using the data presented in Figs. 5 to 8, the FSC of red oak is found to be 100, that of 6 mm Douglas fir plywood is 135; the 12.7 mm gypsum wallboard has a rating of 15, the loose-fill cellulose insulation of 55, and the foam insulation, 427.

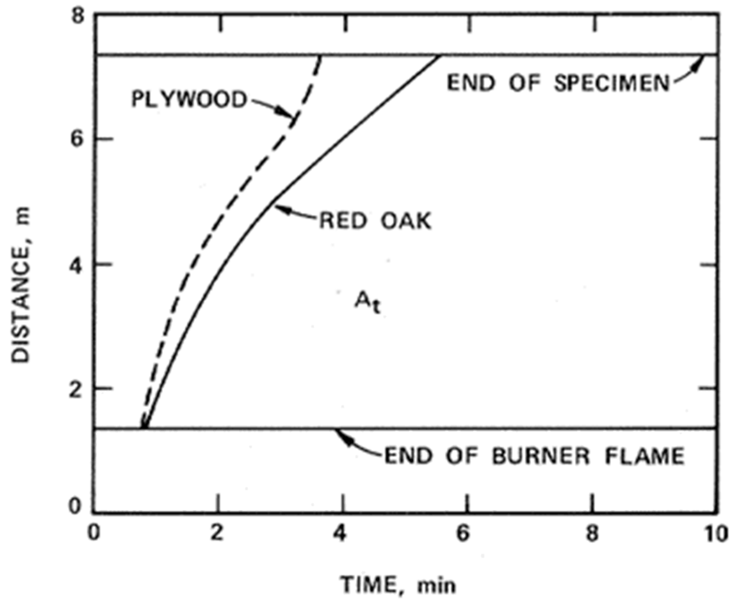

Figure 5 Time - distance curves for red oak and 6 mm Douglas fir plywood. Distance is measured from the burners. The area under A_t = 43.0 m · min for red oak and 47.2 m · min for plywood

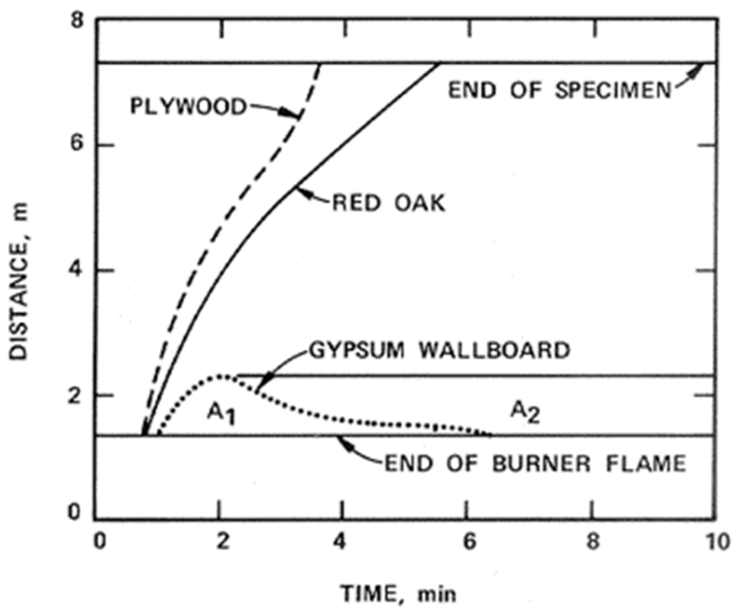

Figure 6 Time - distance curves for 6 mm Douglas fir plywood, 18 mm red oak, and 12.7 mm gypsum wallboard. Note that in the testing of gypsum wallboard, the flame front advances until the two-minute mark and then receded. The area under the curve is given as $A_t=A_1+A_2+8.0$ m · min.

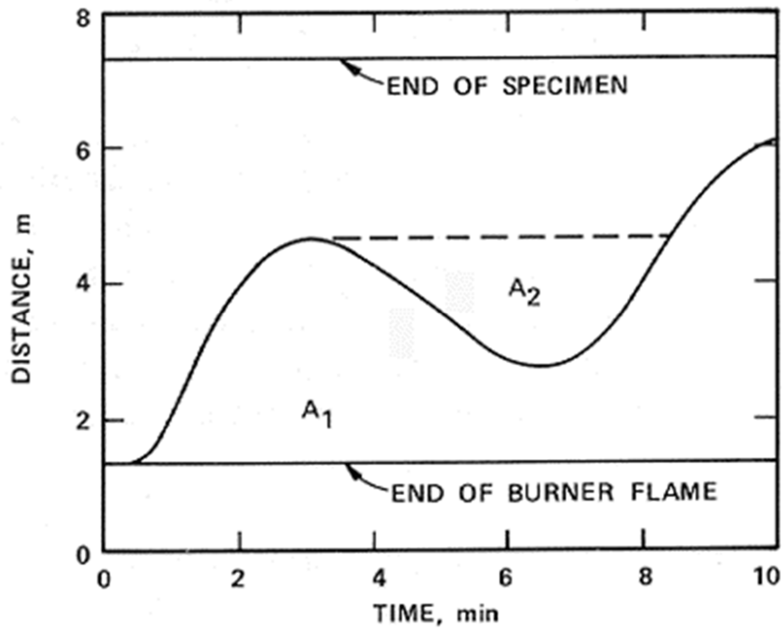

Figure 7 Example of time - distance curve with flame front recession and a subsequent advance

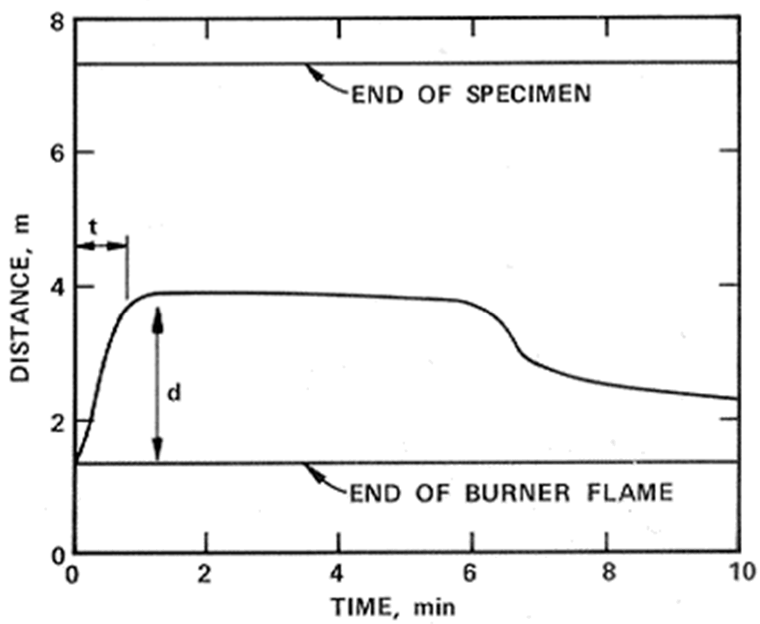

Figure 8 Time - distance curve for a polyurethane foam. The flame advances early in the test. Distance d is 3.7 m and time t, 0.8 min.

Years of testing experience have shown that results can vary from test to test for the same material. For this reason, it is common to conduct three tests on specimens of a product and to quote its FSC as the average of the three tests. Nonetheless, FSC's do provide a ranking of lining materials which reflects their performance in a real fire. In general, the larger the FSC, the faster the fire grows.

Shortcomings of the Tunnel Test

Although the tunnel is useful in selecting firesafe materials, it has shortcomings. Field conditions differ from those of the test; it is not always clear when the relative performance of materials in the field can be determined on the basis of their performance in the tunnel. For example, tunnel test performance bears little relation to how thermal insulation in a cavity wall behaves in the event of fire in the cavity.[7] Even for lining materials, it is sometimes difficult to interpret the tunnel test results; in such cases a second test is used, the Underwriters' Laboratories of Canada test ULC-S127-M82, Standard Corner Wall Method of Test for Flammability Characteristics of Non-Melting Building Materials.[8] Fundamental research into fire growth has shown that more detailed information than that provided by the tunnel is necessary before accurate predictions of flame spread can be made.

Product Testing and Test Results

Four Canadian Laboratories are equipped to perform tunnel tests:

- National Research Council of Canada (NRCC), Ottawa, Ontario (generally, NRCC does not engage in commercial tunnel testing),
- Ontario Research Foundation (ORF), Mississauga, Ontario,
- Underwriters' Laboratories of Canada (ULC), Scarborough, Ontario (2 tunnels),
- Warnock Hersey Professional Services (WHPS), Coquitlam, B.C.

ULC and WHPS also offer certification programs. They test products for manufacturers and list the results in publications released regularly. These publications may be purchased by the general public.[9,10]

After many years of testing, much has been learned about the test performance of interior finish materials. Some of that information is summarized in Table 1, which is a simplification of Table 3.1.A. in the Supplement to the National Building Code of Canada 1985.[11] These ratings apply only to generic materials that conform to standards referenced in the Supplement. The FSC's of materials that are similar to those listed in the table, but actually vary from the specifications of the standards, may differ significantly from the values shown in the table.

Table 1 Assigned name spread classifications for combinations of wall and ceiling finish materials and surface coatings

Materials	Minimum thickness, mm	Unfinished	Paint or varnish < 1.3 mm thick Cellulosic wallpaper < 1 layer
Asbestos cement board	None	0	25
Brick, concrete tile	None	0	25
Steel, copper, aluminium	0.33	0	25
Gypsum plaster	None	0	25
Gypsum wallboard	9.5	25	25
Lumber	16	150	150
Douglas Fir plywood	11	150	150
Poplar	11	150	150

plywood			
Plywood with Spruce face veneer	11	150	150
Douglas Fir plywood	6	150	150
Fiberboard low density	11	>150	150
Hardboard			
Type 1	9	150	*
Standard	6	150	150
Particleboard	12.7	150	*

* Insufficient test information available

Building Code Requirements

Requirements for the Flame Spread Ratings of interior finish materials are contained within the National Building Code of Canada 1985.[12] For buildings which must conform to Part 3, the requirements are contained in Subsection 3.1.11; for those which must conform to Part 9, Subsection 9.10.16 is relevant.

The purpose of these building code requirements is to ensure that, should walls and ceilings become involved in a fire in its early stages, they will not spread flames so quickly that occupants cannot escape. Generally, the lower the flame spread rating of a wall or ceiling, the more time is available to escape. The time required to escape may depend upon the building size, location of the fire within a building, the mobility and level of awareness of occupants, and whether or not sprinklers are present.

In many areas of high risk to occupants, such as exits, flame spread ratings of walls and ceilings are required to be no more than 25. This value was selected as it is close to the value for gypsum wallboard, a material assumed to be safe for the purpose. In practice, any lining material which performs as well as or better than gypsum wallboard is permitted.

In hospitals or prisons, where occupants may have limited mobility or awareness, and in cinemas, where evacuation may be slow due to lack of direction, if there are no sprinklers, walls and ceilings must have a flame spread rating of not more than 75 to ensure sufficient time to escape. If sprinklers are present, the requirements are relaxed to 150, as sprinklers retard fire growth and provide more time for escape.

As another example, interior finish materials used on walls of residential rooms are required to have a flame spread rating not exceeding 150. This value was selected as it is close to the value for 6 mm Douglas fir plywood, a material which has been found to be acceptable on the basis of actual fire experience. In practice, any lining material which performs as well as or better than 6 mm Douglas fir plywood is permitted.

Another way to look at the building code requirements is in terms of options available for escape. Generally, walls in rooms are permitted to have an FSC of 150, walls in corridors leading to exits to have an FSC of 75, and walls in exits to have an FSC of only 25. The least stringent requirements appear in the room, as an occupant can flee from a room fire either to find refuge elsewhere in the building or to escape from the building. More stringent requirements appear in a corridor, as a serious fire there could prevent all occupants of a storey from escaping.The most stringent requirements appear in exits, since a serious fire in the exit could prevent all occupants of the building from escaping.

Combustible Furniture and Furnishings

Early fire growth in a room is not always attributable to flame spread along walls or ceilings. Furniture or other furnishings are more commonly the principal contributors to early fire growth.[13] As mentioned earlier, if a piece of furniture or a wall burns quickly enough to cause the temperature in the upper part of the room to reach 500 to 600 ° C, then flashover will occur in the room.

A critical rate of heat release (or a critical burning rate) must be exceeded (and presumably maintained for some period of time) before flashover can occur in a room.[l4] The temperature in the room can continue to increase only if the rate of heat production (release) in the room is greater than the sum of the rates of heat loss from the room. The equation can be written:

ure increase

eat release > Rate of heat loss to boundaries + Rate of heat loss through openings

A simple model indicates that for a given room the critical rate of heat release required to cause flashover depends principally upon:

- the area of the room boundaries,
- thermal properties of the room boundaries,
- the size and shape of all openings, and
- the duration of burning of the item first ignited.[14]

For typical rooms found in dwellings, the critical rate of heat release is usually about 1 MW.

Upholstered chairs release heat at rates from 0.4 MW up to 2.5 MW when they burn,[l5] so some upholstered chairs will cause a flashover on their own and some will not. This allows for the possibility of selecting 'safe' furnishings in the future. However, the theory still needs some work and it is not yet certain whether society or the marketplace would accept such limits. Clearly, there is a need to develop a means of determining the rate of heat release from burning items of furniture.

Room-Fire Test

To improve the understanding of preflashover fire growth, both ASTM[16] and ISO[l7] are developing standard room fire tests. These tests are intended to evaluate first the contribution of combustible walls or ceilings to room-fire growth.

The tests are conducted in a room with floor dimensions of 2.4 x 3.6 m, and a height of 2.4 m. The walls or ceiling or both are lined with the interior finish to be tested. The experiment is started with a small fire source in the corner of the otherwise empty room. In this early phase, the fire is not intense enough to cause the room to reach flashover; flashover can occur only after the walls or ceiling catch fire. During the experiment, the maximum extent of fire growth along the combustible walls or ceiling, the rates of generation of smoke and toxic gases, and the time to flashover (should it occur) are recorded. Most important, the rate of heat release of the burning material is determined.

The fire performance of products in these full-scale experiments is to be compared with their performance in small-scale flammability tests. The comparison may aid in the development or modification of the small-scale tests. The test results may also prove useful in the development of mathematical models to predict the course of room fires (more about this later).

Room-fire testing has shed light on the utility of the flame spread classification of materials as determined using the tunnel test. When a room is lined with gypsum wallboard (FSC = 15) and a small ignition source (~ 100 kW - equivalent in intensity to a severe waste paper basket fire) is placed in a corner of the room, flashover does not occur.[3] Occupants have a great deal of time to escape. On the other hand, in a room with 6 mm Douglas fir plywood walls and ceiling (FSC ~ 135), the time to flashover is only about three minutes or less, given the same ignition source.[18] The time available to escape has been greatly reduced. In a room lined with a polyurethane foam (FSC ~ 500), the time to flashover can be as low as 13 seconds.[3] There is almost no time for escape. This is the reason that the building code requires a protective barrier to cover such insulation.

Efforts are already under way to broaden the scope of the test method to include the evaluation of the contribution of room furnishings to fire growth. In Sweden, room burn experiments conducted on two sofas ignited by small 40 g wooden cribs, showed interesting results.[l7] Figure 9 shows the heat release rates of two sofas with the same untreated polyurethane padding, and upholstery fabrics of acrylic and wool/viscose. There is a substantial difference in their burning behavior. The fire spreads very quickly on the sofa covered with an acrylic fabric and the peak burning rate is reached within four minutes. The wool/viscose fabric, on the other hand, protects the padding and the fire develops very slowly, reaching a peak intensity of half the magnitude of the acrylic after fourteen minutes. The two sofas were both completely consumed by fire, and both caused flashover conditions to be reached in the room, although at very different times. Clearly the time available to escape was substantially different as well.

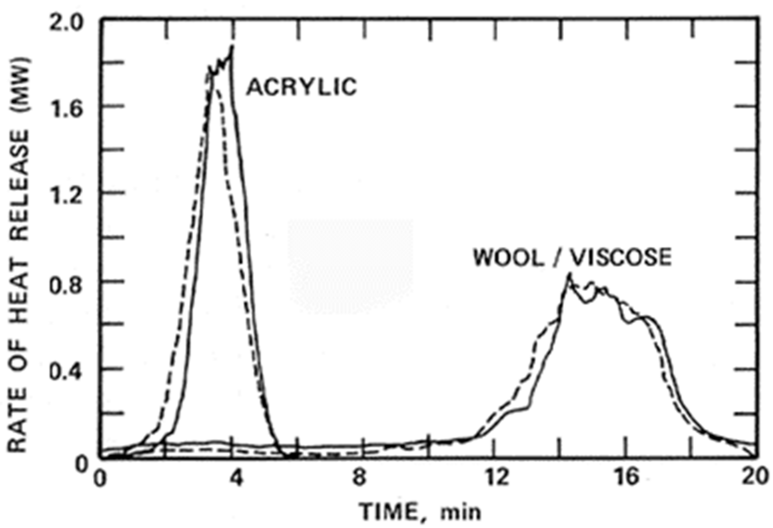

Figure 9 Rate of heat release versus time for two sofas tested in a standard room. The dashed and solid lines reflect results of two separate methods for determining rates of heat release (drawing after Wickström et al, Ref. 17).

Room-fire testing is a promising method for analyzing product performance in a realistic scenario. It provides a very clear indication of the available safe egress time. Unfortunately, room-fire tests are expensive to run and only one scenario can be modeled at a time.

Computer Modelling

In recent years, a great deal of effort has been expended in developing mathematical models to predict various aspects of fire behaviour in buildings. One area of significant activity is the development of models for predicting the rates of fire growth, and production and movement of smoke in fires. These models can be used to predict the time available to escape before a room or building becomes untenable. The models offer a cost-effective method for analyzing the impact of material selection or building design on fire safety.

There are two basic approaches to mathematical modelling of fires - probabilistic modelling and deterministic modelling. Probabilistic models describe fire development as a sequence of events (ignition, flame spread, flashover, etc.) and predict the transition from one event to another by probabilities. Such models are based on years of fire experience but do not rely much on the fundamental chemistry and physics involved in room fires. On the other hand, in deterministic models, the problem and the configuration are prescribed, and the laws of physics and chemistry dictate the evolution of the fire. Both probabilistic and deterministic models consist of a set of mathematical equations that must be solved simultaneously. This is often practical only by using a computer.

Deterministic models can be further subdivided into field models and zone models. In field modelling, the conditions at every point of space,at any moment, are given by the solutions of a complex set of partial differential equations. Generally, field models put large demands on computer power. In zone models, the fire compartment is divided into a group of zones and interactions (mass and heat transfer) between the zones are modelled. Although zone models are still evolving, several are already in use for solving fire safety problems.

In a zone model for a single room fire, the relevant zones might be the burning object, the flame, the heat layer, the cold layer, the vents (openings), target objects (not yet ignited), and the room boundaries. The various important physical interactions between the zones are depicted in Figure 10. For example, heat is transferred to the burning object from the flame, from the upper layer, and from the room boundaries. This heat causes the object to undergo pyrolysis and volatiles (mass) are transferred to the flame. Relationships of this sort must be developed for each zone. The zone model comprises a set of equations describing the interactions between the zones.

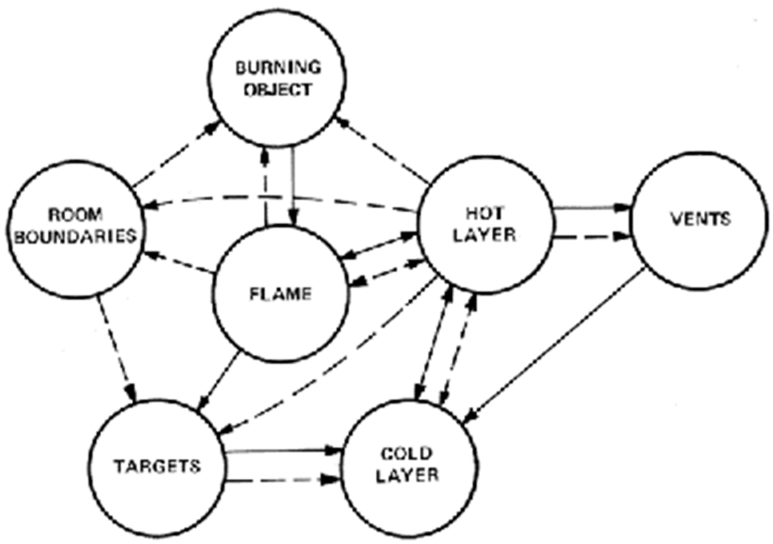

Figure 10 Interactions of the components of a room fire model; --- heat transfer,-- mass transfer

Depending on the scenario being simulated, several zone models are available. Some are designed to consider single room fires only,[20,21] others treat the movement of smoke and fire through an entire building.[22] Some address only the time available to escape a fire,[23] others deal with fire behaviour from ignition to extinguishment. Any model should be used only for the purpose for which it was designed, and only after it has been validated. One of the most frustrating experiences incurred in using models is finding the necessary input data.

The Harvard Mark 5

Developed at Harvard University by H. Emmons and H. Mitler, the Harvard Mark 5 is one of the best known models.[20] It is a deterministic, zone model and one of the most comprehensive developed to date for the prediction of room fire dynamics. In its present form, it does not directly address the safety of occupants in the immediate area.

The situation modeled includes a since room of any size, with one to five vents in its walls, and containing up to five objects. One of the objects (for example a mattress) begins to burn and the subsequent fire behavior in the room is predicted. The model uses the thermophysical properties of materials as input for the calculations. The model has been found to predict with some success the outcome of a series of bedroom fires conducted at Factory Mutual Research Corporation.[20]

Recent improvements in the model make provisions for the burning of walls and ceilings, the possibility of forced-air ventilation, and multiroom fires. In its various levels of development, the model has been used several times for forensic analysis of specific fires, such as the MOM Grand fire and the Beverley Hills Supper Club fire.

ASET (Available Safe Egress Time)

Developed at the National Bureau of Standards (USA) by LY. Cooper, ASET[22] is a deterministic zone model which predicts the time available for occupants to safely evacuate a compartment in the event of a fire. The time that occupants have for escape is the time between the detection of the fire and the on set of hazardous conditions. This is referred to as the available safe egress time. Within the model, the fire growth process is treated less vigorously than in the Mark 5 model. Unlike Mark 5, however, ASET is written in such a manner that the time of fire detection and the time of onset of conditions hazardous to occupants are predicted.

Equivalencies and Design Considerations

Code requirements are intended to provide a minimum acceptable level of safety. Other solutions providing the same or a better level of safety are permitted according to Subsection 2.5 in the NBCC.

It is clear that the flame spread requirements within the code are intended to delay fire growth, providing occupants in the immediate area with sufficient time to escape and firefighters more time to respond. However, the exact time provided by a building code requirement is not usually known. That is, the level of safety required is not quantified.

The following hypothetical examples show how equivalency may be demonstrated.

Example 1

A company designing a highrise office building wishes to line a small meeting room with a new product advertised as having an FSC of 160. According to the NBC, only products with an FSC of 150 or less are permitted. The company is willing to pay for additional fire protection hardware in order to develop a design which provides protection equivalent to the NBC requirement.

Several possibilities exist. One solution might be to equip the room with sprinklers in order to suppress a fire quickly and allow for safe egress. However, it is probably not economical to install them in one room in a building which might otherwise be unsprinklered. In addition, there are some concerns about smoke movement in the presence of sprinkler spray.

Another approach might be to install smoke alarms within the room to ensure that egress begins more quickly than would otherwise be anticipated without automatic detection in the room. To prevent fire and smoke from spreading beyond the room, self-closing doors with a higher degree of fire resistance than required by the code might also be installed.

Mathematical models can also make a significant contribution in the assessment of the above equivalencies. Models can be used to establish the egress time available as well as the time at which fire is expected to spread outside the meeting room. If the proposed solution provides the same or more time for these two events than does the building code solution, it can be reasonably concluded that equivalent safety exists.

Example 2

Prison authorities have learned that a cheaper line of prison furniture has been released. They would like to replace their existing furniture with the cheaper line but are concerned that the new furniture may not provide sufficient fire protection. Unfortunately, the NBC provides no guidance for the selection of furniture.

Prison authorities feel that the existing furniture provides a tolerable level of safety. Several fires involving the existing furniture have occurred but none have resulted in serious loss of life or property.

As materials permitted in a prison cell are restricted and the layout of the furniture can be controlled, it is possible to design room fire tests which can assess the relative performance of the existing and the new furniture within the prison. By selecting a likely ignition source, the resistance to ignition of the two furniture lines can be compared. In addition, the time for the development of hazardous conditions within a cell and within a ward can be determined. If the new line of furniture performs as well or better than the existing line, it is clearly wise to make the change. On the other hand, if the new line performs much worse than the existing line, very serious fires could result.

Summary

The relationship between flammability testing on building materials and contents and the requirements of the National Building Code have been explored. It has been argued that the practice of basing fire safety requirements for interior finish materials on their performance in the tunnel test, as has been done in Canada since 1960, is a sound one. On the other hand, recent developments in fire research, particularly in room-fire testing and computer modelling, will probably foster the development of more exact flammability performance requirements for building materials and contents, and provide a framework for improved fire safety design of buildings.

References

1. Peacock, R.D., and J.N. Breese, 1982.*Computer fire modeling for the prediction of flashover,* NBSIR 82-2516, National Bureau of Standards, Gaithersburg, MD.
2. Moulton, R S., 1961. *Inferior finish for life safety from fire*, NFPA Quarterly,Vol. 55, No.1, pp. 43-50.
3. Abrams, M.S., M.V. D'Souza, P. Higginson, W.S. Metes, J.G. Quintiere, W.J. Parker, R.F. Robins, and J.A. White, Jr., 1985. *Review of ASTM test for surface burning characteristics of building material (E84)* (An ASTM White Paper), Journal of Testing and Evaluation, Vol. 13, No. 2, pp. 89-114.
4. National Building Code of Canada 1960. Associate Committee on the National 14. Building Code, National Research Council of Canada, Ottawa, NRCC 5800.
5. Standard Method of Test for Surface Burning Characteristics of Building Materials and Assemblies, 1983. Underwriters' Laboratories of Canada, ULC Standard CAN4-S102-M83, Scarborough,Ontario, 30p.
6. Standard Method of Test for Surface Burning Characteristics of Flooring, Floor Covering, and Miscellaneous Materials and Assemblies, 1983. Underwriters' Laboratories of Canada, ULC Standard CAN4-S102.2-M83, Scarborough, Ontario, 25p.
7. Mehaffey, J.R., 1986. *Fire performance of combustible insulation in buildings*, in Proceedings of the 30th Annual Technical Marketing Conference - Polyurethanes, Exploring New Horizons, co-sponsored by the SPI Polyurethane Division of SPI Canada Rigid Foam Division, Toronto, 7p.
8. Standard Corner Wall Method of Test for Flammability Characteristics of Non-Melting Building Materials, 1982. Underwriters' Laboratories of Canada, ULCS127-M82, Scarborough, Ontario, 9p.
9. List of Equipment and Materials, 1986. Volume II Building Construction, Underwriters' Laboratories of Canada, Scarborough, Ontario, 709 p.
10. Fire Laboratories Listings, 1986. Warnock Hersey Professional Services Ltd., Mississauga, Ontario
11. Supplement to the National Building Code of Canada 1985. Associate Committee on the National Building Code, National Research Council of Canada, Ottawa, NRCC 23178, 278p.
12. National Building Code of Canada 1985. Associate Committee on the National Building Code, National Research Council of Canada, Ottawa, NRCC 23174, 454p.
13. Phillips, D., and M.A. Kasem, 1985. Upholstered Furniture Fires in Canada, Consumer and Corporate Affairs Canada, L10127-F32 84/85, Ottawa, 29p.

14. McCaffrey, B.J., J.G Quintiere, and M.F. Harkleroad, 1981. *Estimating room temperatures and the likelihood of flashover using fire test data correlations*, Fire Technology, Vol.17, pp. 98-119.
15. Babrauskas, V., 1983. *Upholstered furniture. Heat release rates: measurements and estimation*, Journal of Fire Sciences, Vol. 1, pp. 9-32.
16. Proposed Method for Room Fire Test of Wall and Ceiling Materials and Assemblies,1982. Annual Book of ASTM Standards, Part 18, American Society for Testing and Materials, Philadelphia, PA, pp. 1618-38.
17. Wickstrom, U., B. Sundstrom, and G.Holmstedt, 1983. *The development of a full-scale room fire test*, Fire Safety Journal, Vol. 5, pp.191-7.
18. Fisher, F.L., and R.B. Williamson, 1983. Intralaboratory Evaluation of a Room Fire Test Method, NBS-GCR83-421, National Bureau of Standards (USA), Gaithersburg,MD, 110p.
19. Faby, R.F., 1985. *Building fire simulation model. An overview*, Fire Safety Journal,Vol. 9, pp. 189-203.
20. Mitler, H.E., 1985. *The Harvard fire model,* Fire Safety Journal Vol. 9, pp. 7-16.
21. Smith, E.E., 1985. *Computer based hazard assessment using release rate test data,* Fire Safety Journal, Vol. 9, pp. 47-54.
22. Jones, W.W., *A multicomponent model for the spread of fire, smoke and toxic gases,* Fire Safety Journal, Vol. 9, pp. 55-80.
23. Cooper, L.Y., and D.W. Stroup, 1985. *ASET - A computer program for calculating available safe egress time,* Fire Safety Journal, Vol. 9, pp. 29-46.

Appendix A

Determinatlon of Flame Spread Classificatlon

To determine the Flame Spread Classification (FSC) of a material, the burners are ignited and the advance of the flame front along the test specimen is recorded for ten minutes. The flame front position is plotted as a function of time. The curves for red oak and for 6 mm Douglas fir plywood are shown in Figure 5. The area under the flame front position-versus-time curve (A_t) is calculated.

The FSC_1 (note the subscript 1) is defined interms of the area A_t as follows:

$FSC_1 = 1.85\ A_t$ for $A_t < 29.7$ m · min

$FSC_1 = 1640\ 59.4\text{-}A_t$ for $A_t > 29.7$ m · min

The FSC_l of noncombustible materials is zero, and that of red oak is 100. The values for all other products are determined in comparison with these materials. Using the test results shown in Figure 5 for 6 mm Douglas fir plywood, its FSC_1 is 135. (FSC_1 is not a direct measure of the rate of flame spread. However, the faster the flame gets to the end of the tunnel, the larger is A_t and hence FSC_1).

For some products, the flame front may advance for a while and then recede. For example, the flame front-versus-time curve for 12.7 mm gypsum wallboard is shown in Figure 6. After two minutes of testing, the flame had advanced to 2.3 m, and it then receded. The area under the flame front-versus-time curve is calculated as if the regression had not occurred, and thus A_t is the sum of A_1 and A_2. Using the test results shown in Figure 6 for the wallboard, its FSC_1 is 15.

Occasionally the flame front may recede for a while and then advance again, for example, when testing loose-fill cellulose insulation. In the test shown in Figure 7, the flame spread 4.7 m in three minutes, then receded and subsequently advanced again. The area is calculated as if the flame had spread to 4.7 m in three minutes and then remained at 4.7 m until the flame front again passed 4.7 m (dashed line). The area (A_t) used for calculating the Flame Spread Classification (FSC_1) is the sum of areas A_1 and A_2 in Figure 7.

The FSC_l calculated from the tunnel test gives a ranking of materials which was assumed to reflect their performance in a real fire. For wood-based products this assumption appears to hold up. However, it became evident in the early 1970's that many foamed-plastic insulations with low FSC_1's, if left exposed as a wall or ceiling lining in a room, could spread flames quickly once ignited.[A1]

In Canada, the tunnel standards were amended in 1978 to take account of the unusual behavior of foamed plastics under the test conditions.[A2,A3] Close observation at NRC revealed that the flame front advances rapidly during the early part of the test, but then slows down and in some cases fails to advance further or actually recedes during the remainder of the test period. As the initial rapid flame spread was considered to be of prime importance in the development of a real fire, the use of an equation which gives emphasis to this early spread was introduced.

A second FSC, for foamed plastics (FSC_2), is calculated as

$FSC_2 = 92.3\ d/t$

where *t is* the time in minutes for the flame front to propagate a distance *d* metres, where there is a marked reduction in the advance of the flame front. Although the application of the concept is not without problems, the new calculation gives a classification for foamed plastics that is closer to its performance in real-world fires.

In Figure 8, the flame front-versus-time curve for a polyurethane foam is presented. Compared to the data for conventional materials presented in Figures 6 and 7, the flame advance along the foam commenced much sooner. For this foam, $FSC_1 = 74$ and $FSC_2 = 427$.

In those cases where the flame spread quickly in the early part of the test but it was difficult to establish the point at which the flame front declined, then the FSC_3 is determined by the results from a test conducted in accordance with ULC-S127-M82, Standard Corner Wall Method of Test for Flammability Characteristics of Non-Melting Building Materials.[8]

The Flame Spread Classification (FSC) of a specimen is the greatest of FSC_1, FSC_2 and FSC_3.

Care must be taken when comparing the Flame Spread Classification of a product tested in conformance with CAN4-S102-M83 (ceiling mounted) with that from the American standard tunnel test, ASTM E-84.[A4] In both tests, the advance of the flame front down the tunnel is recorded, but the formulas used to calculate FSC from this information are different. For most building materials, the ASTM formula yields an FSC value about 8% lower than that derived from the Canadian formula; for some materials of very low thermal inertia (good thermal insulators), however, the ASTM figure is much lower than the Canadian one. From the results of corner-wall fire tests, Canadian scientists have argued that the Canadian formulas give a better ranking of lining materials.[A2,A3] Generally, the lower the FSC, the more time there may be to evacuate, should walls become involved in fire.

With thermoplastic materials, or others tested in conformance with CAN4-S102.2-M83 (floor mounted), it is not possible to compare results with those measured in ASTM E-84, where the sample is mounted in the tunnel ceiling. The performance of such materials in the two tests is markedly different; generally, they perform more poorly in the Canadian test.

In addition to determining FSC's for products, the tunnel is used to determine smoke-developed classifications. These classifications are important in high-rise buildings only.

References

A1. Williamson, R.B., and F.M. Baron, 1973. *A corner fire test to simulate residential fire,* Journal of Fire and Flammability Vol. 4, pp. 99-105.

A2. D'Souza, M.V., and J.H. McGuire, 1977. *ASTM E84 and the flammability of foamed thermosetting plastics,* Fire Technology, Vol. 13, pp. 85-94.

A3. D'Souza, M.V., *The basis for flammability test methods,* Second Symposium on Combustibility and Plastics, The Society of the Plastics Industry of Canada, Ottawa.

A4. Standard Test Method for Surface Burning Characteristics of Building Materials, 1986. ASTM E-84, Annual Book of ASTM Standards, Vol. 04.07, American Society for Testing and Materials, Philadelphia, PA, pp. 319-336.

This article was published as part of the technical documentation produced for Building Science Insight '87, "Designing for Fire Safety: The Science and its Application to Building Codes", a series of seminars presented in major cities across Canada in 1987.