FIRE SAFETY IN DWELLINGS AND PUBLIC BUIDINGS*

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Approximately 85% of all fire fatalities in the United States occurred in buildings.[1,2] In most of these the building holds the smoke and toxic combustion products from a fire. It is exposure to these products that accounts for the bulk of fire deaths.

Most fire deaths occur in residences, as can be seen from Tables I and II. While it is not a precise categorization, a useful way to look at fire deaths is to compare those that occur in one or two family dwellings, apartments, and mobile homes with those that occur in industrial, institutional, commercial buildings, and places of public assembly. Only about 8% of fire deaths occur in the latter category. Yet these buildings are the prime focus of building codes in the United States; one and two family dwellings are comparatively uncontrolled. (Hotels and motels do not fit neatly into either category, however, because they are transient residential structures subject to code scrutiny. The fire death rate in hotels and motels is somewhat higher than the fire death rate in residences taken as a whole.) Much can be learned, however, by focusing on the two general classes, residential and nonresidential, separately.

FIRE SAFETY IN DWELLINGS

Assuming that the average person spends about half time in his or her residence, one would expect residential fire deaths to account for approximately 50% of the total. In fact, it is substantially higher than this, some

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TABLE I. ESTIMATED 1979 FIRE DEATHS*

Property use	*Estimate*		*% of all civilian deaths*	
Residential (total)	5,765		74.1%	
One- and two-family dwellings†		4,320		55.5%
Apartments		1,180		15.2%
Hotels and motels		140		1.8%
Other residential		125		1.6%
Vehicles‡	1,535		19.7%	
All other categories	480		6.2%	
	7,780			

*Source: *Fire Journal*, September 1980, p. 53
†Includes mobile homes
‡This category includes highway vehicles, trains, boats, ships, aircraft, farm vehicles, and construction vehicles.

TABLE II. FIRE DEATHS BY OCCUPANCY

Occupancy	*Percentage of fire deaths*	
Residential	72	
Independent of structure	14	
Apparel		11
Apparel plus flammable fluids		3
Motor vehicles	4	
Industrial	3	
Institutional	2	
Public assembly	2	
Commercial	1	
Others	2	
	100	

three quarters of the total, a fact generally explained by pointing out that potential fire victims are at their most defenseless, e.g., asleep. As we pointed out in our earlier paper,[3] the most comprehensive study of residen-

TABLE III. RESIDENTIAL FIRE DEATHS. Maryland 1971-1978

Age	*Total deaths*	*Number able to escape unaided*	*Percentage of total*
0-5	77	0	0
6-9	39	35	90
10-19	60	43	72
20-29	52	27	52
30-39	33	11	33
40-49	56	14	25
50-59	65	17	25
60-69	57	27	47
70+	49	30	61
No age	31	13	42
	519	217	42

tial fire deaths was carried out over a seven-year period in the state of Maryland. We have already discussed the clinical aspects of this study. Inspection of Tables III and IV, based on data from this study combined with population figures, discloses some interesting features. Healthy, fully functioning adults die in fires in far smaller numbers than one would expect from their representation in the population. Most fire victims between the ages of 20 and 60 had some impairment—detected during the postmortem examination—or were otherwise presumed to have been incapable of independent escape (Table V). By far the most frequent fire victims are the very young and those over 60 years of age.

Fire preys disproportionately on those who cannot take mature, independent escape action. It should also be noted that during most of the period of this study smoke detectors were not particularly common in Maryland households. In some sense, then, the figures are a baseline upon which the efficacy of smoke detectors can be calculated in the future. The real test for early warning is the extent to which protection improves for those already at comparatively high risk. For detectors to be most effective, the additional time gained by early warning must be put to use in assisting those who need help to escape.

TABLE IV. BREAKDOWN OF MARYLAND FIRE DEATHS BY AGE, POPULATION AND ABILITY TO ESCAPE

Age	*Total deaths in age group*	*Number presumed "incapable of independent escape" (see Table V)*	*Yearly deaths per 10^5 population in age group*	*Number presumed capable of escape*	*Yearly deaths per 10^5 population in age group*
0–5	77	77	4	0	0
6–9	39	4	.2	35	1.5
10–19	60	17	.3	43	.8
20–29	52	24	.5	27	.5
30–39	33	22	.6	11	.3
40–49	56	42	1.4	14	.4
50–59	65	48	1.6	17	.6
60–69	57	30	1.5	27	1.4
70+	49	19	1.4	30	2.2

TABLE V. CATEGORIES UNABLE TO ESCAPE UNAIDED

1) Victims of "fast" fires
   - Clothing fires
   - Explosions and flash fires

2) Those who may know of fire but must be helped
   - Children under 6 years old
   - Blood alcohol ≥ 0.1% (legal drunkenness)
   - Other drugs (e.g., barbiturates)
   - Coronary artery disease

TABLE VI. WHERE FIRE DEATHS OCCUR

Rank	*Occupancy*	*Item ignited*	*Ignition source*	*Percent of U.S. fire deaths*
1	Residential	Furnishings	Smoking	27
2	Residential	Furnishings	Open flame	5
3	a. Transportation	Flammable fluids	Several	4
	b. Independent (residential)	Apparel	Heating and cooking equipment	4
	c. Residential	Furnishings	Heating and cooking equipment	4
6	a. Independent	Apparel/ flammable liquids	Several	3
	b. Residential	Flammable liquids	Heating and cooking equipment	3
	c. Residential	Flammable liquids	Open flame	3
	d. Independent	Apparel	Open flame	3
10	a. Residential	Interior finish	Heating and cooking equipment	2
	b. Residential	Interior finish	Electrical equipment	2
	c. Independent	Apparel	Smoking	2
	d. Residential	Structural	Electrical equipment	2
	e. Residential	Trash	Smoking	2
				66
Others, all less than 2% of total				100

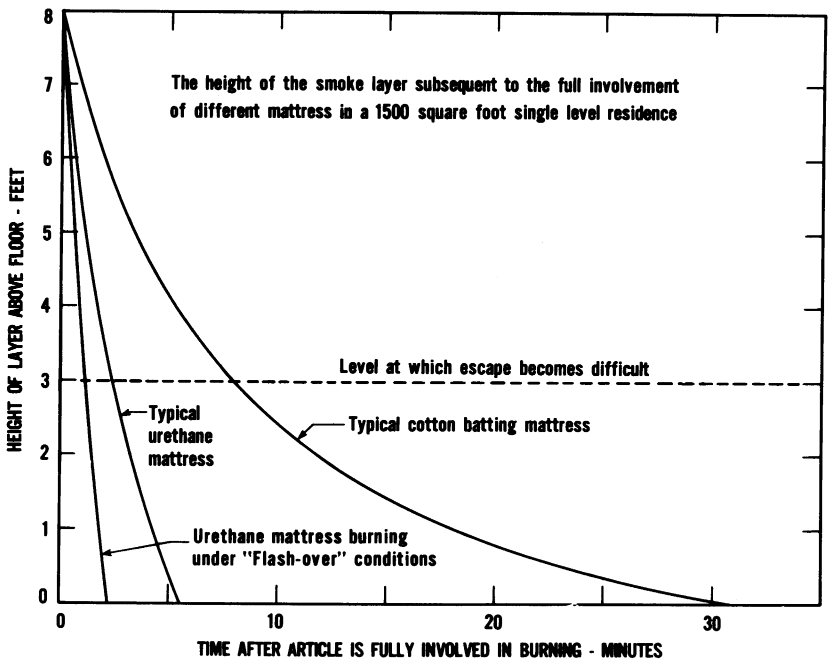
RESIDENTIAL FIRE SCENARIOS

Fatal fires in residences typically involve ignition of the buildings' contents rather than ignition of the structure itself. If the structure itself burns, this is typically after fire fatalities have already occurred.

The most common residential fire death scenarios are listed in Table VI. As can be seen from this table, the instrumentality of furnishings is probative. The most common ignition source is a dropped cigarette, accounting for some 27% of all fire deaths. This fire typically begins as a smoldering one, which may develop into a flaming fire later in the process. With the advent of more synthetic cellular materials in furnishings, the flaming fire appears to be assuming additional importance.

Somewhat different hazards are posed by smoldering and flaming fires. Smoldering fires can be lethal but proceed at a relatively slow rate of development. Flaming fires grow more rapidly and, if they grow rapidly enough, can lead to the phenomenon of room flashover (described below), which poses an extra threat. The generation of hazardous conditions is illustrated for three examples in the figure. The three examples are: Curve A—smoldering fire typical of a cotton mattress; Curve B—flaming fire representative of the burning of a polyurethane type mattress; and Curve C—flaming mattress burning under conditions of flashover. Analogous situations exist for the burning of upholstered furniture. The approach of hazardous conditions is given by the filling of a typical residence with "smoke," which contains lethal combustion products. Being hot, the smoke layer collects initially at the ceiling. As more smoke is produced, the layer descends to a level (here taken as 3 feet) where the carbon monoxide, heat, and reduced visibility restrict occupants' ability to escape. In examining Figure 1 it is important to keep in mind that the times shown are only after the fire has spread over the mattress' entire exposed surface. In reality, there is some additional time between ignition and the descent of the smoke layer during which the fire grows to involve the burning article completely.

A smoldering fire (Curve A) generally begins in a very small area and develops by spreading through the material directly adjacent to the initial hot spot. Often a mattress or chair will smolder until it is completely consumed, and no other article in the room will catch fire. Even so, more than enough smoke and carbon monoxide is produced by such a fire to kill in the room of origin and the adjacent rooms. The reason smoldering fires are so hazar-



dous, as defined by their contribution to fire deaths, seems to be that they occur with high frequency when fire victims are asleep or incapacitated and go undetected. In general, furniture constructed of such traditional materials as untreated cotton batting and wood are more prone to smolder than are those articles characterized by the increasing use of plastics.

We do not know how frequently smoldering fires convert to flaming ones. This is a sensitive function of the ventilation available and the geometry of the burning article. However, available data indicate that the conversion is common. When it occurs, the situation is that of a flaming fire, which is described below. A flaming fire is much more likely to involve other articles in the room, thereby jeopardizing the physical state of the property as well as the safety of the occupants. Curve B in the figure shows the development of a flaming fire due to the typical burning of a urethane mattress. The descent of the smoke layer is far more rapid than with smoldering fires and therefore the time available for escape is correspondingly shorter.

More rapid fire buildup would lead one to expect flaming furnishings fires to represent a larger fraction of fire deaths than is seen in the statistics.

That they do not is probably attributable to the fact that residents are more likely to be awake in situations where open flames are around. One does not generally fall asleep holding a lighted match, but one may very well fall asleep holding a lighted cigarette.

Public attention has been focused on flaming fires. Experiments have shown that fires involving furniture composed of cellular materials, whether synthetic, such as polyurethane, or natural, such as latex foam rubber, grow more rapidly and release more total heat than do fires in furniture constructed from wood, cotton, and other traditional materials.

This results when the heat produced reinforces the developing fire and causes it to grow at an ever increasing rate until it runs out of air or until all combustibles are consumed. At that point, the fire will be so large that burning occurs throughout the room and flames shoot out the doors and windows: this is flashover, or full-room involvement. Flashover can occur with startling rapidity—in as little as two to three minutes from ignition in some cases. Within a few moments of flashover the entire dwelling becomes untenable, flame spreads rapidly throughout the house, and escape is difficult, if not impossible.

Again we emphasize that the likelihood of flashover directly depends upon the rate at which articles burn. If the rate of heat release overpowers the ability of the room environment to dissipate the heat, flashover occurs. Flashover is often observed in our laboratory when modern furniture is burned; it is seldom observable when the only fuel source is traditional, cotton padded furniture. The figure also illustrates the attainment of untenable conditions when flashover occurs (Curve C). Note that the escape time is substantially reduced.

There has been a good deal of discussion in recent months of the role of so called "toxic fumes" and fires involving synthetic materials. Clinical evidence implicates carbon monoxide in a great majority of fire deaths, and carbon monoxide accompanies the burning of synthetic materials as it does the burning of more traditional, cellulose-based materials. It bears repeating that the effects of hydrogen chloride, hydrogen cyanide, and other gases may contribute to early incapacitation, but this is by no means proved. What is often lost sight of in these discussions is that carbon monoxide itself is extremely hazardous; the contribution to hazard from a secondary toxic gas is generally very difficult to detect when the background of carbon monoxide is high.

DESIGN FEATURES OF RESIDENCES

Fire safety requirements of building codes for most classes of residences are scanty. In fact, at present most building codes in the country do not contain separate chapters for one and two-family dwellings. Attention is focused only on multifamily dwellings, and most code provisions deal only with common access areas, such as lobby, corridors, stairways, and the like. Design in single-family houses is characterized by open, rather than compartmented, construction. Compartmentation, or designing fire resistance into interior walls so that a fire's movement throughout the floor is restricted, is usually absent in the average home. Solid core doors may have a fire resistance of some 20 minutes when exposed to a standard time temperature curve, but are typically left open, which negates their effectiveness. In fact, one generally treats an entire residential dwelling as one volume of space, and makes calculations on tenability conditions based on this assumption. Such an assumption was used in the generation of Figure 1.

Given the high fire loads that most American residences contain, and the relative lack of barriers to the propagation of fire and smoke, it is not surprising that the United States has a very high residential fire death rate. However, three measures developed in recent years offer substantial promise in improving the situation.

All mattresses sold in the United States after 1971 are required by law to be resistant to ignition by a dropped cigarette. The Consumer Product Safety Commission has the responsibility of enforcing this requirement. More recently, the upholstered furniture industry has adopted a voluntary labeling program for furniture which is also cigarette resistant. This program is a relatively new one and its efficacy is still in doubt, but both of these approaches offer the consumer some protection where little existed before.

Smoke detectors are now in approximately one half of the dwellings in the United States. Many jurisdictions now require that all new housing contain smoke detectors. At least one jurisdiction, Montgomery County, Md., has a retroactive requirement providing that *all* residences be so equipped. Recent reductions in fire deaths are thought to be due in part to the inclusion of smoke detectors. The United States Fire Administration reports that fire deaths in homes with smoke detectors are about half those in unprotected dwellings.[1] All other things being equal, one would expect this to translate into a 20% reduction in the overall fire death rate. The observed reduction is substantially less. This is thought to be because those homes which voluntarily install smoke detectors already have a high level of awareness, and are at correspondingly less risk to begin with. Unfortunately, the households which have the greatest risk of fire tend to have the least protection.

New sprinklers have recently been developed specifically for residences. The key to this development was a new sprinkler head which has a low thermal inertia so that it goes off earlier in the fire. As was pointed out in the beginning of this paper, this is particularly important because life-threatening conditions develop much earlier in a fire than does severe property damage. A few communities, such as San Clemente, Cal., require new homes to be equipped with residential sprinkler systems. The cost of these systems remains significant when compared to smoke detectors, but it is substantially below what would have been the case a few years ago. Estimates by the United States Fire Administration, which has taken the lead in fostering the new sprinkler technology, are that residential sprinkler systems can be installed for approximately 1% of the cost of the dwelling.

Unless one supposes that substantially increased regulation of one and two-family residences will come about, the key to reducing residential fire deaths lies in increased fire-safety consciousness among home-owners. Awareness of the home fire threat and the availability of moderately priced devices to reduce that threat are crucial.

Fire Safety in Nonresidential Buildings

Despite recent publicity given to highrise fire problems, nonresidential occupancies account for a relatively small fraction of fire deaths. This must be due in some measure to the scrutiny that such buildings get from code officials while being constructed and from fire officials once they are built. Perhaps even more important is that occupants of these buildings are generally awake, alert, and mobile — all of which improve their ability to escape.

Unlike residential deaths, the causes of fatal fires and the circumstances which surround them do not cluster in a small number of scenarios. Electrical ignition sources and the overheating of mechanical and thermal devices are proportionately more common. Although the evidence is more scanty, it appears that building contents are the principal instrumentality of fire deaths in nonresidential buildings, as they are in residences. The spectrum of materials which contribute to the fire is similar, but provisions for containing fire and smoke are often more elaborate.

Indeed, fire protection is a substantial component of the cost of meeting building code requirements. It has been estimated that as much as $10 billion is spent annually as a portion of construction costs which would not be incurred if fire as a threat did not exist. If this were a tax burden or paid by the consumer in explicit form, it would probably be the cause of much more public attention.

ARCHITECTURAL AND REGULATORY PROVISIONS IN NONRESIDENTIAL BUILDINGS.

The dilemma facing modern building designers and code officials is to create a reasonable measure of the fire safety in a building whose future use and contents are unknown. As we pointed out, the building contents play a major role in the fire's severity, and the capability of the occupants is important in determining how readily people can escape. For example, the recent rash of boarding home fire deaths, some of the most significant of which have occurred in New Jersey, is the result of a boarding home clientele which is increasingly old, enfeebled, or of otherwise diminished capacity. Bringing the design of existing buildings into accord with the capabilities of these new occupants has been a real challenge.

Most building codes concentrate heavily on providing well protected means of escape from a burning building. This works best when the building is of moderate size, and clearly becomes more difficult as the size of the building increases without limit. For example, the World Trade Center contains more than 40,000 people during peak hours of a normal day. To evacuate this population, the equivalent of a medium-sized city, on the time scale of the few minutes in which some severe fires can develop, is an unrealistic expectation. Consequently, automatic suppression devices, areas of refuge within the building, and design features aimed at controlling the movement of smoke in the building have received increasing attention during recent years.

In addition, code officials encounter designs which were not envisioned when building codes were written. Atria, for example, are common in new hotels and office buildings, but are clearly at odds with the traditional notion of fire-safe design which tries to limit vertical smoke movement. Most atria contain smoke vents at the top, but since people will be exposed to the smoke, atria are also usually protected by sprinklers to keep very large fires from developing. Cold, wet "sprinklered" smoke moves differently than hot buoyant smoke. Can it be effectively vented by existing systems? The answers are not obvious, yet they typify the kinds of questions building officials are asked daily. Because it is a bit difficult to find new buildings where the owners are willing to let anyone carry out a range of experiments to get the answers, the need for predictive methods of smoke movement is crucial.

The issue is more general than smoke control. Informed and innovative fire protection design can often produce high levels of safety at reasonable cost. But the low-cost solutions must be tailor-made, building by building. Often they make use of different devices and designs than the codes envisioned. The building official does not want to tie the designer's hands, but he must be sure the building is safe. The designer wants the safety, but he would like the building to have many other desirable characteristics as well. In recent years there has been an increasing demand for equivalency systems which preserve the objectives of the code in setting a certain level of safety but allow the largest possible number of ways of getting there.

In 1980 the Center completed work on a Fire Safety Evaluation System for hospitals and nursing homes. This system, developed under contract to the Department of Health and Human Services, provides a means to compare the fire safety of existing structures to that required by the Life Safety Code. It attempts to provide alternative means to provide protection equivalent to that code, and often does so at considerably reduced costs.

SUMMARY

This has been an attempt to survey briefly some of the principal issues in building fire safety. Among the most important points are:

1) Fatal fires occur almost exclusively in buildings, the great majority in residences.

2) The building serves to catch and hold combustion products, inhalation of which is the actual cause of death.

3) Most fatal building fires involve the burning of the contents, rather than the structure itself — these contents are increasingly of synthetic materials.

4) Improved technology is now available, both to make furnishings resistant to small ignition sources and to suppress residential fires.

5) Smoke detectors are now widely used in homes, and some positive effect has been observed in national fire experience.

6) Most code enforcement focuses on relatively large buildings (i.e., those other than one and two-family homes), and the fire safety record of these structures is comparatively good.

7) Seldom is as much attention paid to the fire properties of common building contents, and it is evolutionary changes in these, as well as unforseen characteristics of building occupants, which are major challenges to building regulation.

8) New building designs and materials put great demands on the adaptability of code requirements, leading to increased demands for equivalency systems designed to preserve the safety objective of the code but to increase the number of options available to attain it.

Questions and Answers

MISS BARBARA EISLER (American Lung Association of New Jersey): You spoke about controlling smokers and about controlling the flammability of the products in the home. Have you done any work with controlling the flammability of the cigarette itself? I just read about two people who are suing a cigarette company, claiming that an additive in the tobacco makes the cigarette burn much longer than it has to, and they therefore blame the cigarette manufacturer for the fire that ensued in their home.

DR. BIRKY: Yes, there has been a fairly long-running controversy about that issue. There are cigarettes that are self-extinguishing. They are not generally commercially available.

I cannot comment on whether or not additives are put in cigarettes to keep them smoking or burning. That may be the case, but we have not proved that analytically.

DR. PRESTON MCNALL (National Bureau of Standards): As any inveterate cigar smoker knows, cigars go out; cigarettes don't. An additive is needed to keep a cigarette burning. That is what the additive is for.

DR. DONALD KENT (Life Extension Institute): According to a recent publication, they do actually add a material to keep cigarettes smoldering and not burn out. It is a nitrate compound, if you read the last Surgeon General's report.

SPEAKER: A gentleman by the name of George Washington Hill, about 55 years ago, was the president of the American Tobacco Company. He was instrumental in adding, or insisting that the cigarette companies add, an oxidant. I don't know what they use now, but originally it was a nitrate. They started with potassium chlorate. I believe now, to get more production — that is, faster burning cigarettes — they use a peroxide, but I would not know. However, the other kind of cigarette will not ignite a mattress.

DR. BIRKY: You say it would not? Well, it is necessary for a cigarette to burn a certain length of time before it will ignite mattress material; that is correct. There are alternate ways to beat that problem. One of them I just mentioned, using a polyurethane. Another way is to use a conventional cotton mattress and put a pad between the cotton and the covering such as aluminum foil or something of that nature.

MISS EISLER: You missed the whole point. All of us nonsmokers are paying for all of those things.

DR. BIRKY: I did not miss the point. I said that at the beginning. I agree 100% that we all pay for it; that is correct. We also pay for increased fire and auto insurance as a result of the use of alcohol.

MR. JAMES REPACE (U.S. Environmental Protection Agency): With respect to the polyurethane foam problem, I was told by a consultant that TRIS had been added by certain manufacturers to polyurethane foams to act as a fire retardant, and that it was not uncommonly found in carpet padding, in mattress stuffing, and pillows. Would you care to comment on that?

DR. BIRKY: I have heard the same thing. I don't have proof that TRIS was added to that. Of course, we all know that TRIS was added to children's sleepwear at the beginning, but I cannot either verify or deny that TRIS is added to mattresses to make them comply with the standard. I do not know.

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