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ALSO:

REDUCING RESIDENTIAL FIRE DEATHS

page 8

SFPE

FIRE PROTECTION **Engineering**

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Dear Editor,

In response to Lisa Bonneville's article, "Interior Designers Put Fire Protection Into Practice" published in the Fall 2004 issue of *FPE* magazine: The method she describes of achieving code compliance is exactly the method I have spent the last few years fighting against, among my architectural colleagues, because it does not adequately protect the public. I have been told that architects are getting sued for interpreting codes improperly when the design is also improper. Liability insurance providers for architects and engineers have been telling us not to depend on the building official.

The problem with Lisa's method is that it assumes an ability and willingness of code officials to interpret the codes properly and it assumes an authority they do not have. My experience has been that while code officials know the most basic of rules and some, especially in the larger cities, are quite knowledgeable, most I have known make mistakes. Unfortunately, permit and certificate of occupancy documents do not provide either the design professional or the owner protection in civil court, as civil court precedents have held.[1] Even if your state has a statute of repose for design professionals, the owner has liability for the life of the building.

Here is what is going on: First, the judges in our civil courts have decided, "We don't want any junk science in our court."[2] Secondly, the question before the court is not, "Did the Building Official approve it?" or even, "Does it meet the prescriptive code requirements?" The question is, "Is it as safe as the national experts who wrote the code intended?" We can violate the prescriptive requirements as long as what we do is equally safe. The people who will interpret the code in court will be national experts. In comparison, most building officials I know do not have an education in fire science or fire protection engineering. There are civil court precedents that say roughly, "It is still a fault, even if the code official (or other regulatory official) did approve the plans and the construction."[3] The authority of building officials is only to interpret codes "consistent with its intent and purpose;" there is no quality control I know that audits for their mistakes.

What I recommend is that at minimum you use the model code organization that developed the code and ask for technical interpretations of particular code paragraphs, and then get some independent confirmation. I have found only one answer from many by them to have been less than the best. If you are not sure which paragraphs apply, or whether you have found all of them, I recommend that you ask for help from a licensed design professional who advertises code-consulting services (a few architects do, and more fire protection engineers) or an attorney, because these people can share your professional liability with you if you are sued – as a building official cannot. The national experts I know all seem to "think alike" at least as far as what the code means today. Additionally, there are many books and continuing education programs available to supplement the code itself.

As to the issue of finding other ways to comply when the prescriptive code provisions are not sufficient for one's design, the code is clear: Get the substitute product tested to the same fire test or use one of the methods of calculated fire resistance for certain materials. Beyond that, for "alternative means," you need most or all of a performance code's procedures, because even if it has not been adopted in a particular locale, I believe often it will be the only scientific method suitable for the purpose and therefore suitable for a civil court defense, when a substitute kind of product or different spatial arrangement is proposed. Under the leadership of an architect or engineer acting as "prime professional" on the project, a fire protection engineering firm can develop alternatives that provide the same or less fire risk. But the building official is not your source for design ideas. These, in my opinion, are the minimums you need to defend yourself in civil court.

Jeri L. S. Morey, AIAaffl, SFPE.

1 Robert Cushman and G. Christian Hedemann. *Architect and Engineer Liability: Claims Against Design Professionals*, 2nd edition, (NYC: John Wiley & Sons, Inc., ©1995) p. 148.

2 Steven Babitsky, JD; James J. Mangraviti, Jr. JD; and Christopher J. Todd, JD. *The Comprehensive Forensic Services Manual: The Essential Resource for All Experts*, (Falmouth, MA: SEAK, Inc., ©2000) Chapter 9.

3 Cushman, pp. 296-7.

Dear Editor,

The article on "Fire Alarm Systems Serving Assembly Occupancies: Looking Beyond Specifications" by Jorge Velasco and Edward Fixen, PE, in issue #22 contains an error in Table 1. The table indicates that NFPA (Life Safety Code and 5000 Building Code) requires an emergency voice alarm only when occupant load is over 300, which is a misconception. Technically, when an assembly-use area has an occupant load of 50 or more, and a fire alarm is installed (e.g., as requirement of a mixed occupancy, for smoke control, etc.), then the portion of the fire alarm located in the assembly occupancy (i.e., assembly-use area with over 50 occupants constitutes an assembly occupancy per NFPA, and even IBC, definitions) shall comply with the requirements for assembly – one of which is the voice evacuation feature. The error is mixing the requirement FOR a fire alarm in an assembly occupancy (i.e., assembly occupancy with 300 or more requires a fire alarm) with the requirements for a fire alarm IN an assembly occupancy (requirements for assembly occupancy fire alarms). This is a common error if the structure of the code is not strictly followed. These are two separate code sections that are not dependent

Correction

The editors apologize for omitting Jesse Beitel's name as an author of the article entitled "Unique Interiors on the Las Vegas Strip," which appeared in the Fall 2004 issue.

on each other – one indicates when a fire alarm is required, and the other indicates what a fire alarm must contain.

2003 Life Safety Code (LSC), Section 12.3.4.1(1), and *2003 NFPA Building Code*, Section 16.3.4.1, Exception No.1, exist to clarify that even though the occupant load for an assembly occupancy is less than 300, the requirements for a fire alarm in an assembly occupancy still apply if a fire alarm is installed for "other reasons," in which one of the assembly occupancy fire alarm requirements is to have the voice system.

Below is a copy of the e-mail to/from NFPA regarding this issue where they agree:

This is in response to your April 16, 2004, e-mail regarding NFPA 101, Life Safety Code,* 2000 edition, Exception 1 to Paragraph 12.3.4.1, as it pertains to proper application of fire alarm system requirements for new assembly occupancies.*

Exception 1 to Paragraph 12.3.4.1 clarifies that a common alarm system can be used within a building housing occupancies in addition to an assembly occupancy, provided that system meets the alarm requirements applicable to each of those occupancies. This provision allows an assembly occupancy in a school, hotel, hospital, mall, or other building to be served by the same fire alarm as the predominant occupancy, provided that it also meets the requirements applicable to fire alarm systems in an assembly occupancy, including the requirements for occupant notification via live or prerecorded voice announcements.

Sincerely,
Kirsten M. Paoletti
Associate Fire Protection Technician
Department of Building Fire Protection & Life Safety
National Fire Protection Association

KMP/lc#4880

Important Notice: This correspondence is not a Formal Interpretation issued pursuant to NFPA Regulations. Any opinion expressed is the personal opinion of the author and does not necessarily represent the official position of the NFPA or its Technical Committees. In addition, this correspondence is neither intended, nor should be relied upon, to provide consultation or services.

I believe either a footnote, or correction, should be added to this table – or at least the readers should be informed of the whole requirement of the codes, not just "part of the story."

Sincerely,
Ms. Jaimie Blackstone, P.E.

Author's Response

Ms. Blackstone raises an important point regarding mixed occupancies. While the article focused strictly on assembly occupancies, a clarification regarding mixed occupancies is important. It is correct, per *NFPA 101*®, Section 6.1.14.3.2, or *NFPA 5000*™, Section 6.2.3.2, a fire alarm system serving a mixed occupancy building must be designed to meet the most restrictive requirements of the occupancies involved throughout the building. Conversely, in multiple occupancy buildings where separated occupancies are provided, *NFPA 101*®, Section 6.1.14.4, or *NFPA 5000*™, Section 6.2.4, require that each distinct occupancy within the building comply with its respective occupancy requirements only.

However, this does not change the fundamental code requirement that dictates when a fire alarm system is required for assembly occupancies, whether stand-alone or part of a mixed occupancy building. *NFPA 101*®, Section 12.3.4.1, and *NFPA 5000*™, Section 16.3.4.1, specifically require a fire alarm system in assembly occupancies with an occupant load of more than 300 and theaters with more than one audience-viewing room. Whether an assembly occupancy is stand-alone or part of a mixed occupancy building, the assembly-related requirement for a fire alarm system does not apply unless the assembly occupant load exceeds 300.

NFPA 101®, Section 12.3.4.1(1), and *NFPA 5000*™, Section 16.3.4.1, Ex. 1, are intended to clarify that a mixed occupancy building may have a common fire alarm system, as opposed to separate systems for each occupancy, provided the common system complies with the most restrictive requirements of the occupancies involved throughout the building. For example, a 400-person assembly occupancy within a mixed occupancy office building would trigger the requirement for a common fire alarm system complying with the assembly fire alarm system requirements of *NFPA 101*®, Section 12.3.4, or *NFPA 5000*™, Section 16.3.4, throughout the building.

Nonetheless, while these Sections clarify the proper application within mixed occupancy buildings, they do not lower or change the basic occupant load threshold of 300 specified by *NFPA 101*®, Section 12.3.4.1, or *NFPA 5000*®, Section 16.3.4.1, that dictate when a fire alarm system is required in assembly occupancies. For example, a 100-person assembly occupancy (e.g., large conference room) within a mixed occupancy low-rise office building would not trigger the assembly occupancy fire alarm system requirements of either *NFPA 101*® or *NFPA 5000*™ throughout the predominantly office building. There may be fire alarm system requirements related to the other occupancies within a mixed occupancy building (e.g., high-rise) that would apply throughout the building but the requirements would not be dictated by an assembly occupancy with 300 or less occupants.

In summary, it is important to review all occupancy-related fire alarm system requirements in a multiple occupancy building. Nonetheless, the fire alarm system requirements of *NFPA 101*®, Section 12.3.4, and *NFPA 5000*™, Section 16.3.4, are applicable only to assembly occupancies with an occupant load of more than 300, regardless of whether the assembly occupancy is stand-alone, separated, or part of a mixed occupancy building.

Edward L. Fixen, P.E.
Vice President with Schirmer Engineering Corporation
Author, "Fire Alarm Systems Serving Assembly Occupancies: Looking Beyond Specifications"

The Role of Education in Residential Fire Safety

For more than 25 years, I have been fortunate to work with other fire and life safety educators and alongside dedicated first responders, researchers, public health professionals, and fire protection engineers. I have seen firsthand how the broader safety community performs as a steadfast and mostly unified force, unmatched in its energy and commitment to public safety improvements at the local, state, and federal levels. There is, in my experience, no more powerful ally to have on one's side.

One of the most striking accomplishments of our industry is the way in which it has repeatedly taken up a collective and passionate call to arms in the aftermath of multifatality fires. This approach continues a long tradition – the Triangle Shirtwaist and Cocoanut Grove fires and the hotel fires of the '70s and '80s, for example. More often than not, the result of these efforts has been successful change for the better, ultimately saving lives down the road.

When it comes to advocating for fire sprinklers, our industry – particularly those from the fire arena – especially shines. Whether high-rise building, public assembly, nursing home, or dormitory fire, the calls for fire sprinklers that I've witnessed over the years have been pressing, loud, and resonant. In many cases, the collective industry outcry has helped bring about regulatory change in addition to greater education about sprinklers.

The horrific Station Nightclub fire triggered one of the most sustained and effective debates about sprinkler requirements and other forms of fire protection that I can recall. Our community was, once again, front and center with an immediate and largely cohesive call to action which paid off with a beefed-up state fire code and more stringent national codes.

Unique to the Station fire was its powerful video footage, which brought the reality of fire's growth and deadly spread home to tens of millions of television viewers in a way that we educators never could, no doubt reinforcing the safety community's full court press for code reform.

Each of these incidents is a fleeting window of opportunity – a "teachable moment" in the educator's vernacular. Immediacy is a critical success factor, so we have to be ready when a fire tragedy opens one up. By taking advantage of having a captive audience even briefly, we can help scores of otherwise disinterested people learn how to be safer, and we can help decision-makers choose increased safety through official action. These teachable moments can and certainly do save lives.

So all this has gotten me thinking lately. Why are we so ready to promote sprinklers following major incidents but not following the much more common smaller-scale incidents? To be quite blunt, why does it take a large loss of life to motivate our industry's collective call for sprinklers?

Every day, people die in home fires – more than 3,400 each year with tens of thousands more injured. It is, by any definition, a crisis of epidemic proportion. Yet these tragedies – admittedly small-scale losses in the strictly statistical sense – not only typically go unnoticed in the media, they too often pass without a response from our own community.

Where is the hue and cry for sprinklers when people die in ones and twos? Why aren't we better at utilizing these teachable moments?

Working together, I believe we can marshal that kind of sprinkler education effort, in the same way we do so following major incidents when they strike. We must try.

The safety industry has the credibility to back such an effort, and our first responders need our help. If we personally and professionally advocate for sprinklers in our own cities and towns, the push for more widespread residential fire sprinkler protection will be better underway. And lives will be saved.

Make no mistake, this effort needs your help. National estimates put sprinklers in only two percent of new single-family homes in the U.S., and in only two percent to four percent of multifamily homes. When more than 80 percent of fire deaths occur in home fires, the current number of residential sprinkler systems is unjustifiably low.

To their credit, dozens of communities have taken the ultimate step forward, requiring sprinklers in new construction of single-family homes. It may well be that the only sure way to see real growth in residential fire sprinkler installations is to mandate change, either through national codes, local regulation, or both.

Fire sprinklers represent our most promising avenue to take the strides smoke alarms have helped us make to the next level, and dramatically and permanently reduce the fire death and injury toll in our country.

A sustained and multifaceted campaign of education, advocacy, and assertive regulation is needed if we are ever going to see what America Burning imagined more than 30 years ago – the widespread use of fire sprinklers to protect the occupants of single-family homes.

Imagine the impact it would have if we took the same affirmative action in response to deadly house fires that we have traditionally taken following major fire incidents. Let's join together and use our names, our expertise, and our voices to gin up the dialogue about home fire sprinklers locally and nationally.

Sadly, home fires provide us with a constant window of opportunity to do this. Each of us, in our own cities and towns, will have teachable moments available to us nearly every day. Let's make the most of them, consistently and passionately pointing out when sprinklers would have saved lives.

Meri-K Appy is with the Home Safety Council (HSC).

FM Approvals Suspends Approval on Two Large Drop Sprinklers

FM Approvals has suspended approval of two K11.2 large drop automatic fire sprinkler models – Tyco TY5153 and Viking VK540 – following recent testing.

As of December 15, 2004, the "FM Diamond" mark of approval can no longer be stamped on these large drop sprinkler models.

FM Approvals is continuing to thoroughly investigate the large drop sprinkler issue and will work with the manufacturers and sprinkler industry to identify a path forward.

The announcement follows ongoing benchmark testing, including large-scale fire tests, involving numerous types of sprinklers under various test conditions and modes of operation conducted at the newly opened fire technology laboratory at the FM Global Research Campus in West Glocester, RI. To date, FM Approvals has achieved satisfactory results in virtually all of these benchmarking tests.

For more information, contact
Roger Allard, assistant vice president, FM Approvals,
at roger.allard@fmglobal.com.
FM Global clients may contact their account engineer.

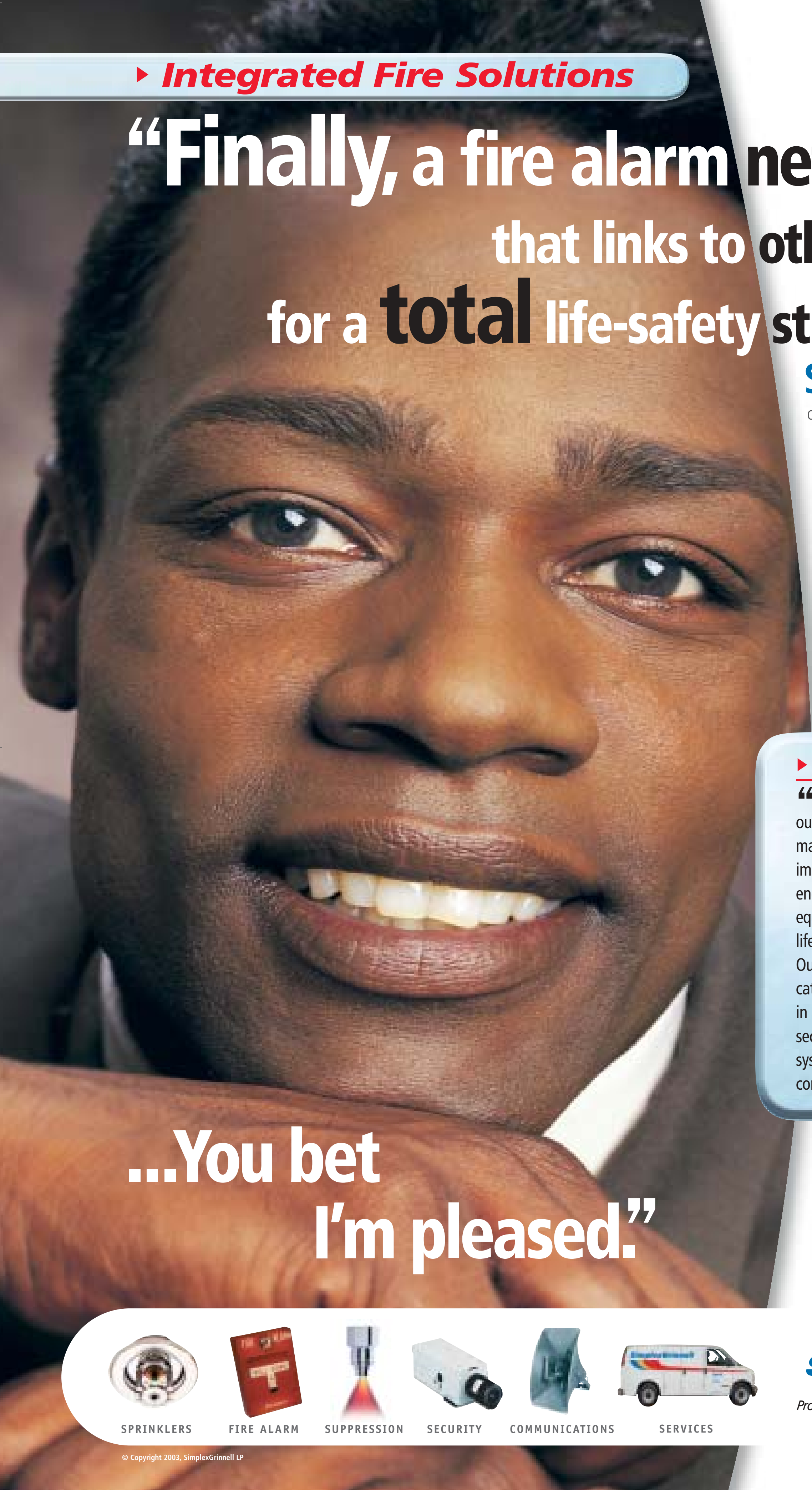
NFPA Reports 70% of All Home Fire Deaths Occur in Homes With No Alarms or No Working Alarms

Seventy percent of all home fire fatalities occur in homes where there are no smoke alarms or no working smoke alarms, a new report from the National Fire Protection Association (NFPA) has found. Despite a drastic rise in home smoke alarm use over the last 25 years, nearly one-quarter of the home smoke alarms in reported fires are not working.

When home smoke alarms don't work, it's mostly because of missing, dead or disconnected batteries. In half of the reported fires where there were no working smoke alarms, batteries were missing or disconnected, and batteries were dead in 15% of these incidents. People too often disconnect or remove batteries because of nuisance activations from cooking or bathroom steam. In many cases, moving a smoke alarm father away from the kitchen or bathroom can reduce these unwanted activations.

According to NFPA's report, *U.S. Experience with Smoke Alarms and Other Fire Alarms*, 19 out of every 20 U.S. homes had at least one smoke alarm. However, four out of 10 home fires that were reported to fire departments in this country occurred in the small percentage of homes that lacked these devices.

For more information, go to
www.nfpa.org.



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Fire Deaths in the United States: How Best to Keep Reducing Them

By Elliot F. Eisenberg, Ph.D.

INTRODUCTION

Over the past 40 years the United States of America has made profound progress reducing all types of fire deaths. Since 1960, the total number of fire deaths has declined by almost 60 percent, and the fire death rate has fallen by over 70 percent. This article begins by showing that these declines have been ongoing for decades, that the improvement has been nationwide (despite wide and persistent variations from state to state), and compared to other western industrialized democracies, the decline in the U.S. fire death rate has been the largest. If, however, the experiences of other nations are a guide, the rate of future improvements in the U.S. may decline.

The article then evaluates which demographic and housing unit characteristics best explain residential fire death rates. To anticipate the findings, inter-county fire death rate differences are strongly correlated with the percentage of new housing stock, differences in household wealth, the percentage of minorities, and the percentage of mobile homes. These findings suggest that a particularly effective way to reduce future fire deaths may be to focus prevention efforts in proportion to the level of these four variables in a community, as opposed to using traditional policies that are largely location invariant.

OVERVIEW

In 1960, the number of fire deaths in the U.S. was 7,645. Five years later, the number had fallen to 7,347.[1] Figure 1 shows that by 1979 the number had fallen to 5,998 and to just 3,326 in 2001, a total decline of more than 56 percent. However, this dramatic decline understates the true improvement in fire safety as the population of the U.S. increased by 105 million people during this 41-year period. Taking this into account, the decline in the fire death rate per million persons (FDPM) fell from 42.3 to 11.7, a decline of over 72 percent.

Equally impressive has been the decline in house fire deaths. Between 1979 and 2001, the number of such fire deaths fell from 4,863 to 2,604, a decline of 46.5 percent, while the residential FDPM declined from 21.7 to 9.13, a drop of 58 percent. Because the decline in residential fire deaths was larger than the reduction in all fire deaths, house fire deaths now account for 78 percent of all fire deaths, down from their recent high of 86 percent in 1993, and are now at their lowest rate since at least 1979.

These findings are based on the annual Multiple Cause-of-Death file collected and compiled by the National Center for Health Services (NCHS), a part of the Centers for Disease Control and Prevention (CDC). Death certificates are coded by local medical authorities and complied by the states and finally by the NCHS. The result is an annual data file that contains a record of all deaths in the U.S.

STATE-BY-STATE VARIATION

Table 1 (page 10) looks at house fire deaths in 2001 and FDPM rates for all 50 states in 1983 (the first year these data were available from this source) and 2001. With the exception of Kansas and Connecticut, every state registered a decline in its FDPM during the 23-year period, suggesting that the steep decline in U.S. residential fire deaths has benefited all states. However, the FDPM rate continues to vary dramatically across the states. In 1983, the rate varied from a low of 6.9 in Utah and Hawaii to a high of 53.2 in Vermont. By 2001, Colorado had the lowest rate in the nation at 2.3, while Arkansas had the highest rate in the land at 28.6.

To further illustrate the dramatic reduction in fire deaths, in 1983, there were four states with FDPM rates greater than 40 – Delaware, Mississippi, South Carolina, and Vermont. However, by 2001, the four states with the highest FDPM ranking were Arkansas, Mississippi, Delaware, and Alabama with FDPM rates of 28.6, 25.5, 21.3 and 19.5, respectively; about half as high as the rates for the four poorest performing states in 1983. Put another way, the average state in 1983 would rank 45th in 2001.

Despite these dramatic improvements, there are some constants. Both Delaware and Mississippi appear in lists of the four least fireworthy states in 1983 and 2001. Also, in 2001, eight of the 12 states with the highest FDPM rate were from the South, while in 1983, 10 of the 15 states with the highest FDPM rates were located in the South. Repeatedly finding the same states with relatively high (or low) FDPM rates suggests that, while improvements have been felt coast-to-coast, systematic unchanging state-specific problems remain.

INTERNATIONAL COMPARISONS

Interestingly, the U.S. findings of declining FDPM rates over time, substantial variation across place, and high rates of path dependence are also in evidence internationally. Figure 2 shows that, between 1979 and 2000, FDPM rates declined in 10 of 13 countries, stayed the same in one, and rose slightly in two others.[2]

FIGURE 1

Fire Deaths and House Fire Deaths, 1979-2001[1]

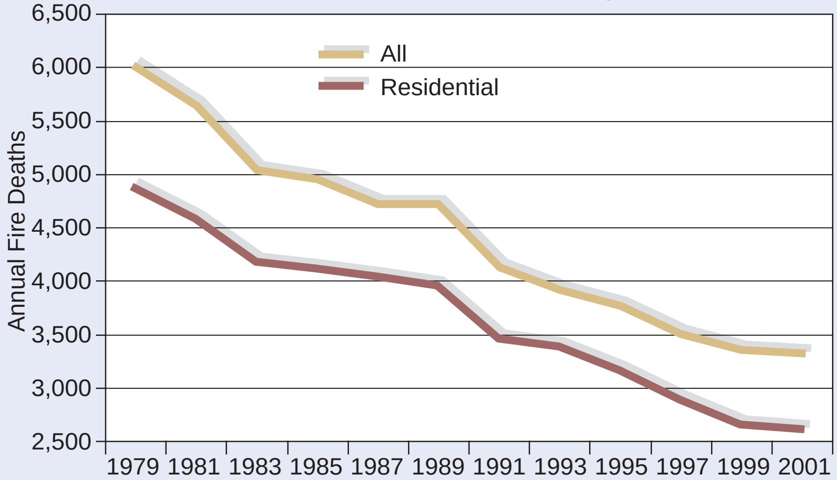

FIGURE 2

International Fire Death Comparisons, 1979-2000 [2]

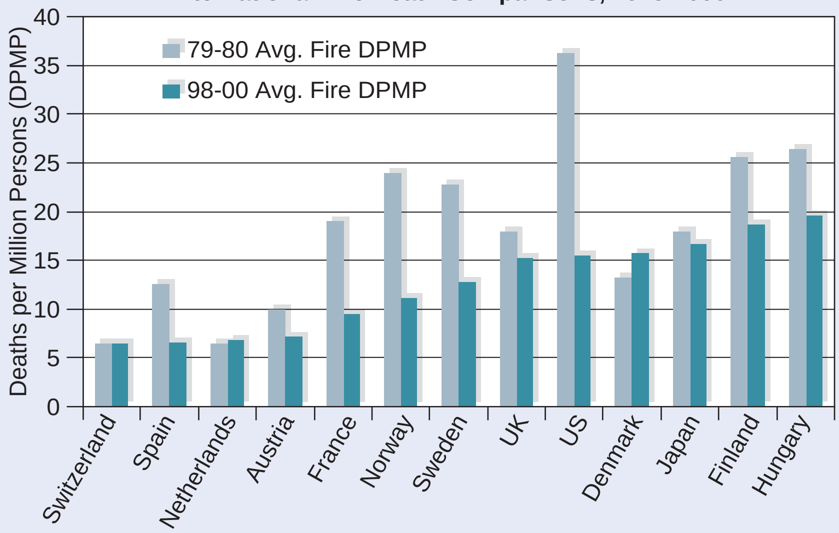

FIGURE 3

International Fire Death Comparisons, 98-00 Average

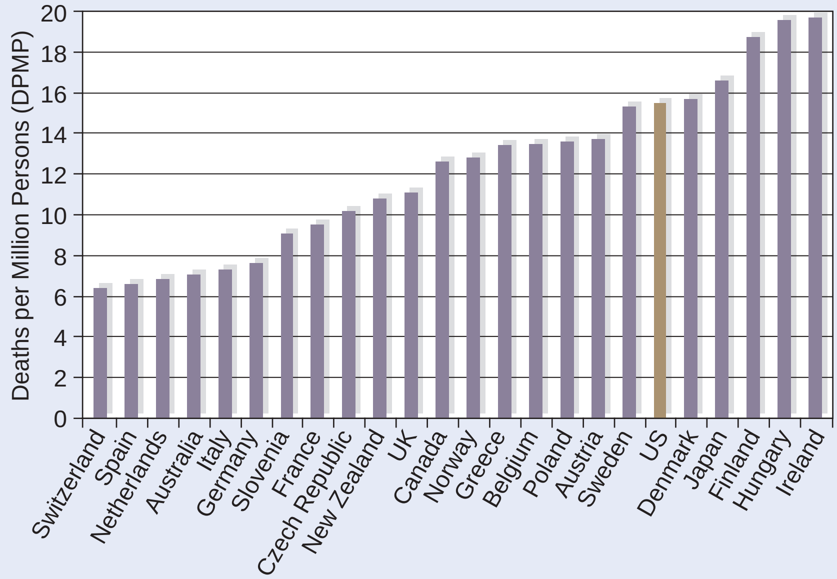

TABLE 1. U.S. Fire Death Rates

	Deaths	Per Million		
	2001	1983	2001	2001 Rank
US	2604	17.8	9.1	NA
Alabama	87	30.8	19.5	48
Alaska	12	35.2	18.9	46
Arizona	35	7.7	6.6	14
Arkansas	77	34.0	28.6	51
California	126	9.4	3.6	4
Colorado	10	8.6	2.3	1
Connecticut	25	7.3	7.3	22
Delaware	17	51.3	21.3	49
District of Columbia	9	33.0	15.7	45
Florida	115	13.6	7.0	18
Georgia	124	32.8	14.8	43
Hawaii	3	6.9	2.4	2
Idaho	5	9.1	3.8	5
Illinois	135	17.1	10.8	34
Indiana	65	19.5	10.6	33
Iowa	23	8.6	7.8	24
Kansas	38	12.8	14.1	42
Kentucky	57	23.1	14.0	40
Louisiana	86	28.1	19.2	47
Maine	8	21.8	6.2	13
Maryland	53	22.8	9.8	29
Massachusetts	46	21.2	7.2	19
Michigan	118	17.9	11.8	38
Minnesota	31	14.7	6.2	12
Mississippi	73	41.8	25.5	50
Missouri	66	17.5	11.7	37
Montana	3	19.6	3.3	3
Nebraska	13	12.5	7.6	23
Nevada	9	7.8	4.3	7
New Hampshire	14	18.8	11.1	35
New Jersey	47	15.5	5.5	10
New Mexico	10	7.8	5.5	9
New York	138	12.5	7.2	21
North Carolina	96	24.2	11.7	36
North Dakota	6	11.7	9.4	26
Ohio	119	17.9	10.4	31
Oklahoma	33	26.6	9.5	27
Oregon	25	15.0	7.2	20
Pennsylvania	125	20.5	10.2	30
Rhode Island	7	15.7	6.6	15
South Carolina	57	42.1	14.0	41
South Dakota	9	10.0	11.9	39
Tennessee	88	24.3	15.3	44
Texas	184	19.1	8.6	25
Utah	9	6.9	3.9	6
Vermont	3	53.2	4.9	8
Virginia	48	19.2	6.7	16
Washington	58	10.7	9.7	28
West Virginia	19	26.0	10.5	32
Wisconsin	37	13.5	6.8	17
Wyoming	3	7.8	6.1	11

Even among countries that appear very similar, fire death rates vary considerably. For example, Finland, Denmark, Sweden, and the Netherlands are all Northern European countries with similarly high per capita GDP and small populations. Despite these parallels, their FDPM rates vary noticeably. In Finland, the FDPM is 18.7, while in the Netherlands, it is less than half as high. And these differences have persisted for quite some time.

Figure 2 also shows that improvements have been quite uneven. Between 1979 and 2000, the 57 percent decline in the United States fire death rate was larger than that experienced by any other country. Other countries that experienced very large percentage declines include U.K., France, Spain, and Norway, each of which saw their rates decline by between 47 and 54 percent. By contrast, fire death rates in Switzerland and Netherlands barely budged. This may, in large part, be because rates in those two nations were already so low by 1979 that further improvement is very difficult.

This explanation is given added weight by examining Figure 3 which provides the most recent fire death rate data for all countries that consistently provide data to the World Fire Statistics Centre (WFSC) in Geneva (except for Singapore, as it is not a democracy and because 80 percent of the population live in public housing) ranked by their fire death rates. (The WFSC does not get its data from NCHS. Thus, its fire death rates for the U.S. are different.) Figure 3 clearly shows that, among the top 24 countries, none has a fire death rate below 6.5 FDPM, and that the variation among the best-performing five or six nations is very small.

This observation was also noted in the 2003 WFSC report when they wrote "Progress has... been particularly marked in those countries which had in the 1980s been suffering relatively high losses (particularly fire deaths), while – naturally enough – those countries already enjoying relatively low loss rates have had difficulty in improving much further."[2]

As an aside, the best-performing nations in Europe are generally smaller or warmer than the U.S., and the two that are large (Italy and Germany) and have relatively low fire death rates have much higher population densities compared to the U.S., which works to their advantage. Conversely, the U.S. population is growing much faster than in any Western European state.

As a result of increasing U.S. population, progressively smaller improvements in fire deaths will manifest themselves differently in the U.S. than in Europe. In the U.S., the FDPM rate may continue to decline, but due primarily to increases in population and not declines in the number of fire deaths, while the number of fire deaths remains constant. As a matter of fact, this trend has recently appeared for the very first time. Between 1998 and 2001, the number of fire deaths fell by only 16, or less than one percent, while the FDPM rate fell by four percent due to rising population. While the decline in the FDPM rate looks impres-

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sive, it masks the serious problem that over the four-year period there was, at best, a very small decline in the number of deaths.

CHANGING U.S. ENVIRONMENT

The large decline in fire death rates in the U.S. has been the result of several factors, including the adoption of increasingly stringent building codes across the country. For example, building and fire codes require improved fire blocking and stopping – which results in better fire containment, which in turn provides more time to escape and/or extinguish the fire – along with better heating and electrical design, which have resulted in the use of fewer extension cords and space heaters. Also, improved fire ratings on upholstered furnishings, bedding and sleeping attire, and the increased use of childproof devices have all helped reduce U.S. fire deaths.

Technological innovation has also played a key role. Table 2 shows how building codes progressively mandated both more and better smoke detectors over time. In 1969, smoke alarms were often unreliable, battery-operated, poorly placed, in few homes, and, most importantly, not required by any of the building codes. Today, all new homes must have hard-wired, interconnected smoke detectors, and many older homes have been retrofitted with them too. In short, homes and their contents are now safer than they have ever been.

In addition, there has also been a strong push to reduce smoking since the first Surgeon General's report linking smoking and lung cancer in 1964.[3] Since smoking is the leading cause of residential fire deaths,[4] any success in reducing it (along with drug and alcohol abuse) necessarily translates into fewer fire deaths. However, since 1990, the percentage of the U.S. population that smokes has declined very little.[5] Thus, this trend will no longer be of much help in reducing the number of fire deaths further.

Collectively, these interventions, public awareness campaigns, and code improvements have cumulatively saved about 155,000 lives since 1960. However, the across-the-board solutions that have worked so well until now are likely to be less effective in the future. In part, this is because many of the most effective solutions have already been adopted, public awareness regarding house fires is quite high, smoking rates are lower than ever, and because fire death rates are much lower than they were in the past. Thus, substantially reducing the number of fire deaths in the future will become increasingly more difficult unless solutions tailored to at-risk populations are considered.

To implement such solutions, more must be known about who is dying, the condition of the house when the fire occurred, as well as any other relevant demographic information. With this knowledge, it would then be appropriate to focus future fire prevention efforts at entire subpopulations, devoting more resources to communities at greater risk – an approach akin to the emergency room practice of triage, where patients with the greatest need get treated first.

Regrettably, much of the available data is not helpful. For example, no data are collected on the age of the structure where a house fire death occurs, despite the obvious link between the two. Similarly, very little data are available linking income, wealth, population density, and other demographic variables to residential fire death rates. And when this information is analyzed, it is done so one variable at a time. For example, a published analysis concluded that "African-Americans and American Indians have significantly higher fire death rates per capita than the national average" and that "male fire death rates exceed that of females by 1.5 to 2 times, or that the elderly of all ethnic groups have the highest fire death rates." [6]

While these results are informative, what is needed is a more complete model that can better account for the many relationships between the different variables. Only this way will it be possible to better understand why fire death rates have behaved as they have in the past and where they may be headed in the future. With this knowledge, targeted interventions can be used and, in the process, save lives.

TABLE 2

Building Code Requirements and Changes Smoke Detectors – 1970s to Present	
1967 National Building Code	No requirements for smoke detectors.
1976 National Building Code	1 smoke detector required.
1979 Southern Building Code	1 smoke detector required.
1983 CABO 1- & 2-Family Dwelling Code	1 smoke detector in sleeping areas (i.e., hallway outside of bedrooms), and smoke detector must be hardwired (not just battery).
1986 CABO 1- & 2-Family Dwelling Code	Smoke detectors now required on each story of structure and in the basement.
1989 CABO 1- & 2-Family Dwelling Code	No changes to the smoke detector requirements.
1992 CABO 1- & 2-Family Dwelling Code	Smoke detectors are required to be interconnected; if one alarm sounds, they all sound.
1995 CABO 1- & 2-Family Dwelling Code	Smoke detectors are now required in each sleeping room in addition to other current requirements.

CABO stands for Council of American Building Officials.

ECONOMIC THEORY

Findings from a number of existing studies consistently show that newer homes experience fewer fire deaths than older homes. A study conducted by the National Association of Home Builders (NAHB) in 1987[7] found that fatality rates increased with the age of homes. For example, houses less than seven years old had fatality rates one-third of houses seven to 17 years old, and one-sixth the rate of houses that were more than 25 years old.

Nearly identical results were obtained in a California Building and Industry Association study released in 1996.[8] That study found that the average fatality rate in residential dwellings in California consistently increased as the housing stock aged. Interestingly, they found this relationship to be true for every succes-

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sive four-year period going back all the way to 1956. More recently, it's been found that, in Dallas, residential fire-related injuries declined in every decade for houses built after 1949.[9] That is, houses built in the 1980s were found to be safer than those built in the 1970s, which, in turn, were found to be safer than those built in the 1960s, and so on.

Other research has found[10, 11] that those at greater risk include persons living in manufactured or substandard housing. This may be because mobile homes are smaller and depreciate at a faster rate than site-built and modular homes; it is rare to see a 50-year-old or 100-year-old mobile home. By contrast, there are tens of millions of 50-year-old homes and millions of 100 year-old homes. Also, as mobile homes are built to a national building code rather than a local building code, they may be less well-suited to local environmental conditions than other homes. Moreover, it may well be that, as mobile homes reach the end of their useful life, preventive maintenance and replacement of old systems, such as heating and air conditioning units, is not done, as the cost of replacement may be very high compared to the value of the mobile home. As a result, the fire risk of such dwellings may well increase over time, relative to traditional units of comparable age.

In addition to structural variables, wealth is highly correlated with reduced house fire death rates.[12] Wealthier households are less likely to defer maintenance, are more likely to be proactive about eliminating potential fire hazards, and are more likely to in-

TABLE 3

Summary Statistics							
Variable Type	Variable Description	Var. Name	# of Obs.	Minimum	Maximum	Average	Std. Dev.
Dependent Variable	Fire death rate	fdpermill	458	0	75.48	8.94	10.68
Housing Stock Age Variables	Percent of stock built after 1994	pctpost94	458	1.10%	34.64%	10.03%	5.67%
	Percent of stock built after 1989	pctpost89	458	2.09%	50.07%	17.83%	8.82%
	Percent of stock built after 1979	pctpost79	458	5.41%	77.33%	33.98%	14.53%
	Percent of stock built after 1969	pctpost69	458	10.56%	92.05%	52.63%	17.55%
	Percent of stock built after 1959	pctpost59	458	20.91%	96.84%	66.29%	16.85%
	Percent of stock built after 1949	pctpost49	458	35.38%	99.22%	78.77%	13.91%
	Percent of stock built after 1939	pctpost39	458	47.12%	99.56%	85.65%	11.27%
Wealth & Income Variables	Percent high school graduates	pctHS	458	11.72%	49.91%	29.04%	6.58%
	Percent college graduates	pctBA	458	6.64%	33.31%	16.12%	5.22%
	Median household income	medhhinc	458	$24,863	$81,050	$44,423	$10,197
	Median family income	medfaminc	458	$26,009	$92,146	$52,792	$11,350
	Per capita income	percapinc	458	$9,899	$44,962	$21,928	$4,810
	Median rent	medrent	458	$361	$1,185	$600	$131
	Log median house value	lmedhseval	458	10.773	13.816	11.682	11.176
	Median house value	medhseval	458	$47,700	$1,000,001	$118,500	$71,392
	Percent in poverty	pctpov	458	2.48%	35.45%	10.88%	4.83%
Housing Market Control Variables	Percent white	pctwhite	458	21.16%	97.94%	78.43%	15.31%
	Percent mobile homes	pctmb	458	0.03%	37.55%	6.48%	6.45%
	Percent urban	pcturban	458	34.49%	100.00%	83.09%	14.38%
	Population density/sq. mile	popdensity	458	21	66,940	1,229	4,202
	Percent occupied	pctocc	458	64.47%	98.46%	92.33%	4.60%
	Percent owner-occupied	pctown	458	19.54%	88.08%	67.26%	9.28%
	Percent single-family detached	pctsfdet	458	0.29%	83.17%	62.14%	12.02%
	Percent of population over age 54	pctage55up	458	11.19%	49.18%	20.89%	4.83%
	Percent of population over age 64	pctage65up	458	4.60%	34.71%	12.38%	3.80%
	Percent of population over age 74	pctage75up	458	1.70%	16.29%	5.83%	2.00%
	Percent of population over age 84	pctage85up	458	0.04%	4.13%	1.44%	0.05%

stall smoke detectors.[13, 14, 15] Moreover, to the extent that wealth and education are correlated,[16] wealthier households are less likely to smoke. As a result, as wealth rises, residential fire death rates are expected to fall. However, the relationship is nonlinear as, beyond some level, the added benefit of more wealth, while always positive, declines. As a proxy for household wealth, average house value is used, and to account for the nonlinear relationship between wealth and education, the logarithm of house value is used.

Other things that may systematically impact residential fire death rates are the characteristics of a housing market. To give an example, the fireworthiness of a unit in Phoenix, AZ, may be quite different than a unit in Birmingham, AL. To account for these differences, it is necessary to include the percentage of the stock that is single-family detached, occupied, owner-occupied, and urban. It has also has been found that the age and race of the occupants are meaningfully related to fire deaths rates.[17, 18] While the signs and coefficients on all the housing market control variables mentioned in this paragraph are not central to the research question being asked, excluding them will bias the coefficients for house stock age, house value, and the percentage of mobile homes – the dependent variables of primary interest – to the extent that any of the housing market variables are correlated with the three variables of primary interest.

For example, were one to regress annual income on the age of a person, the result will be that age appears to increase income. However, the relationship between age and income is more complex; older people are more likely to have more education and more savings. And since education and age, and savings and age, are positively correlated, excluding education and savings will cause the coefficient on age to be larger than it really is. To prevent this, as many variables as possible that affect income should be included in the equation. In fire death research, the housing market variables mentioned in the previous paragraph are analogous to the education and savings variables in this paragraph.

Thus, the multiple regression equation to be estimated is:

$$FDPM = k + \alpha H + \beta M + \gamma WLOG + \delta R + e$$

Where *FDPM* is the county-specific fire death rate per million persons in 2001, *k* is a constant or intercept term, *H* is a measure of housing stock age, *M* is the percentage of mobile homes, *WLOG* is the logarithm of house value, *R* is a vector of real estate market condition control variables, *e* is a normally distributed error term, and the Greek symbols α, β, γ, and δ are the respective coefficients for *H*, *M*, *WLOG*, and *R*.

TABLE 4

Fire Death Rate Regression Results	
Variable	Model 1
Intercept	96.71
	(6.12)
Percent white	-17.01
	(5.55)
Log median house values	-6.43
	(4.80)
Percent post-1989	-9.95
	(1.65)
Percent mobile homes	21.49
	(2.45)
Observations	458
Adj R^2	0.133
F Value	18.53

Absolute value of the t-values are in brackets.

DATA SOURCES

Fire death data come from the NCHS Multiple Cause-of-Death File for 2001. Death certificates are issued and coded by local medical authorities, using internationally agreed-upon codes (ICD-10 codes) defined by the World Health Organization (WHO). Death certificate data are then complied by the states and then the NCHS. As a result, this database includes data on the cause of all deaths in the U.S. for each calendar year. For this study, the fire had to occur in a home, and the death had to be the result of exposure to a controlled or uncontrolled fire in the building (X00, X02), exposure to ignition or melting of nightwear (X05) or other clothing and apparel (X06). It ignores, however, fire deaths from campfires, forest fires, and from ignition of highly flammable material.

Data from the National Fire Incident Reporting System (NFIRS), which is developed by the United States Fire Administration (USFA), or the NFPA National Fire Experience Survey (NFES) were deliberately not used for several reasons. First, NCHS data are available at the county level, while NFIRS and NFES data are not. Second, NCHS data are specifically designed to capture the cause of death, while NFES and NFIRS are primarily designed to measure fires. As a result, deaths from nonreported fires will appear in the NCHS data, but not the NFES or NFIRS data. Lastly, the NCHS database is comprehensive, while both NFIR and NFES rely on sampling.

The county is the unit of analysis for several reasons. First, intercounty variation in the independent variables is much greater than at the state level, and with greater variation, coefficients can be estimated with greater precision. Second, performing a state-level analysis would not provide sufficient enough observations to perform a cross-sectional analysis of this sort. Finally, the smaller the geographic area analyzed, the easier it is to target and implement intervention.

Variable definitions and descriptive statistics are provided for all demographic data in Table 3. The data in the table come from the SF3 (long form) Census 2000 and are at the county level. These data were then merged with the Multiple Cause-of-Death data by county. Since the NCHS suppresses death data for counties that had a population of less than 100,000 in 1990, the sample includes data for the 458 largest counties rather than for all 3,141 counties. Of the counties in the sample, 343 of the counties reported at least one fire death in 2001, and the total population of the counties in the sample is 207 million, or 73 percent of the total U.S. population in 2000.

The county with the highest residential fire death rate in 2001 was Richmond County, VA, with a rate of 75.48 deaths per million persons – almost eight times the national average, but only slightly higher than the next highest county. Not surprisingly, the highest house prices were found in New York County (Manhattan). The county with the newest housing stock, defined as the percentage of its housing stock built after 1979 and after 1989, is Collin County, TX (just north of Dallas-Fort Worth), with half of its stock built after 1989 and 77 percent built after 1979. For purposes of comparison, Clark County, NV, where the fast-growing city of Las Vegas is located, has the eighth-highest percentage of its stock built since 1979 and the second-highest percentage of units built since 1989.

The oldest county in the nation, as measured by percent of housing stock built before 1939, is Schuylkill County, PA – where 53 percent of the stock is more than 60 years old – followed very closely by Suffolk County, MA, and San Francisco County, CA. Manhattan, NY, is the eighth-oldest county in the country, with 43 percent of its housing stock built before 1939.

RESULTS

While several different models were run – some with a slightly larger set of independent variables and some that looked at the FDPM rate in earlier years – the results were surprisingly robust across specifications. Table 4 reports the result for the above cross-sectional FDPM equation with the t-statistics reported for the coefficients in parentheses.

AGE OF STRUCTURE

As expected, the coefficient estimate for the percentage of houses built after 1989 (pctpost89) is negative and statistically significant. This implies that, in counties with newer housing stock, all else equal, the fire death rate is lower. Interestingly, when identical regressions to model 1 were run using different cutoff points for new stock, such as the percentage of houses built after 1979 or 1969 or 1959, the coefficients were of roughly similar size, were always negative, and the associated t-statistics were at least as significant.

MOBILE HOMES

Here, too, the results were as anticipated. The finds show that, in counties with a higher percentage of mobile homes, the fire death rate is higher than in counties that are otherwise identical but with a lower percentage of mobile homes. While this result is not new, the relationship between mobile homes and fire deaths may be complex. For example, it may be that mobile homes are in areas where public services are consistently not as good as elsewhere. In addition, it may be that mobile homes are more likely to be occupied by persons who are relatively old and/or who smoke more.

WEALTH

The negative coefficient for the logarithm of the median house value (logmedval) was strongly negative and statistically significant. Confirming earlier speculation and research, wealth is inversely related to the chances of dying in a house fire. Thus, all else equal, higher wealth is associated with a lower chance of dying in a house fire. Here, too, when similar regressions to model 1 were estimated, using slightly different functional forms for this variable or a slightly different proxy variable, the results were very similar.

HOUSING MARKET CONTROLS

In addition to the variables discussed, a number of housing market control variables were included in the initial regressions. However, except for race, none were statistically significant. In particular, the percent of houses in urban areas, population density, percent of units occupied, percent of owner-occupied units, percent of units that are detached, and the age of the occupants were not found to be significant regardless of the model specification.

While these findings may seem surprising, it may simply be a result of the sample. Were the sample to have had more than just the biggest counties, it is likely that more of the housing market control variables might have been significant. However, because rural counties are not included, the differences in the control variables across the 458 counties in the sample may not be large enough for a correlation to be found. That limitation notwithstanding, the model is well-suited to analyzing counties with large populations.

FUTURE TREND

At present, the model predicts about 8.9 fire deaths per million persons, if average values for all the independent variables are used. However, to better understand the results shown in Table 3, the model can also be used to simulate alternative scenarios by making slight changes to the values of the independent variables.

For example, assuming that household wealth rises by three percent would reduce the fire death rate to 8.72 FDPM and would save 23 lives. The number is not any larger despite the large fall in the FDPM rate because the population is assumed to grow by three million persons per year as well. If household wealth increases by three percent per year for five years, the cumulative increase in wealth could be expected to lower the fire death rate to about 8 FDPM and save roughly 150 lives annually.

The impact of new home construction on fire deaths is slightly more complex. Newly built houses lower the fire death rate as they are safer than existing homes, but they do not lower the number of fire deaths in existing houses. This is because construction of a new house does not, generally, make an old house safer. However, every year, some new houses are built simply to replace previously occupied units lost through demolition or disaster. And in those cases, the number of fire deaths can be expected to fall.

In 2003, about two million new residential units were built, and on average, about 200,000 occupied units per year are lost due to demolition or disaster.[19] Assuming production in 2004 is the same as in 2003, the percentage of new housing stock will rise by about 1.4 percent and result in the fire death rate falling to 8.8 FDPM, which translates into roughly 12 fewer fire deaths each year. Over five years, the cumulative impact of building 10 million new homes and losing one million older units will reduce the fire death rate to 8.3 FDPM, an improvement of 7.3 percent, and, in the process, reduce the number of fire deaths by about 60 per year, an improvement of only 2.4 percent.

Collectively, these findings suggest that, over the next decade, fire death rates should continue their graceful and gradual decline, with the rate of decline in the fire death rate substantially outpacing the slower rate of decline in the number of fire deaths because of continued population growth. There is, however, a caveat which will in all likelihood exacerbate this phenomenon.

A TROUBLING TRUTH

Increases in household wealth and new home construction do not occur evenly across the nation. To the extent that they do not, the results just provided in the two simulations are optimistic. For example, a hypothetical scenario could be constructed where households in Los Angeles experience a 10 percent increase in household wealth next year, while household wealth is stagnant everywhere else. While algebraically this may be the same as every household in the U.S. having their wealth rise by one-third of one percent, the impact is quite different. This is because Los Angeles has a very low fire death rate, about 2.5 FDPM, and as a result, the increase in wealth will result in relatively few deaths being prevented. By contrast, were an imaginary city equal in size to Los Angeles but with the average fire death rate to enjoy the same rise in household wealth, the number of fire deaths averted would be almost four times as great.

Thus, the distribution of the increases in household wealth matters, and to the extent that areas with high fire deaths experience smaller increases in household wealth and fewer housing starts, this reduces the impact of these variables.

Looking at this same phenomenon slightly differently, in 1979, Maryland had 100 fire deaths, with half of them in Baltimore City. At that time, Maryland had a population of 4.3 million, while Baltimore had a population of 770,000. As a result, the FDPM rate for Baltimore was 61 while it was only 14.4 outside of Baltimore.

Between 1983 and 2001, Maryland experienced a 50 percent decline in its number of fire deaths – in line with the rest of the nation. And, just like in 1983, half of the fire deaths in 2001 were still in Baltimore. However, between 1983 and 2001, the population of Baltimore fell by 125,000 to 645,000, while the population of the rest of the state grew to 5.4 million persons. As a result, the FDPM rate in Baltimore fell from 61 to 39, while in the rest of the state it fell from 14.4 to 6. That is, between 1983 and 2001, the FDPM rate fell by 36 percent in Baltimore but by a whopping 58 percent in the rest of Maryland. As a result, the relative chances of dying in a fire in Baltimore, compared to the rest of the state, went from being less than four times as high to almost seven times as high.

Because increases in wealth do not move in lock-step across the U.S., and because new home construction does not occur evenly in all counties in the U.S. – because not all counties grow at the same rate – many locations, including, but by no means limited to, Baltimore City, can be expected to suffer an increasingly disproportionate number of fire deaths. As a result, their FDPM rates will decline much more slowly than the rest of the nation, and thus their relative fire death rates will precipitously rise. Also, reducing the number of fire deaths in these cities will become increasingly difficult.

Unless this problem is successfully addressed, these locations will increasingly become home to a higher and higher percentage of all U.S. fire deaths. As new homes are rarely built in these areas, building code improvements will not help much, and since wealth gains in these areas are often small, relying on increased wealth to help is also likely to be disappointing. Rather, to overcome this problem, and in the process drive fire death rates and the number of fire deaths down still further, narrowly focused interventions based primarily on the age of housing stock and the wealth of the occupants, within a defined geographic area, are likely to be much more effective.

APPLICATION

This research offers a very powerful, clear-cut, and proscriptive recommendation for saving lives: increase fire prevention efforts where, for example, the housing stock is old and households are poor, with the magnitude of the intervention increasing the older the housing stock and the poorer the area. Doing otherwise wastes resources and withholds help from those who stand to benefit from it most. ▲

Elliot F. Eisenberg, Ph.D., is with the National Association of Home Builders.

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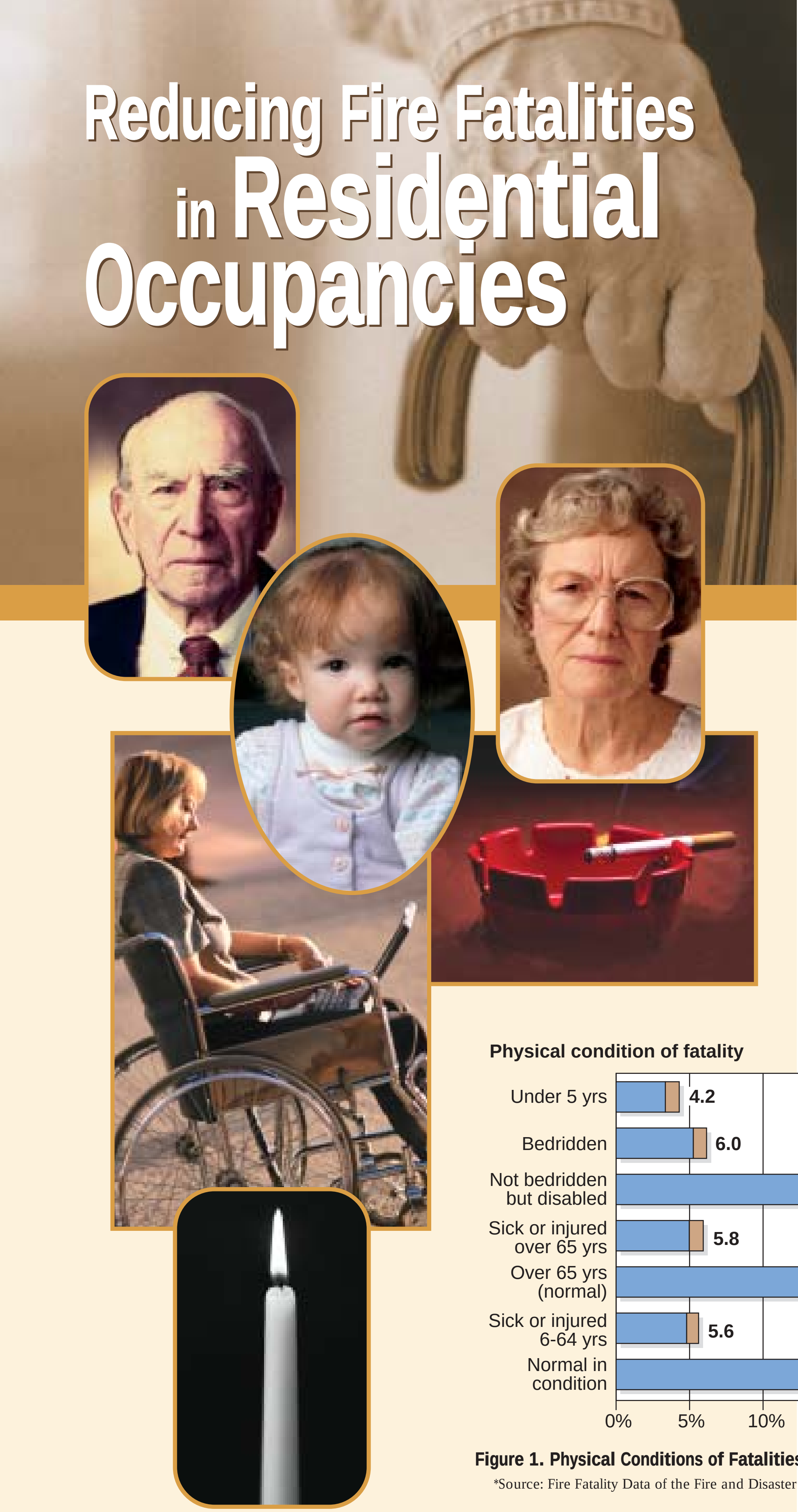
Reducing Fire Fatalities in Residential Occupancies



By Ai Sekizawa, Dr. Eng.

WHICH PEOPLE ARE VULNERABLE TO FIRES?

Frequently, when "vulnerable populations" are contemplated, people who use wheelchairs in public buildings such as assemblies, office buildings, and so on, are considered. However, there are many other cases where people fall into vulnerable populations in a fire. For example, Figure 1 shows the statistical data of fire fatalities by physical condition and by type of occupancy in Japan. This figure shows that the majority of fire fatalities occur in residential homes, and that there are a disproportionately large number of fire fatalities that fall into one of the categories of vulnerable populations, when considering the proportions of these categories in the overall population. Also, there is much variety in vulnerable populations, ranging from the bedridden to the people who are temporarily sick or injured. From this standpoint, vulnerable populations encompass a wide variety of people with physical and mental limitations such as mobility impairment, sight impairment, hearing impairment, mental disability, pregnancy, infancy, etc.

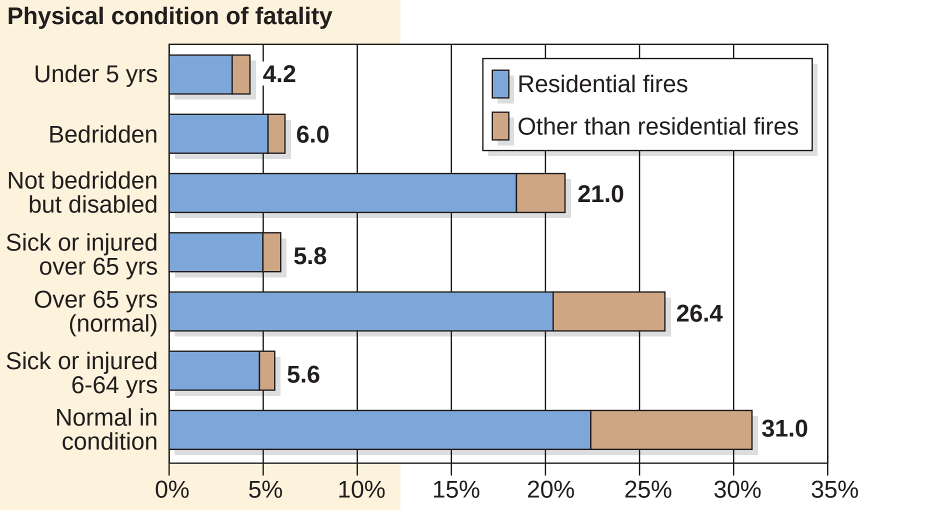


Figure 1. Physical Conditions of Fatalities at the Time of a Fire by Type of Occupancy in Japan.

*Source: Fire Fatality Data of the Fire and Disaster Management Agency for 1995-2001.

Therefore, everybody may be vulnerable to fires depending on the time, place, and circumstances. Also, the fire statistics[1,2] show that the occurrence of fire death depends not only on the severity of the fire itself, but also on the conditions of occupants, such as physical abilities, conditions around occupants, and the type of facility where a fire occurs. Fire safety measures aimed at protecting vulnerable populations do not simply mean additional special attention for these high-risk groups. Rather, better protecting vulnerable populations is best achieved by reviewing the fire safety design approach for the entire population, which is especially true in Japan where elderly people will account for one-fourth of the total population in the near future.

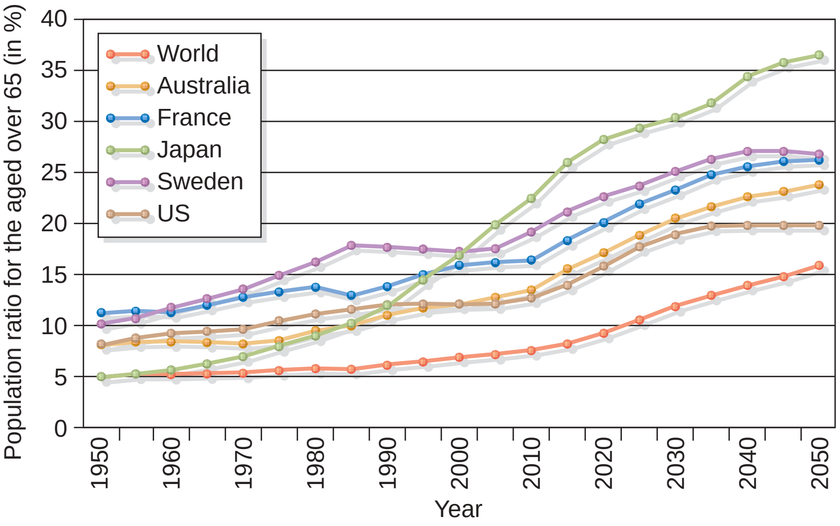


Figure 2. Population Ratio of People Aged 65 and Older from 1950 to 2050.[5,6]

Figure 2 shows how the ratio of people aged 65 and older changes in Japan and in other developed countries from 1950 to 2050. The graph shows a rapid increase in the ratio of people aged 65 and older in the past half-century and the predicted continued growth for the next 50 years. This is particularly significant in Japan, where one-third of the total population will be 65 or older by 2035. In a rapidly aging society, the size of the vulnerable population increases because elderly people find it more difficult to cope with the mental and physical strains caused by fire. This is particularly the case for people aged 75 and older. The increasingly large number of elderly people in society in the near future will undoubtedly lead to a rapid increase in fire fatalities, as the per capita fatality rates increase steeply with age in Japan and in other countries such as the U.K. and the U.S.[3,4]

KEY ISSUES FOR IMPROVING FIRE SAFETY OF VULNERABLE PEOPLE

The reduction of residential fire deaths can be achieved not only by the use of fire protection equipment such as smoke detectors and/or residential sprinklers, but also by many other efforts, such as improvement in fire safety of appliances and furniture used in homes, fire-resistant houses, and fire safety education for the public and people who care for vulnerable people. This is illustrated in Figure 3. In addition to fire protection equipment, such as residential smoke detectors, which work after fires start, mitigating the incidence of fire ignitions with use of safer appliances can be a very effective approach to reduce future fire deaths. When considering strategies to reduce fire fatalities, integrated efforts are necessary, not only to improve fire safety

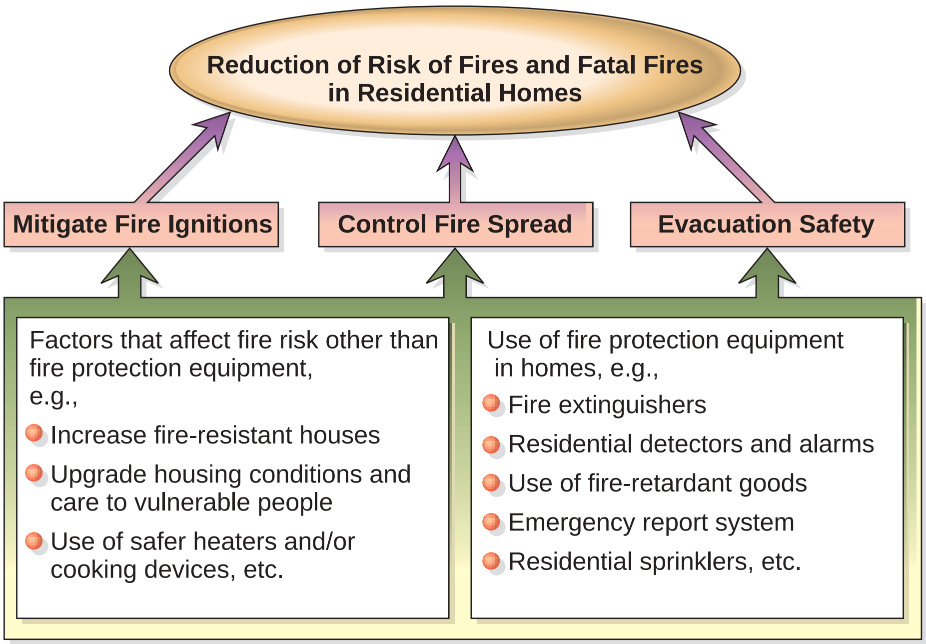


Figure 3. Approaches for Reducing Risk of Residential Fires and Fatal Fires.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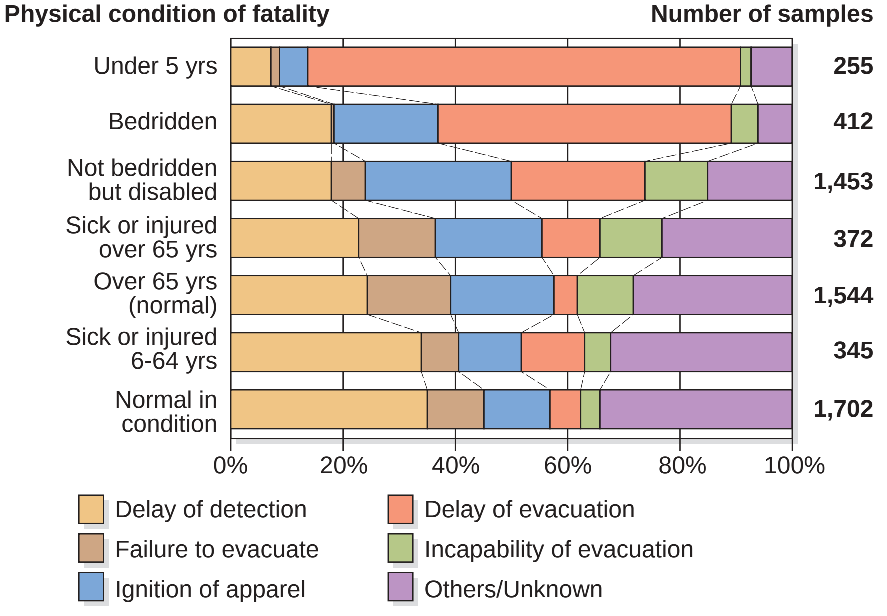

Figure 4. Causes of Fire Death by Type of Physical Condition in Residential Fires.

*Source: Fire Fatality Data of the Fire and Disaster Management Agency for 1995-2001.

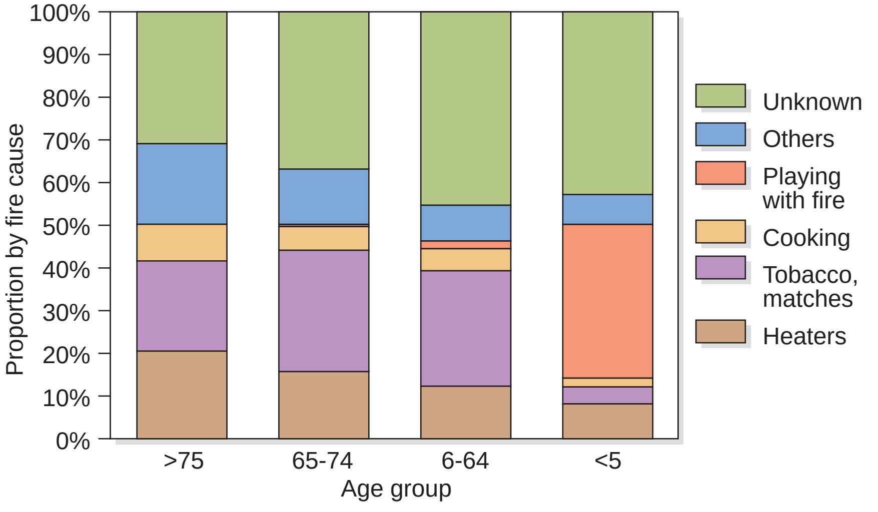

Figure 5. Breakdown by Fire Cause of Fatal Residential Fires by Age Group.

*Source: Fire Fatality Data of the Fire and Disaster Management Agency for 1995-2001.

measures but also to upgrade the overall safety of the environment, such as through the construction of fire-resistant homes, use of more fire-safe appliances and living conditions, and the establishment of cooperative systems involving neighbors and other people living nearby. It's not just the elderly who are at risk.

WHO ARE THE VICTIMS OF RESIDENTIAL FIRES?

The statistics of the incidence of fires and fatal fires have been analyzed[5,6] using the database of Fire Fatality Reports collected by the Fire and Disaster Management in order to understand the risk of fatal fires in relation to various factors. The conditions of fire victims recorded in a fire fatality report include such items as age and whether the victim was sick, bedridden, physically disabled, asleep, or inebriated. The statistics also indicate whether the victim was alone at the breakout of fire, and whether he or she lived alone.

Figure 4 shows an evaluation of fire fatalities by combining types of vulnerabilities with causes of death. The proportion of estimated causes of fire death for each type of physical condition of victims gives a very informative picture on how they were involved in fires that resulted in death. Victims who were bedridden, physically disabled, or less than 5 years old were likely to be killed in residential fires mostly due to incapability and/or failure to evacuate. For victims who were physically disabled but not bedridden or over 65 years old, a relatively large proportion involved ignition of apparel and/or delay of evacuation. By contrast, for the victims who are 6-64 years old, fully physically able, and simply sick or injured, the proportions of the causes mentioned above are relatively small. In this segment of the population, delay of detection is a major factor in fire deaths.

Figure 5 shows the breakdown of fire causes of fatal residential fires for each age group of victims. The proportion attributable to heating equipment increases with the age of victims, ultimately accounting for 20 percent, or one-fifth, of the causes of fires for victims aged 75 and older. This fact also demonstrates how effectively total fire deaths among elderly people can be reduced by mitigating fires caused by heating appliances.

EFFECT OF RESIDENTIAL FIRE DETECTORS IN REDUCING FIRE DEATHS IN HOMES

The number of fire deaths in the U.S. has been continuously decreasing during past two decades, with a total reduction of almost by half in this period. The use of residential smoke detectors is frequently cited for contributing to this dramatic decrease of fire deaths. Functional residential smoke detectors were estimated by the NFPA[7] to reduce fire deaths by 46 percent, which is quite similar to the 56 percent reduction cited for the U.K.[8] In Japan, although residential smoke detectors are not widely used in homes, many homes, such as apartment houses, utilize automatic fire alarm systems.

Sekizawa and Notake analyzed the impact of automatic fire alarm systems in Japanese homes on reducing fire deaths based on the statistical analysis of the fire data of the Fire and Disaster Management Agency.[9] This analysis found that, where automatic fire alarm systems were activated, the number of fire deaths compared to buildings in which fire alarm systems were either not present or were not activated were 59 percent lower in apartment houses and up to 44 percent lower in wooden apartment houses. These values are very close to the estimates for the reduction of fire deaths attributable to residential smoke detectors in the U.S. and the U.K. The Fire Service Law was amended in June 2004 to require the installation of residential detectors in all dwellings in Japan, so future research is necessary to determine the effect of residential detectors in reducing the risks fire death in the future.

RAPID INCREASE OF GREY-TYPES OF NURSING HOMES AND CHALLENGES IN FIRE ADMINISTRATION

In the context of regulation by Fire Service Law in Japan, buildings are classified according to the type of use and the type of occupant (as is in the case in many other countries.) However, so-called “grey-type” nursing homes, which are assisted living facilities, have been proliferating in recent decades with a rapidly aging society in Japan. For example, the number of group homes for older people who are capable of supporting themselves in daily life has increased dramatically.

These facilities have problems from the viewpoint of fire safety because many of them were converted from general apartments and renovated to fit the new needs. Since the regulations applicable to elderly nursing homes do not apply to these buildings, most of these asssted living facilities have been supplied with no more fire protection than ordinary apartments. Code enforcement officials are aware of the potential risk of fires as well as the difficulty in evacuation and rescue when a fire occurs in these institutions. However, they find it difficult to classify these grey-type institutions for aged people because they have no standard policy to control this problem at present. With this in mind, the technical committee set up in 2002 by the Fire and Disaster Management Agency of Japan has a goal of establishing a revised method of regulating these intermediate residential facilities as either those equivalent to special elderly nursing homes or those equivalent to general apartments, depending upon features such as the conditions of occupants and buildings. Also, the Fire and Disaster Management Agency is analyzing the application of residential sprinkler systems as an alternative to other requirements of the Fire Service Law for these intermediate residential facilities.

Because of the rapid aging of society, many developed countries have similar challenges associated with these types of assisted living facilities. The best methods of fire prevention/protection in these types of occupancies should be explored. In addition, the impact of diminished abilities associated with aging, such as decreased mobility, vision, and hearing after people move into these grey-type facilities, can necessitate changing how these buildings are regulated. The question is how this kind of change can and should be observed and by whom. These future issues impact not only fire safety, but also other associated areas such as barrier-free design, social welfare, and housing environment. Fire protection engineers should cope with these problems in collaboration with policymakers, researchers, and engineers in these other fields. ▲

Ai Sekizawa is with the National Research Institute of Fire and Disaster and the University of Tokyo.

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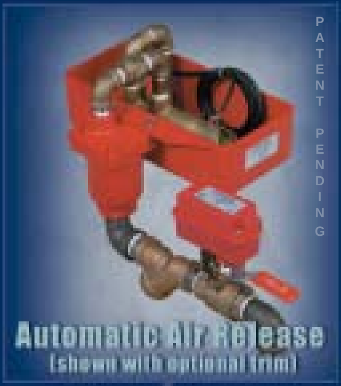

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Residential Fire Safety –

Is the Age of the Occupants Related to the Likelihood of a Fire Starting?

By Ian R. Thomas, Ph.D.

This article investigates whether the age of residential building occupants is related to the likelihood of a fire starting by reviewing fire incident databases for information regarding who is in residential buildings when fires start, who starts fires in or around residential buildings, and whether occupant age a factor in the occurrence of ignition in residential buildings. This analysis is complex, because there is little published information on the occupants of residential buildings in which fires occur. Detailed information regarding occupants is only collected when the occupants are injured or killed due to the fire. A search of the fire literature for information on the relationship between occupant age and the frequency of fire occurrence leads largely to information on the relative frequency of occurrence of injuries and fatalities with the age of the casualty, but nothing on the uninjured. This notwithstanding, fire databases can yield some clues into whether occupants of certain ages are more likely to be involved in starting fires.

The most comprehensive data on fires in the U.S. are contained in the National Fire Incident Reporting System (NFIRS) database.[1] Similar databases are available in many other countries. The NFIRS database contains categorical data on a very large number of fires, including information on where and how the fire started, how big it became, how many people (building occupants and firefighters) were injured or killed in the fire, and much more. However, the age of people involved in a fire is only recorded in the NFIRS database if the person becomes a casualty.

It is also possible to obtain approximate information on the age of some of the people involved with fire starts (whether injured or not) using one of the fields in the database.[1, 2] The only field that gives direct information on the age of uninjured people involved in fire ignition is called ignition factor, a field that can be thought of as indicating a "cause" for the fire. Many ignition factor categories are defined, but the only one with a direct indication of the age of those involved in starting the fire is child play, which appears twice – once under the heading misuse of heat of ignition and again under the heading misuse of material ignited. Even these entries only provide an approximate indication of the age of a person involved with the fire start. Other ignition factor categories that could relate to the involvement of people in the ignition include abandoned, discarded material (smoking material); accidentally turned on, off (often a stove); combustible too close; cutting, welding; falling asleep; incendiary; operational deficiency; overloaded; suspicious; unattended (often a stove again); unconscious, impairment; etc.; but they provide no indication of the age of the occupants.

AGE OF OCCUPANTS

In fires in apartment buildings in the U.S., children playing made up about 6 percent of fires with known ignition factor over the period 1983-1993 (except 1986).[2] Other ignition factors that could be related to people accounted for about 69 percent of fires with known ignition factor. Based on form of heat of ignition, about 74 percent of fires were in categories that may relate to occupants being directly involved in the fire start, so, together with the previous data, this provides a basis for estimating that between 70 percent and 80 percent of fire starts in apartment buildings involve the actions (or sometimes lack of action) of building occupants.

Similarly, in fires in one- and two-family dwellings in the U.S. (using the years 1983 and 1993 as representative samples), children playing accounts for about 5 percent of fires with known ignition factor. Other ignition factors that could be related to people being involved in the fire start account for about

51 percent of fires with known ignition factor. Again, based on form of heat of ignition, about 55 percent of fires were in categories that may relate to occupants being directly involved in the fire start, so, together with the previous data, this provides a basis for estimating that between 50 percent and 60 percent of fire starts in one- and two-family dwellings involve the action or lack of action of building occupants.

Tables 1 and 2 show the proportion of the U.S. population in various age groups and the proportions of fatalities and injuries in fires in apartments and one- and two-family dwellings. Examination of these tables shows that children aged 0-4 years were over-represented in both the fatalities and injuries, and that people aged 60 years and over were over-represented among the fatalities but not the injuries. This over-representation may imply people in these age groups were more likely to be involved the start of fires. It may be that the occurrence of casualties mirrors the occurrence of fires for each age group. However, further analysis of the data above shows that this is unlikely. More likely, the representation of various age groups is overestimated if fatalities are used as the basis, and this may also be the case if injuries are used, but possibly to a lesser extent.

In the case of apartment buildings, for those fires that had fatalities (only about 6 fires in every 1,000 reported to the fire department), there were on average 1.2 fatalities per fire, and for those fires that had injuries (only about 47 fires in every 1,000 reported fires), there were on average 1.4 injuries per fire. For fires producing both fatalities and injuries, the average numbers were considerably greater – about 1.4 fatalities and 2.4 injuries per fire. As is to be expected, these numbers vary for the different ignition factor categories. For children playing, for those fires that had fatalities only (about 9 fires in every 1,000 reported children playing fires), there were on average 1.5 fatalities per fire, and for those fires that had injuries only (about 83 fires in every 1,000 reported fires), there were on average 1.6 injuries per fire, while for fires producing both fatalities and injuries, the average numbers were considerably greater – about 1.4 fatalities and 2.3 injuries per fire. Thus for children playing, simply using fatality or injury numbers would overestimate the occurrence of fires with children involved.

A better way to look at this would be by looking at the average number of fatalities and injuries per fire for each of the age groups. However, it is difficult to obtain this information, and there is often a mixture of age groups involved as casualties in a given fire, making interpretation difficult.

RESIDENTIAL FIRE CASUALTIES

Recent examinations by Thomas and Brennan of the occurrence of casualties (particularly fatalities), principally in

Continue on page 32

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Age Group	% U.S. Population	% Fatalities	% Injuries	Ratio Fatalities	Ratio Injuries
0 – 4	7.6	22.3	14.2	2.9	1.9
5 – 9	7.2	5.8	3.6	0.8	0.5
10 – 19	14.0	5.1	8.7	0.4	0.6
20 – 39	33.0	23.2	44.3	0.7	1.3
40 – 59	21.4	17.7	14.7	0.8	0.7
60 – 69	8.3	10.6	5.7	1.3	0.7
70+	8.5	15.3	8.8	1.8	1.0

Table 1. Apartment Fire Casualties by Age Group Proportions.

apartment building fires, have indicated that a large proportion of fatalities were in the room or close by when the fire was ignited, were involved in some way in the start of the fire, and were often acting habitually in ways that others would see as hazardous or unnecessarily risky.[2, 3]

In investigating whether there was any relationship between ignition factor, age, gender, and casualty outcome (death or injury), it was concluded that variation in outcome with ignition factor indicates that many of the people killed in apartment building fires were responsible for starting the fire either by action or inaction. This was particularly obvious in the case of fires with children playing as the recorded ignition factor.

Fatalities in apartment buildings among very young children (aged 0-4 years) in the children playing case was at a rate 10 times their proportion of the population. This case produced over half the fatalities of children aged under 5 years, almost a quarter of the fatalities in the 5-9 age group, and over one-third of injuries in both age groups. Three-quarters of all children playing deaths were children under 5 years of age, with nearly twice as many boys as girls. Fatalities in the other age-groups were low, as were injuries, for all but the 20-39 age group. This age group accounts for 70 percent of female injuries and 63 percent of male injuries, perhaps indicating the importance of the parental role in the development of the problem as much as it may indicate their attempts at rescue or extinguishment after becoming aware of the fire.

Examination of fires with a reported ignition factor of either falling asleep or impaired revealed that 31 percent of these fires (in total) involved a cigarette or similar as the form of heat of ignition and that these fires resulted in 51 percent of the civilian injuries and 72 percent of the civilian fatalities. These proportions are worthy of comparison with those for which the forms of heat of ignition were either heat from gas-fuelled equipment or heat from properly operated equipment, which were reported approximately one-fourth as frequently (26 percent and 25 percent, respectively) as fires with the ignition factor either falling asleep or impaired. Many of these would have involved stove or cooking fires resulting from unattended operation of the equipment, which was reflected in the much lower proportions of injuries and fatalities (12 percent and 19 percent of injuries and 3 percent and 5 percent of fatalities, respectively). This comparison clearly indicates a strong relationship between involvement in or proximity to ignition and probability of fatality and injury.

The most common outcome of reported fires in apartment buildings was no reported civilian casualties at all (95 percent of reported fires). Of the remaining 5 percent, 89 percent were reported to have only injuries, 8 percent only fatalities, and 4 percent both injuries and fatalities. Overall, of the fatal fires with no civilian injuries reported, only 13 percent have more than one reported fatality per fire. However, for children playing, the proportion was 28 percent, while for incendiary and suspicious, the proportions were also high at 27 percent and 24 percent, respectively. In contrast, impaired was the ignition factor with the lowest proportion, with only 4 percent multiple fatality fires, and abandoned, discarded material was the next lowest category with 10 percent. The latter of these (but perhaps both) can be explained by coronial evidence that the majority of these people

Age Group	% U.S. Population	% Fatalities	% Injuries	Ratio Fatalities	Ratio Injuries
0 – 4	7.6	19.2	9.3	2.5	1.2
5 – 9	7.2	7.6	4.0	1.1	0.6
10 – 19	14.0	7.1	13.3	0.5	1.0
20 – 39	33.0	20.3	38.0	0.6	1.2
40 – 59	21.4	15.3	19.8	0.7	0.9
60 – 69	8.3	9.6	6.7	1.2	0.8
70+	8.5	20.8	8.8	2.4	1.0

Table 2. One- and Two-Family Dwelling Fire Casualties by Age Group Proportions.

live alone, but the explanation may also be because only one person was involved in the activity that resulted in ignition, whereas children playing may often involve more than one child.

Suicide and homicide are not directly identified in the NFIRS data. However, coroners' data and findings indicate that a significant proportion of fires in residential occupancies relate to suicide and homicide. Based on coroners' data, 17 percent of 175 residential fires were deliberately lit, with possibly 80 percent of these being suicidal in intent.[3,4] Two fires resulted in four homicide victims. The total proportion of incendiary fires (9%) plus suspicious fires (7%) in the NFIRS data was similar, leaving open the question of what proportions of the casualties in these fires were suicides and homicides.

GENDER

The overall proportion of the injured in the apartment fires who were female was 47 percent, slightly under their proportion of the overall population (about 51 percent), and the proportion of those killed was 40 percent, well under their proportion of the population. For incendiary fires, the proportion injured was similar all fires at 47%, but the proportion killed was significantly greater at 49 percent. For suspicious fires, the proportion injured who were women was about the same (46%) and the proportion killed slightly less (37%). The higher proportion of females killed in incendiary fires may reflect homicide, but this is not recorded in the data.

These examples show that there is much that can be learned about who is involved in fires and how they are involved, but they also show that there are also many unanswered questions that require more data to be collected and more careful analysis of the available data.

By properly understanding what happens in real fires in real buildings, fire safety engineering can be applied in an economical and effective manner to help achieve appropriate levels of fire safety. There is still a long way to go to completely understand what types of people are more likely to be involved in starting fires, because at the moment it is possible to only partially answer the questions posed at the start of this article. ▲

Ian Thomas is with Victoria University.

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What Have We Learned About the Benefits and Costs of Residential Fire Sprinkler Legislation?

By Chris Jelenewicz, P.E.

Since the first residential sprinkler standard (NFPA 13D) was published by the National Fire Protection Association (NFPA) in 1975 and the first residential sprinkler ordinance was implemented in San Clemente, California, in 1980,[1] the number of households that are now protected with automatic sprinklers has slowly increased. Although these systems have been shown to be extremely effective in protecting lives from the consequences of residential fires, very few jurisdictions have implemented ordinances that require sprinklers in new homes. For instance, it has been estimated that only two percent of all new one- and two-family dwellings are equipped with a sprinkler system.[2]

Some believe the general public as well as some fire service professionals do not fully understand the potential benefits and costs associated with these systems. Fortunately, several communities that have adopted home sprinkler legislation have made attempts to quantify performance. These evaluations have shown that home sprinkler systems are effective in reducing the direct losses of fire in the home. Additionally, several researchers have performed studies that have estimated the costs and benefits of these ordinances. These cost-benefit studies have been useful in providing insight on how home sprinkler legislation can be more cost-effective.

To help provide a better understanding on the value of residential sprinkler system legislation, this article will provide a brief summary on some of the literature that has attempted to define the benefits and/or costs of requiring sprinklers in the home. Additionally, this article will briefly discuss how fire protection engineers are currently working to make these systems more cost-effective.

BENEFITS

The salient benefit to a community that adopts residential sprinkler legislation is the reduction of fire deaths. In addition, these local ordinances provide other benefits, such as limiting injuries and property damage. Studies based on fire data from three communities that have examined the effectiveness of sprinkler legislation in their communities provide insight on these benefits. These communities are Scottsdale, AZ,[3] Vancouver, BC,[4] and Prince George's County, MD.[5] Also, Rohr[6] has completed a study on sprinkler system effectiveness in the United States that includes an analysis of residential fire data.

Reduction of Fire Deaths. When considering the overall effectiveness of residential sprinklers in reducing fire deaths, sprinklers have been very successful in reducing multiple deaths from a single fire in the home. For instance, "NFPA has no record of a fire killing more than two people in a completely sprinklered... residential building where the system was properly operating." Furthermore, over the period 1989-1998 in the United States, it was estimated that fire deaths were reduced by 78 percent when a home was protected with sprinklers. This estimate is based on 2.1 fire deaths per thousand fires in homes protected with sprinkler systems and 9.4 fire deaths per thousand fires in homes without sprinkler systems.[6] It is important to note the data used in this study did not include fire incidents that were not reported to the fire department.

In Scottsdale, 49 fires were reported in single-family homes that were equipped with sprinklers in the 15 years after legislation was implemented.[3] In addition, over an eight-year period in Prince George's County, there were 117 fire incidents in households that resulted in sprinkler activation.[5] In both jurisdictions, no fire deaths were experienced in homes protected with automatic sprinklers. Although it may be difficult to infer significant scientific conclusions from these studies because of the small sample size, observing no fire deaths is an important finding that highlights the most fundamental benefit of these systems.

Besides the United States, other countries have also made attempts to quantify how successful home sprinklers are in reducing fire deaths. For example, in Vancouver over a seven-year period after a sprinkler ordinance was implemented, the city's annual fire death rate was reduced 69 percent. Comparatively over this same period, the fire death rate in Canada decreased by 42 percent.[4]

In New Zealand, a cost-benefit study estimates fire deaths would be reduced by 72 percent if sprinklers are installed in the home.[7] A separate cost-benefit study from New Zealand estimates that

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over a 30-year period, if all new homes in New Zealand are equipped with a residential fire sprinkler system, fire deaths would decrease by 100 persons.[8] On average, 18 people die each year from fire in New Zealand.

Reduction of Injuries. In addition to limiting fire deaths in the home, in Prince George's County, only seven injuries were reported from fire incidents that occurred in homes equipped with sprinklers. Out of these injuries, each injury was determined to be minor in nature.[5]

Protection of Property. Home sprinkler systems have also been documented to be effective in reducing property losses. For example, it was estimated that, in the United States from 1989 to 1998, the average direct property damage per fire was reduced by 42 percent when a home was protected by sprinklers.[6]

Moreover, in Scottsdale, it was estimated that fires in homes protected with sprinklers had an average property loss equal to $2,166. In residences without sprinkler protection, the average property loss was equal to $45,019.[3] Similarly in Prince George's County, when compared to a random sample of structural fires that occurred in unsprinklered single-family homes over a two-year period before the sprinkler ordinance was adopted, the average estimated property loss was $31,667. Conversely, the estimated fire loss was $3,673 for sprinklered homes after the sprinkler ordinance was adopted.[5]

Fire Containment. Another method used to measure home fire sprinkler system effectiveness is to determine if the system contained a fire to an area near the point of fire origin. If a fire can be confined to a small area, the likelihood of fire deaths will be reduced. For instance, over a 10-year period in the United States, 93 percent of all fires that occurred in a home that was protected with sprinklers were confined to the room of fire origin; the statistic was 63 percent for homes without sprinklers.[6]

In Prince George's County, fire damage was estimated by the number of sprinklers activated. Out of 117 fires, one controlled the fire in 106 of the cases. Four of the fires were controlled by the activation of only two sprinklers. In seven fires, more than two sprinklers activated.[5]

OTHER MEASURED BENEFITS OF HOME FIRE SPRINKLER SYSTEMS

Besides evaluating the direct benefits of home fire sprinkler legislation, there have been attempts to quantify other benefits. For example, homes that are equipped with sprinklers require less water to extinguish a fire when compared to homes without sprinkler systems that depend only on the fire department. In Scottsdale, it was estimated that the average fire in a residence was extinguished with approximately 340 gallons (1,300 liters) of water. This is compared to approximately 2,900 gallons (11,000 liters) of water for homes without sprinkler protection.[3]

Additionally, when a residential fire sprinkler ordinance is enacted, local municipalities also benefit. In 1999, the Canadian Mortgage and Housing Corporation[9] (CMHC) performed a cost-benefit analysis on the benefits to municipalities as a result of residential fire sprinkler system ordinances. In this study, benefits were quantified as changes in the cost for a) municipal infrastructure, b) municipal insurance premiums, c) fire department facilities, and d) fire department operations. The study concluded that a municipality can achieve cost savings if a residential fire sprinkler system ordinance is adopted. More importantly, it was concluded that a municipality can obtain maximum benefits if:

- There are future opportunities for new residential development.
- This future growth extends beyond the response areas currently served by the fire department.
- All new buildings (commercial and residential) are equipped with fire sprinkler systems.
- Minimum permitted fire department response times are increased in all areas with new construction.

Therefore, careful community planning is beneficial in assuring municipalities will obtain the maximum possible benefits from enacting residential sprinkler legislation.

In addition, a reduction in the cost for temporary shelter and missed wages that result from a fire in the home is another benefit. A cost-benefit study from Canada estimated per capita costs can be reduced from CAN $2.90 per house per year to CAN $1.02 per house per year if residential sprinkler systems are installed in the home.[10]

Other benefits are more difficult to quantify when considering the impacts on an entire community. These benefits include the value of a) personal time for volunteer firefighters, b) lower insurance premiums, c) savings of having more options in the building and fire codes, and d) the reduction of intangible losses from fire such as pets and family heirlooms. It is recommended that researchers who study residential sprinkler policy in the future attempt to define these benefits so that all benefits are quantified.

INDIRECT MEASURES OF SPRINKLER SYSTEM EFFECTIVENESS

Because some communities have a limited experience with household sprinkler systems, fire data may not be available to estimate the effectiveness of proposed residential sprinkler legislation. In these cases, indirect methods were used to make these predictions.

This was the case in the United Kingdom (UK), where very few homes are equipped with sprinklers. In order to estimate home sprinkler effectiveness, researchers did not want to fully depend on fire data from other countries. As a result, indirect estimates were measured. In this study, it was shown that a strong correlation exists between the risk of fire and the size of the fire. It was assumed that if the fire size can be kept to a minimum, the direct losses from home fires can be reduced. The results of this study concluded that if sprinklers are installed in a home:

- The risk of fire deaths would be reduced by 70 percent (+/– 15%).
- The risk of injuries would be reduced by 30 percent (+/– 15%).
- Property damage would be reduced by 50 percent (+/– 15%).

Interestingly, in addition to the benefits listed above, the U.K. study also estimated the number of fire department rescues would be reduced by 35 percent (+/– 15%). This was the only study found that estimated a reduction in fire department rescues as a benefit.[11] Placing a value on a reduction of rescues may be difficult to quantify in a cost-benefit study. As such, the use of this benefit may provide some insight into the effectiveness of home sprinklers but should not be counted as a benefit in a pure cost-benefit analysis.

ESTIMATION OF COST-EFFECTIVENESS

Although some of the policy evaluations described above examine the consequences of a fire that has occurred in a house equipped with a sprinkler system, these studies do not examine the frequency of fire occurrence and the probable costs and benefits. Fortunately, several studies that have attempted to estimate the cost-effectiveness of home sprinkler systems account for the probability of a fire occurring in the home.

When considering cost-benefit studies that are related to public policy, it is important to understand how "standing" is defined. Standing prescribes whose benefits and costs are counted in a cost-benefit study.[12] For example, in 1984, a study from the National Institute of Standards and Technology (NIST) estimated the costs and benefits of residential sprinklers. This model focused on how the decision to purchase a home equipped with a home fire sprinkler system affects the individual. Therefore, standing for this study was based on the perspective of the individual homeowner.

In the NIST model, it was concluded that home sprinkler systems can be cost-effective for individuals who are part of a community of sprinkler users that can benefit from lower installation costs. It was also concluded that home sprinklers are cost-effective when occupants cannot adequately hear a smoke alarm and/or escape the building. This is often the case when individuals are a) hearing-impaired, b) under the influence of a substance, or c) mobility-impaired such as the very young, the very old, and the physically impaired. The NIST model also estimates that home sprinkler systems are not cost-effective for homeowners whose water purveyors charge excessive water standby fees.[13]

As opposed to the NIST model, Harmathy[14] defined "standing" as the entire nation if all new homes in the United States were equipped with sprinklers. This model estimated that home sprinkler legislation for single-family dwellings is not cost-effective. Nevertheless, it should be noted that the Harmathy and NIST studies were performed in the 1980s. Thus, the data used in these models are out of date and should be updated to be consistent with today's changes in technology.

Notarianni[15] also estimated the cost-effectiveness of mandating residential fire sprinklers in adverting home fire deaths. Standing for this study was defined as the municipality. For that reason, this model did not include individual factors such as a) age, b) taxes, c) insurance costs, and d) an individual's risk aversion. This study considered the variability and uncertainty in fire loss statistics. Because economists recommend that all cost-benefit studies of public policy include a sensitivity analysis to account for variability and uncertainty in statistical data, this is an important factor to consider in future cost-benefit studies.

COSTS OF HOME SPRINKLERS

The costs of home sprinkler systems are always an issue when communities are considering adopting legislation. Therefore, any attempts to reduce costs will be beneficial to assuring cost-effectiveness and the adoption of future residential sprinkler ordinances.

Because the adoption of a sprinkler ordinance creates the opportunity for a new market, experience has shown that once a community adopts residential sprinkler legislation, the cost to install sprinklers in a new home decreases. For instance, it has been estimated the cost to install a sprinkler system in Scottsdale has been reduced to approximately 80 cents per square foot (7 cents per square meter).[3] This is compared to a national average cost of $1 to $1.5 per square foot (9 to 14 cents per square meter).

According to Fleming,[16] unnecessary community requirements such as excessive meter charges and tap-in fees drive up the price of a residential sprinkler system. Consequently, if communities can take actions to eliminate or reduce these unnecessary requirements, system prices can be minimized.

Fire protection engineers are currently working on ways to reduce the cost of residential sprinklers. For example, fire protection engineers from the National Fire Sprinkler Association and the National Fire Protection Association are currently working with local water purveyors to better understand each group's issues so that excessive backflow requirements are minimized and safe drinking water is maintained.[17] Generally, for combination domestic water/sprinkler systems, backflow prevention is not required to maintain safe drinking water. For stand-alone sprinkler systems, a double-check valve assembly is usually adequate. If homeowners are subjected to excessive backflow requirements, in addition to the cost of the backflow device, the added friction loss will increase the likelihood of needing a fire pump to provide adequate water pressure.

Additionally, fire protection engineers from NIST are currently working with the United States Fire Administration (USFA) on researching residential sprinkler designs that will require lower water supply requirements and at the same time will remain effective in reducing the losses from fire. For instance, fire protection engineers are researching the effects that "a one-sprinkler design option" will have on water distribution characteristics and the effectiveness of the system to control a home fire. If a one-sprinkler design is shown to be effective, costs can be reduced for areas with water supply issues.[18] ▲

Chris Jelenewicz is with the Society of Fire Protection Engineers.

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Challenges Facing Engineered Structural Fire Safety

Figure 1. Glass/Steel Bridge, Seattle City Hall.

A Code Official's Perspective

By Jonathan C. Siu, P.E., S.E.

INTRODUCTION

In 1973, construction was completed on two high-rise office buildings – the 62-story First Interstate Bank building in Los Angeles, CA, and the 38-story One Meridian Plaza building in Philadelphia, PA. Fifteen years later, on May 4, 1988, a fire destroyed four floors of the First Interstate building after burning for four hours. Nearly three years after that, on February 23, 1991, a fire burning for over 19 hours gutted eight floors of the One Meridian Plaza building. Although the resources of the Los Angeles Fire Department were severely challenged, they were successful in controlling the first fire, and the resultant damage to the structure was very minor.[1] In the One Meridian Plaza fire, the Philadelphia Fire Department was unable to control the fire before the onset of major structural damage.[2] Due to fear of imminent structural collapse, firefighting personnel were pulled out of the building eight hours before an automatic fire sprinkler system finally controlled the fire. Shortly after the 9/11 terrorist attacks in 2001, the World Trade Center 7 building, completed in 1987, became the first modern fire-protected steel high-rise building to collapse due primarily to fire damage.[3] In all three cases, the buildings were built in accordance with the latest prescriptive codes in effect at the time of construction.

After each of these three major fires, the question has been raised whether prescriptive building codes provide adequate protection for the structure. On one hand, it can be argued that the code-required (prescriptive) fire protection for the structure in the first two fires performed adequately, since neither structure collapsed and no loss of life occurred as a result of damage to the structure. In the case of WTC-7, the building only collapsed after seven hours of fire exposure – a much longer time period than might be anticipated, judging by the prescriptive code requirements. This performance was achieved despite the apparent lack of water for sprinklers and the lack of manual suppression activities. On the other hand, of the three buildings, only First Interstate was put back into complete service, and that took several months to accomplish. The economic losses along with the attendant costs to society in all three cases would argue equally that the prescriptive building code requirements are lacking.

The First Interstate and One Meridian Plaza fires eventually resulted in changes being made to the prescriptive codes to require automatic fire sprinkler systems to be installed throughout all new high-rise buildings. Changes to the building codes are currently being discussed in various forums as a result of the WTC-7 collapse. At the same time, the organizations that promulgate building codes are trying to write codes that are more "performance-based" and less prescriptive, to increase design flexibility. Increasingly, analyses and reports from fire protection engineers are being provided to code officials in lieu of traditional fire protection of structures.

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Figure 2. Mesh Structure, Seattle Central Library.

and the increasing sophistication of the analytical tools available to the fire protection engineer, it must be recognized that code officials will ultimately decide what will be permitted for protection of structures. There are many challenges facing the code official (and by extension, the fire protection engineer) before engineered fire protection can become widely accepted. The four example projects below will be used to illustrate how engineered fire protection is being used in lieu of prescriptive code requirements in the city of Seattle, WA, and will also serve as examples of the challenges facing the code official.

EXAMPLES OF ENGINEERED STRUCTURAL FIRE PROTECTION IN SEATTLE

The Department of Planning and Development (DPD) is the agency in the City of Seattle government that administers the building code. The Seattle Building Code (SBC) allows alternate materials and methods to be used in lieu of prescriptive code requirements, on the condition the alternates provide protection equivalent to that required by the code. The four projects discussed below are examples of structures where engineered fire protection was approved by DPD as an alternate for the protection ordinarily required by the code.

1. Glass/Steel Bridge, Seattle City Hall (Figure 1).

Early in 2003, the City of Seattle completed construction of a new City Hall building. One of the more striking architectural features of the new building is a bridge spanning the public lobby space, used as one of the routes connecting the City Council offices to the Council meeting chamber. The bridge floor and rails are constructed of glass panels with steel supports, and the entire structure is stabilized laterally with steel rods. Given the type of construction of the building, the prescriptive provisions of the SBC require any structure supporting floor loads to be protected by three-hour fire-rated construction. For most steel structures, this protection is provided by spray-applied fireproofing. However, that method would have destroyed the architecture of the bridge. Instead, the fire protection engineer was able to demonstrate that an "expected" fire, uncontrolled by sprinklers and placed in the "worst" location, would not raise the temperature of the steel to the point where the bridge would collapse.

2. Mesh Structure, Seattle Central Library (Figure 2).

In the spring of 2004, construction was completed on the new Central Library for the City of Seattle. A steel mesh structure on the outside of the building provides support for the exterior glazing, as well as lateral bracing for the building against earthquakes and wind. In one portion of the building, the mesh structure is canted at an angle such that it also acts as part of the roof framing, transferring vertical loads to the primary frame of the building. The SBC requires secondary roof framing members (those not directly connected to columns) to have a protection rating of two hours, although there are allowances in the code to lessen the protection if the structure is far enough away from potential fire sources. Again, sprayed-on fireproofing was not acceptable to the architect, and given the nature of the mesh structure, sprinkler protection of the structure was impractical. The ultimate resolution was the product of teamwork between the fire protection engineer and the structural engineer. Once the fire protection engineer was able to show how many members of the mesh structure would be expected to fail under fire conditions, the structural engineer was able to demonstrate that the highly redundant structure was capable of transferring the loads around the failed portion. As added protection, the sprinkler system was designed to provide a greater density of water onto the source of fuel (primarily bookshelves) below the canted portion of the mesh structure in order to control any fire before it would endanger the structure.

3. Roof Framing and Walkways, Fred Hutchinson Cancer Research Center Building (Figure 3).

A four-story atrium connects two wings of the recently constructed Fred Hutchinson Cancer Research Center Building. The roof of the atrium is constructed of glass supported by a steel beam grid. Walkways supported by steel beams cross the atrium to connect the wings at each floor level. Midspan support for the walkways and the roof grid is provided by a group of four steel columns. The architectural design called for the roof and the walkway beams to be unprotected, whereas the SBC required them to be protected for two hours (roof) or three hours (walkways).


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The fire protection engineer considered the likely fuel loading in the atrium and was able to demonstrate that the design fire would not damage the structure.

4. Columns, Space Needle (Figure 4).

The Space Needle at the Seattle Center was constructed in the early 1960s as the centerpiece of the 1962 World's Fair and is Seattle's defining landmark. Originally, the only occupied space in the structure was on the restaurant and observation levels in the saucer-shaped structure at the top. The main columns are steel, constructed in a tripod configuration. Each leg of the tripod consists of two steel sections with flanges in excess of 1-1/2 inches (38 mm) thick. In the 1980s, a midlevel restaurant was added and attached to the inside of the tripod structure. In the 1990s, a new retail and ticketing structure was constructed at the ground level, enclosing the base of the tripod. Because the columns were no longer fully open to the atmosphere, DPD was concerned that heat from a fire would build up sufficiently to damage the columns. Although the SBC would have required three-hour rated protection to be provided for the columns, the fire protection engineer demonstrated the columns would not heat up enough to fail under design fire conditions due to their large size.

The common thread running through these four projects is the desire of the architect to leave the steel structure exposed, without code-required (prescriptive) fire protection. In each case, the fire protection engineer was able to demonstrate the structure would not be damaged by a design fire. However, also common to each case, the code official for DPD had to decide what the goals were, what parameters needed to be addressed, and whether the fire protection engineer had adequately addressed the issues.

CHALLENGES FACING THE CODE OFFICIAL

I. The Balancing Act. When a building is built, the main stakeholders are the developer, the designers/architects, the users of the building, and society in general. The code official is placed in the position of balancing the needs of these stakeholders and of managing the impacts and risks associated with the compromises made to maintain that balance.

On the developer's side, while many are interested in more than their bottom line, ultimately, any building, and therefore any solutions to building code issues, must make economic sense to them. In the example of the Central Library's steel mesh, protecting the mesh with a sprinkler system would have been acceptable by the code. However, this solution would not have been economically feasible to the owner/developer (in this case, the City of Seattle) as it would have taken hundreds of extra sprinklers to provide adequate coverage for the structure.

As another stakeholder, in many building designs, the architect is focused on the aesthetics of the space, or the need to make an architectural/artistic "statement." The unprotected structures in all four cases above are expressions of this artistic nature of architecture. Another example is in old, historic buildings where certain architectural features such as large timber beams and columns must remain exposed to preserve the historic character of the building.

The members of the third set of stakeholders, the users of the building, want to be safe. However, the author's experience is, if they are lessees or owners, they are also very concerned with the economics of the building. Many times, the concern to minimize dollar costs of construction overrides safety concerns. In those cases, they are essentially willing to gamble that a fire, an admittedly somewhat rare event, won't happen to them. This is usually less of an issue with new construction but is a larger issue in older, lower-rent, existing buildings.

Finally, society demands life or economic losses in a single event be minimized – buildings must provide some level of life safety for occupants as well as provide property protection.

Figure 3. Roof Framing and Walkways, Fred Hutchinson Cancer Research Center Building.

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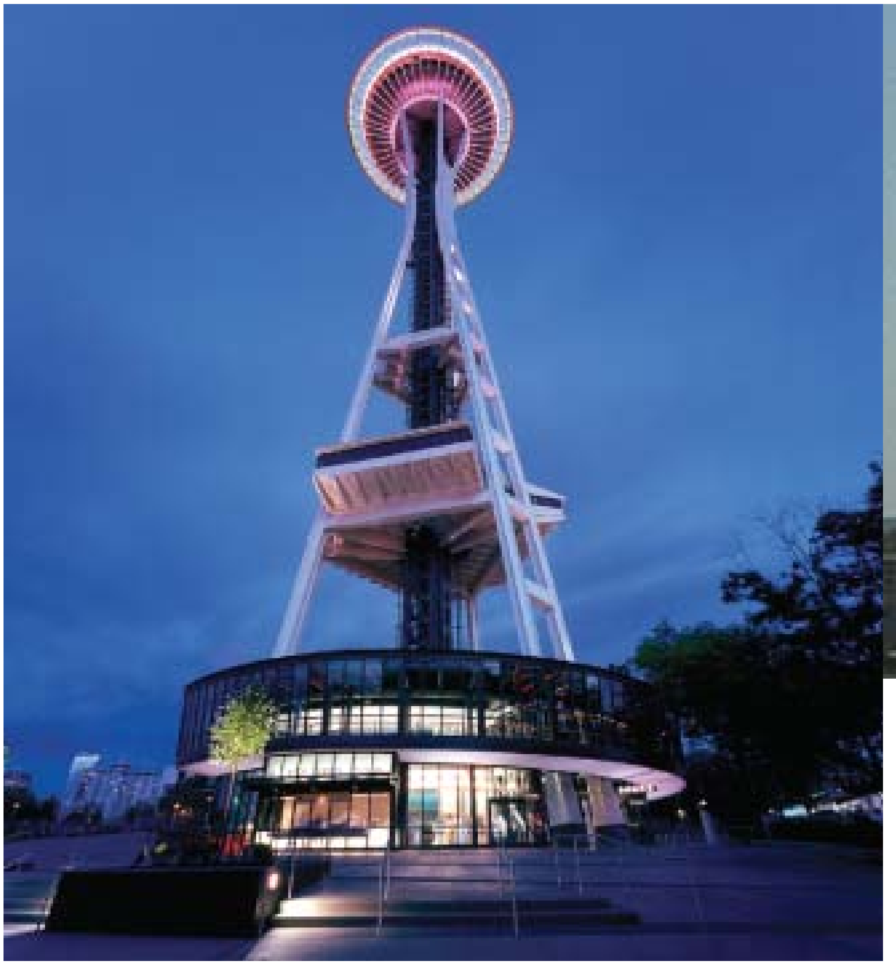

Figure 4. Columns, Space Needle.

(Note that, since the World Trade Center collapses, there has also been a heightened public concern for the safety of emergency responders.) Public outcry does not occur over the many, many deaths in fires in single-family residences each year, but single events with large losses of life, such as the 9/11 terrorist attacks, will generate an outcry. This is recognized in the building codes, which require higher levels of protection for buildings containing large numbers of people. On the economic side, the loss of a large building such as One Meridian Plaza leads to other societal impacts – economic strain on businesses (those formerly housed by the building and those dependent on the business generated by the building), not to mention the cost of demolition and rebuilding. Again, society is willing to endure many small losses but does not tolerate large single losses. On the other hand, similar to the developer's need, society wants solutions to make economic sense. In general, the public is not willing to pay the price for complete safety – such construction would not be attractive or affordable. However, after a large-loss event, there is a danger that societal demands will be used to inappropriately influence (i.e., politicize) changes to codes.

Even though many code officials recognize their role in balancing the stakeholder needs, they also view their main purpose for existence in the construction process as representing the needs of society and the users of the building. Thus, they tend to err on the side of life safety for the occupants of buildings. Fire protection engineering consultants are viewed by many code officials as advocates for the developer or architect, and not necessarily advocates for safety. This lack of trust by the code official is due to many factors that may include:

- *Lack of code official expertise.* Many code officials lack the expertise to properly evaluate engineered fire protection proposals. Because they are not comfortable making the evaluation, they are more likely to depend on the prescriptive codes rather than shifting paradigms, as discussed in the next section.
- *Credibility of the fire protection engineer.* The profession of fire protection engineering is relatively new to most code officials. As a whole, code officials don't know what type of training or other exams a fire protection engineer must take in order to be called an "engineer." Is there a core set of courses a college graduate in fire protection engineering must take, regardless of where he/she goes to school? In some states, there is not a separate professional license for fire protection engineers. Is there a nationally recognized standardized testing program for licensure? Because there isn't the "comfort level" with the fire protection engineering professionals as there is with other design professionals (e.g., architects or structural engineers), the code official is less likely to approve engineered solutions for structural fire protection. In addition, as in any profession, there are those fire protection engineers who are credible, and those who aren't. The code official has to discern whether or not the fire protection engineer is knowledgeable and credible. To establish credibility, the fire protection engineer must be able to explain what the prescriptive code requires, why it's required (what's the intent of the code), and, most importantly,

how their proposal is justified, or how the proposal mitigates the hazards the prescriptive code is trying to address. An engineered fire protection proposal that is not adequately justified is unlikely to inspire code official confidence in the engineer.

Another reason for code official reluctance to deviate from the prescriptive code is the fear of litigation or media exposure. In this author's opinion, this fear is somewhat irrational, as lawsuits involving building code decisions are practically nonexistent. Even so, it is viewed by many code officials (with encouragement from their jurisdiction's attorneys, in many cases) as being a safer course to stay with the strict wording in the code. Additionally, in his/her mind's eye, any failure reflects poorly on the professionalism of the code official, and failures resulting from poor code provisions are easier to live with than failures resulting from risky decisions.

II. The Paradigm Shift. In order for code officials to consider engineered structural fire safety solutions, they must be prepared to consider new methods that are not neatly codified – performance requirements. The prescriptive code requirements are familiar and mostly easy to enforce. Deciding whether performance goals are met requires judgment and the knowledge of the goals. Unfortunately, this shift is difficult for many code officials, as many do not have a professional background that prepares them to make these judgments.

These first two challenges are not under the control of the fire protection engineer. However, there are other challenges that hinder wider acceptance of engineered solutions, even for the professionally trained code officials who are willing to make the paradigm shift.

III. Performance Standards. The code official's first challenge from a technical standpoint (as opposed to philosophical) when presented with a proposal for engineered fire protection is to determine what standards must be met. Attempts are being made in various forums to define performance standards to which buildings can be designed and evaluated. One example is in the *ICC Performance Code for Buildings and Facilities*™, promulgated by the International Code Council.[4] This code sets general standards indicating how occupant lives, property, and firefighters and emergency responders are to be protected. A more specific performance standard for structures in fire is stated as follows:

> "Structural members and assemblies shall have a fire resistance appropriate to their function, the fire load, the predicted fire intensity and duration, the fire hazard, the height and use of the building, the proximity to other properties or structures, and any fire protection features." (§1701.3.11)

Performance requirements relevant to this discussion are stated in the *Building Construction and Safety Code® (NFPA 5000®)* promulgated by the National Fire Protection Association[5] as follows:

> "Buildings shall be designed and constructed to reasonably prevent structural failure under fire conditions for a time sufficient to protect the occupants." (§5.2.2.3)

> "Buildings shall be designed and constructed to reasonably prevent structural failure under fire conditions for a time sufficient to enable firefighters and emergency responders to conduct search and rescue operations." (§5.2.2.3)

While the standards in both these codes are of some help to the code official, they are still vague and don't provide a basis for evaluating or approving a particular proposal. What is "appropriate"? What is "reasonable" prevention of failure? As a result, there is still much left to be decided and negotiated with the fire protection engineer on a particular building.

IV. The Design Event. The most difficult challenge facing the code official is evaluating the design event being proposed. To do this, there are at least three questions that need to be answered:

• *What is the size of the design fire?* For designing exiting systems for building occupants, the prescriptive building codes assume there is one fire burning at a time and it does not fully involve a floor in the building. This may be a reasonable design event for engineered structural fire protection, but in reality, the First Interstate and the One Meridian Plaza fires fully involved floors, and more than one floor was burning at the same time. Preliminary studies of World Trade Center 7 indicate a strong possibility that a larger-than-normal fuel load (a ruptured diesel fuel line for emergency generators) was a contributing factor in the collapse of the building. However, these are extraordinary events and, in the author's opinion, do not represent reasonable design events, especially given the performance standards in the codes. In each of the four examples of engineered fire protection in Seattle, the fire protection engineer assumed a localized fire, with fuel provided by expected furnishings or hazards (books and bookshelves, combustible furniture, retail goods, etc.). None were in an environment that was likely to have high fuel loads.

• *What is the duration of the design fire?* The prescriptive codes require protection for structures ranging from no rating (zero hours) to a rating of three hours, depending on the size and use of the building. (Note that these ratings are based on a standardized fire test and don't necessarily reflect how long the structure would last in a real fire.) Emergency systems are generally required to operate for two hours. The *NFPA 5000*® code says the goal is to "reasonably" avoid structural failure until occupants are evacuated, and search and rescue operations are accomplished. In a large building, evacuation plus search and rescue operations could amount to several hours. In the First Interstate fire, search and rescue operations were not started until the fire was knocked down, nearly four hours after it had started. The design fire durations used to justify the unprotected steel in the Seattle examples were built around the expected fuel load. For example, for the City Hall glass bridge design, the fire protection engineer analyzed the structure for a fire in the adjacent office area and a furniture/kiosk fire immediately below the bridge. The furniture/kiosk fire was determined to be the worst case from the standpoint of heat impingement on the structure. However, the duration of the design fire was less than 10 minutes, since the fuel for the fire was consumed in that time and the heat-released rate of the fire decreased thereafter.

• *What other assumptions are associated with the design event?* While the prescriptive codes generally assume the only protection for structures is the passive protection (e.g., sprayed-on fireproofing or gypsum wallboard enclosures), they do allow fire sprinkler systems to substitute for one hour of required protection. Some fire protection engineers will try to justify performance-based designs by saying fire sprinkler systems will control the fire before it gets hot enough to affect the structure. There is some merit to this idea – if sprinklers are operating properly, then no fire protection is really needed for the structure. However, there is debate among code officials as to how much these active systems should be relied upon. The question is, how subject to failure (human-caused or otherwise) are they? For example, the First Interstate fire started on a floor that could have had operable sprinklers – the problem was construction of the whole system had not quite been completed, so the valves were shut. With this in mind, there is a question as to whether or not it should be assumed that the sprinkler system is operable when engineering fire protection of structures. The *NFPA 5000*® code tries to address this issue by requiring performance-based designs to be analyzed with different elements of the fire protection features (fire-rated doors, fire alarms, sprinklers, etc.) assumed to be ineffective. For the examples in Seattle, DPD required such a "belt-and-suspenders" approach – the design fire was assumed to be burning without being controlled by sprinklers, but the sprinklers were still required in order to further reduce the hazard.

V. Validation of Models. Other hindrances to code official acceptance of engineered structural fire protection are the lack of data to validate the models and assumptions made by the fire protection engineers. Sophisticated programs and modeling techniques are available and can be used by the engineer to calculate, for example, whether or not a certain component of a structure will fail given a specific fire in a specific room configuration. For the glass/steel bridge in Seattle City Hall, the engineer used a computer program to model the spread of heat from the fire source through the open lobby area up to and across the ceiling where the structure is attached. However, the results of engineered structural fire protection have not been tested in real-life situations enough (if at all) to assure the code official the solutions will really work, as opposed to working in a computer program or in a limited, controlled test. The three fires discussed in the introduction are the only major fires in modern high-rise buildings resulting in any kind of structural damage. From an overall societal standpoint, this is good news. However, these fires are not tests of engineered solutions but of the prescriptive code provisions, and so do not contribute to any sort of validation of fire engineering methods. In fact, it can be argued that the prescriptive solutions met the performance goals discussed above – one only collapsed after seven hours of uncontrolled burning, and the other two did not collapse at all despite long fire exposures. Based on the performance of these buildings, many code officials will prefer to rely on the tested prescriptive solutions than on theoretical and unvalidated engineered solutions.

Table 1. Structural Engineering Performance Examples

Issue	Structural Engineering Example
Performance Standard	• Collapse prevention in a major event. Local collapses may occur, but global collapse does not. • Life safety in a moderate event. Building may be heavily damaged, but occupants can evacuate the building. • Light damage in minor event. Limited to cosmetic and minor nonstructural damage only.
Design Event	• Major event: Earthquake with 2% chance of exceedance in 50 years (1-in-2500-year event) • Moderate event: Earthquake with 10% chance of exceedance in 50 years (1-in-450-year event) • Minor event: Earthquake with 50% chance of exceedance in 50 years (1-in-100-year event)
Model Validation	• Tested several times a year around the world by Mother Nature.
Factor of Safety (examples)	• Global overturning: 1.5 • Specific structural components: Varies with materials used for construction. Ranges from 2 to 6 or more.

The lack of data to validate models also means factors of safety are unknown. Structural engineering uses factors of safety ranging from 1-1/2 to 6 to account for uncertainties in loading or material properties. When a fire protection engineer shows the code official a particular beam will not be affected by a particular fire, the code official does not know if there is any sort of safety factor built in to the engineer's analysis to account for uncertainties in the design fire or the structural materials. Even if the engineer does provide a safety factor, there is no standard to guide the code official as to what factor is appropriate.

FURTHER STUDY

In this author's view, the challenges discussed above must be addressed before research on specific issues will be useful. Without the standards, research provides data but not information to the code official. Once the code official is willing to use his/her judgment, he/she needs a standard basis on which to manage the risk of his/her decisions. As a possible model for engineered structural fire safety, Table 1 has some examples that may be used in seismic design by structural engineers that attempt to address these same challenges.

Notice that in Table 1 there are several levels of performance standards depending on the design event, and even the most extreme design, while based on a remote event, is not based on the largest, worst-case event. This is a concept this author has not seen in the engineered structural fire safety proposals presented to the City of Seattle. Instead, in the cases where engineered fire protection have been proposed to the City, it is the code official that makes the judgment as to whether or not the fire protection engineer has proposed a “reasonable worst-case scenario.” With no standards upon which to base a different requirement, this author ultimately elected to rely on the fire protection engineer's professional judgment for the proposed design cases for the four example projects described in this article.

Once the code officials and fire protection engineers can come to an agreement as to the appropriate standards, design events, models, and factors of safety, then there will be two areas of research that would have been helpful in evaluating the proposals in the four examples above:

1. *Effectiveness of fire sprinkler system protection of structures.* As discussed in the challenges above, sprinklers are a primary component in any engineered structural fire safety design presented to DPD. Usually, they end up as adding some extra safety factor as part of the “belt-and-suspenders” approach. However, a preliminary request was made on the Fred Hutchinson building to use sprinklers to “wet” the columns supporting the stairs, walkways, and roof in the atrium in lieu of providing code-required, three-hour-rated protection. DPD raised many objections to this concept, and, ultimately, the architect provided an approved intumescent paint for protection, hidden by some architectural finishes. However, for the expected fuel load in the atrium, it is probable the sprinklers would have been adequate. There is a question, though, how far this concept can be pushed. Further research is also required on the reliability of sprinkler systems if they are to be used as the sole source of protection of structures.

2. *Validation of computer models of heat release/spread.* DPD approved the Seattle City Hall glass bridge on the basis of such a model, as discussed above, and similar models have been used to justify other engineered fire safety designs (not necessarily structural). ▲

Jonathan Siu is with the Seattle Department of Planning and Development.

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The Mosquito and the Picket Fence

A Modern-Day Fire Alarm Fable About Broadband versus Narrowband Signaling

Take a moment to relax and imagine you're in a hotel near Disney World® trying to take a nap after a long day of fun.

The air conditioning is humming away at 55 dBA just like NFPA 72 says it will, and every three minutes, you're reminded that you're just a short distance from the airport. Just as a jet is taking off and rattling the water glass on the night stand, you hear the buzzing of a mosquito and instinctively swat your ear.

You marvel at the greatness of natural selection and wonder why you were able to hear that mosquito over all the other noises.

Why, in some high-noise environments, can the fire alarm system be clearly heard, yet a sound pressure level meter fails to show any increase when the system is tested and the sound level is measured? In this article, the mosquito and the picket fence are analogies used to show how sound and noise are more complex than the simplified, broadband approaches of most codes.

The article will review the fundamentals of sound and hearing, and show how most codes simplify the process of alarm signal analysis and design. By using a more fundamental design-and-analysis approach, now permitted by NFPA 72,[1] it will be shown that by using the concept of "narrowband signaling," systems can be designed to be more effective and less expensive than conventional installations. Finally, some advantages and disadvantages of narrowband signaling are addressed.

The article is divided into two parts and will be continued in the next issue.

FUNDAMENTALS

Sound consists of longitudinal pressure waves. At any point in space, as sound waves pass by, the pressure increases above normal, then goes back to normal, then below normal, before returning to normal to start all over again. See Figure 1. Sound waves have:

- Amplitude – the magnitude of the pressure change, perceived as loudness.
- Speed – which is dependent on the medium, such as air.
- Frequency – cycles per second, perceived as pitch.

Amplitude and frequency are two variable properties that affect the perception of noise and fire alarm signals. A piano is great example of different

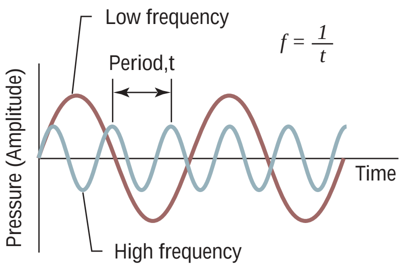

Figure 1. Sound Waves.

pitches or frequencies. The lowest note on an 88-key piano is bass-A, which has a fundamental frequency of about 27 Hz (Hertz = cycles per second). The highest key is high-C at about 4,186 Hz. Middle-C is at about 261 Hz. The range of "normal," or average, human hearing is approximately 20 - 20,000 Hz. Below 20 Hz, the sound may felt by the body rather than heard by the ear.

There is a limit to the resolution of human hearing. The ear is not likely to perceive a difference between 1500 Hz and 1501 Hz. Also, the human brain tends to recognize relative relationships, not absolute values.[2] That is, people perceive the ratio (division) of two frequencies, not their difference (subtraction).

Preferred Frequencies	1 Octave	1/2 Octave	1/3 Octave	Preferred Frequencies	1 Octave	1/2 Octave	1/3 Octave	Preferred Frequencies	1 Octave	1/2 Octave	1/3 Octave
16	■	■	■	160			■	1600			■
18				180		■		1800			
20			■	200			■	**2000**	■	■	■
22.4		■		224				2240			
25			■	**250**	■	■	■	2500			■
28				280				2800		■	
31.5	■	■	■	315			■	3150			■
35.5				355		■		3550			
40			■	400			■	**4000**	■	■	■
45		■		450				4500			
50			■	**500**	■	■	■	5000			■
56				560				5600		■	
63	■	■	■	630			■	6300			■
71				710		■		7100			
80			■	800			■	**8000**	■	■	■
90		■		900				9000			
100			■	**1000**	■	■	■	10000			■
112				1120				11200		■	
125	■	■	■	1250			■	12500			■
140				1400		■		14000			
160			■	1600			■	**16000**	■	■	■

Table 1. Preferred Center Frequencies.[5]

Perception of many senses, not just aural, tends to be logarithmic. In the case of sound, cognitive perception is such that the doubling or halving of frequencies is recognized. That is, the same relative change in pitch going from 100 Hz to 200 Hz or from 2,000 Hz to 4,000 Hz is perceived similarly. So, to better model human hearing and perception of pitch, ranges of frequencies are lumped into intervals, or bands.[3] From this, the definition of "octave-band" arises. An octave is a frequency range where the ending frequency is double the frequency of the starting frequency.[4]

$$f_2 = 2f_1 \quad \text{or} \quad \frac{f_2}{f_1} = 2^n$$

where n=1 for one octave, 1/3 to define a 1/3-octave bandwidth, etc.

While the doubling (or halving) is natural to the human ear, smaller intervals can be perceived. For example, there are definitions for 1/3, 1/6, and 1/12 octave bands. Further standardization is accomplished by the use of "preferred" frequency bands, where the center frequency is defined as listed in Table 1.

The range of pressure amplitude (loudness) that the human ear responds to is quite large. The average ear detects a minimum pressure fluctuation of approximately 2×10^{-5} Pa (Pascals). Pain occurs at about 60 Pa. Because of this large range, the acoustics industry uses the Bel and the decibel as the units of measure. A Bel is defined as the log to the base 10 of a power ratio. For sound pressure, the ratio used is the ratio of the sound pressure to a reference pressure level, in this case, the threshold of hearing, 2×10^{-5} Pa. Since power is proportional to the square of pressure, the Bel and decibel (dB) for sound pressure level (SPL or L_p) are defined as:

$$\text{Bel:} \quad \log_{10}\left(\frac{P}{P_0}\right)^2 = 1.0$$

$$\text{Decibel:} \quad \log_{10}\left(\frac{P}{P_0}\right)^2 = 0.1$$

or

$$L_P = 20 \ \log_{10}\left(\frac{P}{2x10^{-5}}\right) \quad \text{dB}$$

NOISE ANALYSIS

Most sound that the human ear encounters (noise, music, speech, etc.) has many different frequencies, not just one or two. Figure 2 shows the 1/3-octave band distribution of sound that might be found in a certain industrial occupancy.

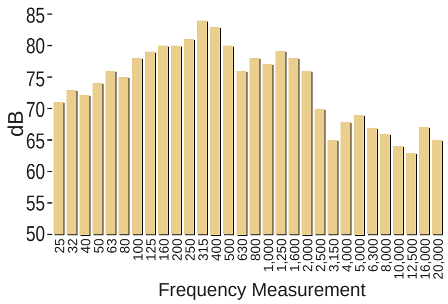

Figure 2. Sample Noise Measurement.

In Figure 2, the sound pressure level (SPL) is higher in certain bands. For example, the peak SPL occurs in the 315 Hz band ($L_{p\,315}$ = 84 dB). The lowest is $L_{p\,12,500}$ = 63 dB. The total sound pressure level is calculated by logarithmically adding the individual components.

$$L_P = 10\log_{10}\left[10^{(L_{P1}/10)} + 10^{(L_{P2}/10)} + \ldots\right]$$

Since sounds can be composed of many different frequencies, early in the last century, researchers wanted to know more about which ones are important to human hearing and which frequency bands are necessary for intelligible communication so that they could build reliable telephone and radio communication systems. One result was an understanding of the perceived variation of loudness as a function of frequency.

No two ears and hearing systems are the same. However, when a sufficient number of test subjects are evaluated, an "average" hearing pattern emerges. Figure 3 shows equal loudness curves for the human ear.[6, 7]

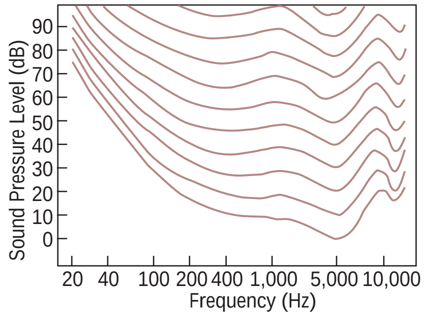

Figure 3. Equal Loudness Curves.

These are subjective equal loudness curves for average human hearing and show how "average" people perceive the loudness of different sounds. For example, a 100 Hz sound would have to be about 45 dB to be perceived to be as loud as a 30 dB 5000 Hz sound. So, whenever a sound pressure level is reported, the frequency must also be reported in order to understand the perceived loudness. These curves represent "normal" hearing. In the second part of this article, hearing deficiencies will be discussed.

It is possible to have two different noise distribution diagrams such as Figure 2, where the total sound pressure level, logarithmically added for all the bands, is the same. Yet one might have most of the noise in lower bands, while the second might have more high-frequency noise. Even though both have the same total SPL, the second would be perceived as being louder. For general noise analysis, including fire alarm signal measurements, it is helpful to "weight" the different frequency bands to adjust for how the human ear perceives the loudness. Table 2 and Figure 4 are the definition of the internationally accepted A-Weighting curve.[8, 9, 10, 11]

Center Frequency (Hz)	A-Weighted Correction
25	-44.7
32	-39.4
40	-34.6
50	-30.2
63	-26.2
80	-22.5
100	-19.1
125	-16.1
160	-13.4
200	-10.9
250	-8.6
315	-6.6
400	-4.8
500	-3.2
630	-1.9
800	-0.8
1,000	0.0
1,250	0.6
1,600	1.0
2,000	1.2
2,500	1.3
3,150	1.2
4,000	1.0
5,000	0.5
6,300	-0.1
8,000	-1.1
10,000	-2.5
12,500	-4.3
16,000	-6.6
20,000	-9.3

Table 2. A-Weighting Factors.

Center Frequency (Hz)	dB	dBA
25	71	26.3
32	73	33.6
40	72	37.4
50	74	43.8
63	76	49.8
80	75	52.5
100	78	58.9
125	79	62.9
160	80	66.6
200	80	69.1
250	81	72.4
315	84	77.4
400	83	78.2
500	80	76.8
630	76	74.1
800	78	77.2
1,000	77	77.0
1,250	79	79.6
1,600	78	79.0
2,000	76	77.2
2,500	70	71.3
3,150	65	66.2
4,000	68	69.0
5,000	69	69.5
6,300	67	66.9
8,000	66	64.9
10,000	64	61.5
12,500	63	58.7
16,000	67	60.4
20,000	65	55.7
L_P=	92	
L_A=		88

Table 3. Compressor Room Noise.

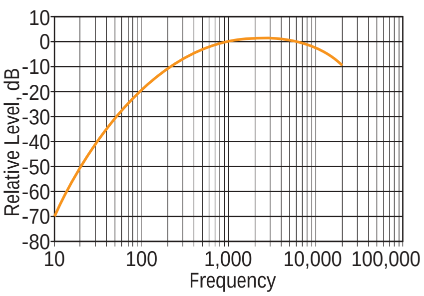

Figure 4. A-Weighting Curve.

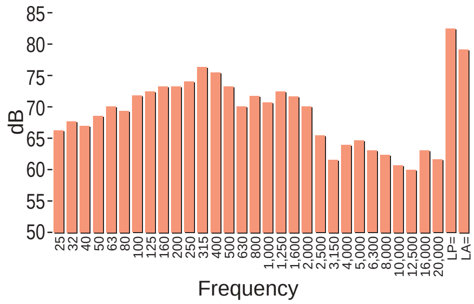

Figure 5. Compressor Room Noise.

So, for example, if a sound is measured as 80 dB at 100 Hz, it can be reported as 80 - 19.1 = 61 dBA. Figure 5 shows the same data as Figure 1 with two additional bars added – the total SPL, L_p, and the total A-weighted SPL, L_A. The 1/3-octave band data are listed in Table 3.

BROADBAND, A-WEIGHTED FIRE ALARM SIGNAL GOALS

Most building and fire codes simply require that the total dBA of a fire alarm signal be some amount louder than the total dBA of the background noise. These codes generally refer to NFPA 72 for the specific requirements. This is called "broadband" because both the noise and the signal are measured over a wide range of frequencies – even if the noise or the signal itself is confined to a more narrowband width.

NFPA 72 has audibility requirements that depend on the type of "operating mode."[12] In the public operating mode, the fire alarm must produce a signal that is "at least 15 dB above the average ambient sound level or 5 dB above the maximum sound level having a duration of at least 60 seconds, whichever is greater, measured 1.5 m (5 ft) above the floor in the occupiable area, using the A-weighted scale (dBA)." By definition, the average ambient sound level is measured over the period of time that any person is present, or a 24-hour period, whichever time period is the lesser. In the private operating mode, the 24-hour requirement would be reduced to a signal-to-noise ratio of 10 dB rather than the 15 dB required for the public mode. (Note that an absolute value is given as dBA, while the difference between two dBA measurements is given as dB.) A minimum 75 dBA would be required by NFPA 72 at the pillow in any sleeping occupancy.

The correct symbology for an A-weighted sound pressure level measured over some time period, *t*, would be $L_{Aeq,\,t}$ where "eq" indicates that it is an average or equivalent value over the time period *t*.[13] For a 24-hour average, the symbol would be $L_{Aeq,\,24}$. Where the noise is measured over a specific period of time, such 6:00 AM to 6:00 PM, *t* could be replaced with "12" if the time period is adequately documented elsewhere ($L_{Aeq,\,12}$). Or *t* could be replaced with an indicator of the period, such as 06-18 ($L_{Aeq,\,06\text{-}18}$).

If the data in Table 4 were the peak values for the occupied period, the fire alarm would be required by NFPA 72 to produce 93 dBA (88 dBA + 5 dB).

NARROWBAND SIGNAL ANALYSIS

Why can someone hear a mosquito over the combined drone of an air conditioner and a jet taking off? There are two basic reasons. First, the mosquito was sitting on a picket fence and second, it was closer than the sources of the other noises.

To say that everyone must wear a life preserver because the surface of the earth is 75% covered by water ignores the fact that 25% of the earth is dry. To see one tree, it is not necessary to look at the entire forest. To see what's behind a picket fence, someone doesn't need to see over the whole fence, just one picket.

Figure 6. Narrowband Signaling.

To hear a fire alarm signal above the background noise, it doesn't have to be louder than all the component frequencies added together – just one. See Figure 6. As long as one of the alarm signal's frequency bands (pickets) is taller than the corresponding noise picket, the signal will be heard, even if the total broadband sound pressure level of the noise is greater than the total broadband sound pressure level of the signal. (There is an additional effect called masking, where one picket affects the size of the adjacent picket. This will be addressed in the second part of this article.)

Frequency penetration alone is not the entire answer. After all, the projection of a four-meter-high fence can hide a taller object when someone is standing right in front of it. As the rear fence in Figure 6 is moved further back, the front fence will hide more and more of the rear fence until it is no longer visible.

So, the codes permit broadband and narrowband noise and signal analysis. If narrowband analysis is used, the signal must penetrate at least one of the noise frequency bands. And it must penetrate by a certain code-specified minimum signal-to-noise ratio.

In the second part of this article in the Spring 2005 issue, the concept of "masking" will be introduced to show how noise in one frequency band can mask or cast a shadow on a signal in an adjacent frequency band. Also, the different code-specified minimum signal-to-noise ratios for broadband versus octave or 1/3-octave band signaling will be discussed. Examples will show how to effectively use narrowband analysis and signal design. Finally, the advantages of broadband and narrowband signaling, and some key pitfalls will be addressed.

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Setting Standards for Excellence

Editor's Note – About This Article

This is a continuing series of articles that is supported by the National Electrical Manufacturer's Association (NEMA), Signaling Protection and Communications Section, and is intended to provide fire alarm industry-related information to members of the fire protection engineering profession.

Resources

SFPE Spring Professional Development Week

March 14-17, 2005

Wyndham Orlando Resort, Orlando, FL

Monday, March 14	Tuesday, March 15	Wednesday, March 16	Thursday, March 17
A Code Official's Guide to Performance-Based Design Review			
Principles of Fire Protection Engineering			
Sprinkler Design for Engineers			
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Continued on page 56

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Qualified applicants should be registered professional engineers and should have fire protection and fire sprinkler design experience. Risk management, insurance loss prevention consulting experience is highly regarded.

Wiginton Fire Protection Engineering offers competitive salaries and benefit packages. Please submit résumé and salary history to:

Ernesto Rodriguez, P.E.
Wiginton Fire Protection Engineering, Inc.
10050 NW 116th Way, Suite 16
Medley, FL 33178
Tel: 305/888-2402 ext. 209 Fax: 305/888-3804 E-mail: exr@wiginton.net

City of Fort Lauderdale, FL – Fire Prevention Engineer

$53,518.40-$75,628.80 + benefit package. Reviews building plans and specs, inspects buildings under construction and existing buildings and ensures compliance with applicable national, state and local laws, ordinances and standards for life/safety. BS in fire protection, or other appropriate engineering field. FL PE required (out of state converted in 1 yr.) plus 5 yrs. exp. as a PE related to fire/life safety of buildings and structures.

Access required application/information www.fortlauderdale.gov.

Apply by January 28, 2005

SFPE Resources

UPCOMING EVENTS

October 6-10, 2005

Fourth Mediterranean Combustion Symposium
Lisbon, Portugal
Info: contact Federico Beretta, beretta@irc.cnr.it

October 17-21, 2005

SFPE Annual Meeting and Professional Development Conference
San Diego, CA
Info: www.sfpe.org

November 2-4, 2005

Fire Safety – Sea Road Rail International Conference
Melbourne, Australia
Info: www.rocarm.com/FSAS05CFP.htm
e-mail: conference@rocarm.com

Fire Protection Engineering

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SCHIRMER ENGINEERING CORPORATION

University of Maryland Now Offers Online Graduate Courses

University of Maryland
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College Park, MD 20740
www.onlinestudies.umd.edu/fire4

Engineers wishing to enhance their knowledge of fire protection engineering will be able to take individual courses completely online from the University of Maryland this spring.

Two graduate-level courses will be offered by the university's Department of Fire Protection Engineering beginning March 7. Smoke Detection and Management covers smoke analysis and response analysis of smoke detectors. The three-credit course is taught by University of Maryland faculty member Jim Milke. Advanced Fire Suppression, also a three-credit course, is taught by Maryland faculty member Fred Mowrer. It focuses on methods of flame extinction, including foam and sprinkler systems, among others.

To be responsive to the needs of working engineers, students have the option of enrolling in individual courses for professional development purposes without being admitted to the online Master of Engineering in Fire Protection degree program. Qualified students may wish to continue their studies and earn the full master's degree. Credits earned by satisfactorily completing online courses may be applied toward the degree.

Courses offer Web-based chat rooms, threaded discussions, and e-mail. Online students also benefit from online admission and registration as well as full technical support and access to the university's rich library resources.

February 21, 2005, is the deadline for submission of a completed application.

BRAINTEASER

Yahtzee® is a game played with five 6-sided dice. Players take turns rolling the dice, trying to get certain combinations of 1s, 2s, 3s, etc. Players may roll the dice up to three times during each turn and are permitted to set aside any subset of the five dice after each roll.

After the second roll, a player has the following combination of dice: 1, 2, 3, 6, 6. If the player keeps the two 6s, what is the probability of obtaining a "full house" (three of one number and two of another) on the third and final roll?

Solution to last issue's brainteaser

A player rolls the following combination on the first roll: 2, 2, 3, 4, 5. If the player keeps the 2, 3, 4, and 5, what is the probability of obtaining a "large straight" (the numbers of all five dice fall in a consecutive sequence) in the two remaining rolls?

To obtain a "large straight," the player must have one of the following combinations of dice: 1, 2, 3, 4, 5 or 2, 3, 4, 5, 6. Therefore, the player must roll either a 1 or a 6 on either the second or the third roll. The probability of rolling either a 1 or a 6 on the second roll is 2/6. If the player does not roll either a 1 or a 6 on the second roll (probability = 4/6), the probability is 2/6 of rolling either a 1 or a 6 on the third roll. Therefore, the probability of completing a large straight on either the second or third roll is:

$$\frac{2}{6}+\frac{4}{6}\times\frac{2}{6}=\frac{20}{36}=0.56$$

Index of Advertisers

Spreading the Word

Morgan J. Hurley, P.E.
Technical Director
Society of Fire Protection Engineers

How do you respond when a friend or family member who is not familiar with the fire protection engineering profession asks you what you do for a living? If you answer by saying that you are a fire protection engineer, the friend or family member will probably not know what fire protection engineers do, or may infer a fire-related profession that has nothing to do with engineering. Perhaps you simply answer by saying that you are an engineer, preferring not to invest the time to educate someone about fire protection engineering. This type of scenario is fairly common for all fire protection engineers.

Fire protection engineering is a small profession; the number of fire protection engineers worldwide is on the order of 10,000. Despite the relatively small number of practitioners, the results of fire protection engineering work impacts almost all members of society. However, fire protection engineering has been described as a "best-kept secret."

The relative anonymity of fire protection engineering extends across society. While average members of society are typically not aware of fire protection engineering, many allied professionals, such as architects and engineers in disciplines other than fire protection engineering, also do not understand what fire protection engineers do.

The fact that fire protection engineering is not well understood by a large proportion of society is partially responsible for many of the challenges faced by the fire protection engineering profession. For example, a potential employer or client would likely not be inclined to use a fire protection engineer if the potential employer or client did not understand the value of fire protection engineering. Similarly, people who are looking for a technically based career would likely not choose fire protection engineering if they were unfamiliar with the profession.

Recently, the Society of Fire Protection Engineers has begun to invest resources to counter the anonymity of the fire protection engineering profession. A public relations committee was formed, which developed a series of long-term goals for the society. A staff member, with primary responsibility for SFPE's public awareness activities, was hired. Additionally, a public relations consultant was retained, and senior volunteers and staff were provided with training on speaking effectively with the media.

One facet of SFPE's public relations strategy was the development of "messages" in support of SFPE's goals. These "messages" are targeted at specific segments of the community, such as allied professionals, enforcement officials, or members of the general public. During the development of these messages, SFPE's media consultant pointed out that fire protection engineers, like most technically based professionals, tend to focus so much on the precision and accuracy of their language that what they say is generally not understood by nontechnical people. Because of this, the messages were developed to be as easily understood as possible by the target audience.

One of the goals developed by SFPE's public relations committee is oriented at educating the general public about fire protection engineering. Specifically, SFPE has set a goal that by 2014, adults will equate fire with life-threatening risk and know that fire protection engineers work to provide solutions to mitigate those risks. The following messages were developed to help members of the public understand fire protection engineering and how it benefits them:

- Fire protection engineers use science to make our world safe from fire.
- Fire is a big problem. Specifically, each year in the U.S.[1], more than 3,000 people die from fire; and on average, there is a civilian fire death every 156 minutes.
- Fire protection engineers design ways to protect people from fire.

SFPE's second goal is to increase the number of qualified fire protection engineers by a factor of four by the year 2014. The following messages were developed to help would-be fire protection engineers understand why fire protection engineering is a great profession:

- Fire protection engineers use science and technology to make our world safe from fire.
- Fire protection engineers are in high demand. The number of jobs consistently outweighs the number of engineers available to fill them.
- A career in fire protection engineering pays well, provides an opportunity for world travel, and gives the opportunity to work in a variety of work environments.
- Fire protection engineers make the world a better place.

Broad use of these messages will help achieve SFPE's goals. Fire protection engineers can use these messages in various ways, for example, by seeking out opportunities to talk about fire protection engineering with family, friends, colleagues, and, when possible, the media. Increasing the awareness of fire protection engineering will help alleviate the challenges faced by the profession.

1 National Fire Protection Association. Fire Loss in the United States During 2002.

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