

# FIRE PROTECTION Engineering

SPRING 2002

Issue No. 14

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# Keys to a Good Working Relationship between Code Officials and Fire Protection Engineers

By **Beth A. Tubbs, P.E.**

It is probably fair to say that, as far as engineering disciplines go, fire protection engineering has traditionally tended to have a strong reliance on prescriptive building and fire codes. This results in a higher level of interaction with code officials than other engineering disciplines often experience. Other disciplines, such as structural or mechanical engineering, tend to work most often with design guides and standards, which, at most, are referenced in the building and fire codes. Fire protection engineers, on the other hand, find that many of their issues are embodied within the prescriptive building and fire codes and referenced standards. Examples include smoke control, means of egress, interior finishes, fire-resistive construction, and active fire protection systems. Therefore, contact with a building or fire official has been a common experience.

In recent years, knowledge of fire behavior has increased, resulting in the creation of more engineering tools and methods for design and analysis. These tools and methods are used in analysis to justify code equivalent approaches in areas such as means of egress and structural performance. The increase in knowledge in fire protection engineering has also led to code revisions to be made more technically correct. A good example of such advancements would be the smoke control provisions. In the past, the code simply mandated six air changes per hour. This was a more simplistic approach that was easier for design and approval, but did not adequately address the hazards of smoke. Now, the current code has a series of equations and assumptions that must be accounted for to result in an acceptable design. This approach, though more technically correct, is also more complex, resulting in a more difficult review and approval process. The use of these tools and application of more advanced technical approaches increases the level of interaction necessary with the code official, and the use of such approaches will frequently raise the discomfort level of the code official. Code compliance, in many cases,

can no longer be demonstrated through a simple plan review. Most jurisdictions will not have the expertise in house to address these types of analysis. Therefore, the relationship with the code official is even more important.

Fire protection engineers and code officials have differing perspectives and responsibilities. The code official is charged with ensuring that the public receives the level of safety from buildings that is specified by statute. The term "code official" is a generic term that embodies the building and fire officials, who also have different perspectives. For instance, the fire official may be more in tune with the needs of the emergency responders than the building official. Fire protection engineers, on the other hand, are responsible for providing an adequate level of safety and for satisfying the needs of the client. The client is typically a building owner or architect.

From a fire protection engineering perspective, keys to a good relationship center upon communication, trust, teamwork, and sound technical judgment. The fire protection engineer should recognize the need to include the code official as early in a project as possible. This includes both the building and fire department (prevention and suppression). This early interaction enables the fire protection engineer to better understand the concerns of the code official. Likewise, the code official can provide feedback during the conceptual stages to avoid difficult situations, such as where the client and engineer agree on a design approach but approval cannot be obtained or costly changes are required to obtain approval. This also gives the code official more time to assess the needs for review and whether a third-party reviewer or peer reviewer may be necessary. Understanding these needs often results in a team approach where the objectives and goals for a project are set with all relative players involved. This provides some confidence to the code official that the objectives and goals are somewhat stable throughout the project. This is the stage of the project where acceptance criteria should be established.

Once the conceptual aspects of a design are agreed upon, the actual design

work occurs. The code official or designated reviewer then reviews the design. To ensure a smooth process, the fire engineer should clearly present all design and construction documents. This means describing which engineering tools, methods, or standards were used and why. Calculations and relevant references should be provided. If a computer model is used, justification for the use of a particular model is necessary. The construction documents should provide enough detail to ensure that the building or system will be constructed as designed. The fire protection engineer should ensure when designing a building that the maintenance and general reliability of the systems chosen are appropriate. This means understanding: first, the abilities of the local fire department to ensure maintenance over time; second, the abilities of the local contractor community to maintain the systems; and third, to suggest or guide the owner as much as possible in creating the necessary policies and procedures for maintaining these systems and the integrity of the overall agreement.

Once the design and construction documents are approved, construction begins. Ideally the fire protection engineer of record should ensure that the building and relative systems are constructed and installed per the construction documents. Unfortunately, this is often the stage where the fire protection engineer is no longer involved. There are, however, some code requirements which would require at least special inspections and testing for systems such as smoke control and active fire protection systems.

The above discussion applies to any fire protection-related project that addresses a regulatory issue whether prescriptive or performance-based. The level of involvement with the code official will vary with the complexity of the project, but this relationship is always important. More guidance on required documentation and on the design process in general can be found in the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*.

*Beth Tubbs is with the International Conference of Building Officials.*



Once again, I want to congratulate SFPE for the wide range of quality articles presented in *Fire Protection Engineering*. "Fire Protection for the Offshore Industry" and "Lessons Learned from a Carbon Dioxide System Accident" are the type of articles interesting to most persons in the fire protection industry, even if you are not a graduate Fire Protection Engineer. I urge your Advisory Board to continue this trend.

I especially want to congratulate Morgan Hurley and James Bisker for their work on the carbon dioxide article. It was well presented, and there obviously was quite a bit of thought and research done in preparing the article.

I am concerned, though, that the real message concerning automatic fire suppression system safety was lost in the text of the article. I would like to emphasize several rules that Fire Protection Contractors and owners should follow, with no exception.

1. Never install a total-flooding CO<sub>2</sub> system without a pneumatic time delay (regardless of system size) if personnel can enter the space.
2. Never install a total-flooding CO<sub>2</sub> system without a pressure-operated siren installed in the protected space.
3. Follow all operating procedures and read the manufacturer's operating manual.

4. Always install and interface pressure-operated discharge switches to sound evacuation alarms, in the event of manual actuation.
5. Always ask occupants of the protected area to "leave the room" while systems are being "armed" or "disarmed." We practice this and document this on our field inspection forms due to the "potential liability" of exposing a person to an unwanted discharge, even with "people-safe" clean agents. Injuries can occur as a result of persons being frightened by the discharge noise or pressures.
6. Always mechanically and electrically disarm the cylinder firing mechanism whenever performing service or inspection work on the system. Our technicians never rely on "system discharge bypass switches," as required by *NFPA 72*. In some cases, we have found switches wired incorrectly to electrically disconnect the system solenoid or actuation device.
7. Use a "buddy system" to confirm that the system is "rearmed" (after notifying the owner's representative) prior to leaving the jobsite. Document rearming of the system.

As a contractor, installing automatic special hazard fire suppression systems, I am very concerned that installation of both protected space evacuation alarms and building notification appliances in the protected area can lead to occupant confusion. *NFPA 72* requires fire protection systems to interface to the building system and NFPA notification appliances in the protected space. I have seen installations that have first alarm appliances, second alarm appliances, and building fire alarm appliances in common space. If installed without distinct tones and signage, this setup can lead to occupant confusion.

We always install signs to identify devices, but our local AHJ claims they cannot mandate this practice, since the code is silent on this issue. Currently, I believe there is an *NFPA 72* proposal to require signage to identify "dual-system" smoke detectors in a protected space.

All special hazard systems should only be serviced by qualified, properly trained persons, regardless of whether they are contractor or end-user employees. NICET certification, trade association membership, and manufacturer training certificates are indicators that can be used to determine the competency of service companies. There are inherent dangers with system firing mechanisms that require proper manufacturer training. Death and injury have occurred during system servicing (i.e., weighing and handling of system cylinders) by improperly trained personnel.

Roger Bourgeois, SET, CFPS  
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## ICC Releases Performance Code

FALLS CHURCH, VA – On January 3, 2002, The International Code Council (ICC®) released the ICC Performance Code for Buildings and Facilities® – the first broad-based, stand-alone model performance building code in the U.S. It includes provisions related to structural, fire protection, energy, and plumbing systems, as well as accessibility, emergency responder safety, and hazardous materials issues.

The publication is the result of a five-year development process that included code officials, academia, designers, researchers, and professional associations. It defines the objectives for achieving the intended outcomes regarding occupant safety, property protection, and community welfare, and provides a framework to achieve the defined objectives in terms of tolerable levels of damage and magnitudes of design events (such as fire and natural hazards). Distinctly different from a prescriptive code, it allows the user to systematically achieve various solutions.

This code still allows the use of a prescriptive building code, such as the IBC, as a design solution.

## Shannon Elected President & CEO of NFPA

QUINCY, MA – At its March 6th meeting, the National Fire Protection Association (NFPA) Board of Directors unanimously elected James M. Shannon president and CEO of NFPA, effective June 1, 2002. Shannon will succeed George D. Miller, who will retire after 10 years as president of NFPA.

Shannon has served as NFPA senior vice president and general counsel since 1991, overseeing all legal affairs with additional administrative and real estate responsibilities for properties.

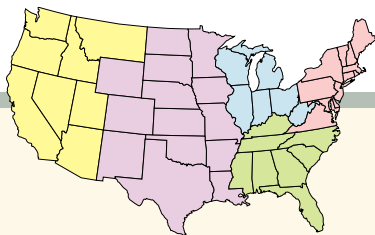
Shannon has had a visible role in the organization's operations and government affairs, both domestically and abroad. Previously, he was elected Attorney General of the Commonwealth of Massachusetts where he pursued numerous policy issues, including a focus

on antitrust. He was also a senior partner in the Boston law firm Hale & Dorr and from 1979 to 1985, and served in the U.S. of Representatives.

## Society of Fire Protection Engineers Launches Redesigned Web Site

BETHESDA, MD – The Society of Fire Protection Engineers (SFPE) has completely redesigned its Web site ([www.sfpe.org](http://www.sfpe.org)). At the redesigned site, you'll find in-depth information about SFPE including a listing of all its chapters, scholarship opportunities, referrals to publications, educational opportunities, technical resources, and more.

The Web site also describes the SFPE Educational and Scientific Foundation, a nonprofit organization founded in 1979 to expand the art and science of fire protection engineering in the public interest.



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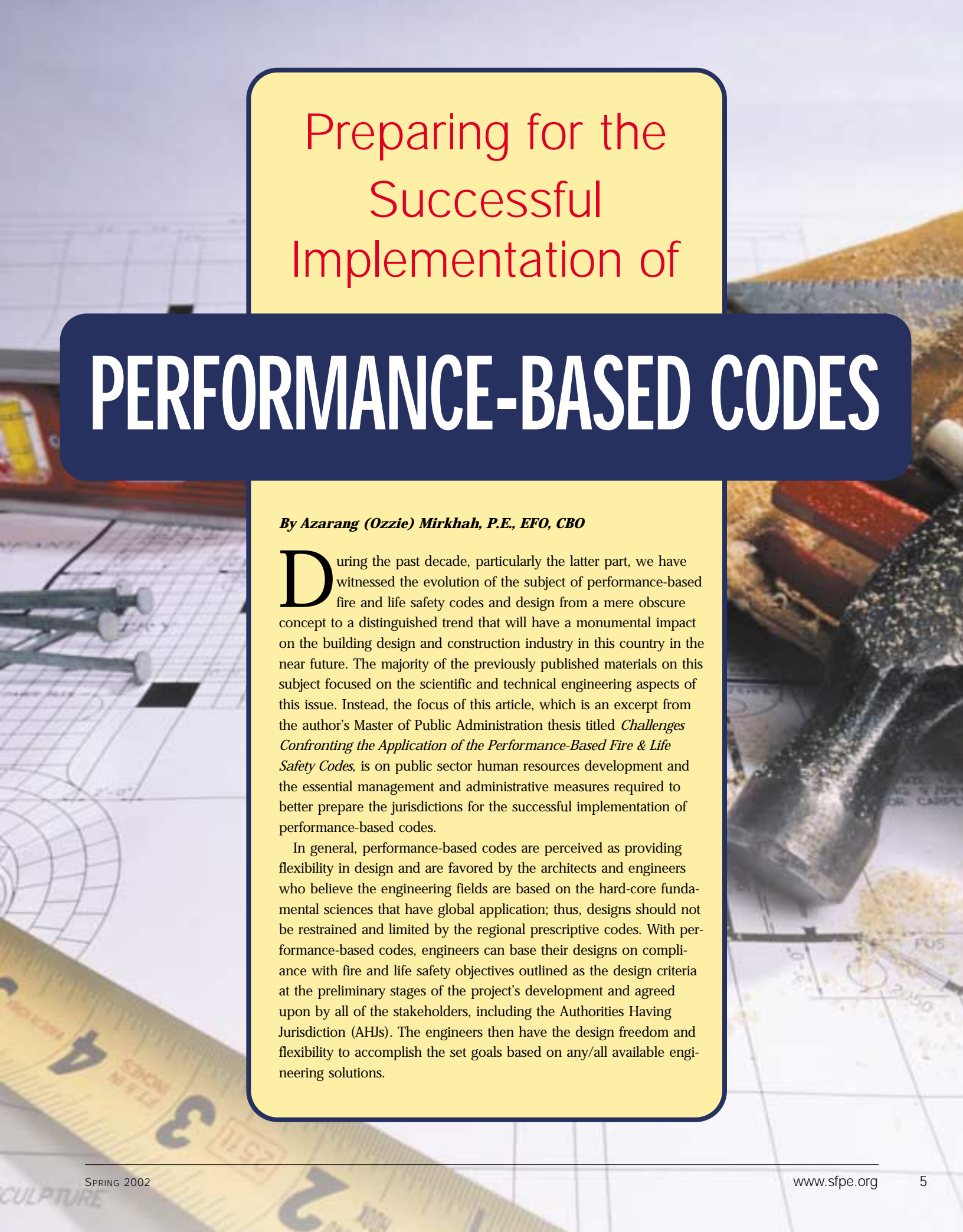
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## Sales Offices FIRE PROTECTION Engineering




## Preparing for the Successful Implementation of

# PERFORMANCE-BASED CODES

**By Azarang (Ozzie) Mirkhah, P.E., EFO, CBO**

**D**uring the past decade, particularly the latter part, we have witnessed the evolution of the subject of performance-based fire and life safety codes and design from a mere obscure concept to a distinguished trend that will have a monumental impact on the building design and construction industry in this country in the near future. The majority of the previously published materials on this subject focused on the scientific and technical engineering aspects of this issue. Instead, the focus of this article, which is an excerpt from the author's Master of Public Administration thesis titled *Challenges Confronting the Application of the Performance-Based Fire & Life Safety Codes*, is on public sector human resources development and the essential management and administrative measures required to better prepare the jurisdictions for the successful implementation of performance-based codes.

In general, performance-based codes are perceived as providing flexibility in design and are favored by the architects and engineers who believe the engineering fields are based on the hard-core fundamental sciences that have global application; thus, designs should not be restrained and limited by the regional prescriptive codes. With performance-based codes, engineers can base their designs on compliance with fire and life safety objectives outlined as the design criteria at the preliminary stages of the project's development and agreed upon by all of the stakeholders, including the Authorities Having Jurisdiction (AHJs). The engineers then have the design freedom and flexibility to accomplish the set goals based on any/all available engineering solutions.



It should be kept in mind that implementing a performance-based code does not mean that all buildings and facilities will be designed and constructed through performance design. A performance code still allows the use of a prescriptive, more traditional method, which is likely to occur in the majority of buildings built under such a system. The difference may be that there could be an increase in performance design simply because the new system provides a better method to undertake a performance-based design than currently exists with the alternative materials-and-methods approach.

Considering that the majority of the AHJs are not engineers by education and are unfamiliar with the tools and methodologies for performance-based design (such as “deterministic hazard analysis,” “probabilistic risk assessment techniques,” “fire dynamics,” and “fire modeling”), how will they be able to develop the design objectives, and evaluate and approve performance-based designs? Clearly, even though adequate for the enforcement of the “cookbook” design approaches outlined in the prescriptive codes, with performance-based codes, the lack of a higher academic engineering education and technical experience will be detrimental. The question then is, “How can the AHJs obtain the necessary technical expertise to enable them to successfully implement and apply performance-based codes?”

In a nutshell, the only timely short-term solution is to bring in the expertise from the outside. The AHJs have two basic choices: (1) hire a staff fire protection engineer (FPE) as their in-house technical expert, or (2) depend on the technical expertise of the fire protection consulting firms in the private sector and obtain their services as

technical consultants. What about the smaller jurisdictions with limited financial resources that cannot afford hiring a staff FPE? For those jurisdictions, a more feasible approach might be to cooperatively divide the financial burden with several jurisdictions and hire a staff FPE to utilize his or her technical expertise. Many fire departments throughout the country have utilized this approach for their fire dispatch and communication centers; they should be able to apply the same concept to their FPE cadre.

Yet another approach could be for a jurisdiction to hire a staff FPE and, by marketing his or her technical services to other jurisdictions, reduce their budgetary impacts by charging for the technical services rendered. Once again, many fire departments have implemented this approach for their service deliveries in specialized responses such as hazardous materials or the utilization of their fire training facilities, so they are not strangers to this concept. Considering that the private-sector concepts of “revenue generating,” “cost recovery,” and “profitability” are still the new fad in the public sector, this revenue-generating venture might be received more favorably by the jurisdiction’s administration.

The other approach that the AHJs could implement for evaluating the fire and life safety systems designed based on the performance-based codes is to rely on the private sector’s technical expertise and out-source this task. Just as they have done in countries such as Australia and New Zealand, AHJs could implement a third-party review system in which the building owner pays a review fee to the AHJ to obtain the services of a private-sector fire protection consulting firm at the time the designs are submitted to the jurisdiction. The AHJs then submit the designs to the private-sector fire protection consulting firm for their review. The problem with this approach is that the review process starts at the design submittal phase of the project and not at the preliminary phase when the design criteria and objectives are established. Identification of the “acceptable risk level” at the preliminary phase of the project is essential and could pose some difficulties for the AHJs if they do not have a staff FPE. That being the case, the most prudent

approach then might be to have a staff FPE on board.

By having an experienced and qualified FPE on their team, AHJs will have the technical expertise to be able to review the design objectives as the criteria for the performance-based designs at the conception phase; evaluate and analyze the computer fire modeling and calculations to determine the integrity of the fire and life safety designs during the plan review and approval phase; and participate in the field testing, final acceptance, and approval during the installation and completion phase of the projects. Active participation of the staff FPE during the entire project cycle, from the conception phase to the completion phase, would provide the concise communication, quality control, consistency, and continuity necessary for the success of the performance-based design projects.

Human resources development is essential in all professional fields. However, the AHJs should realize that it is not possible to expect the entire existing workforce to be adequately trained to perform at the same level as an FPE. For the successful implementation of the performance-based codes, the jurisdictions should educate all their technical cadre to some extent and, in addition to hiring a staff FPE, provide some basic training to enhance the plans examiners’ and the field inspectors’ technical expertise, since they are intimately involved during the construction phase of the projects. Needless to say, training the existing workforce will not have an immediate impact; however, it should be a long-term commitment.

The training and certification process of other technical fields that train the personnel with a high school level of education to function as expert technicians could serve as a valuable model. Paramedic training, for example, is an excellent example. In an emergency life-or-death situation, the quality of medical care delivered by the paramedics in the first few minutes could be even more important to the survival of the patients than the services delivered by the doctors and surgeons at the hospital emergency rooms. By no means do the paramedics have the extensive formal medical education or the expertise that the doctors have. But,

day in and day out in an emergency situation, we all put our lives in the competent hands of those paramedics, and many times they are the ones making the difference between life and death. That being the case, surely in a nonemergency, non-adrenaline-pumping, life-or-death environment, with a systematic training program, the plans examiners and field inspectors could be adequately trained, not to perform as an FPE, but to be of value during the entire design and construction phase of a performance-based design project.

In the paramedics' training program, students are trained to perform highly specialized and technical tasks. The paramedics' program subjects the students to intense scientific, medical, and technical training in order to provide them with adequate expertise to perform first-response emergency medical care. Upon successful completion of the program, graduates are required to complete annual training courses and pass exams in order to maintain their certifications. The example of the paramedics training could serve as a model for the AHJs.

But where is the best place for the AHJs to train and educate their workforce? Since the National Fire Academy (NFA), located at Emmitsburg, MD, has long been the educational Mecca for the fire service in our country, it is the most logical institution to provide this type of technical training. In addition, the NFA's courses are free to attendees, and many costs of attendance are provided in a stipend to state and local governments for their employees, making it the ideal institution to provide an affordable education for the majority of the fire and building officials.

Having the foresight to recognize the importance of this education and the value of this institution, the Society of Fire Protection Engineers (SFPE) and the International Fire Marshals Association (IFMA) worked cooperatively over the past few years with the United States Fire Administration (USFA) and developed a one-day pilot course that was delivered at nine FEMA regions in the summer of 2000. This cooperation has since continued; and with the active participation of the National Fire Protection Association (NFPA), International Code Council (ICC), and the National Institute of Standards and Technology (NIST), a weeklong course is currently under development and scheduled to be delivered at the NFA starting in May 2002.

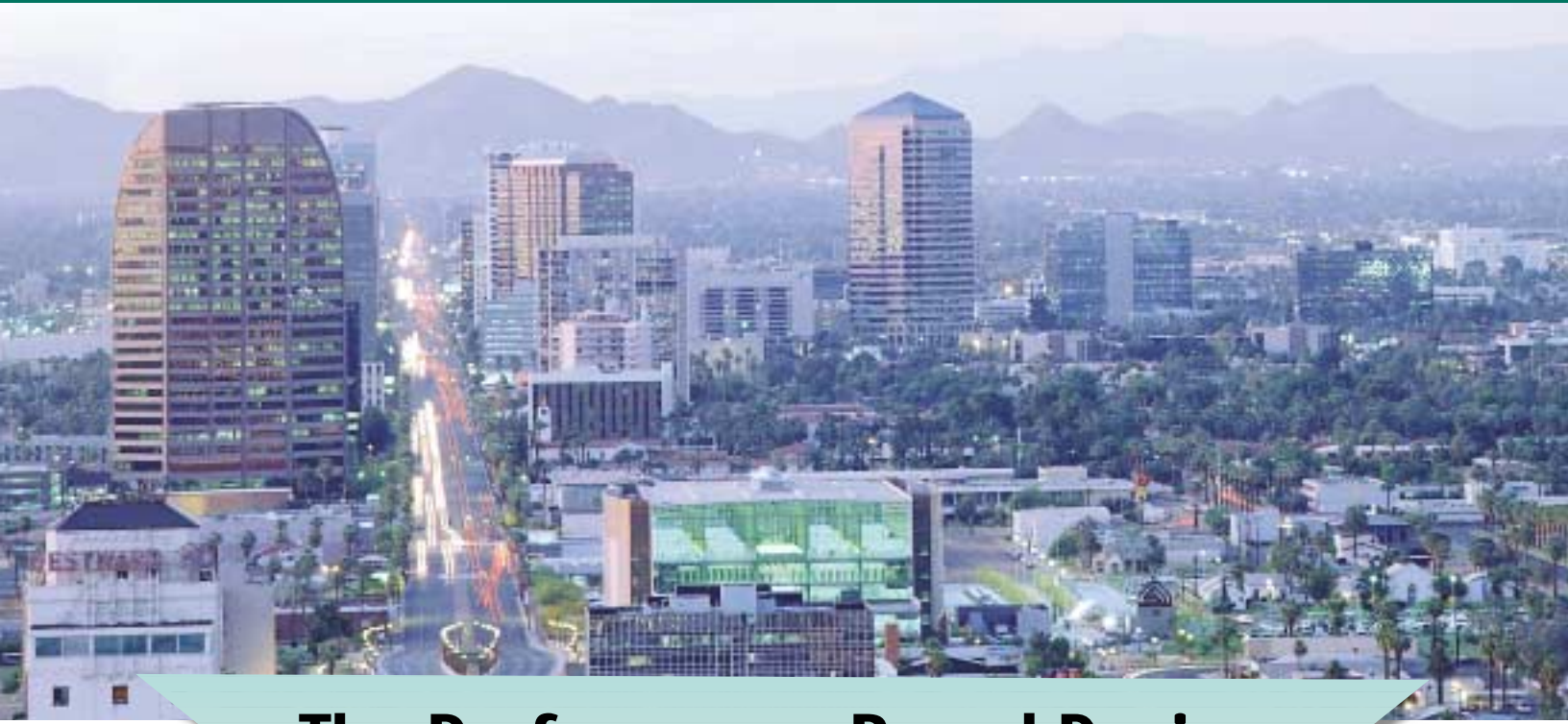
Starting last year, NFA began offering self-study courses through their Web site and the Internet. Considering the close proximity of the NFA to the University of Maryland, SFPE, and NIST, and as a natural evolution of this cooperation, it might not be too far-fetched to visualize training courses developed and offered through the Internet, or maybe even aired on the Fire Emergency Television Network (FETN). At this time, these might be "pie-in-the-sky" plans too far into the future; but for them to materialize, we must first dare to dream. Obviously, thinking "outside the box" is the first step in formulating the future, but it is not enough. We must act outside the confinements of the box and actively pursue creating our own future.

Looking back, we are a lot further along than we were in 1991 when we had the "First Conference on Fire Safety Design in the 21st Century" in Worcester. But we still have a long way to go. The subject of performance-based codes is now on the priority list of many organizations. SFPE has played a monumental role in this transformation. As an organization, however, our most difficult challenges are still ahead

of us. To successfully implement performance-based codes and facilitate performance-based design, we should intensify our focus on adequately training the workforce on all sides – engineers, architects, and AHJs alike.

Why should we invest all this energy on educating AHJs, one might ask? Because, even though an accomplishment, publishing the performance-based codes is only the first step; and there are no guarantees that considering their lack of technical expertise or resources, the jurisdictions will even entertain adopting them. It is important to be cognizant of the fact that, contrary to Australia and New Zealand who have a relatively centralized political structure, our government structure is rather decentralized and fragmented. And since, in our system, the adoption of building and fire safety codes is the responsibility of the state and local jurisdictions, not getting adopted means sitting on the bookshelves collecting dust. So, if we want the performance-based codes to be successfully implemented and not have the same fate as the decades-old concept of "nationwide conversion to the metric measurement system," then enlightenment and education of the AHJs should be at the top of the priority list. Fear of the unknown will be shed under the bright rays of knowledge.

*Ozzie Mirkhah is with the Las Vegas Fire and Rescue in Nevada.*



# The Performance-Based Design Review Process Used in the City of PHOENIX

*By Joe McElvaney, P.E.*

**M**ost model construction codes in the United States allow the use of the concept of alternate methods and materials, or performance-based, design. In most cases, the basis of such designs is equivalency to the prescriptive requirements of the codes adopted by that jurisdiction.

It is important that the design team understands that such a design approach requires the approval of the authority having jurisdiction (AHJ). Therefore, the AHJ should be consulted at the beginning and throughout the project in order to avoid any surprises that may result in costly change orders and potential construction delays.

This article identifies the key elements that the City of Phoenix Development Services Department uses with stakeholders when undertaking performance-based design construction projects. An actual project is referenced in order to illustrate the potential issues related to a unique structure and the

overall success of the procedures employed.

## INITIAL MEETING

A meeting of all the stakeholders should be arranged early in the design. Attendees of this meeting should include building officials, fire marshals, fire chiefs, design team members, contractors, building owners, insurance carriers, and other city departments as applicable.

The following is an outline of topics that should be discussed at the beginning of any project that utilizes a performance-based design:

1. Research and document the history of the fires associated with the proposed use.
2. Develop a fire life safety report that addresses all the aspects of the project.
3. Address uses and limitations of any fire models that are proposed to be used.
4. Identify timelines and the proposed date of occupancy.
5. Address fire department operations throughout the phases of construction as well as when project is complete.
6. Address requirements for third-party reviews, peer reviews, and special inspections.
7. Schedule a postconstruction critique meeting for the project.

As part of this process, it is important that the jurisdiction evaluate their staff's qualifications for the review of such designs. If the qualifications cannot be met by the jurisdiction, other options should be utilized when performance-based design projects are proposed.



# SMOKE FILLING

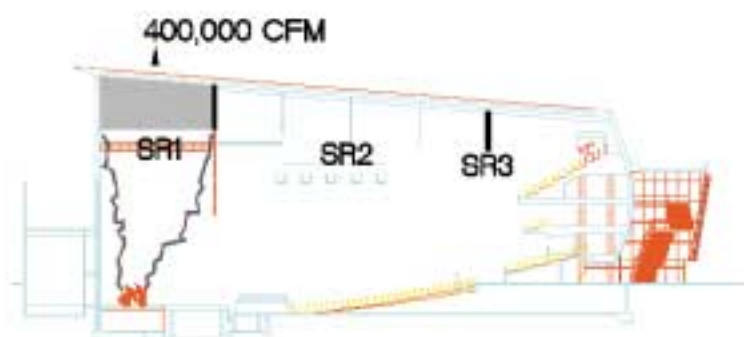
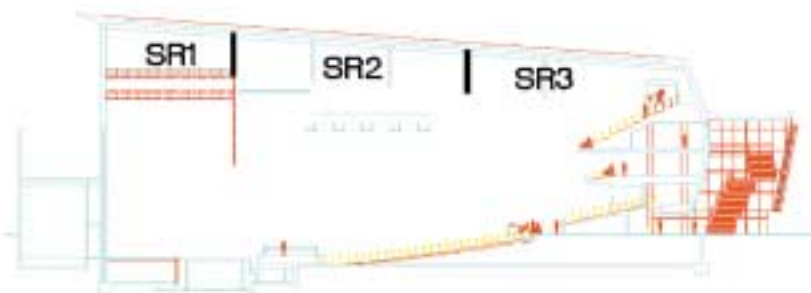
Having the reviewers involved early in the process is essential.

## FIRE LIFE SAFETY REPORT

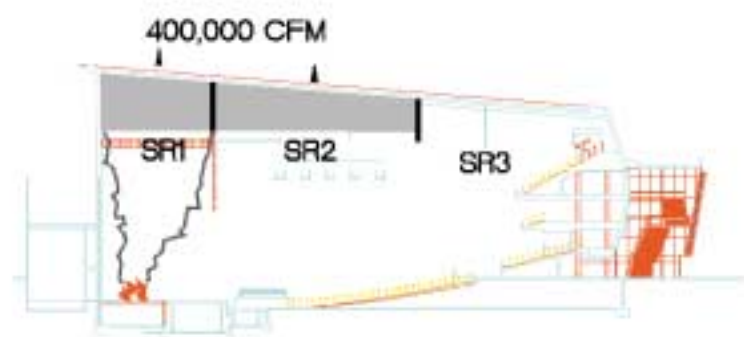
The City of Phoenix Development Services Department requires a Fire Life Safety Report for all projects that use alternate-methods, or performance-based, design. A standardized format for a Fire and Life Safety Report is provided to the design team at the beginning of such projects. After the report is prepared by the design team members, the AHJ and other stakeholders review the prepared report and provide comments. After a review, a meeting is scheduled in order to discuss any issues within the report. The design team then makes corrections and additions based on review comments and changes in the design. It should be noted that several meetings and reviews of the Fire Life Safety Report might be necessary in order to resolve all the issues. This document, with the input of the stakeholders, is key to this type of building design. Without this step in the process, the building and its systems may be inadequate with regard to functionality and fire safety, and may result in costly time delays.

## SMOKE FILLING TIME

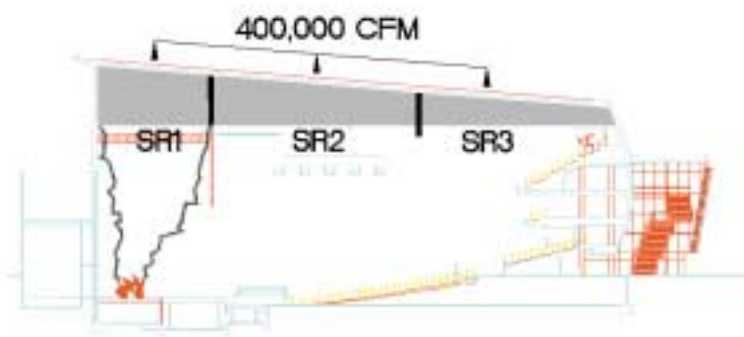
$$= T_{SR1} + T_{SR2} + T_{SR3}$$



UPPER BALCONY EVACUATED  
• TIME: 5 MINUTES



THEATER EVACUATED  
• TIME: 15 MINUTES



THEATER EVACUATED AND FIRE DEPARTMENT ON-SITE  
• TIME: 19 MINUTES

## CASE STUDY

With the rapid growth in Phoenix, AZ, in the past few years, the need for a multifunctional theater complex became essential. Therefore, local business leaders made the decision to construct a multiuse assembly facility which would serve a variety of events including conventional-stage theater, concerts, and boxing matches. The highest anticipated occupancy of 6,000 occupants was established. The construction type will be Type I, Fire-Resistive throughout.

The facility was constructed in accordance with the following codes:

- 1997 Uniform Building Code with local amendments
- 1997 Uniform Fire Code with local amendments
- 1994 Uniform Mechanical Code with local amendments
- 1994 Uniform Plumbing Code with local amendments
- 1996 National Electric Code with local amendments

## FIRE HISTORY

The history of theater fires was evaluated in order to get an understanding of the potential hazards associated with this use. Since the late 1800s, there have been three major-life-loss fires. Based on reports from NFPA<sup>1</sup>, the fire losses within these occupancies can be attributed to the lack of sprinkler protection, the type of interior finishes, and inadequacies of the egress system.

The goal of researching the fire history of similar buildings is to understand the intent of the various code requirements for assembly facilities. This establishes the baseline for the goals of the performance-based design. Also by reviewing incidents in these types of facilities, one can understand which systems or components worked and which failed.

## ALTERNATE-METHODS APPROACH

The first step in the use of an alternated-methods approach, or a performance-based design, is to establish the intent of the prescriptive code requirements.

Since the theater includes a “legitimate stage,” the provisions of UBC Section 405 apply. UBC Section 405.3.1 requires stages having a stage height greater than fifty feet be separated from the rest of the building by a two-hour occupancy separation. The proscenium opening is to be protected with an approved proscenium curtain.

This requirement for the proscenium curtain presented an extreme design hardship due to the need for different stage configurations; therefore, a performance-based design was sought.

Below are some of the design elements that were proposed as equivalents to the prescriptive requirements:

- An engineered mechanical smoke control system
- Passive draft curtains to prevent the spread of smoke to audience seating areas and enhance operation of the smoke-control system
- Quick-response, ordinary-hazard sprinklers located above the stage and audience seating areas
- Infrared beam smoke-detection system
- Smoke detection in normally unoccupied areas to provide early warning of fire in nonoccupied areas
- Emergency voice evacuation system with prerecorded message
- Emergency power to all life safety systems
- More restrictive interior finishes classification to reduce the potential fuel load

## AUTOMATIC FIRE SPRINKLER PROTECTION AND STANDPIPES

The stage and theater seating areas were proposed to be equipped throughout with quick-response, ordinary-hazard sprinkler protection automatic sprinkler system. A Class III standpipe system was also provided at locations specified by the Fire Department.

## FIRE DETECTION SYSTEM

An infrared beam smoke-detection system was proposed in the auditorium space. Spot-type smoke detectors were also proposed on both sides of the draft curtains to detect fires above the beam detectors. The beam detec-

tors and smoke detectors in the stage and auditorium area were proposed to activate the mechanical smoke-control system.

## FUEL LOAD

The control of the potential fuel load is crucial to this performance-based design. Therefore, all storage rooms and other accessory rooms to the stage were proposed to be separated from the stage with one-hour, fire-resistive construction. A more-restrictive interior finish rating was proposed by not utilizing reductions allowed for sprinklered buildings.

## TIME-EGRESS ANALYSIS

The exiting model Evacnet4 was used to model the entire seating area of the Phoenix Theater. Two configurations were modeled: the theater configuration and the boxing ring configuration. The results showed that for both configurations it would take approximately 335 seconds to evacuate the theater, using a safety factor of two results in a total egress time of 670 seconds, or approximately 11 minutes.

## SMOKE-CONTROL SYSTEM DESIGN

The engineered smoke-control system was proposed to be provided in both the stage and auditorium. The mechanical smoke-control system would work in conjunction with use of passive smoke and draft curtains located at the proscenium and within the ceiling of the seating area, thereby creating three reservoir, or smoke, zones.

Axisymmetric plume calculations as prescribed by UBC Section 905.5.2.2 utilizing two design fires of 5,000 BTU/sec (5 MW) and 10,000 BTU/sec (10 MW) were used for the design of the mechanical smoke-exhaust system and smoke-reservoir system. The sizing of the exhaust fans would allow the smoke layer to be maintained at 10 feet (3 meters) above the highest level of discharge, thus protecting occupants from the exposure to the smoke layer. The smoke-control system will operate for a minimum of twenty minutes as required by UBC Section 405.3.3.1.

The draft curtains would further limit the spread of smoke and serve as a passive means to delay the spread of smoke from the stage to occupants on the upper concourse seating areas. Taking into account the smoke-reservoir system in conjunction with the smoke-exhaust system, the total calculated time to fill all three reservoirs was 19 minutes.

This analysis demonstrates that, based on the prescribed fire scenarios, the overall smoke control system will provide the occupants with a tenable environment for safe egress.

### THIRD-PARTY/SPECIAL INSPECTION

The ability to perform third-party or special inspections is essential to any project where alternate methods have been approved by the AHJ. This ensures that all the hard upfront work of the project is carried out. This also helps to ensure that the specifics of the performance-based design are intact, should field changes or value engineering be necessary.

### FIRE DEPARTMENT OPERATIONS

By having the local fire department involved, they can evaluate how the design, construction, and function of the building can affect fire department operations before, during, and after an incident. This input can be beneficial by addressing the fire department needs and can ensure that, in the unlikely event of a fire, the impact to the building is minimized.

### TIME FRAME FOR OCCUPANCY

In most cases, constructions of buildings of this nature are required to follow a rigorous construction schedule due to loan agreements for the construction of the facility. Construction timelines are ever-changing; therefore, they can become the stakeholders' worst nightmare. It is crucial that all stakeholders are made aware of the proposed timeline. This can reduce the chance of unforeseen delays.

### POSTCONSTRUCTION CRITIQUE OF THE PROJECT

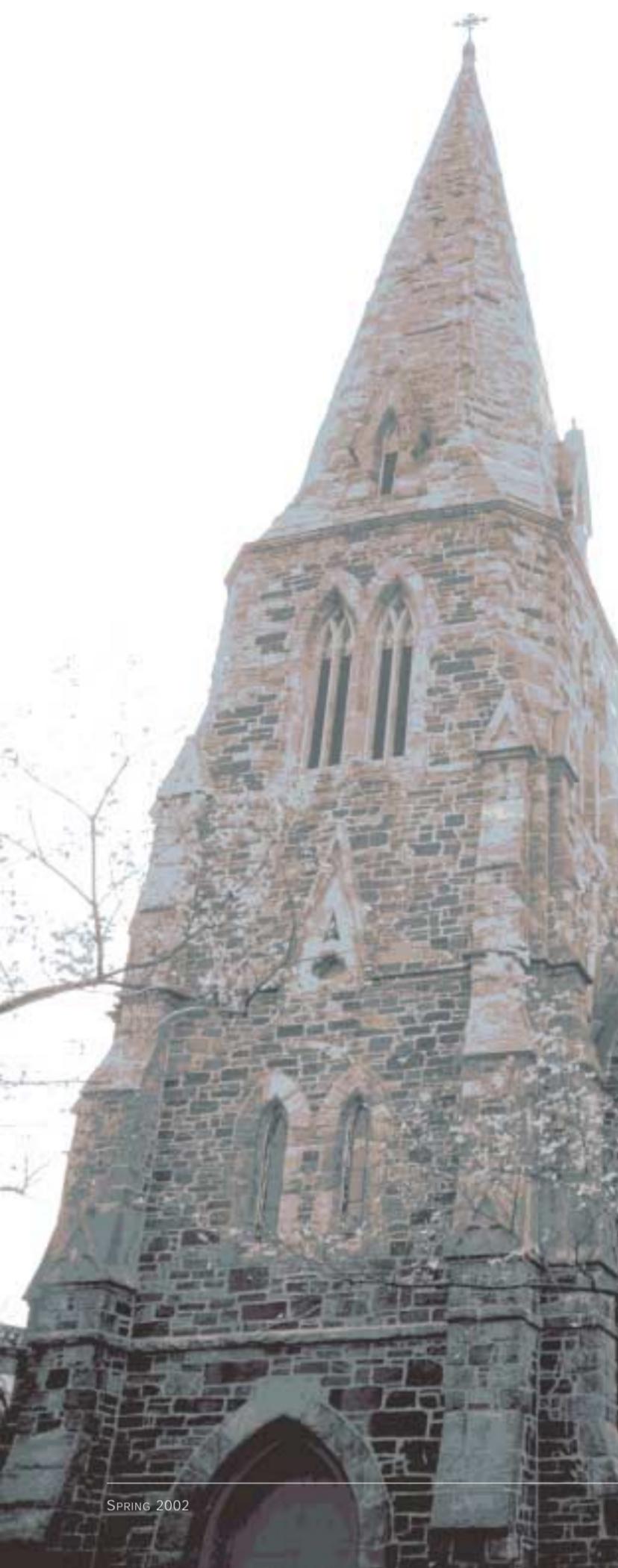
The City of Phoenix typically schedules a meeting after the building is opened so everyone can evaluate the outcome of the job. This provides a great opportunity for all stakeholders to evaluate ways they can improve the

next time a performance-based design/construction project is undertaken.

*Joe McElvaney is with the City of Phoenix, AZ.*

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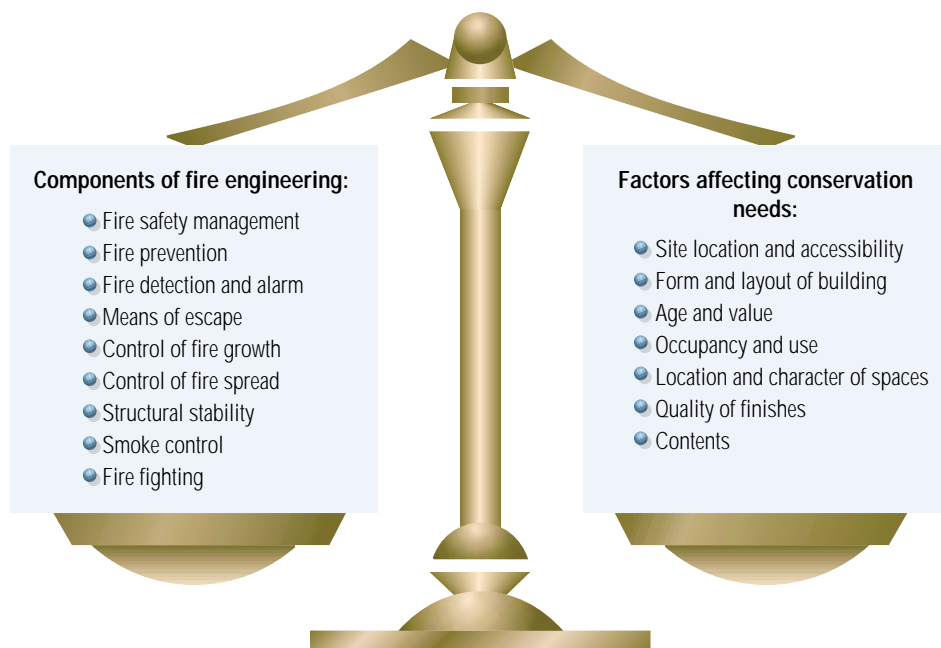
Application of a  
Systematic  
Fire Safety Evaluation  
Procedure in the

# PROTECTION OF HISTORIC PROPERTY

*By Alexander G. Copping, Ph.D.*

## ABSTRACT

The essential qualities of historic buildings are their uniqueness and antiquity. The more valuable a building becomes when assessed for these qualities, the more vulnerable it becomes from a fire safety point of view. Equally, as it becomes more valuable, the introduction of any of the various fire safety systems needs to be carried out with increasing sensitivity.<sup>1</sup> Careful consideration must be given to the size, shape, and color of the parts of the components of fire safety technology. Fire-engineered solutions need to be sought which achieve minimum irreversible damage being caused to the historic fabric and content of the buildings.



**Figure 1. Balancing fire engineering components with conservation needs.<sup>6</sup>**

In achieving effective fire safety solutions, it is important that a fire protection strategy is developed which incorporates both the fire safety and conservation goals of the property. In turn, an essential element of an effective strategy is the application of a fire safety evaluation procedure to aid decision-makers in selecting appropriate fire safety measures. This article outlines the application of such a tool, which has been developed specifically for the content and fabric protection of British parish churches. Traditionally, church management have made decisions on fire safety improvements utilising the advice from their insurers and the fire service. This tool, for the first time, enables custodians of churches to facilitate the systematic evaluation of fire safety of their own properties. For individual churches, the tool allows fire safety system upgrade options to be explored so that cost-effective solutions may be sought. While at the broad estate-management level, the tool enables a priority funding list to be generated.

## INTRODUCTION

There are four fire safety goals relevant to historic building: life safety, content and fabric protection, heritage preservation, and protection of the surrounding environment. The agencies that control the adequacy of fire

safety for these objectives include national authorities, the local authority (life safety), and insurance companies (content and fabric).<sup>2</sup> To satisfy the requirements of these agents, designers and fire engineers may employ prescriptive approaches. Alternatively, equivalent and performance-based fire-engineered approaches may be used, examples of which are detailed in *BSI Draft for Development 240 – Fire Safety in Buildings*<sup>3</sup> and set out in *NEPA 914*, which focuses specifically on historic structures.

It is advocated that fire-engineered solutions should be sought based on the adoption of a philosophy centered on flexibility and innovation. For historic buildings, unlike that for modern buildings, there can be a conflict between fire protection and the conservation of such buildings. It is necessary to achieve a balance between the components of fire engineering and conservation, illustrated in Figure 1. The combination and interactions of such components are inevitably complex and will require the input of a team of experts.

Minimal intervention has become one of the basic components of good conservation. The less original material lost, the less potential there is for damage to the building's cultural significance.<sup>5</sup> However, to give an historic building and its content the best level of protection from fire may require a

level of intervention in the fabric which is unacceptable in conservation terms. At the same time, the loss of the building from fire is unacceptable, and therein lies a central dilemma for those who have to make decisions regarding fire safety.

This dilemma is further complicated by the ultimate threat of closure, and possibly demolition, due to the loss of the economic viability of the building if the cost of compliance with fire safety upgrade requirements is too great. It remains a very delicate process for local planning authorities to make the sensitive judgment of balancing the economic viability of possible uses against the effect of any changes they entail on the special architectural and historic interest of the building or area in question.<sup>7</sup>

## THREAT OF FIRE IN HISTORIC BUILDINGS

By their very nature, historic buildings are particularly exposed to the threat of fire. Their unique structural arrangements coupled with the complex environment present in most historic buildings make them more vulnerable to fire than most modern buildings, as discussed below.

### Vulnerability of Historic Buildings

The construction and arrangement of historic buildings can incorporate features which assist in the rapid development and spread of fire. This may include exposed timber floor structures, walls lined internally with combustible materials, and roofs of thatch or timber shingles. Fire can spread rapidly through hidden voids in floors, walls, and open roofs or other voids in the building fabric, for example, bell pull systems, gas and water pipes, drainage, electricity, ventilation, elevator shafts, chimneys, and flues. The common practice in seventeenth- and eighteenth-century buildings of providing openings in masonry walls twice as wide as the final door (as the exact position of door openings was not confirmed at the time of the erection of the masonry wall) is a typical example of a hidden danger specific to historic buildings.<sup>8</sup> Poor maintenance due to timber shrinkage or fun-

gal and insect attack can create further voids, which would allow the rapid movement of fire and the quick charring of timber. Further weaknesses in historic buildings are caused by later piecemeal and ad hoc repairs and alterations.<sup>9</sup>

The accommodation of facilities for the provision of lighting, heating, ventilation, and other utility services can also enable rapid fire spread. The advent of electric power for lighting and mechanically aided forms of heating and environmental control can now make the original built-in facilities redundant. Often the modern service facilities are much smaller than the originals, creating redundant voids and spaces, such as redundant boiler rooms, oil storage tanks, and extensive brick or stone ventilation flues and passages.

The threat of fire during maintenance and refurbishment activities is significant. Statistics show that approximately 10% of fires in historic buildings are caused as a consequence or direct careless activities of workers.<sup>10</sup> During construction, buildings are generally more vulnerable to fire, regardless of building type or construction method, than when completed. Additional risk is present due to the lack of structural members, the temporary absence of fire-resistive materials, the open exposed condition of the structure, as well as the presence of combustible building material. There are further threats if, during the refurbishment, the building or part of it is still being used. Fire is likely to spread more rapidly because of the absence or impairment of fire suppression and detection systems.

### The Complex Environment of Historic Buildings

Historic buildings constitute a complex environment with regard to the building fabric, contents, and occupants in terms of property usage and management.<sup>11</sup> The effective management of fire safety requires the sympathetic integration of these components, as illustrated in Figure 2.

Invariably, fire safety solutions must satisfy two or possibly three interacting components. For example, deriving successful egress routes under emer-

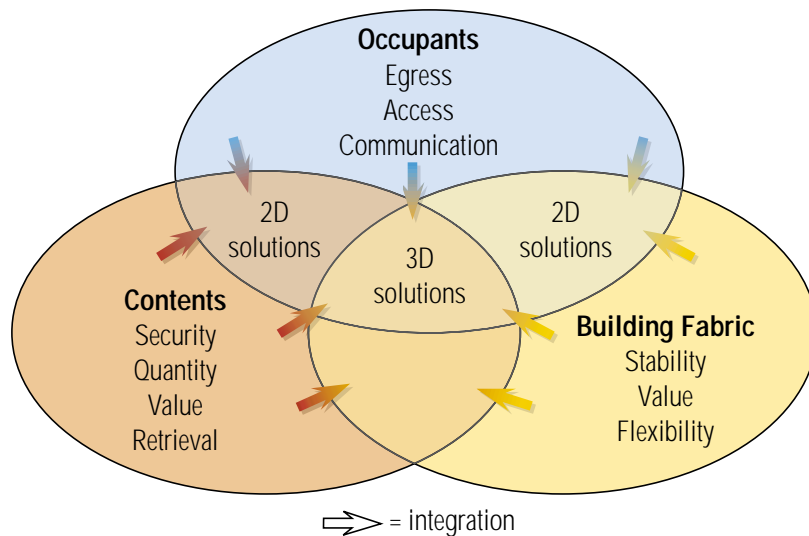


Figure 2. Notion of the complex environment created by historic buildings.

gency conditions is dependent on the value and consequential flexibility of the building fabric. A further example illustrates the need for a three-dimensional solution. The effective retrieval of contents interacts not only with the access routes available but also with the stability of the structural building fabric.

With such complex issues at stake, it is very important to develop a fire protection strategy which incorporates both the fire safety and conservation goals of the property. In turn, an essential element of an effective strategy is the application of a fire safety evaluation procedure to aid decision-makers in selecting appropriate fire safety measures. As historic building types range so widely (for example, from small cottage to grand stately palace), it is argued that the content and structure of the survey assessment elements of such procedures need to be individually designed for specific historic building types, although the protocol may be common to all historic buildings. This article illustrates the application of a procedure developed for the specific requirements of British parish churches.

### FIRE SAFETY EVALUATION PROCEDURE FOR THE PROPERTY PROTECTION OF PARISH CHURCHES (FIRESEPC)

A high level of fire incidents raised concern among insurers of ecclesiasti-

cal estates and the Church of England management regarding the vulnerability of the fabric and content of churches to fire (rather than the threat to life safety. Statistics show that risk to life is not high in churches<sup>12</sup>). The estate of the Church of England includes over 16,000 churches in active use. Seventy-five percent of the estate has a statutory listing, under the Planning (Listed Buildings and Conservation Areas) Act of 1990. Approximately 2,400 churches are Grade 1 and considered to be buildings of exceptional interest.<sup>13</sup> Currently, the management of individual churches is entrusted to Parochial Church Councils (PCC), which consist of a group of well-intended amateurs operating in an autonomous environment with very limited resources. In most cases, no fire safety management expertise exists among PCC members, and, therefore, they are often unaware of the vulnerability of their church to fire or how the risks can be reduced. Similarly, at the diocesan level (PCCs are managed by a diocesan synod), due to lack of fire safety management awareness, examples of structured policies for managing fire safety or assessing fire risks of their churches among the forty-three dioceses of England are rare.

The procedure uses a "points scheme" technique to enable the judgment on the adequacy of fire safety to be made. This work involved assigning numerical values to qualitative descriptions of events, techniques, and

processes by a group of experts representing the interests of those involved in the use, management, and preservation of churches, as well as fire safety engineers. The opinions gathered were brought to a consensus in a series of “Delphi group” meetings through statistical analysis and discussion. A “collated norm” was established from a collection of fire safety guidance documents for places of worship, against which technical value judgments are made and the acceptable level of fire safety is adjudicated.

The assessment is undertaken through an “observational survey.” This is conducted by an expert, knowledgeable in ecclesiastical building construction and fire safety, observing all parts of the building and making judgments on the adequacy of eighteen identified fire safety components. Features of the building which are highlighted through the assessment as being a high fire risk can receive a more in-depth survey, beyond the scope of this evaluation procedure.

The procedure is unique in its evaluation configuration in that an “acceptable level” of fire safety is dependent not only on the level of fire safety adjudged, but also on the vulnerability of the fabric and contents of individual churches. In the context of this work, vulnerability is a measure of both the impact of the loss of the property and the potential magnitude of the loss from fire. The development of the procedure has been outlined in more detail in a previous conference paper.<sup>14</sup> The application of the procedure is demonstrated in the next section.

## PROCEDURE APPLICATION

In this example, the FireSEPC evaluation has been undertaken on ten churches in the Diocese of Leicester. Each church is medieval in origin and is used regularly for religious services and other community functions. As shown in Table 1, the survey assessment produces two results: a fire safety measure [FSM] score and a fire vulnerability rating [FVR] score. The variance between the two scores produces the overall fire safety rating [OFSR].

The OFSR indicates the level of safety compared to the assessment level of

**Table 1. Overall fire safety rating results for the ten sample churches.**

Churches	FSM	FVR	OFSR
St. Peter, Copt Oak	46	29	+17
St. Mary, Barwell	55	51	+4
St. Mary, Humberstone	41	38	+3
All Saints, Wigston	56	56	0
St. John, South Croxton	39	48	-9
St. Andrew, Welham	42	53	-11
St. Michael, Cranoe	39	51	-12
St. Michael, Hallaton	43	57	-14
St. Peter, Tilton-on-the-Hill	41	56	-15
St. Leonard, Swithland	38	55	-17

FSM = Fire safety measure

FVR = Fire vulnerability rating

OFSR = Overall fire safety rating

NOTE: FSM and FVR scores normalized. Max. = 100

NOTE: FSM “collated norm:” 100 = perfect level of fire safety, 40 = minimum level of fire safety regardless of the FVR score.

**Table 2. Acceptability levels.**

OFSR <0	<b>Unacceptable:</b> The level of first safety is considered not to be high enough for the fire vulnerability level of the building.
OFSR 0 – 10	<b>Acceptable:</b> The level of fire safety is considered to be only adequate for the fire vulnerability level of the building.
OFSR >10	<b>Desirable:</b> The level of fire safety is considered to be good for the fire vulnerability of the building.

fire vulnerability. As defined in Table 2, a negative OFSR score is considered to be unacceptable, while scores above zero can fall into one of two categories: acceptable or desirable. The acceptability and desirability boundaries can be applied to the OFSR scatter graph as shown in Figure 3.

If the results of the ten churches are reviewed, a number of notable points can be identified:

- St. Peter, Copt Oak, is the only church to score a desirable OFSR. This is due primarily to the low FVR score [29].
- St. Leonard, Swithland, requires the largest FSM upgrade. But due to the varying levels of property vulnerability, St. Leonard, Swithland, does not require the

highest level of fire safety.

- St. Michael, Hallaton, with an FVR score of 57, requires the highest level of fire safety to achieve an acceptable OFSR.
  - St. Mary, Humberstone, and St. Peter, Tilton-on-the-Hill, both score an FSM of 41. For St. Mary, the score is judged acceptable, as the vulnerability of the building is low [38]; while for St. Peter, the same FSM score is not acceptable, as its vulnerability is high [56].
  - All church FSM scores are low compared to the “collated norm’s” perfect level of fire safety [100]. All Saints, Wigston, with the highest FSM score of 57, is 43% deficient.
- These assessment results provide data to aid the custodians of individual

churches and diocese estate managers in making decisions based on a systematic evaluation rather than the advice of others. The OFSR scores may be utilized in a number of ways: firstly, the scores may be ranked as in Table 1, and decisions regarding the allocation of funding for fire safety upgrading may be taken using the ranked list. Alternatively, the results of each church may be reviewed individually and a postassessment breakdown conducted to produce a fire safety upgrade package.

### DEVELOPMENT OF A FIRE SAFETY UPGRADE PACKAGE

As can be seen in Figure 3, six of the sample churches are shown to exhibit a level of fire safety which is unacceptable for the vulnerability level of the building. For such churches, the creation and implementation of a fire safety upgrade package as shown in Figure 4 is necessary.

The creation of an effective package requires both an evaluation of the existing state of fire safety in the property (this may be the result of the fire safety assessment and/or more in-depth investigations into certain aspects of the building) and a “least-cost upgrade” analysis, to enable a cost-effective upgrade program to be developed.

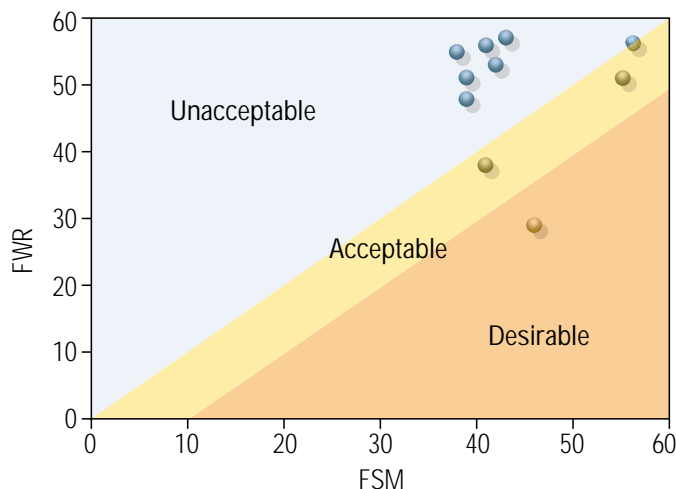


Figure 3. Scatter diagram of FSM versus FWR with acceptable and desirable cutoff levels.

Table 3.  
Upgrade points required to achieve an acceptable and desirable level of fire safety.

Church	OFSR	Upgrade points to an acceptable level	Upgrade points to a desirable level
All Saints, Wigston	0	—	50
St. Andrew, Welham	-11	55	105
St. John, South Croxton	-9	45	95
St. Leonard, Swithland	-17	85	135
St. Mary, Barwell	+4	—	30
St. Mary, Humberstone	+3	—	35
St. Michael, Cranoe	-12	60	110
St. Michael, Hallaton	-14	70	120
St. Peter, Copt Oak	+17	—	—
St. Peter, Tilton-on-the-Hill	-15	75	125

Using the assessment results, it is possible to evaluate the upgrade points necessary for each of the churches. From Table 3, it can be seen that the largest FSM upgrade is required by St. Leonard, Swithland (An 85-point FSM upgrade to an acceptable level of fire safety and an 135-point upgrade to a desirable level of fire safety). It is then possible to equate upgrade points to fire safety systems, and from that, cost options can be presented.

This link between the assessment

results and the actual cost of making improvements is a very attractive proposition. Currently, further research is being conducted into suitable approaches to calculating upgrade costs. Larger field tests are also ongoing to test the repeatability and reproducibility of the evaluation procedure.

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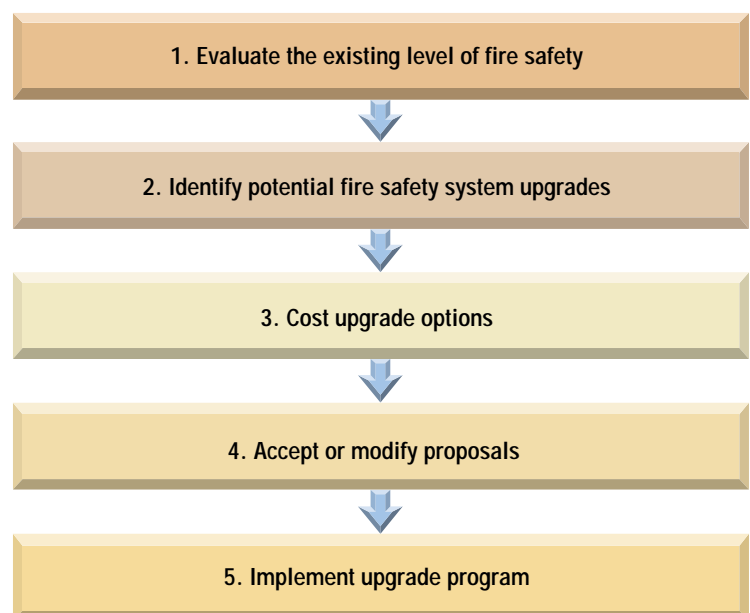


Figure 4. Fire safety upgrade package flow diagram.



Figure 5. St. Leonard, Swithland, requires the largest fire safety upgrade.

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# The National Electrical Manufacturer's Association, Signaling and Communications Section, **3-SB**

**T**he National Electrical Manufacturer's Association (NEMA) was formed in 1926 when the Electric Power Club and the Associated Manufacturers of Electrical Supplies merged. NEMA's primary goal is the standardization of electrical equipment. There are several sections within NEMA that are involved with products related to fire prevention and fire protection. This article describes the organization of NEMA and focuses on the Signaling and Communications Section and its involvement in fire protection.

In the early days of electrical power, there was little or no standardization, not the least of which was how to measure electrical phenomena. Today, we are all familiar with the amp, volt, and Ohm. However, if it were not for trade, professional, and scientific organizations, we might not have measurement standards that consumers can use to compare products and keep creative marketing professionals honest. Also, without product standards, manufacturers would be producing a wide range of incompatible products. NEMA member companies are also concerned with product safety and quality. NEMA has been a supporter of the Consumer Product Safety Commission since its inception in 1972 and was instrumental in getting Underwriters Laboratories safety standards recognized as minimum acceptable federal standards for both domestic and imported electrical products. NEMA also serves its member companies by gathering, compiling, and analyzing market statistics and economics data.

Standards are an important part of national and international commerce. Technical standards that have been openly developed aid the consumer and the manufacturer. They improve safety, lead to known expectations on the part of the consumer and the manufacturer, and assist the purchasers in choosing products with the features they need.

## ORGANIZATION

NEMA is organized into nine Divisions, listed in Table 1.<sup>1</sup> It's not hard to imagine several areas where each division would be involved in product safety and, therefore, fire prevention. Each Division has several *Sections* within it. Each Section might have several *Groups* or *Voting Classifications*. The Section involved most with fire protection products is the Signaling and Communications Section, designated 3-SB. The Signaling and Communications Section represents over 40 manufacturers from the United States, Japan, and the United Kingdom.

The 3-SB Section is composed of three active Groups:

- Fire Alarm Group  
(Described below)
- Healthcare Communications Group (3-SB-6)  
Healthcare Communications systems such as, but not limited to, nurse call, doctor paging, and room monitoring, including associated devices and accessories
- CO Detector Group (3-SB-10)  
Gas Detectors, such as CO Detectors

Table 1. NEMA Divisions

Division	Title
1	Industrial Automation
2	Lighting Systems Division
3	Electronics Division
4	Industrial Equipment Division (deleted)
5	Building Equipment Division
6	Insulating Materials Division
7	Wire and Cable Division
8	Power Equipment Division
9	Diagnostic Imaging and Therapy Systems Division

In addition to the active groups, the Signaling and Communications Section has created, but not yet organized, five additional Groups:

- Security Signaling Systems and Devices (3-SB-II) Electrical signaling systems for intrusion detection and/or access control, including associated devices and accessories
- Paging Systems, Devices, or Accessories (3-SB-V) Paging systems, devices, or accessories, including those of the coded sound and visual type
- Manually Operated Contact Devices (3-SB-VII) Manually operated contact devices of the type principally used as accessories for, or components of, products falling within the scope of the Signaling, Protection, and Communications Section
- Clock and Program Systems (3-SB-VIII)
- Audible and Visible Appliances Not Intended for Use in Either Fire Alarm or Nurse Call Systems (3-SB-IX)

The Fire Alarm Group is the most active in the field of fire protection. Their scope encompasses three main product areas or subgroups:

- 1) Notification Appliances;
- 2) Automatic Detectors; and
- 3) Systems, Devices, and Accessories.

Notification appliances include typical audible and visual signaling equipment such as speakers, horns, and strobe lights. This category would also be involved with alternate alerting strategies, such as bed shakers for the hearing impaired. A key element of this subgroup is that the notification appliances are used in fire alarm systems. The range of the automatic detectors sub-group is a bit broader in that it includes automatic detectors for fire protection and *other related hazards*. The last subgroup is involved with products such as fire alarm control units, fire alarm communications equipment, sprinkler supervisory systems, and the various components, devices, and accessories needed to complete these systems.

## ACTIVITIES

The primary objective of the 3-SB Section of NEMA is "to be the principal source of technical, training, and educational materials essential for the specification and manufacture of reliable life safety products, their installation, performance, maintenance, and inspection."<sup>2</sup>

In general, the regulation, inspection, and permitting of buildings and occupancies relies upon a strongly aligned triad of codes and standards. (See Figure 1.)

In the special case of fire protection, laws and regulations, most often in the form of *Building Codes* and *Fire Codes*, require specific occupancies or types of construction to have certain features, elements, or systems. Those features, elements, or systems, must be properly planned, designed, installed, and maintained in accordance with certain

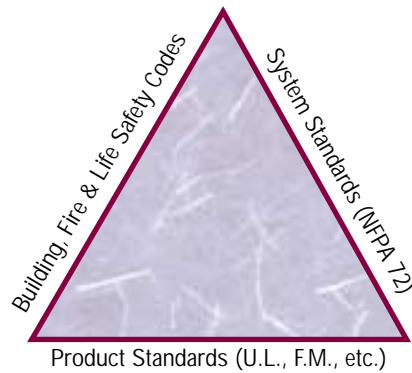


Figure 1

standards. For fire detection and alarm systems, the standard referenced by most building and fire codes is *NFPA 72, the National Fire Alarm Code*. *NFPA 72* references and relies upon product safety and performance standards such as those promulgated by Underwriters Laboratories (U.L.) and Factory Mutual (F.M.). NEMA's Signaling and Communications Section is active in several different ways in all of these areas.

The 3-SB section has several full-time staff at NEMA headquarters in Rosslyn, VA. The staff helps in tracking legislation and code and standards development. NEMA member companies bolster these efforts by supporting individuals to serve on committees and task forces addressing key elements of the section's scope. In addition, the 3-SB section employs industry consultants to monitor and influence codes development. Each of the technical committees of *NFPA 72* has a NEMA representative.

NEMA representation on NFPA committees serves several purposes. First, it serves to keep the section member companies informed of what is taking place in the codes and standards development areas that may affect their products and services. For example, in 1996, a requirement was added to *NFPA 72* to require a trouble signal that had been silenced on control equipment to respond at least every 24 hours. This change, supported by NEMA, required manufacturers to change to products that were being redesigned or resubmitted for listing.

A second reason why NEMA supports representation on codes and standards committees is the issue of standardization, which spawned the creation of NEMA early in the 20th century. For example, a task force of *NFPA 72* is working on the development of a standard fire alarm system interface. Aimed at making easier to train operators, including the fire service, this project has the potential to greatly simplify the use of fire detection and alarm systems, making them a more valuable tool for fire and fire protection management. However, the standard also will have a large impact on the manufacturers of control equipment. NEMA representatives are in a position where they can supply valuable information to the development process on what is and what is not feasible and what current and future manufacturing capabilities are.

Many NEMA member companies produce products

for global marketing. Competing product standards and listing requirements are inefficient and costly to a manufacturer. By supporting representation on the standards-making committees, NEMA works towards harmonization of international standards.

Members of the 3-SB section have been very active in and supportive of industry research. In the past, they have participated in the research project that led to development of a model for heat detection. This effort is ongoing as discussions are now taking place on how to best standardize the measurement during the listing process of a thermal response coefficient for use in calculations.

The International Fire Detection Research Project (IFDRP), organized by the Fire Detection Institute (FDI) and managed by the National Fire Protection Research Foundation (NFPRF), was funded in part by NEMA companies. The project used computational fluid dynamics modeling to study smoke detection. That work resulting in a better understanding of several phenomena, including the "dead air" space at the intersections of walls and ceilings and the zone of nondetection around air supply and return vents.

The 3-SB section is also coordinating industry participation in the FDI's Duct Detector Research Project. That project is investigating the efficacy of duct detectors, including duct smoke detection. What conditions are the detectors exposed to, prefire and during a fire? What are their operational limitations and capabilities? If used, where are they best located? These questions and the research aimed at answering them may lead to changes in product design and use and, therefore, may affect the members of 3-SB. By being an active partner in the project, manufacturers provide valuable data from their own research and experiences to the project team.

Seeing the adverse impact of false and nuisance alarms on fire protection, the 3-SB section has been instrumental in developing and supporting NFPA's National Fire Detection Nuisance and False Alarm Research Project. This work is aimed at understanding the many causes of false and nuisance alarms and developing strategies for reducing them.

NEMA members have also participat-

ed in the Limited Combustible Plenum Cable Fire Test Project (NFPRF) and the Advanced Fire Alarm System Project at the National Institute for Standards and Technology (NIST). The NIST project has developed a prototype system that can be interfaced with using a standard Web browser from a computer or by a handheld computing device with a wireless link. The project is also investigating the ability of a fire detection and alarm system to evolve into a fire management system by using real-time detection data along with fire modeling algorithms to predict possible fire progression and impact.

The triad of occupancy codes, system standards, and product standards is a strong and balanced approach to ensuring quality and performance. But it is not all-inclusive and does not address all issues and problems. NEMA's 3-SB section has tried to fill the gap by producing guides and reports to assist users of their products. These are not product manuals, but rather manuals aimed at improving the overall quality, reliability, and performance of the systems in which their products are used.

The following is a short list of publications that are of interest to the fire protection community. For a more complete list or to search for a specific topic, go to NEMA's Web site at [www.nema.org](http://www.nema.org).

- **NEMA Guide to Code Requirements** – Lists model codes adopted by states and cities.
- **Guide for the Proper Use of System Smoke Detectors** – Provides information concerning the applications of smoke detectors used in conjunction with fire alarm systems. Basic principles to be considered are outlined, as well as operating characteristics of detectors and environmental factors that may either aid or prevent their operations.
- **Guide for Proper Use of Smoke Detectors in Duct Applications** – Provides much-needed information concerning the proper use of smoke detectors in duct applications.

- **Quality Information Guide for Automatic Fire Detection and Alarm Systems** – Provides guidance to the local Authority Having Jurisdiction (AHJ) for establishing programs to ensure highly reliable fire detection and alarm systems. A model municipal code is also included.
- **Training Manual on Fire Alarm Systems** – Provides technical information on basic fire alarm systems in common usage.

NEMA publishes over 500 technical documents each year, and has partnered with Global Engineering Documents to distribute standards and other technical publications. Most standards and publications are available in PDF format for electronic download, or hardcopies may be ordered by phone or fax.<sup>3</sup> In addition, the *NEMA Guide to Code Requirements* is also available on CD.

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- 3 Global Engineering Documents, 15 Inverness Way, East Englewood, CO 80112, USA, Phone: 1.800.854.7179, Phone: 303.397.7956 (outside the U.S.), Fax: 303.397.2740  
e-Mail: [global@ihs.com](mailto:global@ihs.com)  
Web: [www.global.ihs.com](http://www.global.ihs.com)

## Editor's Note – About This Article

This is the first in 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.



APPLICATIONS OF THE

# Fire Dynamics Simulator

## IN FIRE PROTECTION ENGINEERING CONSULTING



**F**ire modeling has become increasingly relied upon for various applications within the fire protection community. Fire protection engineers now use computer fire modeling for a variety of different tasks. These tasks encompass the broad categories of research and development, design of systems, and fire and explosion investigation and reconstruction. As the technology of fire protection continues to advance, computer fire modeling will continue to grow in importance in this multifaceted field.

The majority of all computer fire software or “code” used

today can typically be divided into two methods that are used to solve the fundamental equations within a problem involving fire – the zone method and the computational fluid dynamics (CFD) method. While these two methods differ in their capabilities, each method can be used effectively to solve real-world engineering problems.

Of the two, the zone method is better known within the fire protection community and has been tested for numerous fire scenarios. The zone method requires far less in the way of computer hardware to produce results than does the CFD

method. With computer processor speed continuing to accelerate, it has now become possible for an engineer with a desktop personal computer to run CFD models without having to rely upon sophisticated computer workstations. As processor speeds have increased, so have the number of CFD codes commercially available. In recent years, these codes have been used for a multitude of research and design tasks in various engineering fields, and they continue to be evaluated and validated for various scenarios.

The most widely distributed and well-known of these codes, written specifically for the study of large-scale fire scenarios, is Fire Dynamics Simulator (FDS).<sup>1,2</sup> FDS was produced at the National Institute of Standards and Technology (NIST) and was recently made available to the public. Already, this code has shown much promise in the ability to model fire scenarios for various purposes within fire protection engineering. In fact, many recent conferences within the fire science field have showcased data comparison studies, as well as practical applications and other uses of the FDS code.

This article describes several ways Combustion Science & Engineering, Inc., has used CFD codes, including FDS, to solve problems within the field of fire protection engineering.

## COMPUTATIONAL FLUID DYNAMICS MODELING BACKGROUND

Only within the last 30 years or so has computational fluid dynamics become a useful tool within the engineering community. The usefulness of

this tool has been closely tied to the advent of the personal computer and increasing processor speed. The mathematics behind the code algorithms, though, had been developed much earlier. In fact, numerical schemes for iterative solutions to various equations now computed using the CFD methodology were outlined in the early 1900s.<sup>3</sup>

The biggest challenge that arose in using the CFD methodology was how to properly handle turbulence within the calculation. Three main modeling techniques were composed to deal with turbulent flows. These three techniques are Direct Numerical Simulation (DNS), Reynolds Averaged Navier-Stokes (RANS), and Large Eddy Simulation (LES).<sup>4</sup>

In general, all three of these techniques allow for three-dimensional modeling of complex system geometries. Codes utilizing each technique have been written to allow for flexible geometric production or meshing of

surfaces to describe details of physical surfaces within a model. The main difference between the three techniques is how turbulence is treated.

DNS would be ideal for most problems because it resolves turbulence within the calculation over all length and time scales. DNS directly solves the Navier-Stokes equations

when given appropriate initial and boundary conditions. The problem with using this technique is that it is very computationally intensive. Even today's high-powered workstations could spend weeks or months processing a DNS routine. The long computational time and large space requirements make the DNS scheme unfeasible for a majority of practical applications.

The RANS technique overcomes

some of the computational time requirements of DNS by computing time-averaged solutions for different variables of the modeled equations over a long time scale. This time scale is long when compared to the turbulent motion within the system. Variable data that can be analyzed from using this technique are time averaged and provide less accurate results. STAR-CD is one such CFD code that can implement the RANS technique and is commonly used for diverse applications such as automotive design, combustion in gas turbines, prediction of flame and smoke spread for fire protection, as well as aerospace, biomedical, and chemical processing design.

LES is another commonly used technique. This technique directly resolves large-scale turbulence within the code and uses a submodel to account for the small-scale turbulence. The LES technique is inherently time-dependent since the Navier-Stokes equations are

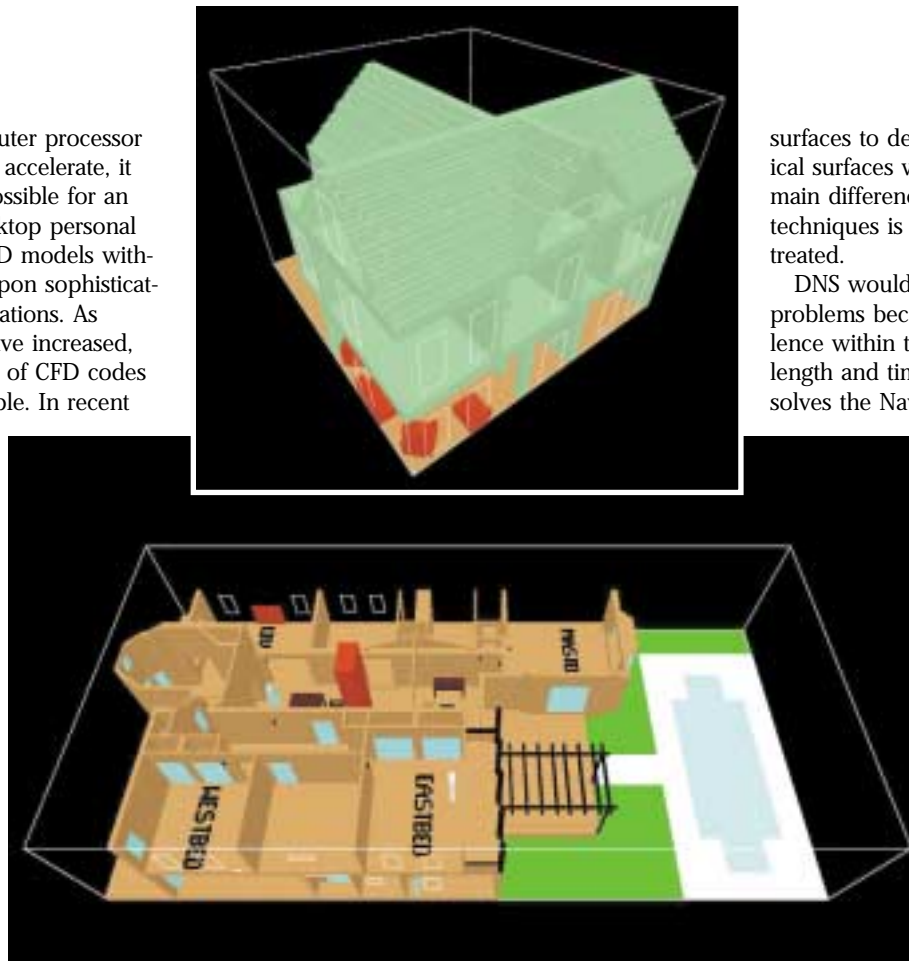


Figure 1. (bottom) Two-level residence manually input into FDS.

Figure 2. (top) Multi-level residence input into FDS using proprietary software routine.

not time-averaged. Transient problems can be solved quickly using this technique. The assumption behind this technique is that only the larger scales that carry most of the energy in the system need to be directly resolved in order to represent a flow accurately, and that the energy dissipation into smaller-scale eddies can be modeled. This approach results in a much more computationally economic model than can be achieved through DNS.

FDS is a unique LES code that was specifically created to deal with problems related to fire. The solver routine within the code was also written to be computationally efficient. With the combination of the fast solver, LES technique, and a state-of-the-art computer workstation, a million-cell system could produce meaningful transient data within a few hours or days, depending on the information needed and the time frame of the transient solution required. Unfortunately, there is a price to pay for this superior speed. The model solver requires a system to be fully rectilinear. Hence, all curved or angled surfaces described within the model must be described as rectilinear. The effects of this approximation can be minimized if the grid density is very high. Body-fitted meshes used in other commercial codes cannot be implemented into this model without losing the large computational speed increase. Even so, complex geometries can be generated in FDS.

### FDS MODEL GEOMETRY

Depending on the system being modeled, the geometry can be quite detailed and complex. Typically, there are two ways to build a geometry in FDS: build it manually, or use commercial mesh generation and then convert the mesh into an FDS input file.

Creating an FDS input file manually can consume a great deal of time when



Figure 3. Man driving an automobile manually input into FDS using proprietary software routine.

the system is fairly large or complex. The model-user must spend time mapping out where the fluid cells and the nonfluid cells will exist and then write an obstacle line into an FDS input file for every blockage necessary to build out a structure within the model. Figure 1 depicts a detailed two-level residence that was created using the manual method. The three-dimensional image was created by using the FDS companion software Smokeview.

An alternative method for constructing blockages within the FDS model was developed by Combustion Science & Engineering, Inc. A software routine was developed to allow for the translation of a three-dimensional CAD drawing file into an input file for FDS that produces the desired blockages within the model. Performance-based design of fire protection systems would be one useful application of this procedure.

The procedure is completed in five steps. First, the structure to be modeled is either measured or the construction plans are obtained. Second, the plans are then inputted into a commercial three-dimensional CAD software package. The three-dimensional CAD file is then used to create a mesh within a commercial mesh-generation software. This software cuts the smooth curves and angles into its rectilinear approximation. The meshed system is then spot-checked for consistency using STAR-CD in order to ensure a good representation. Finally, an in-house piece of software was developed to convert the geometric data from the

commercial CFD code to the traditional text input necessary for the FDS model.

Complicated structures can be produced using this procedure in approximately one-fifth (or less) of the time required to complete the task manually. This method also has the added benefit of being able to reproduce much more complicated structures within FDS than would be possible to achieve manually. Figure 2 shows a multilevel residence with a cross-peaked roof, and Figure 3 shows a

man driving a motor vehicle. Both are good examples of complex geometries that can be generated.

### FDS MODEL COMPARISON, CALIBRATION, AND EXPERIMENTAL USES

Having the ability to construct a model geometry is only a first step in obtaining accurate predictions. Codes, in general, must make assumptions about the physics of the phenomenon being explored in order to obtain equations that can be readily solved. These assumptions may result in situations where the phenomenon under investigation is not properly considered. The use of data-comparison studies and calibration data provide a test to a given code to determine scenarios that are or are not appropriately accounted for using the simplifications made to the physical equations. Through the use of this method to determine model reliability, a reasonable assessment of strengths and weaknesses of the code can be made.

The FDS code has been subjected recently to data-comparison studies and calibration testing. Numerous studies have been published demonstrating its strengths and weaknesses in providing viable solutions to fire scenarios. The five cases presented below are just a limited portion of the studies that have been conducted by Combustion Science & Engineering and demonstrate ways the FDS model is currently being used.

## Room Test with a Convective Flow

The first case conducted involved reproducing a room convective flow test. Figure 4 depicts the test room setup, and Figure 5 depicts the Smokeview representation of this test room. In the actual experimental test program, a variety of tests were conducted that measured several variables within the room including temperature, velocity, and heat flux. No fire was present in these tests; only a heating element was used to induce the convective flows around the test chamber. The FDS model representation of this case was reproduced as close to the detail of the test chamber as could be achieved. A source boundary condition was added to the FDS model of this room to mimic the heating element within the test case. Data collected from the test series was then analyzed and compared with results produced by the FDS model. Comparisons were made between the predicted and actual temperature and velocity profiles at several locations within the test room.<sup>5</sup>

In this study, several variables were adjusted to observe their influence. Cell size dependency, the subgrid scale coefficient (Cs), and the Prandtl number were varied, and the results of each variance were compared to the test data. Figure 6 shows some of the model results.

Overall, the results indicated that the FDS model predictions agreed well with the room test data for both mean temperature and velocity, with one exception near the boundary surface located at the ceiling. The analysis also noted that the temperatures predicted by FDS were dependent upon the cell size and that the Prandtl number also influenced the temperature results.

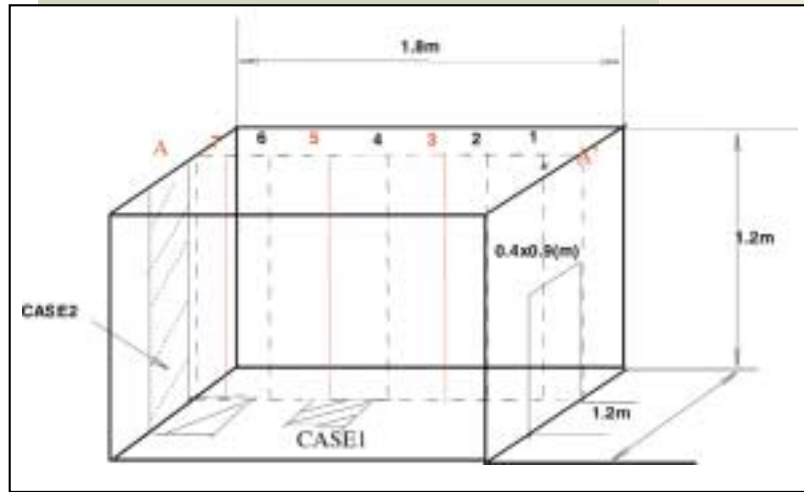


Figure 4. Test room setup.

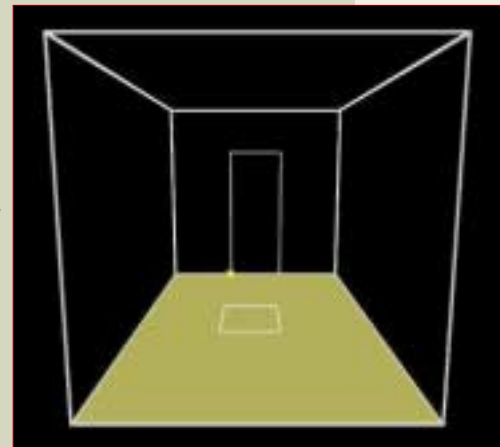
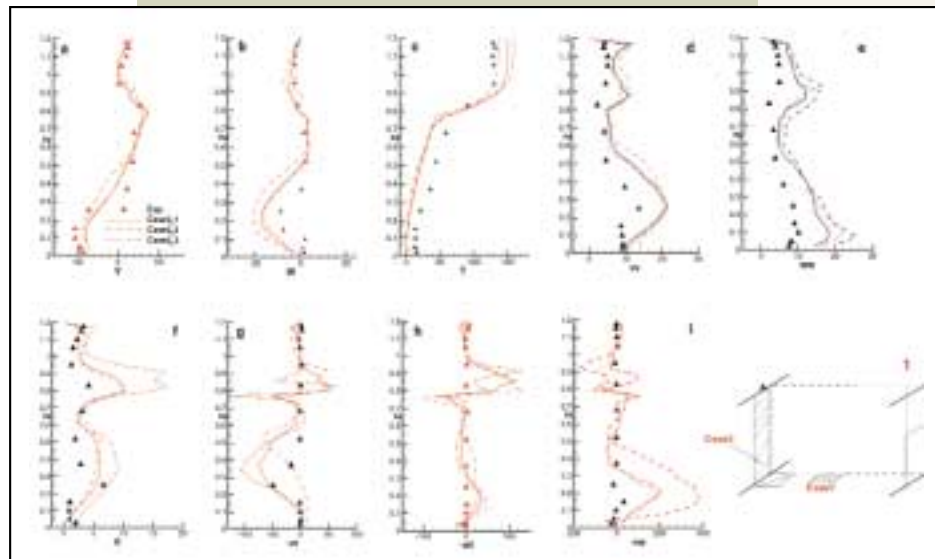


Figure 5.  
Smokeview  
representation.

Figure 6. Comparison  
of FDS results with  
test data.



## Case 2

# Calibration of a Burning Couch

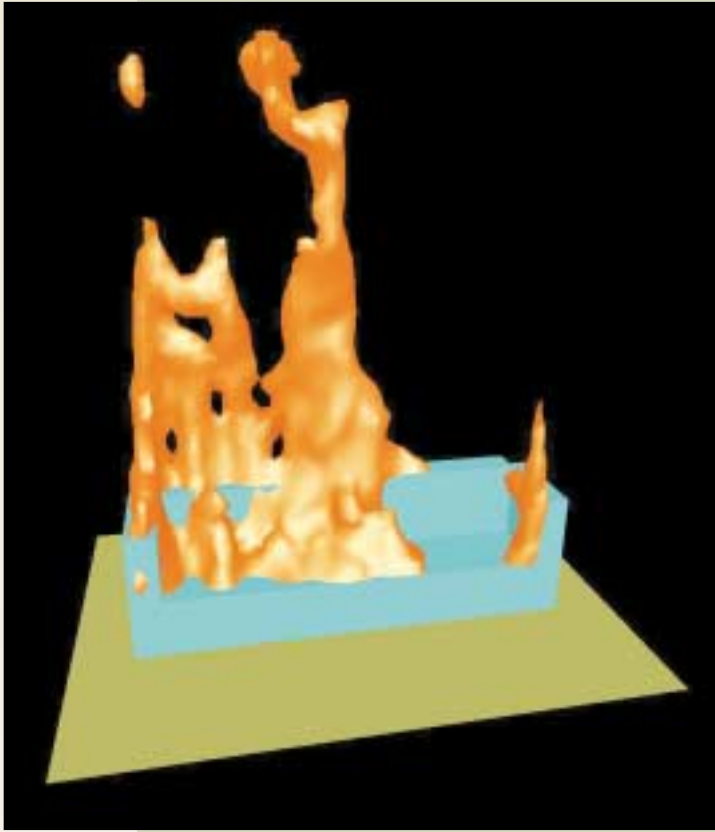


Figure 7. Couch fire simulation.

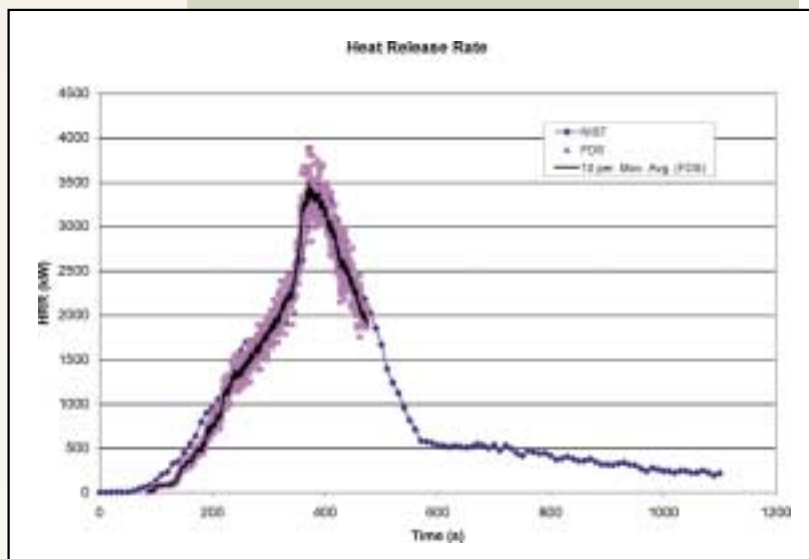


Figure 8. Comparison of FDS results with test data.

The second case illustrated was a model of a burning couch. A source of information pertaining to fire properties and material response to fire is maintained by NIST and can be found at [www.fire.nist.gov](http://www.fire.nist.gov). Among other pieces of information, heat release rate curves for various types of furniture are posted on this site. One in particular, a burning couch, was downloaded, and the data were compared with an FDS model prediction for flame spread and the heat release growth rate. Using the FDS code, the geometry of a couch closely matching the dimensions of the couch burned by NIST was modeled. Figure 7 depicts the fire in progress on the couch. Material properties for the couch were obtained and defined within the model. A small ignition source was added to represent the ignition source used during the NIST test burn. The couch was allowed to “burn” solely based upon its prescribed material properties.

A heat release rate comparison was conducted between the actual data and the predicted values produced by the FDS model. After several iterations of redefining the physical dimensions of the modeled couch (exact dimensions of the NIST couch were unknown, thus a trial-and-error method was used), the model mimicked the entire burning history of the NIST couch. Figure 8 shows the heat release rate comparison between the actual and predicted values.

As a result of this analysis, a consistent burning object with a known heat release rate was produced. This burning object can now be “placed” within any modeled space and produce a similar known fire every time it is used. The benefit of this is that if a situation needs to be modeled that requires a couch as the first item ignited, no work is necessary to produce the desired ignition and early fire growth. This type of model analysis can be done for as many types of furniture as have heat release rate histories available in the literature. The future aim of this type of study is to produce a database of generic furniture that contains the geometry of the item, material properties, and ignition source necessary to reproduce known experimental data. From this database, a model developer could “pull” different furniture and use it as a possible ignition source within a model.

# Case 3

## Sprinkler Activation Study

The third case investigated involved a model of a rack storage arrangement within the Southwest Research warehouse test facility. In this scenario, several tests were conducted with different rack storage commodities to determine how the commodities would react to fire and suppression of that fire. This scenario included a set of test data which was used for comparison with the FDS sprinkler sub-model.<sup>6</sup>

The constructed geometry included the test chamber, commodity rack storage, and sprinkler array. The fire was modeled as the heat release rate data measured in the experimental tests. Sprinklers were also represented in the model, and the appropriate values for the sprinkler parameters (RTI, activation temperature, etc.) were obtained to match the test room sprinklers. Figure 9 depicts the Smokeview representation of the test facility and the boxed commodities within.

The results of the modeling indicated a good agreement between the FDS-predicted sprinkler activation times and the recorded activation times for the first two sprinklers. In fact, the predicted values of activation for these sprinklers were within a few seconds of the actual activation times. FDS also predicted the correct order of actuation for these sprinklers. In the actual test, the chamber overpressurized and blew out the east wall. At that point, a deluge system activated which changed the flow patterns in the room and skewed the rest of the sprinkler activation data. This study demonstrates that the FDS sprinkler activation submodel is reasonable for activation times of the sprinklers closest to the fire, but further studies and model improvement may be needed to expand model accuracy beyond the first ring. Figure 10 depicts a snapshot of the modeled fire in progress. Table 1 is a chart that contains the actual and predicted values of the sprinkler activation.

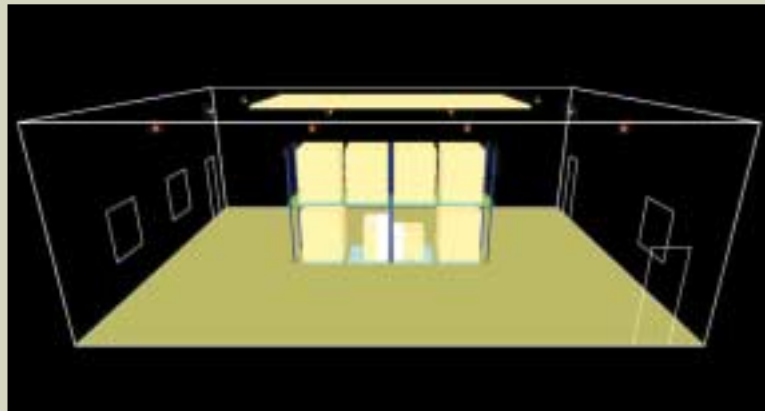


Figure 9. Test facility representation.

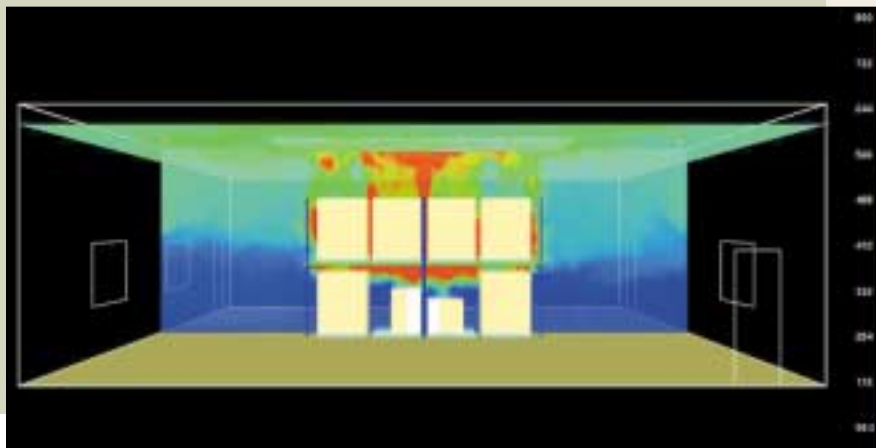


Figure 10. Fire simulation.

Sprinkler identification #	SWRI activation time(s)	Predicted activation time(s)
7	90	95.5
6	95	94.7
deluge system activated	96	—
1	100	118.0
2	100	116.1
8	100	115.6
10	100	115.4
11	100	117.1
5	105	116.2
9	105	120.0
12	105	120.8
3	115	119.9
4	115	122.90

Table 1. Actual and predicted activation time.

# Case 4

## Flow Field for Laboratory Hood and Exhaust Duct

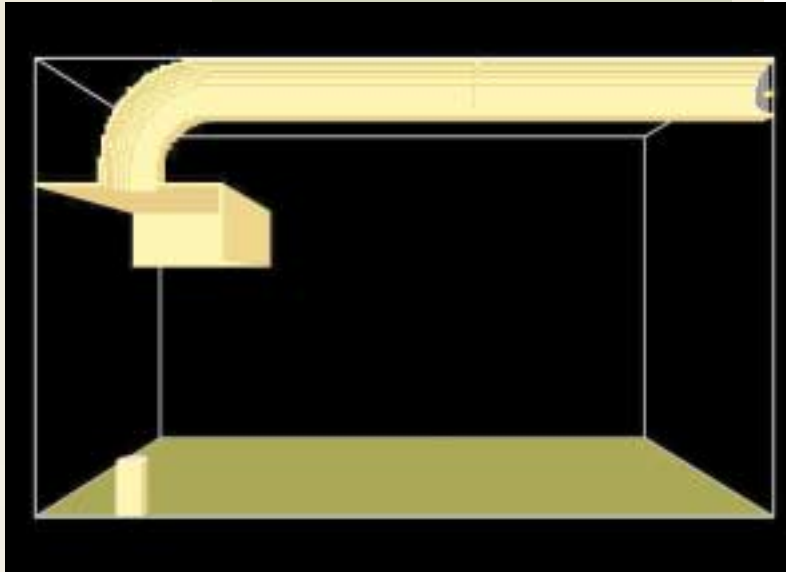


Figure 11. Laboratory hood and exhaust duct representation.

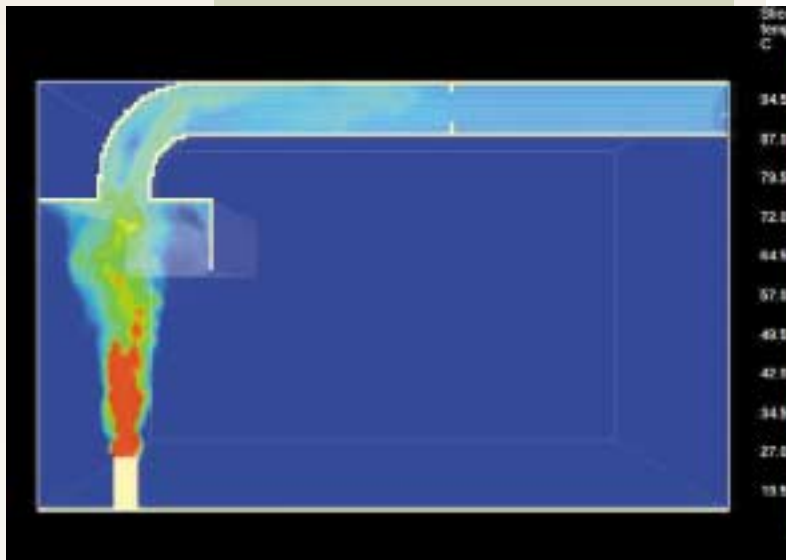


Figure 12. Flow structure simulation.

The fourth case is an analysis of the flow structure within an exhaust duct for a laboratory hood. The geometry for the model was constructed by utilizing the previously described procedure for meshing complicated geometries. Both the hood and the exhaust duct were modeled. Figure 11 depicts the Smokeview representation of the setup.

Measurements were gathered at various points downstream from the hood, and a well-defined heat release history was produced from calorimetry. This history was used as the fire source within the FDS model of the system. The FDS model was used to predict the appropriate downstream velocity and temperature.

In order to perform calorimetry with the exhaust system, a gas sampling device was required at some location downstream from the hood in the exhaust duct. The probe was required to be placed such that a uniform mixture of exhaust gases was sampled. Without knowing the flow structure within the exhaust duct, placement of the sampling probe was originally installed using a trial-and-error method. The FDS model of the hood and duct was used to resolve the flow structure and determine the ideal probe placement location for maximum downstream gas exposure. Figure 12 shows a snapshot of the flow field within the hood and duct.

The hope is that with time and development, the FDS model will become more capable of solving laboratory problems such as this. In time, it is envisioned that both small and large experiments, such as calorimetry experiments, could be predicted using FDS before actually conducting an experiment. In this way, preliminary results from modeling could be used to fine-tune the actual test and produce a more focused and efficient experimental test series.



## Smoke Detector Activation

Smoke detector activation depends on several factors, including the presence of a sufficient concentration of smoke at a detector location as well as flow velocities high enough to overcome the entrance resistance of the smoke detector. Predicting smoke detector activation due to fire can become an important issue in fire investigation and hazard analysis. By correctly modeling the geometry and fire at a fire scene, detector activation times can be garnered and used to construct a possible timeline of events. Examining the applicability of a model with regard to this important problem is the subject of this fifth example.<sup>7</sup>

A two-step procedure for predicting smoke detector activation within a model system was proposed. Both criteria included would need to be tested to ensure good smoke detector activation predictions. First, the movement of smoke or fluid within the model was compared to known fluid flow data. Second, the actual smoke prediction technique was compared to several known data sets of smoke detector activation times.

The first phase of this approach was accomplished by taking advantage of data detailed in the Underwriters Laboratory (UL) 217<sup>8</sup> standard. The standard lists a stringent set of requirements on when smoke from a prescribed fire source must reach each of the sampling locations within a testing room. The geometry of the UL test room was recreated in FDS, and the prescribed fire source was modeled.

A reliable method of modeling smoke was then formulated. The FDS (Version 1.0) code does have a built-in smoke density routine that allows for the tracking of smoke particulate. Unfortunately, this routine is tied to the production of the energy particles used for the transport calculation. This can result in one particle, traveling across the model domain, that represents a large number of soot particulate. Output data produced are extremely scattered and hard to analyze.

A better way to model smoke flow with FDS (Version 1.0) is to create a new gas species that closely resembles air in its molecular weight. By creating this species and giving it an appropriate yield, the model can more accurately track spread and concentration of this "smoke" throughout the domain.

A comparison between the FDS-predicted smoke arrival times and the UL standard expected times was obtained. Table 2 shows the results of the FDS predictions and the UL 217 requirements. The model accurately predicted the smoke arrival times outlined in UL 217.

The second step in the approach was to use this technique to obtain a prediction from an FDS model as

UL Smoke Profiles		
<b>Smoke buildup shall occur:</b>	<b>UL requires(s)</b>	<b>FDS(s)</b>
Ceiling Detector	35-45	40
Sidewall Detector	25-35	34
<b>33% obscuration per meter smoke shall occur:</b>	<b>UL requires(s)</b>	<b>FDS(s)</b>
Ceiling Detector	70-90	74-97
Sidewall Detector	60-80	60-78
<b>33% – 43% obscuration per meter smoke shall remain:</b>	<b>UL require(s)</b>	<b>FDS</b>
Ceiling Detector	90-120 (end)	yes
<b>33% – 56% obscuration per meter smoke shall remain:</b>	<b>UL requires(s)</b>	<b>FDS</b>
Sidewall Detector	80-120 (end)	yes

Table 2. Results of FDS predictions.

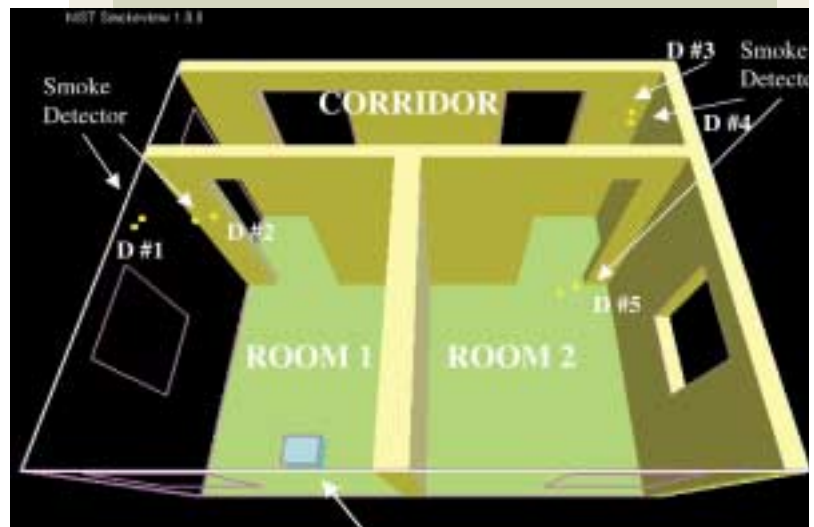


Figure 13. Test setup facility.

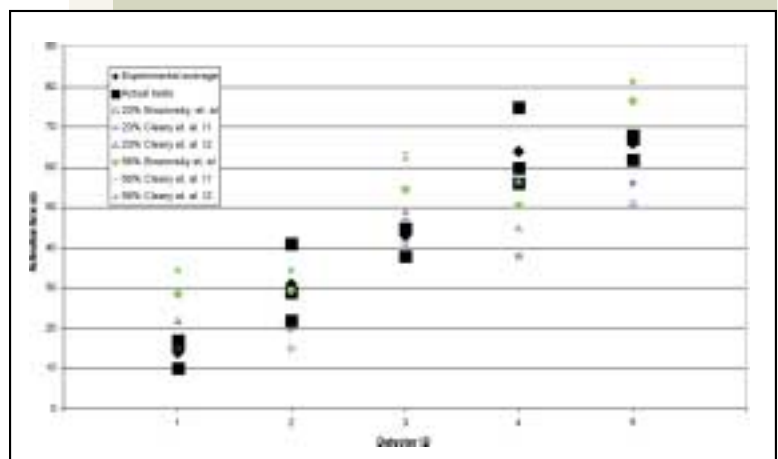


Figure 14. Comparison of predictions and test data.

to when a smoke detector would actually activate. For this step, data were available from several in-house experiments that were conducted in a burn facility. The facility consisted of two small rooms connected by a common corridor. Figure 13 depicts the two room setup. A model was built to represent this test facility and the fire source. Measurements of smoke concentration and temperature were recorded for comparison with the actual data.

To determine when a detector activated within the model, a detailed set of criteria was determined. The first criterion was that the smoke concentration around the detector location needed to be equivalent to 7 % – 17 % obscuration per foot. UL 217 lists this range as a typical observed range of activation with various fire sources within their standard test room and is applicable for all detector types and sensitivities. The second criterion deals with the lag time associated with the flow restriction as the smoke penetrates the detector housing. This lag time is directly dependent

on the velocity of the smoke as it reaches the detector. Figure 14 shows the results of this type of analysis for the room corridor configuration that was modeled. The results produce a bounded range over which the model predicts smoke detector activation.

*Jason Sutula is with Combustion Science & Engineering, Inc.*

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Figure 1. One Embarcadero South

**By Sanjay Aggarwal, P.E.,  
Brian D. Gagnon, and  
Mark D. Reed, P.E.**

## INTRODUCTION

**M**odel building codes such as the Uniform Building Code (UBC) include smoke control requirements for high-rise buildings and large spaces such as atria and malls. UBC smoke control provisions are based upon the system design criteria originally specified in NFPA criteria.<sup>1,2</sup> As building designs become more complicated, the environmental effects on the smoke control system become more difficult to assess. Network flow models, which allow the user to subdivide a building into multiple compartments or zones and evaluate the airflow and pressure difference between these different areas, can be used to analyze the impact of environmental conditions on building smoke

# SMOKE CONTROL ANALYSIS OF A HIGH-RISE BUILDING USING A NETWORK AIR FLOW MODEL

control systems. A network flow model, CONTAM96,<sup>5</sup> was used to analyze the impact of wind and temperature changes on the smoke control system design at One Embarcadero South\* in San Francisco.

Many high-rise smoke control systems are designed to maintain a prescribed pressure difference across smoke barriers within the building. The UBC specifies the pressure differential required, but does not detail how this differential should be developed or maintained. The UBC requires pressure differentials of 0.05 inches of water gage (12 Pa) to be maintained between smoke control zones in sprinkler-protected buildings. Additionally, stairs in high-rise buildings are required to be provided with entrance vestibules. The vestibules are required to be pressurized with respect to the fire zone to 0.05 inches of water gage (12 Pa), while maintained at a negative 0.05 inches of water gage (12 Pa) with respect to the stair. These pressure differentials are intended to prevent smoke movement from one zone to another. This performance-criteria approach allows broad design flexibility in meeting the project's safety goals.

The UBC also includes provisions for smoke control systems designed to exhaust a space to maintain smoke at a specified elevation above the highest walking surface as well as systems designed to maintain a specified airflow through an opening to prevent smoke migration through the opening. Smoke control systems designed using the "Exhaust Method" are typically used in atria, malls, and other similar large spaces. The "Airflow Method" of smoke control is typically used in specialized situations to prevent smoke flow through fixed openings. While there are different means to control the migration of smoke and limit its impact on the building occupants, the project referenced above utilized the "Pressurization Method" of smoke control.

## ANALYSIS METHODS

The smoke control systems for most high-rise buildings can be analyzed using a series of orifice flow and pressure relationships developed from equations presented in the book *Design of Smoke Management Systems*.<sup>3</sup> These equations can be applied inde-

pendently to determine the mechanical exhaust or supply air needed to develop the required pressure differentials for the smoke control zones, as well as the stair pressurization systems. Smoke is prevented from moving between zones by airflow through the building construction elements.

The simplified flow and pressure relationships specified in the reference design text provide useful tools for buildings without openings in the exterior walls and of relatively limited building heights.<sup>3,4</sup> However, the following circumstances represent design scenarios that are difficult to accurately evaluate with the simplified flow and pressure relationships:

- Wind effects on buildings with operable windows.
- Temperature differences between the interior and exterior of the building and the impact of stack effect on taller buildings.
- The impact of mechanically induced airflows and the interaction of adjacent zones.

The simplified flow and pressure relationships described briefly above can approximate these conditions. However, a more accurate assessment of these effects is often necessary in more complicated buildings. CONTAM96 provides a means to more accurately assess the impact of the factors listed above.

CONTAM96 is a multizone indoor air quality and ventilation analysis computer model, developed at the National Institute of Standards and Technology (NIST).<sup>5</sup> NIST has recently released CONTAMW, a Windows-based version of the CONTAM96 model. CONTAM96 simulates the airflow within a building by representing the building spaces as a network connected by airflow paths. The user enters the basic building layout, the ambient environmental conditions, the natural airflow paths throughout the building, and the building mechanical system. The airflow paths are comprised of doorways, windows, vents, and leaks in building assemblies. CONTAM96 can be used to simulate infiltration, exfiltration, room-to-room airflows induced by mechanical means, wind pressures acting on the exterior of the building, and buoyancy effects (stack effect) induced by temperature differences between the building and

the outside. It can also be applied to evaluate pressure differences between compartments, direction of mass flow, and movement of smoke.

## CASE STUDY

### BUILDING DESCRIPTION

One Embarcadero South is a fourteen-story, high-rise building recently constructed in downtown San Francisco, CA, overlooking the Bay Bridge and PacBell Ballpark. Figure 1 shows a view of the front façade of the building.

The lower two floors of the building consist of a parking garage and mixed-use areas. The third through the fourteenth floors of the building contain residential units. Above the ninth floor, the building is divided into two towers. The residential units are provided with operable exterior windows. Figure 2 provides a schematic view of the eighth floor of the building. This floor is typical of the residential floor plates located within the building. The 19 residential units are served by a central corridor, which provides access to the apartment units.

### SMOKE CONTROL SYSTEM DESIGN

The smoke control system design includes a combination of passive and active zones. Each floor was designed as a separate zone. Additionally, each floor of each tower was considered a separate zone. The corridor walls on the residential floors are constructed as



Figure 2. Eighth floor schematic plan.

smoke barriers. The overall smoke control design approach was to maintain the UBC-mandated pressure differential between the stairs, the vestibules, and the fire floors. Additionally, the system was designed to maintain a negative pressure differential between the corridor on the floor of alarm and the floors above and below. The residential units on each floor were defined as passive subzones within the overall floor zone, and the system was designed to prevent smoke migration from the corridor to the residential units.

The initial analysis of the building utilized the flow and pressure relationships and correlations to estimate the fan capacity needed to maintain the pressure differentials required by the UBC in the stair and on the fire floor. The stair pressurization systems were designed to account for a conservative estimate of stack effect, to maintain the code required minimum pressure differentials, and to prevent overpressurization of the stairs. These calculations were completed assuming that the building exterior openings were closed. Due to the existence of operable windows throughout the building, the Authority Having Jurisdiction required a more thorough analysis of the wind effects on the mechanical smoke control system. These effects were modeled using the CONTAM96 network flow model.

## MODEL APPLICATION

The CONTAM96 model was used in this high-rise smoke control analysis to verify that the system could maintain the original design criteria and the pressure differences under a variety of reasonable environmental conditions with different exterior opening scenarios. Additionally, the CONTAM96 model was used to evaluate door-opening forces throughout the building. The program yields the pressure differential across a flow path, allowing the user to evaluate the door opening forces.<sup>1</sup> The program was also used to evaluate the air movement direction between the corridor and the residential units on the floor of alarm. The design intent was to maintain the flow direction from the unit to the corridor in alarm to prevent smoke migration to the individual residential units. The program was not used to evaluate the movement of "hot"

smoke within the building, as the goal of the system is to achieve the code-mandated pressure differentials.

The CONTAM96 model was solved using one-way flow equations based upon connection data described in the ASCOS powerlaw model.<sup>3</sup> Stair enclosures were modeled assuming the stair as a series of vertical zones connected by low-resistance openings. Each of these modeling techniques required the user to specify the dimensions of the opening and/or the configuration of the element. For example, doors are specified in the model by providing an overall area of the opening, a midpoint height of the opening, and a flow coefficient. Stairs are incorporated into the model by specifying the distance between the levels, the cross-sectional area, the density of the people within the stair, and a basic description of the stair treads.

## MODEL INPUT AND RESULTS

The CONTAM96 sketchpad was used to create a schematic representation of the building to be analyzed. This schematic representation is not intended to produce a scale drawing of the building, but is used to represent the general building layout similar to the actual design onto which the user can add the flow paths and mechanical inlets and outlets. Figure 3 represents a sample drawing of the same building floor shown in Figure 2. The building flow paths consist of the various doors and windows, as well as leakage through the walls, floors, and ceiling elements throughout the building. The leakage through the walls, floors, and ceiling elements is generally based upon the leakage area ratios presented in the UBC. However, more specific values are presented in various reference texts based upon the construction of the building.<sup>4, 6</sup>

The model requires mechanical supply and exhaust quantities as inputs, and provides airflow and pressure differences between various zones as output. The output is given for each flow path specified in the model by the user. Therefore, the building smoke control system was specified using the fan capacities calculated by the pressure and flow relationships developed from the equations presented in *Design of Smoke Management Systems*.<sup>3</sup> These

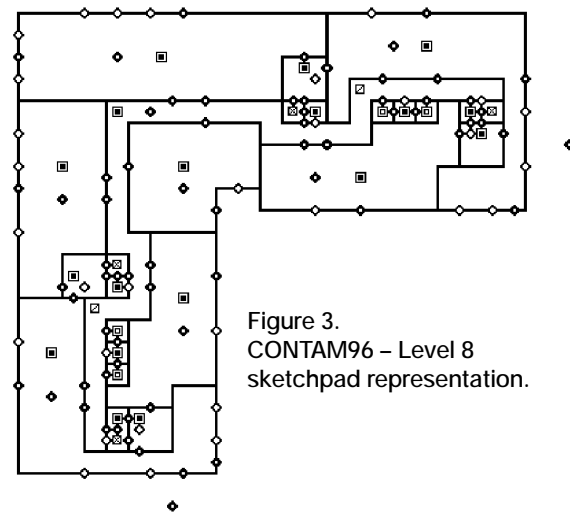


Figure 3.  
CONTAM96 – Level 8  
sketchpad representation.

mechanical systems were simulated using simple air-handling systems, which provide a means to specify the mechanical supply or exhaust in a specific area without having to draw and specify the entire mechanical duct system.<sup>5</sup> Each smoke control zone was provided with exhaust outlets in the corridor area. The stairwell pressurization system was designed as a multi-injection system with injection points located approximately every third floor. This design specification was coordinated with the mechanical engineer for the project. Figure 3 shows a typical floor representation in the CONTAM96 flow model. A more detailed description of the model input and symbols shown in Figure 3 is included in the CONTAM96 users manual.<sup>5</sup>

Each floor was analyzed as part of the CONTAM96 evaluation of the building. Due to the height of this building, stack effect was relatively limited, and the simplified flow and pressure relationships provided a reasonably conservative means to estimate the fan capacity required for the stairwell pressurization system. However, these aspects of the smoke control system were incorporated into the CONTAM96 analysis as part of the overall system.

The exterior operable openings were incorporated into the network flow model in a manner that allowed the user to analyze a variety of window configurations. The ambient environmental data were determined from the data presented in ASHRAE Guidelines for the City of San Francisco,<sup>4</sup> as well as local requirements enforced by the Authority Having Jurisdiction. Wind speeds up to 29 miles per hour (13 m/s) were used to evaluate the smoke

control system design. The stack effect was evaluated by assuming a winter temperature of 37°F (3°C) and a summer temperature of 84°F (29°C).

## WIND ANALYSIS

CONTAM96 evaluates wind effects on the building based upon the pressure coefficients on the exterior walls of a building. These coefficients are functions of the building geometry and local wind conditions and obstructions. Theoretical wind pressure coefficients that are dependent upon the exterior building geometry can be used to develop a general wind profile for the building.<sup>3,4</sup> Alternatively, wind tunnel tests can be performed on a representative model of the building, and wind coefficient factors measured at various points on the building's exterior façade. These measured wind pressure coefficients can then be used to obtain an overall wind pressure profile for the building based upon a variety of wind directions. The latter technique provides a scaled modeling representation, which takes into consideration the flow conditions created by the surrounding structures. The former technique, using the average pressure coefficients for the walls of the building based upon the exterior geometry, was employed at One Embarcadero South due to the unavailability of the wind tunnel test data. These average pressure coefficients were determined for a variety of wind directions.

Following the determination of the exterior wind pressure coefficients for the building, and the development of the basic building geometry in the model, the environmental information was incorporated into the CONTAM96 model at each exterior wall element and window opening. Much of the weather-related information is evaluated in the CONTAM96 model based upon the building geometry, the site conditions, and the ambient weather conditions. Over one hundred design scenarios using different combinations of floors in alarm, exterior building openings, wind directions, and ambient temperatures were analyzed. The scenarios evaluated consisted of a variety of conservative environmental and exterior opening configurations.

## RESULTS

Based on the results of the CONTAM96 modeling, the fan capacities estimated using the flow and pressure relationships required several adjustments. In particular, the effect of the wind on the leeward side of the building creates a negative pressure in the leeward residential units relative to the corridor on the floor of alarm. This results in a slight airflow from the corridor to some of the residential units. Because one objective of this smoke control system is to create positive airflow from the residential units to the corridor on the floor of alarm, the system was adjusted to compensate for the potential wind pressures. This resulted in airflow from the residential units to the corridor, as desired. Conversely, the CONTAM96 modeling indicated that the stair pressurization fan was oversized. This was expected, based on the conservatism included in the stair pressurization calculations used to estimate the fan capacity. At One Embarcadero South, the fan size was not changed because the mechanical design provided a means for adjusting the fan capacity during testing, and it was decreased at that time. These results are consistent with those obtained for other buildings where CONTAM96 or CONTAMW has been utilized.

*Sanjay Aggarwal, Brian Gagnon, and Mark Reed are with Rolf Jensen & Associates.*

## REFERENCES

- 1 NFPA 92A. *Recommended Practice for Smoke-Control Systems*. Quincy: National Fire Protection Association, 1996.
- 2 NFPA 92B. *Guide for Smoke Management Systems in Malls, Atria, and Large Areas*. Quincy: National Fire Protection Association, 1995.
- 3 Klote, J., and Milke, J., *Design of Smoke Management Systems*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1992.
- 4 ASHRAE. *ASHRAE Handbook – Applications*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1997.
- 5 NISTIR 6476. Walton, G., *CONTAM96*. Gaithersburg: National Institute of Standards and Technology.
- 6 Klote, J., "Smoke Control," *SFPE Handbook of Fire Protection Engineering*, 2nd Ed. P.J. Dinunno (ed.), NFPA, Quincy, MA, 1995.

\*Additional information on One Embarcadero South is available at [www.liveatone.com](http://www.liveatone.com)

# Products/Literature

## Dry System Trouble Alarm

Potter Electric Signal Co. introduces the Dry System Trouble Alarm (DSTA). The DSTA is a microprocessor-based local supervisory annunciator designed to monitor low/high air pressure and low room temperature of a Dry Pipe Sprinkler System Riser (Pressure & Room Temperature Switch sold separately). Each unit is equipped with an LED, an internal buzzer, and a set of S.P.D.T. dry relay contacts that may be used for remote annunciation.

[www.pottersignal.com](http://www.pottersignal.com)  
—Potter Electric Signal Co.



## Addressable Charger/Power Supply

The ACPS-2406 is a 24 VDC, 6-amp addressable power supply with an exclusive built-in strobe synchronization and flexible, addressable



Notification Appliance Circuits (NACs) for use in emergency warning. It has two Class A or four Class B NACs. Each of the four NACs can be programmed to run in either synchronized or nonsynchronized modes with System Sensor or Gentex audiovisual devices.

[www.notifier.com](http://www.notifier.com)  
—Notifier

## Cable/Pipe Support

The new Plenum Pier effectively supports cabling and piping in air handling spaces. It is ideal for underfloor and clean room applications because it keeps services off the floor and provides support independent of raised floor pedestals. The Plenum Pier consists of polyethylene foam, which absorbs vibrations and shock, and accommodates expansion and contraction of piping.



[www.erico.com](http://www.erico.com)  
—ERICO®, Inc.

## Mechanical Seal

The Metraflex MetraSeal 120™ is a fast, permanent, fireproof, waterproof, intumescent, mechanical seal that works as a fire stop, filling the gap with a consistently verifiable thickness around any steel, copper tubing, and up to 2-in. PVC/CPVC pipe. Unlike caulk, there is no curing time, so codes are met as soon as the MetraSeal 120 is installed. It is an ideal solution for mechanical rooms.



[www.metraflex.com](http://www.metraflex.com)  
—The Metraflex Company

## New Design For Elastomeric Couplings

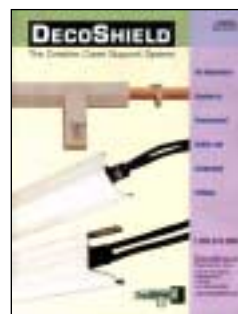


A new design of Jaw In-Shear elastomeric couplings (designated JIS 6-Pin) improves the no-tools elastomeric element locking system, adds six larger

sizes extending maximum bore up to 9 in., and introduces a JIS spacer-type series intended as nonlubricated, drop-in replacements for grid spacer couplings. Features include interchangeability and the advantage of working with both new and old ring designs.

[www.lovejoy-inc.com](http://www.lovejoy-inc.com)  
—Lovejoy, Inc.

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[www.decoshield.com](http://www.decoshield.com)  
—DecoShield® Systems, Inc.

## Duct Smoke Detectors

The D350P and D350RP combine photoelectric detection technology with a housing design that samples air passing through the duct, allowing any developing hazard to be detected quickly. Detection inside the air duct system allows the problem to be isolated before smoke and fire gasses are carried throughout the entire building via the HVAC system.



[www.firelite.com](http://www.firelite.com)  
—Fire•Lite Alarms, Inc.

## Specification Software

SpecBuilder, a new engineering software tool, makes writing and editing Section 13850 performance specifications fast and simple. Its easy-to-use tree format keeps the contents of the specification organized to Construction Specifications Institute (CSI) standards at all times, while its preview panes ensure that what you see will be what you get – from the initial tree view to the final output.



[www.est.net](http://www.est.net)  
—Edwards Systems Technology, Inc.

## Intelligent Detection

The MCS-Aclimate intelligent detector uses the latest advances in software to continuously sample the air in the environment and adjusts its detection threshold accordingly. It does this automatically, with no need for an installer to set sensitivity levels. This new sensor incorporates both thermal and photoelectric technologies that interact to maximize detection. Also, an onboard microprocessor and advanced software focus on rejecting nuisance alarms.

[www.firecontrolinstruments.com](http://www.firecontrolinstruments.com)  
—Fire Control Instruments, Inc.



## Firestop Listings

ProSet Systems presents its Firestop Listings in a 44-page booklet. Among the features of its products are pipe sleeves that automatically firestop, plumbing openings that automatically firestop, cost-effective fabrication methods and systems, and advanced innovative plumbing technology.

[www.prosetsystems.com](http://www.prosetsystems.com)  
—ProSet Systems, Inc.



## Fire Alarm Control Panel

Fike Corporation is pleased to announce the introduction of the Shark analog, addressable fire alarm control panel. The Shark brings Fike's reputation and experience of building high-quality suppression panels to the fire alarm market. By using the latest in technology and manufacturing techniques, the Shark system is feature-rich, cost-effective, and backed up with the same reliability built into all Fike control panels.

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—Fike Corp.



## Fire-Resistant Glass



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[www.pilkington.com/northamerica](http://www.pilkington.com/northamerica)  
—Pilkington North America, Inc.

## Smoke Detector Has Easy-Reach Controls

The FireRay 2000 optimal beam smoke detector allows the user to carry out basic control functions from a convenient location at floor level. Designed for fire protection in buildings with large interior spaces and high ceilings, it comprises an infrared transmitter, a receiver, and a compact, wall-mounted controller. A separate controller allows users to adjust sensitivity levels and check alarm and fault status, without climbing or going to the building's main fire control panel.

[www.ap-c.cc](http://www.ap-c.cc)  
—Air Products and Controls, Inc.





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Info: [www.iafss.org](http://www.iafss.org)

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## UPCOMING EVENTS



# B R A I N T E A S E R

Find the largest prime number that divides  $87! + 88!$ .

Thanks to Jane Lataille, P.E., for providing this issue's brainteaser.

## Solution to last issue's brainteaser

Solve the following equation for  $x$ :

$$(x^2 - 5x + 5)^{(x^2 - 9x + 20)} = 1$$

$x = \{1, 2, 3, 4, 5\}$ . The equation holds whenever the base is 1 or the exponent is 0. It also holds when the base is -1 and the exponent is even.

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The purpose of professional licensure is to establish that an engineer is at least “minimally competent” to practice engineering. As the quality of engineering can affect public safety and welfare, licensure as a professional engineer indicates that an engineer is competent to practice engineering without the supervision of others. Successfully taking a professional engineering exam is but one of many requirements for licensure as a professional engineer.

Like other engineering disciplines, fire protection engineering designs are vital to the safety and well being of the public. Without the fire protection engineering professional engineering exam, there would be no regulatory mechanism to ensure minimum competence of fire protection engineers, which could have a detrimental effect on public safety.

In the United States, professional engineering licensure examinations are divided into two groups: Group I and Group II. The Group I examinations have the largest number of test-takers: electrical engineering, mechanical engineering, civil engineering, and chemical engineering. Group II examinations are for the smaller disciplines: fire protection, naval architecture/marine engineering, agricultural, control systems, environmental, industrial, manufacturing, metallurgical, mining/mineral, nuclear, petroleum, and structural.

Because of the large number of professional engineering candidates in the Group I disciplines, Group I examinations are administered twice a year, while the Group II examinations are only offered once per year. Of the Group II examinations, fire protection typically has the largest or second-largest number of takers.

While there is some overlap between the core knowledge areas associated with fire protection engineering and those associated with the Group I disciplines (e.g., hydraulics, heat transfer, and electric circuits), several fire protection engineering core knowledge areas cannot be found in any of the other ex-

aminations (e.g., fire dynamics and fire suppression). Additionally, for the areas where fire protection engineering overlaps with other engineering disciplines, fire protection engineering frequently requires the integration of different types of systems that would otherwise be designed by engineers of varying disciplines.

While SFPE writes the FPE PE exam, the National Council of Examiners for Engineering and Surveying (NCEES) administers the exam. Similarly, NCEES administers examinations in the other disciplines that are written by other organizations.

The lower number of test-takers in comparison with the Group I examinations creates challenges for all of the Group II examinations. Specifically, because far fewer people take the Group II exams, they are more expensive on a per-person basis than the Group I exams. Also, the lower number of test-takers translates into a lower confidence in the conclusions of statistical analyses of examination results. NCEES has formed a task force to consider what, if any, changes should be made to the administration of the Group II exams in the future to explore these, and possibly other, issues.

The Society of Fire Protection Engineers is privileged to have immediate past president Wayne Moore, P.E., as one of only two liaison members of the NCEES task force that is considering the future of all the Group II exams (full membership on the task force is limited to people affiliated with a jurisdictional licensing board in the U.S.). While the review of Group II exams presents a short-term challenge, we will surely withstand this challenge. Additionally, this process creates an opportunity, in that there is also the potential for increased recognition among licensing boards of the importance of fire protection engineering.

A handwritten signature in black ink that reads "MORGAN". The signature is stylized with a long, sweeping horizontal line extending to the right.