PROVIDING PRACTICE-ORIENTED INFORMATION TO FPEs AND ALLIED PROFESSIONALS

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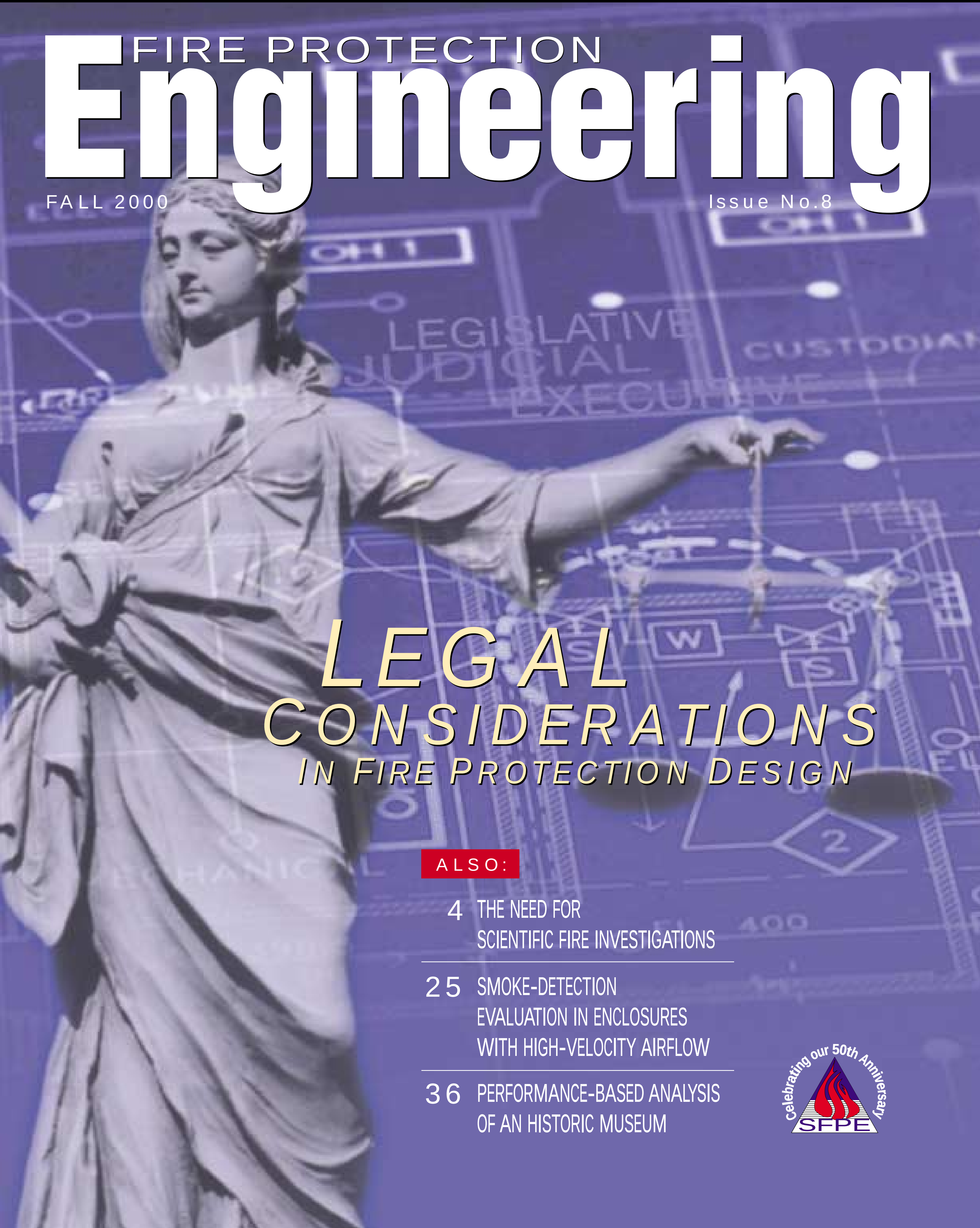

LEGAL CONSIDERATIONS IN FIRE PROTECTION DESIGN

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FIRE PROTECTION
Engineering

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THE REGULATION OF BUILDING SAFETY: THE EVOLUTION OF TECHNOLOGY AND THE LAW

The legal system has been used to control the safety of buildings since at least the time of Hammurabi. However, each time technology changes, there is a reexamination of the relationship between the legal system and building technology. The development of performance-based codes has sparked such a discussion. In a very real sense, there is nothing really "new" about performance-based design. The Code of Hammurabi illustrates that the critical questions for any law dealing with building safety were known from ancient times. Each society in its own era must wrestle with these basic issues.

The first questions deal with whether the goals of the code are public or private. Do codes fundamentally exist to protect public safety or to protect private safety interests? The concern with public safety is the most obvious. The problem of conflagration has evolved directly with the development of cities. Cities tended to have very vulnerable, valuable buildings crammed closely together. Many of the early fire and building codes were concerned with preventing the spread of fire throughout a city or district. Brick exterior walls, clay tile roofs, and other traditional requirements were combined with wider streets and building setbacks to try to avoid spreading fire from building to building. But codes are also used to provide legal protection for individuals themselves. In Hammurabi's famous code, the focus was on private, not public safety.

> *229. If a builder builds a house for some one, and does not construct it properly, and the house which he built falls in and kill its owner, then that builder shall be put to death.*

A second issue involves the question of whether codes are designed to protect lives or also property. One suggestion being made routinely in the performance-based environment is that codes should only protect life safety, and that somehow property protection is a purely private matter between a building owner and an insurer. However, this is clearly a policy choice. All societies depend, at least in part, on the preservation of property in private hands, and codes are an effective means of protecting that property from wanton destruction. The Code of Hammurabi protected both lives and property:

> *232. If it ruins goods, he shall make compensation for all that has been ruined, and inasmuch as he did not construct properly this house which he built and it fell, he shall re-erect the house from his own means.*

A third major issue is the method by which the legal system makes sure that builders create safe buildings. Fundamentally, there are two legal approaches, direct and indirect. The direct approach is found in the typical code environment; the law works directly by specifying the required behavior. At the first stage of the analysis, it does not matter whether it s a prescriptive or a performance code. No matter what form the code takes, all such approaches are direct. The code states what has to be done to be in compliance with the law.

An alternative is the indirect approach. In the indirect approach, the law describes a level of safety which must be achieved or states that damages must be paid to those whose persons or property are injured. The Code of Hammurabi used this indirect approach.

Within the direct approach, there is a wide variety of different combinations of code elements that can be used. Terms such as specification and performance requirements are normally used to differentiate these different concepts. In all cases, however, the government controls what technology can be used and what types of buildings can be built.

One advantage of the indirect approach is technological flexibility. As long as the losses are fully and fairly compensated, the builder will have an appropriate incentive to use the most efficient technology to achieve the required result.

Direct and indirect approaches can, of course, be used together. We have direct regulation of driver's activities, but we also require them to carry automobile insurance to compensate the victims of driving failure.

A fourth major issue is the point in time when the code is applied. Some codes rely on a "one-time approval" of a building, while others use the cradle-to-grave approach, where the building is supervised for safety and compliance throughout its lifetime.

A fifth major issue involves the method of enforcement of a code. Typical alternative forms of enforcement are direct inspection by regulators, self-certification by qualified professionals, and third-party approvals by authorized private bodies.

A sixth issue is the autonomy of the regulator in accepting any kind of variance or equivalence under the code. One of the most important characteristics of modern technology is that subtle changes in the technological mix can cause disproportionate changes in the effect of the technology. As a result, regulators are often in a difficult position when approving new technologies that do not correspond with traditional building systems. Do they have the authority and training to take risks in the acceptance of a new technology?

Every successful building safety regime selects a mix of approaches to address the issues mentioned above. There is no clear right answer to providing safe buildings. However the legal system can be used to flexibly incorporate almost any modern technology to accomplish the policy goals stated by the society.

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THE NEED FOR SCIENTIFIC FIRE INVESTIGATIONS

By Russell A. Ogle, Ph.D., P.E., C.S.P.

Forensic fire investigations are an important source of information about real fires. Fire scenes may contain valuable information about the cause (ignition), growth, and extinguishment of the subject fire. The lessons learned from fire investigations can be a useful form of feedback for the fire protection engineering community demonstrating how materials, products, systems, and people behave in real fires. In the absence of an accurate and reliable fire investigation, critical fire safety data may be lost forever once the fire scene has been rehabilitated. Thus, the fire protection engineering community should have a significant interest in the quality of fire investigations.

FIRE INVESTIGATION: ART VERSUS SCIENCE

The fundamental objective of a forensic fire investigation is to determine the fire origin (where the fire started) and cause (how the fire started). As is true for any accident investigation, the fire investigation task is difficult because an accident is an uncontrolled event. Some information which may be valuable to the investigation will be unavailable because it was not observed, was not recorded, or was damaged by the fire itself. No matter how much information the investigator may obtain, it will never be equivalent to conducting a carefully controlled experiment. Therefore, the investigator is forced to draw inferences from the available (albeit incomplete) data.

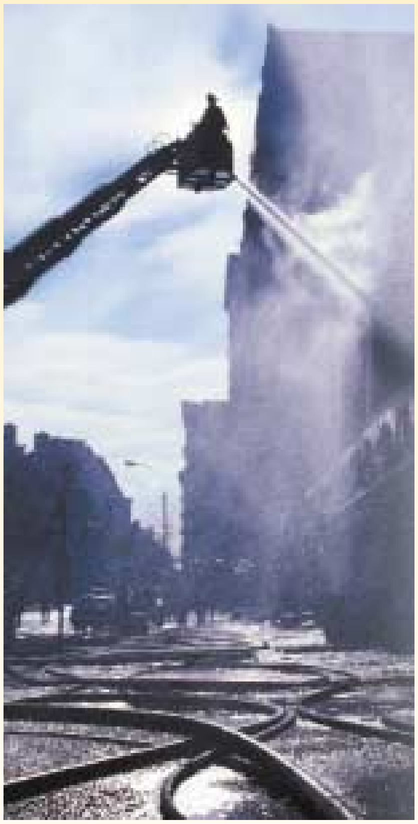
The challenge is to draw reliable inferences from the fire scene data. The thesis of this paper is that the scientific method provides the best strategy for drawing reliable inferences. This is also the thesis of NFPA 921, *A Guide for Fire and Explosion Investigations*[1], the guidance document published by the National Fire Protection Association. This thesis has aroused controversy among some fire investigators who argue that fire investigation is more art than science.[2, 3, 4] Their argument is that the art of fire investigation, i.e., the practical judgment gained through experience, is somehow superior to, or at least incompatible with, the methods of science.

The argument favoring art over science is false. While experience is a valuable source of personal knowledge, it can be a capricious and unreliable teacher. An informal generalization about fire pattern development formed from observation of actual fire scenes is an untested hypothesis. The hypothesis may be true or it may be false. The truth of the hypothesis can only be determined by testing it against further evidence. The testing of hypotheses to arrive at objective knowledge is the essence of the scientific method.

This debate over the role of the scientific method in fire investigation is not just a philosophical debate. It has had a profound impact on the litigation of fire losses.[5] The debate may be less substantive than some believe. The author's own anecdotal experiences have shown him that many fire investigators who have no formal training in science or engineering do indeed conduct scientific investigations.[6] This is not a paradox. The scientific method can be practiced in virtually any technical art. Indeed, the scientific method is the best strategy for seeking knowledge about the external world. How then does the scientific method work in fire investigation?

THE SCIENTIFIC METHOD IN FIRE INVESTIGATION

It is best to first begin by defining some terms. The scientific method is a process of inquiry which relies on four elements: observation, hypothesis, theory, and experiment. The interaction



of these four elements may differ from one situation to another, but the underlying objective is always the same: to obtain an objective understanding of the physical world.[7] Observation is the process of obtaining data from the external world by sense perception. By extension to instruments, observation includes quantitative measurements. An hypothesis is a testable proposition (or set of propositions), while a theory is an hypothesis which has survived testing. The term "theory" is a bit ambiguous for it may refer to a theory of fire causation (i.e., an explanation) or to a body of knowledge which is well accepted by the scientific or engineering community (e.g., thermodynamics). An experiment is a process of investigation in which circumstances are controlled so that variables can be changed one at a time to test an hypothesis. The forensic investigator must be cautious regarding the use of the word "experiment" because, in the legal arena, it has a very specific meaning (i.e., a precise reconstruction of the accident circumstances[8]) whereas the word "testing" is interpreted more broadly. In this paper, the phrase "empirical testing" will be used to denote an experiment, while the word "test" will be used to denote an attempt to prove or disprove an hypothesis.

The implementation of the scientific method requires two forms of reasoning: inductive and deductive.[9] Inductive reasoning is an argument in which the conclusion is probable. Deductive reasoning is an argument in which the conclusion is certain. NFPA 921[1] describes the implementation of the scientific method (pp. 9-10) and identifies the role of reasoning in two distinct steps: analyze the data (inductive reasoning) and test the hypothesis (deductive reasoning). In analyzing the data, the fire investigator is urged to develop a set of reasonable hypotheses as possible explanations for the cause of the fire. Then, the investigator is to challenge these hypotheses in an attempt to refute them. The only acceptable hypothesis is the one which survives these challenges and is best supported by the empirical data. The accepted hypothesis can then be considered to be the best explanation (theory) for fire causation.

There are several criteria which can be used to test fire causation hypotheses. These criteria can be ranked in order of strength, from stronger (empirical data obtained from the specific fire scene under investigation) to weaker (based on empirical data from other fire scenes). The suggested hierarchy of criteria is: physical evidence, empirical testing, engineering analysis, witness statements, and experience. The justification for the suggested hierarchy is based on the degree to which the criterion is susceptible to independent confirmation.

Physical evidence from the fire scene includes the physical appearance (fire patterns) of the fire scene and the physical objects and debris found at the scene. The location and orientation of fire damage patterns can reveal clues about the origin and cause of the fire. Documentation of the fire scene with still photography, sketches, and field notes provides the basic observational data for the fire investigator's future analytical efforts. In addition to documenting the fire scene, the fire investigator may collect physical artifacts from the fire scene, such as samples of unburnt materials, fire debris, consumer products, appliances, or equipment. The collected artifacts can then be subjected to examination and empirical testing. Although the specific documentation and evidence collection efforts depend on judgments made by the investigator, the data are independent of the investigator and his interpretation of their significance. Thus, physical evidence, including the fire scene itself, is the strongest criterion for testing fire causation hypotheses.

Empirical testing in this context refers to an inquiry into the fundamental nature of the artifact or sample. Individual artifacts can be examined visually or microscopically so that features of interest can be interpreted using scientific principles. Samples of materials can be tested for physical properties, chemical composition, or flammability characteristics. Devices can be tested for performance under normal and abnormal conditions. The development of fire damage patterns can be investigated under simulated fire conditions. The observations and measurements produced by testing can be independently analyzed by other investigators. Since empirical testing results in data derived from conditions outside the subject fire, the physical evidence obtained from the subject fire scene is considered to be a slightly stronger criterion than the results derived from empirical testing.

Engineering analysis is a form of deductive reasoning in which scientific laws are used in conjunction with the empirical data derived from the fire scene to establish logical conclusions regarding fire origin and cause. Engineering analysis can provide a useful framework for understanding the significance of physical evidence, designing empirical test programs and analyzing test data, corroborating witness statements, and testing physical intuition (experience). Examples of engineering disciplines which may have relevance in analyzing fire causation are thermodynamics, heat transfer, fire dynamics, and materials science. Engineering analysis is another form of evidence which can be independently confirmed. But engineering analysis is another step removed from the fire scene, and uncertainty is introduced through the use of assumptions and estimated parameters. Thus, engineering analysis is a weaker criterion for testing hypotheses than physical evidence or empirical testing.

Witness statements can provide invaluable observation data if the statements are both precise and accurate. The reliability of witness statements can depend as much on the objectivity of the interrogator as the witness. Simultaneous observations from multiple witnesses may provide one means of independent verification, but this is not a common situation. Depending on the specific circumstances of the subject fire, the witness observations may be susceptible to empirical testing or engineering analysis, but this, too, is not a common situation. Thus, witness statements are less susceptible to independent confirmation than physical evidence, empirical testing, and engineering analysis.

Experience is highly regarded in some quarters of the fire investigation community.[2] With each new fire scene inspection, the investigator acquires new observations of fire damage patterns. It is tempting for the investigator to develop generalizations based on this growing set of observations. While experience is unquestionably an invaluable source of physical intuition, it is potentially misleading if these inductive generalizations are not tested scientifically. For example, similar fire damage patterns observed at different fire scenes may have a very different significance. The significance may become apparent through empirical testing or engineering analysis, but it is unlikely that experience alone will answer the question. The value of experience is that it can become a rich source of insight and perspective. But untested knowledge gained from experience is less reliable than knowledge which has been tested. For this reason, experience is the weakest criterion for testing hypotheses of fire causation.

THE ROLE OF FIRE DYNAMICS

Fire dynamics is one body of engineering knowledge which can play a particularly important role in fire investigations. Fire dynamics is the study of the ignition, growth, and extinguishment of fire.[10, 11] Fire dynamics is based on the disciplines of thermodynamics, fluid mechanics, heat transfer, mass transfer, and chemical kinetics. The analytical tools of fire dynamics can be used to estimate the size of a fire which is capable of causing the observed fire patterns or to estimate flame spread rates based on witness observations.

The power of fire dynamics as a conceptual framework for the analysis of fire causation can be illustrated with an example. Assume that two competing fire causation hypotheses can be divided into four distinct elements (compare with Ogle and Schumacher[12]):

- Ignition Source
- First Item Ignited
- Second Item Ignited
- Magnitude of Fire Damage

The purpose of the fire dynamics analysis is to determine the fire characteristics necessary to cause the observed fire patterns. The first three elements relate to the initiation and spread of the fire. Fire dynamics calculations can specifically test whether the ignition source is capable of igniting the first item in the fire. Given ignition of the first item, further analysis can determine if the fire can spread from the first item to the second. The magnitude of the fire damage refers to the areal and spatial extent of the fire damage, i.e., did the fire achieve flashover? The presence or absence of flashover fire damage can establish an upper limit (failure to flashover) or a lower limit (achievement of flashover) on the heat release rate of the fire. These calculations can then be used to test how well the competing fire causation hypotheses are supported by fundamental scientific principles.

The methods of fire dynamics are not limited to fire protection engineers. Quintiere's recent book[13], NFPA 92[1], and the *Fire Protection Handbook*[14] all present fundamental tools from fire dynamics in a format easily accessible to an experienced fire investigator. Thus, any experienced fire investigator has access to the tools necessary to scientifically evaluate fire causation hypotheses.

Ultimately, however, there will be a number of fire scenes which will defy quantitative analysis. In these situations, the fire investigator must rely on the use of inductive and deductive reasoning as his scientific tools for finding the best explanation of the fire cause. In this respect, the fire investigator is following a strategy employed not only by scientists and engineers, but also historians, police detectives, automotive mechanics, businesspeople, and lawyers. Regardless of the practical art of interest, if the practitioners seek reliable knowledge about the world around them, they must employ a form of the scientific method. In fire investigations, this reduces to developing and testing competing hypotheses.

THE SCIENTIFIC METHOD AND THE RELIABILITY OF EXPERT TESTIMONY

The 1993 decision by the U.S. Supreme Court on *Daubert vs. Merrell Dow Pharmaceuticals* highlighted the legal significance of reliable scientific testimony. The decision established the role of federal judges as gatekeepers of expert testimony, allowing testimony which satisfied certain criteria and barring testimony which did not. The criteria for reliable scientific testimony, often called the Daubert criteria,[15] are:

- Whether the technique or theory has been tested;
- Whether the technique or theory has been a subject of peer review or publication;
- The known or potential error rate; and
- The degree of acceptance of a technique or theory within the relevant scientific community.

The Daubert criteria have been applied to a broad array of expert testimony, including fire investigation[2]. Another recent decision by the U.S. Supreme Court, *Kumho Tire vs. Carmichael*, has reinforced the gate-keeping role of federal judges by affirming that expert testimony from engineering and other technical arts must satisfy the Daubert criteria.[4, 16] How will the Kumho Tire decision ultimately affect fire investigators? The answer, as revealed through case law, will evolve over time. From an engineer's perspective, it appears that the federal courts may hold fire investigators to a higher standard than mere professional experience. Scientific knowledge, with its interplay of inductive and deductive reasoning, may become the standard for reliable expert testimony of fire causation. If the objective of fire investigation is to seek the best explanation of fire causation, then the ultimate consequences of Daubert and Kumho Tire should be positive.

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PATHFINDER: A COMPUTER-BASED, TIMED EGRESS SIMULATION

By Joe Cappucio, P.E.

INTRODUCTION

The FPE community continues to foster performance-based fire protection and life safety design. An important milestone in achieving performance-based design is to develop analytical tools, like computer models, that assist with quantitative hazard analysis.

Computer fire models predict the effects of fire on a building's environment, including the time to untenable conditions, but they do not determine whether occupants can evacuate in that time. The *SFPE Handbook of Fire Protection Engineering, 2nd Edition*,[1] documents an hydraulic model of emergency egress that calculates occupant egress time. PathFinder uses this methodology to calculate occupant egress time, and it then displays occupant location through animation.

MODEL DEVELOPMENT

The goal of this project was to develop an analytical egress simulation tool that could be coupled with a fire model to form a portion of a hazard analysis. The egress methodology implemented in PathFinder follows the spirit of Nelson and MacLennan in their Emergency Movement chapter of the *SFPE Handbook*[1]. One difference between the PathFinder method and the method in the *SFPE Handbook* is that PathFinder tracks individuals while the Nelson and MacLennan model does not. The advantage of this capability is that the PathFinder simulation can track the process of evacuation by room or floor, whereas the methodology in the *SFPE Handbook* can only provide an indication of time at endpoints of an analysis. Note that the SFPE method can generate information on specific rooms; however, the method has difficulty determining the time for floor evacuation due to the intermingling of occupants from various floors within the exit stairways and a nondiscrete method of handling occupants.

PathFinder establishes occupant loading through a user interface that allows population by density or by discrete numbers of occupants. Occupants are initially dispersed randomly within each compartment that contains an initial occupant load. Boundary layers within rooms and along the path of egress, occupant flow rates, and travel speeds are consistent with the methodology in the *SFPE Handbook*.

MODEL PLATFORM

An important goal of the project was to use .dwg and .dxf drawings as the background for model data entry and output animation. After reviewing several potential platform programs, Actrix, produced by Autodesk, was chosen as the platform for PathFinder. Actrix is a CAD-based drawing software package, similar to AutoCAD, although it has fewer capabilities. Actrix has been under development by Autodesk in parallel with the development of the

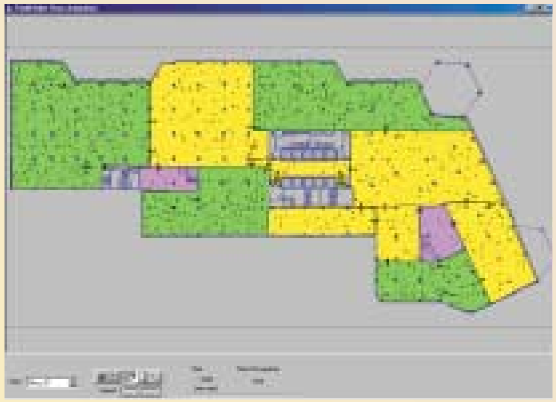
SIMULATION SUMMARY

During the simulation, the user is able to view the animation of each floor of the model. The user is also able to view a summary of the simulation as it progresses. This image shows the number of occupants remaining on a floor in the Floor Occupants column.

The Stairway Occupants columns show the relative percentage of occupants within the stairway compared to the number of occupants who, if they were in the stairway, would result in a flow that approaches zero. (This is represented by the portion of the depiction box that is colored red compared with that portion that is colored white.) Since the discharge level for this example is the first floor, the values indicated at this level represent persons to have discharged the building, hence the green color.

The Discharge Exit Usage columns show the number of occupants who have discharged from the various exits, and it will also indicate the number of occupants predicted to reach areas of refuge when that design option is used in an analysis.

ANIMATION



PathFinder simulates occupant evacuation and displays results as both text reports and through simulation. This image shows the location of occupants on a floor of an office building at the beginning of a simulation. The various colored areas represent the types of occupancies that inhabit the floor. These different occupancies have varying occupant densities, and the coloring scheme allows the user to quickly assess the types of occupancies and their locations on the floor. The CAD background of the floor is also visible and allows the user to identify the various portions of the means of egress during the simulation.

PathFinder model. This required our development team to use several iterations of alpha and beta test versions of Actrix and to coordinate the PathFinder model with these versions. A distinct advantage has been the ability to assist in the development of Actrix through feedback to Autodesk.

The PathFinder model accepts .dwg and .dxf files. Drawing files are not required to develop an egress model using PathFinder. Although the intent is to utilize drawing files, users may sketch floor layouts without CAD-based drawing files. The user then inputs a topological mapping of the building (by floor). This topology describes how the various rooms and spaces are interconnected.

TOPOLOGY

Building topology can be simply described as how the surfaces of the building interconnect and form the spaces in which the building occupants and building equipment are located. These spaces become the rooms, corridors, and stairways that support the building's normal occupancy and utility. Specific surfaces – those with openings capable of allowing human passage (doorways) – generate "human paths" between individual spaces. These paths must ultimately permit an occupant to move from any occupied building space to the outside or area of refuge, either during the normal course of occupancy or during an emergency such as a building fire. Geometric features of these surfaces and spaces determine path lengths to exits, areas of refuge, and the outside. The time required for occupants to reach exits, areas of refuge, and the building exterior can be calculated with the incorporation of travel speed and occupant flow in conjunction with the geometry and topology of the building.

The electronic drawing files contain little direct topological information. The topology is provided by the user, who recognizes such topological features on displayed drawings as connected surfaces that form a room and a door of a certain width between two spaces. Once the topology of a building or building portion is developed from the drawing file, it is preserved as part of the PathFinder analysis and can be updated to include modifications to building geometry and topology.

POST-SIMULATION DATA

A variety of data can be extracted from the simulation. The simulation's data structures have been developed to allow users to retrieve the following post-simulation data:

1 The number of people that have used an exit.
2 The minimum, maximum, and average time for people to exit the building from a given room.
3 The time a room, hall, or stairway becomes empty.
4 The time a floor becomes empty.
5 The time the building becomes empty.
6 The time when everyone on a floor is safe (entered a stairway exit, entered a horizontal exit, or discharged from the building to the exterior).
7 The maximum queue size for a given exit door at any time during the simulation, and the time at which the maximum queue size occurs.
8 The maximum number of persons on a given stair segment at any time during the simulation, and the time at which that maximum occurs. (A stair segment is defined as the area inclusive of the stairway landing at a floor level and the descending stair treads, including intermediate landings prior to the next floor level landing below.)
9 The time when all occupants in the building are safe (left the building, entered an exit, or entered a horizontal exit).
10 The minimum, maximum, and average distance traveled to a point of safety (an exit or a discharge) by room, by floor, or overall within the building.

This output data are tracked internally by the model. Final output data reporting by the simulation has not been definitively determined by the development team.

The simulation provides an optimization of egress time, since behavioral aspects of occupant evacuation are not included in the model. However, the user can superimpose the effects of occupant activities, such as investigation or providing aid to others on the results of the simulation.

Joe Cappucio, P.E. is with Rolf Jensen & Associates.

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Legal Considerations in FIRE PROTECTION DESIGN

By *Christopher B. Wood, J.D.*

INTRODUCTION

Issues relating to design liability involve many components and entities. These issues range from legal actions stemming from negligence to governmental actions under a variety of laws and regulations. This article will serve to review (1) the United States legal system, (2) the types of legal cases which might arise out of fire protection engineering/design,[a] and (3) some approaches to engineering/design that consider what may happen well after the project or product is built and in use. This article uses the United States legal and governmental systems to illustrate the design issues discussed and entities with which the engineer/designer must contend while working on a building or product.

The United States system discussion will directly apply to the many U.S. readers and will also apply to the readers from other countries that sell products in the U.S. The discussion should also provide guidance for the engineers/designers who fall under similar legal and governmental systems. Although this paper may help identify issues for consideration, it cannot substitute for good legal advice. Engineers and designers are encouraged to find a good attorney for assistance with research in finding applicable codes and other requirements as discussed below.

This article is divided into five major sections. The first section describes the legal and political systems' influences on the design process and some of the relationships between the federal and other levels of government. The next three sections give some overview of legal cases, the most common cause of action for design failures (negligence), and legal considerations in engineering practice. The article concludes with a series of points to keep in mind when performing design work and in practicing the profession.

THE LEGISLATIVE, EXECUTIVE, AND JUDICIAL SYSTEM AFFECTING DESIGN

Fire protection engineering crosses so many bounds that a large number of entities have input into the process. For example, the recently published *SFPE Engineering Guide to Performance-Based Fire Protection Analysis of Design of Buildings*[1] has a seemingly daunting list of entities designated as "stakeholders," but those are generally the ones with active input into a project (i.e., in person or by direct correspondence). In addition, many other entities (such as the ultimate user) may exercise some control (possibly implicit control) and/or design constraints on the project. Defining the legal system and its components will help to clarify the identity of some of these other entities. We will necessarily have to cover a large number of entities before being able to bring them together and demonstrate their interaction with the engineering/design project.

The three basic "levels" of government can be defined as federal, state, and local. Most projects fall under the first two levels, and these first two have substantially similar organizations. The federal (national) level is established by and governed under the United States Constitution. The state[b] (province) level is established under either a state constitution or a state charter. The local level is generally a city or town, but may be a county, water district, fire district, or some other established entity with the power to impose control and/or sanctions on projects/buildings. Regional differences are especially evident at the local level. For example, while the Eastern parts of the United States have most power concentrated at the city or town level, many Midwest and Western states have more power concentrated at the district or county level.

The division of powers referred to as branches, within the state and federal governments, are substantially similar and will be addressed together. The three branches of government are (1) legislative, (2) executive, and (3) judicial. These three branches all have control and input into design projects based upon their granted powers and historic use of those powers. To appreciate how their action has input into the design process, it is important to first understand what they are and what they do.

LEGISLATIVE BRANCH

The legislative branch at the federal level contains the House of Representatives and the Senate which, when referred to as a single unit, constitute the Congress. Some state governments have only one body referred to as a House. Members of the legislative body are elected. The Congress' duty is to pass and repeal laws (statutes[c]) deemed necessary to achieve certain goals in the society. Understanding this role is important because only through the passage of laws can the other two branches of government act. In a certain sense, Congress is the starting place because the other branches of government only execute and interpret the laws made by Congress. Congress receives its power from the Federal Constitution and is limited to those powers. Similarly, state legislatures receive grants of power from their charters or constitutions.

EXECUTIVE BRANCH

The second branch of government is the executive branch. The executive branch is headed by the President at

the federal level and, generally, the Governor at the state level. "Managing" or upper-level members of the executive branch are elected or appointed. While initially established to "execute" (i.e., enforce) the laws through the military, militia, and police agencies, Congress has greatly expanded the role of the executive branch over the past several decades through "enabling" legislation. Such enabling legislation grants certain rule-making authority to various agencies in the executive branch.

At the federal level, these executive agencies include groups such as the Occupational Safety and Health Administration (OSHA), the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), the Consumer Product Safety Commission (CPSC), and the Department of Transportation (USDOT) as well as many others. Most of the federal agencies have regulations that relate to fire safety design issues. State agencies under the executive branch may include groups such as a state building board, fire prevention board, and/or a state department of transportation, etc.

Because the executive agencies are created by legislative enactments, an agency's rule-making authority is limited to its enabling legislation. The enabling legislation generally affords the agency the power to pass, promulgate, and generally enforce rules or regulations[d] necessary to perform the agency's function. Sometimes, the enabling legislation also contains other provisions not necessarily reiterated or enumerated in the agency's rules. Therefore, it can be helpful and instructive to read the agency's enabling legislation when trying to understand the scope and goals of various promulgated rules. Because the rules come under their enabling legislation, they have the force of law when enacted under the legislatively established rule-making process.

At times, litigation may be necessary when an agency prevents a particular course of action or design and the agency's preventing actions go beyond its legislative grant of authority or use that authority in an "arbitrary or capricious" manner – the legal test for misuse of power. A denial of variance from an appeal's board, for example, may lead to litigation that tests the board's authority on the particular issue. Engineers may provide guidance to the court or expert testimony to assist the court in making a determination about the board's or agency's previous proceedings.

The legislatures have provided the rule-making process because it is more adept at handling public input which allows agencies to be more responsive to public needs. Also, many agencies have a formal "interpretation" process so that questions, which may not have clear answers under the rules, can be considered and ruled upon before a design continues past a certain point. Many engineers are familiar with similar processes under the National Fire Protection Association (NFPA) interpretation process and the use of code commentaries from model building code organizations such as the Building and Owners Code Administrators International (BOCA), the International Conference of Building Officials (ICBO), and the Southern Building Code Congress International (SBCCI). These model codes are often adopted by state building boards or governmental agencies.

JUDICIAL BRANCH

The third branch of government is the judiciary, or courts. In so many ways, this branch is where "the rubber meets the road" for design liability issues. The judiciary provides the interpretation of laws and the "legality" of laws. Legality involves interpretation of laws under their enabling authority.

The interpretation of laws and regulations is the issue over which most people find themselves in court. There are two generally accepted sources of law in the U.S. legal system and those systems of similar lineage. The first sources of laws are statutes passed by the Congress, state legislatures, or ordinances passed by cities and towns at the local level. Rules or regulations, as discussed above, derive their authority from enabling legislation previously passed by an appropriate legislative body. The body of fire protection regulations and adopted codes and standards fall in this category of rules and regulations.

The second source of laws is the tradition of the court often referred to as "case law." Our U.S. legal heritage comes from the lineage of English Case Law because much of our legal system evolved from the English tradition. Case law, which is the body of published case opinions interpreting both statutory and other case law, becomes precedent and law to each subsequent decision. The published opinions then provide notice of the interpretations of statutes and other precedents. This process provides consistency and allows people to make appropriate decisions on how to conduct themselves under the law. Thus, in addition to researching statutes and regulations, a given set of facts should be reviewed against relevant legal decisions which have previously interpreted the issue or law at hand. This means that fire protection engineering design can be guided by the findings of previous courts in consideration of, for example, alleged design negligence.

LEGAL CASES

This section will consider the manner in which legal cases come about and the specifics of negligence cases that commonly arise. The cases considered would be those that are adjudicated in courts established under the judicial branch as opposed to those decided under arbitration, mediation, or in the quasi-courts of the executive branch, such as administrative law proceedings under the CPSC. A review of the terminology that describes the parties and the differentiation between various types of actions is required to begin this limited discussion of legal cases.

There are two types of cases that may occur in the judicial system: criminal cases and civil cases. Most people are familiar with the concept of "criminal" actions. In all criminal cases, a crime is considered to be committed against society or the state. As such, the case is prosecuted by the state, which is represented by an attorney (referred to as the prosecution) who is a member of the executive branch (i.e., district attorney, attorney general, etc.). The person charged with the crime is the "defendant." In a criminal case, the defendant has a legal right to representation, and an attorney will be provided if the defendant is indigent. Although fire protection engineering analysis may be performed for some arson cases and criminal negligence cases, criminal law has many requirements that differ from noncriminal (civil) cases. (Although criminal cases will not be considered further in this paper, some criminal negligence cases have occurred for negligent design.)

The beginning of a civil case begins with a "wrong" for which the "wronged" or "injured" party seeks compensation in a suit. The injured party is the "plaintiff." The plaintiff is the one considered to be in the best position and with the most interest to fully pursue the case. The plaintiff must prove the elements of its case so that it is "more likely than not"[e] that the plaintiff's allegations are true. The party against whom the action is initiated is the "defendant," as in criminal cases. To add to the overall complexity, a defendant may also sue the plaintiff (countersuit), multiple defendants may sue each other (cross-claims), and, generally, defendants may bring in additional parties (third-party defendants) who might make claims against any of the other parties.

Suits can quickly involve multiple parties. A common example where third-party suits come into existence involves workers compensation cases, for example, an employee burned during a plant fire or explosion. Under workers' compensation laws, the employee relinquishes the right to sue the employer for workplace injuries under a guaranteed compensation plan. The worker may, however, sue manufacturers of equipment involved in a workplace injury. The manufacturer, in turn, may sue the employer, alleging that the employer's actions, rather than the equipment, were the cause of the employee's injuries, and should the employee recover on the claim against the equipment manufacturer, the employer could be found responsible and required to indemnify or pay the award for the defendant.

AN ACT OF NEGLIGENCE

Negligence is a specific area within the general designation of "torts." A tort is "a private or civil wrong or injury ... for which the court will provide a remedy in the form of an action for damages."[2] An insight into why the theory of negligence exists is evident in the following observation: "It has been noted that tort liability for negligence has the effect, and to a degree the purpose, of regulating a defendant's future conduct."[3] This approach aims to have the societal/economic system be self-regulating by eliminating dangerous products and careless manufacturers from the marketplace through the economic incentive to limit their liability through good engineering/design.

In order to understand how the law of negligence influences the engineering/design process, the engineer must have an understanding of the elements of negligence. Through this understanding, the engineer or designer seeks ways to limit liability from negligence. A successful action of negligence must prove four components: (1) the defendant owed the plaintiff a duty of care, "duty"; (2) the defendant breached the duty, "breach"; (3) the defendant's breach of the duty is the legal cause of the plaintiff's damages, "causation;" and (4) the plaintiff suffered an injury, "damages."

The duty of care extends to a number of classes of people. In general, the purchaser and user will be in the class of people to whom the engineer/designer owes a duty. However, the protection extends to many others, including those for whom injury is foreseeable. Designers and engineers owe a duty to those for whom an effect from the building or product is reasonably foreseeable. For a building, the list might include tenants, employees, visitors, etc. For a product, the list might include maintenance personnel or users of manufacturer-expected after-market accessories.

Duties can be inferred from laws or regulations and can include an act or the omission of an act. In some jurisdictions, the mere violation of a statute is negligence *per se* which, once shown, shifts the burden of proof to the defendant to prove the act or omission was not unreasonable (negligent). In other jurisdictions, such a violation is only evidence of negligence, and the plaintiff must show the defendant's specific breach of a duty owed to the plaintiff. Additional sources to show the duty would include the customary usage in the trade, industry, profession, or even the internal standards of a particular company. These might be shown by NFPA codes, standards, and guides (whether or not adopted), SFPE Guides, NFPA and SFPE handbooks, and model building codes or company policies. An egress example might involve the egress time calculations for a quadriplegic rehabilitation center that assumed travel speeds associated with unimpaired pedestrians in an uncrowded passageway when clearly lower travel speeds should be utilized. Failure to consider an alternative design when the technology is available, such as a "defend in place strategy," might also be considered negligence.

Two special notes must be made to the foregoing sources of evidence on duties. First, the customary usage can be negligent. This approach eliminates the argument that "if everyone else is doing it, it must be OK." Numerous courts have decided that "everyone" can be doing a "legally" unacceptable job and held engineers/designers to a higher standard than what the industry was doing. Similarly, codes and standards should be considered minimum requirements that may not represent "reasonable" care under particular circumstances. Second, if engineers/designers either have specialized knowledge or hold themselves out as having specialized knowledge, then the courts may hold them to the higher level of knowledge.

The proving of a breach of duty involves a number of tests. In part, the breach consideration is linked with the duty consideration above. The second part involves the concept of the specific act or omission alleged by the plaintiff. Often this component is termed the "reasonable person test." Did the defendant act in a "reasonable" way. The reasonable person realizes that his or her act (or omission) would create a "risk and its [the act or omission] unreasonable character."[4]

The necessary steps and costs to eliminate a risk were succinctly put forward by Judge Learned Hand. He stated that "the responsibility is a function of three factors: the likelihood that [the engineer's/designer's] conduct will injure others, taken with the seriousness of the injury if it happens, and balanced against the interest which he must sacrifice to avoid the risk."[5] This definition does not establish the premise that everything must be done to eliminate every risk. However, the ease of reduction or elimination of the risk as compared to the probability of the risk and severity of the outcome is to be considered. In building fire protection design, for example, this leads directly into the analysis of the fire scenarios developed and the limitations explicitly described in a fire design brief.[f]

The last two components of negligence, causation and damages, are more legal issues than engineering/design issues. Causation relates the breach to the damages. Causation is not to be confused with "comparative" negligence.[g] Comparative negligence relates the plaintiff's own actions to the damages incurred and reduces the monetary award by the extent (usually a percentage) to which the plaintiff's own negligence contributed to the plaintiff's injuries. Under negligence, the court follows the legal fiction that all such damages can be reduced to monetary compensation. There are numerous ways to calculate the appropriate damages.

The following example shows how the engineers/designers should at least consider other persons that might become involved with a product beyond the expected purchaser. While children may not be the intended users of a cigarette lighter, it is reasonably foreseeable that the lighter might fall into the hands of a child[6] so that the child or damages suffered at the hands of the child's operation of the lighter, a foreseeable event, may be one that a manufacturer should consider in the design. Whether or not the manufacturer breached the duty will encompass considerations such as the technical feasibility, cost of implementing a safety device, and the utility of the product with the safety device. In building design, the use and occupancy for which the design was originally developed, foreseeable changes may include issues such as area and height limitations or fire-resistive construction under applicable building codes. This highlights the need to clarify for the owner/operator the limits outside of which additional analysis must occur for any proposed new use. This example is readily extended to sprinkler design involving issues such as water density, design area, hazard classification, etc.

This section has examined a variety of components that feed into the legal system and the most common cases in engineering/design, negligence. Some attempts have been made to introduce the variety of laws and regulations that impact a project. The very important area of warnings has not been covered here, but there is clearly a duty to warn when a safer design is impracticable. Warnings are a complex area and should be examined closely when needed to implement a useful product for which the risk cannot be eliminated. For example, CPSC and USDOT have statutory wording for a variety of products using labeling trigger words such as "WARNING" or "DANGER."

LEGAL CONSIDERATIONS IN ENGINEERING

There are many sources of engineering and design liability in the process of any particular project. The most common legal action against the engineer/designer is one of design negligence. The best protection against these suits is to act as a "reasonable person," seek to identify foreseeable failure modes, design them out or warn users against them, and provide guidance for the user to avoid the loss. Engineers/designers will be held to the highest of (1) the minimum practice in the industry, remembering that courts have held industry practices to be unreasonable, (2) the person's specific or specialized knowledge when that knowledge is greater than the industry, (3) the specialized skill or knowledge that the engineers/designers represented they possessed, or (4) applicable laws and regulations. These burdens can be met through the application of routine practices.

The first practice involves continual professional development. All persons practicing in the profession should undertake to maintain their knowledge at the industry level. This goal generally takes a multipronged approach. Each engineer/designer will benefit from regular attendance (i.e., annual/biennial) at seminars and other recognized training courses. These courses will help to keep the attendee "up to date" on developments in the industry and applicable codes and regulations. Similarly, the engineers/designers should seek to remain current with publications that depict the latest developments in the industry. This knowledge is part of the "stock in trade" of the design professional.

The second piece of controlling design liability could be considered "diligence in design." Whether designing a building, a building system, or a product, diligence in design involves a three-pronged approach. The three legal prongs can be condensed into three words: (1) "laws," (2) "imagination," (3) "documentation." There are, of course, many other specifications and requirements so that the project (building or product) meets its intended goal and functionality. Those requirements are not considered here, although, of course, at times they may be inconsistent with some of the suggestions made here. When conflicts occur, only the project-specific facts and good engineering judgment can determine which factor must give way to the other.

The first prong is to determine the applicable laws and regulations under which the product or building will be designed. Ensure that all applicable requirements have been met and that they meet or exceed the industry standards and the engineer's/designer's specialized knowledge. Performance-based design objectives must not be below these applicable standards and are implicitly imposed on every project. This is the point at which engineering judgment becomes critical in making sure that the project design is "safe" through the fundamental design, implementation of safety devices, and appropriate warnings.

A project may involve the use of unfamiliar regulations (from a fire safety perspective) such as the design of a hair care product, which falls under the FDA for regulation. Although such products do not fall under the CPSC, that agency's labeling and other requirements may actually be more instructive than the FDA's, which introduces the second prong of "imagination." The engineer/designer may need to invoke the assistance of a research or law firm with access to computerized legal research tools/databases to determine all of the applicable laws and precedent-setting case law. The engineer/designer may need to work closely with the research firm so that appropriate "keywords" and search criteria are used to achieve an effective search.

In some cases, the engineer/designer may have to think as a Walt Disney® "Imagineer." The engineer/designer must not only think of the appropriate manner(s) in which to use a product but must go beyond that to reasonably foreseeable fire scenarios, failure modes, abuses, misuses, and unintended users. The period of use being considered may begin with distribution, first use, and/or commissioning through decommissioning and disposal of a product or building. Such thinking may lead to formalized exercises such as fault-tree analysis for components of a product or the various fire protection devices in building design. The results of this analysis should be stored in the last prong (i.e., documentation).

This third prong is often key in being able to convey the appropriateness of a particular design to users or authorities. Do not assume that the state of the art, as understood during the design, will be understood at the time of a lawsuit for an injured party's damages many years later. Engineers/designers should make an effort to retain documents used in the development and analysis of a design. This documentation should include the applicable laws and regulations researched and employed, the applicable design decisions made with the reasons for those decisions, the scenarios considered for the design's use and misuse, and the calculation procedures and methodologies used. Documentation of design limitations, warnings, and their development should also be retained. Although applicable codes may not be copied into each project's file, the codes should be maintained in a way that they do not become lost when the next code version arrives. That is, maintain an archive copy of the code (maybe one for each office) for later reference in researching the code that existed at the time of the design.

Documentation of considered laws can be formalized in a "code-trace." The code-trace document lists the law or regulation considered down to the specific sections examined including the section designation, title, and applicable year. A summary of the requirements and how the requirements are met will assist when questions arise many years later. Clearly the presumption here is that the design is being made under the guide of "good engineering judgment." As such, documenting the design will allow for the engineers/designers to "refresh their memories" at the time any question arises. Presuming good engineering judgment was used during the design, a failure to recall why a design decision was made can cause a jury to question the credibility of the testifying engineer, leading to the conclusion that something was done incorrectly. Documentation made at the time of the design can provide good evidence as to the "hows" and "whys" of the final design. For those who have been involved in design law suits, one litigation is all it takes to show the value of this documentation. Because the engineer/designer never has any knowledge before the fact of which project will lead to a lawsuit, this documentation should be done for every project. Finally, the documentation should include the limits of the design and the reasons for those limitations.

CONCLUDING REMARKS

Those who observe the legal system of the United States, both within the country itself and from other nations, may feel that the amount of litigation is excessive and a negative influence on the flow of economic activity, particularly in the area of negligence in the design and manufacturing process. As previously stated in this paper, the legal process is a part of the national regulatory philosophy. The legal system is an alternative for specific regulation or law in regard to each transgression perceived to be in need of restraint or control. Law, once made, is difficult to change and consumes considerable time in meeting the ever-fluid needs of a dynamic economy. In the alternative, lawsuits and the threat of legal process provide an incentive for the designer and producer to "protect before the fact" rather than to "produce and suffer the consequences." This process leads to a self-regulating effect, and the lawsuits, once decided, provide the principles on which subsequent designers and producers can reasonably rely for future activities.

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END NOTES

a Engineering and design will be used interchangeably in the paper. There may be some differences in specifics between, for example, design of buildings versus design of products, but many of the general concepts of design liability are shared between the two.

b The term "state" here is used broadly to describe states and commonwealths.

c Statutes are published within the United States Code (USC or "Code") at the federal level or "General Laws" at the state level (e.g., Massachusetts General Laws, MGL, or Massachusetts General Laws Annotated, MGLA).

d These rules at the federal level are found recorded in the Code of Federal Regulations (CFR), and most states a have a similar document at that level.

e "More likely than not" can be thought of as some scintilla of evidence greater than 50/50, otherwise judgment must be for the defendant because the plaintiff did not prove its case.

f See the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*.

g At one time, the concept of "contributory negligence" was used. If found on the part of the plaintiff, contributory negligence was an absolute bar to the plaintiff's recovery. In various forms, all U.S. jurisdictions now use some form of comparative negligence.

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4. 2 Restatement of Torts 2d, 284, comment on clause (a).
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SMOKE-DETECTION EVALUATION IN ENCLOSURES WITH HIGH-VELOCITY AIRFLOW

By Robert M. Gagnon, P.E., and Tyler Mosman

INTRODUCTION

The rapid air flow velocities within computer server machine rooms, especially underfloor, have necessitated an evaluation of the effectiveness of the smoke-detection systems installed in these rooms. Air movement is needed to cool electronic components, which have the potential to heat to the point of ignition without such cooling. Air-handling units in computer server machine rooms force cool air into the underfloor area, through racks of vertical electronic server units mounted to floor openings, into the abovefloor region, and back to the air-handling units for cooling.

Smoke-detection systems, typically used as initiating devices for alarm systems and as mechanisms for operating fire protection systems in computer rooms, are installed in accordance with the requirements of the authority having jurisdiction, using NFPA 72, the *National Fire Alarm Code*®, as the basis for implementation of acceptance criteria.

The 1999 edition of NFPA 72, Table 5-3.6.6.3 and Figure 5-3.6.6.3, provides smoke-detector spacing requirements within abovefloor enclosures where air movement is not expected to exceed 60 air changes per hour. Air velocities can greatly exceed 60 air changes per hour in the constricted underfloor region and in the area above suspended ceilings.

Interviews with plant personnel for a major Internet company yielded evidence of infrequent smoldering fires involving overheated electronic components in machine rooms, with smoke stratification being observed with the air conditioners operating. In these reported fires, smoke detectors actuated, and the notification system operated, but the preaction sprinkler system did not discharge. High air movement velocities enhance the chances for stratification and can negatively affect response times of ceiling smoke detectors.

Table 5-3.6.6.3 Smoke Detector Spacing Based on Air Movement*

Minutes per Air Change	Air Changes per Hour	Spacing per Detector	
		ft^2	m^2
1	60	125	11.61
2	30	250	23.23
3	20	375	34.84
4	15	500	46.45
5	12	625	58.06
6	10	750	69.68
7	8.6	875	81.29
8	7.5	900	83.61
9	6.7	900	83.61

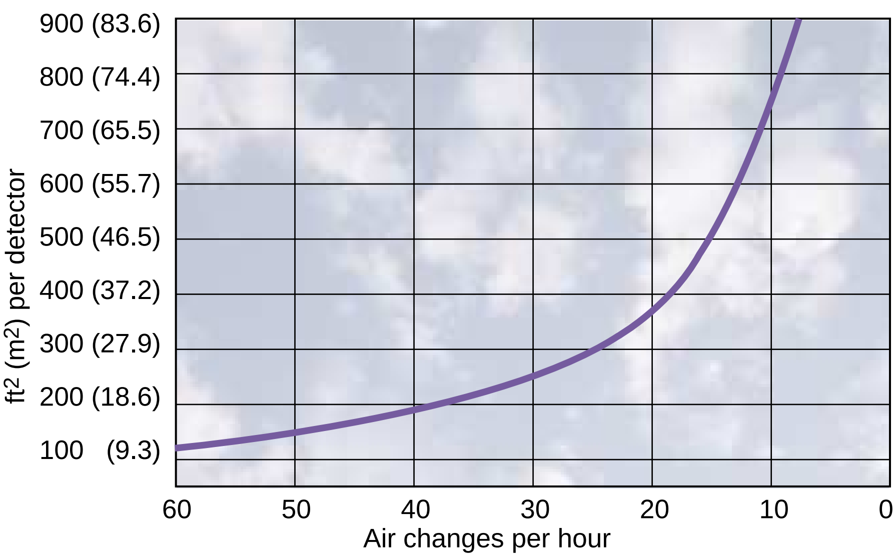

Figure 5-3.6.6.3 High air-movement areas (not to be used for underfloor or above-ceiling spaces).*

DETECTION SYSTEM ARRANGEMENT

The test room is a computer server room whose smoke detection systems had completed acceptance testing in advance of occupancy. Permission was secured to perform smoke detection research that could influence future server room detection design. The following detection systems were installed in the test room, as shown on Figure 1.

1. A photoelectric spot smoke detection system was installed in the test room at the bottoms of the beams at ceiling level.
2. An ionization spot smoke detection system was installed in the test room at the bottoms of the beams at ceiling level, staggered between the photoelectric detectors, as shown on Figure 1. The resulting spacing of the staggered arrangement is 120 ft^2 (11 m^2) per detector.
3. Staggered photoelectric and ionization spot detectors installed within the 2' 4" (0.71 m) deep exposed beam pockets at the ceiling.
4. Staggered photoelectric and ionization spot detectors mounted to the light tracks below the ceiling beams at an elevation of 14 ft (4.3 m) above the floor.
5. One photoelectric and one ionization spot detector installed at the air inlet to each air conditioning unit.
6. An incipient air sampling smoke detection system was installed in the test room at the air inlets of the room air conditioning units.
7. A photoelectric smoke detection system was installed in the 2' 0" (0.61 m) deep underfloor area, at a spacing of 120 ft^2 (11 m^2) per detector.

DETECTION LOGIC

The fire alarm control panel has been programmed to issue a trouble signal to the constantly occupied main control room on the receipt of a signal from any detection device. Upon receipt of a second detection signal, an alarm signal will be issued via the building notification appliance system, and the solenoid valve for the appropriate preaction valve serving the room will be opened. Once the solenoid valve is opened, the preaction valve will not open until a sprinkler opens, releasing pressurized air from the piping system and opening the pneumatic actuator.

RESEARCH OBJECTIVE

The objective of this research is to determine which smoke detectors react the fastest in the presence of light smoke production and high-velocity airflow. Based on the results of the tests, decisions will be made relative to the placement of detectors that is believed to be capable of detecting a smoldering electronics fire in its incipient stage.

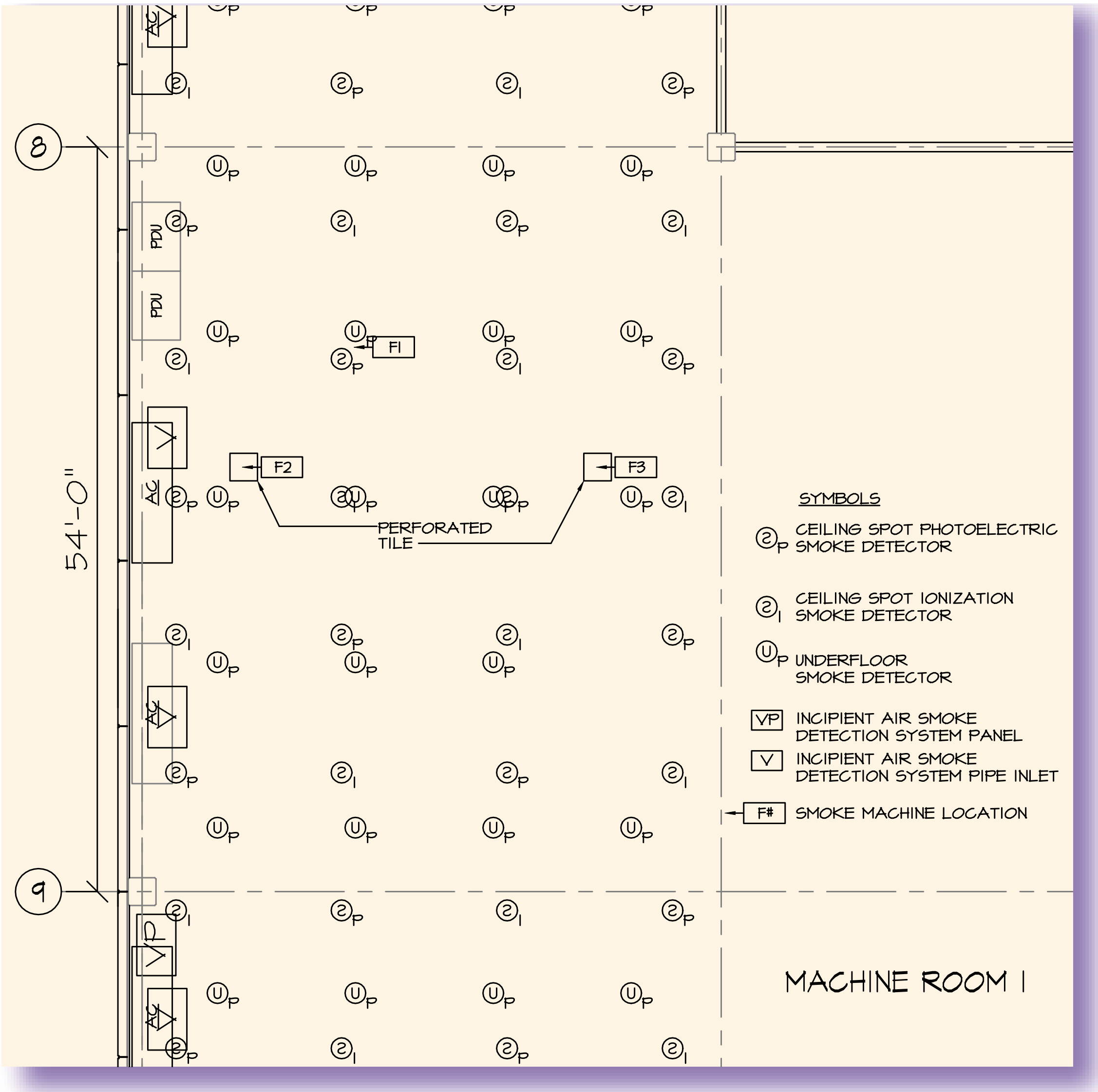

Figure 1. Test room layout.

RESEARCH RATIONALE

Fires in computer machine rooms are rare. A fire in a machine room will most likely involve the overheating of an electronic computer component mounted in a vertical rack and is characterized by a wispy plume of smoke with a low volumetric rate of smoke production in its incipient smoldering stage. Fully developed flaming electronics fires can inundate a large computer server room with smoke. NFPA 72 largely assumes that in the room of fire origin, smoke will rise in a vertical plume to the ceiling and distribute along the ceiling in a ceiling jet sufficient to actuate spot smoke detectors spaced in accordance with NFPA 72 and in accordance with the listing of the detectors.

The electronics fires in computer servers can be attributed primarily to failure of a printed wiring board contained within. Failure modes for printed wiring boards, in addition to loss of cooling airflow, include power surges through the board and component failure. Literature was studied relative to flaming circuit board heat release rates, but smoldering fires would have a small fraction of the flaming heat release rate. NFPA smoke detection spacing is predicated upon a design fire of 100 kW, an order of magnitude less than the design fire of 1 MW used for heat detectors. This research is centered upon the smoldering condition, which would be expected to be significantly less than 100 kW. It is the intent of the fire protection engineer to determine whether it is feasible to design fire alarm systems capable of initiating notification and either manual or automatic suppression sufficiently in advance of the flaming mode to avoid major damage and excessive Internet downtime.

In the room used for this research, the ceiling is in excess of 20 ft (6.1 m) in height, the ceiling configuration features 2' 4" (0.71 m) deep exposed concrete structural tees, an underfloor plenum is present, and air handling units constantly circulate large volumes of air at high velocities. While NFPA 72 has detector spacing adjustment factors for ceiling heights in excess of 10 ft (3 m) (which apply to heat detectors only), spacing advice for beamed ceiling configurations, and spacing modifiers as a function of air changes per hour, the combination of these input variables made for a challenging smoke detection situation in this room.

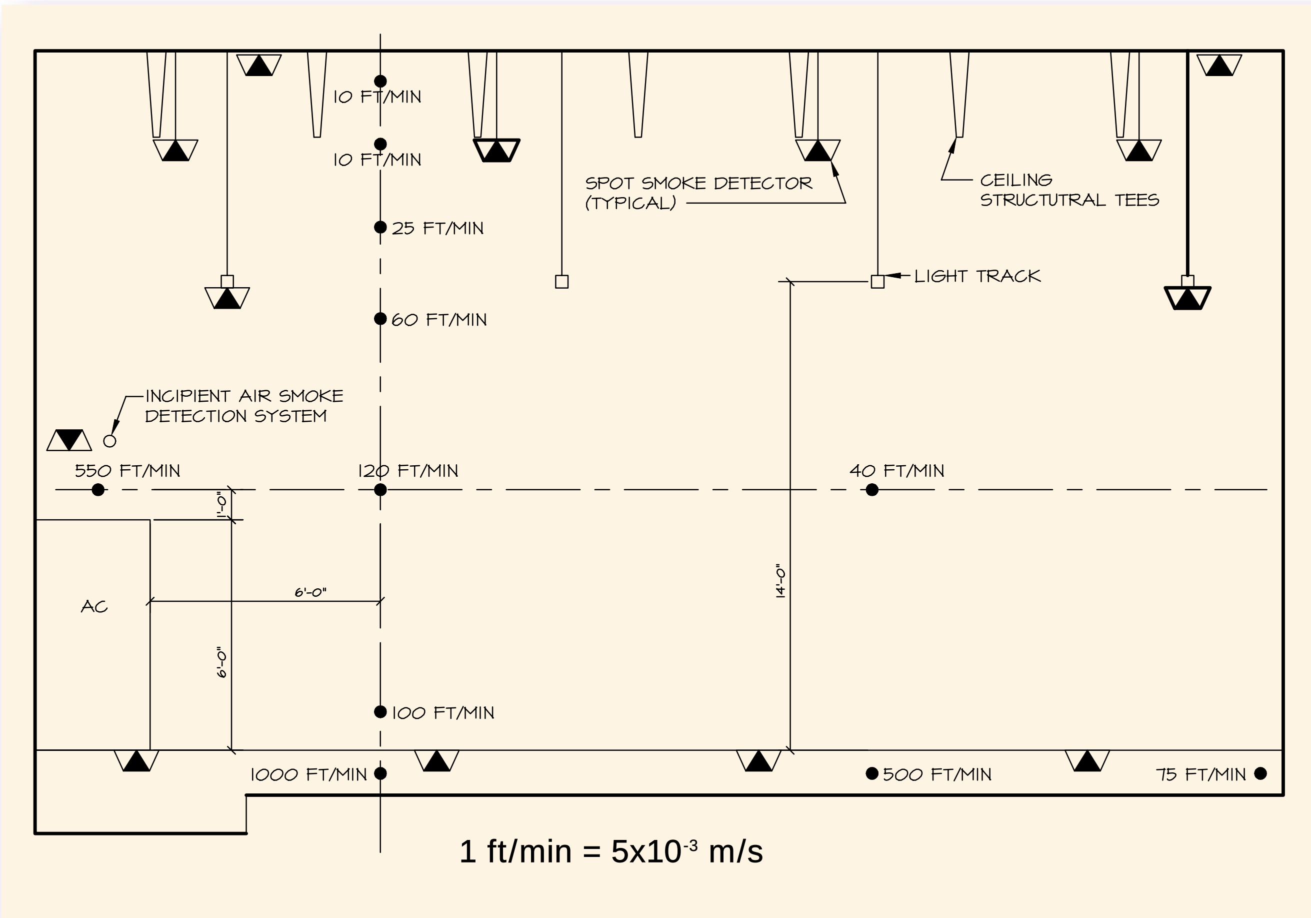

Figure 2. Air velocity profiles in test room (section view).

The concern that inspired the research was that fires producing low heat release rates and low volumetric rates of smoke may result in lengthy smoke detector response times. The research objective is to provide smoke detection systems that will provide efficient notification of an electronics fire involving low volumetric rates of smoke production in the presence of high air velocity movement.

To accomplish the research objective, we used smoke producing machines capable of simulating the low volumetric rates desired, with the objective of making observations relative to the performance of a variety of smoke detection system arrangements in the presence of such a smoke production scenario.

THE SMOKE MACHINE

The smoke machine used was a thermal aerosol generator capable of producing a steady fog output using a concentrated liquid fog fluid.

The smoke machine has a calibrated remote control dial that is capable of being set to a level of between 0 and 11, with a setting of 0 producing no fog, and a setting of 11 producing an extremely dense fog. It is known from previous tests that a setting of 11 will completely fill the room with smoke and rapidly actuate all smoke detectors in the vicinity of the smoke machine. The lowest useful setting for these tests is 2.5, which produces a light wispy plume, congruent with the research rationale.

The fog consists of fluidized droplets ranging from a particle size of 0.25 to 60 microns in diameter. The machine uses up to 0.66 gal (2.5 liters) of glycol-water fog concentrate per hour at a setting of 11.

The mixture is pumped into a cartridge heater within a heat exchanger and is exposed to a temperature of 500°F (260°C), vaporizing the fluid. The fog produced is expelled from the output orifice, and its temperature is 125°F (52°C) at a distance of six inches (150 mm) from the discharge side of the orifice. At low volumetric production rates, the fog cools as it rises to the ceiling due to entrainment of cool ambient air into the plume.

The initial warmness of the fog produced by the machine is responsible for the vertical buoyancy of the fog. This plume effect does a creditable job of simulating a small electronics fire. Rapid cooling of the smoke in a rapidly moving air stream could result in smoke stratification in the presence of high-velocity airflow.

NFPA 72 SMOKE DETECTION DESIGN

Table 5-3.6.6.3 and Figure 5-3.6.6.3, provide design advice for detector spacing in rooms with high air movement, requiring a maximum abovefloor spot smoke detector spacing of approximately 130 ft^2 (12 m^2) per detector in rooms subjected to 55 air changes per hour. The configuration of the test room is amenable for detectors spaced at 120 ft^2 (11 m^2).

The 1999 edition of NFPA 72, Paragraph 5-3.4.6.1, requires detectors within every beam pocket when the beams exceed 12 inches (300 mm) in depth and the ceiling height exceeds 12 ft (3.7 m). For this research, we have installed spot smoke detectors within beam pockets to ascertain their effectiveness relative to detectors spaced at the bottoms of the beams.

NFPA 72 (1999) states that Table 5-3.6.6.3 and Figure 5-3.6.6.3 do not apply to underfloor areas. As can be seen, with a value of 520 air changes per hour underfloor, no corresponding values can be ascertained. Photoelectric spot smoke detectors have been installed at 120 ft^2 (11 m^2) per detector in the underfloor space. In advance of this research, it was a matter of debate as to whether underfloor detectors were doing any good at all.

NFPA 72 (1999) has a spacing adjustment factor for heat detectors mounted to ceilings in excess of 10 ft (3 m), but provides no such advice for smoke detectors within the standard. NFPA 72 Appendix B provides adjustment for ceiling height, but it is assumed that the heat output from an incipient smoldering electrical fire would not be of sufficient energy intensity to warrant the use of Appendix B, which was developed by using geometrically growing flaming fires as its basis.

AIR VELOCITY MEASUREMENT

The test room was fitted with an HVCA system that provided 55 air changes per hour in the abovefloor space and 520 air changes per hour underfloor. The air movement pattern in the test room is shown in Figure 2. A handheld anemometer was employed as the airflow-measuring device for this research.

The air is drawn from the abovefloor space by the air conditioning units, discharged under the floor for distribution through the vertical rack units, then returned to the air conditioners, creating a circular air flow pattern, as shown in Figure 2. Further, a parabolic velocity curve can be interpreted from this figure by observing a vertical plane six ft (1.8 m) from the air conditioner, from floor to ceiling.

The circular air movement could help to predict a predisposition for stratification, and detectors positioned directly in the stratified layer would be expected to activate in advance of other detectors in the room. In a stratified scenario, detectors at the light tracks would be expected to actuate in advance of detectors at the ceiling beams.

TEST PROCEDURE

SCENARIO 1: WISPY SMOKE PRODUCTION ABOVEFLOOR

Scenario 1 used smoke machine location 2 and a setting of 2.5, the lowest setting capable of producing visible smoke.

A photoelectric detector mounted to the light track adjacent to the air conditioner actuated within seconds. Two detectors at the bottoms of the ceiling beams also quickly actuated, and a detector in a beam pocket actuated much later in the test.

Neither the underfloor detectors nor the incipient air smoke detection system activated during this experiment. The incipient air smoke detection control panel fluctuated between 0.3 and 0.10, but would not sustain a 0.8 value for the period of time it would have taken to issue a trouble alarm.

SCENARIO 2: WISPY SMOKE PRODUCTION ABOVEFLOOR WITH INCREASED AIR ENTRAINMENT

Scenario 2 used smoke machine location 3 and a fog setting of 2.5. Location 3 was selected because it was noted in Scenario 1 that a visible stream of fog was taking a path directly into the air conditioning units. It was desired that a smoke machine position be selected to attempt replication of a stratified smoke layer. Location 3 featured placement of the smoke machine output in front of a perforated floor tile, with rising cool air directing the smoke into a vertical plume, which could replicate a smoldering fire in a computer rack unit.

A significant observation during this experiment was that the smoke level was very light and was stratified quite distinctly below the light track level. This observation conforms to the air velocity profile given in Figure 2. Spot detectors at the light track and at the inlet to the air conditioning unit were the first to actuate. One detector at the bottom of the ceiling beams went into alarm. The incipient air smoke detection system showed values of 0.01 to 0.02, significantly less then the requisite level for alarm notification.

This was the most challenging scenario. Air forced through the perforated floor tiles was entrained into the smoke plume and cooled the smoke very rapidly, resulting in a distinctly stratified smoke layer. Even in the presence of stratification, one smoke detector at the bottom of the ceiling structural tees actuated. No detectors in beam pockets actuated during this scenario.

SCENARIO 3: MODERATE SMOKE PRODUCTION ABOVEFLOOR

The smoke machine at location 1 and at setting 3 issued a steady plume which activated a photoelectric smoke detector mounted to the light track closest to the air conditioner within seconds. The second detector actuating was a photoelectric detector mounted directly above an air conditioner inlet. Ten underfloor detectors and two detectors mounted to the bottoms of ceiling beams activated early in the test. Only photoelectric detectors responded to the smoke produced. While one detector mounted within a beam pocket actuated, it occurred very late in the test.

The incipient air smoke detection system went into “alert” mode slightly 3 minutes after the first spot smoke detector actuated, at a sustained setting of .08 on the control panel monitor, and later went into “fire” status at a sustained setting of 2.0.

SCENARIO 4: MODERATE SMOKE PRODUCTION UNDERFLOOR

Scenario 4 used smoke machine location 2, located under the raised floor, and a fog setting of 3. This location was intended to replicate a cable fire beneath the raised floor.

Four underfloor detectors directly adjacent to smoke machine location 2 activated within one minute of commencement of smoke production. However, no abovefloor detectors activated, and the incipient air smoke detection system did not record the requisite level of smoke to emit a trouble signal.

An interesting observation was that, even though the underfloor area was filled with smoke, smoke above the floor was almost visually imperceptible. A real cable fire would most likely have emitted a distinct acrid odor, enhancing the probability of human verification of an underfloor detector alarm or trouble signal, even when visible smoke is not apparent.

SCENARIO 5: HEAVY SMOKE PRODUCTION ABOVEFLOOR

Scenario 5 featured smoke machine location 3 and a fog setting of 3.8. While 3.8 produces only a fraction of the smoke production capability of the machine, it still issued a very heavy plume in comparison to the wispy smoke observed at setting 2.5. Scenarios using fog settings in excess of 3.8 were judged to be unnecessary.

At this setting, there was more of a flooding of the room with smoke, and the stratification noted in Scenario 2 was not nearly as pronounced. As expected, the heavy smoke production resulted in almost immediate response from the fire alarm system, with numerous detectors going into alarm. A detector mounted to a light track was the first actuating, with more than a dozen ceiling detectors actuating shortly thereafter. Detectors at the bottoms of the beams actuated significantly faster than detectors mounted within beam pockets.

Clearly, an electronics fire of major consequence will rapidly actuate numerous detectors in the computer machine room. Higher volumetric rates of smoke production would yield results congruent to Scenario 5 in the early stages, with expanding numbers of adjacent detectors actuating.

CONCLUSIONS

Early notification in the presence of low volumetric rates of smoke production was the research objective. We have studied the literature on hotplate ignition of electronic components, and such scenarios are capable of inundating the room with smoke, which was not our objective. While the ideal experimental situation would seemingly have been to replicate an electronics fire by heating an electronic component to ignition on a hot plate, it was felt that the lighter smoke production emanating from the smoke machine at a low setting of 2.5 more accurately simulates the volume of smoke produced by a smoldering fire in its early stages.

From the research performed, several conclusions can be drawn:

Conclusion 1

Placement of smoke detectors at the bottom of the exposed structural tees is more advantageous to early detection of smoldering fires in machine rooms, given the airflow scenario encountered in this research, than the NFPA 72 placement of smoke detectors within beam pockets. When detectors in the beam pockets did actuate, they responded much later in the experiment than nonpocketed detectors, and in the presence of stratified smoke, did not actuate at all.

Conclusion 2

Looking especially at Scenario 1, where two detectors mounted to the bottoms of the ceiling structural tees actuated in the presence of very light, wispy smoke, it is apparent that a detector spacing of 120 ft^2 (11 m^2) is adequate. Even in the most challenging scenario of stratified smoke in Scenario 2, one detector at the bottom of the structural ceiling tees actuated and emitted a trouble signal to the control panel. While detector spacing was not a variable that was modified for this test, detector spacing greater than that used in this study would be expected to result in increased response times.

Conclusion 3

The underfloor arrangement of photoelectric detectors spaced at 120 ft^2 (11 m^2) appears effective in responding to light abovefloor and underfloor fog production, even in the presence of air velocities up to 1000 ft/m (5 m/s).

Conclusion 4

Photoelectric detectors responded to light fog production earlier than ionization detectors in these tests. Ionization detectors are more likely to be affected by air velocity and less likely to rapidly respond to the atomized liquid droplets produced by the fog machine than photoelectric detectors, but would be more likely to rapidly respond in the presence of solid soot particles produced by burning circuit boards.

Conclusion 5

The incipient air detection system, in the presence of wispy smoke production, did not respond as rapidly as the ceiling and underfloor spot detectors that actuated during this research. An explanation for this is that the air aspirating analysis method is primarily looking for particulate soot found in most smoke samples. The alcohol/water fog-produced by the smoke machine, especially at low fog production settings, may not be presenting a sufficient contrast for optimal evaluation of the air aspirating analyzer. It was also determined that the air aspirating pipe inlet orifice sizes and location required adjustment and retesting, which was subsequently performed.

Conclusion 6

While the response of the photoelectric smoke detectors at the air conditioning units and on the light tracks was impressive, spot detectors installed at these locations were not judged to be cost-productive. Sufficient numbers of detectors at the bottoms of the ceiling structural tees actuated in the presence of wispy stratified smoke to conclude that detectors at these locations will adequately respond without additional detectors. Placement of detectors at the light tracks is of questionable value if the smoke does not stratify. Air aspirating smoke detection is being recommended in lieu of spot smoke detectors at the inlets to the air conditioning units.

Conclusion 7

Airflow patterns, as measured during this experiment and as shown on Figure 2, demonstrate a propensity for smoke stratification at the light track level, at low volumetric smoke production rates, as might be concluded from evaluating the parabolic air velocity profiles recorded.

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The Arts and Industries Building: A Case Study

PERFORMANCE-BASED ANALYSIS OF AN HISTORIC MUSEUM

By Andrew Bowman

Renovation projects in historic buildings are routinely faced with achieving the seemingly incompatible goals of preserving historic architecture and complying with the life safety provisions of modern building codes. The challenge in these situations is to provide a solution that can meet the code-intended level of safety while minimizing the impact on the historic fabric of the building.

This article describes a performance-based life safety analysis conducted by Gage-Babcock & Associates at the Arts and Industries Building (AIB) on the National Mall in Washington, DC. This article not only presents the technical framework of the analysis but also highlights how renovations of historic buildings can benefit from the use of a performance-based approach in lieu of compliance with traditional prescriptive requirements.

BACKGROUND

The Arts and Industries Building had almost become a forgotten treasure among the Smithsonian Institution's sixteen world-famous museums. Originally constructed in 1881 as the United States National Museum, the facility has been overshadowed by the more-acclaimed members of the Smithsonian family such as the National Air and Space Museum, the National Museum of Natural History, and the National Museum of American History. Recently, significant effort has been devoted to determine the feasibility of renovating this museum and restoring the interior to its original historic appearance. The renovation of the AIB, as proposed by the design team headed by the Polshek Tobey + Davis Joint Venture, involves removing infill areas that have been added throughout the years and returning the building to its original configuration, while providing the mechanical, electrical, telecommunication, and fire protection systems required in modern buildings.

PROJECT DESCRIPTION

The Smithsonian Institution, serving as the owner and reviewing authority, has adopted the 1999 edition of the *BOCA National Building Code*[1] while incorporating the 1997 edition of the *Life Safety Code*[2] *(LSC)* in lieu of BOCA Chapter 10. While not adopted at the time of the analysis, the 2000 Edition[3] of the *LSC* was used for guidance.

Additionally, given the building's location on the National Mall and its historic designation, approval of plans by the Fine Arts Commission and the National Capital Preservation Commission (NCPC) was required.

The original interior configuration of the Arts and Industries Building can be likened to modern two-story retail malls. The centers of the first and second floors are open with various occupancies such as offices, a daycare center, a gift shop, and a theater located on the outer perimeter. There is a network of balconies that serves the entire second floor. The majority of the open areas of the first and second floor will be used as exhibit space. At the center of the building is a large 80-foot-high rotunda. The first floor area is approximately 95,000 ft^2 (8,000 m^2) while the second floor is approximately 35,000 ft^2 (3,300 m^2). The calculated occupant load for the building is approximately 4,550 people, which is based on methods from the LSC and is supported as the worst-case scenario based on historical information and projections provided by Smithsonian.

The AIB has several fire protection features that exceed minimum prescriptive code requirements. Smithsonian regulations require that all buildings have complete automatic smoke detection and sprinklers throughout. Complete smoke detection coverage is not required for buildings such as the AIB by any of the model building codes. Additionally, the Smithsonian requires all of its automatic sprinkler systems be designed per NFPA 13 *Installation of Automatic Sprinkler Systems*[4] with a design density of Ordinary Hazard Group II, far exceeding the Light Hazard design density that would be required in office areas, which comprises a large portion of the floor area of the second level. The design density of Ordinary Hazard Group II is consistent with the expected fuel loading in the exhibit spaces and the gift shop. The Smithsonian has also developed criteria which severely restrict the amount of combustible materials that may be used in the construction of its exhibits. This is coupled with an exhaustive review and oversight process by Smithsonian's own fire protection engineers to ensure compliance with Smithsonian regulations. In addition, the Arts and Industries Building has a security staff that is trained to assist in fire emergencies. The diligence of the Smithsonian in providing proactive fire safety measures contributes significantly to the overall level of life safety within their buildings. When conducting a prescriptive-based design, these additional features are typically not considered when determining compliance.

HISTORIC CONSIDERATIONS

Since the scope of the project involved a complete interior renovation, the AIB was expected to comply with current construction and design regulations that were not required during the original construction. As expected with many renovation projects in historic buildings, several egress-related concerns were identified. These concerns were related to one major architectural feature. In the AIB, all of the main exits in the building are on the first floor of the two-story building. This led to prescriptive code deficiencies, such as extended travel distance (approximately 350 ft (110 m) from the most remote areas) and insufficient arrangement of exits (all of the second

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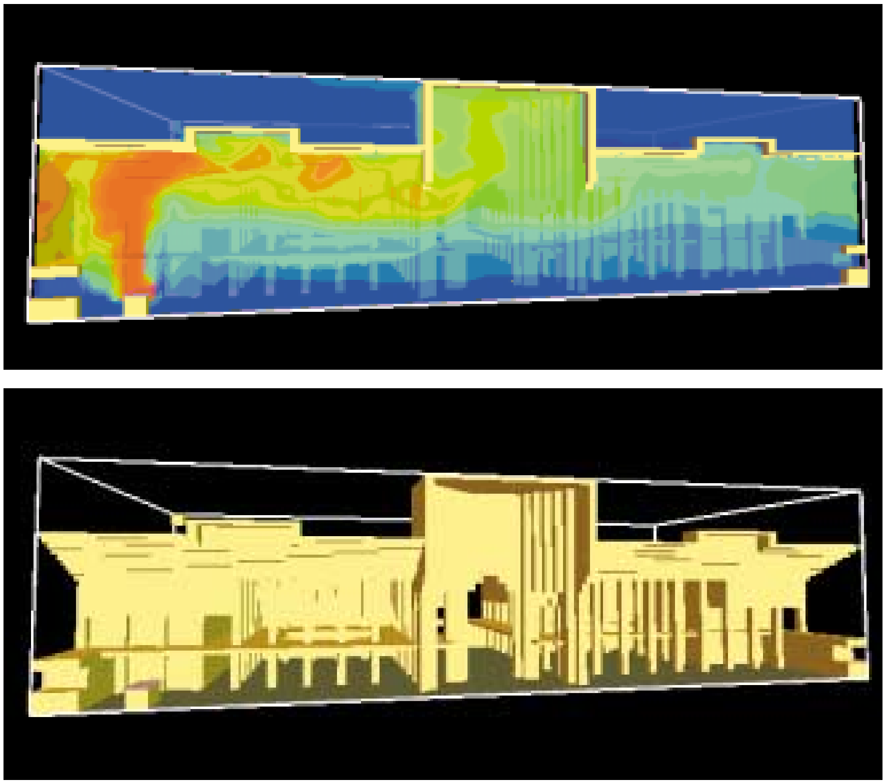

Figure 1. FDS modeling of a fire.

floor exit stairs discharge onto the first floor instead of at least half discharging directly to the exterior). Since the interior and exterior of the building are historic and could not be altered without approval of the Fine Arts Commission and the NCPC, traditional solutions such as providing reconfigured exits were not considered feasible. This prompted the desire for a performance-based analysis and design, since virtually no architectural solution could satisfy existing prescriptive code requirements as well as the concerns of the Fine Arts Commission and NCPC. The conflicting objectives created by trying to balance historic preservation concerns with prescriptive code compliance necessitated a performance-oriented solution, the goals of which were to preserve the historic integrity of the national landmark building and provide an acceptable level of safety.

PERFORMANCE-BASED APPROACH

The approach used in developing the performance-based fire and life safety analysis was based on the guidelines identified in the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*[5] and Chapter 5 of the 2000 edition of the *LSC*. These documents outline a structured approach to proceeding through a performance-based analysis. Key topics include defining project scope, identifying goals, defining stakeholder and design objectives, developing performance criteria, developing design fire scenarios, and developing and evaluating trial designs.

PROTECTION GOALS AND PERFORMANCE OBJECTIVES

The main fire protection goal addressed in the performance-based life safety analysis was that of minimizing fire-related injuries and preventing undue loss of life. This was selected in lieu of other potential goals such as property protection and business interruption since only the means of egress deviated from the code-prescribed minimum criteria.

From this fire protection goal evolved the design objectives. The design objectives were based upon examples found in Table B-1 of the *SFPE Engineering Guide to Performance Based Fire Protection Analysis and Design of Buildings*[5] and are summarized as "providing adequate time for those people not intimate with the first materials burning, those people outside the room or compartment of fire origin, and those people outside the floor of fire origin to reach a place of safety without being overcome by the effects of fire and fire effluents."

These performance objectives are evaluated through the use of fire and egress modeling. Fire modeling helps to evaluate the interior environment during a fire for a wide range of scenarios. Egress modeling is used to determine a range of times in which it is expected that the entire building can be reasonably evacuated. The results of these two models are then compared to determine if at any time the paths of egress are considered untenable. This is accomplished by comparing the predicted conditions to predetermined threshold levels for criteria such as temperature, carbon monoxide, and visibility. This comparison is then used to assess whether or not the performance objectives have been met.

SELECTION OF THE FIRE MODEL

The fire model used for the analysis, Fire Dynamics Simulator[6] (FDS) version 1.0, represents a significant advancement in modeling the effects of fire in complex buildings such as the AIB. FDS, developed by the National Institute of Standards and Technology (NIST), is a field model capable of describing the transport of mass, momentum, and energy from fire-induced flows across hundreds of thousands of separate volumes within a building. Because of this capability, the technical output of the model is well suited for complex buildings. The ability to monitor and record values for important fire phenomena at specific locations throughout the building is an important capability when conducting a complex performance-based analysis. Besides the extensive technical capabilities, FDS includes extremely useful visual output. The visual output includes a three-dimensional viewing program that illustrates the geometry of the building as well as providing a real-time visual representation of fire phenomena. Given the complex nature of the AIB, the ability to visually verify the interior geometry and the resulting fire-growth phenomena is essential in communicating the results. These factors led to the selection of a field model over a zone model. Zone models, while possessing a wide range of capabilities, did not appear to provide sufficient level of detail on the effects of fire (temperature, carbon monoxide, and visibility) given the large-volume nature and extremely complex geometry of the AIB. The hot upper layer and cold lower layer approach of zone models did not provide the level of detail necessary to monitor various conditions on balconies and other egress paths throughout the building.

EGRESS MODELING

In analyses where life safety is evaluated, determining how much time is necessary to evacuate the occupants is essential. One method for predicting evacuation times is through the use of a computer-based egress model. The egress model used for this analysis, EVACNET4[7], is an hydraulic flow-type model requiring specification of initial occupant loads, occupant locations, speed of travel, available egress width, and flow characteristics. EVACNET4 assumes that individuals inside the building take the most direct route out of the building. Since this approach is not initially conservative, the selected input parameters for the AIB analysis were chosen to reflect nonideal conditions. These input parameters included increased occupant loading (above what is expected), reduced travel speed, increased travel distance, reduced exits available (assuming that the largest exit is blocked), delayed initiation of egress, and neglecting convenience stairs, that while likely to be used, are not part of the required means of egress. A fifty percent factor of safety was applied to the calculated results to reflect uncertainty in the model. An additional three minutes was factored in to account for detection time and the inevitable time delay between the first fire alarm and when people actually start to evacuate. The three minutes was a combination of calculated smoke detector activation time along with assumptions about typical egress initiation delays. Results of the modeling were then compared with threshold values for toxicity and temperature determined as part of the performance criteria.

PERFORMANCE CRITERIA AND THRESHOLD VALUES

The *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*[5] defines performance criteria as "criteria stated in engineering terms with which the adequacy of any developed trial designs will be judged." This definition is further clarified as "threshold values, ranges of threshold values, or distributions that are used to develop and evaluate trial designs for a given design solution. Performance criteria might include temperatures of materials, gas temperatures, smoke concentration or obscuration levels, carboxyhemoglobin (COHb) levels, and radiant flux levels." Selection of performance criteria from which to judge the results of the model is one of the most challenging aspects of a comprehensive analysis.

Three performance criteria (temperature, carbon monoxide concentration, and visibility) were evaluated in the AIB analysis and are included in Tables A, B, and C. For many analyses, selection of threshold values is difficult given the wide range of available data and the even wider range of human response to the various criteria. This makes selecting conservative values imperative. The threshold criteria in this analysis were determined by the calculation procedures in the *SFPE Handbook of Fire Protection Engineering*[8]. The thermal tenability for this analysis was determined by calculating the temperature in which an individual could withstand exposure for thirty minutes. The time period of thirty minutes conservatively correlates to the maximum calculated length of time an occupant would take to exit the building. However, for the analysis, if this calculated temperature was exceeded for any length of time (as opposed to thirty minutes) in an area, the area was considered untenable. The same method was used for determining the threshold level for carbon monoxide. The threshold level of visibility was determined to be 10 meters as supported in Section 2, Chapter 8 of the *SFPE Handbook*. The threshold values were then compared to the results obtained by placing simulated "thermocouples" throughout the building to monitor temperature, carbon monoxide, and visibility. This highlights one of the advantages of field models over zone models since zone models would not provide the flexibility to monitor separate points throughout a space with the same level of detail.

DESIGN FIRE SELECTION

Selection of appropriate design fire scenarios is a significant challenge in preparing a performance-based analysis. However, the 2000 Edition of the *Life Safety Code* provides a series of

Table A – Representative Temperature Results for a Design Fire Scenario*

Egress Path Locations	Second Floor Balcony	First Floor Exhibit Space	Rotunda	Exit 1	Exit 2	Exit 3
Time at which last person has evacuated the area **(minutes)	14.8	20.8	13.5	21.5	21.8	20.9
Threshold Temperature	65 °C	65 °C	65 °C	65 °C	65 °C	65 °C
Calculated Temperature***	32.0 °C	36.7 °C	30.5 °C	31.0 °C	35.9 °C	35.5 °C

Table B – Representative Carbon Monoxide Results for a Design Fire Scenario*

Egress Path Locations	Second Floor Balcony	First Floor Exhibit Space	Rotunda	Exit 1	Exit 2	Exit 3
Time at which last person has evacuated the area **(minutes)	14.8	20.8	13.5	21.5	21.8	20.9
Threshold Carbon Monoxide Concentration	950 ppm	950 ppm	950 ppm	950 ppm	950 ppm	950 ppm
Calculated Carbon Monoxide Concentration***	127 ppm	106 ppm	100 ppm	100 ppm	106 ppm	103 ppm

Table C – Representative Visibility Results for a Design Fire Scenario*

Egress Path Locations	Second Floor Balcony	First Floor Exhibit Space	Rotunda	Exit 1	Exit 2	Exit 3
Time at which last person has evacuated the area **(minutes)	14.8	20.8	13.5	21.5	21.8	20.9
Threshold Visibility	10 meters	10 meters	10 meters	10 meters	10 meters	10 meters
Calculated Visibility***	70 meters	95 meters	120 meters	94 meters	92 meters	90 meters

* This design fire scenario assumes one of the four exits is blocked with a maximum heat release rate of approximately 7.5 MW.

** Represents time from ignition, which includes expected delay in detection of fire, delay until evacuation begins, and 50% safety factor.

***Highest recorded value at several points in each location.

eight design fire scenarios that must be addressed. Exceptions are made for scenarios that are demonstrated to be inappropriate for the building use and conditions. Using this approach, the required design fire scenarios were agreed upon and several other design fire scenarios added. While all eight design fire scenarios were evaluated, particular consideration was paid to those fire scenarios addressing exhibits in the open exhibition areas. This was based on preliminary calculations involving expected fuel loading, occupant density, sprinkler effectiveness, complete smoke detection coverage, and fire-rated separations between the exhibit halls and all surrounding areas. The next step, selection of fire characteristics, was based upon not only the expected fuel loading but also took into account several Smithsonian safety measures that are specifically aimed at limiting the combustible materials used to construct exhibits. These measures contribute to a reduced fuel size while also impacting how rapidly the fire will extend beyond the area of ignition. Proactive fire safety measures are especially helpful in potentially high fuel density occupancies such as museums. While not typical of most buildings, these measures were a significant part of the design fire scenario selection for this performance-based analysis.

Each design fire consisted of multiple fuel packages that were arranged to simulate fire spread through an exhibit space. The fire growth curve used to describe a single fuel package was that of a large upholstered sofa with a maximum heat release rate of approximately 3.1 MW. Based upon the expected fuel loading, the number of fuel packages for a given design fire was varied. Therefore, the overall heat release rate for each of the design fires differed based upon the expected fuel loading. For a majority of cases, the effect of sprinkler control was evaluated. Several fire growth curves were used to determine the worst case fire size at the time of sprinkler activation. The heat release rate was then maintained at that level for the course of the simulation. This resulted, for some scenarios, in fire sizes of approximately 4.8 MW for the length of the simulation.

CONSERVATIVE ASSUMPTIONS

Conservative assumptions play a significant role in performance-based analyses since the characteristics of fire in an enclosure are reliant upon many indeterminate variables. One use of conservative assumptions is to fill gaps in the available data or technology used in the analysis. Another use is to help streamline the analysis by utilizing conservative assumptions for marginally important criteria that would not have a dramatic impact on the results, but could significantly increase the complexity of the analysis. A third role of conservative assumptions is to narrow the infinite number of possible design fire scenarios down to a manageable number. For the AIB performance-based analysis, conservative assumptions for variables such as sprinkler effectiveness, performance criteria, detection time, fuel loading, fire department response, occupant loading, egress characteristics, and other pertinent factors fulfilled all three roles.

RESULTS

The results demonstrated that at no point during the necessary evacuation time was the threshold criteria for temperature, carbon monoxide concentration, or visibility reached. These results were obtained using conservative ranges for the design fires, occupant loading, egress characteristics, and performance criteria. The results were especially favorable given the extent of the conservative assumptions.

Based upon the results of the analysis and the overall design philosophy, several fire protection and life safety features were recommended to be provided or improved. These included quick-response sprinklers throughout the building, passive fire protection separating occupancies and some egress routes from the exhibit areas, six new code-compliant stairs from the second floor in addition to the four existing monumental stairs, and recommendations and guidelines to limit the extent of fuel loading in an individual exhibit area. Even though stairs discharging directly to the exterior were not part of the design recommendations, protection of existing internal stairs in the remote corners of the buildings was recommended to facilitate safer travel from the upper level to the lower level for those occupants with the greatest required travel distance.

Tables A, B, and C provide a representative summary of the results from the fire and egress modeling in comparison to the predetermined threshold criteria. The results outline the calculated temperature and carbon monoxide concentrations as well as visibility for a specific area at the time when it is expected that the last occupant has left that location. As an example, the results of the egress model, along with the factors of safety, indicate that the last person will have left the rotunda approximately 13.5 minutes after the fire starts. At that time, the calculated temperature and carbon monoxide concentration are 47% and 11% of the predetermined threshold, respectively. Visibility is approximately 113 meters.

CONCLUSIONS

Renovations in historic buildings have traditionally produced fire and life safety challenges, since the original architecture of the building was not intended to comply with modern-day building codes. However, as renovations of these historic buildings occur, there is a need to provide a high level of life safety while preserving the historic construction. The emergence of performance-based codes and analytical tools such as advanced fire modeling provides a means for identifying acceptable solutions. The application of a performance-based approach can identify where modifications are necessary for life safety, while helping to ensure that the impact on historic architecture is minimized. As demonstrated by the results of the analysis, historic structures such as the Arts and Industries Building can benefit greatly from performance-based codes. Compliance with prescriptive criteria written and intended for modern buildings with little regard for important historic architecture is no longer the sole option available for the fire protection engineer.

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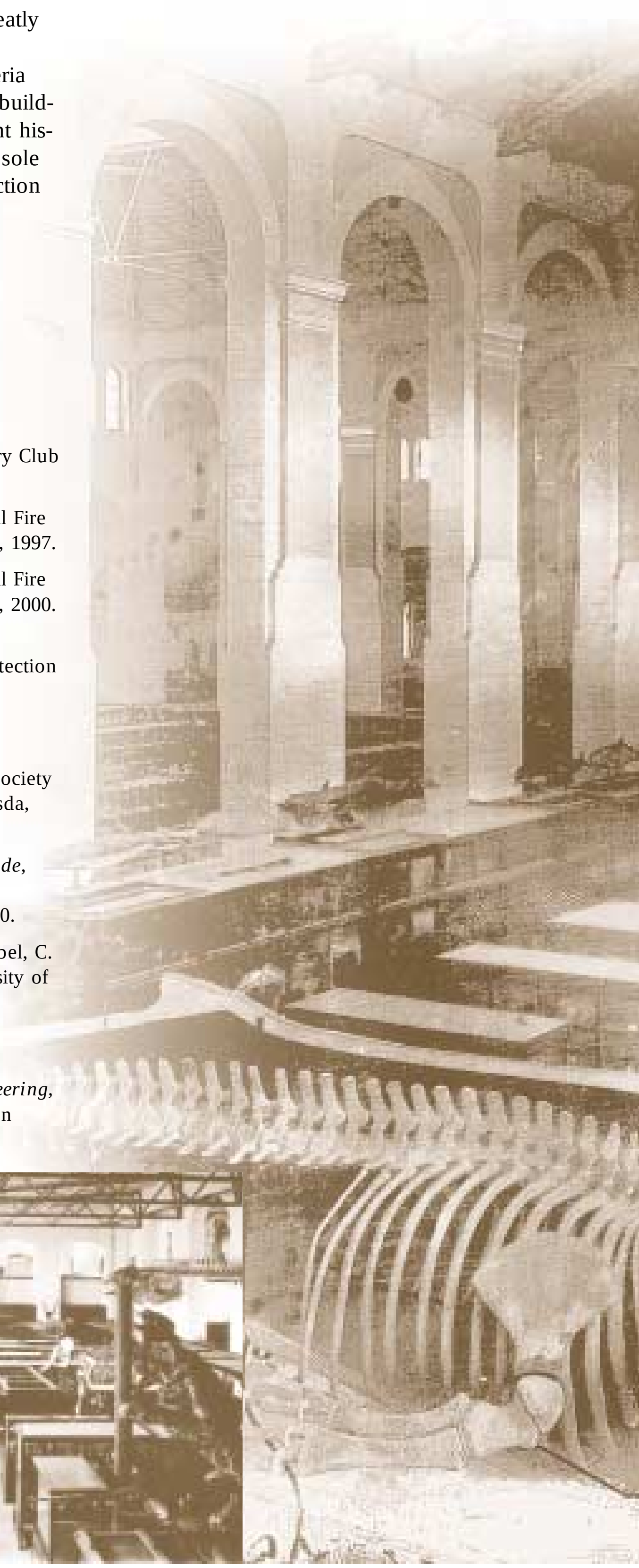

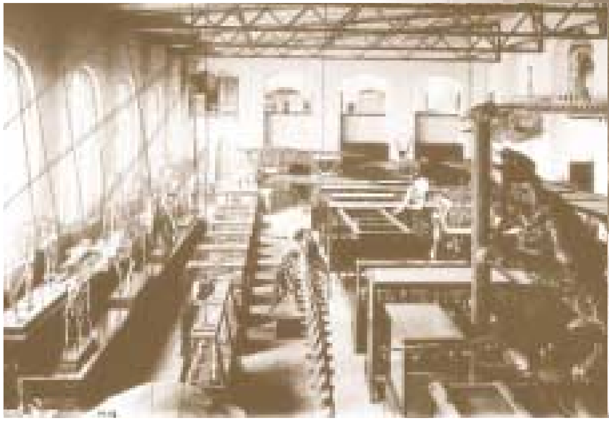

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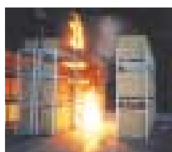

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CCI CODE CONSULTANTS, INC.

Fire Protection Engineers

Koffel Associates, Inc., is a fire protection engineering and code consulting firm with offices in Connecticut, Maryland, and Tennessee that provides services internationally. Positions are available at the following levels:

Senior Fire Protection Engineer
Registered Fire Protection Engineer
Fire Protection Engineers (BS or MS in FPE)
Fire Protection Engineering Technician (AutoCAD experience, NICET, or technology degree desirable)

Responsibilities may include:

- Fire protection engineering and life safety surveys
- Design and analysis of fire protection systems including automatic sprinklers, clean agent, fire alarm and detection, water supply, and smoke management systems
- Code consultation with architects, engineers, developers, and owners during design and construction
- Post-fire analysis and investigation
- Computer fire modeling
- Fire risk and hazard assessments
- Codes and standards development

Koffel Associates, Inc., personnel actively participate in the activities of professional engineering organizations and the codes and standards writing organizations. The firm offers a competitive salary and benefits package including conducting its own in-house professional development conference for all employees.

Fire Protection Engineers

OPPORTUNITY • CHALLENGE • RECOGNITION
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OPPORTUNITY At AHA over 120 professionals work collaboratively on a wide variety of MEP/FP assignments including healthcare, biotech, institutional and corporate projects.

CHALLENGE Our high energy atmosphere gives experienced engineers, designers and drafters first-hand opportunities to test the limits of their knowledge.

RECOGNITION AHA employees work hard. Our benefits package rewards that effort. We offer competitive salary, comprehensive medical & dental insurance, 401k, tuition reimbursement and flexible hours, just to name a few.

We are seeking Fire Protection Project Engineers & Designers. Working knowledge of fire protection systems including production of drawings, specifications, hydraulic calculations, survey reports, inspection services, reviews of contractor submittals and general code consulting. CAD 12 or higher needed. F.E. with ability to become registered preferred. Prior healthcare, biotech, institutional or corporate experience a plus.

Send your resume to:
Michael Joanis, PE
Fire Protection Department Manager
AHA Consulting Engineers
10 Maguire Road, Suite 310
Lexington, MA 02421
Fax: 781.372.3100
e-mail: mjj@aha-engineers.com

EOE

AHA CONSULTING ENGINEERS

Resources

Equip yourself for tomorrow's performance-based design environment with publications and training from SFPE.

Contact SFPE at education@sfpe.org.

Performance-Based Design Online Seminar:

This two-hour seminar will lead participants through a detailed review of the new *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings.* Oriented toward the allied professional, it will feature presentations on each section of the guide, including: definition of project scope, setting project objectives, developing performance criteria, selecting design fire scenarios, developing trial designs, probabilistic and deterministic analysis methods, and creating project documentation. The role of the *Guide* in the fire safety design process and examples of its application will also be presented. October 25, 2-4 p.m. EST.

Performance-Based Design Audiotape

An introduction to the most dynamic new design approach in fire protection today. Focuses on what performance-based design is and how it differs from prescriptive-design methods. Outlines the process and benefits of PBD as well as the qualifications for a PBD professional. Convenient audiocassette program together with an illustrated wall chart of the PBD process. **$44.00**

Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings,

by the SFPE Task Group on Performance-Based Analysis and Design, 2000. This guide outlines a process for carrying out these designs and is essential for anyone who will apply, approve, or be affected by performance-based codes and standards. Chapters cover such topics as defining your project scope and identifying goals; specifying stakeholders and design objectives; developing performance criteria; creating design fire scenarios and trial designs; evaluating trial designs; and documentation and specifications. Equip yourself for the coming era of performance-based codes with this unique guide!

SFPE/NFPA Member Price: $46.75 Nonmember Price: $52.00

Introduction to Performance-Based Fire Safety,

by Richard L. P. Custer & Brian J. Meacham, 1997. This 11-chapter illustrated book presents the basic concepts of performance-based fire safety engineering and includes chapters on design vs. codes, fire dynamics and modeling, hazard analysis and risk assessment, performance criteria, human factors, and a case study illustrating the process.
260 pages $74.25

Working with Code Officials in Performance-Based Design –

extended abstracts from the 1998 SFPE Engineering Seminars – contains the AHJ and fire protection engineer perspectives on several recent case studies of performance-based design. **79 pages $35.00**

BRAIN TEASER

A wire loop is constructed with enough wire so that the loop just touches the top of Mt. Everest when the loop's center coincides with that of the earth's center (i.e., it wraps all the way around the earth). You are placed at the top of Everest and asked to cut the wire and insert a 10-meter section.

Assuming that the radius of the loop is 20,000 km, how far above the top of the mountain will this large wire loop rise?

Thanks to Derrick M. Tjernlund, P.E., for providing this issue's brainteaser.

Solution to last issue's Brainteaser

A grocer purchased 100 kg of potatoes. When they were purchased, the moisture content of the potatoes was 99.0%. Prior to selling the potatoes, the grocer checked the moisture content of the potatoes and determined that it was now 98.0%. How many kilograms of potatoes did the grocer now have to sell?

The following equation can be used to express the mass of the potatoes as a function of water and dry potato mass:

$$m_t = m_{dp} + m_w$$

Since m_t = 100 kg and $m_w = 0.99m_t$, the dry potato mass, m_{dp}, is 1 kg. When the moisture content drops to 98%, $m_w = 0.98m_t$. Substituting,

$$m_t = 1kg + 0.98m_t$$

Solving for m_t, the grocer now has 50 kg of potatoes.

CORPORATE 100 The SFPE Corporate 100 Program was founded in 1976 to strengthen the relationship between industry and the fire protection engineering community. Membership in the program recognizes those who support the objectives of SFPE and have a genuine concern for the safety of life and property from fire.

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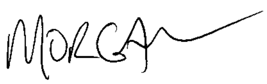
Professional Licensure in California



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

Unlike in other countries, where professional registration is typically managed nationally, licensure in the United States is on a state-by-state basis (as with the article on page 14, the term "state" is used broadly here). For engineers who practice in many states, this requires that they become licensed in each state. Fortunately, states usually allow comity of licensure, which means that someone who is licensed in one state can become licensed in other states without going through the same process as someone who is not licensed at all.

However, there are differences between how states license engineers. For example, some states may differ as to the number of years of experience that they require before considering someone eligible for professional registration, or may allow for a (large) number of years of experience to substitute for successful completion of the P.E. exam.

In California, registered engineers fall into two categories: "practice" and "title." "Practice" engineers are the only engineers that may perform engineering in certain disciplines. In California, the only engineering disciplines that are classified as "practice" are civil (including the subspecialties of structural and geotechnical), mechanical, and electrical. Therefore, the practice of engineering within these disciplines is limited by regulation to engineers registered within those disciplines.

Other engineering disciplines are classified as "title." Regulations in California only allow people who are registered in one of the title disciplines to use the title of that discipline. Since fire protection engineering is a "title" discipline in California, only people who are registered in fire protection engineering may call themselves "fire protection engineers."

Therefore, unlike civil, mechanical, or electrical engineering, engineers of other disciplines are not strictly forbidden from practicing fire protection engineering. However, as a matter of professional ethics and regulations in California, engineers may only practice in areas in which they are competent by education, training, and experience.

The California state legislature is presently reviewing the laws that govern the regulation of engineering. Changes that are presently being considered include:

- Creating definition in state statutory law for "mechanical engineering" and "electrical engineering."
- Evaluating which engineering disciplines currently classified as a "Title Engineer" should be changed to a "Practice," retained or eliminated.

Obviously, changes in both of these areas could impact the fire protection engineering profession. A definition of "mechanical engineering" could be created that would include smoke control or fire suppression system design. Similarly, electrical engineering could be defined to include fire alarm system design.

In fact, early definitions that were proposed could have been interpreted to include these fire protection engineering functions. Since the practice of mechanical and electrical engineering is limited to engineers registered in those disciplines, the effects on public safety could have been adverse. Fire protection engineers have the greatest knowledge and experience in the design of smoke control, fire suppression, and alarm systems, and they could have been prohibited from preparing designs of these systems.

Fortunately, the proposed definitions for "mechanical engineering" and "electrical engineering" have been revised, which will not affect the licensed FPE's design of fire protection systems. Additionally, a study has been commissioned to "determine whether certain title acts should be eliminated or converted to practice acts...". While this language sounds ominous because of the word "eliminated," this will create an opportunity for fire protection engineering to receive increased recognition.

The favorable outcomes to date in the changes described above are due to the activism of several SFPE volunteers and the California Legislative Council for Professional Engineers. Timothy Callahan, P.E., deserves special recognition among this group.