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Historical, Present and Future Perspectives

Means of Egress

Elevator Shaft Pressurization System Standards and Codes for Smoke Control in Tall Buildings

Means of Egress: Lessons Learned



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From the TECHNICAL DIRECTOR



SFPE Completes First Engineering Standard

n December, 2010, the Society of Fire Protection Engineers completed its first engineering standard – the SFPE Engineering Standard on Calculating Fire Exposures to Structures. Publication of this standard is a major milestone in a process that began in June, 2001, when SFPE first considered whether to develop standards.

A number of factors influenced the SFPE board of directors' decision for SFPE to develop engineering standards.

The board's decision that SFPE should proceed with standards development was primarily influenced by the positive recognition and visibility that has accompanied SFPE's development of engineering guides.

SFPE began developing engineering guides in 1995. Since then, 11 guides have been published. Each of these guides has advanced the fire protection engineering profession and further solidified SFPE's position as the worldwide leader of the fire protection engineering profession.

However, many aspects of fire protection engineering are governed by codes and standards, and guides are not suitable for reference in most codes and standards due to the permissive language in which guides are written. Standards, on the other hand, would be suitable for reference.

SFPE developed a set of standards development procedures that meet the criteria of the American National Standards Association. Fire exposures for performance-based design

of structures were selected as the topic for SFPE's first standard due to increasing interest in the subject and the relative maturity of the underlying science.

Performance-based design of structural fire resistance entails three major steps: (1) determination of the fire exposures to which a structure could be subjected, (2) determination of the thermal response of the structure to the exposing fire, and (3) prediction of the structural response to elevated temperatures. SFPE's first standard covers the first of these steps.

SFPE envisions that the SFPE Engineering Standard on Calculating Fire Exposures to Structures will form part of a suite of codes and standards that govern the performance-based design of structural fire resistance. SFPE is also developing a standard that will define how to conduct an analysis of the thermal response of a building structure to the fire exposure. NFPA is developing a standard (NFPA 557) that will provide

the fire loads that are to be used as input data into calculations of fire exposures. The fire load directly affects the duration of the fire exposure.

SFPE's new standard is also consistent with the optional, performance-based option in NFPA 5000. Requirements for the performance-based design of structural fire resistance were added in the 2009 edition of NFPA 5000 (section 5.5.3.3.2).

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These requirements broadly define the fire exposures that should be used and the intended performance. The SFPE Engineering Standard on Calculating Fire Exposures to Structures provides details as to how these fire exposures should be calculated.

The missing piece is a standard that identifies how to predict the response of the structure at elevated temperatures. This is a task that generally requires the expertise of structural engineers, and SFPE hopes to work with the American Society of Civil Engineers on developing such a standard.

The publication of SFPE's first engineering standard is just one more step in SFPE's "technical excellence" goal to "establish SFPE as the primary source of fire protection engineering information and advancements." However, more

work remains. SFPE will continue to develop engineering guides and standards and seek formal reference in codes and standards where appropriate. For a complete listing of SFPE's technical activities, see www.sfpe.org.

SFPE Engineering Standard on Calculating Fire Exposures to Structures

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

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VIEWPOINT > Evacuating High Rises:

A strong international non-consensus

By Anthony Wood, Ph.D.

aving recently returned from a business trip to Seoul, I have been pondering yet again the geographical differences in evacuation approaches for high-rise buildings. When I was last in Seoul six years ago, my hotel room in a high-rise building contained a little white box fixed to a significant anchor in the wall. Intrigued, I opened the box to find a hammer to break the glass and an abseil belt to lower

oneself down to the ground. Standing in my hotel room on perhaps the 20th floor, the mere thought of evacuating that way brought on a significant shiver, but then the all-pervading images of the World Trade Center disaster were still strong in my mind, and this was clearly a last line of escape.

On a more recent trip to Seoul, I visited a tall building that had complete vertical, secondary, inter-unit fire escape routes (i.e., telescoping extendable ladders between a consistently positioned small room in each unit), in addition to the two fire stairs in the core. On the one hand, the loss of floor space (there is one for each unit and thus likely four per floor, in addition to the fire stairs) and security issues would render the system hard to

justify in most towers. Plus, having climbed just one floor, I can testify that it is hardly a comfortable evacuation route, even for the reasonably fit. On the other hand, it does provide "last resort" evacuation in case the lobby access to the normal fire stairs is compromised (i.e., partial evacuation down one or two floors to allow access back into the fire stair). Although I doubt the system would ever be used, I can understand that it would be a comfort to residents, especially in a luxury residential tower where a "personal" escape route might be a strong selling point.

I start this editorial with these two examples to show that there is far from any international consensus on evacuating high rises. While there seems to be debate in the United States regarding the use of elevators for evacuation, the United Kingdom and other parts of the world have been using them for several decades now, at least to evacuate mobility-impaired occupants (and for swifter firefighter access). While the post-WTC NIST recommendations spawned deep U.S. debate on the merits of introducing a third fire stair, the United Kingdom completed

its tallest residential building in 2006 – the 169-meter-high Beetham Tower Manchester - with just one fire stair and a host of other systems (including corridor pressurization) to compensate.

Against this backdrop of cultural differences and the fact that the risk to the buildings and cities is increasing (through terrorism, war, extreme environmental effects or accident

> as urban densities increase), I believe we need to start investigating possibilities at a far more fundamental design level, not as an alternative, but in addition to existing safety mechanisms. For a decade or more, I have been investigating the benefits of physical connections between tall buildings (i.e., sky bridges) on not only evacuation options, but for the enrichment of tall buildings and cities in general. The concept of being able to evacuate occupants at a level other than ground, should the building be at risk, seems sensible, especially if any emergency in a tall building effectively cuts off connection to the ground plane.

Perhaps 50 buildings around the world now utilize significant sky bridges, as demonstrated by the 452-meter, 88-storey Petronas Towers in Kuala Lumpur, Malaysia. The twostory sky bridge at levels 41 and 42 offers

not only the sharing of common facilities between the towers in non-emergency mode, it is also an essential part of the evacuation strategy. This strategy has also resulted in a significant space/cost saving for Petronas, since it allowed the omission of an additional fire stair that would have been needed in each tower from the sky lobby to the ground floor. At an estimated fire-stair area of 18m² per floor, through 42 floors in two towers, this is a floor-area saving of approximately 1,512 m², and an approximated cost saving of more than US\$2.4 million. This cost saving could go a long way to financing the cost of the sky bridge.

While acknowledging that there are massive challenges in incorporating strategies such as this, I do believe that's where the future of the city lies - in professionals working across disciplines to find solutions to a whole set of issues, rather than solving isolated problems in a piecemeal way.

Anthony Wood is with the Illinois Institute of Technology and the Council on Tall Buildings and Urban Habitat.



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A nationwide survey conducted by Society of Fire Protection Engineers (SFPE) in January 2011 revealed that 70 percent of Americans feel safer from fire at home than in a commercial high-rise building and another 24 percent feel no difference in their safety.

"I understand how people would feel safer in an environment they control, but the opposite is actually true," says SFPE Engineering Program Manager Chris Jelenewicz. "Systems that are designed to protect people, property, and the environment from fire are more common in high-rise buildings."

Federal government statistics confirm that in 2009 there were 356,200 residential fires resulting in 2,480 deaths and 12,600 injuries. In the same year, there were 89,200 fires in non-residential buildings resulting in 90 deaths and 1,500 injuries. High-rise building fires make up a small fraction of these non-residential building fires loses.

The results of the 2011 survey are similar to the results of a 2007 survey, which indicated 65 percent of Americans felt safer at home and another 24 percent felt no difference.

"Our goal is to educate the public about the risks from fire and help them understand they can feel at ease when inside a high-rise building," comments Jelenewicz.

For more information, go to www.sfpe.org

New Study on Residential Fire Sprinkler Water Usage

The Fire Protection Research Foundation's (FPRF) new report, Residential Fire Sprinklers - Water Usage and Water Meter Performance Study, finds that the amount of water used in fighting fires in homes without fire sprinkler systems can be many times higher than the amount discharged by a fire sprinkler system with a 10-minute operation. In addition to saving lives and property, sprinklers have added environmental benefits, including water conservation and the potential to reduce water infrastructure demands in communities, according to this study.

The study was designed to provide guidance information on this topic in a format suitable for water utilities and local jurisdictions. It includes the results of a survey of fire departments on their average use of water at fire scenes at single family homes; fire flow calculations for a variety of single family home fire sprinkler systems; and a study of the performance of conventional residential water meters in maximum and minimum fire sprinkler flow scenarios.

To download the report, go to http://bit.ly/t5Z3z.

For more information, go to www.nfpa.org

UTC Fire & Security Pledges \$150,000 for New WPI Lab

UTC Fire & Security has pledged \$150,000 over five years to Worcester Polytechnic Institute (WPI) in Worcester, Mass., towards the build-out of a new fire science research and education center for WPI's graduate program in fire protection engineering. The facility will be housed in a new building at Gateway Park in Worcester, and is expected to open in late 2012.

"Our involvement with this new world-class fire protection laboratory will support the development of the next generation of fire protection leaders and advance the body of knowledge in the field," said Scott Buckhout, president of UTC Fire & Security's Global Fire Products business.

"We are most thankful for UTC Fire & Security's support of our fire protection engineering initiatives," said Kathy Notarianni, professor and head of WPI's Fire Protection Engineering Department. "In this fast-evolving field, of both science and practice, our growing partnership with UTC Fire & Security will help us push the boundaries of education and research to advance fire safety in all its facets."

> For more information, go to www.utcfireandsecurity.com or www.wpi.edu



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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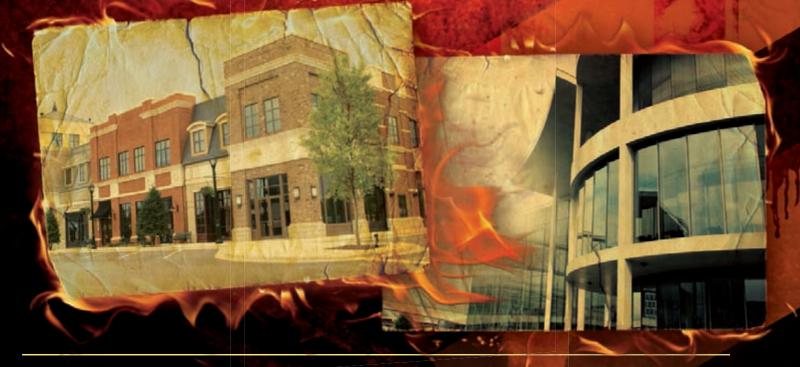
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Historical, Present and Future Perspectives

By Jason D. Averill, Erica D. Kuligowski, Ph.D., and Richard D. Peacock



HISTORICAL PERSPECTIVE

oon after the Iroquois Theater Fire (1906), the Rhoades Opera House Fire (1908) and the Triangle Shirtwaist Fire (1911), the engineering and building code communities in the United States began to consider the movement of people subsequent to an unwanted fire. As a response, the National Fire Protection Association (NFPA) formed the Committee on Safety to Life in 1913. Among the committee recommendations at the 1914 NFPA Annual Meeting were building exit and stair requirements, including sufficient stair width so that "the entire population could, standing still and as closely packed as possible, fit and take refuge in the stairs,"2 which explains why the U.S. national model codes design exits for "capacity" and why the capacity is based on the population of a single floor. The exit was sized to "store" people, motionless within the protected exit enclosure, such that the population of one floor will fit within one flight of the stair, with each person in a space 0.6 m (22 in) wide and standing on every other step.³ By the 1930s, more sophisticated concepts for evacuation (e.g., flow rate for occupants leaving the building) were being developed. These concepts, along with the now-ubiquitous 1.2 m (44 in) stair width, were documented in 1935 by the National Bureau of Standards (NBS, now NIST) report "Design and Construction of Building Exits."⁴ The landmark 1935 NBS report substantiates recommendations for exit system design based on surveys distributed to practicing architects, field inspections, citations to previous investigations as far back as 1909, as well as simple observations of exits and exit component usage during rush-hour and fire drill evacuation conditions for contemporary building designs. These recommendations constitute the primary basis for current egress

requirements, though modifications have resulted from large-loss incidents, as well as subsequent research (e.g., Templar,⁵ Pauls,⁶ Predtechenskii and Milinskii,⁷ and Fruin⁸).

While verification and validation of behavioral theory lags the development of people movement characteristics, there are links between human behavior and building codes.

In addition to stairs, the idea of leveraging the capacity of the elevator system to enhance occupant safety has been long-discussed. Both the aforementioned 1914 NFPA Proceedings and the 1935 Design of Building Exits document discuss the use of elevators for egress from tall buildings, possibly related to the observation that some evacuees in the Triangle Shirtwaist Fire used elevators to evacuate. In 1974, Bazjanac proposed using elevators to evacuate during fire emergencies and presented calculations in 1977.10 The NFPA Life Safety Code (LSC) considered the issue in the 1970s, including a detailed list of problems with using the elevators as fire exits. 11 The LSC Subcommittee on Means of Egress subsequently passed elevator egress provisions in the late 1970s (Section 5-12 proposal), but the action was overruled by the membership attending the association's annual meeting. 12 In anticipation of the Americans with Disabilities Act (which required access to buildings but largely neglected consideration of emergency egress for persons with disabilities), a consortium, including NFPA, the American Society of Mechanical Engineers (ASME) and the Council of American Building Officials (CABO) sponsored a symposium on elevators and fire in Baltimore, MD, in 1991. 12, 13 NIST held a workshop in 1992 with the research community and elevator industry. 14 ASME hosted a followup workshop in 1995. 15 Recently, significant progress has been made regarding the use of elevators for egress, which will be discussed later in this article.

While verification and validation of behavioral theory lags the development of people movement characteristics, there are links between human behavior and building codes. Assembly occupancies, for example, require 50% of the required exit width to be located at the primary entrance since occupants consistently exit buildings preferentially by the exits through which they entered the building. While building codes, models and technologies have evolved over many years, current design is not immune from large-loss events or inefficiencies.

THE PRESENT SITUATION

For 2005, NFPA estimated that the total burden of fire in the United States was between \$267-294 billion (U.S.), or roughly 2 to 2½% of U.S. gross domestic product. ¹⁶ Direct costs, broken out by component:

- Building costs for fire protection, \$46 billion;
- Estimated monetary equivalent for the deaths and injuries due to fire, \$42 billion;

- Other economic costs, 40 billion:
- The cost of career fire departments, \$31 billion (the value of donated time from volunteer firefighters was not included);
- Net costs of insurance coverage, \$16 billion;
- Property loss reported or unreported, direct or indirect, \$13 billion.

Provision of adequate egress provisions (or failure to) contributes directly to the two largest direct costs: installed fire protection and deaths and injuries. Indeed, at first glance, egress is a life safety problem. Of all victims of structural fires in the United States (roughly 2,800 per annum¹⁷), Hall indicates that one-fourth perish during evacuation. ¹⁸ Therefore, as many as 700 persons could be saved

by egress design improvements. Of these, approximately 150 would be in non-residential buildings, nearly 100 would be in apartment buildings and the remainder would be in one- or two-family residences.

In order to improve the outcomes of residential fire scenarios by improving the time to escape, the design of a typical one- and twofamily residence's egress system should be considered. The configuration of common two- or three-story residences requires occupants to egress down to the first floor via an unprotected path. Even in a singlestory home, the configuration of the sleeping areas is often such that occupants must egress through the area of fire origin due to a deadend corridor arrangement serving the bedrooms. However, fire fatalities may be more cost-effectively addressed by reducing the number of fires and the resulting fire growth and spread.



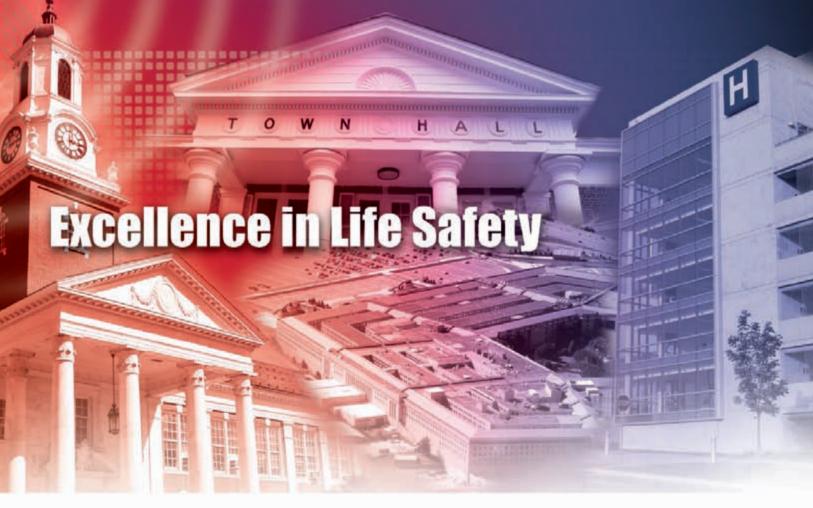
Egress design technologies could significantly reduce the annual life loss in non-residential buildings. Improvements in signage, markings and lighting led to great reductions in egress time from One World Trade Center on Sept. 11, 2001, compared to the 1993 bombing and subsequent evacuation of the same building. On Sept. 11, 2001, self-evacuation and the use of elevators in World Trade Center Building Two (before it was struck by an airplane) led to several thousand lives saved. 19 Validated egress models that accurately convey the expected range of evacuation times are on the critical path to performance-based design (PBD); however, the present dearth of usable input or validation data renders model output subject to uncertainty. If validated egress and fire models with a broad range of appropriate input data were available, an Australian study estimated the potential impact of PBD at 0.5% of the total cost of construction.²⁰ This could translate to national savings of roughly \$5 billion in the United States.

While there are reasons to believe that egress research and implementation will achieve significant reductions in the national fire burden, there are also reasons to wonder whether the problem is increasing. Aggressive building designs, changing occupant demographics (an aging population and an obesity epidemic in the United States and other developed countries) and consumer demand for higher-performing and more energy-efficient systems have pushed egress designs beyond the traditional stairwell-based approaches. While precious little underlying data exists for traditional stair-based egress systems, there is virtually no

technical foundation for performance and economics of emerging systems such as occupant evacuation elevators, active direction egress signage or mass notification technologies.

Egress Modeling

Evacuation calculations are increasingly becoming a part of life safety analyses. In some cases, engineers are using algebraic (hand) calculations to assess life safety, and in others, computational evacuation models are being used. Hand calculations usually follow the equations given in the Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering²¹ to calculate mass flow evacuation from any location within the building. The occupants are assumed to be standing at the doorway to the egress component on each floor as soon as the evacuation begins. The calculation focuses mainly on points of constriction throughout the building (commonly



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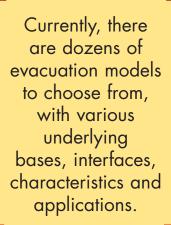
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the door to the outside, transitions between egress components, or where different paths merge) and calculates the time for the occupants to move past these points and to the outside. To achieve a more realistic evacuation calculation, or a more efficient solution, engineers have been using evacuation computer models to help assess key egress design aspects. Currently, there are dozens of evacuation models from which to choose, with various underlying bases, interfaces, characteristics and applications. These models can range from a numerical implementation of the hand calculations (thus having the same

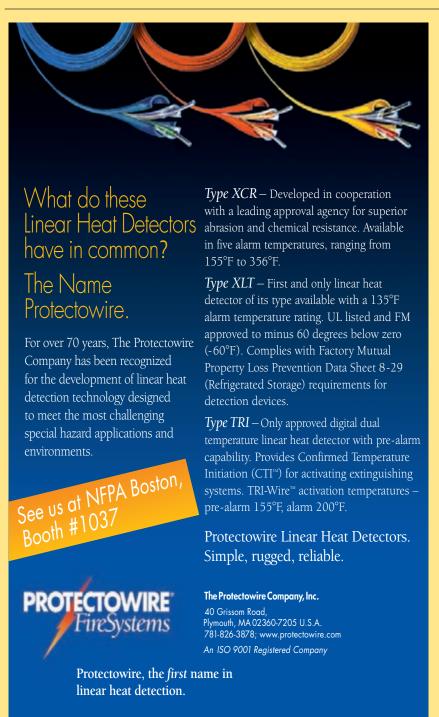
limitations as the hand calculations) to models that have complex equations and occupants with simulated decision-making.

There have been several recent trends in egress model features that have increased the complexity of the evacuation models overall.²²

- More models are including behaviors and decision-making capabilities for the simulated occupants.
- 2. The attributes and decisions of the occupants are often defined in a probabilistic fashion that requires multiple iterations of each simulation to determine the range of expected occupant evacuation times and movement speeds.



- 3. The majority of the available models simulate movement on a continuous grid. The continuous grid is more complex, since occupants are not assigned to a specific cell but can instead be located anywhere in the building.
- Modeling input is now more complex, including incorporation of fire effects into the simulation and CAD drawings' import features.



5. Nearly all current models provide three-dimensional visualization of people movement and building geometry. While this change does not improve the underlying quality of the numerical results, it better enables insight into the evacuation process.

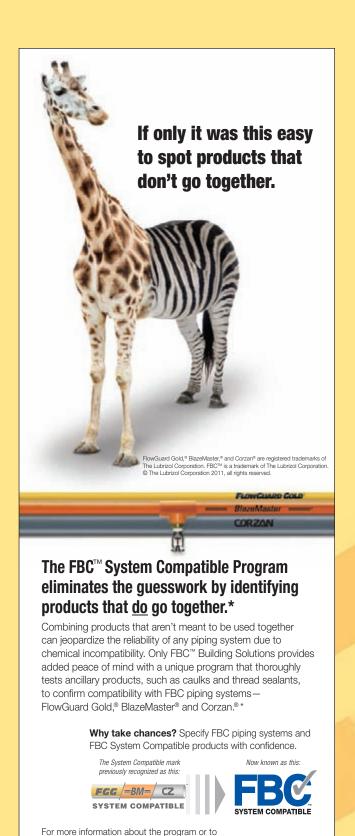
While egress models continue to develop more complex features and formulations, the underlying technical basis for modeling (which includes both rigorous, science-based theory and publicly available, well-documented datasets) has progressed more slowly. The root basis for many models continues to be a handful of historic datasets.²³ As a result, rigorous verification and validation of egress models is typically lacking and is well behind the reliability of fire modeling predictions.

Human Behavior and Emergency Management

Traditionally, evacuation models and users have often made assumptions and simplifications about occupant behavior (i.e., what people do during evacuations) that can be unrealistic and are likely to produce inaccurate results. Behavioral research in the fire community has been conducted, including development of theory (e.g., Sime²⁴ and Bryan²⁵) and data (e.g., Paulsen,²⁶ Keating and Loftus,²⁷ and Proulx²⁸).

Kuligowski is developing a comprehensive conceptual model of occupant behavior during building fires by describing the current state of evacuation modeling of human behavior in fire, identifying gaps in current behavioral techniques, and outlining a general process model for occupant response to physical and social cues in a building fire event.²⁹ A theory should predict the variety of behaviors performed by occupants in a building fire (e.g., seek information, warn, rescue and prepare). Because occupants' actions vary based on their interpretations of and interactions with their physical and social environments, it is crucial to develop a theory of occupant behavior in building fires based on social, psychological and group behavioral processes.³⁰

Social scientific theory has acknowledged for more than 70 years that human action or response is the result of a process. Instead of actions based on random chance or even actions resulting directly from a change in the environment, an individual's actions are frequently the result of a decision-making process. ³¹ Research in disasters, based on social scientific theory, has led to the development of social-psychological process models for public warning response (e.g., Mileti and Sorensen³² and Perry, et al.³³). These models specify that people go through a process of specific phases, including receiving the warning, perceiving a threat, personalizing the risk, and deciding upon a plan of action to protect people and property in response to a disaster.³¹ Additionally, researchers of fire evacuations (e.g., Bryan, ³⁴



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Feinberg and Johnson, 35 and Breaux, et al. 36) have shown that a process involving the phases of recognition and interpretation of the environment influence occupant actions. In these process models, specific cue- and occupant-related factors influence the outcome of each phase of the process (e.g., whether the person hears the warning or interprets the situation correctly). Cue-related factors are described later in this paper. Occupant-related factors include

previous experiences, knowledge about disasters and training. Research remains inconclusive about the direct effects of demographics (e.g., gender, age, income, education, race and marital status) on the decision-making process. An understanding of the decision-making process and its influential factors can be developed into a conceptual model to predict the types of individual behaviors that are likely to occur in building fires.

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People Movement Data

As part of a program to better understand occupant movement and behavior during building emergencies, NIST has been collecting stairwell movement data during fire drill evacuations of multi-story buildings. These data collections are intended to provide a better understanding of this principal building egress feature and develop a technical foundation for codes and standards requirements. To date, NIST has collected fire drill evacuation data in 11 office, municipal and residential building occupancies ranging from six to 62 stories in height that have included a range of stairwell widths and occupant densities. The goal is to provide a solid technical basis for the required number and width of stairs in tall buildings. As the data are converted to spreadsheet and quality control is completed, it is being made available on a public website (http://www.nist.gov/ el/fire_research/egress.cfm) for use by the fire protection and egress communities.

Additionally, to support standardization of egress datasets, Gwynne has developed a standardized format for archive data. The addition to improving the ability of the user to parse and understand the dataset, standardization will enhance the quality of future data collections. By reviewing the standard data reporting and storage format prior to data collection, researchers are provided with a checklist of data collection elements that may increase the number and quality of the collected data elements.

Elevators

Elevators may become a significant component of evacuation from tall buildings in the near future and should dramatically reduce the overall building evacuation time for high-rise buildings when used in conjunction with stairs. Recent code provisions were included in both

the International Building Code³⁸ (IBC) and the *Life Safety Code*.³⁹ Subsequent to the World Trade Center disaster in 2001, a collaborative effort between ASME, NIST, International Code Council (ICC), NFPA, U.S. Access Board and the International Association of Firefighters (IAFF) was launched to reexamine the use of elevators.⁴⁰ This resulted in quarterly task group meetings to develop technical requirements for occupant and firefighter use of elevators during fire emergencies.

A recent economic analysis examined the first- and life-cycle costs for two prototypical office buildings using the IBC alternatives. For new high-rise buildings over 128 m (420 ft) high: (1) an additional exit stair is a cost-effective alternative to the installation of occupant evacuation elevators on a first-cost basis; and (2) occupant evacuation elevators are a cost-effective alternative to the installation of an additional exit stair on a life-cycle cost basis when rental rates are high and discount rates are low.41 Public policy should then balance the economic considerations of stairs versus elevators in the context of potentially significant egress performance benefits afforded by use of occupant evacuation elevators.

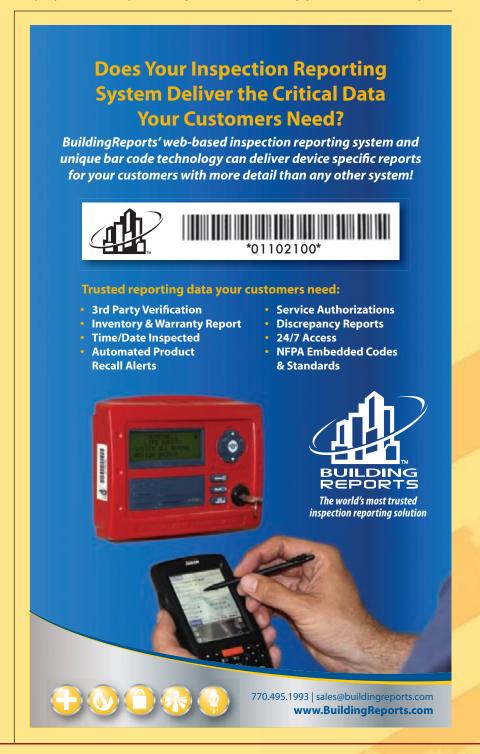
THE FUTURE

A Consensus Research Agenda

In order to maximize the effectiveness of limited resources, the egress community would benefit greatly from a prioritized, consensus-based research agenda. The first five proposed research initiatives discussed here were initially presented at the 5th International Conference on Pedestrian and Evacuation Dynamics in Gaithersburg, MD, in March 2010.⁴² By marshalling limited resources towards

collectively or systematically addressing significant issues, the field can mature more rapidly and maximize the impact of future efforts. A consensus research agenda approach has been successful in other disciplines at guiding both researchers during the proposal development stage, as

well as agencies or organizations that fund research. If a research proposal has the magnitude of the problem validated by an objective, traceable publication linked to the consensus of disciplinary experts, confidence in successful outcomes is increased in both funding and receiving parties. One example of



a successful consensus research agenda is the Firefighter Life Safety Initiatives. 43 A representative crosssection of fire service leaders gathered and achieved consensus on 16 priority research needs. The document subsequently guided grant applications and awards from agencies of the U.S. federal government. A second example of a research agenda includes the six research priorities identified in "Grand Challenges for Disaster Reduction,"44 a document developed by the U.S. National Science and Technology Council's Subcommittee on Disaster Research. Finally, while the "Rethinking Egress" workshop in 2008 did not produce a consensus research agenda, the proceedings document produced several hundred ideas for innovative technologies that may improve building evacuation.⁴⁵

1: Develop and validate a comprehensive theory that predicts human behavior during pedestrian or evacuation movement

Ball bearing and other physicsbased models are inadequate to predict the full range of possibilities for evacuation scenarios. People make predictable, though varied, decisions when confronted with evolving information and conditions, rather than behave like robots or inanimate objects responding to fixed laws of nature. The first step will require theoretical models, several variants of which already exist. The second step will be to develop methods (beyond observational) that can validate the components of the theoretical models. The final step will be to integrate the theoretical models into the egress models.

2: Create a comprehensive database of actual emergency data

The field of evacuation has developed largely on the foundation of a small number of (30+ year-old) data sets. Virtually no information exists that examines the applicability of the existing data for real emergency scenarios. A comprehensive database that catalogues the progress and outcomes for real emergency incidents (the crucible in which theory and drills are tested) is a necessary condition for acceptance and validation of all knowledge in the field. Establishment of the database will require methods to document initial conditions, incident environmental conditions, and occupant information and responses, both during the incident and post-incident. Even if the researchers knew when and where an event would occur, the

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infrastructure to collect, analyze and archive the data has not yet been developed.

3: Embrace variance

The vast majority of current generation models are deterministic. Building evacuations are highly stochastic processes. If one were to evacuate the same building with the same people starting in the same places on consecutive days, the answers could vary. In addition, the number of people present within a building (and the mobility performance of individuals) can vary day-to-day or within a day. The egress community must move away from terms such as "average" and "evacuation time," and adopt tools and techniques that manage distributions of inputs and outputs. Probabilities should be attached to the distributions and a discussion of acceptable risk should take place in every nation and community.

4: Integrate results of evacuation models with fire models to enable accurate and reliable performance-based design

The calculation of Available Safe Egress Time (ASET) is well ahead of any reliable and validated prediction of Required Safe Egress Time (RSET). The interaction of the occupants with the constraints imposed by the emergency (e.g., people evacuating through smoke) has implications for a host of disciplinary contributions (toxicology, psychology, sociology, architecture, engineering, mathematics, to name a few). Scenarios equivalent to design fire scenarios should be developed for building evacuation. In addition, both of these concepts are distributions (as discussed in challenge No. 3), and methods for combining the outcome distributions in a meaningful way that can be understood by the design and regulatory communities for safe and cost-effective building

EGRESS RESEARCH PRIORITIES

- 1. A general human behavior model with a theoretical foundation and numerical validity;
- 2. A database archiving actual building emergency evacuations;
- 3. Methods to embrace the stochastic nature of inputs and outcomes in building evacuation;
- 4. A validated method to integrate distributions of egress calculations with fire hazard calculations;
- 5. Adoption of technology for people movement, data collection and within modeling constructs;
- 6. Round-robin assessment of egress model and user capabilities.

design must be developed prior to realization of the full potential for performance-based design.

5: Embrace technology

Given the paucity of data on simple concepts (such as stairs), it should not surprise anyone that virtually no data exist for use of technology to improve building evacuation effectiveness. Technologies exist and are being developed based on integration of building sensor information, communication technologies, active signage and movement technologies, such as elevators, escalators and alterative escape devices. For these technologies, there are virtually no experimental data, incident data, theoretical models or computational algorithms to encourage adoption of more effective strategies. The egress community must lead the



way in enabling the enhancements by proactively seeking and developing technologies through data and models.

6: Model Validation

In addition to conducting research to establish a strong technical foundation for egress, the fire protection engineering community (a primary user of egress models) should establish a formal round-robin assessment of egress models. Validation efforts are few and largely undertaken using proprietary datasets (not in the public domain) by model developers who are familiar with the validation data, including the outcome. The roundrobin should be conducted using several types of models (assuming that the model is applicable to the scenario), across several different scenarios and by general (though knowledgeable) users, as well as expert users (possibly including developers). Ideally, the process would be consistent with a model validation standard. A round-robin assessment of egress models meeting these criteria will establish several key outcomes:

- Variance of model output given identical inputs for several models
- Variance of model output for different users of the same model given similar initial information
- 3. Benefits of underlying formulation and various sub-models relative to accuracy and simulation time

Although it represents a significant community investment, given the significant life-safety and economic considerations that result from egress model simulations, it would seem prudent to have an objective assessment of inter-model and inter-user capabilities and outcomes.

Jason D. Averill, Erica D. Kuligowski and Richard D. Peacock are with the National Institute of Standards and Technology.

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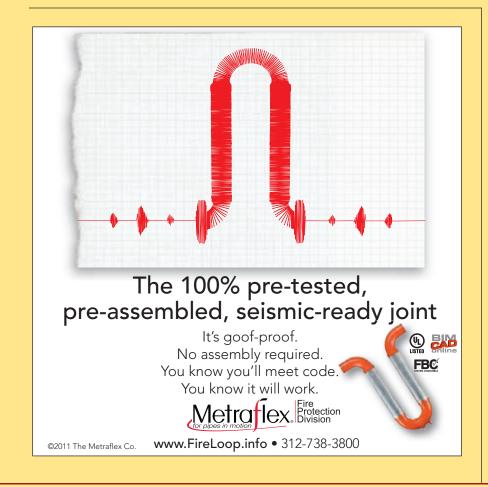
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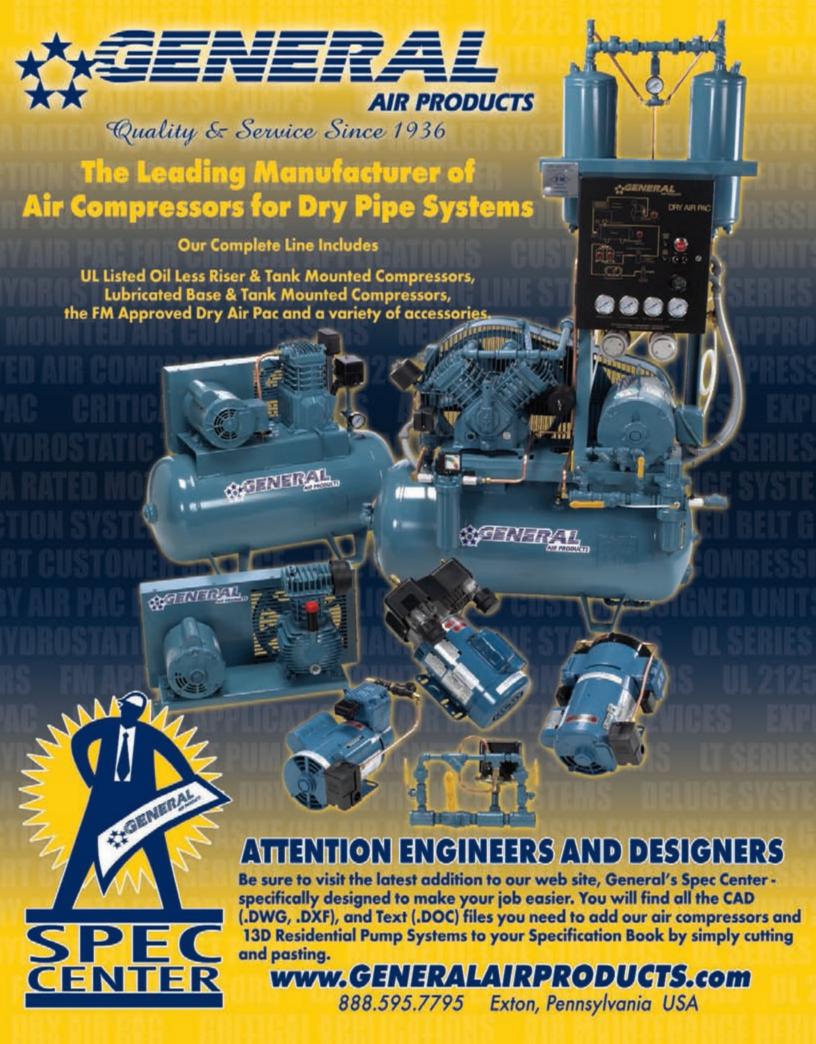


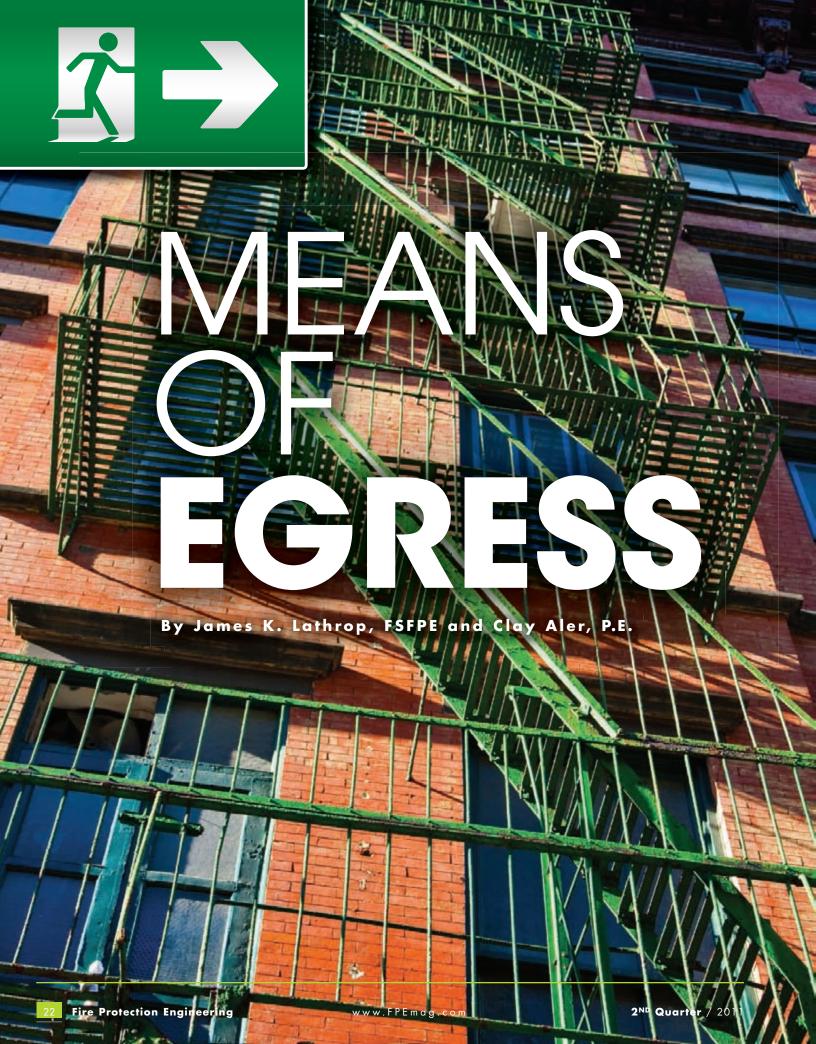
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eans of Egress -"A continuous and unobstructed way of travel from any point in a building or structure to a public way consisting of three separate and distinct parts: (1) the exit access, (2) the exit and (3) the exit discharge," or more simply put, the path from a location in the building to the street. This is the definition of "means of egress" in the NFPA Life Safety Code® (LSC) and in the NFPA Fire Code. The definitions in the International Building Code (IBC) and International Fire Code (IFC) are very similar. The "continuous and unobstructed" portion of the definition is important for obvious reasons and is addressed in requirements within the codes. The IBC does have one significant difference in that it includes "...travel from any occupied portion of a building or...", which implies that unoccupied areas do not have means of egress. This article addresses some of the more interesting or controversial means of egress issues in the LSC over the last decade (as well as in the IBC and IFC), and this subject of egress from areas that are normally unoccupied is the subject of several proposals² for the next edition of the Code. The committee reports that include the proposed revisions for the 2012 edition of the LSC will be considered by the NFPA membership at the NFPA Conference and Expo in June, 2011, in Boston. The 2012 editions of the IBC and IFC have already been finalized.

Although it appears that the IBC and IFC handle this subject with the definition, one quickly discovers that the problem is similar in all four codes in the fact that defining "occupied," "unoccupied" or "normally unoccupied" is much harder than it sounds. The IBC and IFC do not define unoccupied or occupied, but they do define "occupiable space." That is defined as "a room or enclosed space designed for

human occupancy in which individuals congregate for amusement, educational or similar purposes, or in which occupants are engaged at labor, and which is equipped with means of egress and light and ventilation facilities meeting the requirements of this code." This implies that if one doesn't provide the means of egress, the space is not an "occupiable space" and, therefore, is not occupied and,

Starting with the 2006 Edition of the Life Safety Code, the minimum exit stair width was increased from 44 inches (1.1 m) to 56 inches (1.4 m), under certain conditions. This was a result of reaction subsequent to the World Trade Center disaster regarding counterflow on stairs.

therefore, does not need means of egress. It also implies that if one is engaged in labor, it is in an occupiable space which is, therefore, occupied and requires means of egress, even if that labor is only 10 minutes per year. Also, nothing is mentioned of sleeping or residential types of activities, which would be hard pressed to be considered similar to amusement or educational purposes. It is not the intent to be

critical of the definition, only to show that "occupied" is not easy to define. The Life Safety Code defines "occupiable area" as "an area of a facility occupied by people on a regular basis." The obvious problem here is what is "regular basis"? The Code also defines "occupied building" but that definition is restricted to Section 7.2 Means of Egress Components, and is primarily designed to allow doors to be locked under certain conditions when the building is not considered occupied.

MINIMUM STAIR WIDTH

Starting with the 2006 edition of the Life Safety Code, the minimum exit stair width was increased from 44 inches (1.1 m), to 56 inches (1.4 m), under certain conditions.4 This was a result of reaction subsequent to the World Trade Center disaster regarding counterflow on stairs. Firefighters going up the stairs with equipment, and occupants going down the stairs encountered difficulty with this counterflow.⁵ The 2006 Code requires that stairs serving a total cumulative occupant load of 2,000 or more people must be a minimum of 56 inches (1.4 m). This will usually mean stairs serving fairly tall buildings. For example, assuming maximum capacity of the stairs, a 44-inch (1.1 m) stair will not hit the 2,000 cumulative occupant load until it serves more than 13 stories. Less densely occupied occupancies, such as residential, would be taller before they hit 2,000 occupants. During the revision process for the 2009 edition of the Life Safety Code, there were proposals to man-

date the 56-inch (1.4 m) minimums for all new stairs or for all new stairs in high-rise buildings.³ Those supporting the requirement for all stairs are basing it on the increase in obesity, at least in the United States. There are



interesting societal issues in those arguments. Those supporting the requirement for high-rise claim that counterflow is a problem in all high-rise buildings, regardless of cumulative occupant load. These proposals were rejected by the NFPA Means of Egress Committee. Interestingly, the proposals were not resubmitted for the 2012 Edition of the *LSC*, which is currently in process.

HIGH-RISE BUILDINGS – ADDITIONAL EXIT STAIRWAY

The IBC has taken a different approach on the fire-fighter-civilian counterflow issue. In 403.5.2, the IBC now requires an additional exit stairway in high-rise buildings in excess of 420 ft (130 m) in height (over approximately 40 stories, assuming 10 ft (3 m) per story and 20 ft (6.1 m) for the ground floor), exclusive of apartment buildings. The intent is to allow one stairway to be used solely for firefighting operations, without adversely affecting the required exit capacity needed to egress the building occupants. The code intent is not to require a dedicated fire service stairway. Removal of any stair cannot reduce the required exit capacity needed to egress the building occupants, thus allowing the fire department to take control of the one stair best suited to support their operations for that particular emergency.





It will be necessary for the fire department to manage evacuation flow to the remaining stairs. The apartment building exception takes into account the relatively low occupant loads associated with that occupancy, which should not significantly affect the counterflow in the stairways. The exception to the additional exit stairway is to provide occupant evacuation elevators in accordance with the new 3008, which is discussed later in this article.

SLIDING NON BREAK-A-WAY DOOR ASSEMBLIES

Over the last few editions of the *LSC*, there has been an increase in the allowance for using non break-a-way sliding doors. For several years, these have been allowed in business, industrial and storage occupancies for areas with occupant loads of 10 or less, along with other restrictions. In the 2006 Edition, this was expanded to health care occupancies for areas with an occupant load of fewer than 10; in the 2009 Edition, it was expanded to allow this in any occupancy with an occupant load of fewer than 10, unless the occupancy chapter prohibits it. No occupancy chapters prohibit the use of this provision.¹

There are now similar provisions in the IBC. Paragraph 1008.1.2 states that in other than high-hazard occupancies, manually operated horizontal sliding doors are permitted in a means of egress from a space with an occupant load of 10 people or less. This provision now makes the IBC very close to the provisions in the *Life Safety Code*. The only notable difference is that the *LSC* sometimes includes the 10th person and sometimes does not. Not a big issue, but something that should be addressed in the future.

LUMINOUS EGRESS PATH MARKINGS

Both the *LSC* and IBC now have provisions for photoluminescent or self-luminous exit path markings. The significant difference here is that the *LSC* has provisions for this, but leaves it up to the occupancy chapters to mandate it and none do at this time. In the IBC, such marking is now required in exit stair enclosures and exit passageways in high-rise buildings that contain assembly, business, educational, institutional, mercantile and hotels. (See 403.5.5 and 1024.) The exit path markings must meet specific



dimensional criteria, unless the markings are listed in accordance with UL 1994, Luminous Egress Path-Marking Systems.⁴ Where photoluminescent path markings are used, they must be provided with the minimum means of egress illumination (1-ft candle [10 lux]) for at least one hour prior to the building being occupied. This new code language is meant to ensure that occupants can safely egress a high-rise building via stairways in the event the emergency power fails. Much of this is based on work in New York City and by the U.S. General Services Administration (GSA).⁶

EGRESS CAPACITY

A significant change in the IBC lies in paragraph 1005.1, where the increase in egress capacity factors allowed for sprinkler-protected buildings has been removed. Regardless of the presence of complete sprinkler protection or not, the exit capacity factor for level means of egress is 0.2 inches/person (5 mm/person) and 0.3 inches/person (7.6 mm/person) for stairs. This is virtually the same as the LSC. This provision in the IBC had been controversial, especially in a building code, since egress is often needed for situations other than fires. Interestingly,

the LSC never permitted this and the LSC deals primarily with fires. This has been allowed by the IBC since its inception, based on a similar provision in the former BOCA National Building Code. Although some may argue that the LSC does allow an increase in capacity in health care occupancies, it really does not. It provides a decrease in existing occupancies, if sprinklers are not provided. If they are provided, the egress capacity is the same as all other occupancies. This change in IBC language now makes the IBC consistent with the LSC for determining minimum required egress capacity in most situations. This is a significant move toward compatibility.

DEAD-END CORRIDOR LIMITATIONS

Another significant move toward compatibility is the recent changes in the IBC regarding the permitted length of dead-end corridors in several occupancies. Section 1018.4 has increased the permissible length of dead-end corridors with complete automatic sprinkler protection, per NFPA 13. The limit has been extended to 50-ft (30 m) in educational, mercantile, storage, most residential and some institutional occupancies. The 50-ft (30 m) dead-end allowance was previously limited to

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business and industrial occupancies. The change was made because the record of sprinkler protection in such buildings did not warrant the limitation. This change in the IBC now makes the IBC consistent with

the LSC for increased dead-end lengths in buildings with complete sprinkler protection for most occupancies. However, it should be noted that differences still exist for both dead-end corridors and common paths of travel.

HIGH-RISE BUILDINGS – FIRE SERVICE ACCESS ELEVATOR

Something unique to the IBC is a new 403.6.1, which requires that new high-rise buildings with an occupied floor level more than 120 ft (37 m – around 10 to 12 stories) above the lowest level of fire department access must now be provided with at least one elevator specifically designed for fire department use, in accordance with new paragraph 3007. Features of the fire service access elevator include:

- An enclosed elevator hoistway with emergency lighting along its entire height.
- 2. An enclosed elevator lobby at each floor other than the level of exit discharge. The lobby enclosure must be designed as a 1-hr rated smoke barrier with ³/₄-hr rated labeled draft control doors. The lobby must be at least 150 sq ft (14 m²) with a minimum dimension of 8 ft (2.4 m) and have direct access to an exit enclosure.
- A Class I standpipe connection must be located within the exit enclosure providing direct access from the elevator lobby.
- 4. The elevator must be continuously monitored from the fire command center via an interface system that complies with NFPA 72.

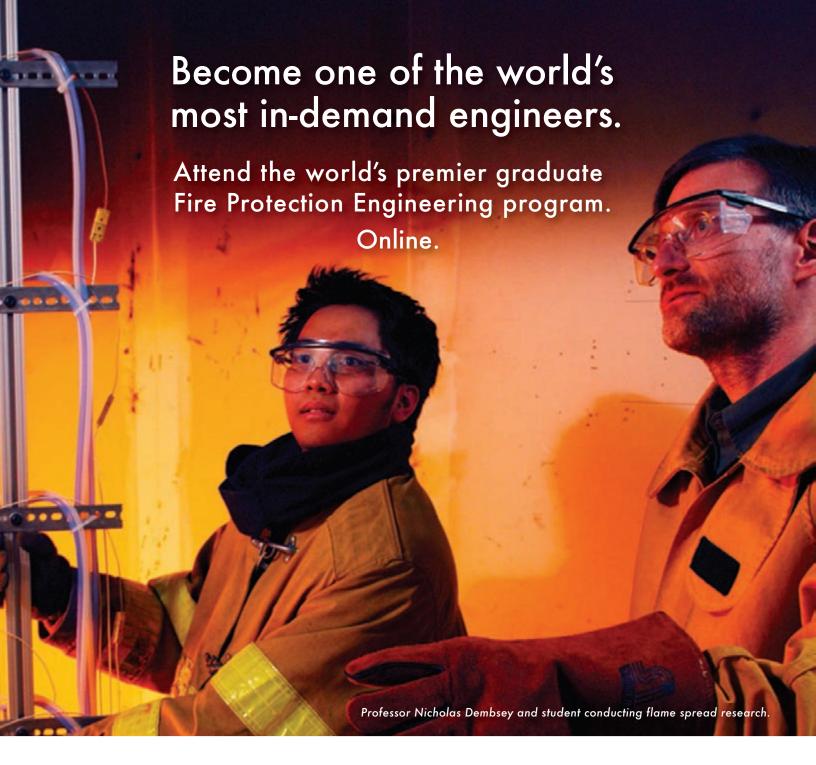


- 5. A Type 60/Class 2/Level 1 standby source of power must be provided and sized to accommodate:
 - a. Elevator equipment
 - b. Elevator hoistway lighting
 - c. Machine room ventilation and cooling equipment
 - d. Elevator controller cooling equipment
- 6. Wiring and cables associated with the elevator must be enclosed with 1-hr fire-resistive construction or be 1-hr rated labeled circuit integrity cable (CIC).

The code intent is to facilitate the rapid deployment of firefighters and to provide a protected means for the firefighters to access the fire floor. There are somewhat similar, although more stringent, provisions in some European codes.

OCCUPANT EVACUATION ELEVATORS

The LSC Committee on Means of Egress has been discussing the subject of occupant evacuation elevators for some time. In the 2009 Edition of the LSC, a new Annex B was added.



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This section provides an

annex that the Authority Having Jurisdiction (AHJ) may adopt if they wish. It provides no credit to the elevator, but provides information, available at the time, for making an elevator useful for evacuation prior to the activation of phase 1 emergency recall (smoke detection or firefighter key-operated recall). It is intended to address egress issues in very tall buildings such as are now being built, or recently constructed in the Middle and Far East. It is currently proposed to move this annex note into the body of the LSC for the 2012 edition.

Similarly, in the IBC, new section 3008 provides design criteria for elevators to be used for occupant evacuation during an emergency. This section is not mandatory, but it does provide the building designer with a code-authorized alternative to providing the additional exit stairway for high-rise buildings exceeding 420 ft (128 m) in height (apartment buildings are exempted from the additional stairway requirement). However, if elevators are to be used for occupant self-evacuation, then all passenger elevators for general public use must comply with this section. These elevators are designed to be used by occupants for self-evacuation only in normal elevator operating mode, prior to phase I emergency recall operation. In general, the same fire protection features required of the fire service access elevator (Section 3007) are applicable to occupant evacuation elevators, plus several additional features. One additional feature of particular note is the prohibition of shunt trips and sprinkler protection being installed in the hoistways and elevator machine rooms associated with these elevators; further, the hoistways must use an approved method to prevent the infiltration of water from the operation of the automatic sprinkler system from entering into the hoistways (i.e., curbs, drains, etc., at door openings).



ELEVATOR LOBBY EGRESS

The LSC has had, for several editions, provisions which require that people must have access to at least one exit from an elevator lobby. This has been an issue in many existing buildings requiring discussions with the AHJ for an equivalency, since it is very common to lock the elevator lobby during off hours in a business occupancy. The 2009 edition of the LSC added a rather long laundry list of items that could be done if it was desirable to lock the elevator lobby. Included in this list in 7.2.1.6.3 are a local switch, sprinklers (with water flow releasing the lock), fire alarm system (including smoke detectors in the lobby), fire alarm activation (other than manual stations) that releases the locks, failsafe activation and more. It should be noted that this provision does not eliminate the option of the building owner or occupant from having an

equivalency from the AHJ. This is just one automatic way of being able to lock the lobby.

James K. Lathrop and Clay Aler are with Koffel Associates, Inc.

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On Elevator Shaft Pressurization System Standards and Codes for Smoke Control i

By Richard S. Miller, Ph.D., and Donald E. Beasley, Ph.D.

levator shaft pressurization has recently received renewed attention as a means of smoke control in tall buildings. The basic idea is that a fan system floods the shaft with ambient air during a fire, thereby preventing smoke from entering the elevator shaft by creating positive pressure differences across all elevator doors. In the absence of fan pressurization, the driving forces of smoke movement, including the buoyancy of hot smoke and stack effect, can cause smoke

flow through an elevator shaft to threaten life at locations remote from the fire.

The International Building Code¹ (IBC) states in part:

708.14.2.1 Pressurization requirements. "Elevator hoistways shall be pressurized to maintain a minimum positive pressure of 0.10 inches of water (25 Pa) and a maximum positive pressure of 0.25 inches of water (62 Pa) with respect to adjacent

occupied space on all floors. This pressure shall be measured... with all elevator cars at the floor of recall and all hoistway doors on the floor of recall open..."

Similarly, for stairwell pressurization systems, Section 909.20.5 specifies a range of +0.10 inches to +0.35 inches of water (+25 Pa to +88 Pa) across any (closed) stairwell door when used in conjunction with an automatic sprinkler system. In both systems, minimum pressure differences are imposed to prevent

	Commercial	Residential
Number of floors above ground	37	37
Number of floors below ground	0	1
Building height	365 ft (111 m)	365 ft (111 m)
Floor area	13,000 ft² (1,200 m²)	13,000 ft² (1,200 m²)
Number of stairwells	2	2
Closed stairwell door leakage area	16 in² (10,000 mm²)	16 in² (10,000 mm²)
Number of elevator shafts	2	2
Cars/doors per elevator shaft	4	2
Closed elevator door leakage area	75 in² (48,000 mm²)	75 in² (48,000 mm²)
Open elevator door leakage area	865 in² (560,000 mm²)	865 in² (560,000 mm²)
Number of residential units per floor	N/A	12
Residential door leakage area	N/A	18 in² (12,000 mm²)
Exterior leakage area to surface area ratio	3.4 x 10 ⁻⁴	3.7 x 10 ⁻⁴
Ground floor open lobby door leakage area	100 ft² (9 m²)	N/A
Garage closed lobby door leakage area	N/A	100 in² (9 m²)
Ground floor closed exterior door leakage area	100 in² (9 m²)	100 in² (9 m²)
Ground floor open exterior door leakage area	40 ft² (3.7 m²)	40 ft² (3.7 m²)
Building temperature	70° F (21° C)	70° F (21° C)

Table 1. Leakage and building parameters for the two models

smoke from entering the shaft, whereas maximum values are specified to maintain proper door functioning.

The purpose of this paper is to bring attention to several phenomena that make strict adherence to the 2009 IBC code Section 708.14.2.1 difficult to achieve in elevator shaft

The purpose of this paper is to bring attention to several phenomena that make strict adherence to the 2009 IBC code Section 708.14.2.1 difficult to achieve in elevator shaft pressurization systems in modern, well-sealed buildings.

pressurization systems in modern, well-sealed buildings. Alternative designs meant to meet the intent of the IBC are not addressed. For example, Ferreira and Klote² suggest a zero net pressure smoke dilution system. The present authors have been studying such smoke control strategies using the CONTAM software developed at NIST.³ The following results represent an extension of previously published research to address the 2009 modifications to the IBC range of allowable pressure differences across both elevator and stairwell doors.⁴, ⁵ Only some of the primary results are presented in this article due to space limitations; additional details of the simulation approach are published elsewhere.⁴, ⁵, ⁶

ANALYSIS

Two 37-story buildings have been modeled in order to illustrate the system operation. Figs. 1a and 1b show upper floor plans for "commercial" and "residential" building models, respectively. Both buildings have additional exterior doors on the ground floors, as well as roofs with stairwell access doors.

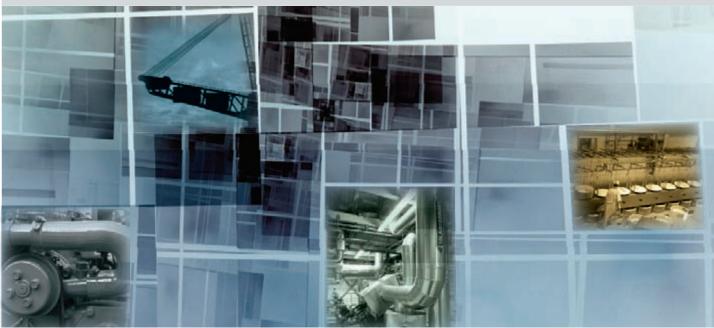


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The commercial model has an enclosed lobby surrounding the ground floor elevator and stairwell shafts with two lobby doors. For the purposes of this paper, the lobby doors are in the open position. The residential model has an additional garage level below ground.

Both sets of elevators and stairwells are enclosed by lobbies. For the purposes of this study, the garage lobby door is in the closed position. All elevator cars are in the Phase 1 position (on the ground floor with open doors) as required by Section 708.14.2.1 of the IBC. All interior building leakage parameters are provided in Table 1.7

Exterior-leakage-area-to-wall-area values were obtained by correlating the simulation results with experimental measurements of pure stack effect pressures in both a commercial bank building⁴ and a Korean residential building⁸ (i.e., the exterior building leakage area was adjusted until the ratio of the across-elevator-door-pressure difference to the theoretical-stack-effect pressure difference between the hoistway and the ambient matched those of the experimental measurements). Separate leakage values are used for the ground floor and the upper floors to match the experimentally measured pressure characteristics. All results are presented for "cold day" (10° F [-12° C]) conditions; however, the influence of the ambient temperature is predominantly on the required fan flow rates.

Shaft pressurization is achieved via fans pressurizing each of the elevator and stairwell shafts simultaneously with ambient air while all elevator cars are on the ground floor with open elevator doors (Phase 1 position) and all stairwell doors are closed. The elevator shaft fans are located on the roof, while the stairwell shafts are pressurized from the basement level. A heat transfer model was also derived,⁶ which predicts the average shaft temperatures as functions of the temperature and flow rate of ambient supply air from the fans.

As changes in the fan flow rates result in changes in the average shaft temperatures, an iterative approach is required (e.g., increasing the flow rate of cold air into the shaft to achieve a desired pressure difference simultaneously decreases the average shaft temperature). In practice, for each simulation, the fan flow rates and average shaft temperatures are iterated until the minimum pressure difference across any set of doors (including the open ground floor elevator doors) is equal to +0.10 inches of water (25 Pa) for any elevator or stairwell door. The across-door-pressure differences that result from this process are presented in Figs. 2 and 3.

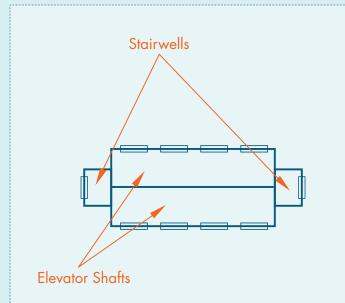


Fig. 1a. Typical upper floor plan for the commercial building model

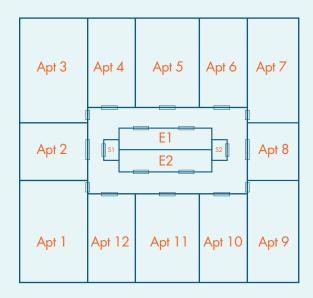


Fig. 1b. Typical upper floor plan for the (b) residential building model

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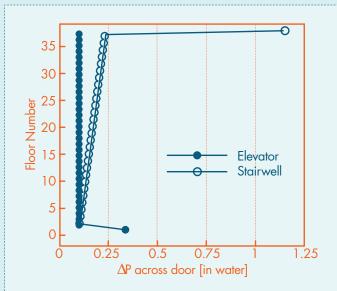


Fig. 2a. Pressure differences across doors as a function of the floor number for the commercial building models: calibration with the exterior building doors open. The respective stairwell and elevator fan flow rates are 4,050 cfm (1.9 m 3 /s) and 85,000 cfm (40 m 3 /s). 1 in water = 250 Pa

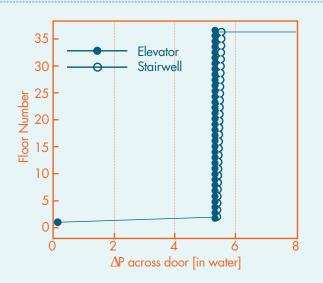


Fig. 3. Pressure differences across doors as a function of the floor number for the commercial building model: calibration with the exterior building doors closed. The respective stairwell and elevator fan flow rates are 22,700 cfm $(10.7 \text{ m}^3/\text{s})$ and 410,000 cfm $(193 \text{ m}^3/\text{s})$. 1 in water = 250 Pa

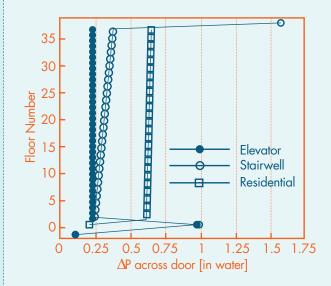


Fig. 2b. Pressure differences across doors as a function of the floor number for the residential building model: calibration with the exterior building doors open. The respective stairwell and elevator fan flow rates are $5,600 \text{ cfm } (2.6 \text{ m}^3/\text{s})$ and $68,000 \text{ cfm } (32 \text{ m}^3/\text{s})$. 1 in water = 250 Pa

FINDINGS

Fig. 2 presents pressure differences across both elevator and stairwell doors for both building models when the systems are calibrated with the exterior building doors opened (as is typically the case). Maximum pressures are only slightly violated for the commercial building elevator doors on the ground floor (Fig. 2a). A nearly vertical profile is observed for upper elevator door pressures due to the large amounts of air needed to overcome the multiple per floor, and relatively large, elevator doors (fan flow rates are provided in the figure captions). Therefore, the elevator shaft temperature is near ambient and the stack-effect pressure gradient is minimized.

In contrast, the stairwells have much smaller leakages and fan speeds. Therefore, they have larger than ambient temperatures and exhibit stack-effect-related pressure gradients. The roof-level-stairwell-door pressure difference is very large due to the pressurized stairwell being in direct connection to the ambient pressure rather than the pressurized building interior. Also, substantially larger stairwell

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fan speeds are needed when operating in conjunction with elevator pressurization, indicating a strong interaction between the systems (not shown).^{4, 5, 6}

In contrast, the residential building model pressures are more complex (Fig. 2b). Much larger ground-floor pressure differences are required to produce the minimum +0.10 inches water (25 Pa) pressure differences within the shafts. This is primarily due to the existence of the garage level with its enclosed lobby and closed lobby door, which yields the minimum shaft pressure differences.

In addition, and perhaps even more importantly, the

large elevator shaft fans leak air into the building on all floors through the elevator doors. This is observed to produce very large pressure differences of approximately 0.65 in water (162 Pa) across the residential doors on all upper floors (i.e., greater than 70 lbf {310 N} of force on a typical door). These forces are directed from the corridor towards the inside of the residences.

Such large forces could result in either difficulty in opening doors or in injuries resulting from rapid door openings. These forces are also sensitive to the enclosed garage-level lobby door leakage area. If the garage doors open directly to the ambient (i.e., no lobby), the minimum pressures across elevator doors move to the ground floor, and the residential door forces are reduced by more than 50% (not shown). The authors are not aware of any other published study that has examined the

effects of elevator pressurization on residential doors.

Although other sections of the IBC address allowable residential door forces, there is no direct mention of this possible interaction pertaining to elevator shaft pressurization in the section.

Another factor found to be important for elevator shaft pressurization is the position of the exterior building doors. Pressurization systems could certainly be required to operate when exterior doors are closed (at night, on cold days, etc.). Although, in practice, elevator pressurization systems are calibrated with the exterior building

doors propped open, strict adherence to current IBC language makes no allowance for improper performance if the exterior doors are closed. Fig. 3 presents the (hypothetical) requirements of a system calibrated with the building exterior doors closed for the commercial building model. Greater than 5 inches of water pressure (1.3 kPa) differences are observed on all upper floors (and approximately 50 inches of water {13 kPa} for the roof-level stairwell doors – not shown).

The explanation for this is as follows. Air is forced into the shaft from the roof, and some is "lost" along the way through

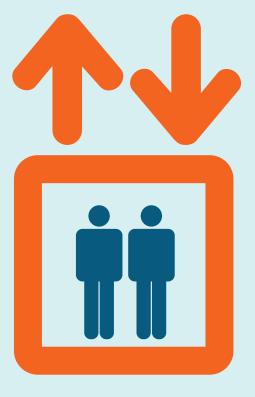
the closed elevator doors and into the building interior. However, a relatively large flow rate is needed to achieve the +0.10 inches of water (25 Pa) pressure difference across the first-floor open elevator doors due to their much larger leakage areas (this ground-floor pressure difference is also highly sensitive to changes in the fan speeds).

With the exterior doors closed, this air flowing into the first floor from the shaft has no direct path to escape the building and acts to pressurize the first floor. Therefore, the second floor interior building pressure is much less than on the first floor. However, the pressure within the shaft only varies hydrostatically and is only slightly lower at the second floor. In this case, the across-elevator-door-pressure difference is increased substantially on the second floor (as well as on all remaining floors).

Fan flow rate requirements are greater than five times larger than when calibrated with the exterior

building doors open. Such large flow rates can cause serious problems on their own because even stairwell pressurization (only) systems can cause doors to slam shut and create difficulty opening stairwell doors during testing. However, the most serious issue is the very large pressure differences observed on all upper floors across both the stairwell and elevator doors (Fig. 3).

Such pressures result in forces in excess of 500 lbf (2000 N) acting on the doors and would certainly prohibit proper door functioning. These large pressure differences are not a direct function of the building height or the stack effect. They are



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dictated by the number of elevator cars and their associated leakages as the flow rate needed to produce a desired pressure difference is only a function of the leakage area. These pressure issues (described above) are directly related to the well-sealed nature of the ground floor when exterior doors are closed.

POSSIBLE SOLUTIONS

The authors have explored many system configurations and have yet to find any that strictly satisfy the pressure limitations of Section 708.14.2.1 of the IBC under all operating conditions and/or positions of the exterior doors (including the use of louvers, vents and/or changes in the fan location).⁴ However, at this point it is clear that one primary source of problems with strict adherence to the IBC code language is related to

the position of the exterior building door (more directly, to cases where the shaft air has no escape route to the outside ambient and pressurizes the building).

One sensible addition to the IBC language would, therefore, be to require an open flow path to the ambient from any floor to which the elevator cars may be recalled, and perhaps garage level floors as well. This could be accomplished by requiring either automatically opening louvers or doorways during system activation. This would greatly alleviate problems with open-floorplan buildings such as the commercial building model (Fig. 2a), but not necessarily for more complicated buildings (Fig. 2b).

Richard Miller and Donald Beasley are with Clemson University.

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LESSONS



LEARNED

By Carl F. Baldassarra, P.E., FSFPE

he Iroquois Theater. The Triangle Shirtwaist Factory Fire.
The Cocoanut Grove. The Beverly Hills Nightclub.
The DuPont Plaza. The World
Trade Center. The Station Nightclub.

To those in fire protection engineering, these names represent major fire losses that have caused significant changes in code requirements, building design, enforcement and education. With many of those events, there were repetitive failures in the design, enforcement and operation of buildings. Although the fire protection principles have been well-known for many years, an analysis of these losses shows repeated violations of many of the same fire protection principles.

The following examples illustrate this point:

- The fire at the "absolutely fireproof" Iroquois Theater (1903) resulted in 602 fatalities: mostly attributable to blocked exits; a confusing egress path; inward-swinging doors; inadequate exit signage; combustible interior finish; and a lack of fire suppression.¹
- The Triangle Shirtwaist Factory fire (1911) resulted in 146 fatalities: attributed to locked exits; inadequate exit capacity; combustible contents; and a lack of fire suppression.²

- The Cocoanut Grove nightclub fire (1942) caused 492 fatalities: owing to inadequate exit capacity and arrangement; inwardswinging doors; inadequate exit signage; combustible interior finish; vertical openings; and a lack of fire suppression.^{3,4}
- The Beverly Hills nightclub fire (1977) resulted in 165 fatalities: due to inadequate exit capacity and arrangement; combustible concealed spaces; and a lack of fire suppression.⁵
- The DuPont Plaza hotel fire (1986) caused 97 deaths: attributed to locked exits; vertical openings; an unusual fire load; and a lack of fire suppression.⁶
- The Station nightclub fire (2003) resulted in 100 fatalities: Major factors leading to those deaths included inadequate exit arrangement; combustible interior finish; and a lack of fire suppression.⁷

It is not surprising that there were many violations of the same fire protection principles in these major losses of life. Yet, those in the fire protection community should be in a position to recognize buildings with these deficiencies and act before the next event occurs.

Reglations are often enacted following such tragedies – typically on a local basis – and often in an

emotionally charged atmosphere. It is human nature to act so that tragedies are not repeated, but it is also human nature not to act unless faced with a recent or imminent threat.

Fire safety regulations reflect the needs of society, particularly for public buildings. They seek to balance the perceived risks with the reality of economics, and they sometimes wane when fire tragedies fade into the history books.

Not all fire safety improvements are borne from tragedy. In the early 1970s, a number of technical committees were formed to develop criteria for two types of buildings that

Since 1977, the number of reported fires has dropped by 52%, reflecting better building design, construction methods, product safety, fire prevention and enforcement.





were growing in popularity: covered mall shopping centers and atrium buildings. Today, all model codes have comprehensive provisions for these building types, employing technical knowledge and experience with fundamental fire protection principles - all developed before any major loss-of-life event. These provisions have been effective for more than 35 years.

Over the years, events such as those described above have prompted research into areas involving fire growth, people movement and human behavior. These activities have led to improved codes, improved analytical techniques for complex building designs and models for complex egress scenarios. Building and fire codes have significantly evolved to require improved fire protection features, including active systems such as automatic fire sprinkler systems and fire detection systems. The safety of products, such as heating equipment and electrical appliances, has improved. The level of code enforcement and the aualifications of those involved in it have improved. Public education and public awareness have also improved.

Since 1977, the number of reported fires has dropped by 52%, reflecting better building design,

construction methods, product safety, fire prevention and enforcement. At the same time, the number of fatalities has dropped 47%, again reflecting those same measures, plus improved regulations for fire detection and fire control through automatic sprinklers and construction features. During the last 25 years, the fire death rate in the United States has fallen by about one-third. Although direct property losses due to fire have increased over the last 25 years, there has been a 25% reduction in property damage when measured as a percentage of the nation's GNP. In addition, during the last 55 years, there have been only five U.S. incidents, each having more than 100 fatalities; there were 44 such incidents in the previous 55-year period, reducing the frequency of those incidents from roughly once per year to once per decade.4

Nevertheless, concerns remain. The World Trade Center event of Sept. 11, 2001, showed the potential of extreme events affecting tall buildings and how to reasonably safeguard them. The relatively simple and effective philosophy of "defend in place" was challenged and strategies are being explored that could more effectively protect the building and its occupants to allow for a complete building evacuation.



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In addition, threats other than fire, e.g., chemical attacks, gunwielding terrorists and similar threats, directly challenged the time-based people movement assumptions. Risk assessments are now performed on major public and iconic buildings and additional, non-traditional measures are considered to meet their safety needs.

One new technology resulting from this event is the use of elevators as part of the means of egress. Provisions have been adopted into the IBC8 and NFPA 1019 to allow, if not encourage, the use of "hardened" elevators as a component of the building's overall egress design. This technology also provides a solution for safely moving disabled building occupants in the same manner as able-bodied occupants, rather than sending them to areas of refuge to wait for rescue. The same technology also provides firefighters a means of reaching the fire scene on the upper floors of a building.

Certain other building features resulting from the 9/11 tragedy, such as the hardening, number and separation of stairway shafts, will continue to be reviewed and debated. Fundamental to this, of course, are the design basis events to be considered and the risk of such events. This work is on-going.

Larger, taller and more complex buildings are being built. Society demands new methods and new materials to build more energyefficient and sustainable buildings. These are worthy endeavors that benefit society in many ways, but fire protection engineers cannot forget or disregard the knowledge of fundamental fire protection principles while doing so.

Perhaps the single greatest challenge to the fire protection community is dealing with the existing building stock, especially buildings built before code provisions for new construction began to require significantly more in the way of built-in fire protection. There are perhaps thousands of these existing buildings, which should be identified to determine their fire risk.

In addition, fire prevention activities should be emphasized as an important element in preventing future large-loss fires. Fire prevention includes: code enforcement through plan review and facility inspections; education and training; fire investigation and fire data management. The balance of this article will focus on the value of facility inspections.

THE VALUE OF FIRE **INSPECTIONS**

Fire inspections of major facilities are often conducted by the fire department, insurance representatives, owner representatives and private sector organizations on behalf of one of the previously mentioned entities.

In some cases, the frequencies of such inspections are specified for various types of public buildings considered to have high-risk factors, such as schools, hospitals, theaters and other places of public assembly. Typically, for those communities that perform such inspections, annual inspections are conducted, but they may be more frequent at large public assembly facilities.

Inspection activities involve reviewing the overall facility to determine whether:

- changes have occurred since the last inspection or since original construction without those changes being reviewed for code compliance;
- all means of egress are maintained in a usable and operable condition:
- no unusual fire hazards have been introduced;





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Means of Egress: Lessons Learned

- routine hazards are being properly controlled;
- pre-fire incident plans are updated;
- all fire protection systems are in an operable condition and have been properly serviced;
- the facility's emergency plan (if any) is current and necessary drills have been conducted.

The inspections usually include either witnessing actual operational tests of fire protection systems, such as flowing water from a sprinkler system's test connection or fire pump or activating occupant notification systems and alarm system connections to notify the fire department. This is more important today than ever, as the number of buildings required to have active fire protection systems by building and fire codes has increased substantially over the last 25 years. Active systems tend to make up for deficiencies that may exist in the construction or operation of the building. An operational system is also important for that reason.

The inspections conducted by the fire department under the jurisdiction of a code or ordinance has a legal basis, providing for the public's health, safety and welfare, and may bring with it legal action and fines if significant or repetitive violations are found. Nevertheless, for even the code-compliant facilities, the time spent on site with the facility representative is more valuable than what simply appears in the written report. Periodic visits by a good fire inspector will provide a level of education and interest in maintaining a fire-safe facility on a year-round basis, often providing technical information about the operation and testing of the fire protection systems to building operating and management staff. They will likely maintain an awareness and interest in good fire protection practices, such as keeping egress facilities usable, long after the fire inspector has left the premises. A number of private sector organizations, such as

In order to meet the challenges associated with preventing the next major life-loss fire, persons performing these activities must be qualified.

insurance carriers and owners, invest considerable resources as part of an effective loss prevention program.

FIRE INSPECTOR QUALIFICATIONS

A knowledgeable and effective fire inspector is a key component in a loss prevention program. Although reports suggest that fire safety concerns were raised at the "new" Iroquois Theater when it was inspected shortly after construction and one month before the fatal fire, fire department supervisors ignored the concerns of the inspector and the nation's largest public assembly fire life loss occurred. The investigation into the Beverly Hills Supper Club fire criticized the efforts of the fire inspector who visited the facility four months prior to the fatal fire and said the exit facilities were adequate, calling the work a "myopic inspection effort."9 Tragically, The Station nightclub was inspected prior to the fire.⁷ Not only did the inspection not identify that a change of use had occurred (which would have required significant fire safety features be provided), but the inspector either did not see or did not appreciate the imminent danger to life associated with the exposed foam material applied to the walls and ceiling in stage area.

In order to meet the challenges associated with preventing the next major life-loss fire, persons performing these activities must be qualified. NFPA has several professional qualifications standards for fire service personnel, including NFPA 1031¹¹ and NFPA 1037.¹² Certification to these standards is accomplished through third-party accredited agencies.

As fire department budgets have been subject to pressure, citizens need to keep in mind that the less-exciting, less-glitzy work in fire prevention is an important element in community safety and that those efforts should receive their support. Fire protection engineers can play a role as citizens as well as practitioners when the opportunity exists to help identify and correct substandard buildings.

Carl Baldassarra is with Rolf Jensen & Associates, Inc.

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"means of egress" from a building has three distinct parts. The strategies and code requirements for signaling to occupants differ for each part. Why should system designs differ? How do code requirements differ? What are the best practices for occupant alerting, notification and communications in the different parts of a means of egress?

WHAT IS A MEANS OF EGRESS?

To understand the requirements for occupant notification, it is necessary to understand the components of a "means of egress". The model building, fire and life safety codes have very specific definitions for the term "means of egress" and for the three principal components that make up a means of egress. For example, the International Building Code uses the following definition:

If occupant notification is required in the occupiable areas, audible and visual signaling in accordance with NFPA 72 will be required.

MEANS OF EGRESS. A continuous and unobstructed path of vertical and horizontal egress travel from any occupied portion of a building or structure to a public way. A means of egress consists of three separate and distinct parts: the exit access, the exit and the exit discharge.¹

Working backwards, the exit discharge is the part between the termination of an exit and a public way. The exit discharge is a path that leads away from a building. The exit is that part of a means of egress that is generally separated from the rest of the building. The separation is provided by fire-rated construction and by protection of any openings using fire-rated doors or dampers as required. An exit provides a protected path from the exit access to the exit discharge. On the level of exit discharge, a door that leads directly from the building to the exit discharge would be the exit, without any required enclosure. The exit access is that part of a means of egress that leads to an exit.

OCCUPANT NOTIFICATION REQUIREMENTS

The requirements for occupant notification originate in building, fire and life safety codes. Those codes also refer to the *National Fire Alarm and Signaling Code*.² Together,

these documents detail the requirements for signaling in the means of egress.

For occupancies or user groups that require occupant notification, signaling is usually required throughout the occupiable parts of the building. For example, in a school or office, it is important that occupant notification be provided for the classrooms, offices, corridors and other occupiable spaces. However, it would not be necessary to have occupant signaling in small closets and crawl spaces

that are not intended or suitable for being occupied. An electrical or telecommunications room or a small file room may not normally be occupied, but are occupiable spaces that must have occupant notification.

If occupant notification is required in the occupiable areas, audible and visual signaling in accordance with NFPA 72 will be required. Visible appliances applied per NFPA 72 will also be

required in certain spaces that might be used by persons with impaired hearing. The codes and accessibility standards, such as the ADA³, require visible signaling in all public and common use spaces. This includes corridors, toilet rooms, kitchenettes and break rooms.

Classrooms in a school would require, and benefit from, the use of visible signaling. Conference rooms in offices are provided with visible notification appliances if there are employees with hearing impairments or persons from outside the company that might be in the room. However, small offices would not require visible signaling unless occupied by a person with a hearing impairment. Other employee work areas might not require visible signaling to be installed, but might require that the wiring be installed for future accommodation if the space is used by a person with a hearing impairment.³

Once an occupant enters an exit, he or she is in a protected space, separated from the useable building spaces. There is no need, and no code requirement, to operate occupant notification appliances – audible or visible – in an exit. In fact, building, fire and life safety codes and NFPA 72 explicitly state that visible appliances are not required to be installed in exit enclosures and elevators. ², ⁴

The requirement for installing audible occupant notification appliances in exit enclosures differs where selective



signaling is used to partially evacuate or relocate occupants. In that case, the audible appliances (loudspeakers) are provided in the exit enclosures, but are arranged for manual use only; they do not provide any automatic occupant messaging.² Loudspeakers in an exit enclosure must be on a separate paging zone that permits emergency forces to provide specific and discreet information and directions to persons using the exit.

Code requirements recognize that exit enclosures are safe, protected locations and that occupants in an exit enclosure are in the process of leaving the building or relocating to a safe area. Providing occupant notification appliances, particularly strobe lights, can impair the movement of people in exit enclosures.

Providing tone-only audible signals in an exit enclosure, such as a stair, would be confusing: Does the signal mean persons in the stair must continue to leave the building? Or, does the signal mean they should not be in the exit enclosure? Any person that tries to re-enter from an exit enclosure to a floor of the building will hear and see the notification appliances operating on that floor. In the case of a selective evacuation/relocation system, the notification appliances will not operate on floors where it is safe for occupants to re-enter the building.

Similarly, the codes exempt elevator cars from the requirements for occupant notification appliances. If the elevator is threatened by fire or smoke, the elevator car will be on its way to a safe location – the primary or alternate recall level.⁵ If the elevator is not threatened, the car will continue to the occupant's chosen destination, where the elevator lobby is safe – at least there would not be any smoke that would have initiated Phase I elevator recall to some other level. Once out of the elevator, if notification appliances are operating, occupants have access to protected exit enclosures. Although

elevators are not required to have occupant notification appliances, the codes require that they have two-way communications to an attended location.⁶

There are no requirements in the model building, fire and life safety codes or in NFPA 72 for occupant notification in the exit discharge. However, some local jurisdictions require audible and/or visible appliances at the exit termination – on the outside near the entrance/exit door. The idea is that the signals provide an indication to persons on the outside of a building that they are not supposed to enter the building. Most jurisdictions do not have that requirement because people will get that same information when they try to access an occupiable part of the building.

Signaling to occupants who are in a means of egress is not a difficult concept once the definitions of exit access, exit and exit discharge are understood. Fire protection engineers are familiar with the definitions and need only apply the coordinated code requirements for audible and visible occupant notification. Still, other disciplines and trades might not be as familiar with the means of egress concepts that drive the occupant notification requirements.

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BRAINTEASER



Problem / Solution

Problem

t a child's birthday party, the father arranges three children in a line on three chairs, in such a way that child C can see both child A and child B, child B can see only child A, and child A can see none of the other children. The father shows them 5 hats, 2 of which are black and 3 of which are white. After this, he blindfolds the children, places one hat on each of their heads, and removes the blindfolds again. The father tells the children that if one of them is able to determine the color of his hat within five minutes, they will all receive extra ice cream. None of the children can see his own hat. After four minutes and 59 seconds, child A shouts out the (correct) color of his hat. What is the color of his hat, and how did he know?

Solution to Last Issue's Brainteaser

Find the values of x and N that satisfy the following expression: $x^N = 2x^{(N-1)} - x^{(N-2)}$. If both sides of the equation are divided by $x^{(N-2)}$ and rearranged, the equation becomes: $x^2 - 2x + 1 = 0$. This equation is valid for x = 1 for any value of N and x = 1 for any value of N > 2.

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Beverly Hills Fire Protection



Beyond its glamorous infamy, the city of Beverly Hills, CA, has municipal management issues much like those of any city.

The initial challenge was to reduce the variety of legacy fire alarm systems



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operating in the city hall, library, police headquarters, fire department and other municipal buildings. The city's chief engineer teamed-up with JAM Fire Protection Inc. to upgrade the level of fire protection and provide emergency communications (a.k.a., mass notification). The new system was also expected to reduce maintenance costs, simplify monitoring and allow for future expansion. JAM selected a Gamewell-FCI E3 Series® combined fire alarm and emergency communications system (FA/ECS) as its simple solution.

Starting with the library and several historic city structures, JAM networked the fire alarm systems within and between buildings to simplify system monitoring and speed response to alarms and maintenance alerts. Although original plans did not call for an emergency communications system as part of this fire alarm upgrade, the city favored the E3 Series' enhanced programming and added the necessary Local Operator Consoles (LOCs) to offer a supervised means of delivering immediate

notifications to any areas of the network.

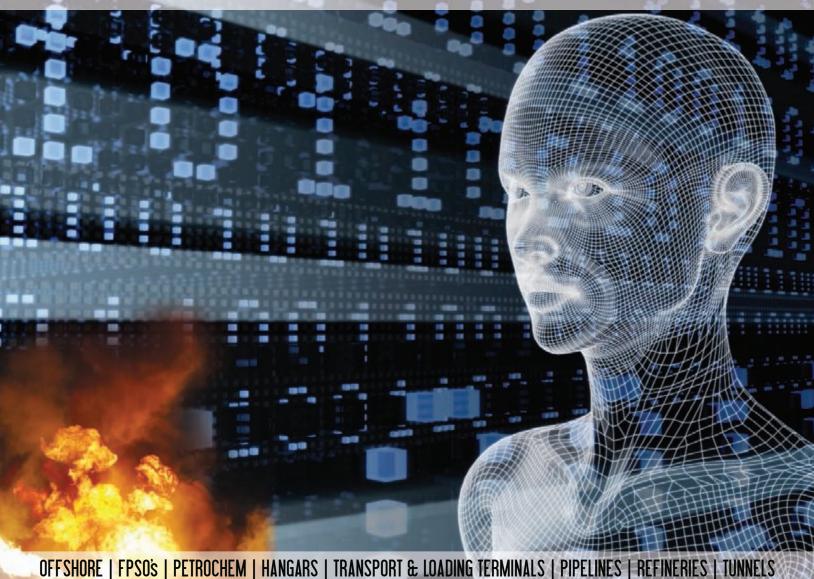
JAM integrated the networked FA/ECS monitoring system on top of the city's existing Local Area Network (LAN). Two FocalPoint® graphic work stations, located in the chief engineer's office and fire department, provide a detailed view of all buildings and the FA/ECS network. The FocalPoint system is also programmed to deliver alerts to standard mobile devices.

JAM used existing conduit runs and equipment when possible, while adding new Gamewell-FCI technology to provide additional voice communication and monitor everything through one interface. The E3 Series' distributed audio design provides a more "survivable" design to ensure continuous, clear and accurate communications in the event of breaks in the network.

JAM and Gamewell-FCI provided an economical approach to making the municipal center of Beverly Hills safer and easier to manage.

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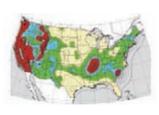
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