WHITE PAPER / **PERFORMANCE-BASED DESIGN**

DESIGN ALTERNATIVES FOR SPECIAL INDUSTRIAL OCCUPANCIES

BY Stephen Kostka, PE

One size does not fit all when achieving and maintaining optimal asset protection and life safety for special industrial occupancies. Performance-based fire design helps complete the protection of people and property, especially for special industrial occupancies.

Code requirements prescribed to uniquely sized and shaped buildings and structures, such as aerospace or ship manufacturing plants, may result in only an illusion of fire protection for occupants, assets and emergency personnel. While the International Building Code (IBC) permits expansive building areas and heights among several types of uses, there is limited corresponding guidance on life safety or asset protection for these different structures. The National Fire Protection Association (NFPA) also does not provide regulation specificity to these special-purpose designs.

These exceptionally massive buildings and structures with distinctive uses are often labeled special industrial occupancies. Per the IBC 2021 Edition, a special industrial occupancy is a building or structure designed to house special industrial processes that require large areas and heights. Special industrial occupancies include many types of industrial, manufacturing and power production buildings. This terminology readily applies to all unusually sized structures and unique uses that test prescriptive code requirements.

Whether developing an aerospace or ship manufacturing site, solar panel factory or power plant, performance-based fire design is an appropriate application to provide proper safety without compromising building or structure functionality. Performance-based design offers alternative, innovative and cost-effective solutions while still maintaining facility code compliance. This approach takes into account the specific characteristics of the building plans under consideration. Pinpointing the proper elements to analyze and identifying the alternatives to apply to an unconventional project requires an experienced and qualified team. Additionally, the IBC allows building area, number of stories, and building height code exceptions for buildings that fall into the special industrial occupancy classification.

FIRE ALARM SYSTEM

To adequately notify occupants and emergency personnel of a fire, a fire alarm system must be able to detect a fire and alert occupants prior to them being impacted by the effects of a fire; this is a basic expectation. Within a special industrial occupancy, however, there are unique factors to keep in mind such as work locations, moving equipment and the employees wearing hearing protection.

Prescriptive fire codes generally require full fire alarm notification with ceiling/wall mounted strobes and horn/speaker coverage, as well as notification activation from sprinkler water flow monitoring. In contrast, performance-based fire design solutions for alerting occupants can utilize specialized strobe coverage and horn device placement throughout the building to achieve indirect notification. Wireless smoke detectors and pull stations can be used for spaces where walls and ceilings frequently move. Additionally, air-sampling or beam-type smoke detection may be selected for effective protection of high-ceiling spaces.

Fire alarm performance-based design is not unique to special industrial occupancies, and NFPA 72 allows for performance design of strobe coverage in Chapter 18.

FIRE SUPPRESSION SYSTEM

A fire suppression system is provided to contain, suppress and potentially extinguish fire events before fire department response. Depending on building layout and hazards present, approaches to suppression can involve sprinkler systems, clean agent systems, standpipe systems or other active suppression solutions. For a sprinkler system, water or foam may be distributed via automatic or deluge systems feeding sprinklers or nozzles. Code-required suppression systems are intended to allow time for fire department response to fully suppress a fire event. While sprinklers have been proven to be effective in almost all locations and scenarios tested, tall ceiling spaces may limit a sprinkler system's ability to respond to a fire. Fire sprinkler testing has been conducted on many different ceiling heights and configurations. For special industrial occupancies with tall ceiling heights that have sprinklers tested to the ceiling height, it is recommended that those facilities be provided with automatic sprinkler protection, as traditional sprinklers have been shown to activate unnecessarily at such elevations.

Research findings from the National Institute of Standards and Technology (NIST) and fire protection manufacturers such as Victaulic and others have shown that larger water

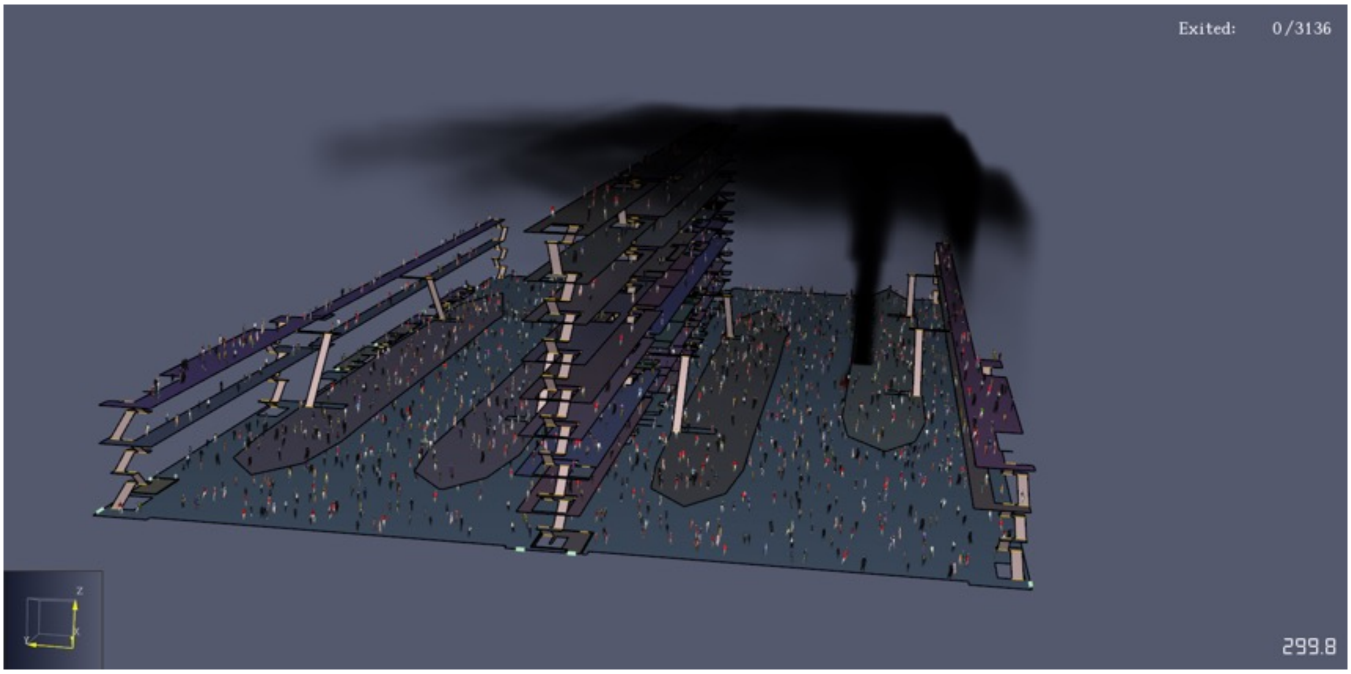

FIGURE 1: *Pathfinder and fire dynamics simulator demonstrates fire alarm activation.*

droplets and quick-response sprinklers better control fires in buildings and structures with taller ceilings. However, owners of facilities with tall ceilings need to conduct proper tests to identify whether worst-case scenario heat release rates will trigger these sprinklers in the event of a fire. For buildings with ceilings above 70 feet, a performance analysis needs to be conducted to confirm that the intent of sprinkler protection is adequately met by the planned system. As full-scale fire testing is impractical for most scenarios, a combination of fire modeling and hand calculations may be used to determine if sprinklers will activate during worst-case fire scenarios. All possible uses and fuel loads expected during the life cycle of the building help define a worst-case fire. Special care is given to select multiple potential fire scenarios based not only on ideal conditions but also on any incidental storage or buildup of materials that may occur during building operations.

A performance-based analysis is conducted to determine if sprinklers will activate with a selected worst-case scenario of variables. In its Fire Protection Handbook, NFPA provides the following to determine heat release rates required to trigger a sprinkler at a particular elevation:

$$\text{Total Heat Release Rate} = 0.014*(T_{operation} - T_{\infty})^{3/2}*(h_{ceil})^{5/2}$$

The temperatures at the top of a smoke plume are verifiable by hand calculations of smoke plume temperature provided by the following equation, provided by NFPA:

$$\text{Average Temperature of Smoke Plume} = \left(\frac{18.8*Q_c^{2/3}}{(z-z_0)^{5/3}}\right) + T_{\infty}$$

To verify hand calculations and to provide additional information about ceiling temperatures, a fire protection engineering team should perform fire modeling. A fire dynamics simulator (FDS) is a computational fluid dynamics (CFD) model of fire-driven fluid flow. The associated software solves the NIST fluid dynamics equations appropriate for low-speed, thermally driven flow, emphasizing smoke and heat transport from fires.

If modeling and hand calculations indicate that sprinklers will not adequately supply their code-intended protection, alternative protection should be selected utilizing a performance-based design process.

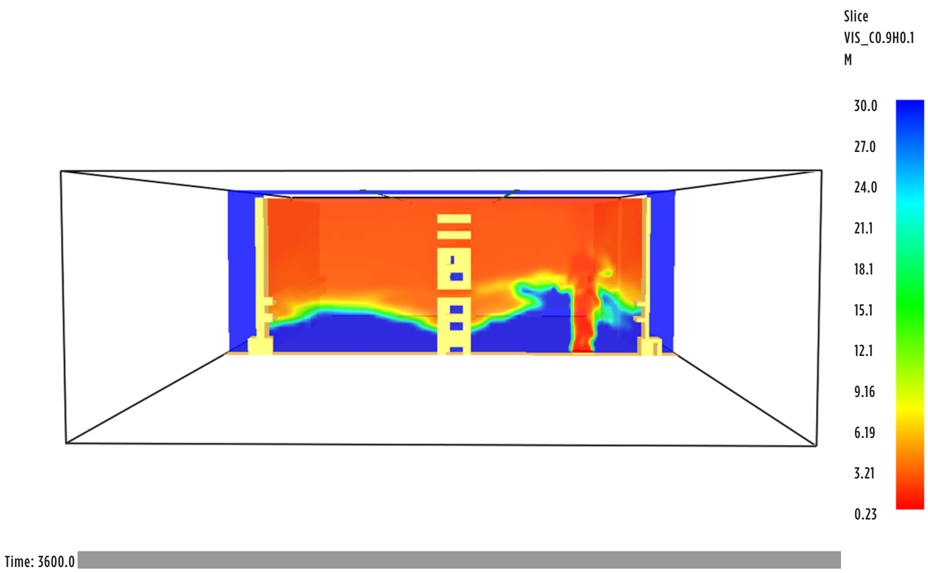

FIGURE 2: *Roof vents fire test.*

LIFE SAFETY

Construction plans are required to meet standards that allow for egress from fire hazards. A life safety plan maps the area plotting critical indicators such as egress routes, fire barrier locations and fire extinguisher placement. This plan addresses maximum travel distance to exits dependent upon code requirements and the suppression systems present. For special industrial occupancies, the constraints of open floor areas could mean that exit passageways cannot be used to meet code requirements for travel distances. Instead, egress travel distances may require performance-based design alternatives to prescriptive parameters.

Performance-based design of occupant egress should be implemented on as few code requirements as required. Requirements practical for the building, such as common-path and dead-end travel requirements, should be maintained. Performance-based occupant egress distances should be determined to follow the intent of the code and protect occupants and emergency personnel from the effects of fire throughout a fire event. Additional passive and active fire protection building features may be designed to provide an alternative but equal protection.

PERFORMANCE-BASED DESIGN CASE STUDY

The fire protection engineering team at Burns & McDonnell recently examined fire alarm and suppression systems and egress plan code requirements using performance-based design analysis and solutions. Plans for a manufacturing hall called for an approximately 180,000-square-foot floor area and a 126-foot tall ceiling. The building was classified as a moderate-hazard factory industrial (F-1) occupancy due to the combustibles used in the product manufacturing process. Due to the requirements of the industrial processes housed within the building, the space was determined to be an IBC special industrial occupancy.

The open floor plan and constantly moving obstructions challenged standard wall-mounted horn and strobe devices. Many occupants needed to wear hearing protection while performing their job duties. Providing adequate notification of fire under these conditions required fire alarm devices above and beyond code prescriptive requirements for the site.

For the examined building, strobe devices were wall mounted to building columns at both the facility's ground level and at a 40-foot level angled downward to provide illumination over possible manufactured part obstructions.

Additionally, a new fire alarm system was designed to provide rapid notification of fire events and to expedite fire department response. Infrared cameras and air-aspirating smoke detection were examined as means for rapid fire detection.

As the examined building is a large F-1 occupancy, a sprinkler system was required within the manufacturing hall per the IBC prescriptive code. The effectiveness of sprinklers located along the 126-foot-tall ceiling was analyzed based on a worst-case scenario applying hand calculations and FDS. The worst-case heat release rate selected for the examined building was 35,000 kilowatts (kW), assuming a buildup of insulation, pallets and materials within and around a section for manufactured parts. The selected worst-case peak heat release rate was chosen carefully and selected through coordination among end-user owners and the authority having jurisdiction (AHJ).

Due to the building's ceiling height, it was determined that a heat release rate of 91,760 kW would be required to activate a sprinkler. As the worst-case fire scenario has a lower heat release rate than is required to trigger a sprinkler, no fire within the examined special-purpose building was shown to activate a sprinkler. FDS analysis was performed to substantiate hand calculations and equation findings. It was determined that the temperature of the smoke plume at the ceiling reached 135°F, which is below the 225°F temperature required for a sprinkler to be activated. Between fire modeling and hand calculations, it was determined the 126-foot-tall ceilings would inhibit the activation of sprinklers in the event of a fire in the building.

With the understanding of the AHJ, the fire protection engineering team decided that since sprinklers were code required for the building — even though the high ceilings rendered sprinklers ineffective — an alternative protection would be required. As an alternative, performance-based design strategies were put in place to determine effective

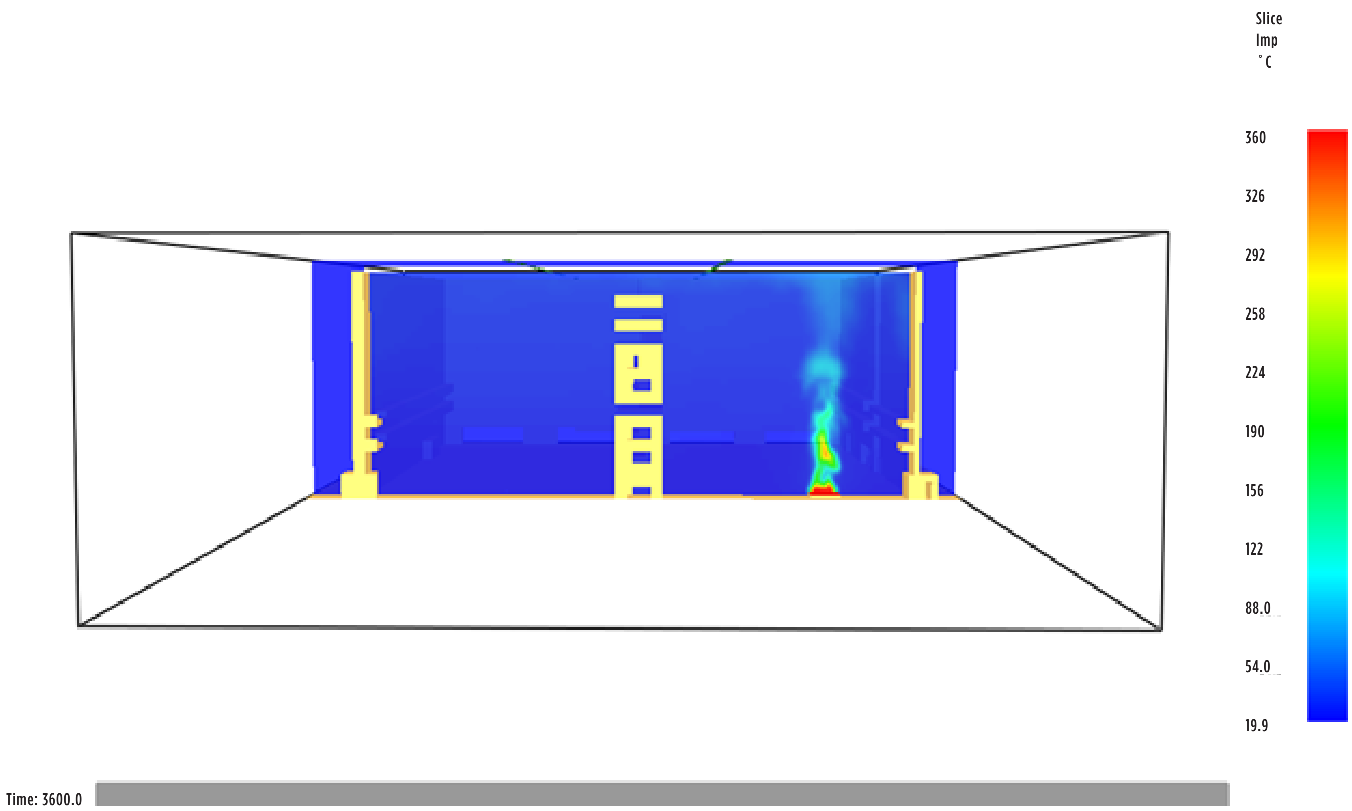

FIGURE 3: *Roof vents fire test.*

protection that would meet the intent of NFPA-required automatic sprinkler protection. An existing, on-site fire department would be considered the primary means of fire suppression at this facility. By working with the fire department and utilizing the department's familiarity with the facilities and frequency of training in existing buildings, the team uncovered nontraditional methods of improving response time.

A new automatic standpipe system was designed and spaced closer than prescribed code dictates to allow for faster fire department response. The new automatic standpipe system included hose valve stations in locations that would allow firefighter response to be both above and below fire events, utilizing mezzanines for coverage. In addition, smoke vents located at the ceiling level were increased in capacity beyond code requirements. Hand calculations and FDS modeling were used to confirm that the smoke layer of a worst-case fire would not descend to the breathing height of occupants on the ground level.

Because of the expansive floor area and frequently changing floor obstructions as manufactured parts moved within the building, the travel distances for the space were expected to be in excess of IBC requirements. As a further complication for egress, an open eight-story structure consisting of floors and mezzanines was located through the center core of the facility. The center core structure required life safety analysis to address egress from the space. There was no need for performance-based design alternative protection for facilities that can provide compliant solutions to code-prescriptive egress requirements. For example, while egress travel distance was increased for the designed manufacturing facility, common path requirements and dead-end travel limits were not altered.

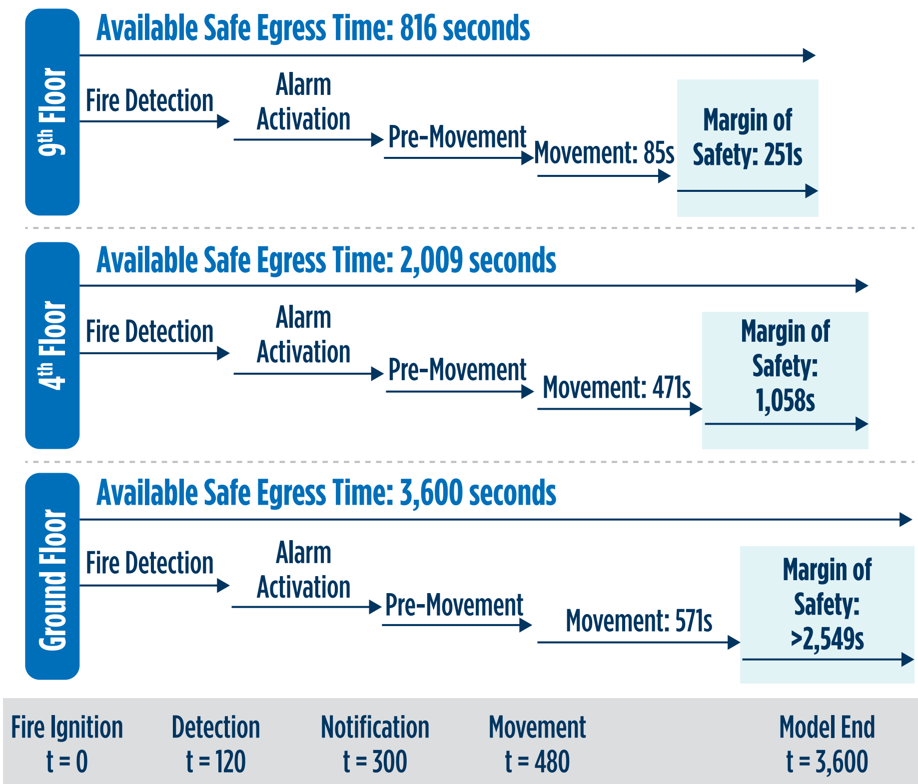

FIGURE 4: *Available and required safe egress time (not to scale).*

Additionally, for the special purpose industrial facility, travel distance increases were offset not only by a combined fire and egress model verifying travel times but also by dedicated maintained pathways away from the different sections of the manufacturing areas. While special industrial occupancies will require performance-based design for elements of fire safety, code-prescriptive fundamentals, when still effective, are preferable. The Burns & McDonnell team performed egress modeling, supported by hand calculations and paired with FDS modeling, to determine the amount of time it would take occupants to egress the facility. For each floor of the facility, occupants' egress times were compared to the time it would take for the smoke layer to drop to the floor of occupant egress. Occupants can be considered safe when they have entered an exit passageway or left the building. By providing excess safe egress time, occupants are provided with adequate time to egress the building plus additional time as a safety factor in the event of a fire.

CONCLUSION

Fire protection and life safety alternatives determined by performance-based design will be different for every project, but rapid notification, alternative suppression systems, removal of hazards and infrastructure for fire department response must always be examined as ways to provide equivalent protection to prescriptive code requirements.

Performance-based design should only be utilized for aspects of a building that cannot meet code requirements or where code parameters would not provide adequate protection. FDS modeling or hand-calculation based recommendations will always be theoretical in nature and more open to mistakes than tried-and-true code prescriptive requirements. If performance-based design is necessary for a special industrial occupancy, code prescriptive requirements should be augmented rather than removed, or rewritten whenever possible.

When guided by a qualified team of fire protection engineers, performance-based design can be the key to meeting regulations while maintaining complete building protection and life safety. Performance-based design can be a vital tool to evaluate special industrial occupancies. Each building or structure examined requires unique, personalized evaluation to confirm that proper protection is met. By determining the intent of code requirements, alternative protection features may be selected to improve safety and provide a desired spinoff effect and cost-effectiveness.

BIOGRAPHY

STEPHEN KOSTKA, PE, is a fire protection engineer for Burns & McDonnell, with experience in fire alarm, life safety and fire suppression systems in the design of challenging industrial, substation and military facilities. He has been involved in the design of multiple industrial and special industrial buildings in both client-side engineering and consultant engineering roles. In addition, he has worked on some of the world's largest dry docks and industrial buildings, designing safe, practical solutions to life and property safety challenges. He earned a bachelor's degree in fire protection engineering from the University of Maryland.

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