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Emerging Issues for Fire Safety in Tall Buildings: A view from the NFPA HRBSAC and FPRF

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Abstract

As the global urban landscape witnesses a resurgence of the skyscraper, NFPA and its affiliated Research Foundation, are exploring emerging safety challenges and solutions. The release of the Guidelines for Developing Emergency Action Plans for All-Hazard Emergencies in High-Rise Office Buildings by the High Rise Building Safety Advisory Committee (HRBSAC) in 2014 highlights the need to plan, prepare and be able to manage various hazard scenarios. The Research Foundation has conducted four studies in the past year on emerging issues in high rise fire safety, including mixed evacuation strategies, emergency communication messaging, combustible exterior wall fire hazards, and high rise timber construction. In addition, a recent Foundation report on Disaster Resiliency connects safety information for the built environment including high -rise buildings, to the potential need to offer enhanced tall building code provisions. This paper will review the results of these studies and their future implications for the global skyscraper.

Keywords: Emergency Communication; Evacuation; Façade; Fire Safety; Resiliency; Timber

The National Fire Protection Association (NFPA) and its research affiliate, the Fire Protection Research Foundation, have safety at the core of their mission to deliver information and knowledge on hazards, emerging trends and innovations in technology and materials. While much of that work is identified and completed by the 225 Technical Committees that operate within NFPA, support for and to those committees can come from several areas. Through a combination of Foundation activities, NFPA investigations and case studies, and input from a handful of advisory committees, a number of resources directed at the high-rise environment are readily available from NFPA.

One Goal-Multiple Approaches: The High-Rise Building Safety Advisory Committee (HRBSAC)

Created in 2004, the HRBSAC is one of three technical advisory committees that exist at NFPA. The HRBSAC reports to the NFPA Standards Council with a scope and span of responsibility as follows:

> Scope: This committee was appointed by the NFPA Standards Council to identify existing needs and emerging issues within the high-rise building environment, produce recommendations as to how NFPA can provide a leadership role on such issues, and ensure that the NFPA codes and standards process included current subject matter on high-rise building safety, emerging technologies, and other matters that impact those who work in, live in, or operate high-rise buildings.

Figure 1. High-Rise Buildings (Source: National Fire Protection Association)

Following the September 2001 terrorist attacks, much discussion centered on the "safety" of high-rise buildings and what could be done to make these structures "safer." Philosophically, high-rise buildings are safe and traditionally have the most conservative set of design rules when compared to other buildings. These features include extensive use of fire resistive construction, installation of automatic sprinkler systems and standpipe systems, installation of automatic fire alarm systems that include emergency voice alarm/communication systems (EVACS), emergency power, and an emergency command system among other features.

As the extensive studies began to emerge from the National Institute of Standards and Technology (NIST) on the WTC 1, WTC 2, and WTC 7 building performance, it was important for NFPA to have a small but effective group in position to assist in properly translating those studies and their associated recommendations. Since the impact of those reports would be far reaching and thus impacting everything from structural fire resistance, system performance, emergency management, first responder safety, and occupant emergency planning, an advisory committee that reflected those perspectives was appointed. In 2015, those ideas and considerations continue to be evaluated and implemented at different levels.

Fire safety concerns and impacts have long been a challenge in the high-rise environment at NFPA dating back to the turn of the 19th Century. Likewise, fire safety has also been a theme since the founding of CTBUH in 1979. Conference papers, publications and reference resources have been integral in many of the CTBUH programs.

Since its creation eleven years ago, the HRBSAC has generated concepts, ideas and thinking that has, or is, resulting in changes to NFPA Codes and Standards, created documents for use by the public, and has established research projects that have moved the industry forward with regard to "safety" in high-rise buildings.

Emergency Action Plans for All Hazard Emergencies in High-Rise Office Buildings

As it was envisioned to operate in 2004, the committee has had, and continues to have, a positive impact on NFPA Codes, Standards, programs and projects. While much of the work that HRBSAC is involved in is contributory (to a Code, Standard, or Foundation project), the release of the "Guidelines to Developing Emergency Plans for All Hazard Emergencies in High-Rise Office Buildings" marks the first document that is within the exclusive domain of HRBSAC.

Developed over a period of three years, the Guide is intended to provide a road map for the development of an appropriate planning document that can be implemented by building owners and operators. Unlike most low-rise buildings and structures, occupant and first responder safety in a high-rise building is a more complex challenge. As noted previously, a combination of brick and mortar solutions apply that include myriad structural, fire safety, system, and operational plans. The Guide is structured to govern various hazard planning scenarios that include not only fire but also severe weather, work place violence, and utility disruptions. Based on content that has been developed on a case by case basis in North America, the Guide covers the waterfront with regard to the planning side of the equation.

Since the collective of individuals, processes, systems, features, and plans must work to achieve safety, the Guide document has been arranged to identify areas of responsibility and the role that each of these elements plays when viewed from the human capital perspective. In this scheme, the building owner has the overall responsibility to implement the content of the Guide and establish a robust set of actions for the building.

The Guide works to address the three basic occupant evacuation strategies that are part of any building emergency plan. Those strategies, shown in Table 1 are especially important to consider in the high-rise environment.

The Guide is centered on a set of management operational plans that can be used to prepare the occupants and building staff about what measures should be taken based on a certain hazard event. The Guide recommends development of an Emergency Action Plan, or EAP, that is hazard based. This approach is critical since the occupant response to a fire, power outage or weather related event is very different. Even the response to a fire event is dependent on a variety of factors including fire location, fire growth/size, intervention by building systems or construction features, and occupant awareness of the fire.

Successful development, implementation, and execution of the EAP is driven by a Building Emergency Response Team (BERT). This group is made up of a combination of employees who work for the building management team as well as employees or representatives of the building tenants. The BERT has to provide the details and unique characteristics associated with the particular building and establish the specific actions and protocols that occupants

Table 1. Occupant Evacuation Strategies

Occupant Evacuation Strategy	Managed Sequence	Unmanaged Sequence
Shelter in Place	No movement - shelter in place upon direction	No movement - shelter in place per prior instruction
Relocation or partial evacuation	Managed or controlled partial evacuation In-building relocation on same floor In-building relocation to different floors Occupants of some floors leave building	Unmanaged movement
Shelter in Place	Managed or controlled total evacuation	Unmanaged or controlled total evacuation

Table 1: Occupant Evacuation Strategies (Source: National Fire Protection Association)

are expected to take during any particular emergency situation.

The creation and implementation of the EAP is a critical and central part of the process that requires ongoing updates to reflect changes in building fit out, new tenants, or other factors that may require the EAP to be altered. It is essential that individuals for this process include those in a leadership position that have occupant and building safety issues as a priority. In order to ensure this, the Guide recommends appointment of a Fire and Life Safety Director (FLSD) and a Deputy Fire and Life Safety Director (DFLSD). These entities have focused responsibilities that span across normal building operations as well as when an emergency occurs. The FLSD is accountable for conveying information about the nature of the emergency as well as the appropriate actions that occupants should be taking. In addition, the FLSD is given wider duties that include high level oversight of inspection, testing, and maintenance (ITM) of certain building systems and features.

During an emergency event, the FLSD is also the conduit between the on-site incident commander and the building occupants. In that role, the FLSD can share first-hand knowledge of the status of building systems or features, any special circumstances that need to be considered, and the status of the occupant relocation/ evacuation progress.

Beyond the planning and written portion of the EAP, the assignment and defined roles for certain individuals, including the occupants and the assortment of hazards that must be considered, the Guide also recommends that drills, exercises, and information that educates the occupants on the need and importance of the EAP to be developed. At some point, all building occupants have the responsibility for their own safety. The Guide provides the tools to engage the building owner and the occupants by helping to establish those boundaries that include awareness and expected actions of the occupants.

Emergency Evacuation Planning

NFPA's Research Foundation has recently conducted a number of studies designed to inform egress planning and emergency communications for high-rise buildings. Highlights for two of those projects are provided here.

Total Evacuation Systems for Tall Buildings

Building codes establish the minimum requirements for the safe design of a high-rise building. Nevertheless, additional life safety measures are often necessary to mitigate the risks that arise from the complexity of these types of buildings and the possible difficulties in fire-fighting and rescue operations.

Recent events such as the World Trade Center evacuation have raised a greater sense of awareness on this topic [Averill et al., 2005]. This event has resulted in a paradigm shift in the assessment of high-rise building safety. It demonstrated the importance of providing robust means of egress and the need for further investigating the interactions between the infrastructure, the evacuation procedures and the behavior of the occupants [Galea et al., 2008a].

Several Questions Have Been Prompted About the Adequacy of the Current Emergency Procedures

for high-rise buildings. What type of evacuation scenarios should be considered when designing high-rise buildings? What egress components (e.g., stairs, elevators, refuge floors, sky-bridges, etc.) are suitable to evacuate high-rise buildings? What emergency procedures should be employed to improve evacuation efficiency? All these questions do not have simple answers and they often depend on the specifics of the building under consideration [Sekizawa et al., 2009]. The role of safety designers is made even more difficult by the fact that there is still a lack of knowledge about occupants' behavioral processes that may take place during the evacuation of a high-rise building [Kuligowski, 2011].

Egress models are efficient tools to analyze and compare different evacuation strategies [Machado Tavares, 2008]. They can be used to provide qualitative and quantitative information on occupant's use of different egress components and strategies. They can in fact allow the representation of the occupant's decision making process in the case of complex evacuation scenarios [Gwynne et al., 1999]. The Foundation initiated this project at the request of HRBSAC to investigate the effectiveness of different total evacuation strategies in high-rise buildings by means of egress modelling. The scope was to obtain recommendations on future possible changes in the existing codes.

The report presents the analysis of seven evacuation strategies among the most commonly used in the current high-rise building practice. The case study building is a hypothetical building which permits the testing of different egress design configurations. The building is made of two identical twin towers, each made of a 50 floor office building. The two towers are linked with two sky-bridges at different heights. The strategies under consideration include a single or combined use of egress components, such as stairs, occupant evacuation elevators, service elevators used as shuttles, transfer floors and sky-bridges. Two egress models have been applied to simulate the strategies, namely Pathfinder [Thunderhead Engineering, 2012] and STEPS [Mott Macdonald, 2012]. The models employ two different modelling approaches to simulate people movement: Pathfinder represents the movement of the agents using a system of coordinates (i.e. it is a continuous model), while STEPS simulates

Figure 2. High-Rise Timber Buildings (Source: Hermann Kaufmann)

the movement in a grid (i.e. it is a fine network model) [Kuligowski et al, 2010]. The comparison of the results of two models using different modelling approaches allows cross validation between the model results.

Results show that the use of two stairs for high-rise building evacuations provide higher evacuation times compared with any other strategy employed. Results about the evacuation time using three stairs or a combination of elevators and stairs present lower results than the use of two stairs. The use of three stairs or a combined use of stairs and elevators presents evacuation times in approximately the same range. NFPA101 [2012] currently does not automatically require the third stair (NFPA 101 7.14.1.3). Three (or more) stairs may be required in relation to occupant loads and travel distance. There is therefore the need to evaluate the possibility of adopting in NFPA101 the prescription of a third means of escape, and discuss about the possible egress component(s) to be used, i.e., either a third stair, the use of Occupant Evacuation Elevators (OEEs) or sky-bridges.

The effectiveness of the strategies including elevator and stair usage is strictly linked to the information provided to the occupants and the accepted occupant waiting time for elevators. There is a need to adopt solutions able to increase the likelihood of the occupants to wait longer for elevators in order to optimize the efficiency of the strategies involving elevators. The current maximum waiting time for elevator (approximately 10 minutes) substantially affects the effectiveness of the strategies employing OEEs as egress components. The individual use of OEEs for elevators provides in fact the lowest evacuation times, although it represents at the moment an ideal case. Elevator signage and elevator messaging strategies are therefore a key issue that needs to be further investigated by the fire research community and that need to be fully addressed by legislators.

Readers of the results of this study need to carefully consider the assumptions made during the modelling work. Modelling results are in fact dependent both on the limitations of the modelling tools employed (e.g., models do not represent fatigue, the representation of the behaviors of people with disabilities is very simple, etc.) and the assumptions made (e.g., the sky-bridge scenario is an ideal case in which only the evacuation of one tower has been considered, the representation of the choice between different egress components is based on a limited number of experimental data-sets, etc.). Nevertheless, the current study showed that evacuation modelling tools can be effectively employed to qualitatively rank different total evacuation strategies in high-rise buildings.

Guidance Document: Emergency Communication Strategies for Buildings

The purpose of this report is to provide guidance to system designers, building managers, and/or building emergency personnel responsible for emergency communication on how to create and disseminate messages using basic communication modes (audible and/or visual technology). The guidance provided is taken directly from a report published by NIST, which was based on a review of 162 literature sources from a variety of social science and engineering disciplines (Kuligowski et al. 2012) and the prioritization of the specific findings extracted from each literature source. This three-year effort was funded by the U.S. Department of Homeland Security, Science and Technology Directorate and the Fire Protection Research Foundation (Kuligowski and Omori 2014).

This document first provides guidance for building managers, emergency personnel, alarm system manufacturers, codes/standards committees, or others responsible for emergency communication on the ways in which alerts and warning messages should be created, formatted, and disseminated. The guidance is divided into two main parts: guidance on alerts and guidance on warning messages. Although these two parts often get confused, it is important to distinguish between the purpose of an alert and a warning message. An alert is meant to grab peoples' attention, notifying them that an emergency is taking place and that there is important information, which will be provided to them. The purpose of a warning message is to give that important information to building occupants. Guidance on the construction and dissemination of both alerts and warnings is provided here.

Rapid-onset emergencies often come with little warning and can have a major impact on communities. In order to provide clear, effective instructions for a threatened population, it is important to create message templates ahead of time for a variety of different emergencies.

The report provides examples of message templates for five types of emergency, using various forms of emergency communication technology. All bracketed text can be altered and replaced with text that better suits the needs of the building occupants, emergency scenario, emergency response strategies, and the technology being used. Please see Kuligowski and Omori (2014) for more information on the process associated with the development of these templates. Each template follows the guidance presented in this document.

Figure 3. High-Rise Timber Buildings (Source: Norman Muller)

New Building Materials and Systems and High-Rise Building Fire Safety: Two Hazard Analyses

In response to requests from the insurance industry, the Foundation has recently conducted two projects designed to assess the fire hazards associated with the introduction of two emerging high-rise building materials and systems. The first project explores what we do and don't know about high-rise timber construction fire

performance. It includes a review of current wood construction systems for high-rise buildings (Cross Laminated Timber and others) and an assessment of the available information on their fire performance including test data, fire incident reports, available fire design guidance, and selected global case studies of six-story-plus timber buildings, which includes information on fire safety design features. The report identifies and prioritizes gaps in available information, including contribution of timber framing to compartment fire growth and development and the performance of structural connections and penetrations in fire environments. A Phase II program has recently been initiated to experimentally inform some of these gaps.

The second project, also about to enter a second experimental phase, has an overall goal to develop the technical basis for fire mitigation strategies for fires involving exterior wall systems with combustible components. Many combustible materials are used today in commercial wall assemblies to improve energy performance, reduce water and air infiltration, and allow for aesthetic design flexibility. These assemblies include Exterior Insulation Finish Systems (EIFS or ETICS), metal composite material (MCM) panels, high pressure laminates, foam plastic in cavity walls, and water-resistive barriers (WRB). The combustibility of the assembly components directly impacts the fire hazard. For example, the insulation component of EIFS, and other emerging related systems (for example Structural Insulated Panel Systems (SIPS) is combustible foam which exhibits rapid flame spread upon fire exposure. There have been a number of documented fire incidents involving

Figure 7. Disaster Resiliency (Source: AP)

combustible exterior walls but a better understanding was needed of the specific scenarios leading to these incidents to inform current test methods and potential mitigating strategies. The goal of the first phase project is to compile information on typical fire scenarios which involve the exterior wall, compile relevant test methods and listing criteria as well as other approval/regulatory requirements for these systems, and to identify the knowledge gaps and the recommended fire scenarios and testing approach for possible future work. The second phase of the project will compare the relative performance of MCM panels in standard tests and real scale configurations.

Resiliency

The final study of relevance to the high-rise building community, Disaster Resilience and NFPA Codes and Standards, goes beyond the specific topic of fire safety and looks at the concepts of disaster resiliency. The term resiliency has been used with increasing frequency in the context of how we build for, plan for, and respond to the variety of events that could interrupt the desired normalcy. Often these disruptive events are characterized as disasters, so disaster resiliency is a common pairing of terms for discussing and defining the concept. In response to the growing use of the term, the Fire Protection Research Foundation requested a review of NFPA's codes and standards and appropriate outside literature to identify how the terms and concepts apply to the NFPA's activities. The title selected for that initiative was Disaster Resiliency and NFPA Codes and Standards. Since its formation, the NFPA has addressed fire as the disruptive event. The objective of this project was to include other disruptive events (disasters) in addition to, or in place, of fires. The report includes a literature review that provides relevant extracts from a variety of sources and is intended

Figures 4, and 5. Combustible Exterior Wall Fires (Source: National Fire Protection Association)

Figure 6. Disaster Resiliency (Source: AP)

to include a pathway for understanding how the concepts of resilience could apply to the wide range of NFPA codes and standards. It then maps specific provisions in NFPA codes and standards to these concepts, both for benchmarking and an identification of a path forward for incorporating resilience concepts. A gap assessment was also conducted to identify knowledge gaps or other barriers to implementation.

As the global urban landscape continues to see a resurgence of the skyscraper, NFPA and its Research Foundation will continue to explore solutions to safety challenges.

References:

Averill JD, Mileti DS, Peacock RD, Kuligowski ED, Groner N, Proulx G, Reneke AP & Nelson HE (2005). **Final report on the collapse of the world trade center towers. Federal building and fire safety investigation of the World Trade Center Disaster, Occupant Behaviour, Egress and Emergency Communications**, September. NIST NCSTAR 1-7.

Galea ER, Sharp G, Lawrence PJ & Holden R (2008a). **Approximating the Evacuation of the World Trade Center North Tower using Computer Simulation**, Journal of Fire Protection Engineering 18 (2), pp. 85-115.

Sekizawa A, Nakahama S, Ebihara M, Notake H, Ikehata Y (2009). **Study on feasibility of evacuation by elevators in a high-rise building. In: Proceedings of the 4th Human Behaviour in Fire Conference**. Interscience Communication pp. 65-76.

Kuligowski ED (2011). **Terror defeated: Occupant sensemaking, decision-making and protective action in the 2001 World Trade Center disaster.** Dissertation. University of Colorado. Machado Tavares R (2009). Evacuation Processes Versus Evacuation Models: "Quo Vadimus'?" Fire Technology, 45 pp. 419-430.

Gwynne SMV, Galea ER, Owen M, Lawrence PJ, Filippidis L (1999). **A review of the methodologies used in the computer simulation of evacuation from the built environment**. Building and Environment 34(6) pp. 741-749.

Thunderhead Engineering (2012). Pathfinder 2012.1.10802 Version. Technical Reference.

Mott MacDonald Simulation Group (2012). **Simulation of Transient Evacuation and Pedestrian movementS STEPS User Manual 5.1 Version**.

Kuligowski ED, Peacock RD, Hoskins, BL (2010). **A Review of Building Evacuation Models NIST**, Fire Research Division. 2nd edition. Technical Note 1680 Washington, US.

Kuligowski, E.D., S.M.V. Gwynne, K.M. Butler, B.L. Hoskins, and C.R. Sandler. (2012)

Kuligowski, E.D. and Omori, H., 2014. **General Guidance on Emergency Communication Strategies for Buildings**, 2nd Edition. NIST Technical Note 1827, National Institute of Standards and Technology: Gaithersburg, MD.