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Considerations and Challenges for Refuge Areas in Tall Buildings

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Biography

Mr. Daniel J. O'Connor P.E. is the Chief Technical Officer of Aon Fire Protection Engineering Corporation (Aon FPE) and received his B.S. degree in Fire Protection Engineering from the Illinois Institute of Technology in 1979 and his M.S. Degree in Fire Protection Engineering from the University of Maryland in 1992. In 2004 Mr. O'Connor was elected to the grade of *Fellow* in the Society of Fire Protection Engineers. Mr. O'Connor is the Chair of the Society of Fire Protection Engineer's Task Group on Human Behavior. Mr. O'Connor is a member of five NFPA Technical Committees that include NFPA 72, *National Fire Alarm & Signaling Code*, and is the immediate past Chair of the NFPA 101 Technical Committee on Healthcare Occupancies. Mr. O'Connor is currently Co-Chair of the Council on Tall Buildings and Urban Habitats (CTBUH) Fire Safety Working Group. He has been involved in numerous tall building projects during his career including the Trump tower in Chicago, the proposed 610 meter (2000 feet) Chicago Spire, and the 112 story Doha Convention Center and Tower for which he provided fire/life safety and building code peer review services. Most recently he has been assisting with concepts development for several significant projects in Korea and China.

Abstract

This paper will review the work to-date of the CTBUH Fire Safety Working Group regarding the history, use and applications of various types of refuge areas used in buildings. Several points have been used as the basis to justify the need for refuge spaces and floors within tall buildings.

- Super tall buildings are subject to long evacuation times (1-3 hours)
- Evacuation down long stair routes can be physically demanding for occupants with low stamina
- Stairs are not conducive for movement of people with permanent or temporary disabilities
- Total evacuation may not always be desirable or feasible. Stairs (even pressurized stairs) can become contaminated by smoke while multiple doors are open or doors that fail to close.
- Fire department operations can conflict with occupants egress movement and result in smoke entry into the stairway.

The concepts for the design and implementation of refuge spaces, however, have been found to be rather variable in actual application for tall buildings around the world. The refuge floor concept can have some challenges of efficiency, sustainability, and even life safety. These issues and concerns are discussed. The challenge is to identify the problems that refuge floors solve or endeavor to solve, and then determine how those problems can be solved using other techniques that offer equivalent

safety, sustainability and cost effectiveness. The paper also addresses alternatives to minimizing or eliminating dedicated refuge areas/floors in the overall design of a tall building. The CTBUH Fire Safety Working Group intends this paper to foster better understanding and consideration of the concepts and of refuge areas/floors prior to application in the overall design of any tall building.

Keywords: Refuge floors, refuge areas, sustainability,ventilation, cost, challenges

Introduction

Tall buildings offer the advantages of housing people and business operations efficiently and vertically in urban areas. One of the great efficiencies is that relatively few independent exit stairs are needed to serve the population of a tall building housing potentially thousands of occupants. Given a floor plate with reasonable (meets code limitations) travel distances to the exit stairs, it is common that only two or three independent exit stairs would be required to fulfill legal requirements for a tall building whether it be 20, 50 or 100 stories high. The provision of automatic sprinkler systems and compartmentation features afforded by fire resistive floor systems are generally accepted measures, which safely allow for evacuation of only a few selected floors during a fire or similar emergency to other floors remote and protected from the fire or similar emergency. Of course, there are concerns for scenarios or events that may warrant a more wide scale evacuation or even total evacuation of a tall building.

Although elevators may play a bigger role in total building evacuations (Proulx et al 2009) in the future there are a variety of reasons and concerns that stairs (Peacock et al 2009) and elevators alone (Heyes 2009) are not adequate to support occupant needs during a partial or total building evacuation process. Major points that have been recognized in the building community are as follows:

- Tall buildings with large occupant loads are subject to long evacuation times (1-3 hours)
- Evacuation down long stair routes can be physically demanding or tiring for occupants with low stamina
- Stairs are not conducive for movement of people with permanent or temporary disabilities (Proulx and Pineau 1996) that include
  - Mobility impaired occupants – wheelchairs, walkers, canes
  - Health impaired occupants – those with respiratory or cardiac issues
  - Temporary conditions – pregnancy, broken limb or injury
- Total evacuation may not always be desirable or feasible. A partial evacuation may be appropriate to move only those occupants in or near the affected fire or emergency zone to another area of relative safety. (Lay 2008, O'Connor and Cohn 2008)
- Stairs (even pressurized stairs) can become contaminated by smoke when multiple doors are open or doors fail to close. (Bukowski 2009)
- Fire department personnel will often rely on exit stairs for staging and hose deployment operations. Such fire department operations can conflict with occupants egress movement and result in smoke entry into the stairway while doors are held open by hose lays.

One or more of the above points have been cited as the basis for justification for refuge spaces or refuge floors in tall buildings. The global experience of refuge spaces in tall buildings varies, but includes at least two basic approaches: dispersed protection and consolidated protection.

The refuge area/floor concept can pose issues related to design efficiency, sustainability, and even life safety. These issues are addressed in the following pages. The challenge is to identify the problems that refuge floors solve or endeavor to solve, and then determine how those problems can be solved using other techniques that are safer, more sustainable and more cost effective. There may be conditions in which a refuge floor is an appropriate technique in the overall design of a tall building, but potential problems and risks of refuge floors should be understood and adequately

considered to in the overall design of any building that utilize refuge floors.

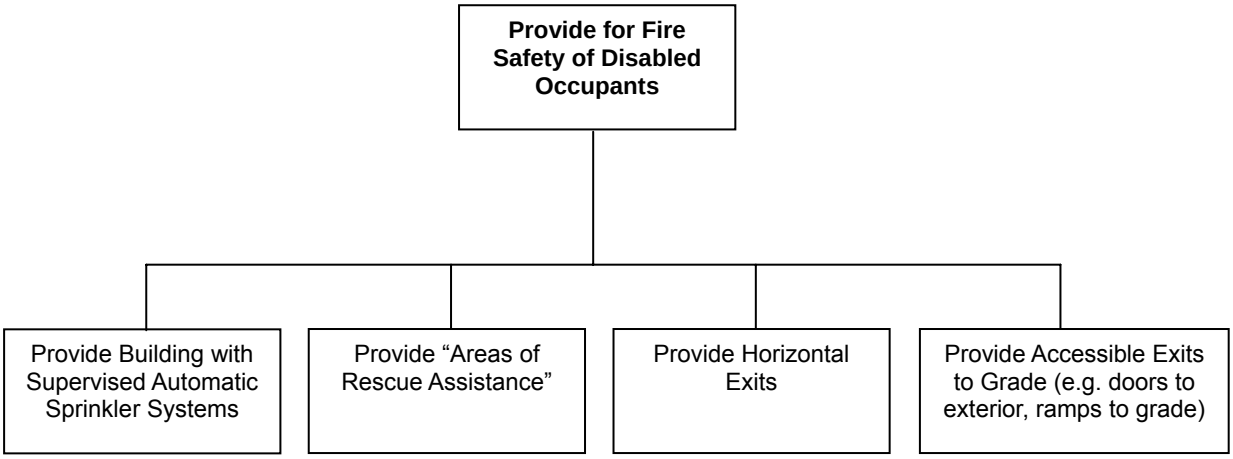
The Dispersed Approach

Refuge areas in tall buildings have been developed for a variety of reasons in various parts of the world. These include both life safety for all occupants, and to respond to the needs of people with disabilities. The dispersed approach is most common in Europe, the Middle East and North America. In the United States, for example, the dispersed approach is reflected in the Federal Law, the Americans with Disabilities Act (ADA) initially implemented in 1991 (U.S. Federal Register/Vol. 56, No.144, July 1991.) The document that defines building design standards to implement that law is the "Accessibility Guidelines for Buildings and Facilities" (ADAAG) (US DOJ 1991), which established two key premises regarding the design of exits in tall buildings:

1) Where a multi-floor building used stairs for exits, it was recognized that some disabled individuals could not avail themselves of such exits and, therefore, ADAAG required protected "Areas of Rescue Assistance" or the provision of a "horizontal exit" which enables disabled occupants to readily seek refuge. Horizontal exits are constructed using continuous fire barriers (2-hour or greater) and self/automatic-closing fire doors to divide a floor area into independent fire/smoke-protected zones.

2) Another alternative to providing "Areas of Rescue Assistance" or a "horizontal exit", and the most commonly practiced alternative, is for the building to have a supervised automatic sprinkler system. The fact that supervised automatic sprinkler systems have integrated monitoring and signaling features used to indicate conditions that could impair the satisfactory operation of the sprinkler system(s) is key to this alternative.

Effectively, the ADAAG recognized any one of four methods to provide for the safety of occupants during a fire event in the building.



The most common and effective solution for tall buildings is the supervised sprinkler system approach. The "areas-of-rescue-assistance" option is generally not an the option desired by architects or developers for reasons of cost and loss of useable and /or leasable area.

The Consolidated Approach: Using Refuge Floors

The consolidated approach (gathering of occupants onto a few refuge floors) has become most common in many areas of Asia in recent years. The impetus for the refuge area in some parts of the world is attributed to several accidental fires, including the 1996 Garley Building fire in Hong Kong. It is noted (Chow and Chow 2009) that the Hong Kong government modified its existing fire code requirements from 1996 to 2005 to address the concerns for occupant safety in high-rise buildings. These requirements focused more on providing refuge areas in terms of an entire floor or large portion of a floor in those high-rise residential buildings taller than 40 stories.

Refuge floors provide the option for occupants to pause during the evacuation process, and they provide the option of being an assumed safe holding area for occupants. Occupants who are exiting can pause and rest at the refuge floor until they feel they are ready to descend further down the exit stairs (either to the next refuge floor or to the exit discharge). Alternatively, occupants may be directed to the refuge floor and kept there awaiting further instructions.

Specific requirements vary by jurisdiction, but typically refuge floors are required for buildings greater than approximately 100 meters (328 feet) in height. For such buildings, every 16th to 20th floor is required by the applicable building codes or regulatory authority to be reserved and designated as a refuge floor. Theoretically the occupants from the 15 to 20 floors immediately above a refuge floor can (or perhaps in some circumstances are required) to exit down to the refuge floor, either to rest or to await further instructions or permission to egress out of the building.

One interesting design configuration that is frequently incorporated in to the refuge floor concept is the interruption of exit stairs. Typically, the exit stairs above the refuge floor discharge onto the refuge floor, so that stair users must leave the stair enclosure before entering the refuge floor. From the refuge floor it is possible to re-enter the stair if they desire to continue down. The interruption has the dual advantage of making the exiting occupants aware of the availability of the refuge floor; and the interruption or segmentation of the stairs into separate compartments, can mitigate stack effect, and thus improve the performance of stair pressurization systems over the full height of each segment of the stairs.

Initially, it seems like a very compelling idea to create an entire floor that will function as an area of refuge within a building where a large number of building occupants can be gathered. However, upon further examination, questions arise about whether a refuge floor provides an increased or a decreased level of safety, and whether there are more effective and efficient ways to accomplish the goals that refuge floors attempt to achieve.

Design Issues and Challenges

The occupant load anticipated to use a given refuge area is based on good-faith design estimates or theoretical worse-case (full code calculated) population loads of the floors being served. For example, an office building with about 2,325 m² (25,000 ft²) of floor area per floor would have about (2,325 m² divided by 9.3 m² per occupant =) 250 occupants per floor. Therefore the refuge floor would theoretically need to accommodate about (15 floors x 250 occupants per floor =) 3,750 occupants. For some jurisdictions, it has been proposed that refuge floors might only be every 20th floor. For those locations the theoretical maximum would increase to be about (19 floors x 250 occupants per floor =) 4,750 occupants on the refuge floor. The density of occupants would be high and the resulting crowd poses building design and crowd management challenges.

The actual utilization of a refuge floor is, however, not easily estimated or predictable and is dependent on highly variable factors at the time of an emergency incident. Such factors include the fire incident location, extent of fire spread, nature of the occupants and nature of the emergency communications/alarms in the building.

Assuming that the estimated hundreds or thousands of occupants would assemble on a given refuge floor, this approach then poses a number of issues related to the comfort and safety of those occupants for the duration of the stay. Amenity and safety features that need to be considered are as follows:

- Toilet and drinking water provisions
- Seating facilities or standing room accommodations only
- Emergency power for lighting and refuge floor amenities
- Protection of floor from increasing /spreading fire effects
- Ventilation/HVAC design and reliability for duration of the event

The issue of ventilation/HVAC system design for a refuge floor is perhaps the most significant cost and implementation concern. Natural ventilation concepts where two or more sides of the building façade are open to the atmosphere have been implemented in a number of constructed buildings.

Several studies have reviewed the viability of this concept and cited issues with the reliability of this method of ventilation showing problems with smoke contamination of the refuge floor (Chow and Chow 2009; Kwok et al 2000; Cheng 2006). For enclosed refuge floors an HVAC system approach system would need to be designed to maintain a reasonable level of comfort for the occupants on a fully utilized refuge floor.

The HVAC systems need to perform three functions: 1) provide adequate fresh air to occupants; 2) maintain any pressurization necessary to keep the building occupants and the exits clear of smoke; and 3) maintain the temperature within the refuge floor at a range that does not negatively impact human survival or the ability those occupants to be mobile. This third function is of a greater concern for buildings in high temperature climates. If the HVAC system cannot perform any one of those three functions, it will become necessary for the occupants on the refuge floor, to relocate from the refuge floor to another location. The costs and energy needed to provide for the large population on a refuge floor for the occasionally (if not rare) event are counter to sustainable building design objectives. Other potential concerns are related to HVAC system failure. What if the intakes for the HVAC for the refuge floor are located above the fire floor, and begin drawing in smoke from the fire floor, and therefore must be shut down? How long can occupants remain on a refuge floor that has lost its HVAC system, and if it becomes necessary to evacuate that refuge floor, how much time will be required to evacuate that refuge floor?

Challenges of Life Safety

Human behavior is an area of concern and uncertainty when refuge floors are implemented. Although training and evacuation drills are important factors to encourage proper evacuation actions there are potential issues that may not simply be addressed by evacuation drills (Bukowski 2008). Factors such as crowding, uncertainty about the conditions, increased heat, difficulty breathing, physical discomfort from long standing or sitting, and other factors can increase levels of stress and impatience. Large crowd behavior under such conditions can be difficult to predict and difficult to manage.

The provision of a refuge floor does not mean that occupants will utilize the floor as intended. Overcrowding or non-use are both potential outcomes. However, assuming a refuge floor is “appropriately” utilized, it should be recognized that the refuge floor becomes an assembly occupancy. The increased density poses crowd management risks and subjects a large percent of the building population to fire/smoke exposure risks in a single location. Should the refuge floor need to be evacuated there can be crowd issue due to the large number of occupants competing for access to a limited number of evacuation routes (stairs and elevators)

Challenges of Cost Effectiveness

Refuge floors result in a reduction in the usable floor area and therefore the efficiency within a building. The dedicated refuge floor concept, where an entire floor or large portion of a floor is given over to the exclusive (single purpose) use as an area of refuge, is an exceptionally expensive requirement. It will result in an increase in construction cost, and will add to ownership and operations costs over the life of a building after construction is completed.

This applies to buildings that are leased or rented, (including offices, apartments and hotels) and results in a continuing loss of revenue for building owners over the life of a building. It also applies to residential buildings, as the refuge floors will either result in a decrease the size of living units (a prospective owner will only have a fixed amount of money to spend on the purchase of a new unit) or the use of refuge floors will increase the cost of units (if the units are not reduced in area, but remain constant, and the costs of the refuge floor is passed on in the form of an increase in purchase cost), or a combination of both.

Depending on the requirements of spacing (refuge floors every 15 to 19 floors) this would result in a minimum of one or two additional floors to be used solely as refuge floors. So, instead of constructing 50 typical office floors, the need would be to construct 52 or 53 floors in order to provide the same amount of office space. Therefore, in the simplest of terms, these two or three additional floors would result in a minimum increase in construction costs of approximately 4% to 6%.

There are a number of other added costs which are not estimated at this time, but collectively are significant. These differ from city to city and market to market, and therefore the extent will vary from building to building. An estimate of these costs is not made at this time, but these costs are acknowledged and itemized here as follows:

- Added Costs from Additional Construction Time to add floors
- Increased Maintenance Cost – cleaning, HVAC for normally empty space
- Loss of Efficiency/impact on leasing, usability for multi-floor tenants
- Property Tax Issues – floor area that fails to generate revenue, yet taxes are to be paid
- Loss of Zoning Potential – reduced building height or area allowed in a given zoning space

Challenges of Sustainability

Is a refuge floor consistent with sustainability? In brief, based on the information noted above, the answer would be “no”. In brief, they require a significant increase in use of material and energy resources, both during construction and operation during the life of a building, but they do not provide a commensurate increase in use or value.

Alternatives and Solutions

For many buildings, the thoughtful implementation of a combination of “defend-in-place”, and evacuation of floors in a selective and strategic sequence, would provide the same, or better level of life safety, and at a less financial cost, than a refuge floor system. This approach has been effective for many of the world’s tall buildings. There are always methods that can be implemented to improve that approach, and continued effort to do so, should be encouraged. Some key ideas to consider in lieu of the dedicated refuge floor or to minimize the impact of the concept are as follows:

- Most, if not all floors, can serve as refuge space.
- Refuge floors can double as useable occupancy.
- Buildings with bridge connections need not rely on refuge floors.
- Cost savings of eliminated refuge floors can be better spent on highly-reliable fire safety systems and “defend-in-place” strategies.
- Property tax and zoning regulation relief for buildings using a refuge floors concept

Most, if not all, floors of a building can effectively be viewed as a refuge floor. Given appropriate levels of floor-to floor compartmentation, highly reliable sprinkler/water supply systems, and effective facilities for prompt and capable fire department response it is believed large refuge areas or floors can be effectively eliminated. If refuge floors are mandatory there are several potential opportunities for mitigating the financial impact of refuge floors. One of the most significant changes would be to permit refuge floors to have uses during non-emergency times. The zoning regulations could be modified to “recapture” floor area lost to refuge floors; tax regulations could be modified to eliminate costs for the areas of refuge floors. Such solutions pose both technical and political complications.

Conclusion

In conclusion, the opportunities for mitigation of the negative financial impact of refuge floors seem minimal compared to the costs of construction and ongoing costs of operation and maintenance. And so the question remains, is there a more cost effective, sustainable method of accomplishing what refuge floors are endeavoring to accomplish?

The CTBUH Fire Safety Working Group believes the concept of a refuge floor needs to be reconsidered. It may make sense for some areas of buildings of exceptional height or special occupancy conditions, but should be used only with caution, and with implementation of strategies or design elements which eliminate the design and life safety problems noted above. Refuge floors may be a appropriate solution for special or unique situations, and should not be a strategy of first choice without careful consideration.

An advancement of the concept of refuge floors might be to designate and equip certain typical floors

(usable tenant floors) grouped in one area, as refuge floors. Such floors would be designed to provide the necessary area, amenities, and HVAC system performance required to accommodate the building occupants. However, the effectiveness of such an approach returns to the question of what is it that refuge floors can provide that cannot already be adequately provided on typical floors? What is the benefit of concentrating many occupants into one area, verses having them protected-in-place, or evacuated in an orderly manner with their colleagues and neighbors? These questions and others will continue to be discussed and evaluated by the CTBUH Fire Safety Working Group with the intent of delivering a full and complete treatise on this subject in the near future.

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