**Whitepaper on High-Rise Building Evacuation**

www.lifesavingkit.com

## Introduction

The magnificent skyscrapers and towering high-rises that comprise the skylines of the World's largest cities no longer represent just architectural and engineering masterpieces. Today, high-rise buildings denote power, prestige, wealth, and success. Some even embody national pride. Countries, cities, and even businesses compete against their rivals to possess the tallest and most impressive of these buildings. More than just steel, concrete, and glass, high-rise buildings are fast becoming a staple in major cities and financial centres all over the world.

According to the Emporis website, a database on buildings & the real-estate industry, there are now more than 88,500 high-rise buildings located in more than 7,000 cities worldwide.[1] Prominent cities such as Hong Kong, New York, Singapore, and Sao Paulo boast having over 2,000 high-rise buildings in their limits alone.[2] Other large metropolises such as Shanghai, Dubai, London, and Chicago continue to grow their skylines as well – not far behind. High-rise buildings have undeniably become the status symbols and landmarks of today.

Sadly, as demonstrated by the terrorist attacks on New York City's World Trade Centre towers in 1993 and 2001, and the bombing of the HSBC building in Istanbul in 2003, skyscrapers have increasingly become more attractive targets for terrorists due to their landmark prominence. Various studies of the 9/11 terror attacks and past incidents of high-rise building fires have identified two significant safety issues that need to be addressed: First, in the event of a fire, explosion, aircraft collision, or earthquake, how will the structural integrity of the building be preserved long enough to allow the occupants adequate time to evacuate? And second, in the event that the building's primary means of egress are compromised or unusable, such as in the 9/11 terror attacks on the World Trade Centre (WTC) towers, how are the occupants to safely evacuate the building?

To date, the discussion surrounding these two critical safety issues has primarily focused on how best to augment and harden the structural aspects and redundancy of buildings – specifically their elevator shafts, stairwells, and critical junctures. Some reports have even suggested installing new and more effective fire suppression systems that utilize foam rather than water. The problem is that no matter how structurally resilient a building is made, if a fire breaks out and renders the primary means of egress, stairways and elevators, unusable, the building just becomes a stronger tomb. The dilemma of how to evacuate a building in the event its primary means of egress are compromised or unusable remains the foremost safety issue for occupants working and living in high-rises, and even low-rises, today.

## Objective

The aim of this whitepaper is to illustrate the safety risks that face occupants of high-rise buildings. Through an examination of the vulnerabilities of high-rise buildings, the inadequacies of their evacuation processes, and past case studies, the strategic need for evacuation devices that provide a secondary means of egress when the primary means, stairways and elevators, are compromised or unusable, is demonstrated. Such an examination can be used by individuals, to enhance their personal safety, companies, to improve business continuity and limit liability, and insurers, to reduce litigation costs and potential payouts.

### Definition

The principal defining characteristic of a high-rise building is naturally its height. However, the specificity of the definition varies greatly depending on the source. For example, the Emporis website, which is directed towards academics, engineers, and researchers, strictly defines a high-rise building as:

> "A building 35 meters or greater in height, which is divided at regular intervals into occupiable levels [... with] an edifice [...] based on solid ground, and fabricated along its full height through deliberate processes (as opposed to naturally-occurring formations)."[3]

Similarly, The National Fire Protection Association defines a high-rise building as:

> "A building greater than 75 feet (25 m) in height where the building height is measured from the lowest level of fire department vehicle access to the floor of the highest occupiable story."[4]

Yet, most fire departments and construction companies operate on a much simpler and more subjective definition of a high-rise as a building that "is too tall for a fire department ladder truck to access from the outside."[5]

### Threats to High-Rise Buildings

According to Ron Klemencic, the leader of a U.S. group of construction experts formed after the 9/11 attacks, buildings simply cannot be designed to "'withstand inbound airline or missile attacks.'"[6] The general consensus among industry experts today is that the WTC towers performed remarkably well on 9/11, having structurally survived the initial aircraft collisions. In fact, many industry experts credit the structural resilience of the WTC towers with saving countless lives by granting the occupants time, although limited, to escape from the buildings before they collapsed.

Hence, the single greatest exogenous threat to high-rise buildings today is a terrorist attack. Taking the form of a missile strike or an explosive detonation, a terrorist attack has the potential to transform a majestic high-rise into a pile of rubble.

A missile attack, whether it be by Rocket Propelled Grenade (RPG) or Man Portable Air Defence system (MANPAD), or simply a hijacked commercial airliner, is extremely difficult structurally to defend against. It is impractical to construct all civilian high-rise buildings with enough structural resilience or external protection to withstand a significant missile strike or strikes. And structurally withstanding the initial strike is only half the challenge.

The damage caused by a missile strike is threefold. First, the missile inflicts damage on a structure kinetically by exerting destructive energy in the form of force. Second, the missile inflicts damage on a structure thermodynamically by releasing destructive energy in the form of heat and blast overpressure. And third, the missile inflicts damage on a structure through the creation and spread of fire and any other substance, chemical, biological, or radiological for example, that it is carrying.

Similarly, an explosive detonation, such as by a truck bomb or other device strategically placed within or around a building, inflicts structural damage thermodynamically, in the same way as a missile, and through the creation and spread of fire and other potentially hazardous substances contained within. Historically, truck bombs have been the terrorists' weapon of choice against high-rise buildings: Consider the devastation of the 1995 bombing of the Murrah Federal Building in downtown Oklahoma City, the 1993 bombing of the WTC towers in New York City, and the 2003 bombing of the HSBC bank in Istanbul to name a few.

Missile strikes and truck bombs indeed have the potential to deliver hazardous chemical and biological agents to the occupants of high-rise buildings. However, the immense heat generated by the explosion of a missile or bomb would naturally burn-up the majority of any chemical and biological agent present. Overcoming the laws of physics requires a significant technological capacity and proficiency; one rarely possessed by terrorists. As a result, terrorists have disproportionately relied upon the simple, yet effective, raw explosion to kill civilians in their past attacks.

The by-product of most explosions is fire. A fire can also arise under a number of other conditions and circumstances such as electrical malfunction and human error. Lethal in its production of noxious smoke and gases, searing heat, the speed with which it spreads, and its ability to induce structural weakening and eventual collapse in buildings, fire, in an independent capacity, poses the greatest safety risk to occupants of high-rise buildings today.

## Inadequacy of Primary Evacuation Methods

In the event that a fire occurs in a high-rise building, the only way to ensure the complete safety of all its occupants is by conducting a full-scale evacuation. However, because the primary evacuation systems present in most high-rise buildings today are inadequate, this seemingly simple, yet essential, task can be dangerous and problematic. The primary methods of evacuation in high-rise buildings today fail to provide occupants with a timely, safe, and effective egress.

A building's passenger elevators, in the event of a fire, are automatically returned to its main level and shut down to await reactivation by firefighters – unusable for egress.[7] A building's stairways, typically designed according to the evacuation needs of their respective floor populations rather than the evacuation needs of the entire building, are not intended to handle the cumulative effect of fleeing occupants – congestion.[8] Congested stairways, by inhibiting occupant egress and firefighter ingress, increases the risk of injury and death to both: When combating a building fire, the standard practice for firefighters is to tap into the building's internal water system, known as a standpipe, located in the stairwell below the fire, and then drag a hose upstairs with which to douse the flames.[9] A congested stairway full of fleeing occupants inhibits firefighter access to the standpipe and their moving between floors. The result: A greater amount of structural damage inflicted onto the building, possibly enough to induce complete or partial collapse, and a greater likelihood of incurring occupant fatalities from smoke inhalation.

Another inadequacy of the primary evacuation systems found in most of today's high-rise buildings is in their design. Elevators are typically grouped in a convenient central location on all floors – the "elevator lobby" or "sky lobby" layout. It is this layout that makes them vulnerable to compromise.

If a fire were to originate or spread into the elevator lobby, the heat and choking smoke would prevent occupant access to the elevators on the floor. As a result, occupants would be forced to negotiate the stairway down to the floor below or subsequent floors below in order to gain access via a clear elevator lobby; this assuming, of course, that the elevators are even operational. However, relying on a building's stairways to provide occupants with a safe method of egress is dangerous in itself due to the combination of the *Stack* effect and the *Breaking-of-the-Seal* effect.

> "[The] Stack effect is a natural phenomenon affecting air movement in tall buildings. It is characterized by a draft from the lower levels to the upper levels, with the magnitude of the draft influenced by the height of the building, the degree of air-tightness of exterior walls of the building, and temperature differential between inside and outside air."[10]

Thus, during a fire, smoke and toxic gases are carried upward through a building in a natural air draft that causes the upper floors to be contaminated first, with smoke then proceeding downwards, contaminating the subsequent floors down to the fire floor.[10]

Even in buildings that are compartmentalized to contain the spread of smoke and fire, the stairwells can quickly become the most dangerous place for occupants to be. As occupants on lower floors begin evacuating the building, opening doors to corridors and stairwells in the process, smoke, due to the Stack effect, naturally diffuses into stairwells and begins rising towards the upper floors. Occupants on higher floors, therefore, become unable to use the stairways for egress due to their rapid contamination. This Breaking-of-the-Seal effect, the opening of doors that results in the loss of smoke containment, is one reason why occupants are told never to wait to evacuate until the fire department arrives: When firefighters enter a burning building, they unavoidably prop open the building's hallway and stairwell doors with their hoses and other equipment. Smoke, as a result, rapidly spreads and contaminates the passageways and stairwells of the building[11] making the prospect of successful evacuation even less likely and more dangerous. In situations such as this, "protecting in place," or securing oneself against smoke contamination in a room or office, is the recommended course of action.

It is important to note that elevator shafts, like stairwells, are vulnerable to smoke contamination as well. Due to both the Stack effect and the Breaking-of-the-Seal effect, smoke penetrates into both the elevator carriages and shafts during a fire. Additionally, when elevator carriages are forced to make stops on smoke filled floors, both the elevator shaft and the carriage itself can quickly become contaminated beyond usable limits.

The most common vulnerability found in high-rise buildings today, however, is in the Heating, Ventilation, and Air Conditioning systems (HVAC). The design of most HVAC systems inadvertently amplifies the Stack effect and defeats compartmentalization measures:

"[The] central air system in a high-rise building interconnects 10 to 20 floors for the purpose of heating and cooling. Ducts, shafts, and poke-through holes penetrate fire-resistive floors, walls, and ceilings. These air-conditioning openings and holes allow fire and smoke to spread throughout the 10 or 20 air-conditioned floors of a high-rise building."[12]

With the HVAC system's design inadvertently aiding the rapid spread of toxic smoke to the upper floors and stairwells of a building, not only are the occupants' chances of safe egress further reduced, but as the floor itself becomes heavily contaminated with smoke, the occupants' total chance of survival diminishes significantly as well.

Hence, due to both the design flaws inherent in high-rise buildings today and the inadequateness of their primary evacuation methods, occupants cannot rely solely on their building's stairways or elevators for safe egress.

### Case Study #1: Garley Building Fire, Hong Kong (1996)

During welding work in an elevator shaft in the basement of the 16-storey Garley Building in Hong Kong, highly flammable materials ignited and caused a fire that travelled up the elevator shaft and rapidly spread throughout the top three floors of the building.[13] Because the building's windows could not be opened to let the heat and smoke out, and because the stairways were heavily contaminated with smoke or impassable due to the fire, 39 people were killed, 22 of which were found charred in a single office on the 15th floor, and 80 people were seriously injured.[13]

### Case Study #2: Meridian Bank Building Fire, Philadelphia (1991)

When a pile of linseed soaked rags left by a contractor on the 22nd floor of the 38-storey Meridian Bank Building ignited, it precipitated a massive 12-alarm fire that eventually brought 51 engine companies, 15 ladder companies, 11 specialized units, and over 300 firefighters to the scene.[10]

With a "well-developed" fire existing on the 22nd floor, fire spreading via the stairwell down to the 21st floor, and heavy smoke contamination of the stairwells and floors immediately above the 22nd floor at the time when the fire department arrived, the situation for occupants still remaining on the floors above the 22nd looked grim. So severe was the smoke contamination in the stairwells above the 22nd floor that three firefighters tragically lost their lives when they became disoriented and could not find their way to fresh air before their air supply ran out.[10] An eight member rescue team launched to recover the three fallen firefighters also became disoriented in the thick smoke and ran out of air as well. Luckily, however, they were rescued by another team and sustained only moderate injuries.[10]

After an eleven hour firefighting effort failed to bring the blaze under control, firefighting efforts in the interior of the building were suspended due to the risk of structural collapse. However, the fire was controlled when it reached the 30th floor and the automatic fire suppression system triggered.[10]

Miraculously, the only fatalities resulting from this fire were the three brave firefighters who succumbed to smoke inhalation after they became disoriented and ran out of oxygen. By demonstrating the difficulty and danger that smoke contamination poses to firefighters, this case study illustrates the insurmountable feat that an evacuation, under similar conditions, would be for an occupant. Thus, this case study is a perfect example of how the primary evacuation methods of today's high-rise buildings are simply inadequate at providing occupants with a safe and reliable means of egress.

## Case Study #3: WTC 1 & WTC 2 Terrorist Attack, New York City (2001)

On the morning of 11 September 2001, in a coordinated terrorist attack, two commercial airliners, both Boeing 767s, were hijacked and subsequently flown into the 110-storey WTC 1 and WTC 2 towers. Over 3,000 people were killed in the attack including some 343 emergency responders.[14]

According to a report produced jointly by the Federal Emergency Management Agency (FEMA), the Structural Engineering Institute of the American Society of Civil Engineers (SEI/ASCE), the city of New York, and several other Federal agencies and professional organizations, it was the fire produced by the initial impact explosion that eventually induced complete structural failure in the two buildings:

"As each tower was struck, extensive structural damage, including localized collapse, occurred at the several floor levels directly impacted by the aircraft. Despite this massive localized damage, each structure remained standing. However, as each aircraft impacted a building, jet fuel on board ignited. Part of this fuel immediately burned off in the large fireballs that erupted at the impact floors. Remaining fuel flowed across the floors and down elevator and utility shafts, igniting intense fires throughout upper portions of the buildings. As these fires spread, they further weakened the steel-framed structures, eventually leading to total collapse."[14]

With the buildings' primary means of egress, stairways and elevators, blocked by raging fires and suffocating smoke, the prospect of safe egress for the two buildings' occupants was effectively nil. As a result, some occupants opted to jump from their office windows and plunge to their death rather than to suffocate or be burned alive.

Because it is impossible to protect high-rise buildings from such catastrophic events like those witnessed on 9/11, the lesson to heed from the tragedy is that high-rise buildings should be equipped with some form of secondary means of egress in case the primary means, stairways and elevators, fail or are compromised.

## Conclusions

In today's volatile times, reliance upon the primary methods of evacuation in high-rise buildings, stairways and elevators, is foolhardy and dangerous for occupants and costly, in terms of litigation, insurance, and loss of business continuity for companies.

It is much too risky to stake one's life or a company's human capital on the effectiveness of a building's stairways and elevators during a crisis – especially when considering the threats that high-rise buildings face, the inherent design vulnerabilities of some, and the severe inadequacies of their primary means of egress.

The current focus of the dialogue surrounding high-rise safety issues is on how best to augment and harden the structural aspects and redundancy of buildings. This is insufficient and impractical. Enacting various measures that structurally harden stairwells, elevator shafts, critical junctures, and other vulnerable parts of high-rise buildings may indeed grant occupants extra time to evacuate in the event of fire; however, such resilience techniques do not provide occupants with a secondary evacuation method when the primary means of egress, stairways and elevators, are compromised or unusable. The primary concern of every high-rise occupant, including companies, should be how to get out in an emergency. The most pragmatic solution lies not in structural strengthening or external augmentation but in the widespread adoption of secondary evacuation devices.

Cutting-edge secondary evacuation systems such as automatic harness-based lowering devices, mass-evacuation carriages that deploy from a buildings rooftop, and even inflatable slides that deploy from points on each floor to the ground, provide occupants and companies with a fail-safe should the unthinkable happen, once again, to a high-rise building.

More than just architectural gems, today's high-rise buildings are symbols of power, prestige, wealth, success, and national pride. Unfortunately, these very same qualities make them the perfect targets for terrorists and wrongdoers. If we are to continue building towards the sky, we must take every possible precaution to make our buildings, and their occupants, as safe and secure as possible.

## End Notes


[1] “About the Idea.” Emporis. 14 July 2004. <http://www.emporis.com/en/ab/wh/in/ab/>.
[2] “Most Active: Cities Worldwide.” Emporis. 14 July 2004. <http://www.emporis.com/en/bu/sk/st/ma/ci/>.
[3] “Basic Definition.” Emporis. 16 July 2004. <http://www.emporis.com/en/ab/ds/sg/ra/bu/de/hi/>.
[4] “OSHA Fact Sheet: Evacuating High-Rise Buildings.” Occupational Safety & Health Administration. 16 July 2004. <http://www.setonresourcecenter.com/safety/publications/evacuating-highrise-factsheet.pdf>.
[5] Schirmer Engineering Corporation. 16 July 2004. <http://www.schirmereng.com/project/highrise.shtml>.
[6] “Skyscraper Safety.” CBS News. 12 December 2001. <http://www.cbsnews.com/stories/2001/12/12/archive/main321019.shtml>.
[7] “High-Rise Building Fires.” *Firefighting & Emergency Operations*. v2. Book 4. June 2002. Fire & Rescue Departments of Northern Virginia. <http://www.firetactics.com/hi-rise.pdf>.
[8] Siikonen, Marja-Liisa; Kim Barlund; Risto Kontturi. “Transportation Design for Building Evacuation.” 2003. Kone Corporation. 1.
[9] Farrell, Jennifer. “Flashover in Florida High-Rise Fire.” 16 October 2002. St. Petersburg Times. <http://www.firetactics.com/CLEARWATER.htm>.
[10] Routley, Gordon J., Charles Jennings, & Mark Chubb. “High-Rise Office Building Fire: One Meridian Plaza Philadelphia, Pennsylvania (February 23, 1991).” *United States Fire Administration Technical Report Series*. Federal Emergency Management Agency. <http://www.firetactics.com/meridian.pdf>.
[11] Proulx, G. “Highrise Evacuation: A Questionable Concept.” National Research Council Canada, Institute for Research in Construction. March 2001. 10.
[12] Dunn, Vincent. “High-Rise Fires.” FDNY Homepage Newsletter. August 2000. <http://www.workingfire.net/misc4.htm>.
[13] Grimwood, Paul. “Operational Aspects of High-Rise Firefighting.” Firetactics.com. 16 March 2003. <http://www.firetactics.com/HIGH-RISE1.pdf>.
[14] “Executive Summary.” *World Trade Center Building Performance Study*. FEMA. <http://www.house.gov/science/hot/wtc/wtc-report/WTC_ExSm.pdf>.

Picture, pg.5: <http://home.hetnet.nl/~hongkongphotopage/index.html>.


 

## About Lifesavingkit

Lifesavingkit supplies evacuation systems. It is a subsidiary of Ozonelink , a high-tech homeland security solutions provider enabling governments and organizations around the world to prevent, protect from, respond to, and recover from terrorism, natural disasters, and other emergencies. This whitepaper was written by Joshua Haberkornhalm, an intern with Ozonelink.

DoublExit manufactures external evacuation systems from buildings including offices, hospitals, apartments, and control towers.

Jubilee House, Merrion Avenue, Stanmore HA74RY United Kingdom
T: +44 207 100 5675 F: +44 208 416 3834

info@lifesavingkit.com www.lifesavingkit.com

 