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Fire Safety Strategies for Supertall Buildings in Hong Kong

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In the course of updating fire safety standards in Hong Kong, an array of fire safety issues in supertall buildings were found, raising concerns about the effectiveness of existing codes. By reviewing fire safety strategies adopted in Hong Kong, this article illustrates how these concerns can be addressed globally and specific areas that require further study.

Introduction

Hong Kong is densely populated with more than seven million people living in an area of 1,108 square kilometers. The vast majority of people are settled in a small residential zone of about 76 square kilometers and an even smaller commercial area of about 4 square kilometers.

The increasing number of supertall buildings in Hong Kong CBD (see Figure 1) has intensified concerns over fire safety. However, additional fire safety requirements in supertall buildings often become a competing objective to innovative architectural designs. These requirements can raise construction costs for some new projects; most importantly, they might not guarantee substantial and quantifiable enhancement in fire safety for future supertall buildings. There is little research available on fire safety provisions for supertall buildings, which makes it difficult to develop effective standards. Therefore, a performance-based approach is suggested for future supertall building projects in Hong Kong to identify fire safety concerns and formulate fire safety strategies.

High-rise and Supertall Buildings

There is no consensus on the definition of tall and supertall buildings among international fire safety standards, including Hong Kong's local regulations. For example, the Hong Kong Fire Service Installations Code describes high-rise to be buildings that exceeds 30 meters. In the global context, 23 meters and 18 meters are adopted in NFPA 5000 and BS 9999: 2008, respectively. Buildings with more than 40 stories have been classified as ultra high-rise buildings (Lo 1997; Lo et al. 2002; Lu et al. 2001) or supertall buildings (Chow & Chow 2009 , 2010) and the Hong Kong Fire Safety Code requires a refuge floor to be constructed in buildings above this height. The China Fire Code imposes a similar requirement and defines supertall buildings as building exceeding 100 meters.

However, studies have shown no significant increase in fire risk in buildings at or above 40 stories. Very few big high-rise building fires have been recorded, though the fire load density was surveyed to be very high (Arup 2010). Therefore, it is suggested that other factors, such as wind, culture, fire department capability, and law enforcement strength, should also be considered in determining the minimum fire safety provisions of supertall buildings, in addition to height.

The Guideline for Very Tall Buildings (SFPE 2012) and the China Fire Code state that a multiplication factor should be used to estimate the Required Safe Egress Time (RSET – the time required to escape to a safe place) of supertall buildings as occupants may require more time to escape. Also, firefighting lifts are required by the China Fire Code and the Hong Kong Fire Safety Code for buildings exceeding 24 meters and 30 meters respectively. These provisions show that effective vertical transportation is necessary for firefighting in high-rise buildings of at least 40 stories, not to mention buildings of 300 meters or above.

Although no significant increase in fire risk could be shown in buildings at or above 40 stories, there is a question mark on whether existing fire safety provisions are effective in coping with elevated fire risks in supertall buildings with heights exceeding 300 meters.

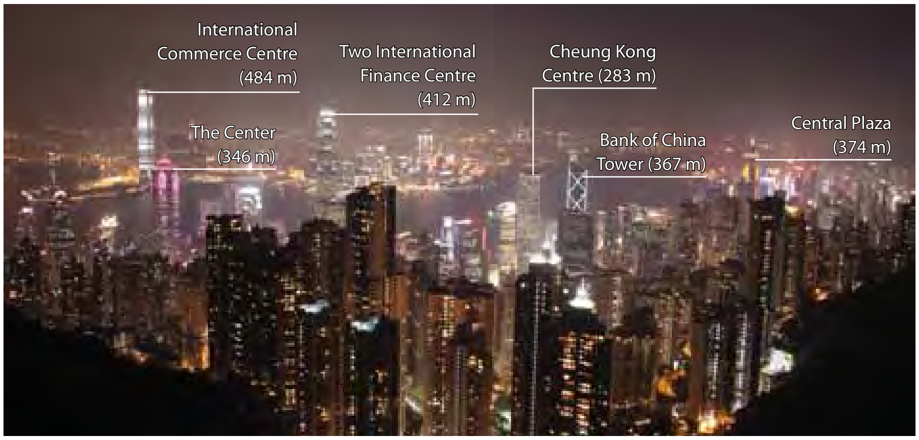

Figure 1. Scenic view of Hong Kong CBD from the Peak. © Yuliantina Widjaja

Fire Safety Concerns in Hong Kong

Fire safety requirements for supertall buildings in Hong Kong follow either a prescriptive approach or a performance-based approach. Differences between the two approaches can be illustrated by the fire detection and alarm systems of two supertall buildings. In Supertall Building A (412 meters, completed in 2003), the fire detection system is divided by four refuge floors to form five zones. Fire alarms will sound in the whole building if any fire detectors in any one zone is actuated (see Figure 2).

On the other hand, the fire detection system of Supertall Building B (484 meters, completed in 2010) is divided into four zones: hotel, office, podium, and basement. When a detector is activated, only alarms on the fire floor, one floor below and two floors above the fire floor will be actuated. Alert messages will be broadcast on non-affected floors in the same zone and other unaffected zones (Whittall 2012). Fire alarms in other zones will not be actuated unless total evacuation is required (see Figure 3). Despite the differences between alarm zoning and actuation scope, both approaches were accepted by the local authority.

Evacuation

Different approaches and standards are used in evaluating evacuation systems:

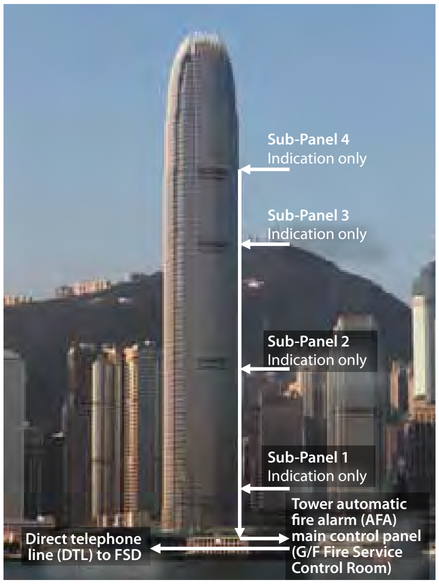

Figure 2. Schematic diagram of the design of the fire detection system of Supertall Building A. © Authors

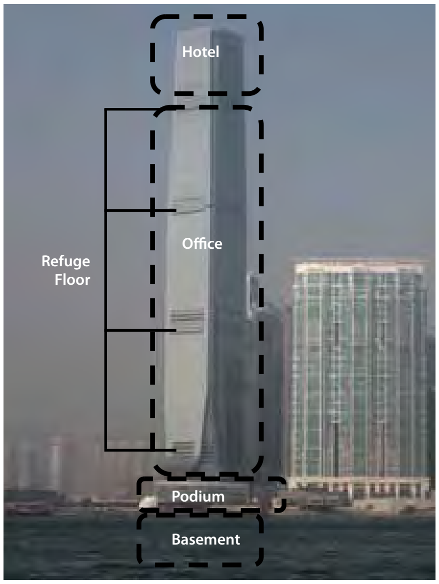

Figure 3. The zoning arrangement of the fire detection system in Supertall Building B. © Authors

> “According to the Hong Kong Fire Safety Code, refuge floors are mandatory for non-industrial buildings higher than 25 stories, industrial buildings higher than 20 stories, and residential buildings exceeding 40 stories.”

Staircase reliability

In high-rise buildings around the world, evacuees may flee through protected staircases, external windows, or via adjacent buildings in some cases. However, evacuees in supertall buildings in Hong Kong can only rely on staircases, since only staircases are accepted by the Hong Kong Authority as a means of escape. Therefore, the reliability of staircases is paramount in ensuring the safety of occupants. Nevertheless, prescriptive staircases do not always guarantee effective evacuation.

The concept of refuge areas/floors

The concept of refuge floors was introduced to Hong Kong in 1996. According to the Hong Kong Fire Safety Code, refuge floors are mandatory for non-industrial buildings higher than 25 stories, industrial buildings higher than 20 stories, and residential buildings exceeding 40 stories. By using an intermediate refuge floor within a certain number of floors, occupants could reach a temporary place of safety within 10 floors. On the other hand, many international fire codes stipulate the requirement of an area of refuge (about 1.5 x 1.5 meter located at the protected staircase) for the temporary safety of people with disabilities. However, caution has to be paid if an area of refuge is used in calculating total evacuation time (TET) or RSET. Evacuees may be reluctant to wait for rescue on a refuge floor after the collapse of the World Trade Center on September 11, 2001.

In the Hong Kong Fire Safety Code at least 50% of the gross floor area on a refuge floor shall be designated as a place of refuge. However, if the occupancy factor of 4.5 m^2/person for a typical residential development is adopted, the occupancy factor of the refuge floors would be 0.22 m^2/person. If a greater occupancy factor, such as 1 m^2/person in restaurants and 0.5 m^2/person in a banking hall as stated in the code is considered, there would be too many evacuees on the refuge floor. Therefore, the prescriptive refuge area calculation in supertall building should be further studied.

Counter flow problem

Clashing between emergency responders and evacuees may increase the time for rescue and evacuation (SFPE 2012). For this reason, a "hydraulic flow" approach (Chow 2006) may not be applicable in estimating the evacuation time of occupants with different physical strengths (Kady & Davis 2009). To ensure safe evacuation, clashing has to be incorporated in the calculations. Indeed, the NFPA 5000 has pointed out this deficiency. What's more, the China Fire Code incorporates clashing in the calculation of evacuation time

Lift evacuation

Apart from traditional means of evacuation via stairs, lift evacuation could be an effective alternative. There are standards on evacuation using lifts. However, more research on validating the reliability and effectiveness of lift evacuation has to be conducted, particularly in supertall buildings, in order to be accepted by the Hong Kong authority.

Law enforcement in evacuations

Effective evacuation relies on unobstructed means of escape (MoE) with adequate width and an ordered evacuation. Although the width of MoE in supertall buildings is regulated by the Hong Kong Fire Safety Code, the authority, owners, and/or facility managers of supertall buildings should ensure

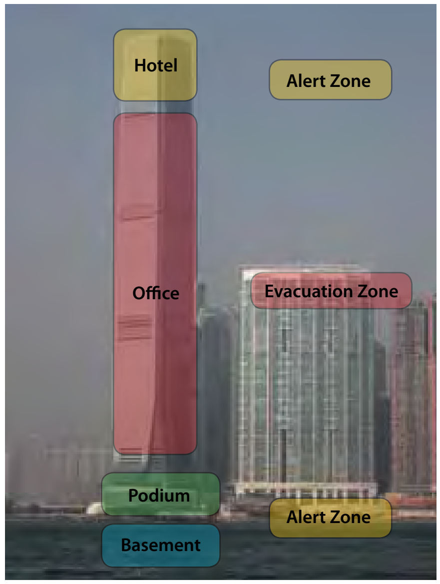

Figure 4. An illustration showing phased evacuation on office floors of Supertall Building B. © Authors

all MoE in supertall buildings are free from obstruction and combustibles. In addition, change in use and structural alterations of buildings have to be approved by the building authority in advance because it may lead to increases in occupant load, travel distance, and fire load.

Fire Detection and Alarm

It is understood that if a fire is detected early, the RSET would be decreased. The increased margin of safety is based on the assumption that occupants were safe when all of them entered the protected staircase. However, the shaft configurations of supertall buildings pose a challenge. More evacuees would be queuing to enter the escape routes in a supertall than in conventional buildings. To maintain the same level of RSET and the safety margin, detection time in supertall buildings has to be shortened with better alarm zoning.

In addition, it is suggested that evacuating some floors above and below the fire floor by means of a zoned detection and alarm system may alleviate congestion in the MoE (Bukowski 2010). This approach has been adopted in some supertall buildings such as the Supertall Building B in Hong Kong (see Figure 4).

As the reliability of fire detection and alarm systems is crucial to the effectiveness of such an approach, the Hong Kong Fire Services Department (FSD) has issued a circular letter specifying measures to be carried out in case of shutdown or repair of detection and alarm systems, such as the provision of standalone smoke detectors in buildings adopting performance-based design. Additional firefighting staff and equipment are also deployed and more frequent patrolling intervals are imposed.

Fire Suppression

The provision of fire suppression systems in supertall buildings requires additional attention in Hong Kong. Suppression systems might have unintended consequences unique to supertalls. For example, sprinkler water might cool down hot smoke while stack effect might cause smoke logging. Therefore, the suppression philosophy in supertall building has to be revisited.

Also, the use of fixed fire pumps for the fire hydrant/hose reel (FH/HR) system to replace intermediate booster pumps may lower the reliability of the FH/HR system in supertall buildings. If both of the FH/HR pumps fail, firefighters have to manually lift heavy portable pumps to deliver firefighting water.

For this reason, the Hong Kong FSD imposed specific measures to maintain the suppression strength in supertall buildings. First, fast response sprinkler heads are installed in special hazard areas. Also, owners of fire service installations (FSIs) are obliged to employ a registered FSI contractor to inspect the FSIs of their buildings at least once every 12 months. Moreover, periodic maintenance and functional tests during joint exercise/drills are conducted between the building management and FSD personnel.

Fire Service Intervention

Fire service intervention can be discussed in terms of means of access (MoA) and active suppression by firefighters.

Supertall buildings have extremely high façades which are out of reach of aerial ladders. Therefore, additional fire safety requirements are imposed by worldwide building codes. For example, NFPA 5000 and the Hong Kong Fire Safety Code require the distance between an emergency vehicular access (EVA) and fire service access point should not be longer than 10 meters and 18 meters respectively. Apart from the distance, the width of EVA for new buildings should be no more than 4 meters and 7.3 meters as required by the China Fire Code and Hong Kong Fire Safety Code, respectively. However, the provision of a reliable rescue staircase and stairway may be even more crucial to fire service intervention, though firefighters may need some time to reach the uppermost floor of a supertall building by staircase.

Fireman lifts are required in tall and supertall buildings for the conveyance of manpower and equipment to the fire floor. The Hong Kong Fire Safety Code stipulates the dimension, rated load, and speed of a fireman's lift. Nevertheless, there is no additional requirement for fireman's lift in supertall buildings despite more manpower and equipment.

Table 1 lists the fire service installations (FSIs) requirements for high-rise commercial and domestic buildings. Currently there are no additional FSI requirements for supertall buildings with height exceeding 300 meters. FSIs for supertall buildings are the same as high-rise buildings. However, in view of the possible differences between normal tall buildings and supertall buildings in vertical transportation strategy of firefighters and firefighting water, extensive verifications of existing fire safety provisions are necessary.

Smoke and Fire Spread

Buoyancy, stack effect, and ambient wind have determining effects on fire growth, particularly at high level. In addition, higher fire risk, the acceleration of fire and smoke spread, and the aggravation of fire damage due to characteristics of supertall buildings must be investigated.

The validity of smoke movement and control deduced by computational fluid dynamics (CFD) software is often subject to challenge, since they are predicted by numerical approximation. Even if the software could be well verified, considering all fire dynamics in supertall buildings (e.g., stack effect, external wind loading, and fire whirl) in a single fire model to generate a converged result could be a great challenge.

He and Beck (1996) interpreted stack effect as "the pressure difference that can be experienced between an enclosure and its surroundings if the air temperature inside the building is different from that outside." Scholars assert that stack effect may affect smoke movement. For example, pressurization of staircases is widely adopted in supertall buildings in Hong Kong and should be pressurized to 50 Pa. However, the pressure difference between ground floor and the roof due to the stack effect in supertall buildings may be up to 1 kPa. Therefore, using CFD modeling to predict smoke movement in a vertical shaft should be cautious (Zhang et al. 2006; Zhao & Chow 2009).

The Buildings Department of Hong Kong has issued the Code of Practice on Wind Effects in Hong Kong 2004 which addresses structural stability of a building façade. Nevertheless, the effect of natural wind to smoke and flame spread is not discussed, not to mention the effect of natural wind on a refuge floor. As high wind speed may accelerate fire growth in supertall buildings, empirical study on natural wind effect to ventilation-controlled fire growth and smoke spread is necessary.

Fire Service Installations (FSIs)	Commercial High-rise	Domestic High-rise
Audio/visual advisory system	✓	
Automatic actuating devices	✓	
Automatic fixed installation other than water	✓	
Emergency generator	✓	✓
Emergency lighting	✓	✓
Exit sign	✓	✓
Fire alarm system	✓	✓
Fire control center	✓	
Fire detection system	✓	
Fire hydrant/hose reel system,	✓	✓
Fireman's lift	✓	✓
Portable hand-operated approved appliance	✓	✓
Pressurization of staircase	✓	
Sprinkler system	✓	
Static or dynamic smoke extraction, system	✓	
Ventilation/air conditioning control system	✓	

Table 1. Fire service installations (FSIs) required for commercial and domestic use according to Hong Kong Fire Service Department (FSD).

Interaction between Different Risk Parameters in Supertall Buildings

Apart from physical fire safety requirements, fire safety management also plays an important role in supertall buildings. Occupancy arrangement, fire load density, and their interactions can help determine the level of fire risk.

Mixed-type occupancy

Due to economic development, mixed-type occupancy is commonly found in supertall buildings. For example, laboratories may be present in commercial buildings, but visitors may not be aware of the risk. Moreover, illegal occupancies, such as the over-storage of dangerous goods, pose additional fire risk to supertall buildings.

Fire load density and heat release rate

Prescriptive fire safety strategies in supertall buildings may be insufficient to address high fire load in dense commercial floors and mixed type occupancies. For example, cartons of paper stored in modern office may be uncontrollable by the prescriptive-designed hazard group. Also, evacuation in hotels may be longer than in offices during certain hours due to the sleeping characteristics.

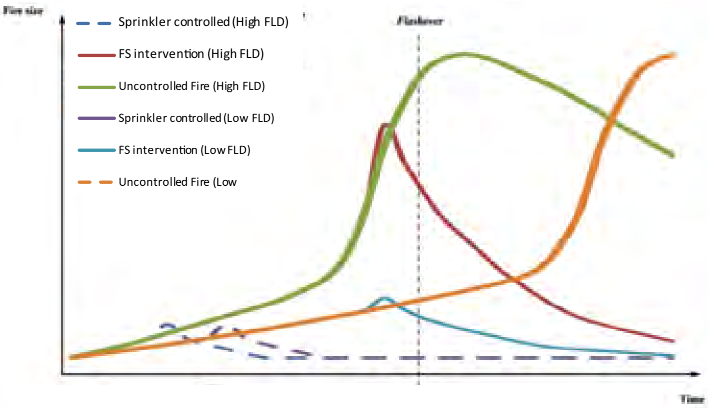

Figure 5. Timeline analysis on stakeholders' actions in low-rise building fires. © Authors

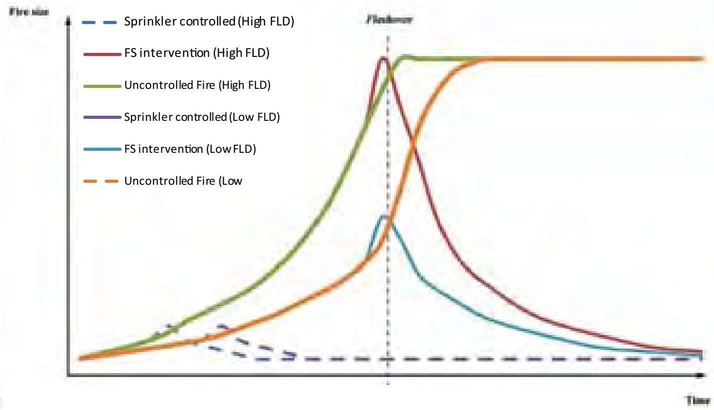

Figure 6. Timeline analysis on stakeholders' actions in high-rise building fires. © Authors

For this reason, Hong Kong has restricted mixed occupancy in building design. Nevertheless, systematic controlling measures to excessive fire load and incompatible occupancies are still required.

Evacuation of People with Disabilities

Barrier free provisions have been incorporated since 1997 and the revised Design Manual – Barrier Free Access 2008 incorporates more barrier free access provisions and accommodate the growing elderly population.

Barrier free access requirements in the manual are similar to NFPA 5000 and BS 9999:2008, which is based on the presumption that 1 in 200 persons is disabled. Nevertheless, it is reported that 142,740 people (about 2% of the population) are receiving disability allowance in Hong Kong. Also, not every building has a tailor-made evacuation strategy, as there is no such requirement in the manual (except hospitals and care home for elderly and disabled due to licensing requirements). Therefore, the requirements in providing barrier free access facilities and the associated evacuation strategy have to be reviewed.

Fire Safety during Construction

Several major fires have been reported in the construction of quasi-supertall buildings, such as the Beijing CCTV Headquarters in 2009 and a residential complex in Hong Kong in 2005. Water supply was found to be critical since vertical water relays for firefighting is strenuous and time consuming. For this reason, installation of a standpipe system is required in buildings under construction.

In Hong Kong, fire safety during construction of supertall buildings is governed by the Fire Services Department (FSD) with reference to the height, layout, and configuration of the building. FSD mandates a temporary commission of a fire hydrant system. Moreover, the top most hydrant should be within 30 meters from the topmost floor.

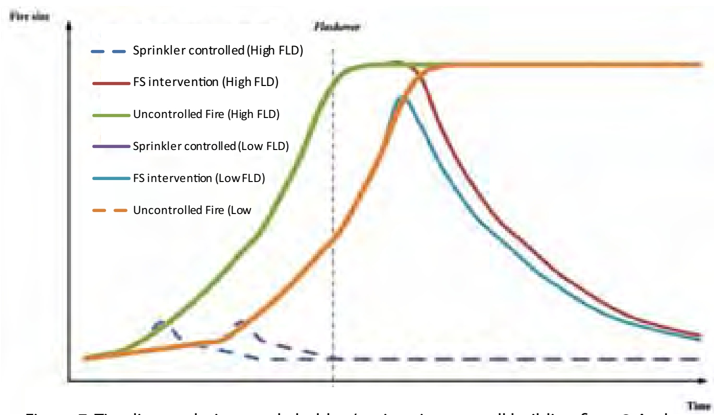

Figure 7. Timeline analysis on stakeholders' actions in supertall building fires. © Authors

Management and Maintenance

Effective evacuation in supertall buildings also relies on the performance of fire service installations (FSIs), such as sprinklers, fire hydrant/hose reel, drencher systems, and passive fire protection elements, including smoke reservoir and smoke extraction. Although these provisions are incorporated in the Deed of Mutual Covenant in Hong Kong, there is an overriding concern about how these requirements can be effectively implemented.

Similar to NFPA 5000 and BS 9999:2008, the Hong Kong Fire Safety Code stipulated the extent of passive fire protection elements required in new buildings. On the other hand, all FSIs should be inspected at least once every 12 months in accordance with the Hong Kong FSI Code, but the frequency of maintenance, inspection, and testing of passive fire protection elements has not been specified.

Analysis on Stakeholders' Actions

Figures 5 to 7 illustrate how fire safety concerns are approached in Hong Kong. The three figures are drawn based on the assumptions that:

1. Flashover time, which is easier to determine than time to tenability, because it can be judged by flame moving out of an opening, is shorter when floors are higher (due to better ventilation) and when fire load is higher (due to more burning surfaces). Anemometric data compiled by the Hong Kong Observatory (HKO 2013) found stronger winds in higher altitude. Taking

into account two fire compartments with same size, layout, area of opening, and building material, stronger wind is more likely to speed flashover;
2. Ventilation rate is the same and is not a limiting factor to fire size until flashover;
3. Fire service response times are constant so the operation time of fire hydrant is the same in the three figures.

In low-rise buildings and low level atria, natural ventilation is usually weaker (HKO 2013) and restricts the development of fire. Therefore, firefighters may arrive well before flashover and prevent it from occurring. However, many unburnt fire gases and toxic smoke are generated in the long smothering stage, which may become untenable even without flashover.

In high-rise buildings, stronger winds at higher levels speed up the increase in heat flux and the generation of unburnt gases. As the increases speed up, the available safe egress time (ASET) will be shortened and flashover will occur earlier. Also, flashover may occur at the time when firefighters arrive. On the other hand, due to dense population and high fire load density in Hong Kong, the safety margin is usually tight. A small reduction (e.g., 10%) of ASET might already make the ASET shorter than the RSET. Nevertheless, competent property management staff could react more swiftly in a high-rise building fire. Therefore, the RSET in high-rise buildings are also reduced and safety margins are not compromised.

In supertall buildings, ventilation due to ultra strong wind at supertall level is likely to affect fire development. It may be argued that sprinklers, which are mandatory to all commercial buildings in Hong Kong regardless of height, may greatly reduce the chance of flashover. However, an illegal closure of a sprinkler system's subsidiary valve resulted in firefighter deaths in a big fire in 2007 and so sprinklers cannot be regarded as fail-safe. To maintain the safety margin in supertall building, RSET has to be reduced dramatically. Nevertheless, total evacuation in supertall buildings may take hours to complete. Therefore, phased evacuation has to be considered in order to minimize the RSET. Moreover, protected staircases or refuge floors may serve as the end of the phased evacuation.

To address shorter flashover time in supertall buildings, early detection and suppression are essential. Figures 5 to 7 assist fire safety professionals to identify potential risks and formulate strategic solutions. However, the fire scenario and duration of stakeholders' activity may vary according to particular situations and coordination of stakeholders.

Conclusion

Current research questions whether existing codes for high-rise buildings are sufficient to cope with the unique characteristics of supertall buildings. Also, occupants in supertall buildings may find it difficult to evacuate in the same manner as in shorter high-rise buildings. All these suggest that a new fire safety standard for supertall buildings is required. Despite the fact that Hong Kong, a city on the cutting edge of supertall building construction, has imposed additional fire safety provisions for supertall buildings, a comprehensive standard is necessary.

This study highlights several fire safety concerns in supertall buildings that are worth investigation. Further studies on improving the existing situation are suggested. ■

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