WITH THE RAPID INCREASE in population in the Far East, especially the development of big cities in China, and the increasing number of non-accidental fires, fire ‘safety’ in dense urban areas has to be considered carefully. Big accidental fires had happened before in old hi-rise buildings such as the big Garley Building fire, cross-harbour tunnels and buses in Hong Kong, and in many old hi-rise buildings and new shopping malls in China. Non-accidental fires reported over the world included the terrorist attack fires in the World Trade Centre on September 11, 2001 (WTC-911); arson fires in universities in Beijing; and underground railway arson fires in South Korea and Russia. Several arson fires were also reported in Hong Kong in a bank, a karaoke, and an underground train vehicle.

As there might be difficulties for new architectural features to cope with the prescriptive fire codes, building fire safety for some projects was provided by performance-based design (PBD). There are many examples on green and sustainable buildings, especially those with extensive use of glass. As reviewed, architectural features of hi-rise buildings, deep
plan, framed structure, and sealed enclosure are commonly found. Fire safety of these four features should be considered carefully. Taking the supertall buildings (i.e. those higher than 40 levels in Hong Kong) as an example\cite{25,26}, fire safety design guides have not yet been developed through systematic studies.

Further, there are many new materials made from combustible materials with fire retardant systems. These materials passed the fire tests (such as ignition)\cite{27} but are not necessarily safe in real fires under high radiation heat fluxes in post-flashover fires\cite{28}. Up to 440 kW/m\textsuperscript{2} were reported\cite{30} in high-rack storage spaces. The four double-deck bus fires in Hong Kong\cite{5} and Shanghai\cite{29} which burned up all combustibles within 15 minutes are good examples of this. These issues will be reviewed in this paper. Basically, many works, including unpublished consultancy reports on big construction projects, started from the implementation of performance-based design on fire safety since the 1980s, although some activities were supported after several big fires happened in late 1990s. Another bigger theme is on protecting the environment by using halon substitutes, both for fire engineering systems and fire retardants.

**Fire Safety Concerns in Selected Buildings**

As pointed out by Hyett\cite{23,24}, both designers given the responsibility of developing new architecture projects and facility managers operating systems in existing buildings must have a sense of sustainability. Saving a small amount of energy for building use will protect the environment to a great extent as the servicing life of a building is very long. As observed in the past in temperate countries, a large amount of energy was consumed for lighting in commercial buildings and for heating in residential buildings. The situation in the tropical areas might be different, as air-conditioning systems are provided...
for comfort and for giving a more productive environment in the workplace. New environmental control systems using less energy are now available. Even fire protection systems are designed to cope with green or sustainability criteria. Using clean agent in total flooding gas protection systems as a substitute for halon is a good example. All these new efforts will protect the environment.

Building green is a shared target of many government departments. Green building is brought about in Hong Kong with many new special features such as:

- Providing more natural ventilation based on wind action for reducing cooling loads while operating mechanical ventilation and air-conditioning (MVAC) systems;
- Utilizing more daylight instead of illuminating by artificial tungsten filament lamps with lower efficacy, leading to wide use of glass;
- New light materials but better thermal insulation to reduce the Overall Thermal Transfer Value (OTTV) of building envelopes;
- Internal building void; and
- Double skin facade.

These new architectural features are able to save the non-renewable energy and maintain a healthy natural environment. It is beneficial in terms of the environmental aspect, but might give adverse effects in other areas such as fire ‘safety’. Some of the above examples on ‘green’ projects have difficulties in complying with the fire safety codes.

Take window openings for introducing natural ventilation as an example. Wind action might generate a pressure difference across the building envelope and when a fire occurs, the open windows for air distribution might create a pathway for spreading smoke. A negative pressure would probably be generated on the leeward side of the building. Flame and smoke would then spread out through the windows easily to other levels, or even to adjacent buildings.

In addition, many hi-rise buildings are constructed in the Far East. Symbolic hi-rise buildings over 1,650 feet high have been constructed in Taipei. Among the top 100 hi-rise residential buildings in the world, over half of them are in Hong Kong. Some of them are over 650 feet high. Numerous problems on fire safety had been pointed out by officers responsible for fire safety, developers, contractors, engineers and building operators.
It is nice to stay at high positions with good harbor views, but not easy to come down if there is a fire. Symbolic buildings might even have an increased possibility of terrorist attack as at the WTC-9/11.[6]

Several fire safety problems in supertall buildings have been debated before—the evacuation pattern, design of means of escape and means of access, and sprinkler systems—and there are numerous concerns about fire safety in those buildings.[25,26]. The total evacuation time might be up to 30 minutes, even if an elevator is used and there is an orderly evacuation.[42]. Even the big fire that occurred[e.g. 2,3,43] during the elevator replacement in the old hi-rise Garley building of less than 15 stories led to a serious disaster.

As a result of that big fire, additional actions taken by government in Hong Kong were:

- Old high rise buildings, i.e. those erected before 1972 without tight fire regulations, were requested to upgrade their fire safety provisions.
- A New Fire Services Ordinance[44] on sprinkler systems was created.
- A Fire Safety Inspection Scheme[45] on structural stability, external finishes and fire safety was implemented.
- A request that temporary doors with adequate fire resistance be installed in the elevator shaft while replacing the elevator.

Whether those actions are workable for the existing hi-rise buildings is questionable. It has not yet been demonstrated that providing these fire safety provisions in supertall buildings will give adequate protection.

Another concern are architectural features with glass constructions[22]. As demonstrated years ago, glass panes fell off the wall of a full-height glass tower office building during a typhoon. This suggested that there are potential risks associated with the glazed buildings. Attention should also be paid to the building’s ability to resist wind load. Though glass is not combustible in a fire, it will be weakened when heated up to a certain temperature. Toughened glass is able to endure higher temperature, but might be fragile after exceeding its critical limit. For example, cracking may occur when heated up over 550 degrees F[46]. Glass itself is a poor conductor, difficult to transfer heat from the area exposed to the fire to the other region. Temperature difference between the hot and cool sides will give
thermal expansion. Cracking will occur when the induced thermal stress reaches the critical value\(^{(47)}\). Aluminum windows framework, will be weakened when heated up to 400 degrees F, even melted at about 1,000 degrees F. Severe distortion may induce stresses across the glass plate being held up by the frame and the entire glass panel might fall down\(^{(48)}\).

Failure of glass panels due to explosion or failure of the fittings for fixing the glass panels would give a higher air intake rate to sustain combustion. As a result, higher heat release rates would be emitted to cause severe damages. Big fires might result due to providing fresh air to burn the large amount of combustibles (allowed storing up to 1135 MJ\(^{m.sq.2}\) in Hong Kong\(^{(13)}\)). Wind action might lead to fire whirls\(^{(49)}\) or mass fire\(^{(50)}\).

A big fire occurred in a new building with glass features in Dalian, Liaoning, China on September 18, 2005. Flashover occurred with flames coming out of many levels. As observed by the author, some glass panels fell down. Fire safety of glass features with double skin facade\(^{(38,39,51)}\) is a concern. Smoke, heat and even flame might be trapped inside the air gap. The consequence will be very serious when the interior glass panels are broken, but not the external ones.

### Total Fire Safety Concept

Hardware fire safety provisions are required in buildings\(^{(e.g. 11-15,25,26,52)}\):

- **Passive Building Construction**
  
  Passive measures can provide effective fire protection to the construction elements of buildings. Items covered in the local codes\(^{(12)}\) include compartmentation, fire-resistant construction, means of escape for occupants and means of access for firefighters. The objective is to reduce the occurrence of accidental fires by making the building materials and components more difficult to ignite. Even if the material is ignited, only a small amount of heat will be given out at the early stage of a fire. It is designed to confine the fire within the place of origin without affecting the adjacent areas. The spreading rate should be slowed down through compartmentation and a protected corridor, lobby and/or staircase. The building structure should be able to withstand the fire for some time so that occupants can evacuate safely.

### Active fire protection system

Active fire protection systems are necessary for detecting a fire and giving early warnings; controlling, suppressing or extinguishing the fire; operating smoke management systems to give visibility and more tenable conditions; and operating other emergency systems such as emergency lighting and stand-by generators. However, fire safety management is not yet considered carefully in the codes of many countries. Those passive building construction and active fire protection systems hardware must be controlled by good fire safety management software\(^{(20,53,54)}\). Good fire safety management should ensure that, even if a fire occurs, it can be confined to a small area, occupants can be evacuated within a short time and damages to the building can be minimized. A fire safety plan\(^{(20,55)}\) outlining clearly the procedures for maintaining protection equipment, staff training, fire prevention and evacuation procedures must be worked out scientifically.

Basically, building fire safety codes deal with accidental fires. But after the WTC-9/11 incident\(^{(6,53,55)}\) and so many arson fires, there are concerns that non-accidental fires should be considered as well. With so many political and social issues,
there will be a higher possibility of having terrorist attacks and arson fires than before\textsuperscript{10,53}. Therefore, the objectives\textsuperscript{83-89} of protecting against accidental fires, arson fires, terrorist attack fires and disaster fires due to earthquakes should be clarified.

The total fire safety concept\textsuperscript{11,12} in buildings is suggested by including three parts:

- Passive Building construction for fire safety
- Active fire protection systems
- Fire safety management

Building fire safety objectives were discussed by Rasbash\textsuperscript{[57]} in a lecture in October, 1977 (published in 1996). In defining the fire safety objectives, both the nature of risk and acceptability of the risk should be considered. There are two reasons for working out the objectives:

- Technical nature of the risk itself varied, so different balance of fire precautions required.
- Different targeted fire safety required different resources allocation.

Based on the above argument, ten fire safety objectives for building control were listed. The author believed that the most important objective is to protect the public as a whole from anxiety following disquieting incidents.

Part two of this article will discuss the importance of Performance Based Design (PBD) in the design of hi-rise buildings around the world. dh

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