

# Fire Safety Technology Related to Building Design and Construction

W.K. Chow

Department of Building Services Engineering, The Hong Kong Polytechnic University Hong Kong, CHINA

**Abstract:** Fire safety technology related to building design and construction will be discussed in this paper. Four areas on possible fire hazards and fire safety provisions; performance-based design; flawed concept of timeline analysis; water suppression system in atrium including sprinkler and its alternatives with water gun and sidewall long-throw sprinklers are reported. The proposed annual inspection scheme on the design criteria in fire safety design to ensure assumptions made in the fire safety assessment by the Hong Kong Fire Services Department should serve as an example of good practice.

**Keywords:** Fire hazard, performance-based design, fire engineering, water system

## 1. Introduction

Many supertall buildings of height over 300 m, deep underground subway stations 40 m below ground level, large halls over 28,000 m<sup>3</sup> and long tunnels up to 30 m long were built or to be built [1] in dense cities in the Far East such as Hong Kong. Occupant load is high such as large numbers of passengers up to 70,000 per hour as surveyed in the subway systems [2]. Fire codes and regulations set up were not demonstrated [3-7] to be supported by in-depth research. Therefore, fire safety provisions in most of these buildings of large construction projects in the Far East [7,8] were determined by performance-based design (PBD) [9], known as Fire Engineering Approach (FEA) [7] in Hong Kong. There are major fires in such dense urban areas with big cities. All these have drawn deep fire safety concern in those projects with fire safety provisions determined by PBD/FEA.

Fire safety technology related to building design and construction for those projects will be discussed in this talk. Four areas on possible fire hazards and fire safety provisions [3-7]; performance-based design [7-9]; flawed concept of timeline analysis [10,11]; water suppression system in atrium [12] including sprinkler and its alternatives, water gun and sidewall long-throw sprinklers are reported.

Real fire scenarios encountered in the Far East are proposed to be included in hazard assessment while adopting PBD. How the approach would affect firefighting should be included in the study. Overseas standards and codes [7,13] cannot be applied without in-depth justifications of whether the fire safety requirements and data concerned are applicable to local environment. More important, social

responsibility and education of citizens must be considered. Evacuation studies with the timeline approach [10,11] adopted in the past twenty years should be reviewed. Importance of studying heat release rate to get a reasonable design is pointed out. The practice of annual checks on the criteria and assumptions in fire safety design with PBD/FEA was proposed by the Hong Kong government Fire Services Department [14].

## 2. Fire Scenarios and Fire Safety Provisions

Real fire scenarios [11,14] should be considered in fire safety assessment while applying PBD/FEA to determine fire safety provisions. Design facilitating firefighting and rescue such as providing more means of access should be included in supertall buildings, for example. Fire scenarios should be worked out with full-scale burning tests.

An accidental fire can be started from a small size fire with low heat release rate. Burning only a litter bin gives up to 300 kW as in Fig. 1 [15]. Flashover might occur easily and even the materials treated with fire retardants should be assessed by more vigorous tests under high radiative heat fluxes [16].



Fig. 1 Litter bin of 300 kW

The heat release rate [17] of a fire is an important parameter affecting the course of a fire and acts as the driving force. It is the most important parameter in fire hazard assessment. A better understanding of it would provide information for predicting the following:

- Fire environment such as the smoke layer temperature, smoke layer interface height, radiative heat flux, rate of smoke flowing out and air intake rate through the openings.
- Likelihood of flashover.
- Upward flame spreading over walls.
- Ignition of items placed adjacent to a burning item.

There are very few experimental data available from systematic full-scale burning tests, especially for local products and building configurations. There were strong arguments on using too big or too small a design fire. Some design fires of even 0.5 MW had been proposed before [8]. Local geometrical configurations and heat release rate database for combustibles must be clearly understood. However, such information is absent in Hong Kong. It is obvious that compiling a database using full-scale burning tests on common combustible arrangements is necessary.

A recent Exchange Meeting of Society of Fire Protection Engineers Asia-Oceania Chapters [18] reported that burning four trains in Japan can give a heat release rate up to 48 MW. Some Korean trains would give 20 MW upon burning. However, very low heat release rates of 5 MW to 6.2 MW of train fire were specified in the new fire safety code! The peak heat release rate in those incidents depended on the ventilation provision which would be very high at high levels of a supertall building. Occupants can sense high air flow after opening a window or balcony door. The heat release rate might grow from 8 MW for a room fire at ground level to over 160 MW in a room at height 800 m as reported [19].

Fire codes [3-7] are basically provided for protecting against accidental fires. There are

hardware fire safety provisions or passive construction elements [3-5], and active fire engineering systems known as fire service installations [6] in Hong Kong. Software fire safety management [7,20] should also be implemented.

Passive building construction elements are fire resistant constructions [3], means of escape [4] and means of access [5]. All these codes are grouped together in the new code for building fire safety [7]. Active fire engineering systems [6] are alarm and detection system, suppression system, air-smoke system, and other auxiliary systems such as emergency lighting and exit signs.

It is important to ensure that all those hardware fire safety provisions on passive design and active fire protection systems work and occupants can take appropriate fire action. A fire safety plan [7] should include a building maintenance plan; a staff training plan; a fire prevention plan and a fire action plan.

Further, effect on firefighting strategy, rescue strategy and potential occupational safety and health effects to firemen should be studied in all FEA/PBD projects [21].

### 3. Performance-Based Design

For projects having difficulties to comply with such prescriptive fire safety codes [3-6], FEA [7,8] has to be applied in Hong Kong. The approaches and methodology of FEA are similar to PBD documented in many countries [e.g. 9]. There are many debates on design data, accuracy in engineering tools such as fire models [22] and acceptance criteria. Since no large accidents have occurred yet in these FEA projects in Hong Kong, statistical data available is still not adequate to work out the fire risk parameters.

Although a new professional discipline has been developed, such as the Hong Kong Institution of Engineers – Fire Engineering Division, there is not yet systematic training in a first degree programme in Fire Engineering [23]. As raised in many conferences such as the recent FireAsia 2012 [24] held in February 2012 in Hong Kong, a first degree programme appropriate to the Far East should be developed to cope with the industry need.

However, there are many difficulties [23]:

- The potential job market is not big enough, depending on the demand.
- The PBD research results in advanced countries cannot be applied directly to the Far East. However, local PBD fire research is limited. There was no systematic fire research even in drafting the new building fire code for over 10 years.

At the moment, fire engineers from other disciplines such as Building Services Engineering, who are holding PhD degrees in fire engineering are doing the job. Therefore, PBD is very similar to a piece of minor research project with very rough study due to time and resources limitations.

Carrying out full-scale physical experiments for fire hazard assessment takes huge resources. Therefore, very few experiments were done in fire safety assessment of PBD. Note that a main reason for using PBD is for cost reduction as raised in Singapore. Fire engineering tools [22] including correlation relations and fire models are then applied. Fire models have been developed for studying different stages, but not applied in an appropriate way [25].

#### 4. Timeline Analysis

The ‘timeline analysis’ or timeline approach [9-11] was commonly applied in PBD/FEA in the Far East. However, it was criticized recently to be a flawed concept in fire safety assessment. The Available Safe Egress Time (ASET) was simulated by fire models by referring only to reported data on tenability criteria on thermal exposure and smoke. The Required Safe Egress Time (RSET) was estimated with evacuation software following ‘robotic’ action. ASET and RSET are then compared.

Serious concerns were raised [11] while implementing FEA in Hong Kong since 1998. Scenarios with small design fires were used to get long ASET even for many projects on crowded and big halls. Human behaviour under local conditions was not investigated in depth. The occupant loading was low to give short RSET. The safety margin is only taken as a percentage of RSET, not several times of RSET. ASET was commonly estimated by free fire models with reference to lower values on tenability limits recommended by different international design guides such as CIBSE Guide E and NFPA. Apart from carbon monoxide, smoke toxicity of other chemical species is not included.

Many mistakes [25] were made in using fire models, particularly in Computational Fluid Dynamics (CFD). The estimated ASET in many big projects is then very long. Increase in carbon monoxide upon discharge of water by sprinkler and water mist was seldom discussed. Only one or two small fire scenarios were used to estimate ASET. RSET was simulated by evacuation model without including human behaviour of local citizens. Therefore, the estimated RSET is very short even in a crowded subway station as in Fig. 2.



Fig. 2 Heavy passenger loading in local subway stations

This approach leads to concern as several post-flashover big fires [26,27] had occurred in Hong Kong and Mainland China. As reported before, the timelines of fire development and evacuation process with all those components reported in the literature should be briefly reviewed for suitability in Hong Kong.

#### 5. Atrium Water Suppression Systems

Atriums have been built in large buildings [8] in the Far East since the development of Tsimshatsui East in Hong Kong during the early 1980s. Since then, tall atriums up to 100 m in height are found in shopping malls, banks, public transport terminals and multipurpose complexes in other big cities. Automatic sprinkler systems have of necessity been installed on the high ceiling during the past 20 years. There are many problems, as discussed [12] for sprinkler at height on reducing the buoyancy of smoke due to cooling. Air dragging effects through momentum transfer with water droplets disturb the stability of the smoke layer. Smoke logging is dangerous for people staying on the atrium floor.

The level of combustibles may be very high to give 8 MW fire [8] on the atrium floor during festivals. Installing a traditional sprinkler system is not appropriate in tall spaces. Long-throw sidewall sprinklers are appropriate and should be installed in many new large and tall shopping malls in Hong Kong.

Water gun system [28] was proposed to protect the atrium. The fire origin and its type can be detected first. Water would be discharged from the water gun controlled by the detection system. As the systems will just target at the burning objects, similar to a local application system, the discharged amount of water will not be so high. It takes an advantage of having lower chance of flooding damages. There are three parts in most of the water gun system:

- A system based on optical section detection technology.
- The dual wavelength detector.
- The water gun.

However, there are problems of reliability in discharging water even without a fire. In addition, whether the system can control the heat release rate to a certain value by the small amount of water is a concern.

Sidewall long-throw sprinklers [29] were installed in tall atria unlikely to store high amounts of combustibles, especially they were installed at height. Sprinkler nozzles were installed at the sidewalls in many shopping malls of height up to 5 m in the Far East. Water discharged can travel long distances up to 8 m from the wall. Field tests had been carried out in halls of height up to 14.5 m. The same water coverage can be achieved as the normal sprinkler head. Water distribution at the floor level complied with the practising rule [30]. As the sprinkler head for this design is not immersed in a smoke reservoir as in normal sprinkler systems, it will be activated by the fire detection system. Once a fire is detected, it will act on the fire directly, instead of cooling the smoke layer. In this way, the fire can be controlled at a certain size.

Performance of sidewall long-throw sprinkler installed at height in tall atria unlikely to store high amounts of combustibles was evaluated. Fire suppression tests [29] with small fires less than 0.5 MW were carried out. The discharged sprinkler water spray was able to control a testing wood crib fire less than 0.5 MW. Therefore, in tall places unlikely to store combustibles, long-throw sprinklers at height can provide adequate water coverage.

However, there are two concerns [31] not yet studied for atria storing high amounts of combustibles:

- The large buoyancy of hot gases from the big fires with long burning duration would induce much stronger turbulent airflow.
- The long distance travelled by the water droplets in the sprinkler spray discharged in a tall atrium would experience much stronger air dragging effect. Air entrainment towards the fire plume and sprinkler water spray would be entirely different from that for a small fire.

Performance of the system under big fires had not yet been studied systematically. It is not clear whether the system can work in tall atria storing high amounts of combustibles.

## 6. Conclusions

Rapid development of the construction industry due to the growing number of people living in such high density cities is a key issue. Substantial fires reported in the past have provided painful lessons. After the big Garley Building fire [26], old high-rise buildings erected before 1972 without tight fire regulations were requested to upgrade their fire safety provisions with an ordinance on sprinkler systems set up. New architectural features such as deep plan, high-rise framed structures and well-sealed buildings,

the use of new materials, and new styles of living might bring new fire safety problems. The situation is worse in supertall buildings, deep underground subway stations, large halls and long tunnels [1]. PBD/FEA was allowed for buildings having difficulties to comply with the prescriptive codes.

However, PBD was not applied only for this reason. As identified in a conference at Singapore [32], cost reduction appeared to be the main drive in the past decade. Consequently, design fires of low heat release rate were used to give fire safety provisions which might not work as expected [8]. The timeline analysis was even criticized to be a flawed concept when not used properly. Water suppression system in a tall atrium is another example as shown in the above. Those points must be watched. The proposed annual checking of assumptions, criteria and conditions in PBD/FEA by the government Fire Services Department is a very good starting point [14] to provide adequate, not more nor less, safety.

## References

- [1] Chow, W.K. "Fire engineering for high density cities", In: Edward Ng (Editor), *Designing High Density Cities – For Social and Environmental Sustainability*, Chapter 15, Earthscan – James & James Science Publishers, London, UK, 2009.
- [2] Chow, W.K., Qu, L., and Edgar Pang, C.L., "Incidents on fire and ventilation provision in subway systems in Hong Kong", *International Journal of Engineering Performance- Based Fire Codes*, 2011, Vol. 10, No. 3, pp. 41-47.
- [3] Buildings Department, *Code of Practice for Fire Resisting Construction*, Hong Kong, 1996.
- [4] Buildings Department, *Code of Practice for Means of Escape*, Hong Kong, 1996.
- [5] Buildings Department, *Code of Practice for Means of Access*, Hong Kong, 1996.
- [6] Fire Services Department, *Codes of Practice for Minimum Fire Service Installations and Equipment and Inspection, Testing and Maintenance of Installations and Equipment*, Hong Kong, 2005.
- [7] Buildings Department, *Code of Practice for Fire Safety in Buildings 2011*, The Hong Kong Special Administrative Region, September 2011.
- [8] Chow, W.K., "Performance-based design on fire safety provisions in Hong Kong", *Proceedings of the 2011 SFPE Annual Meeting: Professional Development Conference and Exposition*, 24-25 October 2011, Portland, OR, USA, 2011.
- [9] *CIBSE Guide E: Fire Engineering*, The Chartered Institution of Building Services Engineers, London, UK, 2010.
- [10] V. Babrauskas, J.M. Fleming, and B.D. Russell, "RSET/ASET, a flawed concept for fire safety assessment", *Fire and Materials*, 2010, Vol. 34, pp. 341-355.

- [11] Chow, W.K., “Six points to note in applying timeline analysis in performance-based design for fire safety provisions in the Far East”, *International Journal on Engineering Performance-Based Fire Codes*, 2011, Vol. 10, No. 1, pp. 1-5.
- [12] Chow, W.K., (ANS“Performance of sprinkler in atria”, *Journal of Fire Sciences*, 1996, Vol. 14, No. 6, pp. 466-488.
- [13] *NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems*, National Fire Protection Association, Quincy, MA, USA, 2007.
- [14] Lo, C.H., CPD lecture on “Fire engineering in Hong Kong”, The Hong Kong Polytechnic University, Hong Kong, China, 15 July 2011.
- [15] Chow, W.K. Lecture Notes for the Workshop on “Fire Dynamics” for professional officers in the Buildings Department, Topic 11: Heat release rates and design fires, 21-23 February 2005, Organized by Research Centre for Fire Engineering, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, 2005.
- [16] Chow, W.K. CPD lecture on “Recent train fires and fire safety desired”, Organized by Research Centre for Fire Engineering, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China, 29 April 2004.
- [17] Babrauskas, V. and Grayson, S.J. Heat Release in Fires, Elsevier Applied Science, London, UK, 1992.
- [18] Proceedings of 2011 Exchange Meeting for SFPE Asia-Oceania Chapters – Transportation Fire Safety, *Korea Railroad Research Institute & SFPE Korean Chapter*, Seoul, Korea, 28 April 2011.
- [19] Chow, C.L. and Chow, W.K. “Heat release rate of accidental fire in a supertall building residential flat”, *Building and Environment*, 2010, Vol. 45, No. 7, pp. 1632-1640.
- [20] Malhotra, H.L. Fire safety in buildings, *Building Research Establishment report*, Department of the Environment, Building Research Establishment, Fire Research Station, Borehamwood, Herts, WD6 2BL, UK, 1987.
- [21] Chow, W.K. “High risks on firefighting in fire engineering approach projects adopting flawed concept in fire safety assessment”, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, 2012. Available at: [http://www.bse.polyu.edu.hk/researchCentre/Fire\\_Engineering/Hot\\_Issues.html](http://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/Hot_Issues.html)
- [22] Cox, G. *Combustion Fundamentals of Fires*, Academic Press, London, 1995.
- [23] Chow, W.K. A presentation in the workshop on “The challenges of fire safety education to train highly qualified fire protection engineers and scientists”, *10th International IAFSS Symposium*, Maryland, USA, 19-24 June 2011.
- [24] *Proceedings of FireAsia 2012*, Hong Kong Convention and Exhibition Centre, Hong Kong, 8-10 February 2012.
- [25] Chow, W.K. and Fong, N.K. “Common mistakes made in using CFD in FEA projects”, CPD lecture, Organized by Research Centre of Fire Engineering, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, To be held on 21 April 2012.
- [26] Woo, K.H. *Final Report of the Inquiry into the Garley Building Fire on 20 November 1996*, Printing Department, Hong Kong, 1997.
- [27] *South China Morning Post*, “An accident just waiting to happen”, 1 December 2011.
- [28] Chow, C.L., Chow, W.K. and Yuan, H.Y. (watergun1ASRb) “A preliminary discussion on selecting active fire protection systems for atria in green or sustainable buildings”, *Architectural Science Review*, 2004, Vol. 47, No. 3, pp. 229-236.
- [29] Chow, W.K., Gao, Y., Zou, G.W. and Dong, H., (ExptSWLT1\_Abstract) “Performance evaluation of sidewall long-throw sprinklers at height”, *Proceedings of the 9th AIAA/ASME Joint Thermophysics and Heat Transfer Conference*, 5-8 June 2006, San Francisco, California, USA, Paper AIAA-2006-3288.
- [30] *LPC Rules for Automatic Sprinkler Installations*, The Loss Prevention Council, London, UK, 1987.
- [31] Cheung, K.P. and Chow, W.K. “Concerns on installing long-throw sprinklers in tall halls”, *International Journal of Engineering Performance-Based Fire Codes*, To appear, 2012.
- [32] *Proceedings of Fire Safety Asia Conference (FiSAC) 2011*, Suntec, Singapore, 12-14 October 2011.