NECESSITY OF IN-DEPTH EVALUATION OF LONG-THROW SPRINKLER INSTALLATION AT TALL ATRIA STORING HIGH AMOUNTS OF COMBUSTIBLES

W.K. Chow
Research Centre for Fire Engineering, Department of Building Services Engineering
The Hong Kong Polytechnic University, Hong Kong, China

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ABSTRACT

Long-throw sprinklers were installed at height to protect tall atria which are unlikely to store high amounts of combustibles. Water coverage at the protected area was demonstrated to be adequate. However, there are concerns on long-throw sprinkler installation in tall atria likely to have high combustible contents. 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. These concerns will be pointed out and briefly discussed in this paper.

Further, the resultant aerodynamics induced by the sprinklers and the big fire would affect the performance of the smoke exhaust system protecting the atrium. The design concept of integrating long-throw sprinkler with static smoke exhaust systems with natural vents in very deep underground halls should be explored more carefully as the consequence can be very serious. Indoor aerodynamics resulted from fire and sprinkler water spray is complicated. Loss in smoke buoyancy would not keep a stable layer at the top which would then move out from the natural vents. Safety of firemen moving down to a deep underground environment filled up with smoke and hot steam must be evaluated vigorously.

It is obvious that the concept of long-throw sprinkler in a tall atrium storing high amounts of combustibles should be further explored with in-depth research. Performance of the system integrated with natural vents in very deep crowded underground railway stations with a tall hall should be vigorously evaluated. The physical hazards must be assessed carefully under big fires with systematic full-scale burning experiments. Before working out appropriate design guides, long-throw sprinkler installation can only be used in tall atria storing small amounts of combustibles.

1. INTRODUCTION

There are many tall atria in shopping malls, public transport terminals, hotels, cargo terminals and banks constructed all over the world since 1980 [1]. Some atria are observed to store high amounts of combustibles as in Fig. 1. Burning such combustibles would give a big hazardous fire [2]. It is difficult to protect these atria by sprinklers as raised years ago [3]. Water guns with an infra-red ray scanning fire detection and interlocking controller system were used in huge space fire suppression with flame sensors [4]. Although appropriate design can give a wide water coverage area, their effectiveness in controlling a fire [5] should be further explored to demonstrate suppression capability and reliability. Sidewall long-throw sprinklers at height activated by a fire detection system are therefore recommended [6] as an appropriate system for tall atria unlikely to store large quantities of combustibles. As demonstrated by the preliminary field tests [6], water distribution density required in acceptable standards can be provided in the protected coverage areas.

However, two concerns were pointed out recently on long-throw sprinkler installation at height [7,8] in atria storing high amounts of combustibles as in Fig. 1:

1) Aerodynamics resulted

Under a big fire with high heat release rate, if happened, the resultant air flow due to dragging of water spray and fire-induced buoyancy will be very strong. Smoke might fill up the whole atrium space due to the turbulent motion. Consequently, a clear two-layer pattern would not form in a very tall atrium (and even in an atrium with a normal ceiling height of 3 m) under a bigger fire. Smoke cannot be kept at sufficiently high positions, affecting occupants and firefighters staying below.

Occupants might be able to leave the atrium as indicated by the results from evacuation simulation in a reasonably short time [9]. However, robotic motion assumed [10] in the simulations should be justified. Perhaps, orderly evacuation can be ensured by directing movement by security guards with firefighting experience. Further, evacuation packages were developed without including appropriate human behavior in the Far East [11]. In addition, health effect of firefighters is a deep concern. Firemen must upgrade their personal protection equipment under such fire scenario. Very few in-depth studies on this special issue were carried out. The author had evaluated the performance of the portable breathing apparatus [12], but only under small fires and without water action. Further, the performance of the smoke exhaust system, particularly static smoke exhaust in tall halls, will be affected. Integrating long-throw sprinklers at height with static smoke exhaust system should be further justified, particularly for those railway stations located deep underground [13]. It is very dangerous for firemen moving down to deep space. The maximum depth of an underground car park might be 7 levels in Korea. Any depth over 20 m should be watched. Computational Fluid Dynamics predictions are now under challenges [14]. All assumptions and predictions are suggested to be justified by at least, scale modeling experiments [15].

Fig. 1: High combustible content in a tall atrium

2) Control of heat release rate

It is difficult to control the combustible content inside a big atrium. Putting in festival decorations such as tall Christmas trees as in Fig. 1 made of materials not passing the non-combustibility test would give high heat release rates upon ignition. The possible heat release rate upon burning combustibles in a tall atrium was complied with some guides. However, results [16] are not supported by full-scale burning tests and some approaches are even taking average heat release rate as peak heat release rate [17]. Overseas results suggested that burning a normal small domestic tree would give at least 7 MW [18]. A plastic tree ten times taller than that might give 70 MW! Igniting adjacent combustibles of the tall tree would give very different fire phenomena [19]. Consequently, it is difficult to suppress the fire and control the heat release rate to the expected value, say 2 MW, even if water coverage of long-throw sprinkler satisfied the acceptable design rule [20]. That is why the observed arrangement as in Fig. 1 is a deep concern to fire officers [20]. Firemen have to stay inside the hall with hazardous environment to rescue trapped and hurt occupants, and fight against the big fire!

Both concerns implied that more vigorous studies with full-scale burning tests on long-throw sprinklers in tall atria under big fires must be carried out. Apart from studying the water coverage of the protected area, there are still no in-depth research with systematic studies using appropriate numerical simulations nor in-depth experimental studies addressing these two points. In this short note, how to address these two points will be discussed. There will be problems not only to those sprinklers installed in tall atria, but also to buildings of normal height likely to store high amounts of combustibles.

Research is an on-going updating process. Systems, such as total flooding gas protection system with halon, widely used yesterday might have to be substituted by new technology. It is good that the proposed installation has attracted interest of the general public [7]. Active updating and upgrading of safety systems would be good for building occupants, operators and firefighters.

Note that there are deep concerns on having so many big post-flashover fires. As raised previously after the big Fa Yuen Street fire, projects with difficulties to comply with prescriptive fire codes should be watched [22]. Projects going through fire engineering approach (FEA) in Hong Kong, in fact performance-based design (PBD), must include intervention of fire services, impact on firefighting and rescue strategies, and potential safety and health effect to firefighters. This was just pointed out and discussed in a railway conference recently [23]. For example, asking firemen to walk through a much longer travel distance must be watched. Their equipped portable breathing apparatus can only operate for 30 minutes, might not be appropriate for taking actions in places with extended travel distances. Very few FEA/PBD reports include vigorous analysis on safety and health of firefighters; warning them to upgrade their equipment in very hazardous environment and revising their normal training schedule in suppressing big fires. It is good to learn that the fire authority in Hong Kong [21] is taking appropriate actions in watching all FEA projects approved after 1998.

2. SIDEWALL LONG-THROW SPRINKLER

The sidewall long-throw sprinkler is a relatively new design to tall atria unlikely to store high amounts of combustibles, especially when it is 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 Loss Prevention Council (LPC) rules in the UK [24]. 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. Because of resources limitation, fire suppression tests [6] were only carried out on small fires less than 0.5 MW. The discharged sprinkler water spray is 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, the two concerns listed above were not studied for atria storing high amounts of combustibles. Since the 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.

3. NOMINAL DISCHARGE DENSITY

Sprinklers are required in many building uses for controlling fires [25]. Upon actuation, water would be discharged from the sprinkler head. The amount of water received at the floor level is important and should satisfy the specified requirements [26,27]. An important design parameter, the design density of the water spray is specified clearly in the design guides such as the LPC rules [24]. The value should be adequate in the Assumed Maximum Area of Operations (AMAO), say 5 mm/min, for a sprinkler system of Ordinary Hazard (OH) class in shopping malls.

The water discharge density [20,24] specified by the nominal discharge density NDD (in mm/min) is applied to a group of sprinklers, rather than a single sprinkler on the mass flux density. This would give the maximum rate of heat removed by water in the protected area. NDD can be deduced from the water application rate required for a particular fire load [24,26].

NDD (in mm/min) is given by the water flow rate into the protected area Q_f (in L/min) divided by the area of coverage under consideration A_c (in m^2).

$$NDD = \frac{Q_f}{A_c} \qquad (1)$$

In field measurement, NDD is a measure of the distribution of water flux varying along the radial distance and circumference of two long-throw sprinklers mounted in radial formation. This is the operating characteristic of two long-throw sprinklers covering the same area where the container area is fixed. The testing criteria on water coverage for a system classified as Ordinary Hazard Group III (OH III) under LPC Rules in the UK [26] are summarized [20,24,28] as:

- The minimum water flow rate for each sprinkler is 131 L/min [28].
- The minimum water pressure is 2 bar [28].
- Not more than 10% of the protected area has a water discharge density less than 1.125 mm/min [24].
- The minimum average water discharge density is 5 mm/min [20].

4. CURRENT PRACTICE ON WATER COVERAGE ONLY

There are always resources limitations in projects with fire safety provisions developed by FEA or PBD. A possible simple explanation is that many such PBD projects are only for reducing the construction cost as raised recently due to whatever reasons [29]. Fire research results on PBD developed in advanced countries were applied to many developing countries without in-depth justification. Some FEA engineers in the Far East even challenged why the authority did not accept those overseas PBD practices. They forgot the citizens in developing areas do not even queue up in bus stations [29,30]. It is extremely difficult to evacuate them orderly in crowded halls by following 'robotic motions' [10], even with security guards.

Mainland China had paid hard effort in funding research to support code development while developing their dense urban areas. Current practice of evaluating the performance of sprinkler system is only on demonstrating water coverage discharged by the sprinkler system. Even so, numerous labor works were required to deduce the optimum angular correction to the horizontal [6] in that particular application. This is a relatively simple part. As reported before [6], field measurements were carried out in a hall with adequate ceiling height. The protected area of 20 m^2 of length 8 m and width 2.5 m at ground level as specified in the LPC rules was set up.

A test rig as in Fig. 2a was constructed with a pair of sidewall long-throw sprinklers installed at height of 14.5 m to carry out field tests with details reported [6]. The water discharge density received in the protected area was measured by 96 cubic water collection containers of size 0.5 m. The collection containers were arranged in the protected area 20 m^2 (8 m by 2.5 m) as shown in Fig. 2b. Water was kept discharging for 10 minutes. The volume of water distributed over the measurement area was measured to calculate the NDD in the covered area. Based on the calculated water discharge density, the accepted range of protected area for each sprinkler arrangement was then determined.

A summary of the test results is:

- The proposed protected area 20 m^2 (8 m by 2.5 m) received an average NDD above 5 mm/min.
- None of the proposed protected area received water less than 1.125 mm/min.

It is obvious that LPC criteria [20,24,28] can be satisfied for sprinklers installed at such a tall hall under a flow rate of 270 L/min. The tests are relatively easy to demonstrate that water coverage satisfies the requirement.

5. SMALL FIRE TESTS

Some preliminary test results on evaluating suppression by long-throw sprinklers at height with small wood crib fires were reported [6]. A wood crib of 20 kg ignited by a 0.6 m diameter pool fire with 1 litre gasoline was used. The heat release rate was less than 0.5 MW. Sprinkler water pressure was 0.31 MPa and flow rate 16.5 m^3hr^{-1}. Water was discharged at 4 min 33 s.

As observed, the fire was extinguished at 7 min 40 s. The sequence of pictures is shown in Fig. 3. Under small fires, the system can work as expected to suppress the fire.

One of the deep concerns discussed in above is on the complicated air flow pattern due to sprinklers under a big fire. Consequently, smoke and steam would fill up the tall atrium. This point must be addressed carefully because even in the preliminary tests with a small fire, smoke and steam were observed clearly to fill up the space as in Fig. 3.

It is very obvious that in-depth studies are required to evaluate the performance of long-throw sprinkler at height. Full-scale burning tests with big fires should be carried out to address the above two points of concern raised recently [7] on tall atria storing high amounts of combustibles giving heat release rates much higher than 0.5 MW.

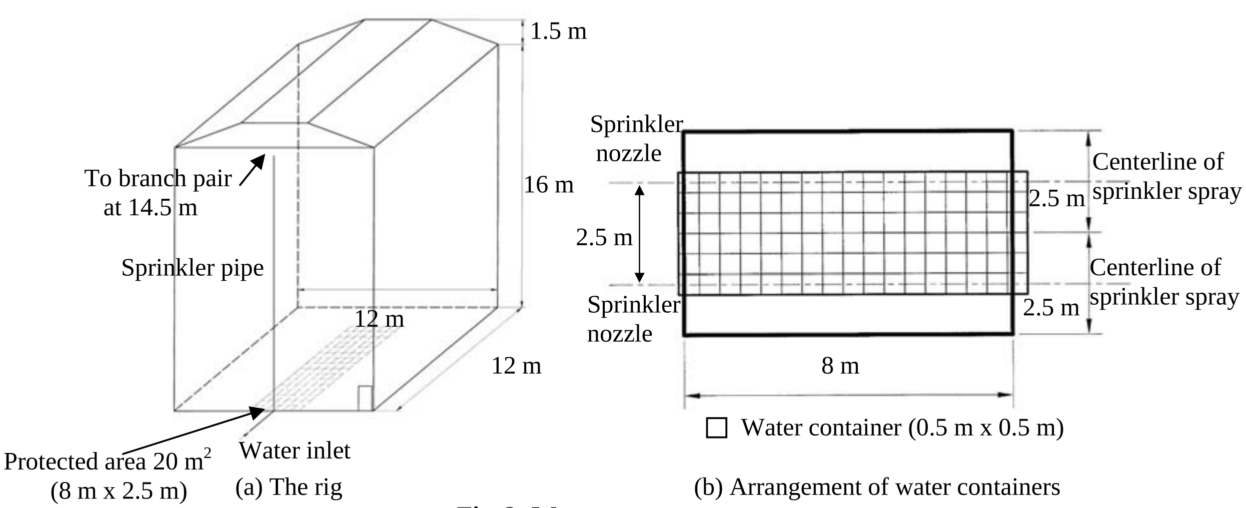
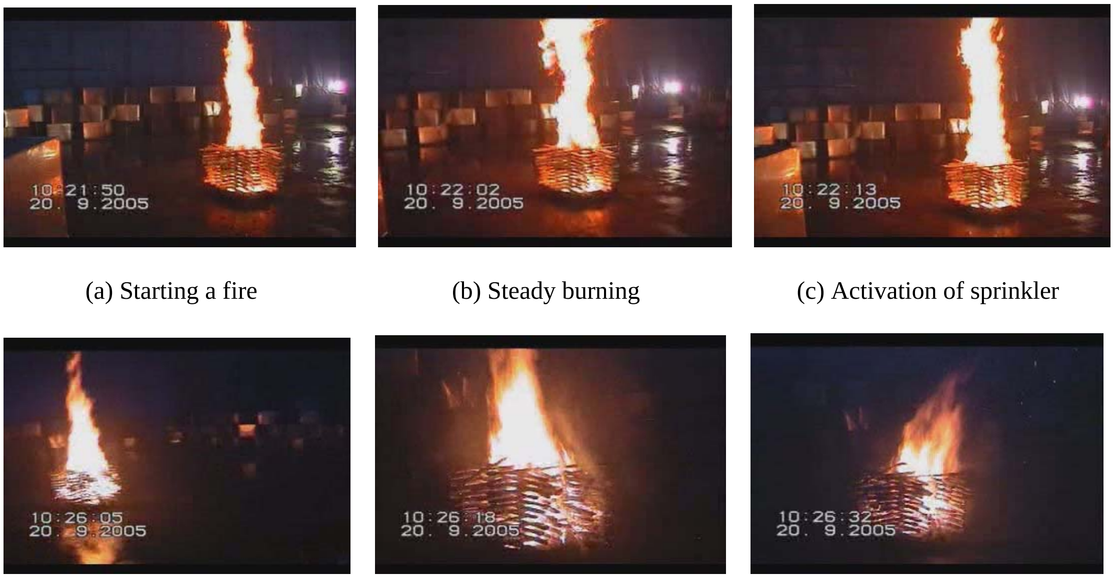


Fig. 2: Water coverage test



(a) Starting a fire (b) Steady burning (c) Activation of sprinkler

(d) Smoke and steam filled up the hall (e) Closer look (f) Controlled

Fig. 3: Action of long-throw sprinkler on a small 0.5 MW wood crib fire

6. NECESSITY OF PERFORMING LARGE-SCALE FIRE TESTS

The two concerns raised recently [7] on the performance of long-throw sidewall sprinklers at height in atria storing high amounts of combustibles had not been addressed in the literature. There is no evidence that those concerns would give problems or not. The resultant turbulent motion due to air dragging of sprinkler and fire-induced buoyancy would affect the air entrainment rate, dispersion of gas and evaporation of water. These phenomena depend on the building geometry, fire size, building height and operation condition of the sprinkler. Further, thermal radiation cannot be scaled down. Therefore, further systematic long-term research with full-scale burning tests with big fires must be carried out.

For places storing large amounts of combustibles as in Fig. 1, the heat release rate of a fire can be very high, depending on the ventilation provision. Therefore, a bigger fire is required for testing the performance of the long-throw sprinkler system in atria storing a large amount of combustible goods. The testing fire must be big enough (for example over 5 MW) to demonstrate that the heat release rate can be controlled down to the specified value of 2 MW upon activation of the sprinkler. Using a low testing fire of 0.5 MW would not demonstrate anything even for halls of lower height below 5 m! The performance of the system under big fires of at least 5 MW must be evaluated to address the concern.

7. CONCLUSIONS

Preliminary tests on long-throw sprinklers with a wood crib fire reported years ago indicated that heat released can be controlled, if the burning object is very small [6]. Water discharged will still give adequate NDD to satisfy the LPC criteria [20,24,28]. Such tests indicated that sidewall long-throw sprinklers can be installed at height up to 14.5 m in atria unlikely to store lots of combustibles. The effect of air movement due to operating mechanical ventilation or smoke exhaust system is not significant in affecting the water coverage. Water discharged from the high sprinkler nozzles can control fires less than 0.5 MW.

However, it is not clear whether long-throw sprinklers can work in a tall atrium storing high amounts of combustibles. Mixing of smoke with air and steam should be watched. For halls likely to store high amounts of combustibles, even though they are not tall atria, the performance of the system to control a big fire, say at least 5 MW, must be evaluated. Whether the high heat release rate can be controlled at the design value, say 2 MW, upon activation of the sprinkler must be evaluated. Even using furniture with Combustion Modified High Resilient (CMHR) polyurethane foam might not necessarily be safe under high heat fluxes [31] emitted in post-flashover fires. Performance of the sprinkler system cannot be evaluated just by demonstrating the phenomena by one or two small-scale field tests. Field tests with a small 2 MW fire even in a hall lower than 5 m would not indicate anything abnormal. Burning combustibles to give a big fire in a tall atrium will be very different. This part must be further explored for shopping malls with a tall atrium having a high combustible content as raised recently [7].

The design concept for tall atria storing high amounts of combustibles [32] must be justified with full-scale burning tests on big fires. The situation is even worse while integrating with static smoke exhaust system for crowded deep underground tall halls of subway stations [13,33]. Loss in smoke buoyancy cannot keep a stable layer at the top. In-depth investigation is needed to justify the proposed concerns due to large air entertainment rate of water droplets travelling for a long distance, and buoyancy-induced air flow due to a big fire.

REFERENCES

1. W.K. Chow, "Smoke movement and design of smoke control in atrium buildings", International Journal of Housing Science and Its Applications, Vol. 13, No. 4, pp. 307-322 (1989).

2. W.K. Chow and W.K. Wong, "On the simulation of atrium fire environment in Hong Kong using zone models", Journal of Fire Sciences, Vol. 11, No. 1, pp. 3-51 (1993).

3. W.K. Chow, "Performance of sprinkler in atria", Journal of Fire Sciences, Vol. 14, No. 6, pp. 466-488 (1996).

4. T. Yamada, "Evaluation system of code equivalency for alternative design of fire protections system in Japan – Towards the intelligent fire protection system", pp.15-23. Proceedings of the Mini-symposium on Fire Safety Design of Buildings and Fire Safety Engineering, 12 June 1995, Tsukuba, Japan – Edited by Y. Hasemi and Y. Hayashi, Building Research Institute, Ministry of Construction, Japan (1995).

5. C.L. Chow, W.K. Chow and H.Y. Yuan, "A preliminary discussion on selecting active fire protection systems for atria in green or sustainable buildings", Architectural Science Review, Vol. 47, No. 3, pp. 229-236 (2004).

6. W.K. Chow, Y. Gao, G.W. Zou and H. Dong, "Performance evaluation of sidewall long-throw sprinklers at height", 9th AIAA/ASME Joint Thermophysics and Heat Transfer Conference, 5-8 June 2006, San Francisco, California, USA, Paper AIAA-2006-3288 (2006).

7. K.P. Cheung, "Concerns on installing long-throw sprinkler in tall atria", Department of Architecture, University of Hong Kong, Hong Kong (2012). Available at: http://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/Hot_Issues.html

8. W.K. Chow, "Response to concerns on installing long-throw sprinkler in tall atria", 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

9. W.K. Chow and C.L. Chow, "Evacuation with Smoke Control for Atria in Green and Sustainable Buildings," Building and Environment, Vol. 40, No. 2, 2005, pp. 195-200.

10. V. Babrauskas, J.M. Fleming and B.D. Russell, "RSET/ASET, a flawed concept for fire safety assessment", Fire and Materials, Vol. 34, pp. 341-355 (2010).

11. W.K. Chow, "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, Vol. 10, No. 1, pp. 1-5 (2011).

12. W.K. Chow, Expert witness in court, Coroner's Court, Hong Kong (2009).

13. W.K. Chow, "Static smoke exhaust in big halls with high occupancy", Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong (2011). Available at: http://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/Hot_Issues.html

14. W.K. Chow, C.L. Chow and S.S. Li, "Simulating smoke filling in big halls by computational fluid dynamics", Special Issue on "Advances in Computational Fluid Dynamics and Its Applications", Modelling and Simulation in Engineering, Vol. 2011, Article ID 781252, 16 pages, doi: 10.1155/2011/781252 (2011).

15. H.K. Chan and W.K. Chow, "Scale modeling studies in smoke control with natural vents", Abstract accepted to 2nd International High Performance Buildings Conference, Purdue, 16-19 July (2012).

16. Hong Kong Airport Authority, Hong Kong International Airport Tenant Design Guideline, Appendix A Sample Fire Engineering Report, , April 2011 version, Issue no. 3 (2011). https://extranetapps.hongkongairport.com/iwov_extra/ListFile?path=/etra/Extranet/TSP/Procedures/Tenant+Design+Guideline.pdf&place=n

17. W.K. Chow, "A note estimating the heat release rate of combustibles of different building uses", International Journal on Engineering Performance-Based Fire Codes, To appear (2012).

18. D. Madrzykowski, "Impact of a residential sprinkler on the heat release rate of a Christmas tree fire", NISTIR 7506, Fire Research Division, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, MD 20899-8661, USA, May (2008).

19. W.K. Chow and S.S. Han, "Scale modeling studies on flame stretching and swirling in a room with natural vents", ASME 2011 International Mechanical Engineering Congress & Exposition, IMECE2011, November 11-17, 2011, Denver, Colorado, USA, Paper no. IMECE2011-62087 (2011).

20. LPC Rules for Automatic Sprinkler Installations, The Loss Prevention Council, London, UK (1987).

21. Gregory C.H. Lo, CPD lecture on "Fire engineering in Hong Kong", Organized by Research Centre for Fire Engineering, Department of Building Services Engineering, The Hong Kong Polytechnic University, 15 July (2011).

22. W.K. Chow, "Lesson learnt from the Fa Yuen Street Big Fire", Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong (2012) – In Chinese. Available at: http://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/Hot_Issues.html

23. 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).

24. LPS 1039: Issue 5 Requirements and Testing Methods for Automatic Sprinkler (2002).

25. Fire Services Department, Code of Practice for Minimum Fire Service Installations and Equipment, Hong Kong (2005).

26. BS 5306 Part 2: Fire Extinguishing Installations and Equipment on Premises. Specification for Sprinkler Systems, British Standard (1990).

27. NFPA 13, Standard for the Installation of Sprinkler Systems, National Fire Protection Association, Quincy, Massachusetts, USA (1996).

28. W.K. Chow, P. Chan and S. Pearce, Lecture notes for CPD Lecture "Atrium Hot Smoke Test: Theory and Practice", Research Centre for Fire Engineering, The Hong Kong Polytechnic University, Hong Kong, 12 June (2004).

29. Proceedings of Fire Safety Asia Conference (FiSAC) 2011, Suntec, Singapore, 12-14 October (2011).

30. W.K. Chow, "Performance-based design on fire safety provisions in Hong Kong", 2011 SFPE Annual Meeting: Professional Development Conference and Exposition, 24-25 October 2011, Portland, OR, USA (2011).

31. W.K. Chow, "Fire hazard assessment on polyurethane sandwich panels for temporary accommodation units", Polymer Testing, Vol. 23, No. 8, pp. 973-977 (2004).

32. W.K. Chow, "Fire hazard assessment of combustibles in big terminals," International Journal of Risk Assessment and Management, Vol. 5, No. 1, pp. 66-75 (2005).

33. W.K. Chow and J. Li, "On Atrium Smoke Management System Design," ASHRAE Transactions, Vol. 111, No. 1, pp. 395-406 (2005).