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## Fire and Explosion Hazards to Watch in Developing Big Dense Areas Such as the Guangdong-Hong Kong-Macao Greater Bay Area

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**Abstract:** Possible fire hazards in big cities with manufacturing areas in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) will be pointed out in this paper. Many projects with new architectural features have difficulties in complying with the prescriptive fire codes. Consequently, performance-based design (PBD) in fire engineering approach (FEA) has to be applied in the GBA. The four fire code systems will be outlined first. New fire hazards to watch in developing the GBA will also be discussed. These include wind action on tall residential building fires, crowded subway station evacuation, vertical greenery system, and fire and explosion hazards in innovative technology manufacturing plants. The problems identified while applying timeline analysis in PBD-FEA of these projects will also be introduced by taking crowded subway stations as an example. Hazards due to burning heavy goods vehicle fires on or near to vehicular bridges and footbridges without adequate fire resistance construction are also discussed.

**Key words:** fire safety; explosions; dense urban areas; Greater Bay Area

## 粤港澳大湾区等密集发展地区的火灾及 爆炸危险分析

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**摘要:**针对粤港澳大湾区(GBA)等具有众多制造生产区的大城市存在的火灾危险性进行了研究。目前,许多具有新型建筑特色的项目很难遵守消防规范,因此,粤港澳大湾区在消防工程方法(FEA)上不得不使用性能化设计(PBD)。首先概述了4个消防规范系统,随后讨论了粤港澳大湾区(GBA)在发展过程中可能存在的新型火灾危险,其中包括了高层住宅建筑火灾中风的作用、拥挤的地铁站人员疏散、垂直绿化系统以及新型技术制造厂的火灾和爆炸危险。文章以拥挤的地铁车站为例,介绍了在PBD-FEA中应用时间线分析时所发现的问题。最后,文章讨论了在没有足够耐火性结构的车辆桥梁和行人天桥的附近,由于重型货车发生了燃烧形成火灾时所可能造成的危险。

**关键词:**消防安全;爆炸;密集的城市地区;大湾区

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The Guangdong-Hong Kong-Macao Greater Bay Area (GBA) is a rapidly developing huge dense urban area in the Asia-Oceania (AO) area with enormous economics volume. Numerous big construction projects for commercial, residential, industrial, exhibition, public transport and many other uses have been developed or under planning. There are many big halls, supertall buildings, heavy traffic long or short tunnels, subway systems, industrial areas, etc. High-performance buildings have been constructed with new green sustainable architectural features. All these buildings would have fire hazards very different from traditional buildings<sup>[1]</sup>. Green constructions have failed to comply with the fire safety requirements in the GBA<sup>[2-7]</sup>. Tall timber apartments, an emerging popular type of green constructions, are obvious examples<sup>[8-10]</sup>. Therefore, fire safety provisions have to be determined by the performance-based approach<sup>[11]</sup>, commonly labelled as performance-based design (PBD)<sup>[12-18]</sup> or fire engineering approach (FEA)<sup>[15-18]</sup> as in other AO areas during the past three decades.

However, there are many hidden fire problems identified in thousands of PBD-FEA projects<sup>[11,19]</sup> in the AO areas. Although very few fire disasters have occurred, yet in these PBD-FEA projects, new hazard scenarios are encountered. The insurance premium is high for the existing projects. Some buildings are requested to upgrade fire safety provisions for facing new challenges. Software fire safety management has to be enhanced by the owners<sup>[20-22]</sup> first, as it is easier to do. Additional firefighting equipment has to be allocated to fire departments concerned. Firefighters have to get additional training in handling the more hazardous environment with some fire safety provisions failing to comply with the codes. Consequently, the operating cost for these buildings with inadequate fire safety provisions determined by PBD-FEA projects becomes very high. An obvious example is the airport terminal buildings using cabin design without providing full coverage of the large halls with sprinklers and smoke exhaust systems. The assumed fire hazard scenario of not putting combustibles outside the cabin is frequently inspected. Long-throw sprinklers are then provided in catering areas to face the new challenges.

In this paper, fire hazard in the PBD-FEA approach of the GBA will be discussed. PBD-FEA implemented in the past three decades will be reviewed first. Wind effect on tall residential buildings, crowded subway station evacuation, and green architecture with vertical greenery system (VGS) will be discussed. Some controversial concepts<sup>[23-24]</sup> such as the timeline analysis will also be introduced. Fire hazards of VGS have not yet been thoroughly studied. Vegetation grown along building façades provides fuel for the spread of fires. The direct action of a window flame plume from a post-flashover room fire would ignite VGS as observed from physical modeling studies. Fire and explosion hazards in

innovative technology manufacturing plants will be discussed. An obvious example is the manufacturing plants for Light Emitting Diodes (LED), as a big fire occurred in India in 2017. Burning heavy goods vehicles (HGV) on bridges should be watched with fire resistance construction enhanced.

## 1 Fire Code Systems

As reviewed before<sup>[11, 25]</sup>, four fire code systems can be identified. These are Prescriptive Code (PC)<sup>[17]</sup>, Fire Engineering Approach (FEA)<sup>[15-17]</sup>, Performance-Based Design (PBD)<sup>[12-14]</sup>, and Engineering Performance-Based Fire Code (EPBFC)<sup>[26]</sup>.

Fire codes in most AO areas including the Hong Kong Special Administrative Region in GBA are basically prescriptive, or known as the deemed-to-satisfy (DTS) approach<sup>[27]</sup> in Australia. The fire codes on passive building constructions and active fire protection systems are updated<sup>[25, 28-31]</sup> regularly. Applying PC in large-scale construction projects with new architectural features should be watched. Efforts were made to review the PC and the necessity of upgrading some parts<sup>[17]</sup>. However, very few research papers supporting the code specifications have been published to describe the fire science and engineering concept adopted. Buildings failed to comply with PC requirements might not be allowed to construct in many AO areas. Consequently, the architectural designs have to be changed to follow the PC requirements. An alternative is that architects can demonstrate these new architectural features are safe under big fires. For some projects, the building owners can sign an undertaking, so that they will shoulder all the responsibilities should any big disastrous fires occur. Consequently, some buildings might have to recruit their own firefighting teams.

On the other extreme, there are proposals on moving to EPBFC<sup>[3, 26]</sup> as in structural codes, wind engineering codes, ventilation codes and environmental codes. However, the research funding supporting the establishment of performance-based fire codes is very limited<sup>[32]</sup>. Therefore, EPBFC can only be implemented occasionally in countries like New Zealand<sup>[33-34]</sup>. It is difficult to adopt a new engineering performance-based code system at the moment because of limited fire research<sup>[32]</sup>. The fire safety provisions of such building projects can only be determined by PBD<sup>[12-14, 35-36]</sup>, if the objectives, acceptance criteria and approaches are derived through long-term research in fire science and engineering<sup>[33]</sup>.

A PBD code system can only be established with a clear requirement of prescriptive data. But in AO places with limited fire engineering research, FEA<sup>[2-4]</sup> is implemented to ensure that fire safety provisions are equivalent to those required in PC. There are no clear acceptance criteria<sup>[12-14]</sup> spelled out as in PBD of other countries. FEA is used to demonstrate equivalence to PC<sup>[17]</sup> in places like Hong Kong.

Obviously, PBD-FEA supports innovative architectural design such as big crowded airport terminals with long travel distances in enclosed spaces. However, there are many other reasons for using PBD-FEA to provide fire safety as summarized in the literature. PBD-FEA might be used to reduce<sup>[37]</sup> the construction cost in some cities where the fire officers, without consulting engineers, have to be responsible for the hazardous consequences. A previous example was on arguing that fire resisting structural walls are not required in libraries and footbridges linking up buildings. Even fire hazard assessment for vehicular tunnels was only based on small fire scenarios of less than 5 MW 20 years ago.

However, burning a heavy goods vehicle (HGV) can give a heat release rate of 100 MW. Consequently, many problems start to appear as experienced before<sup>[11, 19, 38]</sup>.

Several examples leading to possible disastrous hazards are selected for discussion in the following section. These features might not satisfy PC which cannot be updated so rapidly to assess these buildings. There must be supporting research and development on specifying the PC requirements. Similarly, applying without including experimental studies in PBD-FEA hazard assessment reports would have many problems. A total fire safety concept should be applied in these buildings by implementing fire safety management to ensure that passive building constructions and active fire protection systems are working as expected.

## 2 Crowded Subway Station Evacuation

Timeline analysis was applied in many PBD-FEA projects in crowded subway systems. The Available Safe Egress Time (ASET) is estimated and compared with the Required Safe Egress Time (RSET). ASET is predicted by fire models using tenability limits for human beings. RSET is estimated by evacuation software. Values of ASET and RSET are then compared to see whether ASET is longer than RSET. There are concerns as pointed out before<sup>[23-24]</sup>.

Small fire scenarios of only up to 5 MW are commonly used in very big halls in shopping malls and deep underground public transport interchanges in estimating ASET. Furthermore, tenability of toxic gases usually includes only carbon monoxide. RSET is not estimated under crowded conditions, thus yielding small values of evacuation time. The ‘safety margin’ (SM) given by the following equation only constitutes a small percentage of RSET in many projects

$$SM = ASET - RSET \quad (1)$$

In conclusion, ASET might be much shorter than the value calculated using fire models based on current tenability limits only for heat and carbon monoxide under a small design fire. However, RSET can be longer than the value predicted by evacuation studies when the occupant load is higher than the design value.

Officers approving PBD-FEA projects are now watching the concerns and requesting appropriate justifications for all new and existing projects involving timeline analysis, particularly in crowded underground subway stations<sup>[4, 39]</sup>. A more realistic fire scenarios with a bigger design fire of higher heat release rate should be applied to get reasonable values of ASET in new projects. Occupant loading has to be controlled within the design value by installing appropriate real-time measurement devices for counting the number of occupants entering and leaving the space concerned. Higher ‘safety margin’ should be provided to cater for uncertainties.

For those existing PBD-FEA projects with small SM, firefighters have to take action in a very hazardous environment. Firemen without adequate training and special equipment can be hurt while working in such fire sites. More inspections have been conducted to ensure that the design fire scenario is properly maintained. For example, tall plastics Christmas trees should not be allowed to put in a tall hall of a shopping mall with smoke extraction system design with a 5 MW fire only. Frequent inspections<sup>[38]</sup> of PBD-FEA projects have been successfully implemented in HKSAR.

### 3 Wind Effect on Tall Residential Building

Tall residential buildings of height above 200 m with openable windows and balcony, which are common in the AO areas, have many problems on fire safety. Long-term survey study on fire load density indicated that high amount of combustibles over the local upper limit of  $1\,135\text{ M}\cdot\text{Jm}^{-2}$  used to be stored in residential flats<sup>[17]</sup>. Wind-induced air-flow rates through openings at upper levels of these tall buildings can be very high. Stack effect in areas with large indoor and outdoor temperature differences will also give high ventilation rate through leakage areas. Adequate oxygen is then supplied to burn up all stored combustibles to give a big fire.

Stack effect and wind action on possible increase in the heat release rate for fires in supertall residential buildings have been reported in the literature<sup>[40]</sup>. Air intake rates through openings to rooms at high levels due to stack effect and wind action were estimated by simple empirical formula. The maximum heat release rates for well-developed room fires in these tall buildings under different stack and wind conditions were determined by varying two parameters. Air flow rate through openings in an 800 m tall building induced by wind gust can be over 20 times the value at ground level. Consequently, the heat release rate in room fires at height under wind action can be much higher than one at low level.

### 4 Burning Greens Can Give Disasters

Almost all countries are promoting the construction of more green and sustainable buildings<sup>[2, 41-44]</sup> for the future generations. New buildings should be designed by following different guides such as Building Environmental Assessment Method (BEAM)<sup>[43]</sup> in the HKSAR of Mainland, Leadership in Energy and Environmental Design (LEED)<sup>[44-45]</sup> in USA. Existing buildings should be upgraded by replacing old electrical and mechanical systems, such as mechanical ventilation and air-conditioning systems, as it is difficult to change the construction elements.

However, there are many conflicts<sup>[45-46]</sup> between green constructions and the fire safety regulations as experienced in the past three decades. In fact, some architectural design features, such as a double-skin building façade, does not comply with the PC in some countries in the AO regions<sup>[47]</sup>. Many green constructions failed to comply with PC. The hidden adverse effects on fire hazard for some architectural features were discussed<sup>[48]</sup>.

VGSs have been widely adopted in new green construction projects worldwide<sup>[49]</sup>. Green façades can reduce wall surface temperatures up to  $12\text{ }^{\circ}\text{C}$  in Singapore<sup>[50]</sup>. Although they have great environmental and aesthetic benefits, there are potential fire hazards related to green buildings<sup>[51]</sup>. Dried plants due to inadequate irrigation are easily ignited, and such combustibles would give very quick fire spread. Very few reports<sup>[6, 52-54]</sup> on building fires involving burning greens are available. Fires from green buildings have not yet been examined systematically. For example, very few studies have investigated the consequences of burning plants grown on green façades.

Vegetation grown along building façades provides fuel for the spread of fires. The direct action of a window flame plume would ignite plants<sup>[54-55]</sup>, including dry or dead leaves, planter boxes, foams and laminar layers of felt sheets<sup>[56]</sup>. Heat, flame, smoke and hazardous chemicals generated from burning plants can spread to different parts of the building and to nearby areas. The heat and toxicity of the

smoke can affect firefighters without appropriate protection. Scientific aspects of VGS fires<sup>[57]</sup> should be explored. Preliminary VGS fire tests with scale models were reported<sup>[58]</sup> by scale models on green plant *Cynodactylon* (Linn.) Pers. or Bermudagrass widely used in tropical and subtropical areas. Fire hazard scenarios due to window plume are confirmed to be a hazardous scenario with the following observations:

1) Window flame plume from a post-flashover room fire would act on the VGS. Flame impingement would act at the plants.

2) As wet plants are not easy to be ignited, proper irrigation is important.

3) Dry plants can be ignited readily with flame spread.

4) Burning broad leaves plants would give a bigger fire.

5) Though irrigation is important to provide wet plants, watering plants might not be allowed in dry seasons in some areas due to water conservation.

Full-scale burning tests on vertical upward fire spread over part of a real-scale 7 m tall VGS were performed and reported<sup>[59]</sup>. Three plants commonly used were burnt: *Buxus microphylla*, Fragrant Plantain Lily, and *Matteuccia struthiopteris* (results will be reported in later articles). An example of the testing results is shown in Fig.1. It is observed that fire spread over dry plants quickly, with large amount of smoke coming out.

These test results are useful for deciding fire tests for the assessment of VGSs. Appropriate fire protection, fire-fighting and rescue strategies for buildings with VGSs can then be recommended.

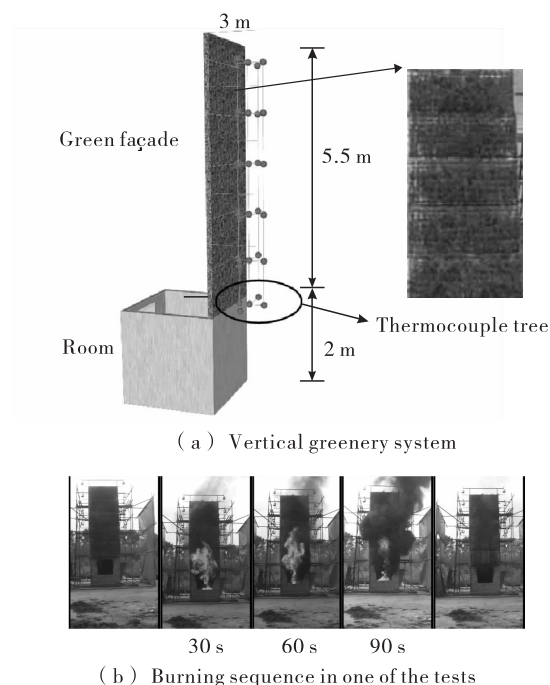


Fig.1 Burning greenery systems can give disasters

## 5 Fires in Factories Involving Innovative Technology

There are many huge industrial areas in the GBR. Many fires occurred before with a summary reported in factories making traditional products<sup>[1,60]</sup>. Many industrial areas are now focusing on innovative technology. However, the fire hazards in relation to these new technologies are not well understood.

Big fires in innovative technology factories have been reported. For example, fires in factories for light-emitting diodes (LED) have been reported all over the world. Several fires in LED factories in China were reported<sup>[61-64]</sup>. Fires occurred in the production lines or circuit boards storage areas and others. One big fire occurred in November 30, 2017 in India<sup>[65]</sup>. Fire broke out in a four-storeyed factory building manufacturing LEDs. The ground floor was used as a godown and three floors as offices. Around 250 employees worked at the factory. The top floor was used for manufacturing LED lights. It was reported that the fire was due to sudden sparks from a soldering machine on the fourth floor.

Many workers suffered from burns afterward.

It appears that there are no special requirements on factories manufacturing innovative products. Fire safety provisions in some factories even do not comply with updated fire codes. However, new manufacturing processes might have fire hazards not yet encountered before. A detailed fire hazard assessment is required but has to be supported by in-depth studies.

## 6 Bridge Fire

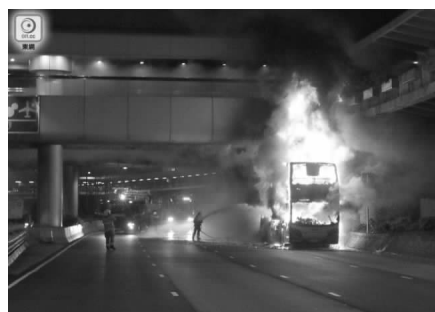
There are many bridges for vehicles, railway and even for passengers constructed in the GBA (Fig.2). An accident on burning a double-deck bus next to a footbridge<sup>[66]</sup> is shown in Fig.2. Note that burning a bus gives a heat release rate of about 10 MW.

Many Heavy Goods Vehicles (HGV) travel on some vehicle bridges, particularly those connected to certain tunnels. Upon burning HGV in an accidental fire, a high heat release rate is expected. As burning one HGV can give over 100 MW, burning several HGVs together during traffic jam gives even higher values. Burning such HGVs adjacent or under the bridges have to be watched as reported in some talks<sup>[68]</sup>. Such fire scenario was not considered until after the falling down of the bridge at Georgia, USA<sup>[69]</sup> due to burning an HGV. There were two bridge fires reported in Italy<sup>[70]</sup>, with a HGV hitting an oil tanker to give a fire, followed by an explosion. Another big fire also involved an oil tanker with explosion in Iran<sup>[71]</sup>. A car was burnt on a cable bridge in Turkey<sup>[72]</sup>. In many cases it is not known whether bridges were constructed with adequate fire resistance period. It appears that a long enough fire resistance period, say up to 4 hours, might be required in heavy traffic vehicular bridges and crowded footbridges<sup>[73]</sup>.

There were some studies on bridge under fire. However, most of the works were on smaller fires based on standard temperature time curves<sup>[74-75]</sup> with earlier design values, up to peak 35 MW<sup>[76]</sup>. Therefore, the fire behaviour of bridges with burning HGVs should be explored thoroughly. Fire codes adopted overseas might not be appropriate in the GBA because the combustibles, burning behaviour, firefighting provisions, human behaviour and responsibility of owners after having big disasters are very different.



(a) A footbridge under construction



(b) Burning a double-deck bus only under a bridge<sup>[67]</sup>

**Fig.2 A bridge can be very dangerous without adequate fire resistance**

## 7 Current Practice

As reported to the Chief Executive of the HKSAR while the principal author receiving the Gold Medal of the Hong Kong Institution of Engineers in March 2018<sup>[77]</sup>, fire engineering professionals in the AO regions are experienced to handle the design for supertall buildings, deep underground subway stations, large halls, long tunnels and green architectures for dense urban areas in the GBA. Fire officers and professionals have been trained to use PC for decades. Furthermore, firefighting and rescue strategies are based on the assumptions that the buildings satisfying the PC. Adequate education and training has been developed by the principal author for professionals, officers, owners and all related personnel in the past thirty years to carry out firefighting and rescue operations for buildings with fire safety provisions determined by PBD-FEA. Hong Kong engineers are able to cope with regular PC updates to face new challenges, and implement PBD-FEA more realistically. They are having vigorous training to handle projects using timeline analysis<sup>[23-24]</sup> with low SM in many projects.

As discussed recently about the fire hazards of green constructions<sup>[5, 7]</sup>, the challenges on fire safety only came from the officers as raised. Fire hazards identified by the officers cannot be solved satisfactorily. As a result, many green construction projects were rejected by the government. There are even more fire hazards associated with new ignition sources. Burning heaving goods vehicles (HGV) next to a footbridge can be very hazardous. Internal fire whirls which can be generated in a room fire with appropriate ventilation provision.

However, there is no systematic research to obtain the necessary data for fire hazard assessment in PBD-FEA. Even the fire safety objectives in FEA have not been investigated with thorough research. Long-term fire research is required before implementing PBD and EPBFC. It will take a long time before EPBFC can be implemented successfully, because such fire research is not even started in this part of the world.

Appropriate fire engineering education at degree and higher levels<sup>[78]</sup> are needed. Fire engineering curriculum has been introduced<sup>[78]</sup> to enable officers and professionals to understand the possible fire problems for buildings in Hong Kong. In contrast to other engineering disciplines, basic fire science should be integrated with real-life practices. Novice fire scientists without working experience in a construction site might not even understand the problem, which might be solved by common sense. It is difficult for them to communicate with the professionals.

An encouraging move is that fire officers in most of the GBA are very active in upgrading themselves. Safety codes<sup>[79]</sup> are therefore updated to provide more reasonable fire protection<sup>[74]</sup>, say in crowded railway and subway stations with parallel traders.

## 8 Conclusions

Both PBD and FEA are not yet EPBFC, and there are many problems in the implementation of them as raised years ago<sup>[80]</sup>. There must be systematic research on the fire safety objectives, acceptance criteria, engineering tools for hazard assessment, statistical fire records, verification methods and more importantly, training and education of engineering professionals. The relevant fire data for buildings with green architectural features have to be collected systematically. More funding has to be



allocated to support the fire research activities required. Furthermore, officials are suggested to familiarize themselves with the performance-based approach.

It is fortunate that no big fires have ever occurred in the PBD-FEA projects. Otherwise, the court cases, insurance claims and other affairs relating to legal responsibilities after the big fire would take years to handle. In places with strong government backup, the responsibility will be passed on to the most senior government department of that area. Consequent to several big fires occurring in the AO regions, such as the 108 h long mini-storage fire in Hong Kong in 2016, hidden fire hazards for buildings with fire safety provisions determined by the performance-based approach should be watched. For example, smoke emitted from burning light structure with fibre-reinforced polymers would affect the health of firemen in firefighting and rescue. Using small design fires much lower than that experienced in real scenarios during firefighting can lead to serious consequences. The big London fire in 2017 is a good lesson to learn and must be avoided in developing GBA.

An immediate action to take in evaluating PBD-FEA reports for new buildings is to justify the heat release rates estimated by full-scale burning tests. An acceptable scenario must be agreed on to ensure that adequate fire protection can be provided. An additional section on the effect on firefighting must be included in the PBD-FEA report. Firemen must be informed to ensure that they can take appropriate actions in firefighting. PBD-FEA projects only for reducing cost should not be allowed. A cost analysis report on fire safety provisions in those places with difficulties to comply with the fire code should be submitted to demonstrate that the objective of PBD is not for cost reduction. PBD-FEA should only be implemented when there are no fire safety codes.

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## References:

- [1] CHOW W K. Fire and explosion hazards to watch in developing big dense areas such as the Guangdong-Hong Kong-Macao Greater Bay Area[R]// 2019 International Conference on Urban Public Safety and Emergency Rescue. Changzhou: [s.n.], 2019.
- [2] CHOW W K. Fire safety in green or sustainable buildings: application of the fire engineering approach in Hong Kong [J]. Architectural Science Review, 2003, 46(3): 297-303.
- [3] CHOW W K. Performance-based design on fire safety provisions in the Far East[R]//2011 SFPE Annual Meeting: Professional Development Conference and Exposition, Engineering Technology Conference. Portland: [s.n.], 2011.
- [4] CHOW W K. Experience on implementing performance-based design in Hong Kong[R] //The 9th Asia-Oceania Symposium on Fire Science and Technology, Hefei: [s.n.], 2012.
- [5] The Fire Protection Research Foundation, National Fire Protection Association, Quincy. Safety Challenges of “Green” Buildings-Request for Proposals for Project Contractor[Z]. MA: [s.n.], 2012.
- [6] EARL T. Green construction: implications for fire safety and flame retardants[C]//25<sup>th</sup> Annual Conference on Recent Advances in Flame Retardancy of Polymeric Materials, BCC Research, Stamford: [s.n.], 2014.
- [7] YOU T G, YIN M, MARTIN D, et al. Quantification of green building features on firefighter safety: problem definition, data collection, preliminary analysis and experimental plan[C]//SFPE 10th International Conference on Performance-Based Codes and Fire Safety Design Methods. Gold Coast: [s.n.], 2014.
- [8] BABER D, GERARD R. High-rise timber buildings[J]. Fire Protection Engineering, 2014(63):10-20.

- [9]CHOW W K, NG Y W, YUE T K. Case study on high-rise residential building using CLT[C]//12<sup>th</sup> International Conference on Performance-Based Codes and Fire Safety Design Methods. Honolulu: [s.n.], 2018.
- [10]CHOW W K, NG Y W, YUE T K. Case study on high-rise residential building using CLT[J]. SFPE Fire Protection Engineering Magazine, 2018(79): 36-42.
- [11]CHOW W K. Performance-based approach to determining fire safety provisions for buildings in the Asia-Oceania regions[J]. Building and Environment, 2015, 91: 127-137.
- [12]British Standards Institute. Application of fire safety engineering principles to the design of buildings-code of practice: BS7974[S]. UK: British Standards Institute, 2001.
- [13]Building Construction and Safety Code: NFPA 5000—2006[S]. [S.l.:s.n.], 2006.
- [14]CIBSE. Guide E; Fire engineering[M]. London: The Chartered Institution of Building Services Engineers, 2019.
- [15]Guide to fire engineering approach. Practice note for authorized persons and registered structural engineers PNAP 204 [S]. Hong Kong: Buildings Department, 1998:5.
- [16]PNAP 204 Practice note for authorized persons and registered structural engineers: guide to fire engineering approach in 1990. (Re-issued under new categorization in August 2009 as Practice Note for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers)[S]. Hong Kong: Buildings Department, 2009:4.
- [17]Code of Practice for Fire Safety in Buildings 2011[Z]. Hong Kong: Buildings Department, 2012:4.
- [18]LAM C M. Fire safety strategies for the new Chek Lap Kok international airport[C]//Conference Proceedings of Asiaflam'95. Hong Kong: [s.n.], 1995.
- [19]CHOW W K. Hidden fire problems: consideration after the Fa Yuen Street big fire[J/OL]. Hot Issues in Fire Engineering, 2011.[http://www.bse.polyu.edu.hk/researchCentre/Fire\\_Engineering/Hot\\_Issues.html](http://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/Hot_Issues.html).
- [20]FAN W C. 公共安全科技的一点思考[C]//2019 International Conference on Urban Public Safety and Emergency Rescue. Changzhou: [s.n.], 2019.
- [21]CHOW W K. Appropriate upgrade of fire safety provisions in existing big transport terminals[C]//3<sup>rd</sup> International Conference Fire Safety Performance-based Design Lisbon, Portugal: [s.n.], 2018.
- [22]CHOW W K, WU M. Fire safety in big public transport terminal buildings[C]//Iberian-Latin-American Congress on Fire Safety (CILASCI 5). Porto: [s.n.], 2019.
- [23]BABRAUSKAS V, FLEMING J M, RUSSELL B D. RSET/ASET, a flawed concept for fire safety assessment[J]. Fire and Materials, 2010, 34: 341-355.
- [24]CHOW W K. Comment on 'RSET/ASET, a flawed concept for fire safety assessment' by V. Babrauskas, J.M. Fleming and B.D. Russell[J]. Fire and Materials, 2013, 37(3): 257-258.
- [25]CHOW W K, DONG X. Legislation, codes of practice and standards in Hong Kong and mainland China[M]//STOLLARD P. Fire from First Principles: A Design Guide to International Building Fire Safety. 4th ed. London and New York: Routledge, 2014: 159-175.
- [26]CHOW W K. A preliminary discussion on engineering performance-based fire codes in the Hong Kong Special Administrative Region[J]. International Journal on Engineering Performance-Based Fire Codes, 1999, 1(1): 1-10.
- [27]Australian Building Codes Board. Building Code of Australia[Z]. [S.l.:s.n.], 2014.
- [28]FAN W C, HUO R, YAO B, et al. A brief review on active fire protection engineering systems in China[J]. Journal of Applied Fire Science, 2001, 10(4): 329-342.
- [29]HUNG W Y, CHOW W K. Review on fire regulations for new high-rise commercial buildings in Hong Kong and a brief comparison with those in overseas[J]. International Journal on Engineering Performance-Based Fire Codes, 2001, 3(1): 25-51.
- [30]CHOW W K, XIA L C. Building fire codes and performance-based design in China: mainland and Hong Kong[J]. Journal of Applied Fire Science, 2005/2006, 14(3): 223-238.
- [31]CHOW W K, HU L H, YANG R X. A preliminary review on building fire codes and application procedure for new projects in China[J]. International Journal on Engineering Performance-Based Fire Codes, 2006, 8(3): 88-98.
- [32]TORERO J. Structures in fire or fires in structures: what do we need to know to achieve innovative fire safety[C]//International Fire Conference & Exhibition Malaysia (IFCEM 2012). Kuala Lumpur: [s.n.], 2012.
- [33]FEENEY M, JAMES M. Case study for a high-rise residential building using Cross-Laminated Timber (CLT)[C]//

- 12<sup>th</sup> International Conference on Performance-Based Codes and Fire Safety Design Methods, Honolulu; [s.n.], 2018.
- [34]FLEISCHMANN C. CPD lecture on “Performance-based design in New Zealand and the new verification method” [Z]. Organized by Research Centre for Fire Engineering, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, 2012.
- [35]HADJISOPHOCLEOUS G V, BENICHO N, TAMIN A S. Literature review of performance-based fire codes and design environment[J]. Journal of Fire Protection Engineering, 1988, 9(1): 12-40.
- [36]CUSTER R L P, MEACHAM B J. SFPE engineering guide to performance-based fire protection analysis and design of buildings[Z]. Society of Fire Protection Engineers and National Fire Protection Association; Massachusetts, 2000.
- [37]ANON. Proceedings of Fire Safety Asia Conference (FiSAC) 2011[C]. Suntec;[s.n.], 2011.
- [38]LO G C H. CPD lecture on “Fire Engineering in Hong Kong”, organized by Research Centre for Fire Engineering [Z]. Department of Building Services Engineering, The Hong Kong Polytechnic University, 2011.
- [39]SHI C L, ZHONG M H, TU X W, et al. Deep underground subway station fire experiment and numerical analysis [M]. Beijing: Science Publisher, 2009.
- [40]CHOW C L, CHOW W K. Heat release rate of accidental fire in a supertall building residential flat[J]. Building and Environment, 2010, 45(7): 1632-1640.
- [41]CHOW W K, CHOW C L. Green influences[J]. Fire Prevention & Fire Engineers Journal, 2003, 63: 34-35.
- [42]BEAM Society Limited. Building environmental assessment method[EB/OL]. [http://www.beamsociety.org.hk/en\\_index.php](http://www.beamsociety.org.hk/en_index.php).
- [43]HUCAL M C. LEED[R]: the Green Building Rating System. (The LEED Guide)(Leadership in Energy and Environmental Design)[J/OL]. Environmental Design &., 2004(July). <http://www.usgbc.org/leed>.
- [44]AMOÊDA R, BRAGANÇA L, MATEUS C, et al. BSA 2012-proceedings of the 1st international conference on building sustainability assessment[M]. Porto; Green Lines Institute, 2012.
- [45]CHOW W K. Building fire safety in the Far East[J]. Architectural Science Review, 2005, 48(4): 285-294.
- [46]CHOW W K. Fire engineering for high density cities[M]//NG E. Designing High Density Cities-For Social and Environmental Sustainability. London; Earthscan-James & James Science Publishers, 2009.
- [47]CHOW C L. Full-scale burning tests on double-skin façade fires[J]. Fire and Materials, 2013, 37(1): 17-34.
- [48]HUNG W Y, CHOW W K. Architecture features for the environmental friendly century[C]//Sustainable Building 2002: 3<sup>rd</sup> International Conference on Sustainable Building. Oslo; [s.n.], 2002.
- [49]KÖHLER M. Green facades-a view back and some visions[J]. Urban Ecosystems, 2008, 11(4): 423-436.
- [50]WONG N H, TAN A Y K, CHEN Y, et al. Thermal evaluation of vertical greenery systems for building walls[J]. Building and Environment, 2010, 45(3): 663-672.
- [51]MANSO M, GASTRO-GOME J. Green wall systems; a review of their characteristics[J]. Renewable and Sustainable Energy Reviews, 2015, 41: 863-871.
- [52]Department for Communities and Local Government, Ministry of Housing. Fire performance of green roofs and walls [Z/OL]. UK, 2013. <https://www.gov.uk/government/publications/fire-performance-of-green-roofs-and-walls>.
- [53]FISK R. Plant fire causes shed blaze in Castle Hill Avenue, New Addington[EB/OL]. [2019-10-10]. [http://www.suttonguardian.co.uk/news/11492126.Plant\\_fire\\_causes\\_shed\\_blaze\\_in\\_New\\_Addington/](http://www.suttonguardian.co.uk/news/11492126.Plant_fire_causes_shed_blaze_in_New_Addington/).
- [54]MCNEILAGE A. Green walls ‘need building code’ to reduce fire hazard[EB/OL]. [2019-10-10]. <https://www.smh.com.au/national/nsw/green-walls-need-building-code-to-reduce-fire-hazard-20120914-25xf1.html>.
- [55]CHOW C L. Assessment of fire hazard on glass buildings with an emphasis on double-skin façades[D]. Cambridge: University of Cambridge, 2009.
- [56]OTTELE M. The green building envelope; vertical greening[D]. Delft; Delf University of Technology, 2011.
- [57]CHOW C L, HAN S S, DAHANAYAKE K C, et al. Fire hazards with vertical greenery systems[J]. Fire Protection Engineering Magazine, 2018, 31.
- [58]CHOW C L, HAN S S, WAN Y, et al. Scale modelling observation on fire spread over vertical greenery system [C]//3<sup>rd</sup> International Conference on Fire Safety Performance-Based Design. Lisbon; [s.n.], 2018.
- [59]CHOW C L, CHOW W K. Full-scale burning on vertical greenery system[C]// Engineering Mechanics Institute Conference 2019. Pasadena; [s.n.], 2019.

- [60] YUNG W Y. Industrial fire in Southern China and experience from Hong Kong, B(Eng) research project report[Z]. Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, 2015.
- [61] Alibaba Business Circle. Experimental secret: what is the cause of LED lights explosion? [EB/OL]. (2017-07-25). <https://club.1688.com/threadview/49324301.html>.
- [62] Ore Radio Forum. LED energy-saving lamps burned continuously, the reason you can't think of would be it[EB/OL]. (2016-03-19). <http://www.crystalradio.cn/thread-844899-1-1.html>.
- [63] A sudden fire accident in a factory in Fuyong Street, Shenzhen, caused three deaths and one injury[EB/OL]. (2010-12-01). <http://news.163.com/10/1201/08/6MQAEFAK00014AEE.html>.
- [64] A fire broke out in an LED circuit board factory in Zhuhai[EB/OL]. (2014-12-24) [2019-10-10]. <http://news.jc001.cn/14/1224/849412.html>.
- [65] LED factory fire: worker suffers 95% burns[EB/OL]. (2017-11-30) [2019-10-10]. <https://timesofindia.indiatimes.com/city/noida/led-factory-fire-worker-suffers-95-burns/articleshow/61856349.cms>.
- [66] Road closed in central after KMB bus bursts into flames in the heart of Hong Kong[EB/OL]. (2019-05-11). <https://www.scmp.com/news/hong-kong/law-and-crime/article/3009860/roads-closed-central-after-kmb-bus-bursts-flames-heart>.
- [67] 隧巴中环起火 烧穿行人桥底[N/OL]. 东方日报, 2019-05-12. [https://orientaldaily.on.cc/cnt/news/20190512/00176\\_064.html](https://orientaldaily.on.cc/cnt/news/20190512/00176_064.html).
- [68] CHOW W K. About hidden fire and explosion hazards associated with modern life in dense urban areas[C]// HKIE SSC-Safety Symposium. Hong Kong: [s.n.], 2018.
- [69] ATLANTA M. No sign of terror in highway fire[EB/OL]. (2018-03-31). [http://www.hartfordcitynewstimes.com/video/atlanta-mayor-no-sign-of-terror-in-highway-fire/youtube\\_0aa169ac-2355-5d75-ae87-59753167fbcc.html](http://www.hartfordcitynewstimes.com/video/atlanta-mayor-no-sign-of-terror-in-highway-fire/youtube_0aa169ac-2355-5d75-ae87-59753167fbcc.html).
- [70] Tanker truck explodes after collision with lorry near Bologna airport[EB/OL]. (2018-08-06). <https://www.theguardian.com/world/2018/aug/06/italy-tanker-truck-explodes-on-motorway-near-bologna-airport>.
- [71] 21 killed in a bus crash on a road in central Iran[EB/OL]. (2018-09-18). <http://www.daily-sun.com/post/336989/2018/09/18/21-killed-in-a-bus-crash-on-a-road-in-central-Iran>.
- [72] ROBINSON J, SLOANE M, BETTI R, et al. Experimental investigation of the post-fire mechanical behavior of high-strength steel suspension bridge wires[C]//Engineering Mechanics Institute Conference 2019. Pasadena: [s.n.], 2019.
- [73] Motorway bridge collapses in Genoa, Italy, killing about 30[EB/OL]. (2018-08-15). <https://www.scmp.com/news/world/europe/article/2159698/dozens-dead-after-motorway-bridge-collapses-genoa-italy>.
- [74] CHOW W K. Necessity of upgrading fire safety provisions in operating big transport terminals through scientific research[R]//1<sup>st</sup> National Seminar on Thermal Safety Science and Technology (NSTSST). Hefei: [s.n.], 2018.
- [75] GARLOCK M, PAYA-ZAFORTEZA I, KODUR V, et al. Fire hazard in bridges: review, assessment and repair strategies[J]. Engineering Structures, 2012, 35: 89-98.
- [76] AZIZ E M, KODUR V K, GLASSMAN J D, et al. Behaviour of steel bridge girders under fire conditions[J]. Journal of Constructional Steel Research, 2015, 106: 11-22.
- [77] CHOW W K. Response to chief executive, Hong Kong institution of engineers annual dinner (prize presentation ceremony)[Z]. Hong Kong: Convention and Exhibition Centre, 2019.
- [78] CHOW W K. The need for fire engineering education in Hong Kong[J]. International Journal for Fire Science and Technology, 2012, 31(2): 49-62.
- [79] Fire Services Department, Hong Kong Special Administrative Region. Guidelines on formulation of fire safety requirements for new railway infrastructures[Z]. [S.l.:s.n.], 2013.
- [80] KONG K S M, CHOW W K. Possibility of using engineering performance-based fire codes for higher education institutes[C]//One-day Symposium on Advances in Building Services. Hong Kong: [s.n.], 2000.

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