Fire Safety Management System in Modern High-rise Buildings
- Hong Kong Perspective

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ABSTRACT

The erection of 7627 blocks of high-rise building within the territory of 1092 km\(^2\) makes Hong Kong popular and famous for it’s ‘Concrete Jungle’ in the world. It has long been a question of life safety and property protection in fire situations of these buildings. Bitter experience learnt from the major building fires in the past twelve years together with the result of a territory-wide building survey within the period are discussed in this paper. In addition, the fabulous, complex and innovative building designs using fire engineering approach to meet with these building features are other great challenges to building fire safety. To secure the overall fire safety in these buildings, a total fire safety concept by employment of the fire safety management system, combined use of the hardware (active and passive fire protection systems) and software (building management and knowledge base of the management staffs) and a safety audit system to ensure mitigation to the potential risks posed are also introduced and discussed.

KEYWORDS
High-rise building, fire engineering approach, active and passive fire protection systems, fire safety management system, fire safety audit system

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1. INTRODUCTION

Hong Kong is a Special Administration Region of mainland China. Its territory area is just 1092 km² with a population of seven millions. High-rise building is defined in the Code of Practice for Minimum Fire Service Installation as those structures when building height reach thirty metres [FSI 2005]. The development and the trend to build more high-rise buildings is the only solution to the problem. Because of the trend, controlling authorities and building safety professionals raised great concerns on the safety of people staying in these high-rise buildings, in particular we still have such buildings erected in this ‘concrete jungle’ for more forty year. Not to say the big fires happened in the past twelve years claimed tens of lives and injuries. Despite a number of follow-up actions have been taken by the controlling authorities including the enactment of laws, it appears that the subsequent good fire safety practices might have been deteriorated as reflected in the increased number of fires at institutional buildings and the housing estates which are generally high-rise [FSD 1998-2007]. It is true that new buildings when we first move-in are considered safe but might not be true years after. To keep these buildings in good and safe condition, maintenance and good management to these buildings are solutions for the purpose. To meet with the objective, implementation of the fire safety management system and monitored by a fire safety audit system will greatly secure the overall safety of the buildings.

2. CONCEPT OF FIRE SAFETY IN BUILDINGS

The safety concept is to maintain building fire safety to a reasonably practical standard so as to provide a safe place for the people to live in and protect property in the building. To ensure the purposes can be met, we have to consider the following basic controlling measures:

- Control ignition of materials
  - ignition sources
  - ignitability of the material
  - combustibles

- Control fire spread
  - combustibility
  - fire propagation
  - spread of flame

- Control of fire resistance
  - building materials
  - non-structural material – fixtures

- Control illegal building works
  - removal or addition of building works
  - alteration of building works

- Controlling and enforcing follow-up and subsequent actions in the routine maintenance work are properly carried out especially those required by laws.
The controlling measures mentioned required a systematic and manageable approach to handle. This involves a management team to manage the defined objectives and execute and monitor the measures. However in defining the objectives, the management has to be well conversant with the fire safety concept or in a more generic representation by the total fire safety concept [Chow 2004].

The principle of the concept involves the following stages:

- Identification of risks from the building and building environment;
- Using the passive fire protection and active fire protection systems to mitigate the identified risks;
- Since these protection systems require physical management actions to follow up and will therefore oversee by the fire safety management system.

This concept can be represented by the following figure:

![Fire Safety Management System](image)

**Figure 1:** Total fire safety concept diagram

3. MAJOR FIRE SAFETY PROBLEMS AND IRREGULARITIES IN EXISTING BUILDINGS

To have a closer look into the issues, I have selected some past major fire incidents and a building survey conducted by Hong Kong Fire Services Department for discussion.
Table 1. Major fires in the past 12 years

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>Type of Building</th>
<th>Injuries/Fatalities</th>
<th>Major irregularities/problem identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov./1996</td>
<td>Commercial 15-storey</td>
<td>80/41(*)</td>
<td>• Replacement of metal lift doors by wooden partition during maintenance work in lift lobbies; Unsatisfactory building management</td>
</tr>
</tbody>
</table>
| Jan./1997  | Commercial 20-storey | 13/17              | • Non-functioning of the sprinkler system; 
• Wedged-open of lobby protection doors; 
• Unsatisfactory building management |
| April/1997 | Residential 20-storey | 37/9               | • Storage of plastic foam containers and commercial commodity; 
• Wedged-open/defective smoke lobby doors; 
• Unsatisfactory building management |
| May/2007   | Industrial 23-storey  | 6/1(†)            | • Sprinkler system failed to work |
| Aug./2008  | Composite 15-storey | 55/4(**)           | Major irregularities include(‡): 
• Wedged-open lobby protection doors; 
• Sub-standard smoke lobby door; 
• Large amount of combustions used in the ‘Karaoke Box’ |

(*) Including one fire fighter
(**) Two fire-fighters
‡ The irregularities were based on the information from the media and my personal judgment. A death inquest will be convened in the coming months.

4. TERRITORY-WIDE BUILDING SURVEY ON FIRE SAFETY [FSD 1998]

Subsequent to the major fire incidents in 1996 and 1997 (Table 1), Fire Services Department conducted a territory-wide fire safety survey with a view to improve the fire safety in the community by analyzing the survey results and formulated a package of administrative and legislative measures. During the survey, a total of 27148 nos. of pre-1987 building were inspected. Survey data collected were analyzed by giving a Fire Safety Index which was composed of Fire Services Installation (FSI) Index on the provision and maintenance of the FSIs and Fire Safety Management (FSM) Index on the condition of the fire safety management in the buildings. The inspection result was summarized in the following diagram and tables.
Figure 2: Diagram showing the distribution on the unsatisfactory surveyed buildings

Table 2. Buildings required improvement

<table>
<thead>
<tr>
<th>Buildings required</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectification of FSI defects</td>
<td>1,984</td>
<td>7%</td>
</tr>
<tr>
<td>Upgrading of FSI</td>
<td>19,152</td>
<td>70%</td>
</tr>
<tr>
<td>Improvements to fire safety management</td>
<td>10,858</td>
<td>39%</td>
</tr>
<tr>
<td>Improvements to both FSI and FSM</td>
<td>10,361</td>
<td>38%</td>
</tr>
</tbody>
</table>

Table 3. Statistics on Fire Hazards Reported by the Survey Team

<table>
<thead>
<tr>
<th>Type of Hazard</th>
<th>Industrial</th>
<th>Commercial</th>
<th>Domestic</th>
<th>Institutions</th>
<th>Composite</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floating obstruction</td>
<td>124</td>
<td>109</td>
<td>215</td>
<td>23</td>
<td>2,091</td>
<td>2</td>
<td>2,564</td>
</tr>
<tr>
<td>Locked roof/ground exit</td>
<td>61</td>
<td>88</td>
<td>411</td>
<td>32</td>
<td>1,950</td>
<td>6</td>
<td>2,548</td>
</tr>
<tr>
<td>Defective/ Missing smoke stop door</td>
<td>254</td>
<td>116</td>
<td>170</td>
<td>24</td>
<td>1,988</td>
<td>4</td>
<td>2,556</td>
</tr>
<tr>
<td>Metal gate erected across means of escape</td>
<td>54</td>
<td>7</td>
<td>156</td>
<td>0</td>
<td>658</td>
<td>0</td>
<td>875</td>
</tr>
<tr>
<td>Defective FSI</td>
<td>270</td>
<td>71</td>
<td>228</td>
<td>27</td>
<td>1,381</td>
<td>7</td>
<td>1,984</td>
</tr>
<tr>
<td>Total</td>
<td>763</td>
<td>391</td>
<td>1,180</td>
<td>106</td>
<td>8,068</td>
<td>19</td>
<td>10,527</td>
</tr>
<tr>
<td>Fire Hazard Abatement Notices issued</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1449</td>
</tr>
</tbody>
</table>
From the given details on existing buildings, either from the major fire incidents or the building survey, we can summarize the irregularities into three major categories, i.e. failure in active fire protection systems (e.g. defective sprinkler, detection system etc.), failure in passive fire protection system (e.g. removal of protected lobbies, defective lobby doors etc.) and unsatisfactory fire safety management system (e.g. wedge open of lobby doors, floating obstruction in common area, locked exits etc.) in the buildings.

5. IMPROVEMENT OF THE TOTAL FIRE SAFETY CONCEPT MODEL

Since the early nineties, Buildings Department and Fire Services Departments of Hong Kong accepted the application of the performance-based building designs due to complex nature, innovative, or special building feature of the nowadays buildings provided that the application of fire engineering design as an alternative to the prescriptive provisions providing this approach, have to observe the following fire safety concerns raised by the Director of Fire Services [FSI 2005]:

- The design will not provide inferior safety standard to the prescriptive requirements;
- The methodology for application of the fire engineering approach should outline a structured fire engineering principle(s) to the assessment of total building fire safety effectiveness; and
- To achieve the pre-identified design objective(s) having taken into consideration of the objectives of fire service installations and equipment for the protection of life and property of the people within the buildings and the firefighting personnel in the event of emergency situations.


Fire Safety Management System for high-rise buildings

- Maintenance on existing provisions of fire protection systems
  - Including the annual inspections as required by laws
  - Code-complied designs
  - Performance-based designs
  - others

- Routine inspection on existing provisions
  - Active fire protection system
  - Passive fire protection systems
  - Building fire safety management
  - others

- Staff training
  - Familiarization of the emergency procedure
  - Staff duty and responsibility
  - Appropriate use of first-aid fire fighting equipments
- To be familiarized with the fire protection systems
- General knowledge in fire safety
- Regular fire drills with staff and occupants
- Identification of fire hazards
- others

- Emergency actions
  - Emergency procedure to be followed, including call to the emergency departments, fighting the fire if consider safe
  - Inform and assist the occupants to evacuate immediately
  - Assist the fire fighters in emergency situation
  - others

- Other activities

In view of the new building designs and the known common irregularities in building and building management, it is therefore in need of a new fire safety concept with an audit system to secure the effectiveness in executing/enforcing the fire safety management system. The structure of the new system on total fire safety concept is modified as below:

![Modified Total Fire Safety Concept diagram](image)

**Figure 3: Modified Total Fire Safety Concept diagram**

### 6. THE FIRE SAFETY AUDIT SYSTEM

The audit system is a system used to monitor and ensure the effective operation of the established fire safety management system. It offers a practical way to identify the potential hazards due to inadequate maintenance, inspection on fire service installations and unsatisfactory fire safety management. The priority/weight of the basic event in the fire safety management system indicates its severity and impact of the event on life safety and property damaged. A team of fire experts, professionals might be required to define/decide the acceptable ranking of each event. Some decision making models such as analytical hierarchy process (AHP), Delphi etc. can be adopted to evaluate the priority according to the judgements from the experts based on variant factors including type of building occupancy, provision of fire service installations, characteristic of occupants etc. To evaluate the inadequacy or deficiency of the fire safety management system, physical inspection or validation test of the sub-system can be used to give the score of each event. The approach
provides a quantitative model to evaluate the performance of existing fire safety management system and decide the remedial action to be taken for improvement.

It seems to be a complicated system in achieving the goal because of the involvement of different professionals in drawing up the decision at the beginning. However, once the decision has been made, it is just a matter of simple calculation with individual inspection result. In fact, there are some tools (computer software) in the market can help. The structure of the audit system is shown as below.

![Diagram of Fire Safety Audit System](image)

**Figure 4: Diagram of Fire Safety Audit System**

### 7. THE ANALYTICAL HIERARCHY PROCESS (AHP) [Saaty 2000]

The analytic hierarchy process (AHP) was developed by Professor Thomas L. Saaty in 1970s. The AHP provides a comprehensive framework for structuring a complex system and quantifying its elements. It is best suited for multi-criteria decision-making problems that yield priorities for decision alternatives. The process to establish such a fire safety audit system is briefly described as follows:

- **Step 1:** Set the fire safety level as the top objective of the fire safety audit system;
- **Step 2:** Breaking down the system into a hierarchy of decision categories and independent decision elements (attributes);
- **Step 3:** Seeking expertise advice to make pairwise comparisons of the decision elements and determine the importance and impact of each element on the fire safety level;
- **Step 4:** Synthesize the comparisons to get the local priorities of the elements with respect to each category/top objective (Local priority);
- **Step 5:** Determine whether the input data satisfies a “Consistency Test”. If it is not satisfactory, return to Step 3 and repeat the pairwise comparisons process; and
Step 6: Summarize the results to produce the overall priority of each decision elements (Total priority).

After deriving the overall priority of the decision elements, site inspection and validation test can be conducted to evaluate the performance and functions of existing provision of the sub-system as defined in the fire safety audit system. Its performance can be indicated in the numerical score for a given range (i.e. 1~100 indicates the performance/function from worst to best). Finally, the fire safety level of the building can be evaluated as follows:

**Fire Safety Level (L)**

<table>
<thead>
<tr>
<th>1) Maintenance on existing provision of fire prevention system</th>
<th>Local Priority</th>
<th>Total Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance on Sprinkler System</td>
<td>$k_{11}$</td>
<td>$R_1 \cdot k_{11}$</td>
</tr>
<tr>
<td>Maintenance on Detection System</td>
<td>$k_{12}$</td>
<td>$R_1 \cdot k_{12}$</td>
</tr>
<tr>
<td>Maintenance on Smoke Extraction System</td>
<td>$k_{13}$</td>
<td>$R_1 \cdot k_{13}$</td>
</tr>
<tr>
<td>Others</td>
<td>$k_{1m1}$</td>
<td>$R_1 \cdot k_{1m1}$</td>
</tr>
<tr>
<td>2) Inspection on existing provision of fire prevention system</td>
<td>$R_2$</td>
<td>$R_2 \cdot k_{21}$</td>
</tr>
<tr>
<td>Inspection on escape route</td>
<td>$k_{21}$</td>
<td>$R_2 \cdot k_{21}$</td>
</tr>
<tr>
<td>Inspection on building layout</td>
<td>$k_{22}$</td>
<td>$R_2 \cdot k_{22}$</td>
</tr>
<tr>
<td>Inspection on building occupants</td>
<td>$k_{23}$</td>
<td>$R_2 \cdot k_{23}$</td>
</tr>
<tr>
<td>Others</td>
<td>$k_{2m2}$</td>
<td>$R_2 \cdot k_{2m2}$</td>
</tr>
<tr>
<td>3) Staff training</td>
<td>$R_3$</td>
<td>$R_3 \cdot k_{31}$</td>
</tr>
<tr>
<td>Staff duty and responsibility</td>
<td>$k_{31}$</td>
<td>$R_3 \cdot k_{31}$</td>
</tr>
<tr>
<td>Appropriate use of fire extinguishing equipments</td>
<td>$k_{32}$</td>
<td>$R_3 \cdot k_{32}$</td>
</tr>
<tr>
<td>Familiar with the fire prevention system</td>
<td>$k_{33}$</td>
<td>$R_3 \cdot k_{33}$</td>
</tr>
<tr>
<td>Others</td>
<td>$k_{3m3}$</td>
<td>$R_3 \cdot k_{3m3}$</td>
</tr>
<tr>
<td>4) Emergency actions</td>
<td>$R_4$</td>
<td>$R_4 \cdot k_{41}$</td>
</tr>
<tr>
<td>Identify the fire hazards and fire causes;</td>
<td>$k_{41}$</td>
<td>$R_4 \cdot k_{41}$</td>
</tr>
<tr>
<td>Inform the occupants to evacuate immediately</td>
<td>$k_{42}$</td>
<td>$R_4 \cdot k_{42}$</td>
</tr>
<tr>
<td>Assist the fire fighters</td>
<td>$k_{43}$</td>
<td>$R_4 \cdot k_{43}$</td>
</tr>
<tr>
<td>Others</td>
<td>$k_{4m4}$</td>
<td>$R_4 \cdot k_{4m4}$</td>
</tr>
</tbody>
</table>

Fire safety level (L) of the building can be estimated as:

$$L = \sum_{j=1}^{N} \sum_{s=1}^{m_j} R_j k_{js} x_{js}$$

Where $R_j$ is the local priority of the $t$-th category;

$k_{js}$ is the local priority of the $s$-th item in the $t$-th category;

$x_{js}$ is the score of the $s$-th item in the $t$-th category, it is obtained from physical inspections according to check list/s prepared in the fire safety management system;

$N$ is the total number of categories in the fire safety audit system;

$m_t$ is the total number of the items in the $t$-th category;
8. CONCLUSION

The total fire safety concept allows the building management to exercise their duties and responsibilities in a more systematic and effective manner. The application of an audit system is just another management tool with a view to secure the safety to both people and properties in nowadays complex, innovative, and tall buildings. The success in meeting the ultimate fire safety objectives relies on the joint efforts of the stakeholders, developers, building professionals and the government bodies. Finally, I think we would agree that new buildings with legal occupation permit would be very safe for us to live in, yet human factors are the main considerations in fulfilling and maintaining the overall safety of the building as well as this fire safety concept.

9. REFERENCES

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