ON EVALUATING BUILDING FIRE SAFETY FOR BUSINESS OCCUPANCIES

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ABSTRACT

Fire safety evaluation for business occupancies in Hong Kong is studied in this paper. Local fire safety codes were briefly outlined and compared with the safety parameters of the Fire Safety Evaluation System, National Fire Protection Association (NFPA-FSES). Main differences in the rating of flame spread for interior finishes, different views on calculating the travel distances for means of escape, and classification of dead-ends are identified. Based on the study, a fire safety ranking system is proposed by assigning possible scores to different attributes.

1. INTRODUCTION

Consequent to several big building fires in the past years [e.g. 1], people are now starting to concern about fire safety. New fire codes [2-6] are implemented. Though there is not yet engineering performance-based fire codes [e.g. 7], the engineering approach would also be considered [8]. The Authorities are now starting to review the fire safety aspects and the fire protection systems installed in existing buildings [9]. However, it is impossible to implement codes which are not supported by advanced research and development works.

Out of all types of building uses, 'business occupancies' [10] including prescribed and specified buildings for offices, business trades, supermarkets, banks or any entertainment [6], should be studied urgently. Occupants are supposed to be awake and alert in these buildings. However, they might not be so familiar with the building environment as in their homes, depending on the business nature [11]. There might be crowds of people staying in there and visitors might even have difficulties in locating the toilet. How about finding the escape routes in case of fire?

In this paper, how fire safety provision for business occupancies should be upgraded is investigated. The local fire codes [2-5] were reviewed to give a clearer picture. The fire safety evaluation system proposed by National Fire Protection Association (NFPA), labeled as NFPA-FSES [12-15] in this paper, was studied. Differences between the NFPA-FSES and the local fire codes were pointed out. Based on the study, points to note in working out a ranking system [16-19] for assessing fire safety for local buildings used for business occupancies were illustrated.

2. REVIEW OF LOCAL FIRE SAFETY CODES

Building fire safety is ensured by the implementation of various statutory regulations on passive building protection and on the provision of active fire services installations. The safety aspects on building structures and evacuation routes are taken care of by the Buildings Department (BD); and the active fire protection systems (or fire services installations) by the Fire Services Department (FSD).

- Passive building protection is based on:
  - Buildings Ordinance, Chapter 123 [20].
  - Building (Planning) Regulations, Chapter 123 subsidiary legislation [21].
  - Code of Practice for Means of Access for Firefighting and Rescue (MoA code) [2].
  - Code of Practice for Fire Resisting Construction (FRC code) [3].
  - Code of Practice for the Provision of Means of Escape In Case of Fire (MoE code) [4].

  Under the Buildings Ordinance (Cap. 123), design layouts of the premises would not be approved by the Building Authority if they do not meet the minimum requirements as stated in the codes. For example, requirements described in the FRC code are:

- Compartmentation design with the spaces enclosed by fire barriers on all sides.
- The fire-resistance period (FRP) of the construction should be long enough to stand a fire with a certain severity calculated from the fire load; and also long enough for occupants to evacuate.

In the MoE and MoA codes, protected means of escape are protected corridors, lobbies and staircases.

- Fire services installations are based on the key references:

  - Code of Practice for Minimum Fire Service Installations and Equipment and Inspection and Testing and Maintenance of Installations and Equipment (FSI code) [5].
  - Fire Services Ordinance (Cap. 95) [22].
  - Fire Service (Installations and Equipment) Regulations (Cap. 95 sub. leg.) [23].
  - Updated FSD Circular Letters for new changes [e.g. 24].

  Fire services installations should be provided to minimize fire damage, protect life and property. The systems are used to detect and extinguish fire, give warnings and ensure safe egress of occupants. There are different requirements for different premises with different functions, with the minimum installations specified in the FSI code. The FSI code itself is updated frequently, with the latest version appeared in 1998. Circular Letters would be issued when there are new requirements or revisions before the new version of FSI code is released [e.g. 24].

  Typical fire services installations required for existing premises such as basement storeys, low-rise and high-rise commercial buildings are [5]:

  - Water based systems including fire hydrant/ hose reel systems, and automatic sprinkler systems.
  - Non-water based systems such as gas protection systems and smoke management systems.
  - Detection and alarm systems.
  - Others such as emergency generators, emergency lighting, exit signs, etc.

3. NFPA 101A GUIDE ON ALTERNATIVE APPROACHES TO LIFE SAFETY

The fire safety evaluation system (FSES) [12,13] is a schedule approach developed to determine equivalence to the NFPA Life Safety Code [12]. This allows an alternative approach for design to satisfy the regulation if they provide the same level of fire safety, i.e. an equivalent concept to the U.S. codes for promoting economical upgrading of fire safety. The objective is to compile an equivalent system that is easily workable and presents useful information for the amount of effort paid, i.e. the result is to see whether the design complies or not with the codes.

The most important part of NFPA-FSES is on the fire safety parameters introduced and scores assigned to each parameter under different conditions. In the NFPA-FSES for business occupancies, 12 parameters are identified. As classified by NFPA 101 [12,13], business occupancies are used for transactions and mercantile such as government offices, adult instructional facilities and classrooms buildings under 50 persons. The 12 parameters are on assessing: construction, segregation of hazards, vertical openings, sprinklers, fire alarm, smoke detection, interior finish, smoke control, exit access, exit system, corridor/ room separation (compartmentation) and occupant emergency program. In fact, these give some views on the items to be considered in the fire safety code.

- Parameter FSES 1 - Construction

  This safety parameter is mainly used to determine the effects of the construction types and building heights on the safety of the occupancies. According to NFPA 220 Standard [25], building construction is classified as noncombustible (Types I and II) and combustible (Types III, IV and V).

- Parameter FSES 2 - Segregation of hazards

  The charges against non-segregated areas are determined by four steps:

  - Step 1: Identify the hazardous areas

  Hazardous areas are spaces with dangerous storages or abnormal office activities so that there is a potential of producing a fully-developed fire.

- Step 2: Determine the level of hazard

The levels of hazard are classified into two levels of structurally endangering and nonstructurally endangering.

- Step 3: Determine the fire protection provided

After the above two steps, the fire protection to be provided has to be determined. There are two types of fire protection: automatic sprinklers or other appropriate extinguishing systems; and a complete fire enclosure with sufficiently long FRP. Those complete fire enclosures for segregation hazardous areas shall include:

(i) structural framing members;
(ii) partitions; or
(iii) fire protection rated doors separating the hazardous areas.

If only one type of provisions (i) to (iii) is provided, the hazardous area is classified as having single protection.

Parameter values would be assigned based on whether there are provisions of necessary fire protection.

- Step 4: Determine the degree of deficiency and assign parameter values

The parameter value is determined by the degree of deficiency of the hazardous areas based on whether they are structurally endangering or nonstructurally endangering. No deficiency, single deficiency or double deficiency will be marked, depending on whether there are no protection, with only sprinkler protection, with only fire-resistive enclosure, or with both sprinklers and fire-resistive enclosure. Segregation from exit routes or exposed exit system is considered.

- Parameter FSES 3 - Vertical openings

Vertical openings are penetrations through floors such as exit stairways or ramps, inclined escalators or vertical hoistways for elevators and conveyors, vertical shafts for pipes or ducts of the building services systems. Marks will be assigned, depending on whether they are open (or with incomplete enclosure), or enclosed with appropriate fire resistance structure.

The openings are classified as ‘open’ if they are unenclosed; or enclosed but have doorways without doors; or with unprotected openings other than doorways; or with some materials without any sustained fire stopping capabilities. Parameter values will be determined by the number of stories that are connected by vertical openings in the open (or incomplete enclosure); or determined by the FRP for those openings that are enclosed with fire barriers such as wall or partitions.

- Parameter FSES 4 - Sprinklers

Sprinklers must be equipped with an automatic alarm, and assessment is on whether the entire or part of the building is equipped.

- Parameter FSES 5 - Fire alarm

Fire alarm should be installed to provide indication and warning to ensure life safety. Credits will be given to those notifying the Fire Department.

- Parameter FSES 6 - Smoke detection

Activated smoke detectors should sound the alarm throughout the zone of origin. Their locations inside the building will determine the marks.

- Parameter FSES 7 - Interior finish

Classification is based on the flame-spread ratings of interior finish tested with NFPA 255 [26]. Interior finishes for both the exit routes and the rooms/suites would be assessed together. Classes A to C are classified for interior wall and ceiling finish, and classes I and II for interior floor finish.

- Parameter FSES 8 - Smoke control

Smoke control is assessed mainly according to whether smoke barriers are provided:

- None

No smoke barriers are provided.

- Passive

With continuous smoke barriers which might not necessarily have a fire resistance rating, but might have protected openings.

- Active

Should be tested and accepted to have no smoke leakage between compartments or zones. Occupancies possessing the active smoke control system are required to provide sprinklers for the whole building.

- Parameter FSES 9 - Exit access

  Dead-end is a corridor that affords access having only one direction to a required exit. The charge for dead-end access is a key element. If there are no dead-ends longer than 50 feet (about 15 m), the travel distance will be assessed.

- Parameter FSES 10 - Exit system

  Exit systems are the paths of travel from a room to outside. Multiple routes are assessed and there are two cases where occupants can select two separate means of egress routes to outside. Deficiency would be marked if the system fails to satisfy the requirement under NFPA 101 [12,13].

- Parameter FSES 11 - Corridor/room separation (compartmentation)

  The quality of separation between two rooms and the corridor would be assessed. Levels of protection are classified as:

  - incomplete,
  - smoke resistive,
  - fire resistive, or
  - there are no separation at all.

- Parameter FSES 12 - Occupant emergency program

  This is determined by the number of fire drills practiced every year.

Of the above 12 parameters, 8 parameters are on calculating a building's fire control score, and 10 for an egress score. Adding the 12 scores together will give a general fire safety score.

4. COMPARISON OF SAFETY PARAMETERS IN NFPA-FSES WITH THOSE APPEARED IN LOCAL CODES

- FSES 1: Construction

  Non-combustibles and combustibles are classified under NFPA 220, Standard on Types of Building Construction [25]. Non-combustibles are materials that will not ignite, burn, support combustion and release flammable vapor when subjected to fire or heat. Those materials passing the American Society for Testing and Materials (ASTM) E 136 [27] are non-combustibles. Limited-combustibles are those not complying with the definition of non-combustible materials, and have a potential heat value not exceeding 8141 $kJkg^{-1}$. Those failing the ASTM E 136 [27] with increase in combustibility and flame spread rating are combustibles.

  In comparing with the local FRC code, there are clear descriptions in the fire resistance construction [28]. Except the testing standards, awareness on the fire safety of structural elements are similar.

- FSES 2: Segregation of hazards

  The fire load density (FLD) is taken as an important risk factor as it would affect the fire severity. Whether the hazard levels are structurally endangering or not depends on the relative values of the FRP and the fire severity which is computed from the fire load in a room of a given geometry.

  For non-structurally endangering hazard level, the possibility of flashover is estimated from a curve plotting room area against the possible burning rate. Burning rates per unit area for the combustibles such as upholstered furniture can be assessed by some recommended data. The key point lies on assigning a burning area to get the total burning rate. If the burning rate would lead to flashover, then it is classified as a structurally endangering level. Duration of fire is the important factor in structural fire resistance, not to exceed the FRP.

  The next part is to determine whether there are sprinklers or structural partitions. If both are provided, this will be rated as no deficiency.

  Therefore, this part depends on the FLD, room geometry including areas and openings, burning rate, burning area, and flashover. All these required good knowledge in fire science. Most of these terms are not yet put in the local fire codes. However, in using the engineering approach on local projects, heat release rates of a design fire are assessed many times, and useful experience can be gained. For example, selecting the design fire for an office, say 0.5 MW, should have good reasons for justifying the figure. Note that an acceptable design fire for one building may not be acceptable in another.

- FSES 3: Vertical openings

This includes shafts for building services, as well as stairs and lifts. For a 'space' or 'incomplete enclosure' opening, the number of floors connected to the opening is important. For this configuration, smoke spreading is the first point to consider, followed by the possibility of igniting combustibles in other levels due to spreading of fire. For an enclosed opening, the protection of openings is the 'key' and so FRP is an important parameter.

This point has not yet been laid down clearly in the code. However, there are some requirements on ventilation openings, heights, etc. in the ventilation code.

- FSES 4: Sprinklers

This requirement is similar to the local FSI code on believing that installing sprinkler system would give good protection. A similar requirement is stated in the FSI code that the sprinkler should be linked to an alarm gong.

Higher marks are assigned in the NFPA Life Safety Code [12] to fast response type of sprinkler than a standard type. This point has to be investigated further for local condition as activating a sprinkler before evacuation of occupants might be dangerous. The situation of people being exposed to hot steam generated by the fire should be reviewed carefully.

- FSES 5: Fire alarm

Providing fire alarm is very important and it is required in the local FSI code.

- FSES 6: Smoke detection

This is regarded as an important part in the local FSI code.

- FSES 7: Interior finish

In the NFPA Life Safety Code [12], the flame-spread ratings of interior finish materials tested under NFPA 255 [26] is important. In NFPA 255, there is a horizontal duct of 7.62 m long, and with a section of 4.51 m by 3.05 m. Two gas burners are placed at the 'fire end', and the other end is the 'vent end'. Samples of about 7.32 m and 5.14 m long are fixed at the ceiling of the duct. Upon ignition of the materials, distances of the flame spreading at different times are measured through the observation windows. The flame-spread rating is calculated from the measured flame distance/time curve, based on some formulae.

In the local requirement, materials would be tested under the British Standard (BS) 476 Part 7 on the surface spread of flame [29]. The sample is subjected to a furnace of size 1 m by 1 m and kept at 1000°C. The flaming condition would be very different from the NFPA 255 [26].

However, in applying the engineering approach, other flame spreading standards should be considered where necessary [e.g. 30,31]. In fact, this point should be reviewed to decide whether more updated full-scale burning tests such as the room-corner fire test [32] have to be specified in the local codes.

- FSES 8: Smoke control

This part is emphasized in the local FSI code with the space volume being an important factor. However, the geometry of the space was not considered. This might not be so good for atria. Note that two atria of same volume but different shapes would have different smoke filling time [33,34].

- FSES 9: Exit access

This is an important part in both NFPA Life Safety Code [12] and local codes. However, dead-ends and travel distance are not calculated in the same way. Both factors would affect the egress score and so should be considered carefully. The means of escape and means of access are described separately in the local codes, indicating their importance.

- FSES 10: Exit system

Again, this is considered as important in the local codes.

- FSES 11: Corridor / Room separation (compartmentation)

This is on compartmentation and confinement of the fire. Both local codes and NFPA Life Safety Code [12] considered this as very important.

- FSES 12: Occupant emergency program

This is on fire safety management and should be considered carefully. It is suggested to keep a 'fire safety manual' in the new British Standard on Fire Safety Engineering [35].

5. FIRE SAFETY RANKING SYSTEM (FSRS)

A fire safety ranking system (FSRS) [e.g. 19] can be worked out to assess the safety level of each unit concerned. This is similar to a "ranking" method [36] on fire risk analysis. "Attributes" identifying the ingredients of fire safety are listed for providing means to assess the goal achievements [16]. Simplified but robust models for heuristic decision-making are then developed by applying multi-attribute evaluation.

There are several ways in working out the attributes in a FSRS for local use:

(a) Based on fire codes

A FSRS can be worked out by following the local fire codes, say giving full marks for those satisfying the new codes. However, codes implemented at different times might be different. For example, in the recent proposal for karaokes [37], the requirement on corridor width had been changed from 0.9 m to 1.05 m and then 1.2 m. Therefore, those old karaokes passing earlier requirements have to upgrade their fire safety provisions to satisfy the new codes within a transition period. This might be unfair to the owners as putting in new fire services installations would disturb their normal business.

An alternative approach is to have different marks assigned to different attributes of the FSRS [19]. A given attribute might have the upper limit divided into different ranges with different marks assigned for the ease of further mathematical analysis. The FLD might be divided into different intervals from 0 to the upper limit of 1135 MJm^{-2} in local codes with different marks assigned.

(b) Based on Fire Science and Engineering

A FSRS can be set up by referring to hazard assessment on different building designs. However, criteria [35] have to be set up. For example, parameters can be worked out as:

- Time budget for compartment fire
  - Time for the smoke layer to move down to the clear height
  - Time to flashover
  - Time to tenability limit

- Time budget for fire services installations
  - Time to detect a fire
  - Time to sound the alarm
  - Time to produce steam at harmful levels for water systems
  - Time to activate sprinkler and time to extinguish a fire if there is a sprinkler system
  - Time delay before discharging gas for gas protection systems

- Time budget for occupants to evacuate [35]
  - Recognition time to response to alarm
  - Response time
  - Travel time
  - Time to make decision to escape
  - Time to evacuation

- Heat release rate

  A question [38] used to be asked is:

  How big is the fire?

  The answer to this question is in fact on the resultant heat release rate. This is different from FLD of which fire behaviour of structure is affected. There is still no correlation between FLD and the heat release rate because the burning process depends not only on the type and amount of combustible contents, but also on how the materials are burnt. Design fires [39] should be specified for different scenarios.

- Smoke production rate

  Current material tests [40] on deducing the smoke production rates from results measured in a cone calorimeter are worthwhile to consider.

6. PROPOSED FIRE SAFETY RANKING SYSTEM

A FSRS with attributes divided into two areas, hardware on passive building design and fire services installation; and software on management, is proposed for business occupancies. Hardware requirements are based on local MoE, MoA and FRC codes by the BD; and FSI code by the FSD. Software management is on keeping the key parameters low and enhancing fire safety management.

Hardware requirements are:

- Part 1: Passive building design

  Assessment is based on the building where the business unit is located. Attributes on assessing the building are:

- Following the FRC code with appropriate FRP.
- Following the MoE and MoA codes including the number of exits and corridor width (i.e. 1.2 m), and whether there are "dead-ends".
- Whether the height of building is less than the maximum height that FSD fire engines can reach (50 m at the moment).
- For new buildings, the width of staircase depends on the number of persons per floor. The maximum travel distance is also specified in the regulations.

At the moment, there is a pass/fail situation if the engineering approach is not used. If the design on fire resistance structure and escape routes does not comply with the BD requirements under FRC, MoE and MoA codes, then it is regarded as 'fail'. This can be changed to check whether:

- The FRP to be longer than the estimated fire severity based on well-known equation [41].
- Evacuation time is faster than an agreed value, say 3 minutes.
- Flame spreading: New tests [32] apart from BS 476 Part 7 surface spread of flame tests [29] to be revised [30,31].

• Part 2: Fire services installations

Assessment is based on the provision of fire services installations following the local FSI code. Another important point is whether the systems are maintained properly.

Six groups of fire services installations suggested to be surveyed are:

- smoke doors,
- smoke control system,
- automatic sprinkler system,
- fire detection system,
- manual fire alarm,
- fire hydrant/hose reel system.

Marks will be assigned to each group if the systems are in good conditions. Further, time budget might be:

- Detection time within a reasonable value, say 1 minute.
- Extinguishing time of automatic fire control systems such as sprinkler to be an agreed value, say 3 minutes.

Software management is:

• Part 3: Keeping the key parameters to below critical values appeared in the local codes

Fire codes were developed based on simple concepts that without storing any combustibles, there would be no accidental fire. Also, if there are no people staying inside the building, evacuation is not a problem.

Therefore, FLD and occupancy level are assessed. There is an upper limit FLD_u of 1135 MJm^{-2} in the local codes. This was implemented over ten years ago in Hong Kong with the value estimated to compare the fire severity [42] with the FRP based on the equation by Law [41]. The following are proposed:

- $FLD \leq FLD_u/4$
- $FLD_u/4 < FLD \leq FLD_u/2$
- $FLD_u/2 < FLD \leq FLD_u$
- $FLD_u < FLD$
- Storing dangerous goods

The occupant load factor (OLF) is a density factor on area occupied by a person. Points are assessed by referring to the upper limit of OLF_u for a certain use of building:

- $OLF \leq OLF_u$
- $OLF_u < OLF$

• Part 4: Fire safety management

The importance of fire safety management [35,43-46] is emphasized. A fire safety manual should be kept. This is an issue on the 'software' side to be addressed separately. Evacuation is a key element for life safety. Evacuation pattern with different designs of means of escape can be studied by using fire models and evacuation models.

7. CONCLUSION

A preliminary study on the fire safety evaluation of business occupancies was made. Reference was made to the NFPA-FSES and the local fire codes. The two codes were compared with key differences highlighted. These two sets of codes are dissimilar systems and seem not good to compare. But such a comparison would give a wider scope to investigate the factors to consider in working out a new set of codes for the buildings in the 21st century.

It is proposed that a Fire Safety Ranking System should be used for quantifying fire safety for business occupancies. Basically, there are two parts on hardware provision and software management. Fire models [e.g. 47] should be helpful in the analysis.

The study is just the first stage of a long-term study programme. Further investigation must be carried out to study the performance of fire services installations and to work out good fire safety management [35,43-46].

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