REVIEW ON THE LOCAL CODE OF PRACTICE FOR THE PROVISION OF MEANS OF ESCAPE

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ABSTRACT

Engineering performance-based fire codes (EPBFC) are to be developed in Hong Kong. Before implementing EPBFC, or even writing down what should be done, such as the fire safety objectives, current prescriptive fire codes should be understood. The first step is to identify those areas where prescriptive fire codes are difficult to follow, but applying EPBFC would give better fire safety provision. One of those areas should be taken out for detailed investigation of feasibility of implementing EPBFC. In this paper, design of means of escape is selected to study thoroughly. The Means of Escape (MoE) code will be reviewed with respect to the local characteristics of buildings and occupants. Points of concern are outlined with limitation of applying prescriptive codes demonstrated by a case study. The necessity of developing EPBFC is pointed out.

1. INTRODUCTION

Fire safety professionals including fire safety officers and regulators, building designers, fire protection products suppliers, insurers, researchers and educators are now facing a challenge on the possibility of implementing the performance-based fire safety design. The improvement in technology [1,2] over the past decade has enabled most advanced countries [3] to grapple with performance-based fire safety engineering design and codes. The major international shift to performance-based regulations has been happening mainly in New Zealand [4-7], Australia [8-11], Scandinavian countries [12,13], UK [14-16], Japan [17], Canada [18], and USA [19,20]. Although fire safety in most of the traditional buildings is still designed by following prescriptive-based codes, more and more cases of performance-based designs are used in buildings with new architectural features where how to provide fire safety is still uncertain.

Local government of Hong Kong (now the Hong Kong Special Administrative Region HKSAR) [21] is now trying to develop engineering performance-based fire codes (EPBFC). Before doing so, fire safety objectives and engineering criteria required to support these regulations must be developed. This should be supported by well-planned long-term research activities and if carried out properly, lots of advantages as pointed out later can be achieved [22,23]. The initial step is to review the current prescriptive-based building codes system and evaluate its inadequacy. Appropriate approach to establish the EPBFC can then be determined. This step is considered necessary particularly during the transition period of allowing performance-based approach design without clear guidance on the EPBFC, i.e. the engineering approach [24] of fire safety design.

Of the four prescriptive codes [25-28], MoE code [25] is the most important one as identified earlier [29]. At least two questions are used to be raised on the provision of escape routes:

- Q1: Where should alternative approach be applied?
- Q2: What are the acceptance criteria and how are these assessed?

This paper aims at further investigating buildings evacuation when there is a fire to illustrate the rationale behind the MoE code [25] requirements. Prescribed design parameters and criteria governing the fire safety solutions as stated in the code are discussed in detail. The inadequacy and deficiency of the MoE prescriptive requirements with respect to the local building types and occupancy characteristics are identified with examples quoted.

2. BACKGROUND

As reviewed in the literature [e.g. 30], advantages of using EPBFC over the prescriptive approach are:

- Defining clear fire safety objectives and leaving the means of achieving those objectives to the designers;
- Allowing innovative design solutions that fulfil the defined performance requirements;
- Eliminating technical barriers to trade for a smooth flow of industrial products;

- Allowing international harmonization of regulation systems;
- Permitting the use of new knowledge as it becomes available;
- Allowing cost-effectiveness and flexibility in design;
- Enabling the prompt introduction of new technologies to marketplace;
- Eliminating the complexity or deficiency of the existing prescriptive regulations.

There are four key prescriptive-based fire codes in Hong Kong [31]:

- Means of Escape (MoE) Code [25]
- Fire Resisting Construction (FRC) Code [26]
- Means of Access for Fire Fighting and Rescue (MoA) Code [27]
- Fire Services Installation (FSI) Code [28]

The first three codes concern the passive means of fire safety design and are taken care of by the Buildings Authority. The last code concerns the active means of fire safety provisions (known as fire services installation in Hong Kong) and is governed by the Fire Services Department.

Among these codes, the MoE code appeared in January 1960 [32] is the first published guide for building evacuation design. Some minor amendments were made to the code over the intervening years, with the majority of requirements kept unchanged until 1996 when the current edition of MoE code [25] was published. Extensive development effort was paid and consultation was held before publishing that. This is a prescriptive code [25] but an alternative fire engineering approach is allowed to give fire safety provisions of equivalent safety level to that expected by the code. This alternative approach is considered pertinent to some large and complex buildings. A practice note [24] was issued later by the Buildings Department in 1998, outlining the framework for what should be considered in the fire engineering approach. This indicated that the new government recognized the necessity of adopting alternative (performance-based) approach design. The two broad questions Q1 and Q2 as stated earlier had been raised many times by fire engineers. It is quite difficult for both the designers and the responsible officers to implement such design approach. Note that the SAR government, after smooth reunification to China, is very open in accepting new ideas, in comparing with in the colonial stage. A Fire Safety Committee has been established in the Buildings Department in 1998 to consider those designs based on the engineering approach [24]. Individual cases of over 30 projects were considered. However, tremendous human resources are required! Without a new set of local performance-based fire codes, the above two questions Q1 and Q2 cannot be clearly addressed:

- Answer to the first question Q1 in this transition period is quite subjective. This is usually determined either by the Authorized Person (the person responsible for the project) or the approving officer, when prescriptive requirements are thought to be insufficient to achieve fire safety. This subjective decision depends on how much those experts know about fire engineering. For example, experts should be appointed to carry out Computational Fluid Dynamics (CFD) simulations for studying fire-induced air flow, not just relying on an engineer without good training in CFD. CFD itself is a rapidly developing subject where even in describing the turbulent effects, there had been lots of arguments on selecting different approaches such as Reynolds Averaging Navier-Stokes equation or large-eddy simulations [e.g. 33]! At the moment, alternative approach is adopted when the prescriptive requirements are difficult to follow.

- The second question Q2 is even more difficult to answer as an equivalent safety level as that of the prescriptive solution should be clearly demonstrated.

3. THE EVACUATION PROCESS AND MEANS OF ESCAPE

Once an accidental fire starts in a room within a building (i.e. the enclosure of fire origin), it takes time for the fire to develop to untenable conditions for the occupants. Good use of this time for evacuation would provide life safety. As the fire grows and develops, more places would be affected with more occupants involved. The physical time available would be reduced but this may not match with the time perceived to be available by the occupants. Passing right information to all the occupants through proper communication system is important. The evacuation strategy should ensure that, in the event of fire, the occupants are able to leave the building without being exposed to untenable condition [8]. For example, a time chart for evacuation was shown in BS DD240-1997 [14,15]. There, the time to become untenable, i.e. the Available Safe Escape Time ASET and the escape time Δt_{esc} (the interval between the time at which a fire warning is transmitted to the occupants of a space and the time at which those occupants are able to reach the place of safety) are defined and Δt_{esc} should be shorter than ASET. Δt_{esc} is the summation of time from ignition to alarm Δt_a, pre-movement time Δt_{pre} (including recognition time and response time) and travel time Δt_{trav}.

A typical objective for designing means of escape is [e.g. 34]:

> ***"The building shall be designed and constructed so that there are means of escape in case of fire from the building to a place of safety outside the building capable of being safely and effectively used at all material times."***

To achieve this objective, the human factors and the building design factors with active and passive fire safety provisions taken into account should be considered. Human factors refer to the occupant characteristics and their capability to respond to emergency situation. Building design factors refer to the provision of fire warning systems for early alerting people and the provision of sufficiently safe exit path (with adequate fire-rated enclosure and/or smoke control system) leading to the place of safety.

- Occupant characteristics

  The evacuation time Δt_{eva} (might be taken as starting from the time the alarm is sounded Δt_a [14], i.e. $\Delta t_{esc} = \Delta t_{eva} + \Delta t_a$) is dictated by the nature of occupants including their knowledge of the building, their physical and behavior attributes, their number and distribution and the level of assistance available to them from staff or helpers or wheelchairs. The specific factors to be considered [e.g. 14] are familiarity with the building, alertness, mobility, social affiliation, role and response, position, commitment, focal point, and other additional aspects.

  The occupant characteristics are considered with respect to six different occupancy types [35] varying from Type I for occupants awake and predominantly familiar with the building (e.g. offices, commercials, colleges, schools and industrial premises, etc.) to Type VI for occupants held in custody (e.g. prisons).

  'Multiple-use' buildings are commonly found in Hong Kong. Their means of escape for one 'use' should not be prejudiced by another. For example, one 'use' will be closed outside trading hours and so independent means of escape should be provided for the other more continuous 'use'. Moreover, where security requirements (such as for airport restricted area and paid-area in train stations) potentially compromise the availability of exits, suitable measures must be taken to ensure that exits are available to all occupants under emergency conditions.

- Building characteristics

  Another influencing factor to the evacuation time, thus the provision of means of escape, is the characteristics of the building. Specific factors [14] are the type of alarm system, the design configuration of spaces and evacuation routes, and the provision of signage, lighting and smoke control system.

  Therefore, an evacuation system should have a 'software' part including the human behavior; and a 'hardware' part such as building layout and services. Relationships between the software and the hardware are very complex, and might be studied by system dynamics [36].

4. REVIEW OF THE MoE CODE

The objective of setting up the MoE code [25] is to satisfy the Building Authority's requirements on providing adequate evacuation routes to give public safety. This is a prescriptive approach specifying clearly on what should be followed for the associated fire safety design requirements. To ensure safety, these prescriptive requirements, guidance structure and their applications should be followed. Doing this would also protect the authorized person (people with great responsibility on building projects) in case accidents happen. However, because of the new architectural features, fire professionals often raise questions on whether prescriptive approach can provide 'real' fire safety. These questions are not difficult to answer if fire safety science and engineering can be applied properly. Although the code follows the old British system without publishing the associated background research works as Appendices, some information is available in the literature. Of course, reviewing those physical rationale would take a long time and require some knowledge on fire science, and it is not quite easy to do that quickly. Note that time schedule is important in Hong Kong. 'Rushing' to complete a construction project might downgrade the engineering quality. However, as said in the above, the new SAR government is now very open in accepting fire safety measures different from the code if those are demonstrated to be of the same safety level.

Modern concept is that safe means of escape may be achieved by using passive measures such as fire-rated structural enclosure or active systems such as smoke management systems, or a combination of passive measures and active systems. It appears that if these are put in properly, occupants would not be subjected to undue hazard in a fire [14,34]. Further in-depth investigation must be carried out to support that significantly, especially to tune up the parameters concerned to suit local characteristics. The MoE code governs the passive measures to accomplish the target of avoiding occupants being exposed to undue hazard. Requirements in that code are to ensure the building or every single room is provided with sufficient number of wide enough exits (to outside the fire room and the building), where each exit point shall not be too distant apart, to allow occupants to leave the room at an early time of a fire incident, thus away from smoke or heat as fast as possible. The minimum number and width of exit doors are governed by the capacity of the room or storey. Other specific passive requirements include the provision of self-closing doors and protected lobbies to the escape staircase, which are for the purpose of impeding the passage of smoke to the escape staircase.

Human behavior and their activities involved would affect the recognition time and pre-movement time in the event of a fire. There is limited consideration in the MoE code with respect to the human behavior in response to emergency situation. The staircase safety design requirements for people movement such as straight flight step numbers, tread wide and riser height are specified. Traditional stair safety and design are available overseas in North America, Europe, and Japan [37]. These design specifications include movement information without considering their response to a fire. Note that whether these data work in Hong Kong or not has to be demonstrated by further studies, not just simply copying without engineering judgement. For staircase width, the MoE code allows a larger discharge value for a sprinklered building than for a non-sprinklered building. This indicates that staircase width can be smaller for a sprinklered building, where a relatively longer flow time is allowed due to the presence of fire alarm system, which might shorten the recognition time and sprinklers would probably control the fire.

Key elements in the MoE code are summarized as follows:

- Occupancy types

  The mobility of occupants, their familiarity with the surroundings and the ease of way-finding posed by the setting can have significant effect upon the time required to evacuate the building. 44 types of buildings and areas are defined in the FSI code [28]. Occupant conditions and activities in the building are recognized. Minimum active fire safety measures are prescribed as the condition for the local authority to approve the building design. The requirements of active fire safety measures for the purpose of early or safe evacuation such as fire alarm system, staircase pressurizations and smoke extraction system are specified according to the building classification. Detection system is required for occupancies where there is sleeping risk (e.g. hotels and dormitories). However, the combined effects of these requirements, along with certain travel distances to exits, are usually not mentioned in the MoE code or any other local standard.

- Occupancy capacity and exit requirements

  Different occupancies are classified by an occupancy factor A_{per}, i.e. the usable floor area per person. With it, the number of occupants using the storey can be estimated. The value of A_{per} varies from 0.5 m^2/person for assembly halls to 30 m^2/person for warehouses, godowns and storage areas. The width and the number of exit doors (routes) are calculated by the capacity of the room (storey). The minimum requirements of exit routes are shown in the code [25] and reproduced in Table 1.

- Staircases requirements

  Buildings having more than 6 storeys or taller than 17 m require not less than 2 exit routes (staircases). For non-domestic buildings or composite buildings exceeding 15 storeys in height above the lower ground storeys where two or more exit staircases are required, people using one staircase should be able to gain access to at least one of the other staircases at any time without having to pass through other persons' private premises. The maximum horizontal distance between two staircases should be 48 m.

  Discharge value of all staircases, which is the staircases capacity for holding people during total evacuation, should in all cases larger than the total occupancy capacity. The discharge value for a staircase in a non-sprinklered building varies from 210 of staircase width 1,050 mm for one storey to 972 of staircase width 1,900 mm for 10 storeys. While the discharge value for a staircase in a sprinklered building varies from 420 of staircase width 1,050 mm for one storey to 1,332 of staircase width 1,900 mm for 10 storeys. For each additional storey, the discharge value for a staircase should increase from 32 of staircase width 1,050 mm to 68 of staircase width 1,900 mm. For sport arenas, stadia, convention centers, passenger terminals or buildings of similar uses, the total width of staircases serving a building having a total capacity of not less than 10,000 persons should be 1.2 times the total width of exit routes as that of other buildings.

- Travel distance requirements

  The specified maximum travel distances for people to reach the nearest exit door (staircase) in various building designs are shown in Table 2. Where there is a dead-end, the maximum travel distance should not exceed 18 m.

- High-rise buildings escape strategy

  'Egress' and 'refuge' are the two strategies adopted in the building design for fire safety. The MoE code recommends sufficient provision, design and construction of the staircases, exits (including doors) for all occupant accommodation (e.g. assembly halls, warehouses) and circulation areas (e.g. basements, lift lobbies). These building elements provide a simple and direct escape from the building when the fire alarm is sounded. Refuge floor is the second escape strategy and it is recommended for all high-rise buildings of more than 25 storeys. The refuge floor provides a space of temporary safety within the building during emergency escape.

- Place of large occupancy

  Fire engineering approach is considered a viable means for escape design for a building of total capacity more than 10,000 persons. The MoE code recommends the following design factors for rationale behind the prescribed means of escape provisions: total evacuation of the building; evacuation time (from a storey to a protected area) of 2.5 min for non-sprinklered buildings and 5 min for sprinklered buildings; flow rate of people in descending staircase of 80 persons/metre/ width/min (0.8 reduction factor for ascending flow rate) and staircase holding capacity in the range of 3.5 to 3.9 persons/m^2. All these criteria can be used to assess the escape provisions when fire engineering approach is adopted.

Table 1: Requirements of escape routes [25]

Capacity of room or storey	Minimum number of exit doors	Minimum total width / mm		Minimum width / mm	
		exit doors	exit routes	exit door	exit route
4 – 30	1			750	1050
31 – 200	2	1750	2100	850	1050
201 – 300	2	2500	2500	1050	1050
301 – 500	2	3000	3000	1050	1050
501 – 750	3	4500	4500	1200	1200
751 – 1000	4	6000	6000	1200	1200
1001 - 1250	5	7500	7500	1350	1350
1251 - 1500	6	9000	9000	1350	1350
Over 1500	7 or higher as required by the Authority	To be calculated at the rate of 300 mm per 50 persons		1500	1500

Table 2: Direct distance and travel distance for building exit routes [25]

Configuration	Use of premises or part of premises	Type of exit route*	Maximum travel distance / m	Maximum sum of direct and travel distance / m
Single staircase building	Any	A	18	24
		B	12	24
		C	18	18
Building with more than one staircase	Offices, schools, and shops	A	36	45
		B	24	36
		C	30	30
	Premises other than offices, schools, and shops	A	30	36
		B	24	36
		C	30	36

*Type A exit route is along balcony approach or internal corridor with ventilation; Type B exit route is along internal corridor without ventilation; Type C exit route is within a storey, which is partitioned into rooms, but not along balcony approach or internal corridor.

A summary of prescriptive means of escape requirements [25,28,35] is shown in Table 3 for the six types of occupancies [35]:

I Familiar with the building and awake
II Unfamiliar with the building but awake
III Possibly sleeping but familiar with the building
IV Possibly sleeping but unfamiliar with the building
V Require assistance
VI Held in custody

The premises types [28] B1 to B6 are:

B1 Commercial building: any building or that part of building, intended to be used for business, trade or entertainment.
B2 Industrial building: any building used wholly or used in any process for or incidental to any of the following purposes: (i) making of any article; or (ii) altering, repairing, ornamenting, finishing, cleaning or washing or breaking up or demolishing of any article; or (iii) adapting for sale of any article being a building in which work is carried out by way of trade or for purposes of gain.
B3 Institutional building: any building used wholly or in part for club premises, education establishments, hostels, hospitals, prisons and sanatoria.
B4 If it is not a car park building, the building type should follow occupancy of the other parts of the building.
B5 Domestic building: a building intended to be used for habitation.
B6 Hotel: any building used wholly or part primarily for the purposes of accommodation on a commercial basis.

Whether the existing fire codes [25-28] will work with new architectural features and modern living styles is a big question. Obvious examples are designing fire safety systems to cope with major disasters [38] for large open plan space and railway stations. It appears that the fire codes [25-28] were developed based on relatively older information. These, of course, are demonstrated to be suitable for older generations of buildings which are 'typical' in size, shape and use [39]. It is difficult for the design guide to state clearly the best means of escape design for different building types with supporting research results published. Otherwise, it would appear as piles of PhD degree theses!

Time constraints imposed in the projects might not allow designing fire safety measures by reviewing the literature thoroughly. Therefore, some might wonder the 30 m maximum travel distance criterion for a large open plan at ground floor to have dedicated escape corridors is not necessary if people can escape directly to a place of ultimate safety through a longer travel distance. However, this part is also clearly recognized by the government and so fire engineering approach is accepted. For example, designing MoE for large occupancy with over 10,000 people would be considered separately. If fire professionals can submit a detailed scientific report with good demonstration that the proposed fire safety design are supported by fire science and engineering, such as systematic full-scale burning tests in Japan [e.g. 40] or Taiwan, the government would accept the proposal.

Specific international codes and standards [20] for those buildings with particular hazards or geometry would all be considered specially by taking into account of the presence of fire detection, fire alarm, firefighting and smoke management systems.

5. AREAS FOR IMPROVEMENT

Basic means of escape requirements in accordance with the prescriptive codes [25,28] for various occupancy types and building usages are summarized in Table 3. They are categorized in accordance with the six occupancy types as discussed by grouping the occupancy characteristics and their possible response to egress. There are concerns on the following areas and improvement is expected:

- Maximum travel distance is one of the most important design parameters, which has significant impact on building designs. The limitations on maximum travel distance are classified by the different uses of the premises with three exit route approaches:

  - balcony approach (with ventilation);
  - internal corridor (without ventilation); and
  - a type other than the above two.

  The first approach deserves the largest travel distance and direct distance. For offices, shops and schools, the maximum sum of the two distances are 45 m, 36 m and 30 m respectively. The travel distance limitations are shown in Table 2 and illustrated in Figs. 1a to 1c. With respect to the occupancy types, the maximum travel distance requirements are different for (i) offices, shops and schools and (ii) other occupancies. Occupants in offices, shops and schools are awake to recognize a fire at an early stage. But their familiarities with the building layout are different such as occupants in a shopping mall would be less familiar with the building than the occupants in schools or offices. Thus, offices, schools and shops are categorized into different occupancy types from the performance-based design viewpoint. Whether there are fire protection systems installed in the building is not discussed. In comparing to the guides of other countries [e.g. 20], they have different types of occupancies for buildings with and without sprinklers. How those values were derived is not clearly described in the code, but perhaps in the literature or meeting minutes. The reasons why only sprinklers were considered to be beneficial in terms of relaxing the requirement are not specified. However, there are supporting research works on the movement of people stated in the appendix [37].

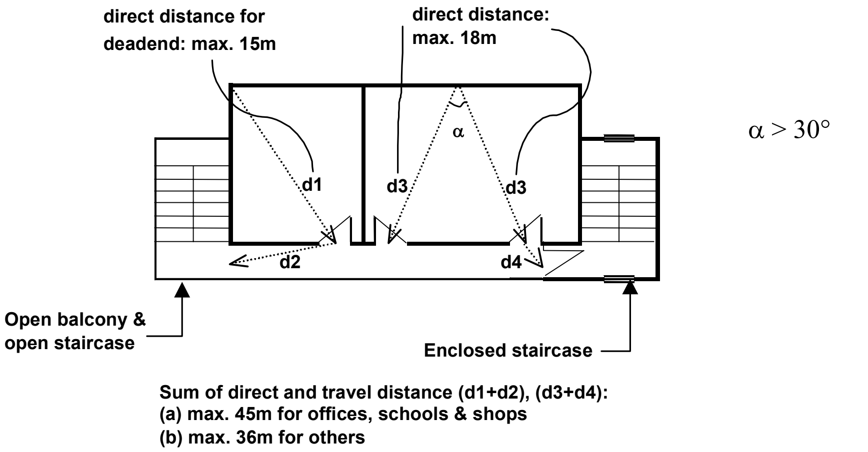
- Generally speaking, the passive means of escape requirements are storey/building capacity orientated. It is because the exit width, exit number and staircases capacity are determined by the room capacity and the building capacity irrespective of the occupancy characteristics for various building usages. For example, a large lecture room in a university and a restaurant inside a shopping mall can have a similar room capacity but their occupants response to escape are different due to their building familiarity and activities involved. It is obvious that using the same criteria for passive means of escape design would give a simpler design; and this is usually on the safe side by adopting the more stringent requirements in lieu of a case-by-case design evaluation based on actual performance. Those prescriptive requirements are not so flexible in implementing building design for various building and occupancy types.

- It seems that the active fire safety systems (i.e. described in the FSI code) and the passive means of escape provisions (i.e. described in the MoE code) are provided separately as the two codes [25,28] are taken care of by different government departments. This would pose difficulties in establishing an integrated means of escape design which satisfies both the safety requirements and effective use of resources to avoid over-provision.

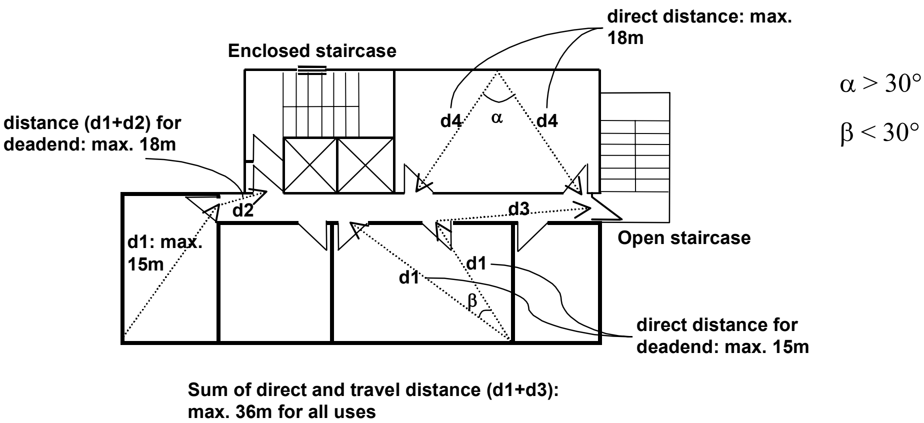
  For example, a large exhibition hall of dimensions 80 m × 80 m × 8 m (high) would require smoke extraction due to its fire compartment exceeding 28,000 m^3, and at the same time it is required to fulfill the 30 m maximum travel distance for the open plan layout. To satisfy the prescriptive requirements, either an escape corridor is required to be constructed along the central zone, which leads to the staircases at the perimeter area; or a staircase should be constructed at the centre of the open plan layout to limit the travel distances for the entire layout to within 30 m. There is no specification on the merit of the smoke extraction system, which might give a tenable condition for people to escape. Moreover, for high population open plan layout, queuing time is usually a more significant factor to govern the room evacuation time than travel time. Whether limiting only the travel distance for some buildings such as large open areas can give fire safety should be studied. Further, the risk to life safety would be higher in places of large occupancy such as stadia and convention centers as recognized in the prescriptive code [25]. Exit width should be 1.2 times larger than the required exit width in order to reduce the queuing time. Whether an active fire safety measure for escape purpose such as a smoke extraction system is required, appears not depending on the fire compartment volume, openable windows area and fire load regardless of the occupants density.

  It is now possible to go through the Fire Safety Committee with officers from both departments on assessing that. But without a set of well-established engineering performance-based fire codes, this approving procedure would require tremendous resources.

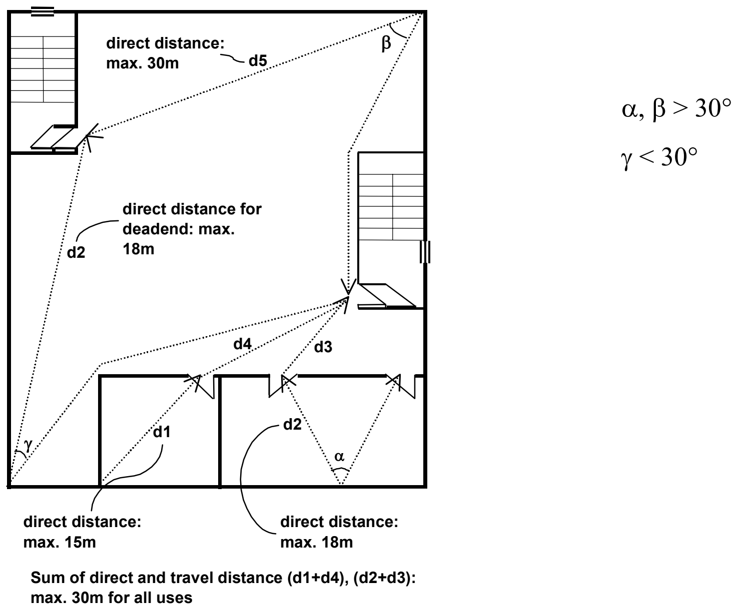
- Other than premises with typical building geometry and common usage such as offices and shops, there is very limited guidance or reference to relevant overseas standards [20] for special usage construction, though again, there is a channel by going through the Fire Safety Committee. Taking a warehouse or containers terminal building as an example, it is obvious that building codes [25-28] are not sufficient to provide appropriate guidance on fire safety design for high pile storage buildings. Typical warehouse layout comprises a large plan area with high ceiling and fire load of stacked goods. There are high-level racks for goods storage. Storage buildings are usually considered as high fire load usage and somehow would require in-rack sprinklers for fire suppression. People access to these racks are steel platforms and unenclosed steel staircases. Occupants are workers who should be familiar with the building layout and awake to respond to emergency. When following the prescriptive guide [25] for the MoE design, a question might be raised:



(a) Balcony approach [25]



(b) Internal corridor [25]



(c) Other than balcony approach and internal corridor [25]

Fig. 1: Calculation of traveling distance [25]

Table 3: Prescriptive means of escape requirements [25,28,35]

Occupancy type [35]	Usage of storey	Premise types [28]	Means of Escape Requirements							
			Passive Provisions [25]					Active Provisions [28]		
			Room capacity / m^2/person	Escape width / mm	Distance to exit route/door / m	Staircases: Separation x / m	Staircases: Discharge value	Alarm system (Note 4)	Smoke control	Staircase pressurization
I	Offices	B1	9	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
I	Committee rooms, conference rooms, meeting rooms, common rooms, function rooms & waiting rooms	B1	1	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
I	Flatted factories	B2	4.5	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
I	Warehouses, godowns & storages	B2	30	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
I	Classrooms, lecture rooms, libraries & study rooms	B3	2	Note 2	Note 3	6 < x < 48	> BC.	R1	NR	NR
I	Kitchens attached to restaurants	Note 9	4.5	Note 2	Note 3	6 < x < 48	> BC.	R1	As per building type	
I	Industrial workplaces	B2	Note 1	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
II	Assembly halls, auditoria & stadia	B1	0.5	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
II	Galleries, banking halls, betting centers & public service counters	B1	0.5	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
II	Dance halls, disco & reception areas for restaurants	B1	0.75	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
II	Dinning areas, lounges	B1	1	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
II	Short-term rented committee rooms, conference rooms, function rooms & waiting rooms	B1	1	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
II	Museums, exhibition halls, trademarts & display areas	B1	2	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
II	Supermarkets, showrooms, jewellery shops, pawn shops & money exchangers	B1	2	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3
II	Shopping areas	B1	3 (Note 5) 4.5 (Note 6)	Note 2	Note 3	6 < x < 48	> BC.	R1	R2	R3

	Car parks	B4	1.5 space/ person	Note 2	Note 3	$6 < x < 48$	> BC.	R4	NR	As per building type
	Public transport facilities (e.g. railway stations, bus terminuses)	-	N	Note 2	Note 3	$6 < x < 48$	> BC.	N	N	N
III	Tenement houses, barracks & dormitories	B3	3	Note 2	Note 3	$6 < x < 48$	> BC.	R3, R5	NR	NR
	Self-contained flats with corridor or balcony access having 5 or more flats on each floor served by each staircase	B5	4.5	Note 2	Note 3	$6 < x < 48$	> BC.	NR	NR	NR
	Flats other than the two above	B5	9	Note 2	Note 3	$6 < x < 48$	> BC.	NR	NR	NR
	Hostels	B3	Note 7	Note 2	Note 3	$6 < x < 48$	> BC.	R3, R5	NR	NR
IV	Hotels	B6	Note 7	Note 2	Note 3	$6 < x < 48$	> BC.	R3, R5	R2, R6	R7
V	Hospitals	B3	Note 7	Note 2	Note 3	$6 < x < 48$	> BC.	R3, R5	NR	R8
	Nursing homes	B3	N	Note 2	Note 3	$6 < x < 48$	> BC.	R3, R5	NR	R8
VI	Place of custody	B3	N	Note 2	Note 3	$6 < x < 48$	> BC.	R3, R5	NR	NR
Any	Any usages in basements	-	As per usages listed above	Note 2	Note 3	$6 < x < 48$ (Note 8)	> BC.	R9	R10	R11
	Atria in any buildings	-	As per usages listed above	Note 2	Note 3	$6 < x < 48$	> BC.	R1	R12	As per building type

Notes:

1. Determined by the Commissioner for Labor according to the specialized trade process.
2. Data listed in Table 1, but for buildings having a total capacity exceeding 10000 persons for sport arenas, stadia, convention centers, passenger terminals or similar uses, the total width of staircases should be 1.2 times the values listed in Table 1.
3. According to Table 2.
4. Alarm system refers to any installations, which automatically provide warning signal upon detection of fire such as sprinklers and smoke/heat detectors.
5. For basements, G/F, 1/F & 2/F.
6. For 3/F and above.
7. Determined by the Authority based on the detailed layout plan.
8. Each level of basement should be provided with one independent staircase leading to G/F.
9. Building type should follow the building in which the restaurant is located.

* Abbreviations for Table 3 can be found at the end of the paper.

Should the unenclosed steel staircases be considered as protected escape route, which should be enclosed by fire rated construction?

The required number of designated fire-rated escape routes depends on the allowable maximum travel distance. It was recognized in an overseas guide [20] that population density in a storage area is low. Travel distance requirements are varied for different hazard types of storage:

- low hazard (low combustible content): no limit;
- ordinary hazard (content burns with moderate rapidity): 60 m without sprinklers and 122 m with sprinklers and
- high hazard (content burns with extreme rapidity or explosion is likely): 23 m without sprinklers and 30 with sprinklers.

Threats to life in storage occupancy would be different for different hazard levels. Types of storage, population density and available active fire safety measures (e.g. detection/alarm system) should be taken into account for providing means of escape for storage area. Of course, it is no good to follow the overseas guide without in-depth investigation, as the living styles in those countries might be different. An overall performance picture with social responsibility of citizens included should be provided by carrying out in-depth investigation.

• Space volume is another important parameter in the local FSI code [28] in deciding whether smoke control systems have to be installed. Smoke extraction systems are required for buildings above ground with space volume greater than 28,000 m^3 for atrium and 7,000 m^3 for any fire compartment. They are also required for buildings with a fire load density above 1,135 MJm^{-2} and with openable windows of total aggregate area less than 6.25% of the floor area. Installation of smoke control system is to enhance life safety and property protection by reducing smoke threat, and lower the fire and smoke temperatures to improve the fire performance of structure or aid firefighting [35]. It is essential to ensure that the details and the objectives of the smoke control system are consistent with the planning of the spaces within the building and the means of escape in it. It appears that specifying only the space volume for whether smoke extraction system is required is not adequate as the geometry of the concerned space and the population density area are not considered.

Applying the code to design fire safety means in atria is an obvious example. There, the smoke filling times for atria with the same space volume but different geometries would be very different [41]. Atria having longer smoke filling time would give more time for fire detection, evacuation and fire control. The smoke filling time for an atrium with a large space volume might not be short. Therefore, a smoke extraction system might not be necessary, depending on the heat release rate of the design fire. These have to be worked out from past experience on fire and scenarios analysis.

Another important factor in determining whether a smoke extraction system is required is the population density. Design values of population density depend on the floor area in the local building code [25]. Population density for atria is not specified. The population density for a shopping mall (usually adopted for atria in commercial buildings) should be 3 m^2 per person. Atria with large floor area are expected to have a higher population density, especially those for public access. The number and width of exits depend on the population density of the atria floors and the egress time. A time constant taking the atrium geometry into account was recommended [41] to compare the smoke filling time and the available safe egress time for determining whether smoke extraction is required.

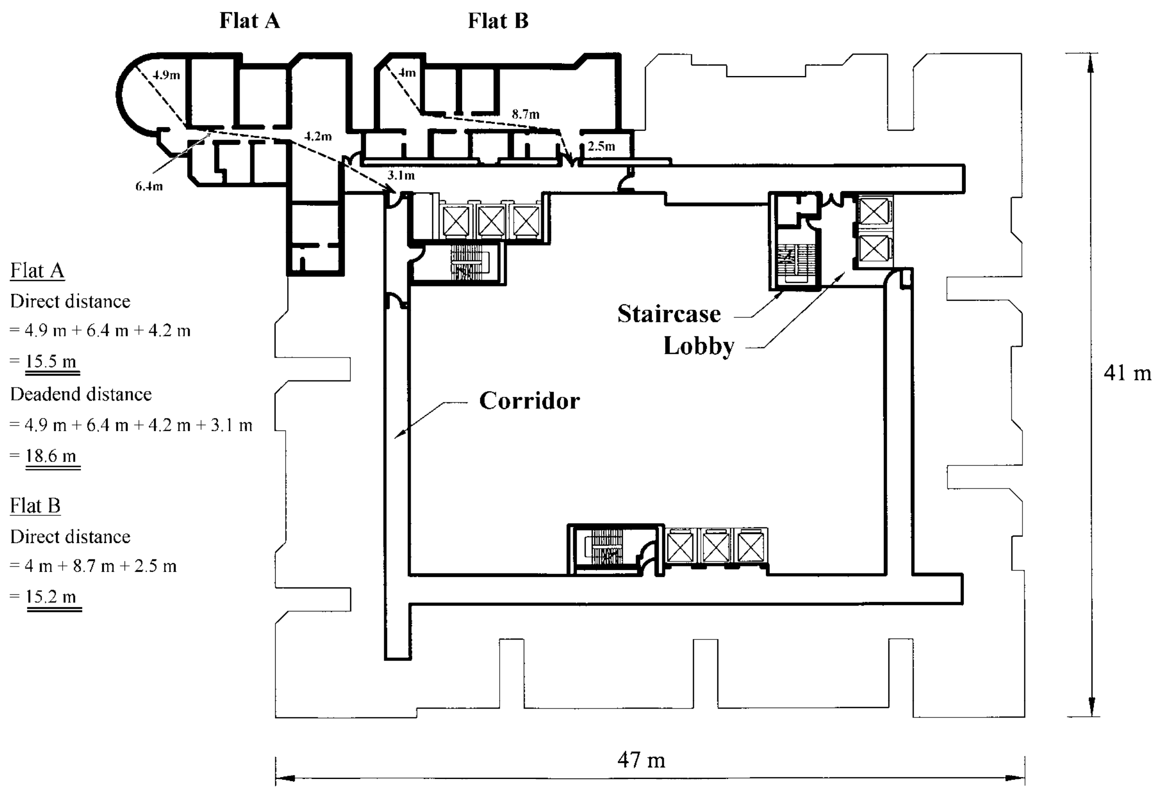
Further, the use of atrium floor might be changed. Evacuation time might be delayed by putting in partitions for exhibition [42]. Fire safety management [14,15,43] should be implemented properly. Building operation team should be monitored by the government to ensure that the fire safety plan is carried out properly, not locked in a safe as a 'peacock feather' [43,44].

6. A CASE STUDY

Hong Kong is a densely populated city where the land price is expensive. Most buildings (e.g. residential, hotels and commercial) are high-rise structures for maximizing space uses. The total usable floor area of buildings for lease or sale purpose should be maximized. As discussed, the means of escape design such as the maximum travel distance is an important parameter affecting the building layout design as well as the number of exit points required. The goals of cost-effectiveness and life safety should be fulfilled in an optimum way. Using prescriptive approach, this can be complied with easily and may proceed without knowing the reasons behind. It is not necessary to spend time on searching for the background literature nor attending CPD programmes to understand the physical principles behind. The four local prescribed codes [25-28] look simple and not so complicated as compared to those overseas [34]. There are not much descriptions on the combined fire safety design for different building types.

For example, residential buildings with many individual flat units are connected by more than one common corridor. Each unit has at least 1-hour fire isolation to other units and to the common corridor. A small accidental fire of low heat release rate is likely to be confined in the fire flat, which people's escape behavior and potential fire hazard would really be different from a densely populated sprinklered shopping mall with large floor area and dedicated escape corridors.

Taking a high-rise service apartment building as an example, according to FSI code [28] on hotel occupancies, the building is required to be protected by sprinkler system and smoke detection system and have corridors with either openable windows or smoke extraction. For MoE design, the number of staircases is dictated by the maximum travel distance and minimum staircase separation distance. The number of exits and their widths are governed by the room/storey capacity. Based on FRC code [26], hotel bedrooms are to be 1-hour fire-rated from other part of the building (e.g. corridors). Fig. 2 shows a typical floor plan of the service apartment building. Three escape staircases and other utilities provision (lifts and plant rooms) are allocated at the interior zone to maximize window areas for the apartments. Flat A has a direct distance of 15.5 m and a deadend travel distance of 18.6 m, which exceeds the code limits by 0.5 m and 0.6 m, respectively. Flat B has a direct distance of 15.2 m, which exceeds the code limit by 0.2 m. Code-compliant design might require additional staircase or additional flat exit or alternation of flat layout. Question will then be raised on whether the additional 0.2 m to 0.6 m escape distance would affect the total evacuation time and the goal of life safety. Logically, an adult only takes one step to walk 0.6 m distance. It appears that evacuation time would only be extended slightly. Therefore, the MoE code is then questioned.



Scale 1:300

Fig. 2: Typical layout of service apartment

The above MoE design is compared to the US prescribed guide [20] for new Hotels and Dormitories, and found to be satisfactory. Based on reference [20], the maximum travel distances within a guest room/suite to a corridor door for non-sprinkler and sprinkler protected building are 23 m and 38 m, respectively. Maximum travel distances from the corridor door of any guest room/suite to the nearest exit for non-sprinkler and sprinkler protected building are 30 m and 60 m, respectively. Guest room/suite with area exceeding 185 m^2 would require at least two exit access doors remotely located from each other. US criteria only impose deadend travel limit in corridors, where all corridors serving as access to exits should have not less than 1-hour fire rating. Deadend limits for non-sprinkler and sprinkler protected building are 10.7 m and 15 m, respectively. It is found that the typical floor plan in Figure 2 well satisfied the US prescribed requirements but not the local code [25]. People might ask:

Is the local requirement too stringent?

No, local code [25,26] requirements are reasonable but are relatively broad and general, and more importantly, governed by separate documents [25-28] independently. That is, fire-rated partition layout is not included in escape distances measurements as in Figs. 1a to 1c. However, the US guide [20] specifies the fire safety design with particular concerns on the building layout characteristics. It has separate requirements for travel distance within guest room/suite and within corridor.

A fire engineering approach should be adopted to assess whether the service apartment with extended travel distances is acceptable. Perhaps, the service apartment layout with slightly longer deadend distance exceeding the limit by maximum 0.6 m would have insignificant effect on the overall evacuation time. It might even be safer with the presence of a sprinkler system. It seems the designs satisfying overseas guide should be safe. However, both building and occupant characteristics in USA and Hong Kong are very different. For example, US citizens would complain when they see some fire extinguishers are not put in the right positions. Local citizens seldom complain and some building operators might even lock the emergency exits by chains as in old highrise industrial buildings! Therefore, before working out the performance requirements, design objectives, acceptance criteria and assessment methodology from detailed research with social responsibility of citizens taken into account, only the engineering approach can be relied on.

7. CONCLUSIONS

The requirements of the Means of Escape code for new buildings in Hong Kong are reviewed, with basic concept of evacuation outlined. The current active and passive means of escape provisions are discussed. All these are useful in understanding the present situation on regulations for means of escape provisions in Hong Kong with respect to various occupancy and building types.

In the local codes [25-28], prescriptive-based is still the main approach. It is now argued that the traditional prescriptive-based codes might not satisfy with economic efficiency and, sometimes, might not give a practical solution due to narrow coverage of the prescribed code. A case study of the horizontal means of escape design in a service apartment has been presented to demonstrate the inappropriateness of strict application of the prescribed approach and the necessity of having EPBFC to achieve a cost-effective performance-based design. Long-term research should be carried out to draft the appropriate EPBFC. Only preliminary recommendations can be made:

- Occupancy characteristics and their involved activities as well as building familiarity are important factors affecting the occupants' response to fire or evacuation. One of the most important design parameters related to building layout design, maximum travel distance, should be governed by various occupancy types which are of similar occupancy characteristics.

- To increase design flexibility as well as the overall evacuation planning, the overall fire safety performance with respect to occupancy density and types, fire compartmentation arrangement and the effect of active fire safety installations should be considered as a whole.

- For buildings with non-typical geometrical ratio such as high ceiling storage layouts and atria of various dimensions, engineering performance-based fire safety design is considered appropriate to determine safe and cost-effective fire safety provisions. The evacuation characteristics, population density and the effect of active fire safety systems should be assessed simultaneously.

- Fire safety management [14,15,43,44] must be implemented properly. Much tighter regulations should be set up immediately with very serious monitoring on how the fire safety plan is implemented. Perhaps even old buildings, especially those constructed years ago with poor provisions on both passive design and active fire protection system, might be safe if fire safety management is good. Management team should be well-trained as that in China where security guards are either appointed from policemen or fire-fighters. Their responsibilities are much more than locking up cars parked illegally!

Without clear performance-based design guides standardized and tailored for local use, significant amount of professional efforts and time would be required. Note that cost-effectiveness is not only counted for the cost-effective building design (benefit to developers), but also for saving engineering and documentary time of architects, fire engineers, developers and government officers (benefit to the public/taxpayers). But without in-depth research, this can never be achieved.

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Abbreviations for Table 3 [25,28,35]

BC Building total capacity.

N Not specified in code, will be determined by the Authority.

NR Not required.

R Required.

R1 Automatic alarm system is required for buildings with total floor area exceeding 230 m^2.

R2 Required for any fire compartment exceeding 7,000 m^3 in that building where (i) the aggregate area of openable windows of the compartment does not exceed 6.25% of the floor area of that compartment; and (ii) the design fire load is likely to exceed 1,135 MJm^{-2}.

R3 Required for building with the uppermost floor exceeds 30 m above ground floor discharge point where (i) natural venting of staircase is not provided; and (ii) the aggregate area of openable windows of the rooms of the building does not exceed 6.25% of the floor area of those rooms, calculated on a floor-by-floor basis; and (iii) the cubic extent of the building exceeds 28,000 m^3; and (iv) the design fire load is likely to exceed 1,135 MJm^{-2}.

R4 Required for covered parking area, which is not open for its entire length or width on at least two sides.

R5 Required for any floor for sleeping accommodation.

R6 Required for all internal means of escape serving all guest rooms leading to a pressurized or naturally ventilated staircase; a protected lobby or open air, unless the route itself is provided with openable windows of aggregate area exceeding 6.25% of the floor area of that route.

R7 Required where natural venting of staircase is not provided and the aggregate area of openable windows of the rooms of the building does not exceed 6.25% of the floor area of those rooms, calculated on a floor-by-floor basis.

R8 Required for building with the uppermost floor exceeds 30 m above ground floor discharge point where natural venting of staircase is not provided; and the aggregate area of openable windows of the rooms of the building does not exceed 6.25% of the floor area of those rooms, calculated on a floor-by-floor basis.

R9 Required for the entire basement area except the parking areas less than 230 m^2 floor area, strong rooms and safe deposit vault.

R10 Required for (i) any fire compartment exceeding 7,000 m^3 where the design fire load is likely to exceed 1,135 MJm^{-2} and; (ii) industrial basement; and (iii) basements of 3 or more levels except solely for car parking purposes.

R11 Required for basements of 3 or more levels where (i) no open air access routes for firemen are provided; (ii) the cubical extent of the basement exceeds 7,000 m^3 and (iii) the design fire load of the basement exceeds 1,135 MJm^{-2}.

R12 Required for any above ground fire compartment exceeding 28,000 m^3 or any basement fire compartment exceeding 7,000 m^3.