Part G

Guidelines on Fire Engineering

This Part contains ten Sections:

- **Section 1 – Introduction**
- **Section 2 – Framework for Fire Engineering**
- **Section 3 – Introduction to Fire Engineering**
- **Section 4 – Methodologies of Fire Engineering**
- **Section 5 – Fire Safety Sub-systems**
- **Section 6 – Design by Fire Engineering**
- **Section 7 – Fire Safety Assessment Report**
- **Section 8 – Bounding Conditions**
- **Section 9 – Computer Models**
- **Section 10 – References**

Section 1 - Introduction

Clause G1.1 Use of this Part

The Guidelines in this Part are developed to:

(a) provide guidance for complying with the fire safety objectives in the Buildings Ordinance and the Performance Requirements stipulated in Part A; and

(b) provide a framework for fire engineering to develop an Alternative Solution.

Clause G1.2 Objectives of this Part

The objectives of this Part are to:

(a) provide guidance for the process of applying fire engineering for fire safety design in buildings; and

(b) provide guidance on the available methodologies on conducting fire engineering.

Clause G1.3 Limitations of this Part

This Part has inherent limitations, including:

(a) the Guidelines are not applicable to protect those person(s) directly involved with fire ignition (initiation) (e.g. arson). Fire safety provisions are not generally designed to protect such persons;

(b) the Guidelines are intended to be used by persons who have adequate qualifications, experience and knowledge in the field of fire engineering; and

(c) the Guidelines are not applicable for fire hazards related to handling of explosive materials.

Section 2 - Framework for Fire Engineering

Clause G2.1 Performance Requirements and Level of Safety

The Performance Requirements in Part A may apply differently to different buildings and different Use Classifications, e.g. the Performance Requirements related to means of escape are interpreted and applied differently for a shopping centre, a high-rise domestic building and a hospital. Although there is no explicit level of safety stated for the Performance Requirements in Part A, when adopting a performance-based approach, the Building Authority will normally accept a level of performance not inferior to that of the Deemed-to-Comply provisions. The Deemed-to-Comply provisions in Parts B to E provide a benchmark on the acceptable level of fire safety of buildings.

Commentary

It is not possible to design or obtain a goal of absolute safety for all building occupants, with respect to fire safety. There is always a finite risk of injury, death or property damage as a result of a fire. Due to the difficulty in predicting the outcomes of fire and its impact on life safety and property safety, all fire safety solutions, whether performance-based or those complying fully with the Deemed-to-Comply provisions will have a certain risk to life and property associated. Deemed-to-Comply provisions in this Code provide a benchmark with respect to the acceptable level of risk, with regard to the risk of fatality, injury and loss of adjacent structures through fire. It is not intended that this benchmark should be “absolute safety” or “zero risk” because these concepts are not achievable and the benchmark risk needs to take into account what the community expects and the cost to the community, which may only be determined by a cost benefit analysis.

In order to complete a performance-based assessment (Alternative Solution), acceptance criteria must be developed in order to analyse the outcome of the design. The relationship between the acceptance criteria and the relevant Performance Requirements may vary in different scenarios and must be considered on a case-by-case basis, which is part of the fire engineering approach process.

Clause G2.2 Complying with the Framework for Fire Engineering

This Part provides guidance on the application of fire engineering for the formulation of an Alternative Solution for fire safety provisions in buildings to comply with the fire safety objectives, Functional Statements and Performance Requirements in Part A.

For example, an Alternative Solution for the provisions of means of escape may be formulated as follows:

Step 1 Fire Safety Objectives

The fire safety provisions in a building should achieve the fire safety objectives and they should be provided for:

1. Protection of life of building occupants.
2. Minimization of fire spread between fire compartments.
3. Prevention of building collapse as a result of fire.
4. Facilitation of firefighting and rescue by fire services personnel.

Step 2 Functional Statement

The Functional Statement clarifies the fire safety objectives. The Functional Statement for means of escape is provided in the Building (Planning) Regulation 41(1), stating "*Every building shall be provided with such means of escape in case of emergency as may be required by the intended use of the building*."

Step 3 Performance Requirements

The Performance Requirements provide the criteria by which a solution for fire safety can be formulated. The Performance Requirements consists of two parts:

(a) The Performance Requirement itself; and

(b) The guidance to the Performance Requirements which provides the factors to be considered for demonstrating compliance.

Performance Requirements B1 to B7 should be complied with.

Step 4 Relevant Performance Requirements

Performance Requirements under various Functional Statements may need to be satisfied for an Alternative Solution. For example, an assessment of means of escape requires assessment of all Performance Requirements B1 to B7 but Performance Requirement C1 may also have to be evaluated as this relates to the protection of the means of escape from fire.

All relevant Performance Requirements should be assessed against the Deemed-to-Comply provisions for an Alternative Solution.

Step 5 Guidance

The guidance lists a "checklist" that should be considered in conjunction with each of the Performance Requirement. For example, the assessment of means of escape for a high-rise domestic building (Use Classification 1), as part of an Alternative Solution, should be based on the assessment of Performance Requirements B1 to B7.

Taking Performance Requirement B1 as an example, which states that:

"A building, fire compartment or storey should be provided with adequate means of escape for all occupants to evacuate safely without being overwhelmed by the effects of fire."

This indicates that the design must satisfy that the subject building has adequate number of required staircases and exits of adequate width, both of which have adequate protection allowing all occupants to evacuate in case of fire. The number and design of required staircases or exits and the protection required to achieve a safe evacuation can be further determined by an evaluation of the guidance in G2.3. For example, each Performance Requirement can be addressed in detail through the use of the guidance, which assists the design of appropriate fire safety provisions that satisfy the relevant Performance Requirement and hence, meet the Functional Statement and finally achieve compliance.

This process can be carried out for all relevant Performance Requirements, as part of an Alternative Solution and the process of evaluation should be supported through calculations and detailed assessment.

Step 6 Demonstrate Compliance

Compliance with the Performance Requirements can be achieved by:

(a) *Complying with the Deemed-to-Comply provisions in this Code, or*

(b) *Formulating an Alternative Solution which complies with the Performance Requirements, or*

(c) *A combination of (a) and (b).*

Compliance has to be demonstrated by proving that all relevant Performance Requirements are satisfied. The Alternative Solution involves a process of setting the relevant acceptance criteria and then providing an assessment that demonstrates the acceptance criteria are met. The fire safety sub-systems in Section 5 provide the evaluation methodology for detailed assessment.

Commentary

It is expected that most of the Alternative Solutions will be based on demonstrating a building is safe and complies with the Performance Requirements, the Functional Statements and the fire safety objectives through fire safety provisions.

The interpretation and application of Performance Requirements will vary for different buildings or Use Classifications.

Because of the uncertainties that can arise from the qualitative Performance Requirements and interpretations in the methods and data available to determine whether the acceptance criteria have been met, it is recommended that sensitivity assessment and design redundancies (with careful evaluation on relevant safety factor) are addressed as part of the fire engineering assessment to be evaluated by utilising the fire safety sub-systems (see Section 5).

Clause G2.3 Evaluation Criteria on Guidance to Performance Requirements

The following criteria should be evaluated when considering the Guidance to Performance Requirements:

Guidance to Performance Requirements for Means of Escape

	Guidance Statement	*Evaluation of Factors*
B-a	**Use Classification of the building**	The Use Classification of a building will have impact on the number of exits required, due to the number of occupants in the building. The Use Classification also determines whether the occupants of the building are potentially asleep, awake, familiar with the building or require assistance to evacuate.
B-b	**Occupant capacity, nature, location and awareness**	The total number of required staircases or exits is dependent on the number of occupants and the travel distances expected. Care should be taken for high occupancy buildings and where occupants maybe unfamiliar with the building.
B-c	**Fire hazard, its potential growth and duration**	The fire hazard within the Use Classification may impact adversely on evacuating occupants and will need to be considered with regard to the speed of fire growth, intensity and smoke spread.
B-d	**Building height**	Occupant evacuation may be more difficult for taller buildings and hence extra provisions such as refuge floors are provided.
B-e	**Building area and fire compartment area**	Required staircases and exits are dependent on the overall building size and the fire compartments that separate the building. Openings between fire compartments, especially floor voids can increase the risk of fire and smoke spread impacting on evacuation.
B-f	**Security measures impairing escape**	Doors to a required staircase may be electronically secured and security devices which can be released in case of fire or other methods to ensure exit and access must be considered.
B-g	**Fire safety provisions installed within the building**	The fire safety provisions within the building may assist the timely evacuation of occupants by providing earlier detection or allowing faster movement to a safe environment.
B-h	**Type, number, size, location and layout of exit routes**	Exit routes must be adequately sized and readily located for all occupants to evacuate safely and used efficiently. Exit signs assist occupants finding their ways to the required staircases.
B-i	**Suitable resting areas to avoid fatigue**	For tall buildings, refuge floors are required to allow occupants descending to have a short rest at intermediate floors before they continue using the required staircases.

B-j	**Suitable construction to prevent slipping and falling**	Staircases should be constructed to reduce the risk of occupants slipping and falling through the provision of handrails, tread and riser dimensions and lighting.
B-k	**Temperature, visibility, toxicity of smoke**	The exposure of occupants may be received from a fire will need to be assessed if the proposed layout of the floor has exits and protection of exits that differ from the Deemed-to-Comply provisions.
B-l	**Protection from adjoining and adjacent buildings**	Required staircases within a building will need to be protected from a fire in an adjoining or adjacent building.
B-m	**Fire service intervention**	Appropriate access to the building and firefighting equipment to allow firefighters to suppress a fire is required.

Guidance to Performance Requirements for Fire Resisting Construction

	Guidance Statement	***Evaluation of Factors***
C-a	**Use Classification of the building**	The Use Classification of a building will have impact on the fire load, fire intensity, duration of burning and the hazard to the occupants. The Use Classification will also have impact on firefighting operations.
C-b	**Occupant capacity, nature, location and awareness**	The total number of occupants, their location within the building and their ability to evacuate, will need to be considered with regard to the FRR and compartmentation to be provided.
C-c	**Fire hazard, its potential growth and duration**	The fire hazard within the Use Classification will have impact on the FRR and compartmentation required. The impact on evacuating occupants will need to be considered with regard to the speed of fire growth, intensity and smoke spread.
C-d	**Building height**	Building height will be a factor for consideration for the determination of FRR, compartmentation and firefighting access.
C-e	**Building area and fire compartment area**	Overall building size and compartmentation need to be considered to reduce the impact of a potential fire. Fire compartmentation may also be utilised to separate more hazardous areas to facilitate evacuation of occupants. Openings between fire compartments, especially floor voids can increase the risk of fire and smoke spread.
C-f	**Building location in relation to property boundaries**	The potential for fire to spread between buildings must be considered and openings should be provided with appropriate fire barriers.
C-g	**Location of roof having regard to other buildings**	The potential for fire to spread to other buildings via a roof must be considered.

C-h	**Required duration of tenable conditions to be maintained in fire compartments other than that of fire origin**	Fire compartment and fire barrier may be required to prevent untenable conditions occurring before occupant evacuation in parts of a building remote from the area of fire origin. This will be of particular importance where floor voids are present.
C-i	**Active fire safety provisions installed within the building**	The active fire safety provisions within a building may assist in providing protection to evacuating occupants and assist firefighting operations.
C-j	**The timing of the works**	Where a building or fire compartment is undergoing alterations or additions, the works being undertaken may result in hazardous conditions and the extent that these works impact on occupants and firefighting operations should be considered.
C-k	**Fire service intervention**	FRR and compartmentation will assist firefighters in carrying out their firefighting operations.

Guidance to Performance Requirements for Means of Access

	Guidance Statement	*Evaluation of Factors*
D-a	**Use Classification of the building**	The Use Classification of a building will have impact on the fire load, fire intensity, duration of burning and the hazard to the occupants and firefighters. The Use Classification will also impact on the numbers of persons and assistance that may be required from firefighters for complete evacuation.
D-b	**Occupant capacity, nature, location and awareness**	The total number of occupants, their location within the building and their ability to evacuate, will need to be considered with regard to the FRR and compartmentation to be provided to assist firefighting operation and safe evacuation.
D-c	**Fire hazard, its potential growth and duration**	The fire hazard within the Use Classification will have impact on the FRR and compartmentation required for firefighting access and operations. The impact of the fire hazards on evacuating occupants will need to be considered with regard to the firefighting access.
D-d	**Building height**	Building height will be a factor for consideration for the determination of FRR and compartmentation to assist firefighting access and their operations.
D-e	**Building area and fire compartment area**	Overall building size and compartmentation need to be considered with regard to firefighting access.
D-f	**Active fire safety provisions installed within the building**	The active fire safety provisions within a building may assist in providing protection to evacuating occupants and assist firefighting access and operations.

D-g	**Building location in relation to property boundaries**	EVA needs to be considered with regard to the location of the building and neighbouring buildings. The potential for fire to spread between buildings must be considered and openings should be provided with appropriate fire barriers.

Guidance to Performance Requirements for Fire Safety Management

	Guidance Statement	*Evaluation of Factors*
F-a	**Use Classification of the building**	The Use Classification of a building will have impact on the fire safety maintenance required and the motivation to complete the maintenance correctly. The Use Classification also determines the need for fire safety management and training to assist safe evacuation of occupants.
F-b	**Active fire safety provisions installed within the building**	The active fire safety provisions within a building will determine the type of maintenance to be provided and the fire safety management strategy to be implemented.
F-c	**Fire hazard, its potential growth and duration**	The fire hazard within the Use Classification will have impact on the need for fire safety management plans to be in place and well practiced to assist evacuation of occupants. The fire hazards within a building may also have impact on the type and frequency of fire safety maintenance.

Section 3 – Introduction to Fire Engineering

Clause G3.1 Introduction

The Building Authority recognizes that fire safety may be approached in a number of ways the best of which is not necessarily prescriptive, namely an alternative approach. This is particularly pertinent to buildings of special hazards which, because of their size, use, complexity or location, may necessitate special consideration and specific standards. The alternative approach may be a performance-based approach whereby the relevant Performance Requirement(s) need to be identified and demonstrated through a fire safety assessment.

Where an alternative approach is adopted to develop an Alternative Solution, the relationship between the Deemed-to-Comply provisions and the Performance Requirements must be considered. An FSAR should be submitted to illustrate the formulation of an Alternative Solution.

Commentary
The International Standards Organisation (ISO) defines fire safety engineering as:

"*The application of engineering principles, rules and expert judgement based on a scientific appreciation of the fire phenomena, of the effects of fire, and the reaction and behaviour of people, in order to:*

- *save life, protect property and preserve the environment and heritage;*
- *quantify the hazards and risk of fire and its effects;*
- *evaluate analytically the optimum protective and preventative measures necessary to limit, within prescribed levels, the consequences of fire*."

Clause G3.2 Relevant Considerations

The approach to develop and complete the FSAR will vary for each building, due to variation in the number and type of non-compliances with the Deemed-to-Comply provisions in this Code. The aspects that require a detailed assessment are:

(a) Number and inter-relationship (if any) of the non-compliances with the Deemed-to-Comply provisions in this Code.

(b) Alternative Solutions to be addressed.

(c) Relevant Performance Requirements.

(d) Building site and access.

(e) Building form and construction.

(f) Use Classification and interaction of occupants.

(g) Occupant capacity and means of escape.

(h) Fire hazards and ignition sources.

(i) Credible fire scenarios and sensitivity assessment.

(j) Fire safety provisions to be provided.

(k) Management measures.

(l) Fire service intervention.

Clause G3.3 Application

A performance-based approach using fire engineering can be adopted to formulate an Alternative Solution when there is genuine difficulty in complying with the Deemed-to-Comply provisions in this Code, especially for buildings of special hazards (due to their size, use, complexity or location).

Fire engineering aims to attain an overall level of safety that is equivalent to that which would result if fire safety was achieved through full compliance with the Deemed-to-Comply provisions in this Code and it can offer higher flexibility in design of buildings.

Commentary

Fire engineering allows detailed assessment of the fire safety provisions (taking into account the active, passive and management provisions) which will be most appropriate for the occupants, building and site characteristics and fire service intervention. The performance-based approach must take into account the potential for future changes or variations that may occur, with any significant variation in building form, fire load or occupancy characteristics that should be addressed by a new assessment as required by the Bounding Conditions (see Section 8).

However, despite advances in the science, fire safety is not a well-defined problem as certain areas of knowledge are still not yet well-developed and some variables depend on the assumed future state of a building. In fact, fire engineering is not as mature as other traditional engineering disciplines, with the absence of any simple approach that can be readily accepted and understood by the practitioners and related parties. Thus, there are constraints in the application of fire engineering.

Clause G3.4 Safety Margins and Safety Factors

There are various safety margins or safety factors that can be utilised for fire engineering. A safety margin can be used for a time-based assessment whereas a safety factor can be used for other comparative assessments or test verification methods. As an example, life safety fire engineering assessments are typically performed utilising a deterministic time based analysis and therefore the use of safety margins is more appropriate than safety factors.

Safety margins are adjustments made to compensate for uncertainty in the methods, calculations, assumptions and engineering judgement employed in the development of engineering designs. Safety margins do not necessarily need to be a number, for instance, in calculating the physical evacuation time for a group of people that has a mix of ambulant occupants and mobility impaired occupants, an inherent safety margin will have been included if the calculation assumes the majority of occupants are mobility impaired with a slower travel speed.

On the other hand, safety factors are adjustments made to numerical quantities of some uncertain parameters in order to provide an appropriate degree of reliability.

Safety Factors and Safety Margins for Use in Design

Safety factors or safety margins for fire engineering will vary, depending on the type of assessment and analysis being undertaken. Safety factors for normal scenarios as part of a fire engineering design will typically range from 1.5 to 2.0. Where the degree of reliability has been verified with the carrying out of an analysis with single system failure, the safety factor used can be suitably reduced or even be omitted.

Safety margins will be dependent on the worst credible fire or potentially a "worst credible fire" with single system failures to ensure the overall design is robust.

Commentary

Safety factors are commonly used, but need to be applied carefully, due to the number of inputs that a design is dependent on. Providing an overall safety factor of 1.5 may not be practical as the inputs will differ markedly in the make-up of the analysis – i.e. calculation of means of escape time is based on detection time, which can be calculated fairly accurately relative to other inputs. Pre-movement time will have a wide range of values compared to other inputs. Travelling time and queuing time can be calculated reasonably accurate.

Safety margins or safety factors should be determined according to the nature of the problems and the degree of knowledge available to solve such problems. They should be developed as part of the acceptance criteria for the fire engineering, to be confirmed on a case-by-case basis. The authorized person who is responsible for the fire engineering approach must be able to justify and explain the safety margins or safety factors utilised for their specific case.

Engineering Judgement

A performance-based approach to design may require more engineering judgement than other form of analysis, as part of the design and approval process. The level of judgement for fire engineering is higher than many other engineering disciplines because a fire engineering approach requires a fire safety strategy to be developed from first principles, which is the basis of performance-based design that requires consensus between the designers and the Building Authority on all assumptions, inputs, limitations and acceptance criteria, on a case-by-case basis.

Fire engineering is a newer field of engineering and greater judgement is needed. The assumptions of a fire engineering design should be more conservative and should normally have higher safety factors.

Commentary

To provide a structured approach to fire engineering analysis, the use of the fire safety sub-systems is recommended to be utilised for all Alternative Solutions (see Section 5).

Section 4 –Methodologies of Fire Engineering

Clause G4.1 Introduction

Fire engineering offers a flexible alternative where compliance with the Deemed-to-Comply provisions in this Code is impractical. It provides an Alternative Solution achieving:

(a) a level of safety that is equivalent to that which would result if fire safety was achieved through full compliance with the Deemed-to-Comply provisions in this Code; or

(b) an acceptable level of safety such that the agreed acceptance criteria and the Performance Requirements are satisfied.

Clause G4.2 Complying with the Performance Requirements

Fire engineering provides a framework to demonstrate that the Performance Requirements are satisfied even though some of the design solutions adopted fall outside the Deemed-to-Comply provisions in this Code where additional fire safety provisions are proposed to compensate for the deviation or shortfall.

If the design being considered is not substantially different from the Deemed-to-Comply provisions or can be readily accommodated by adopting conservative assumptions, it may simply be a case of demonstrating like-for-like substitution or "equivalence" with Deemed-to-Comply provisions and fire safety objectives without having to embark on a full fire safety strategy. However, a practical test is required to demonstrate the equivalence.

Clause G4.3 Assessment Methodologies

There are two types of assessment methods:

(a) Qualitative analysis – use of engineering judgement with documented reasoning and arguments, to compare an Alternative Solution against the Deemed-to-Comply provisions, without calculations.

(b) Quantitative analysis – utilising numerical methods to assess an Alternative Solution, which may involve data and probabilistic methods. There are two means to carry out quantitative analysis, i.e. deterministic and probabilistic.

Deterministic Methods

This method is based on making predictions of the likely outcomes in the event of a fire and selecting appropriate fire safety provisions to achieve the required objectives. Application of this method is typically through showing a level of fire safety equivalent to the Deemed-to-Comply provisions, but it may also take an absolute approach to satisfy the Performance Requirements.

A hazard analysis has to be carried out, followed by an engineering approach based on the accepted fire loads and demonstrating the ability to resist such loads, based on physical relationships derived from scientific theories and empirical results of fire dynamics. The credible fire scenarios, timeline analysis, fire/smoke models and evacuation models have to be established.

Commentary

The approach is often assisted by fire models and computational methods and can offer a more certain indication of achieved safety. Provided the hazards are identified, it is possible to devise strategies for the management or design solutions which will ensure reasonable safety of the occupants, and the protection of essential emergency plant and equipment.

Probabilistic Methods

Risk in the context of fire engineering consists of two components, i.e. the likelihood of occurrence and the consequence. Probabilistic method is essentially an assessment of risk for evaluating the fire safety performance to justify an Alternative Solution. It is based on assigning reliabilities to the performance of various fire safety provisions and assigning frequencies of occurrence of events. The risk of a fire starting and developing with the likely effects of the fire at the worst location and time of ignition should be analysed.

The fire loads, the number and location of occupants and the fire safety provisions should also be assessed to verify whether the acceptance criteria are met. The first two steps are to determine the geometry, construction and Use Classification and to identify the relevant Performance Requirements. The third step is to identify deviations from the Deemed-to-Comply provisions and to propose an Alternative Solution to address the deficiency. The risk levels associated with the proposed fire safety provisions can then be established.

The method is a scenario analysis, considering all possible scenarios. Some parts of the analysis can be quantified with numbers (quantitative analysis), but much of the analysis requires engineering judgement on the development and consequences of a fire and the likely location and movement of people (qualitative analysis).

Commentary

Probabilistic methods require data for events such as fire starts, causes and implications. Due to the lack of such data in Hong Kong, such methods should be used with caution. An absolute risk level evaluation should be carried out only if quality data are available and an acceptable level of risk is clearly defined. Otherwise, a comparative risk evaluation should be carried out to ascertain relative levels of fire safety for the building, where the Deemed-to-Comply provisions are used as a base case.

Probabilistic methods for assessment can only be of limited use due to the lack of internationally recognised and mature assessment methods. At present, there are no tools available for calculating risk in absolute terms, which have been successfully validated and are reliable in their operation.

Evaluation Acceptance - Equivalence or Absolute

One of the most accepted approaches of demonstrating that an Alternative Solution complies with the Performance Requirements is a process of demonstrating “equivalence” (or carrying out a comparative assessment). The term “equivalent” is used to show an Alternative Solution adopted achieving a level of fire safety comparable with the level of safety achieved by the Deemed-to-Comply provisions.

Demonstrating equivalence to the Deemed-to-Comply provisions is where equal performance between the designed system and what is expected under full compliance with the Deemed-to-Comply provisions is achieved i.e. the outcome under a given fire scenario should be similar for either the complying system or the proposed Alternative Solution.

The fire safety performance of an element or fire safety sub-system should be compared to the level of fire safety that would be achieved in an identical building in which that element, or fire safety sub-system is designed in compliance with the Deemed-to-Comply provisions.

There are two evaluation methods to establish the level of fire safety for a particular Alternative Solution.

The use of “equivalent level of fire safety” is one evaluation method for assessing the fire safety level achieved by an Alternative Solution. It is often the base-line performance for fire engineering.

The other method is an absolute evaluation. An absolute evaluation is carried out where the results of the analysis are matched against the Performance Requirements without comparison to the Deemed-to-Comply provisions, hence requiring agreed acceptance criteria. This requires more substantiation through calculations and also requires prior agreement of the analysis inputs and acceptance criteria by the Building Authority.

Clause G4.4 References

The following are useful references:

- *International Fire Engineering Guidelines*, Australian Building Codes Board, Canberra, Australia, Edition 2005, 2005.
- Drysdale, D., *An Introduction to Fire Dynamics*, 3rd Edition, John Wiley and Sons, Chichester, UK, 2011.
- Society of Fire Protection Engineers, *SFPE Handbook of Fire Protection Engineering*, National Fire Protection Association, Quincy, MA, 4th Edition, 2008.
- Klote, J.H., and Milke, J.A., *Design of Smoke Management Systems*, American Society of Heating and Air-Conditioning Engineers, Inc., Atlanta, GA, 1992.
- NFPA 92B, *Guide for Smoke Management Systems in Malls, Atria, and Large Areas*, National Fire Protection Association, Quincy, MA, 2009.
- *CIBSE Guide E Fire Safety Engineering*, The Chartered Institution of Building Services Engineers, London, 3rd Edition, 2010.
- Karlsson, B., and Quintiere, J. G., *Enclosure Fire Dynamics*, CRC Press, Boca Raton, FL, 2000.
- Pauls, J.L., and Jones, B.K., “Building Evacuation: Research Methods and Cases Studies”, *Fires and Human Behavior*, John Wiley and Sons, New York, 1980.
- BS 7974, *The Application of Fire Safety Engineering Principles to the Design of Buildings*, British Standards Institute, London, 2001.

Section 5 – Fire Safety Sub-systems

Clause G5.1 Introduction

The framework of fire safety “sub-systems” should be used to assess, evaluate and document all the fundamental aspects of an Alternative Solution for a building.

The sub-systems form a set of parameters that must be considered for all Alternative Solutions. The interaction of the sub-systems and their direct correlations with the Performance Requirements should be identified for setting the design principles and the basis of the assessment fundamentals. All sub-systems must be considered even though some of them fully comply with the Deemed-to-Comply provisions. The sub-systems are described below:

Sub-system 1: Fire Initiation and Development - fire science principles and fundamentals.

Sub-system 2: Smoke Development, Spread and Control - assessment of smoke development is required to assess life safety, considering smoke movement, visibility and smoke layer temperature.

Sub-system 3: Fire Detection, Warning and Automatic Suppression - active fire safety provisions relevant to the fire hazard, to relevant standards, with regular inspection, testing and maintenance carried out to ensure the systems are operable at all times.

Sub-system 4: Fire Spread, Impact and Control - fire spread can be limited by the fire safety provisions installed. Assessing fire development, pre-flashover and post flashover fires is required for assessment of life safety and the impact of fire on property.

Sub-system 5: Occupant Characteristics and Evacuation - prediction of occupants’ behaviour and egress must be based on analysis of occupant characteristics and the fire safety provisions provided.

Sub-system 6: Fire Service Intervention - interaction of firefighters must be considered.

Commentary

The fire safety sub-systems provide a framework for carrying out a fire engineering design. All sub-systems should be examined in a holistic manner. Some of the sub-system aspects may fully comply with the Deemed-to-Comply provisions and hence may need little justification, whereas other sub-systems may have significant non-compliances and require substantial assessment but all must be considered.

Sub-system 1 - Fire Initiation and Development

Fire initiation and development is a fundamental of any performance-based assessment for fire safety. Information and inputs to the assessment of this sub-system that may be required as part of an Alternative Solution include:

(a) fire compartment characteristics;

(b) fire load density;

(c) expected fuel configuration;

(d) ignition sources;

(e) expected design fires;

(f) rate of heat release;

(g) fire compartment ventilation and limitations;

(h) development of smoke;

(i) calculation of temperature in smoke layer; and

(j) time to reach flashover or if flashover is reached.

Assessment should be based on considering the likelihood of fire occurrence and not just assuming a fire occurs. In general, due to the lack of data and tools, a probabilistic assessment on absolute terms (e.g. probability of fire deaths per year) cannot be undertaken.

The approach must be based on realistic assessment of the likely fire growth rate, likely fire size and rate of fire spread through a fire compartment, based on the ventilation available.

Commentary

To understand the likelihood of a fire developing and growing, statistical information is required on the location of a fire, how it develops and the effectiveness of active fire suppression systems etc.

Sub-system 2 - Smoke Development

The interaction of occupants with smoke is a fundamental for assessment of life safety. The assessment should be based on smoke layer height and visibility, with consideration of toxicity, where appropriate. The acceptance criteria for life safety with regard to smoke are to be based on:

(a) smoke movement and layer height;

(b) smoke visibility; and

(c) smoke layer temperature.

Information and inputs to the assessment of this sub-system that may be required as part of an Alternative Solution include:

(a) occupant characteristics;

(b) fire compartment characteristics;

(c) fire load density;

(d) expected fuel configuration;

(e) expected design fires;

(f) rate of heat release;

(g) fire compartment ventilation and limitations;

(h) effects of elevated temperatures on elements of building construction;

(i) calculation of temperature in smoke layer;

(j) smoke layer height and interface height;

(k) smoke visibility / optical density;

(l) effect of fire suppression systems on properties of the fire and smoke;

(m) smoke control equipment present, active and passive;

(n) relevant standards to be complied with; and

(o) maintenance and testing.

If a probabilistic method is undertaken, the data on the effectiveness of smoke control measures (both active and passive), elements of construction and fire suppression systems are required.

Sub-system 3 - Fire Detection, Warning and Automatic Suppression

To mitigate the hazards represented within the other sub-systems, active fire safety provisions are required. These provisions provide warning to the occupants and may also provide automatic suppression in case of fire.

Performance-based design is not expected to occur on a sub-system level, unless in special circumstances, e.g. specialised smoke management or fire suppression systems within tall atria.

Information and inputs to the assessment of this sub-system that may be required as part of an Alternative Solution include:

(a) fire compartment characteristics;

(b) expected design fires;

(c) rate of heat release;

(d) calculation of temperature in smoke layer;

(e) smoke layer height and interface height;

(f) smoke visibility / optical density;

(g) types of smoke or heat detection equipment;

(h) types of automatic suppression systems;

(i) activation of smoke control measures through fire alarm panel;

(j) activation of other fire safety provisions through fire alarm panel;

(k) activation of warning systems to occupants;

(l) activation of alarm system to the Fire Services Department;

(m) smoke control equipment present, active and passive;

(n) relevant standards to be complied with; and

(o) maintenance and testing.

> **Commentary**
>
> An assessment of this sub-system requires a thorough understanding of the potential failure modes and likelihood of failures of the sub-system. The likelihood of failure or activation of a system is also reliant on the type of maintenance and testing carried out. This data are not available in Hong Kong at present.

Sub-system 4 - Fire Spread, Impact and Control

Fire spread can be limited by either active or passive fire safety provisions or a combination of both. Generally the fire barriers of a fire compartment will limit fire and smoke spread, as will the type of fuels present and internal linings. The other key system for fire control is the use of fire suppression systems, especially automatic sprinkler systems. Hose reels and extinguishers can also be used.

The Fire Services Department provides the last means of defence against fire spread within a fire compartment and between fire compartments or buildings. Assessing the impact of fire service intervention is also required.

Information and inputs to the assessment of this sub-system that may be required as part of an Alternative Solution include:

(a) fire compartment characteristics;

(b) fire load density;

(c) expected fuel configuration;

(d) expected design fires;

(e) rate of heat release;

(f) influence of lining materials;

(g) ventilation and limitations;

(h) calculation of temperature in smoke layer;

(i) smoke control equipment present, active and passive;

(j) automatic alarm systems;

(k) automatic suppression systems;

(l) time to flashover or if flashover is reached;

(m) sealing of all penetrations;

(n) use of the time-equivalence concept;

(o) knowledge of inherent fire resistance performance;

(p) effects of elevated temperature on elements of construction;

(q) structural stability of load bearing building elements;

(r) relevant standards to be complied with;

(s) fire service intervention; and

(t) maintenance and testing.

Commentary

An assessment of this sub-system requires an understanding of the expected failure processes for fire seals, fire barriers, automatic systems and fire service intervention. Also the likelihood that occupants will extinguish a fire by using devices such as hand-held extinguishers or hose reels should be considered.

Sub-System 5 - Occupant Characteristics and Evacuation

Occupant escape from fire is made up of the following components:

(a) detection of fire and occurrence of the warning cue;

(b) recognition of the cue and pre-movement activities of occupants; and

(c) movement to a safe place.

Fire initiation is based on the fuel characteristics and ventilation, which is determined within sub-system 1. The time for detection of the fire and an alarm to be activated is developed within sub-system 3.

Recognition of an alarm or cue is dependent on the occupant characteristics within the fire compartment and also within the building as a whole. The ability to recognise an alarm and then act on it is dependent on the type of warning system provided, which is required to be tailored to the expected occupant characteristics.

Occupant movement is dependent on the mobility of the occupant, the number of occupants, number of exits, travel distance to exits and ability to make decisions as to which exit to choose.

Information and inputs to the assessment of this sub-system that may be required as part of an Alternative Solution include:

(a) fire compartment characteristics;

(b) occupant characteristics, including physical and mental capabilities;

(c) occupant numbers and distribution;

(d) prior fire safety training for occupants;

(e) presence of a warden system and its effectiveness;

(f) established fire emergency organisational structure and procedures;

(g) frequency of false alarms;

(h) building layout and exit route characteristics;

(i) type of detection;

(j) occupant warning systems and mode of alarm;

(k) life safety protection systems;

(l) fire service access, search and rescue abilities; and

(m) maintenance and testing.

All components are times and together they equate to the total evacuation time. The total evacuation time is the Required Safe Egress Time, i.e. RSET.

Commentary

Pre-movement time is a very difficult value to estimate, given the reliance on the human characteristics, especially if the occupancy involves sleeping groups or persons who have paid to enter an area. Pre-movement times have been researched for many years and ranges of values have been established within the fire engineering field. This information is a very important input into the design process and the assumed values, the range of values and how they are applied are required to be justified.

Pre-movement time is therefore usually not a discrete value but a range of values, given that people react differently due to their own perceived risk and also their location to the fire event. Some occupants are of relatively long pre-movement times because they are remote from a fire event and hence are not directly at risk. Typically a range is considered appropriate, due to the uncertainty and expected range of pre-movement times that will be possible for any design or actual fire.

Data on how people may react in a fire in Hong Kong is also relevant, categorised for example by age group, sex, physical and mental capability, level of education, any prior fire training received, responsibility held at the time of fire, ability to recognise and respond to alarms etc. An assessment will be highly dependent on the human factors.

Sub-system 6 - Fire Service Intervention

Often the impact of the Fire Services Department is ignored with an assumption that firefighters would arrive after all occupants have evacuated. This is a very conservative approach as the Fire Services Department is often on the fire ground when occupants are still leaving the building.

One method of predicting fire service intervention is to utilise a design methodology that is provided by the Fire Services Department. This is often entitled as an “intervention model”. This is a formalised method for quantifying the operations of the Fire Services Department. It is typically an event-based methodology that considers the time taken for the various firefighting functions to be performed.

Information and inputs to the assessment of this sub-system that may be required as part of an Alternative Solution include:

(a) building and fire compartment characteristics;

(b) occupant characteristics and numbers;

(c) exit path characteristics;

(d) fire safety provisions;

(e) dispatch and routes details;

(f) EVA;

(g) ability for investigation;

(h) area and time for set-up;

(i) means of access available;

(j) availability of water supplies;

(k) prevention of spread of fire to other buildings; and

(l) fire control and extinguishment.

Commentary

Intervention Model of Fire Services Department

This section provides the Fire Services Department's intervention model with guidance on methodologies that may be adopted for quantifying the following:

(a) the arrival of the fire service at the fire scene;

(b) investigation by the fire service;

(c) fire service set-up;

(d) search and rescue;

(e) fire service attack;

(f) fire control; and

(g) fire extinguishment.

The components of fire service intervention that will need quantification may be grouped under two main headings:

(a) pre-fire control and extinguishment activities; and

(b) fire control and extinguishment.

The first group of activities relates mostly to the series of events that take place from the time the fire service is notified to the time it is ready to attack the fire. The effect of fire service activities does not lend itself easily to quantification and many aspects of the procedure will need to be based on qualitative judgement rather than numerical calculations.

Computer models may provide guidance on how to quantify fire control and extinguishment events and times. Other methods based on thermodynamics and heat transfer theory may also be utilized for this purpose. However, it will be necessary to utilize the expertise of the local fire service to validate many of the decision-based input parameters used.

The computer model should assume the following prioritized outcomes:

(a) the safety of building occupants who must be able to leave the building (or remain in refuge floor) without being subject to untenable conditions;

(b) the protection of firefighters who must have reasonable time to search for any trapped occupants, before conditions become hazardous to their safety occur; and

(c) the protection of adjacent fire compartments and buildings from fire spread due to radiation, flame impingement, flying brands or structural collapse.

The computer model should be used (in whole or in part) to generate the following information:

(a) the time taken for firefighters to reach a particular location in a building;

(b) the water flow rate required for fire extinguishment or control that is necessary to compensate for deletion of a sprinkler system;

(c) the required water flow rate and building separation necessary to prevent fire spread to adjoining property;

(d) the time firefighters will be inside a building for search and rescue activities during which firefighter tenability and structural stability should be maintained; and

(e) the robustness of the Alternative Solution.