# Section 6 - Design by Fire Engineering

## Clause G6.1 Application of Fire Engineering at Different Stages

The application of fire engineering at different stages of a project (fire engineering process) is described below for new buildings. For existing buildings, the role and involvement will differ, depending on the alterations, additions or changes in Use Classification that are proposed:

**(a) Building Planning / Feasibility**

(i) The role of fire engineering is to identify areas of non-compliance with the Deemed-to-Comply provisions and provide generalised design advice regarding occupant type, numbers, FRR, fire safety provisions, site access, neighbouring buildings etc. in broad terms.

**(b) Schematic Design**

(i) As the design detail advances, the major fire safety provisions can be confirmed.

**(c) Detailed Design**

(i) As the design proceeds to a detailed design stage, all fire safety provisions and Alternative Solutions should be addressed in detail. The FSAR should be completed for submission and acceptance.

**(d) Construction**

(i) During construction stage, fire safety provisions may change or require re-assessment. A revised FSAR should be submitted as appropriate.

**(e) Commissioning**

(i) Towards the end of the construction, all fire safety provisions will require inspection and commissioning. The authorized person should be involved and confirm that all fire safety provisions are installed as per the approved plans, FSAR and related documents (reports, drawings and specifications).

**(f) Management in Use**

(i) The authorized person should assist in documenting all Bounding Conditions that will form part of a fire safety management plan. He should also assist to develop maintenance and management procedures for the building owners.

## Clause G6.2 Fire Engineering Process

### Feasibility and Schematic Design

During the early stages of a project, whether it be a new building or addition and alteration works to an existing building, fire engineering may be used in two different ways, namely in the design and assessment of fire safety sub-systems or in the evaluation of a specific fire safety provision.

In the early stages of a project, where the building design is evolving, the fire engineering process may contribute to the development of the design and the evaluation of the various design options. In the later stages, when the design has become essentially fixed, a fire engineering evaluation should be carried out to demonstrate that the Alternative Solution complies with the relevant fire safety objectives and Performance Requirements in this Code, utilising the approach and methodology of the fire safety sub-systems.

From this latter process, an FSAR is generated which forms the basis of the documentary evidence required in support of an Alternative Solution.

## Clause G6.3 Pre-submission Enquiry

If fire engineering is adopted, the authorized person should consider the implications of fire safety on the building design and consult the Building Authority at the early stage so that the fire safety objectives can be agreed at the outset. In this connection, the Building Authority may be approached prior to submission of general building plans for agreement in principle to any fire engineering design being considered.

The authorized person should take on a pivotal role in the consultative procedures when the fire strategy and fire engineering design is being developed.

The authorized person should then submit the FSAR together with the general building plans to the Building Authority for approval.

## Clause G6.4 Assessment Approaches

The principles of design of Alternative Solutions should be based on assessing the fire safety sub-systems and their interaction with each other.

The basis of many life safety assessments for a fire engineering approach is the utilisation of the “time-line” method where the “required time” for egress is compared with the ”available time” for egress. This approach is the “RSET versus ASET” approach, where RSET is the Required Safe Egress Time and ASET is the Available Safe Egress Time. This involves the interaction of the sub-systems 1 to 5. This can lead to the assessment and justification. For example, travel distances that exceed the Deemed-to-Comply provisions in this Code.

An Alternative Solution should follow one of the following three assessment methods for fire engineering:

(a) Assessment Type 1: Qualitative analysis or quantitative with calculations, generally based on a simple assessment involving a single sub-system. This may be an equivalence assessment.

(b) Assessment Type 2: This assessment involves a quantitative analysis of more than one sub-system, but does not involve detailed analysis of all sub-systems. The assessment can be a deterministic, absolute or comparative analysis, based on the assessment of multiple fire scenarios. An equivalence assessment may form part of this process.

(c) Assessment Type 3: This assessment involves all six sub-systems and the evaluation should be based on probabilistic methods. As there is currently no method or means to establish an absolute acceptance criterion, only comparative analysis will be accepted. This assessment can only be used for special or complex buildings.

Assessment Type 2 is the most common type of analysis. A time line assessment is illustrated in Diagram G1, showing the basis of Assessment Type 2, which consist of the following aspects:

(i) evacuation assessment, made up of detection time, pre-movement time, physical travel time, and time to exit from a fire compartment;

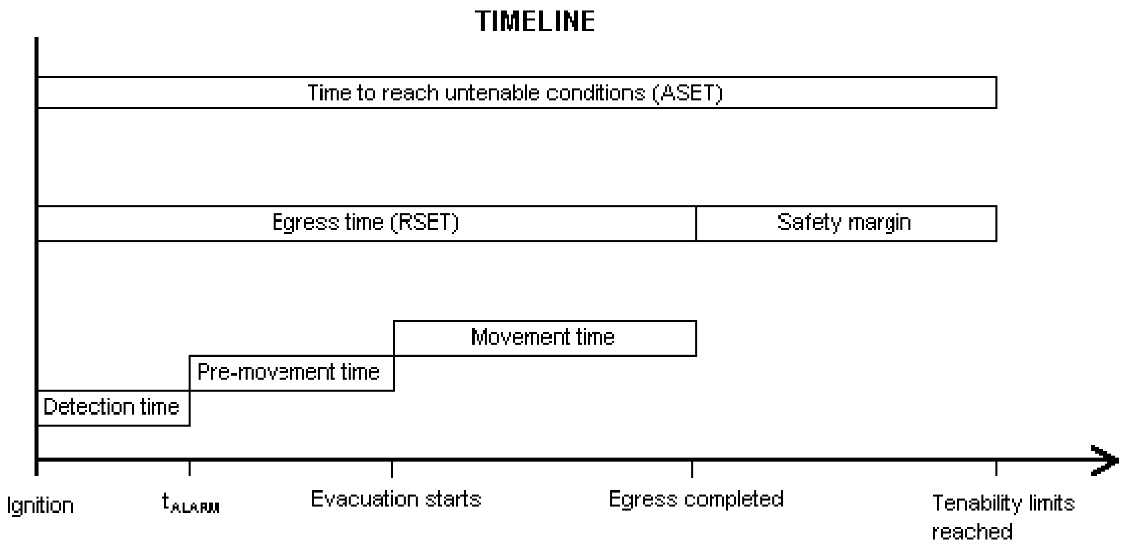
(ii) fire development calculations showing rate of heat release for a fire within the fire compartment for a range of scenarios;

(iii) smoke development calculations for the fire compartment; and

(iv) safety factor or safety margin as part of the comparison of the two timelines.

Time line assessments provide a very clear and transparent process for assessing a fire safety design. The time line assessment has three parts – tenability calculations, means of escape calculations and a safety margin (or factor).

**Diagram G1: Graphical Representation of a Timeline Assessment**




## Clause G6.5 Design Fires

A design fire is an engineering description of the development of a fire for use in a design fire scenario. Design fire curves are described in terms of heat release rate (HRR) versus time. The formulation of a design fire is crucial to any fire safety design as the design fire acts as the "test load" to the proposed fire safety strategy.

A fire is either fuel controlled or ventilation controlled. Fuel controlled fires are typically represented by short period fires, with steep HRR curves. If the ventilation is limited within the fire compartment, then the HRR will be limited, due to the limited oxygen available for combustion. Ventilation controlled fires are typically represented by longer duration fires with HRR curves that have a less steep curve.

In developing a design fire, the effects of the fire growth characteristics, the mass of fuel, the layout of the fuel and the effects of the fire compartment on the combustion processes should be taken into account as appropriate to justify the design fire.

A typical schematic HRR curve for a fire compartment is shown in Diagram G2 below. This curve illustrates the main aspects of HRR within a fire compartment. Each phase is further described.

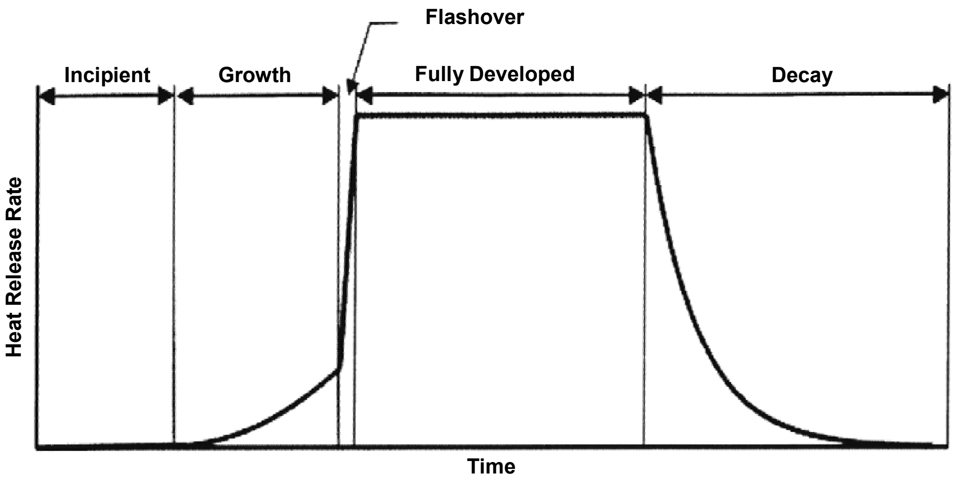



**Diagram G2: Typical Phases of a Fire Curve**

### Incipient Phase

The incipient phase of a fire can last a few milliseconds to days depending on the initial fuels involved, ambient conditions, ignition source, etc. In most cases, the incipient phase is ignored and the growth phase is started from time zero.

### Growth Phase

The growth phase is considered to begin when the radiation feedback from the flame governs the mass loss rate. Assuming the fire compartment is vented, the burning rate is primarily influenced by the fuel properties and orientation. During the growth phase the fire spreads across the fuel surfaces, increasing the burning area and corresponding HRR. The mass loss rate is assumed to be independent of the fire enclosure and governed more by the flame-spread rate.

The growth phase is the most important aspect of the design fire. This is typically modelled with a $t^2$ rate of growth.

**Commentary**

The ability to predict flame spread through empirical models has encouraging results but is limited to comparatively simple geometries such as room corners. Research on the growth rate for complex objects like upholstered furniture and complex storage arrays is ongoing. Therefore, fire safety consultants are forced to using experimental data or correlations to estimate the fire growth rate.

### Flashover

Although there is no universally accepted definition for flashover, it can be described as a transition from a developing fire to full room involvement. This transition typically occurs over a short time span measured in seconds. The increase in radiation from the upper layer not only ignites all of the combustibles in the room but also enhances the mass loss rate of all the burning objects.

Typical definitions of flashover including:

(a) Gas temperatures at near ceiling level in the order of 600°C;

(b) Radiation heat flux at floor level exceeding 20 kW/m$^2$; and

(c) Flames emerging from enclosure openings.

These definitions are practical criteria for physical observation only. From a modelling point of view, flashover is modelled as a linear transition from a growing fire to a fully developed fire over a very short period of time.

**Fully Developed / Post-Flashover**

In the fully developed or post-flashover phase of the fire, all of the combustible objects in the fire compartment are burning including the floor (if combustible). The mass loss rate is controlled either by fuel surface area or the available air supply. In most cases, the fire is controlled by the available oxygen, i.e. ventilation controlled.

**Commentary**

Some fire models calculate the ventilation rate into and out of a fire compartment and have the capability to adjust the HRR within the fire compartment accordingly. Any excess fuel that cannot burn within the fire compartment due to a lack of oxygen is available to burn in other locations where there is sufficient oxygen (i.e. outside the openings).

**Decay Phase**

Once a fire has consumed most of the available fuel the HRR will diminish.

### Determining Appropriate Design Fires

A fire engineering assessment should be based on the establishment of appropriate design fires, which should be based on:

(a) Use Classification of the fire compartment;

(b) fire load energy density information;

(c) typical configuration of fuels;

(d) ventilation conditions; and

(e) fire suppression systems or passive fire safety provisions.

A range of design fires should be established for an assessment or a conservative design fire may be chosen.

Initiation of a fire, or the ignitability of an object is normally not analysed but assumed to occur and the growth of fire is modeled. The initial growth of the fire, once started, can be particularly important for aspect of fire spread and tenability. Estimating fire spread between objects is often calculated to assess how quickly a fire within a fire compartment may spread.

**Commentary**

Different design fire scenarios should be developed with an aim to approximate credible fire scenarios (including small arson with small fire size, as appropriate) to test the robustness of the Alternative Solution.

The number, type and location of design fires are dependent on the building type and the Alternative Solutions being assessed. A risk-based approach to developing design fires can also be utilised, where the design fires to be chosen are not clear or there are a multiple number of design fires to be assessed.

Quantification of design fires will be dependent on the Use Classification, the ventilation, the agreed types of fuel present and will therefore vary between projects and be applied on a case-by-case basis for each project.

A significant amount of detailed information relating to design fires is available through peer-reviewed journals and key references. The process of choosing and quantifying the appropriate design fires is to be based on the realistic expectations for ignition hazards, fire growth, combustibles reasonably expected and fire duration, based on the ventilation conditions.

By considering possible scenarios as part of the FSAR, the expectations of analysis for the fire engineering assessment can be readily determined. The fire safety sub-systems approach to analysis assists in developing the appropriate sensitivity of input parameters and redundancy of fire safety provisions installed.

A common method of describing growing fires is the "T-squared" (or $t^2$) concept. T-squared fires are generic fire growth rates based on fuel characteristics and are the most common and practical curves for estimating the growth of a fire. These curves are defined in NFPA 92B [1] and Enclosure Fire Dynamics [2]. The "T-squared" curves as they are often referred to are design tools to represent fire growth rate of general combustible items. There are four curves used, slow, medium, fast and ultra-fast.

[1] NFPA 92B, *Guide for Smoke Management Systems in Malls, Atria, and Large Areas*, National Fire Protection Association, Quincy, MA, 2009.

[2] Karlsson, B., and Quintiere, J. G., *Enclosure Fire Dynamics*, CRC Press, Boca Raton, FL, 2000.

Examples on Design Fires

Typical examples on design fires are provided in Table G1 for reference. These examples are deduced based on the parameters given in the Table. The suitability on adopting the design fire provided in Table G1 should be considered diligently and be verified on case-by-case basis.

**Table G1 – Examples on Design Fire Sizes**

| **Use Classification** | | **Examples on Design Fire Size** |
|---|---|---|
| 1. Residential | | For considering a pre-flashover fire, the growth rate of design fire for residential is medium. See Note (1).<br><br>For considering a post-flashover fire, the most commonly used design fire depends on Ventilation Controlled Fire. Note (2) illustrates an example on the calculation methodology. |
| 2. Hotel and similar Transient Accommodation | | Sprinkler controlled fire for a hotel room with a headroom of 3.0m and standard response type of sprinkler is expected to be about 1.7MW. |
| 3. Institutional | 3a. Health/child care facilities | Sprinkler controlled fire for a hospital with a headroom of 3.0m and standard response type of sprinkler is expected to be about 1.7MW. |
| | 3b. Detention and correctional centres | Sprinkler controlled fire with a headroom of 2.5m and standard response type of sprinkler is expected to be about 1.5MW. |
| 4. Commercial | 4a. Business facilities | Sprinkler controlled fire for an office with a headroom of 2.5m and standard response type of sprinkler is expected to be about 1.5MW. |
| | 4b. Mercantile facilities | Sprinkler controlled fire with a headroom of 2.5m and standard response type of sprinkler is expected to be about 1.5MW.<br><br>If no sprinkler is provided, the fire size is expected to be based on fuel load density obtained by measured survey loads, q, which is given in $MJ \cdot m^{-2}$. By assuming a conservative burn-out time of 20 minutes (i.e. 1200 s), the unit heat release is estimated to be:<br><br>$Q_U = q / 1200$<br><br>where $Q_U$ ($kW \cdot m^{-2}$) is the unit heat release rate and q ($kJ \cdot m^{-2}$) is the measured survey load. See Note (3) for an example. |
| 5. Assembly | 5a. Places of Public Entertainment | Sprinkler controlled fire with a headroom of 2.5m and standard response type of sprinkler is expected to be about 1.5MW. |
| | 5b. Educational establishments | |

| Use Classification | | Examples on Design Fire Size |
|---|---|---|
| | 5c. Transport facilities | See Note (4) for vehicle fires. |
| | | Range from 5 MW to 22 MW for train fire. See Note (5). |
| | 5d. Other Assembly Premises | Sprinkler controlled fire with a headroom of 2.5m and standard response type of sprinkler is expected to be about 1.5MW. |
| 6. Industrial | | Sprinkler controlled fire for an industrial building or a warehouse with a headroom of 3.5m and standard response type of sprinkler is expected to be about 2.0MW. |
| 7. Carpark | | Carparks should be protected by sprinklers as required by FSI Code. Any fire in the carpark is expected to be controlled avoiding any fire spread from one vehicle to another. See Note (6) for details. |
| 8. Plant rooms & the like | | Sprinkler controlled fire for a plant room and the like with a headroom of 3m and standard response type of sprinkler is expected to be about 1.7MW. |

Notes:

(1) Reference can be made to *CIBSE Guide E Fire Safety Engineering*, The Chartered Institution of Building Services Engineers, London, 3rd Edition, 2010.

(2) An example for a residential unit with the living room dimension of 6m (L) x 3m(W) x 3.2m (H), having two windows of 3m (W) x 2.5m(H) and 0.8m(W) x 1.2m(H) based on the equations in CIBSE Guide E and CIBSE TM19 [3]. The rate of burning is calculated as:

$$R = 0.02\left[A_o h^{1/2}\left(A_T - A_o\right)(W/D)\right]^{1/2} \qquad \text{(Equation 1)}$$

Where,

$A_o$ = Sum of window areas, m² = 3 x 2.5 + 0.8 x 1.2 = 8.46m²

$A_T$ = Total area is the area of room surface (wall, floor, ceiling), m²

= 6 x 3 x 2 + (3+6) x 2 x 3.2 = 93.6m²

h = Weighted average of window height, m

= (3 x 2.5 x 2.5 + 0.8 x 1.2 x 1.2 ) ÷ 8.46 = 2.3525 m

W = Width of the wall containing window, m = 3m

D = Depth of room behind the window, m = 6m

[3] CIBSE Technical Memoranda TM19, *Relationships for Smoke Control Calculations*, Chartered Institution of Building Services Engineers, London, 1995.

For multiple openings with different heights, h can be calculated by:

$$h = \frac{\sum A_i h_i}{A_w}$$

(Equation 2)

where, i = 1, 2, 3…..represents different windows.

$$D/W = \frac{W_2}{W_1}\frac{A_{w1}}{A_w}$$

(Equation 3)

where,

$W_1$ = Width of wall 1 (containing the greatest window area), m = 3m

$W_2$ = Width of wall 2 (depth of room behind the greatest window area), m = 6m

$A_{w1}$ = Window area on wall 1, m² = 3 x 2.5 = 7.5 m²

$A_w$ = Sum of window areas on all wall, m² = 8.46m²

Therefore, $D/W = \frac{W_2}{W_1}\frac{A_{w1}}{A_w} = \frac{6}{3} \times \frac{7.5}{8.46} = 1.77$

$$R = 0.02\left[A_o h^{1/2}(A_T - A_o)(W/D)\right]^{1/2} = 0.02\left[8.46 \times 2.3525^{1/2}(93.6 - 8.46)(\frac{1}{1.77})\right]^{1/2} = 0.5kg/s$$

The equivalent heat release rate is given by Q = $H_c$ x R, where $H_c$ is the heat of combustion (kJ/kg) and R (kg/s) is the mass rate of burning. When assuming the burning material is wood ($H_c$ = 13.0 x $10^3$ kJ/kg), the calculated heat release rate is equal to 13.0 x $10^3$ x 0.5 = 6.5 MW.

(3) Design Fire based on Measured Survey Load

$Q_U$ = q / 1200

where $Q_U$ (kW · $m^{-2}$) is the unit heat release rate and q (kJ · $m^{-2}$) is the measured survey load.

A commonly used value of unit heat release rate for retail shop is 550 kWm$^{-2}$ as shown in Table 6.3 of CIBSE Guide E. Therefore, when considering an example of a retail shop with the floor area of 50 m², the total heat release rate is about 550 kW/m² x 50 m² = 27.5 MW.

(4) For Use Classifications 5c and 7, the examples of fire size for different types of vehicles for road tunnel design can make reference to NFPA 502, *Standard for Road Tunnels, Bridges, and Other Limited Access Highways*, National Fire Protection Association, Quincy, MA, 2011 and Ingason, H., "Design Fires in Tunnels", Second International Symposium, Lausanne, 2006. The following should also be considered:

(i) The designer should consider the rate of fire development (peak HRR may be reached within 10 minutes), the number of vehicles that could be involved in the fire, and the potential for the fire to spread from one vehicle to another.

(ii) Temperatures directly above the fire can be expected to be as high as 1000°C to 1400°C (1832°F to 2552°F).

(iii) The HRR may be greater than in the table if more than one vehicle is involved.

(iv) A design fire curve should be developed in order to satisfy each specific engineering objective in the design process (e.g., fire and life safety, structural protection, etc.).

(5) The examples on design fire sizes are adopted in some projects of Mass Transit Railway Corporation. The design fire sizes depend on the type and model of the trains.

(6) Though sprinklers are provided for carparks, there is experiment comparing the fire sizes for two different situations: (1) a free burning vehicle with no sprinkler and (2) a burning vehicle with sprinklers. The fire sizes of the two situations are very similar. This is because the vehicle has a canopy at the top which can shield off the sprinkler water and cannot effectively suppress or control the fire inside the car.

**Commentary**

Examples of the expected HRR for various items may refer to NFPA 92B [4],, as are the design curves. They represent a general worst credible fire scenario that is easily compared, as a basic design tool. When fuel items are burnt and the data recorded, it can be compared with the $t^2$ fire growth curves.

The amount of fire load has been traditionally perceived to be related directly to fire growth rate, i.e. a higher fire load density will lead to a faster fire growth. Scientifically, how fast a fire grows depends on the fuel properties (e.g. liquid fuels burn much faster than solid fuels), the exposed surface area, and the amount of external heat energy and oxygen available to the fuel.

The quantity of fire load has also been used to represent the degree of fire hazard in buildings. Whilst it is correct that an enclosure having more fuel will lead to a longer fire duration (under same ventilation conditions), sole reliance on fire load density to characterize fire hazard has not addressed other parameters that equally contribute to the fire hazard, including potential fire growth rate, flame spread properties of furnishings, ease of ignition of the dead and live fire load in the enclosure, the potential ventilation available through door and window openings, and the likely types of ignition source.

The following references are suggested:


- *CIBSE Guide E Fire Safety Engineering*, The Chartered Institution of Building Services Engineers, London, 3rd Edition, 2010.
- PD 7974-1, The *Application of Fire Safety Engineering Principles to the Design of Buildings – Part 1: Initiation and Development of Fire within the Enclosure of Origin (Sub-System 1)*, British Standards Institution, London, 2003.
- ISO/TR 13387-2, *Fire Safety Engineering – Part 2: Design Fire Scenarios and Design Fires*, British Standards Institution, London, 1999.
- NFPA 92B, *Guide for Smoke Management Systems in Malls, Atria, and Large Areas*, National Fire Protection Association, Quincy, MA, 2009.
- Society of Fire Protection Engineers, *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*, National Fire Protection Association, Quincy, MA, 2000.
- NFPA 502, *Standard for Road Tunnels, Bridges and Other Limited Access Highways*, National Fire Protection Association, Quincy, MA, 2011.
- Ingason, H., “Design Fires in Tunnels”, Second International Symposium, Lausanne, 2006.


[4] NFPA 92B, *Guide for Smoke Management Systems in Malls, Atria, and Large Areas*, National Fire Protection Association, Quincy, MA, 2009.

In general, smoke control (smoke hazard management) systems are designed to:

(a) reduce the impact of smoke and heat on occupants evacuating from a fire compartment where a fire is located; and

(b) limit the spread of smoke between fire compartments.

The impact of smoke from a fire can be controlled through both active and passive fire safety provisions. Active fire safety provisions are activated by smoke detection or sprinkler protection and include fans to exhaust smoke, operable vents or other systems such as smoke curtains and shutters. These systems will control and vent both heat and smoke to reduce the spread of smoke and also permit evacuation by occupants.

Smoke can also be controlled by passive fire safety provisions, which includes compartmentation that limits fire spread within a building.

**Commentary**

The design for the control of smoke within a fire compartment or atrium is complex and requires detailed understanding of fire growth, fluid dynamics and building safety systems.

The design for smoke hazard management systems must include careful consideration of make up air. The impact of wind would only be considered for smoke control with the use of natural ventilation.

Smoke hazard management for occupant safety will have different design and acceptance criteria than smoke clearance systems, which are designed to vent smoke to assist firefighting activities.

Guidance for the design of smoke hazard management systems should be sourced from guides such as those listed below:

- PD 7974-2, The *Application of Fire Safety Engineering Principles to the Design of Buildings – Part 2: Spread of Smoke and Toxic Gases within and beyond the Enclosure of Origin (Sub-System2)*, British Standards Institution, London, 2002.
- 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, Chartered Institution of Building Services Engineers, London, 3rd Edition, 2010.
- ISO/TR 13387-5, *Fire Safety Engineering – Part 5: Movement of Fire Effluents*, British Standards Institution, London, 1999.
- Klote, J.H., and Milke, J.A., *Principles of Smoke Management*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA, 2002.
- Morgan, H.P. et al., *Design methodologies for smoke and heat exhaust ventilation*, BRE 368, Construction Research Communication Ltd, London, 1999.

Occupants within a building need various cues before they decide to evacuate. These cues include visually seeing smoke or warnings from other persons. Another cue is an effective alert and warning system. This includes tones and recorded or live messaging systems, with clear instructions.

The time taken from when a fire is detected, either through smoke detection or other form of detection to when occupants start to evacuate, is the pre-movement time. The pre-movement time is a variable as persons will receive different cues and persons in different locations will react in a diverse manner. The pre-movement time varies as persons have different commitments to the activities they are involved at the time of the fire, whether that be working, shopping, sleeping or watching a movie. Hence, pre-movement time should be a distribution.

Pre-movement time also varies between Use Classifications. Persons who are asleep typically take much longer time to react and prepare themselves to evacuate. Persons who are working are relatively alert and are more familiar with the exits and surroundings. Table G2 summarizes various well-referenced pre-movement times. The same set of guidelines should be applied consistently throughout the whole fire safety assessment.

### Table G2 – Summary of Pre-movement Times

| Pre-movement time | | | | | | |
|---|---|---|---|---|---|---|
| | PD7974[1] | | SFPE[2] | NZ Framework[3] | | CIBSE Guide E[4] |
| | T1[a] | T2[b] | | Origin | Remote | |
| **Occupants are awake and familiar with the building (office, industrial)** | | | | | | |
| Voice alarm signal/ trained staff | 0.5 [c] | 1 [c] | < 1 | | | |
| Standard alarm signal throughout the building | 1 [c] | 2 [c] | 3 | 0.5 | 1 | 1 |
| Local/ Standard Alarm Signal & non-trained staff | > 15 [c] | > 15 [c] | > 4 | | | |
| **Occupants are awake and unfamiliar with the building (Retail, restaurant, cinema, theatre)** | | | | | | |
| Voice alarm signal/ trained staff | 0.5 [d,e] | 2 [d,e] | < 2 | 0.5 | 1 | |
| Standard alarm signal throughout the building | 1 [d,e] | 3 [d,e] | 3 | 1 | 2 | 3 |
| Local/ Standard Alarm Signal & non-trained staff | > 15 [d,e] | > 15 [d,e] | > 6 | | | |
| **Occupants are sleeping and familiar with the building (Dwelling – individual occupancy)** | | | | | | |
| Voice alarm signal/ trained staff | - | - | < 2 | | | |
| Standard alarm signal throughout the building | 5 | 5 | 4 | 1 | 5 | 5 |
| Local/ Standard Alarm Signal & non-trained staff | 10 | > 20 | > 5 | | | |
| **Occupants are sleeping and familiar with the building (Serviced flats, hall of residence)** | | | | | | |
| Voice alarm signal/ trained staff | 10 | 20 | < 2 | | | |
| Standard alarm signal throughout the building | 15 | 25 | 4 | 1 | 5 | 5 |
| Local/ Standard Alarm Signal & non-trained staff | > 20 | > 20 | > 5 | | | |
| **Occupants are sleeping and unfamiliar with the building (Hotel, boarding house)** | | | | | | |
| Voice alarm signal/ trained staff | 15 | 15 | < 2 | | 5 | |
| Standard alarm signal throughout the building | 20 | 20 | 4 | 1 | 10 | 20 |
| Local/ Standard Alarm Signal & non-trained staff | > 20 | > 20 | > 6 | | | |
| **Occupants are awake and require assistance (Day care, clinic, dentist)** | | | | | | |
| Voice alarm signal/ trained staff | 0.5 [f] | 2 [f] | < 3 | | | |
| Standard alarm signal throughout the building | 1 [f] | 3 [f] | 5 | 1 | 2 | 2 |
| Local/ Standard Alarm Signal & non-trained staff | > 15 [f] | > 15 [f] | > 8 | | | |
| **Occupants are sleeping and require assistance (Hospital, nursing home)** | | | | | | |
| Voice alarm signal/ trained staff | 5 | 10 | < 3 | | | |
| Standard alarm signal throughout the building | 10 | 20 | 5 | 5 | 30 | - |
| Local/ Standard Alarm Signal & non-trained staff | > 10 | > 20 | > 8 | | | |

All values are in minutes

Note a: Pre-movement time of the first few occupants

Note b: Pre-movement time of the last few occupants

Note c: For a large complex building, add 0.5

Note d: For a simple multi-storey building, add 0.5

Note e: For a large complex building, add 1.0

Note f: These times depend upon the presence of staff

References used:

[1] PD 7974-6, The *Application of Fire Safety Engineering Principles to the Design of Buildings – Part 6: Human Factors: Life Safety Strategies – Occupant Evacuation Behaviour and Conditions (Sub-System 6)*, British Standards Institution, London, 2004.

[2] Proulx, G., "Movement of People," in SFPE Handbook of Fire Protection Engineering, 3rd ed., Section 3, Chapter 13, P.J. DiNenno et al. (Eds.), National Fire Protection Association, Quincy, MA, 2002.

[3] Beever, P, et al., "A New Framework for Performance Based Fire Engineering Design in New Zealand," *8th International Conference on Performance-Based Codes and Safety Design Methods*, Sweden, 2010.

[4] CIBSE Guide E Fire Safety Engineering, Chartered Institution of Building Services Engineers, London, 3rd Edition, 2010.

## Clause G6.8 Tenability Criteria

For the purposes of assessing quantitative modelling results, tenability criteria are required, which are assumed to provide an indication of the level of life safety for evacuating occupants with respect to the heat and smoke conditions within the building. Authorized persons should propose for the Building Authority's acceptance the most appropriate tenability criteria for their Alternative Solution.

Factors that may affect the tenability criteria include Use Classification and variation in size of fire compartments or buildings.

Tenability is normally determined by assessing one or all of the following:

(a) smoke layer height;

(b) radiated heat transfer;

(c) convected heat transfer;

(d) toxicity;

(e) visibility;

(f) smoke temperature.

### Smoke Layer Height

2m should be adopted as the acceptable smoke layer height unless otherwise justified by the authorized person.

**Commentary**

Whilst accepted values for smoke layer height have varied in the past for Hong Kong, Paragraph 1.1.2(a) under Part IV of Fire Services Department Circular Letter No. 4/96 states that apart assisting firefighters, a smoke extraction system has advantages:

"*assisting in the provision of clear egress for escaping persons. Generally a smoke free zone of 2m in height is to be aimed for in the design. "Smoke free" does not imply complete elimination of smoke, but that visibility is not greatly impaired".*

Values adopted overseas are provided below for information:

- PD 7974-6, The *Application of Fire Safety Engineering Principles to the Design of Buildings – Part 6: Human Factors: Life Safety Strategies – Occupant Evacuation Behaviour and Conditions (Sub-System 6)*, British Standards Institution, London, 2004.
- In Australia, the National Construction Code Series (previously referred to as the Building Code of Australia) requirements for smoke exhaust capacity in Spec E2.2b, are based on keeping smoke 2m above the floor.
- In New Zealand, as described in the Fire Engineering Design Guide [5], a layer height of 2m is used.

[5] *Fire Engineering Design Guide*, Centre for Advanced Engineering at the University of Canterbury, Christchurch, New Zealand, 2008.

### Radiated Heat Transfer

Radiated heat transfer occurs when the smoke layer is above occupants' heads, and is a function of the smoke layer depth, smoke layer emissivity, and distance from the smoke layer to occupants. Radiated heat transfer can also impact on occupants who are in the hot smoke layer. A value of 2.5 kW/m$^2$ (in the order of 200$^o$C) is acceptable to occupants for a short period of exposure.

### Convected Heat Transfer

Convected heat transfer only occurs once occupants are in contact with the smoke layer, and is therefore a function of the occupant height and the smoke temperature.

### Toxicity

Toxicity becomes an issue when occupants are in contact with the smoke layer. The relative conservativeness of the layer height limits should be an indication of the confidence in the modelling being conducted, and the other levels of redundancy and contingency in the design. It is very specific to the Use Classifications and the occupants. If toxicity becomes an issue when occupants are in contact with the smoke layer, the authorized persons should consider this factor for special cases. It is recommended that the CO concentration should not exceed 1,000ppm.

### Visibility

Visibility can delay evacuation until such time as the other three factors above cause untenability but it is only an issue if the smoke has descended to a height where it impacts on evacuating occupants. The optical density should not exceed 0.1m$^{-1}$ (i.e. 10m visibility).

### Smoke Temperature

If the smoke layer falls below the acceptable smoke layer height, it is recommended that the temperature should not exceed 60$^o$C.

### References for Use

The following references are useful for determining acceptance criteria:


- PD 7974-6, The *Application of Fire Safety Engineering Principles to the Design of Buildings – Part 6: Human Factors: Life Safety Strategies – Occupant Evacuation Behaviour and Conditions (Sub-System 6)*, British Standards Institution, London, 2004.
- CIBSE Guide E Fire Safety Engineering, Chartered Institution of Building Services Engineers, London, 3rd Edition, 2010.
- ISO/TR 13387-8, *Fire Safety Engineering – Part 8: Life Safety - Occupant Behavior, Location and Condition*, British Standards Institution, London, 1999.
- *SFPE Engineering Guide to Human Behavior in Fire*, Society of Fire Protection Engineers, Bethesda, MD, 2003.
- Purser, D.A., "Assessment of Hazards to Occupants from Smoke, Toxic Gases, and Heat," in SFPE Handbook of Fire Protection Engineering, 4th ed., Section 2, Chapter 6, P.J. DiNenno et al. (Eds.), National Fire Protection Association, Quincy, MA, 2008.
- *SFPE Engineering Guide to Predicting 1st and 2nd Degree Skin Burns*, Society of Fire Protection Engineers, Bethesda, MD, 2000