Singapore Civil Defence Force

Singapore Fire Safety Engineering Guidelines 2025

1st edition: 2015
2nd edition: 2025

Published by:
Singapore Civil Defence Force
91 Ubi Avenue 4
Singapore 408827

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CHAPTER 1

1.0 INTRODUCTION

The Singapore Fire Safety Engineering Guidelines (SFEG) provides a means for Fire Safety Engineers (FSEs) to carry out Performance-Based (PB) designs to meet the objectives of the Fire Code (Code of Practice for Fire Precautions in Buildings). Where the design of fire safety works deviates from the prescribed or deemed-to-satisfy requirements stipulated in the Fire Code, the FSE may embark on an alternative solution i.e. PB approach to address these deviations.

The root and sub objectives for the PB design to achieve are stipulated in Fire Code 2013 and can be found in SCDF website and Annex J. FSE shall be cognizant of these objectives when developing their PB design method.

The SFEG therefore seeks to guide the FSEs and Peer Reviewers in preparing the relevant documents for submission to SCDF. The documents to be prepared by the FSE include the (1) Fire Safety Engineering Design Brief (FEDB), (2) Fire Safety Engineering Report (FER) and the (3) Operations and Maintenance (O&M) Manual while that of Peer Reviewer includes the Peer Reviewer's Report (PRR).

This SFEG comprises two main parts, namely:

> Part 1: PB regulatory framework, fire engineering design concepts, submission documentation requirements, administrative and technical guidelines.
>
> Part 2: Common alternative solutions to prescribed requirements and the general design approaches to address them.

While the latter part outlines the general design approaches to common alternative solutions from prescribed requirements, these are not mandated approaches and users are advised to apply them with care in view that buildings differ in terms of its design layout, fire load, occupant characteristics, etc.

Similarly, care must be exercised by the user when using any information in this document. SCDF shall not be held responsible for any wrongful design or misuse of information arising from the use of this document.

1.1 REGULATORY FRAMEWORK

1.1.1 A FSE is required to be appointed for the preparation of alternative solutions as part of the building plan submission to SCDF.

1.1.2 The FSE is required to produce a preliminary report - Fire Safety Engineering Design Brief (FEDB) to be submitted to SCDF for in-principle agreement (IPA).

The FEDB outlines the proposed fire safety engineering approach, methodology, and software tools etc.

1.1.3 The FEDB will be assessed by SCDF. Upon the in-principle agreement of the FEDB, the FSE can proceed to prepare the Fire Safety Engineering Report (FER) and the Operations and Maintenance Manual (O&M Manual).

1.1.4 After the preparation of the above documents by the FSE, the Peer Reviewer (to be engaged by the owner so as to avoid conflict of interest) shall assess the documents and ensure that the alternative solution is incorporated in the Building and M&E plans. The Peer Reviewer shall produce a report of his assessment in a Peer Reviewer's Report.

1.1.5 The Project QP is responsible for collating all the above documents for plans submission to SCDF. The alternative solution shall be endorsed by the FSE. QPs who are also qualified FSEs may endorse in the capacity of both the QP and the FSE.

1.1.6 The submitted plans and documents may be selected by SCDF for subsequent audit checks. Upon completion of the fire safety works, the owner is required to engage a Registered Inspector who is another FSE to inspect the performance-based aspects of the fire safety works. The flowchart below illustrates the process for the Performance-Based plan submission.

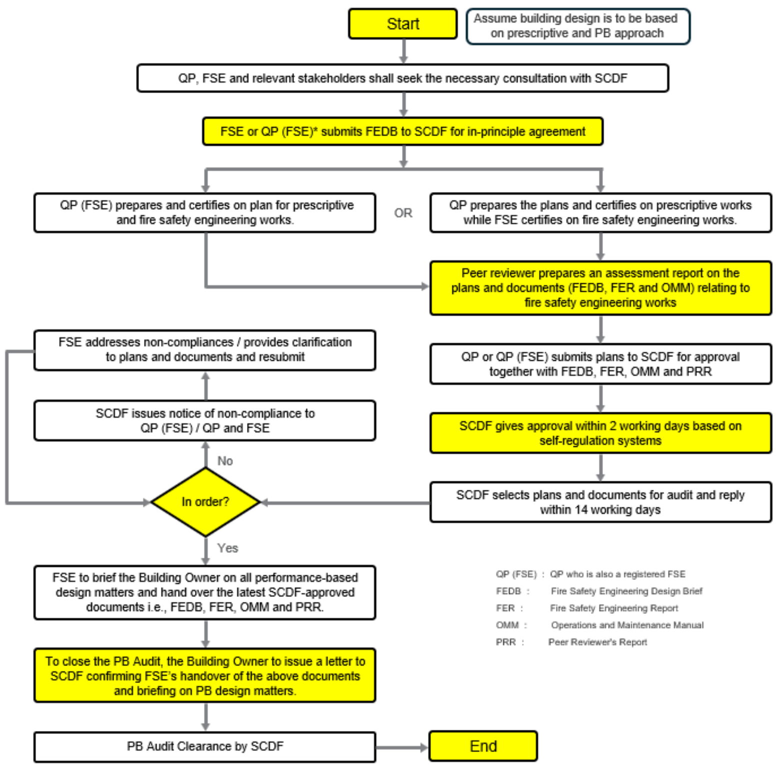

Figure 1.1 : The Performance-Based Plan Submission Framework

1.1.7 For fire safety engineering designs involving structural solution, the owner must engage a FSE who is also a Professional Engineer (PE) in the civil/structural engineering discipline. If the FSE is not a PE (civil/structural), the owner will need to engage a PE (civil/structural) to work together with the FSE. The Peer Reviewer would also need to be a PE in the civil/structural engineering discipline. If he/she is not a PE (civil/structural), then the review shall also be endorsed by another independent PE (civil/structural).

1.2 DEFINITIONS

1.2.1 The abbreviations listed in the following table are used in this Guideline: -

Abbreviation	Definition
† BS	British Standard / BS EN
† CP	Code of Practice
† NFPA	National Fire Protection Association
† SS	Singapore Standard

† latest version shall be used.

1.2.2 Alternative solution
Engineering solution for the fire safety works to satisfy any fire performance requirements in the Fire Code, being a solution that is based on:

a. A deterministic or probabilistic analysis of fire scenarios or both types of analysis or

b. A quantitative or qualitative assessment of design alternatives or both against the fire performance requirements in the Fire Code

1.2.3 Available Safe Egress Time (ASET)
"ASET" refers to the time available for escape for occupants. This is the calculated time interval between the time of ignition of a fire and the time at which conditions become such that the occupant is estimated to be incapacitated (i.e., unable to take effective action to escape to a place of safety).

1.2.4 Computational fluid dynamics (CFD)
"CFD" refers to the computational method that solves equations to represent the movement of fluids in an environment.

1.2.5 Design fire
"Design fire" refers to the quantitative description of assumed fire characteristics within the design scenario.

1.2.6 Design fire scenario

"Design fire scenario" refers to the specific scenario which defines the specific characteristics of the building, occupants and fire that are pertinent to the fire safety engineering analysis.

1.2.7 Detection time
"Detection time" refers to the time interval between ignition of a fire and its detection by an automatic or manual system or people.

1.2.8 Evacuation time
"Evacuation time" refers to the time interval between the time of warning of a fire being transmitted to the occupants and the time at which the occupants of a specified part of a building or the whole building are able to enter a place of safety.

1.2.9 Fire decay
"Fire decay" is the stage of fire development after a fire has reached its maximum intensity and during which the heat release rate and the temperature of the fire are decreasing.

1.2.10 Fire growth
"Fire growth" refers to the stage of fire development during which the heat release rate and the temperature of the fire are increasing.

1.2.11 Fuel load
"Fuel load" refers to the fire load quantity of heat which can be released by the complete combustion of all the combustible materials in a volume, including the facings of all bounding surfaces (Joules).

1.2.12 Fire safety engineering
"Fire safety engineering" is the application of engineering methods based on scientific principles to the development or assessment of designs in the built environment through the analysis of specific design scenarios or through the quantification of risk for a group of design scenarios.

1.2.13 Fractional effective dose (FED)
"FED" is the fraction of the dose (of toxic gases or thermal effects) that would render a person of average susceptibility incapable of escape.

1.2.14 Heat of combustion
"Heat of combustion" is the thermal energy produced by combustion of unit mass of a given substance (kJ/g).

1.2.15 Heat release per unit area
"Heat release rate per unit area" refers to the rate of thermal energy production per unit area generated (Qr) by combustion (kW/m2). For purpose of calculating the fire perimeter or fire size for non-sprinkler-controlled fire, the values are given in Table 1-1.

Building Use	Heat release rate per unit area, Qr (kW/m2)
Industrial	260
Storage	500
Offices	290
Shops	550
Horel rooms	249

Table 1.1 : Commonly used values of heat release rate (Fire Code & CIBSE Guide E)

1.2.16 Heat release rate (HRR)

"HRR" is the rate of thermal energy production generated by combustion (kW or MW.

1.2.17 Optical density of smoke

"Optical density of smoke" is the measure of the attenuation of a light beam passing through smoke expressed as the logarithm to the base 10 of the opacity of smoke.

1.2.18 Pre-movement time

"Pre-movement time" is the time interval between occupants being informed to evacuate and the time in which they begin to travel to a safe location.

1.2.19 Registered Inspector

A "Registered Inspector" is a person who is registered under the Fire Safety Act to be qualified and competent to inspect fire safety works in buildings to ascertain the degree of compliance of fire safety requirements.

1.2.20 Required Safe Egress Time (RSET)

"RSET" is the time required for escape. This is the calculated time period required for the occupants to travel from their location at the time of fire ignition to a place of safety.

1.2.21 Response Time Index (RTI)

"RTI" is the measure of the reaction time to a fire phenomenon of the sensing element of a fire safety device.

CHAPTER 2

2.0 FIRE SCENARIOS

This chapter sets out fire scenarios and sensitivity analyses that the FSE is required to consider (qualitatively and/or quantitatively), depending on alternative solution(s) proposed. Refer to Part 2 of the SFEG to determine which fire scenarios to apply.

These scenarios may not be exhaustive and that FSE would need to consider other scenarios where appropriate.

2.1 Base case

Design fire scenarios are representative of typical(s) fire within the occupancy considering its usage, population size, fuel load and ignition sources, ventilation, means of escape provisions, etc

Depending on the scope of the performance-based assessment, there could be more than one base case design fire scenario. The design fire locations shall be located at the most onerous/credible locations.

SCDF may also request for other base case analysis to be conducted, depending on the nature of the project and the extent of the alternative solutions.

2.2 Sensitivity analysis

Sensitivity analysis shall be conducted to test the robustness of the proposed design. These mandatory studies as described below (where applicable) may not be exhaustive and the FSE is to propose all relevant sensitivity analysis in the FEDB.

FSE to tabulate the different sensitivity tests considered for each base case fire scenario and explain why (if any) the scenario is not applicable for a particular base case. SCDF may also request for other sensitivity analyses to be conducted, depending on the nature of the project and the extent of the alternative solutions.

2.2.1 Sensitivity Test 1 – Buoyancy test

a. A 1 MW fire to test buoyancy for natural smoke control system.

2.2.2 Sensitivity Test 2 – Wind effects

a. One side of vents (side with the most openings) is assumed to fail, i.e., vents modelled to be in closed position, or subjected to wind effects that may negatively affect smoke venting for natural smoke control system.

2.2.3 Sensitivity Test 3 – Fan efficiency

a. To assume n-1 fans operating during fire mode, where n is the number of duty fans. (Not required if there are 2 or more standby fans).

b. Alternatively, a 20% increase in fire size (peak HRR) can be adopted in lieu of fan failure.

2.2.4 Sensitivity Test 4 – Increase in fire growth rate

a. Fire is assumed to grow at a faster rate using t-squared fire e.g. from medium to fast or from fast to ultrafast.

2.2.5 Sensitivity Test 5 – Fire rendering an exit unusable

a. A fire starts in the vicinity of an escape route and can potentially block an exit. Applies to premises/spaces where there are at least 2 exits.

b. FSE should consider the largest exit or the most-utilized exit to be blocked.

c. FSE would need to consider this if the alternative solution involves means of escape and/or engineered smoke control.

2.2.6 Sensitivity Test 6 – Delay in detection time

a. Failure of primary smoke/fire detection system (i.e. the first device that detects the smoke/fire).

b FSE would need to consider this if the alternative solution involves means of escape and/or engineered smoke control.

2.2.7 Sensitivity Test 7 – Smouldering Fire

a. This scenario addresses the concern regarding a slow, smouldering fire that poses a threat to sleeping occupants such fires may fill the rooms with toxic gases but may not be large enough to be detected by fire alarms or other occupants.

b. Would typically be considered if the alternative solution involves sleeping occupancies. Subject to SCDF request on a case-by-case basis.

2.3 Summary of fire scenarios

FSE shall provide a summary of all fire scenarios assessed in table format, including base case and sensitivity analysis, in the fire engineering reports. The deviation addressed by each fire scenario shall be indicated

FSE shall also provide justification with a sensitivity test table to explain how certain sensitivity tests are chosen/considered by the FSE for each fire scenario.

CHAPTER 3

3.0 AVAILABLE SAFETY EGRESS TIME (ASET)

As part of the performance-based analysis, ASET is compared against RSET after applying the relevant safety factor. The factors that affect the ASET are discussed below. As not all input parameters can be accurately predicted, safety factors are applied to the analysis to cater to these uncertainties

3.1 Fire hazards

The FSE would need to identify all possible fire hazards within the scope of his/her study and determine which would be selected as design fires

3.2 Design fires

Depending on the scope and objectives of the fire engineering analysis, the design fires would generally fall into two main categories, which are pre and post flashover fires.

3.2.1 Pre-Flashover fires are generally used for most design fires unless the design involves structural fire engineering analysis (where post flashover fires are used). For pre-flashover fire scenarios, the minimum details to be documented are as follows.

a Type and nature of fuel. The FSE would need to document the fuels present in the area of study. This includes the location, storage method, quantity or any other special characteristics/considerations.

b Type of smoke plumes

(1) **Axis-symmetric plumes at the centre of room of fire origin**

Such plumes produce lower smoke entrainment rates and higher smoke temperatures and are generally applicable to all fire scenarios.

(2) **Corner plumes at corner of room of fire origin**

Such plumes produce lower smoke entrainment rates and are applicable to corner spaces that are most remote from ventilation openings/exhaust points.

(3) **Under a balcony/Spill plume, window plumes and balcony/line plumes**

Such plumes produce higher smoke entrainment rates and lower smoke temperatures and are applicable to spaces containing intermediate/multiple levels such as atrium spaces and multi-storey buildings.

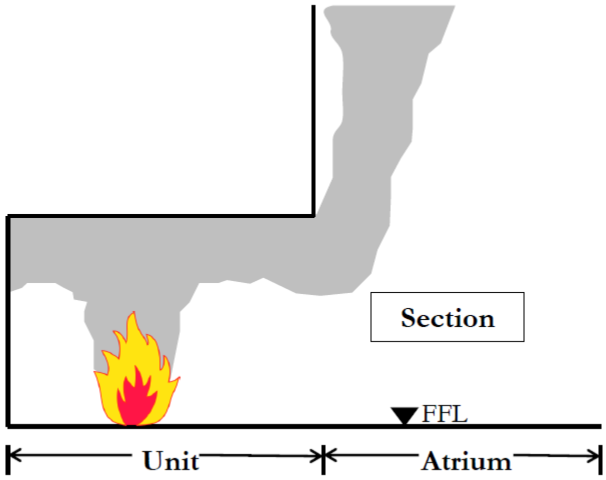

Figure 3.1 : Spill plume

c **Fire size/growth rate**

The fire growth rate generally depends on the type of fuel load, which can be generally characterised by the building usage e.g. residential, commercial, etc. In the event a building has different fuel loads e.g., due to mixed occupancies, the FSE is advised to adopt a more conservative fire growth rate or seek a consultation with SCDF. (Refer to Table 3.1)

d **Method of determining fire size**

In most cases, the design fire size can be determined by the active fire protection systems that are installed.

(1) If automatic sprinkler system is installed, fire size can be determined based on 2^{nd} ring of sprinkler activation

(2) If alternative water suppression systems are installed in lieu of sprinklers, fire size can be determined-based on the following:

(i) Pre-action sprinklers

Total time taken to activate (i) automatic fire detection system (e.g. smoke or heat detectors, flame detectors, air-sampling detectors, beam detectors, etc) including the time for the water to fill the pipework (water flow lag) and (ii) sprinkler system.

(ii) Deluge system

Time taken to activate automatic fire detection system (e.g. smoke or heat detectors, flame detectors, beam detectors, etc) and for the water to be discharged

(iii) Water monitor system

Time taken to activate automatic fire detection system (e.g. flame detectors, etc) and for the water to be discharged

Based on the product specifications, FSE shall determine the minimum fire size that would activate the water monitor system. Thereafter, FSE shall then apply a safety factor (minimum 2) to determine the fire size to be modelled. FSE shall include the fire size justification in the fire engineering reports.

For sprinkler protected buildings, where water monitor systems are installed in areas that are within the effective height of sprinklers, the design fire size shall be based on 2nd ring sprinkler activation, rather than water monitor system activation.

(3) If the building/space is not protected by automatic sprinklers or other water-based fire protection systems, the fire size to be determined by fuel load and burning area.

(4) Annex A gives a general guide to how fire size can be determined under various conditions.

e Soot yield

FSE may adopt a soot yield, which refers to mass of soot generated during combustion divided by the mass loss of the test specimen, not lower than 0.1, unless he/she has justification to adopt other values.

The default soot yield value for industrial buildings and warehouses shall be 0.1. FSE may propose a different value only if the type of fuel load in the building is of specifically known usage during operation and does not change over its occupancy period.

Table 3.1 : Design Fire Characteristics (Pre-Flashover)

Location / Usage	**Fire growth rate**
Areas of special/high hazard or Industrial (performance requirements also provided under prescribed Code of Practice for Fire Precautions in Buildings)	- Depends of fuel load burning - Pool fires (e.g. fuel, etc) will be nearly instantaneous

	High rack storage potentially between Fast t^2 to Ultrafast t^2; potentially t^3
Back of house areas / service areas	Depends on fuel load burning but generally Fast t^2
Retail	Fast t^2
F&B (restaurants, food courts, coffee shops, hawker centres, fast food outlets)	Fast t^2
Car parks in general, including Ductless Jet Fan (DJF) system	Fire growth rate for vehicles shall be instantaneous. With sprinkler protection, the total HRR for the following types of vehicles are as follows : 4 MW for cars/forklifts 10 MW for general goods vehicle 20 MW for buses/coaches
Offices, homes/apartments, and dormitories	Fast t^2
School classrooms, lecture halls, museums	Medium t^2
Places of assembly (auditorium, theatres, performing arts)	Seating – Medium t^2 Stage - Fast t^2 If there is no control on the type of materials used for scenery, staging props (i.e. use of polystyrene, polyurethane, non-fire-retardant drapes and curtains, etc), stage – Ultrafast t^2
Exhibition (e.g. convention, expos, etc)	Fast or Ultrafast t^2, depending on items exhibited
Recreational, amusement, night entertainment	Fast t^2 If there is no control on the type of materials used for scenery, staging props (i.e. use of polystyrene, polyurethane, non-fire-retardant drapes and curtains, etc), stage – Ultrafast t^2

3.2.2 Post-Flashover (Structural fire engineering analysis)

a Ventilation Controlled

In a post-flashover fire, the heat release rate can be limited by the amount of air that can enter the fire affected compartment.

Ventilation controlled heat release rate, Q_v :

$Q_v = 1.5 \times A_v \times h^{1/2}$

Where:

A_v is total area of wall openings (m^2)
h is the weighted average height of openings (m)

b Time-Temperature Curves

References can also be made to other guidance documents including time-temperature curves, e.g. parametric, ISO 834 standard curve, etc.

3.3 Acceptance criteria

Where the fire engineering assessment requires an assessment of human tenability to be made, the following limits of acceptability will apply:

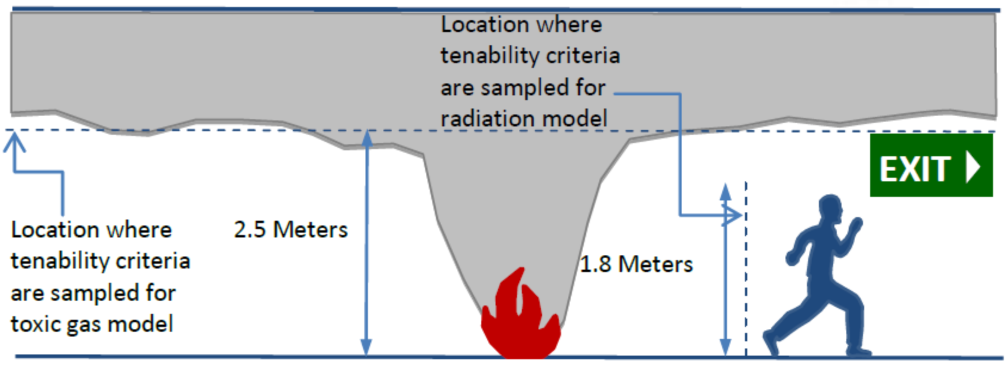

Figure 3.2 : Tenability criteria to be sampled at 2.5m from the finish floor level.

3.3.1 Smoke Temperature – The upper layer smoke temperature shall not exceed 200°C measured at 2.5m height from finished floor level and the lower layer smoke temperature shall not exceed 60°C.

3.3.2 Radiation – Where occupants are expected to egress past a fire, the radiative heat flux shall not exceed 2.5 kW/m^2.

3.3.3 Visibility at 2.5m above the floor level shall be greater than 10m.

3.3.4 Fractional Effective Dose (FED)

Where the FED is proposed to be used as an acceptance criterion, for example, in situation where the ceiling is low and the use of acceptance criteria 3.3.1 to 3.3.3 is not feasible, the FSE would need to justify for FED criterion to be adopted in the design and subject to SCDF's agreement. Fractional Effective Dose (FED) for toxic gases shall not exceed 0.3.

3.4 Computational Fluid Dynamics (CFD) modelling

In carrying out the CFD modelling, the following steps are recommended:

3.4.1 Define fire modelling goals

To state clearly that the results of the CFD modelling shall be used to justify the performance-based design.

3.4.2 Characterise the fire scenarios

Characterise the relevant fire scenarios from fire ignition, growth, detection, fire suppression and smoke control (if applicable). Selected scenarios should represent a complete set of fire conditions that are important to test the robustness of the proposed fire engineering design. These are discussed further below:

a Enclosure

Define the enclosure being studied in the CFD modelling. The enclosure details should include the identity of the enclosures that belong in the fire model analysis, the physical dimensions of the enclosures included in the fire model, and the boundary conditions of each enclosure

b Fire Locations

The fire locations used in the CFD modelling shall follow the proposed fire locations established from earlier sections of this guideline.

c Fire Characteristics

The source fire is the critical input for the fire scenario and is often described as the "ignition source." The source fire is typically characterised by a heat release rate though other important aspects include the physical dimensions of the burning object, its composition, and its behaviour when burning.

d Minimum details needed to describe the fire are:

(1) Heat Release Rate (HRR)
(2) Fire growth rate (for T-square fire)
(3) HRR per unit area
(4) Fire perimeter
(5) Soot yield
(6) Heat of combustion
(7) Type of smoke plume
(8) Sprinkler or non-sprinkler-controlled
(9) Toxic substances (for FED analysis if allowed)

The HRR chart is to be included in the FEDB, FER and Peer Reviewer's Report to demonstrate the fire characteristics. The fire characteristics used in the CFD modelling shall follow the fire hazards identified and design fire(s) established in Table 3.1 of this guideline.

3.4.3 Selecting the CFD software

Given the availability of different CFD models, the FSE is responsible to assess its suitability for use in the fire engineering study. Whilst this set of guidelines is written predominantly for FDS considering its wide use in the fire engineering fraternity in Singapore, they also apply in a similar manner to other CFD models.

A list of commonly used CFD software is as follows:

a Fire Dynamic Simulator (FDS)
b Fluent
c Phoenics

Use of any CFD software not listed above shall be justified by FSE. The use of any particular CFD software (including its version) must be reflected in the FEDB, FER and Peer Reviewer's Report.

3.4.4 Computational domain

The computational domain should be as close as reasonably practicable to the actual enclosure. Simplification (such as modelling a slightly curved wall as a straight wall) can be accepted if it does not adversely affect outcome of the CFD modelling.

Where inlet and/or exhaust vents are located at the domain boundaries, FSE has to include an additional 5m buffer outwards to account for the aerodynamics of the vents.

Where wind effects are being modelled, the domain should be extended correspondingly to take this into consideration.

3.4.5 Boundary conditions

Assumptions on the type of surface and material properties such as ambient temperature and properties of surfaces must be included. In situations where adiabatic/inert surfaces are assumed, justification on why such assumptions are considered appropriate must be included.

Assumptions on ambient temperature & external wind effect for the areas being modelled must be included.

As a guide, ambient temperature in air-conditioned spaces can be taken to be 24 ^{o}C while that of non-air-conditioned spaces, 32 ^{o}C.

Should other temperatures be adopted, FSE will provide the justifications.

3.4.6 Mesh and grid resolution

The type of meshing i.e. structured vs unstructured and grid resolution can have significant impact on the accuracy of CFD computation, particularly for large eddy simulation models.

In the case of FDS, FSE has to state whether single mesh or multi-mesh is to be used. Other information includes screenshots to illustrate the mesh set up, the mesh boundaries and the respective grid resolution. The recommended fine grid resolution should follow the FDS user guide. Fine grid shall extend at least 5m (in x, y and z direction) from the edge of burner in all directions. Progressive increase in grid resolution shall follow aspect ratio of 1:2.

FSE shall document the specification of mesh grid(s) in the report in alignment with fire modelling input parameters.

3.4.7 Duration of simulation

For steady-state CFD modelling, the simulation should be iterated until the results converge.

For transient CFD modelling, the simulation should continue until steady-state condition is observed. As a guide the fire size should reach the design fire size. Temperature and visibility readings should be taken to demonstrate that the readings have stabilised.

The duration of the simulation shall be adequate to demonstrate that life safety criteria (e.g. ASET/RSET with safety factor) can be met, or minimum 1200 s, whichever arrives first.

3.4.8 Smoke management systems

Relevant smoke management system i.e. engineered smoke control system, smoke purging system or smoke vents must be included in the CFD modelling.

For the case of engineered smoke control / purging system, the following information shall be provided

a Ductwork layout (Deeper than 10% of floor height)
b Beams (Deeper than 10% of floor height)
c Extraction grilles

d Make-up air paths
e Heat/Smoke detectors (where applicable)
f Sprinkler heads (where applicable)
g Storage racks. FSE may assume a reasonable racking structure if the actual design is not known yet.

The actual system design layout must also be included for comparison with the CFD model.

For the case of natural smoke vents, the following information shall be provided:

a Smoke vents and replacement air inlet's location including orientation and aerodynamic free area
b Smoke detectors (where applicable)
c Sprinkler heads (where applicable)

In the FER, the FSE is to include all relevant architectural plan & elevations for comparison with the CFD model.

FSE shall state the assumptions with respect to ramping up the operation of the smoke management system. As a general guide, the smoke management system is at 0% capacity at start of simulation and should reach full design capacity in accordance with the Fire Code requirements.

3.4.9 Fire detection system

Fire and smoke detectors must be included in the CFD model if they are provided to the actual spaces.

3.4.10 Fire suppression systems

It shall be assumed that the fire is maintained at the design fire size and not mitigated by the suppression system in the modelling study.

3.4.11 Visibility factor

When modelling visibility in CFD modelling, FSE shall adopt a visibility factor (C-factor) of 3 to ensure sufficient level of life safety.

3.4.12 Documenting the output

a FSE to include output quantities for visibility, temperature and velocity. Additional output quantities e.g. carbon monoxide, heat flux, FED may be required depending on the scope of the performance-based design.

b In addition to slice files/snapshots, other output parameters such as radiometers, thermocouples, etc shall be included in the FER as the slice files may not capture all the relevant details.

c For slice parameter, FSE has to include slices in all three planes (x, y and z-planes).

(1) At least 3 slices of X-plane & Y-plane with one cut along the centreline of the fire origin. Include additional slices at critical areas in the model. More slices may be required if a spill plume forms part of the analysis.

(2) At least 2 slices of Z-plane at 1.7m (estimated human height level), and 2.5m above the finished floor level. Include additional slices at critical areas in the model. Where the mesh does not match, FSE shall provide slices at the next higher/available height (i.e. 1.8m and 2.6m).

(3) For the X, Y and Z planes, the slice/snapshot shall be taken at :
(i) At the 8-minute mark
(ii) ASET timing
(iii) RSET timing (with safety factor)
(iv) Steady state (If it is earlier than RSET with safety factor)
(v) At the 20-minute mark (if no failure shown beyond (iii)
(vi) Any other slices that SCDF or the FSE deems fit.

(4) Any legends accompanying the modelling outputs shall be legible

d Include the following CFD results in the FER.

(1) Graphic overall heat release rate output
(2) Visibility readings
(3) Temperature readings
(4) FED readings (if applicable)
(5) Visibility, temperature and FED readings should be taken at the reference height as defined under the tenability acceptance criteria.

e Modelling source codes

Where the fire engineering report contains CFD modelling, the source codes of all design fire scenarios shall be submitted together with the fire engineering report. This also applies to the Peer Reviewer's Reports.

3.5 Zone modelling

Zone models can be adopted to determine ASET. However, the compartment size limits for the use of zone models shall be according to the maximum reservoir sizes stated in the Fire Code, or the size limits stipulated by the respective software user manual, whichever is lower.

In projects where zone models are used to determine ASET, SCDF may still require the FSE to conduct CFD simulation.

A list of commonly used zone modelling software is as follows:

a. CFAST
b. Branzfire/B-Risk

Use of any zone modelling software not listed above shall be justified by FSE. The use of any particular zone modelling software (including its version) must be reflected in the FEDB, FER and Peer Reviewer's Report.

3.6 Validation of CFD and zone models

If the proposed software is new or has limited application in Singapore, SCDF may require validation of the software before being allowed for use. The current ways of validating CFD and zone models are:

a. validation against fire tests and;

b. validation against literature and past fires and;

c. validation against other models and third-party validation.

3.7 Replacement air for smoke control systems

Replacement air for engineered smoke control shall be provided fully by natural means. Where mechanical replacement air is proposed by FSE for SCDF's consideration, e.g., high containment facilities, laboratories that handle biological agents or toxins, clean room, deep underground infrastructure like rock cavern, tunnel, the following shall apply:

3.7.1 Limits

Maximum of 50% of the required replacement can be provided by mechanical means.

3.7.2 Standby fans

At least 2 standby fans (n+2) shall be provided for each mechanical replacement air system, such that in the event any fan fails, the required replacement air rate will still be met. The standby fan shall be automatically activated in the event the duty fan fails.

3.7.3 Interlocking the smoke extract fans with the replacement air fans.

The smoke extract fans shall interlock with the replacement air fans such that in the event the extract fan fails, the replacement air fans shall be adjusted accordingly. This is to avoid over-pressurising the affected area and push the smoke to unaffected areas.

3.7.4 Time for standby fans to be fully operational

The time taken for the make-up air system as part of a smoke ventilation system within a smoke zone to be fully operational shall not exceed 60 secs from the time of activation.

3.7.5 Injection Points

Location of replacement air injection points shall be marked up clearly in the report.

3.8 Determining the Available Safe Egress Time (ASET)

ASET is determined when the area/space under the fire engineering assessment fails any tenability criteria.

If there is any observation of smoke logging in CFD result slice files which FSE deems not affecting the ASET, FSE shall provide justification.

Some examples of such situation include:

3.8.1 Extent of spill plume is limited to vicinity of the room of fire origin.

3.8.2 If the means of egress is well defined, the remaining clear width of the egress route is sufficient for safe egress.

3.8.3 Smoke logging condition is some distance away from exit points.

3.8.4 For an open space where the means of egress is not clearly defined, the smoke logged area within the space is transient and its scale does not adversely impact egress.

3.8.5 Tenability has been achieved after increasing smoke exhaust rate.

CHAPTER 4

4.0 REQUIRED SAFE EGRESS TIME (RSET)

Required safe egress time or RSET is the time required for escape. This is the calculated time required for occupants to travel from their location at the time of ignition of fire to a place of safety. The RSET would need to be less than the ASET, with relevant safety factors applied.

RSET = ($t_d + t_n + t_{pre}$) + (t_{trav} and/or t_{flow})

where:
t_d = detection time from deterministic modelling
t_n = time from detection to notification of occupants
t_{pre} = time from notification until evacuation begins
t_{trav} = time spent moving toward a place of safety, and
t_{flow} = time spent in congestion controlled by flow characteristics

4.1 Detection time (t_d)

Time interval between ignition of a fire and its detection by an automatic or manual system. The detection time shall be based on the activation of the 1st ring of the detector system. The following methods can be used to estimate the detection time (t_d)

a. Based on CFD modelling conducted with the detectors/sprinklers above a fire using approved fire models.

b. Based on Alpert's[11] ceiling jet correlation or other relevant methods.

c. Based on zone models.

4.1.1 For automatic detection, the input parameters used in the modelling study shall be the same as the properties of the detectors/sprinklers used in the design as well as the layout of the detectors/sprinkler.

a. Response Time Index (RTI) of sprinkler/detector.

b. Activation temperature (T_{act}) of sprinkler/detector.

c. C-factor for sprinklers.

d. Optical density at alarm for smoke detectors.

e. Radial distances adopted shall be based on a code-compliant (Code of Practice for Installation and Servicing of Electrical Fire Alarm System /

Code of Practice for Automatic Fire Sprinkler System / NFPA, etc.) system design.

Where there are no automatic fire detection systems installed, manual/human detection time can be estimated based on smoke layer height reaching 10% of the room height.

4.2 Notification Time (t_n)

This is the time required for building management to confirm with DECAM companies whether the fire alarm is a false alarm, or a confirmed fire and this time is taken to be 120 seconds. FSE to justify if other timings are adopted.

4.3 Pre-movement time (t_{pre})

Pre-movement time is the time interval between occupants being informed to evacuate and the time in which they begin to travel to a safe location. Refer to Table F-1 in Annex F.

Annex F presents a detailed explanation on some of these factors involved in estimating the pre-movement times. Any of the pre-movement times obtained from New Zealand document, C/VM2[2] in Table A6-1 can be used in the egress design and the FSE would need to justify his/her choice.

4.4 Movement time (t_{trav} or t_{flow})

The time taken by occupants to move to a place of safety is determined by the longer timing of travel time (t_{trav}), or flow time (t_{flow}):

4.4.1 Travel Time

The time taken to move to the doorway of the exit staircase (e.g., analysing egress from compartment/floor) or the final exit door (analysing total building evacuation)

a For horizontal travel, the travel time will be calculated based on the estimated walking speed. Horizontal travel speed can be calculated using equation below

$$S = k - akD$$

Where

- S is horizontal travel speed (m/s)
- k is 1.4 for horizontal travel
- a is 0.266
- D is the occupant density of the affected space (persons/m^2)

Horizontal travel time is then calculated using equation below:

$t_{trav} = L_{trav} / S$

Where

L_{trav} is the maximum travel distance (m)

b For vertical travel, the values used for the factor k are a function of the stair riser and thread as shown in Table 4.1.

Table 4.1 : Constants relating to horizontal and stair travel (extracted from PD-7974 Part 6)

Exit route element		**k**	**Speed**
Corridor, aisle, ramp, doorway		1.40	1.19
Riser (mm)	Tread (mm)		
191	254	1.00	0.85
178	279	1.08	0.95
165	305	1.16	1.00
165	330	1.23	1.05

c Table 4.2 and 4.3 also lists some typical travel speeds for occupants of different levels of mobility, both for horizontal travel as well as vertical travel via staircase.

Table 4.2 : Typical horizontal travel speeds for occupants of different mobility levels

Speed Of Horizontal Surface				
Subject Group	Mean	Standard Deviation	Range	Inerquartile Range
All Disabled	1.00	0.42	0.10-1.77	0.71-1.28
With Locomotion Disabilities	0.80	0.32	0.24-1.68	0.57-1.02
No Aid	0.95	0.32	0.24-1.68	0.70-1.02
Crutches	0.94	0.30	0.63-1.35	0.67-1.24
Walking Sticks	0.81	0.38	0.26-1.60	1.49-1.08
Rollator	0.57	0.29	0.10-1.02	0.34-0.83
No Locomotion Disability	1.25	0.32	0.82-1.77	1.05-1.34
Electric Wheelchair	0.89	-	0.13-1.77	-
Manual Wheelchair	0.69	0.35	0.13-1.35	0.38-0.94
Manual Wheelchair	0.36	0.14	0.11-0.70	0.20-0.47
Assisted Wheelchair	1.30	0.94	0.84-1.98	1.02-1.59
Assisted Ambulant	0.78	0.34	0.21-1.40	0.58-0.92

Source:Table 3-13.2 from Section 3, Chapter 13: "Movement Of People: The Evacuation Timing", The SFPE Handbook of Fire Protection Engineering, 3rd Edition, NFPA Inc., Quincy, Massachusetts, 2002

Table 4.3 : Typical travel speeds along staircase for occupants of different mobility levels

Speed On Stairs				
Subject Group	Mean	Standard Deviation	Range	Interquartile Range
Ascent				
With Locomotion Disabilities	0.38	0.14	0.13-0.62	0.26-0.52
No Aid	0.43	0.13	0.14-0.62	0.35-0.55
Crutches	0.22	-	0.19-0.31	0.26-0.45
Walking Stick	0.35	0.11	0.18-0.49	-
Rollator	0.14			
Without Disabilities	0.70	0.24	0.55-0.82	0.55-0.78
Descendent				
With Locomotion Disabilities	0.33	0.16	0.11-0.70	0.22-0.45
No Aid	0.36	0.14	0.11-0.70	0.2-0.47
Crutches	0.22	-	-	-
Walking Stick	0.32	0.12	0.11-0.49	0.24-0.46
Rollator	0.16	-	-	-
Without Disabilities	0.70	0.26	0.45-1.10	0.53-0.90

Source: Table 3-13.3 from Section 3, Chapter 13: "Movement Of People: The Evacuation Timing", The SFPE Handbook of Fire Protection Enginnering,3rd Edition , NFPA Inc., Quincy, Massachusetts, 2002

4.4.2 Flow Time

Time taken for all the occupants to flow through a restriction, typically a doorway, when queuing is necessary.

a The flow rate of persons passing through a particular point along an exit route can be calculated using the equation below

$$F_c = (1\text{-}aD)kDW_e$$

Where:

F_c is the calculated flow rate (persons/s)

D is the occupant density near flow constriction (persons/m^2)

W_e is the effective width of component being traversed (m)

k and a are defined in Section 4.4.a above.

b The effective width for various exit route elements can be determined from Table 4.4, by subtracting the boundary layer on each side from the measured exit width. For doorways that are not mechanically held open, a maximum flow rate of 50 persons/min/door leaf is recommended for design.

Table 4.4: Boundary layer width used to determine effective width

Exit Route Element	**Boundary Layer On Each Side(m)**
Stairway-walls or side tread	0.15
Railing or handrail	0.09
Theatre Chairs, Stadium Bench	0.00
Corridor wall and ramp wall	0.20
Obstacle	0.10
Wide Concours, passageway	0.46
Door, Archway	0.15

SFPE Handbook of Fire Protection Engineering, edition 3 (Table 3.14.1)

c For flows through a doorway, the occupant density to be determined using equation below can be estimated to be 1.9 persons/m^2. This value can be referred from the New Zealand Document C/VM2[2] document.

The flow time can then be determined from the flow rate using equation.

t_{flow} = Number of occupants / F_c

4.5 Evacuation Models

Hand calculations to determine movement time may be allowed for occupancies with a lower occupant loading, such as factories and warehouses.

However, for buildings/spaces with large occupant loads such as in shopping centres, exhibition halls, offices and places of public resort and the like, evacuation modelling would be required by SCDF.

4.5.1 Validation of models

If the proposed software is new or has limited application in Singapore, SCDF may require validation of the software before being allowed for use. The current ways of validating evacuation models are:

a validation against code requirements; (e.g. NFPA 130) and;

b validation against fire drills or other people movement experiments/trials and;

c validation against literature on past evacuation experiments (flow rates, etc) and;

d validation against other models and third-party validation.

4.5.2 Approved evacuation software

A list of commonly used evacuation modelling software is as follows:

a. Simulation of Transient Evacuation and Pedestrian Movements (STEPS)
b. Pathfinder
c. Simulex
d. Exodus
e. MassMotion

Use of any evacuation modelling software not listed above shall be justified by FSE. The use of any particular evacuation modelling software (including its version) must be reflected in the FEDB, FER and Peer Reviewer Report.

CHAPTER 5

5.0 FIRE ENGINEERING REPORTS

All fire engineering reports need to be endorsed by FSE. Fire engineering reports that are "DRAFT", "PRELIMINARY" or not endorsed by FSE will not be recognised by SCDF. If other disciplines were also involved in the performance-based design (e.g. PE Civil) they shall also endorse on the fire engineering reports.

FSE to remove all document restrictions (e.g. prohibiting highlighting or copying) as SCDF officers may need to process the reports (e.g. highlighting/copying) for presentation purposes.

Drawings (including mark-up drawings) shall be in pdf format and not editable for ease of reading and review.

5.1 At the Building Plan approval stage, the following (simply termed as the "PB Package") must be submitted to initiate the Performance-Based audit process. FSE to name the documents accordingly for easy identification

a Declaration form

b Fire Engineering Design Brief (FEDB)

c Fire Engineering Report (FER), including any letter of undertaking.

d Peer Reviewer's Report (PRR)

e Operations and Maintenance Manual (OMM)

f Source codes for all simulations carried out

g Mark-up drawings (may be formatted as part of the FER)

5.2 Where a fire engineering report is submitted to support a waiver application, the following documents must be submitted together with the waiver application.

a Fire Engineering Report (FER), including any letter of undertaking.

b Source codes for all simulations carried out

5.3 MARKED UP DRAWINGS

Fire safety provisions that form part of the performance-based design strategy should be highlighted on the respective architectural or Building Plan (BP) and/or Mechanical and Electrical (M&E) plans that are submitted to SCDF for approval. This is to facilitate the audit and documentation of the performance-based strategy by SCDF.

These fire safety provisions to be included in the plan submissions fall into these broad categories

5.3.1 Architectural items in the BP submission

The following information to be included in this category but not limited to:

a. Table/summary of architectural alternative solutions

b. Area/floor(s) under the performance-based study to be indicated (via clouding or other means

c. Mark out non-compliances (e.g., length the path of extended travel distance/s)

d. Details of occupant loading and egress capacity for all affected floors

e. Fire shutters, smoke curtains/barriers

f. Floor to floor height

g. Compartmentation lines, including fire resistance rating

h. Natural vent openings and their sizes/areas (m^2)

i. Replacement air doors/windows/vents and their sizes/areas (m^2)

j. Waivers and consultations applied for and summary of the waiver decision (if any)

5.3.2 M&E items in the M&E plan submission

The following information to be included this category but not limited to:

a. Table/summary of M & E alternative solutions

b. Smoke control system detail

c. Area/floor(s) under the performance-based study to be indicated (via clouding or other means)

d. Smoke zones

e. Smoke curtains/barriers

f. Waivers and consultations applied for and summary of the waiver decision (if any)

5.3.3 Breakdown of the M&E plan

The mark ups for M&E plan can be further broken down to the following:

a. Mechanical ventilation

(1) Fan capacity and to also indicate duty and standby fans

(2) Extract points

(3) Replacement air doors/windows/vents and their sizes/areas (m^2)

(4) Demarcation of smoke zones

b. Fire protection

(1) Sprinkler/Water monitor coverage, etc

(2) Sprinkler details (Discharge rate, Response Time Index, etc)

5.3.4 Mark-up Drawings for FEDB & FER Submissions

Mark-up drawings are to be part of all fire engineering reports. These drawings should capture all alternative solutions and fire safety provisions that support the performance-based design. It should also capture all the elements of the FSE's trial design concept in their alternative design.

Mark-up drawings would be used by SCDF when deliberating on the performance-based fire safety issues for FEDB and FER approval.

5.3.5 Unlike the drawings for the formal building plan/M&E plan submission, the Mark-up drawings need not be broken up into the architectural and M&E sets. However, the reference set must include all performance-based floors and relevant elevations/sections. Items to be marked up on the mark-up drawings include (but not limited to):

a. Details of all alternative solutions (alternative solutions are to be numbered, (e.g. D1, D2, etc)

b. Design fire scenarios. FSE to mark up location and fire size of all fire scenarios, including sensitivity studies. All design fires to be numbered (e.g. BC01, SS01, etc).

c. Floor height/s

d. Fire shutters and smoke curtains

e. Compartment walls/boundaries, including fire resistance rating

f. Occupant Loading and Egress Capacity

g. If they are alternative solutions and form part of the performance-based design solution, the reference drawings should show

   (1) How reservoir length/area is measured

   (2) Paths of extended travel distance

   (3) Paths of extended travel distance for internal discharge

h. Mechanical ventilation fans and ductwork. To indicate how many duty fans operate during fire emergency and how many standby fans are there. Ductwork to be shown clearly.

i. Differentiate separate smoke control zones

j. Smoke control activation matrix

k. Path(s) of replacement air. To also show openings on the elevation

l. Path(s) for natural smoke exhaust. To also show openings on the elevation if it is a naturally ventilated smoke control system

m. Sprinkler details (e.g., temperature rating / RTI / Discharge density)

n. Beam detector location, if any

FSE should apply the appropriate presentation style (font/line colours)consistently so that important details can be identified clearly.

5.3.6 For drawings to be submitted at the Building Plan approval stage (together with the FER, PRR & O&M Manual) the submission could contain both (1) the formal BP/M&E set of drawings for approval and the (2) set of mark-up drawings. The design team may choose to combine both sets into a single set of drawings that would be used for approval and presentation/deliberation by SCDF.

Mark-up drawings must be endorsed by the FSE

5.3.7 The above mark ups need not be in a single drawing as long as all relevant details are captured

5.3.8 Other administrative requirements include:

a. To indicate : **FEDB Mark-up Drawing** or "**FER Mark-up Drawing**" at the top right-hand corner (if the formal submission drawings are separate from the reference drawings

b. Soft copies of mark-up drawings submitted shall be in pdf format. They can be compiled as part of the FER/FEDB report or a separate file/document.

c. Waiver of fire safety requirements applied for, including the waiver reference numbers and summary of the waiver decision(s) (if any)

d. Consultation reference numbers if QP/FSE has sought consultation

CHAPTER 6

6.0 OPERATIONS & MAINTENANCE (O&M) MANUAL

The O&M Manual explains what the building operator and fire safety manager (FSM) should do to maintain and operate the fire safety systems.

It also gives instructions to the building operator on the restrictions placed on the contents in the building e.g. daily operations, addition & alteration works to the building and change of use of the building, based on FSE's assumptions and design considerations.

The O&M Manual can also be used to communicate to the tenants and occupants about these restrictions and their responsibilities. It can also be used as a guide for future renovations and changes to the building. The updated O&M Manual must be given to the owner/client (together with the fire engineering report) after the performance-based audit is closed.

6.1 The cover page shall clearly state that the O&M Manual is prepared for:

a. Building Owner/Managing Committee/Agent
b. Facilities Director/Manager
c. Fire Safety Manager / Company Emergency Response Team (CERT)

6.2 Role & responsibilities of building operator

State the role and responsibilities of the building operator and fire safety manager (FSM), if applicable, in ensuring that the components of the performance-based design are in place, operating properly and a label, "This building has performance-based fire safety design" to be affixed to the main fire alarm panel or zone chart.

This is to alert or remind the building owner and QPs that this is a performance-based building and the Operations and Maintenance Manual must be understood before undertaking any addition and alteration works.

Design considerations with potential impact to life safety or building operations shall be stipulated for the building owner to adopt. Amendments or deviations from the requirements in the operations and maintenance manual may affect the performance-based analysis and solutions.

6.3 Future Addition & Alteration (A/A) Works

State what the building operator needs to do with respect to compliance to the existing Fire Safety Design if there are A&A Works in the future. A letter of no objection from the FSE or QP shall be required as part of the QP's submission if the A/A works clearly do not affect the Performance-Based (PB) design of the building. See SCDF circular on "Certification by QP for A/A Plans Involving Performance-Based Fire Safety Designs" dated 10th October 2013. (Annex G)

6.4 Affected Areas with PB design

The scope and floor plan of the affected area(s) with PB design shall be clearly shown and demarcated from the other areas that were designed based on prescribed code requirements.

6.5 Identification of sub-systems

Identify and describe the relevant sub-systems (sequencing, critical design features) for the project and their interaction with each other. Some examples are:

a. Fire detection
b. Fire protection
c. Emergency warning
d. Occupant evacuation
e. Smoke management
f. Electromagnetic lock

Where applicable, the above-mentioned sub-systems shall be included for inspection and maintenance as part of the process of obtaining Fire Certificate (FC) for the building.

The O&M manual shall specify that the building operator is advised to inform the QP that this is a performance-based design building

6.6 Maintenance plan

Commissioning, maintenance and subsequent yearly testing and inspection plans shall be developed in accordance with the minimum requirements of the relevant codes of practice and manufacturer's guidelines. If the performance-based design requires a higher level of servicing such as higher frequency of maintenance, the FSE shall highlight the additional requirements in the O&M Manual.

6.7 Documentation of inspections/testing and their results shall be maintained with the building records. FSE shall emphasise the need to maintain inspection records.

6.8 FSEs would need to conduct a briefing to the client/end user/building operator on all performance-based issues when the Fire Engineering Report is cleared. Official letters must be submitted to SCDF from the client stating that they have been briefed by the FSE and received the O&M Manual. The template can be found on the SCDF website.

6.9 Restrictions

List the restrictions placed on the building operations. These restrictions may include content in the building, building use/purpose/activity and occupancy, and reliability and maintenance of systems. For example:

a. Storage height
b. Storage content
c. Limitation on transport vehicle in warehouse
d. Commercial activity in certain parts of the building
e. Activity with potential change in occupant type

6.10 Compensatory actions

Highlight compensatory actions that must be taken if a fire protection system is impaired (e.g. requires servicing or maintenance, causing it to be out of service temporarily) or removed from service. Any impairment or removal of fire protection system may be subject to total review of the fire safety systems by a FSE.

6.11 Relevant circulars

FSE to include all relevant circulars affecting buildings with performance-based design. These include

a. Certification by QP for A/A plans involving Performance-Based fire safety designs dated 18 Oct 2013 and

b. Identification of buildings with Performance-Based fire safety designs & certification by QP for A/A plans dated 5th June 2012

6.12 Credentials and Endorsement of FSE

Include name, credentials and endorsement of the FSE who prepared the manual. FSE shall also include contact details (email and phone number).

CHAPTER 7

7.0 PEER REVIEWER

The Peer Reviewer is another FSE, engaged by the building developer/owner, who is responsible to check the adequacy of the performance-based solution prepared by the FSE. The Peer Reviewer is required to submit an official report, i.e., Peer Reviewer's Report (PRR) to SCDF detailing his comments on the FSE's work. It is expected of the Peer Reviewer to conduct a separate fire and/or evacuation modelling to verify the design solution proposed by the FSE, preferably using different software from that used by the FSE.

In addition, the Peer Reviewer should comment on the assumptions, fire safety engineering approach, methodology, design parameters and software tools in the FER, etc proposed by the FSE. The Peer Reviewer will also need to endorse on the relevant declaration form when submitting the Peer Reviewer's Report.

The Peer Reviewer shall have no vested interest in the project that is being reviewed, or any involvement thereof which may be construed as a conflict of interest. As the Peer Reviewer must be independent from the project FSE, the Peer Reviewer should only be involved after the FSE had completed the FER.

7.1 Role of Peer Reviewer

7.1.1 To review the robustness of the fire engineering study by the FSE, including reviewing design objectives, assumptions, methodologies, input parameters used by FSE.

7.1.2 . To review the fire engineering analysis performed for consistency between FEDB and FER. If there are inconsistencies, the Peer Reviewer needs to document the reasons and highlight the inconsistencies clearly in the Peer Reviewer Report.

The Peer Reviewer would also need to review and comment on the source codes of all modelling studies, the Operations & Maintenance Manual and any other reports/documents that form part of the performance-based assessment.

7.1.3 To perform independent sensitivity analysis (e.g. increasing fire size, increasing soot yield, increasing fire perimeter to reduce buoyancy, introduce MV failure, reduce walking speed, reduce awareness factor of exits, increase pre-movement times, etc)

7.1.4 Peer Reviewers should not be restricted or influenced in their design preference. Peer Reviewers may determine their own technical approaches and acceptance criteria which may be different from the FSEs.

7.2 Stage of involvement of Peer Reviewer

Peer Reviewers shall only be involved after the FSE had completed the FER in order to maintain the level of independency.

7.3 Modelling for Sensitivity Analysis

Peer Reviewers shall use a validated modelling tool to conduct independent assessment. The validated modelling tool shall preferably be different from that used by the FSE.

In the event that the Peer Reviewer uses the same modelling tool, the required pre-processing for setting up the model must be independently performed by the Peer Reviewer.

7.4 Dispute resolution

Any dispute or difference in opinion (e.g. technical approaches, acceptance criteria, etc.) arising between the FSE and Peer Reviewer should be discussed and resolved between the FSE and Peer Reviewer. In the event that a common resolution cannot be reached, the concerns must be brought to SCDF for resolution.

CHAPTER 8

8.0 REGISTERED INSPECTOR (FSE)

8.1 When are Registered Inspectors (FSE) required?

For projects containing alternative solutions, the areas under the performance-based assessment have to be inspected by a SCDF registered RI, who must also be a FSE. His scope of work involves the checking of on-site installation of fire safety engineering works for compliance with the approved PB plans, FER and Operations & Maintenance Manual and to surface irregularities to SCDF. As such, performance-based projects would require RI (FSE), RI (Arch) and RI(M&E).

8.1.1 If the RI(Arch) is also an FSE, he/she can be responsible for both the fire safety works listed in Part I of the First Schedule of the Fire Safety (Registered Inspector) Regulations and the performance-based works of the project. See Annex H.

8.1.2 If the RI(M&E) is also an FSE, he/she can be responsible for both the fire safety works listed in Part II of the First Schedule of the Fire Safety (Registered Inspector) Regulations and the performance-based works of the project. See Annex H.

CHAPTER 9

9.0 FIRE ENGINEERING ASSESSMENT IN SUPPORT OF WAIVER APPLICATIONS

Where waivers are sought for the clauses from the Fire Code, which are listed in Annex K, it is mandatory that these waiver applications must be supported by fire engineering assessment(s) endorsed by a Fire Safety Engineer. Unlike a full performance-based plan submission process where fire engineering design brief and Peer Reviewer Report are required, this process only requires a fire engineering assessment to be conducted by a FSE to provide scientific based evidence in support of the waiver application.

The list is not exhaustive. It will be updated according to the prevailing Fire Code. Refer to SCDF website for the latest version.

9.1 Assessment of residential corridors (for relevant clauses listed in Annex K)

Assessment of residential corridors shall generally follow the following methodology.

9.1.1 Main door of unit of fire origin.

The main door shall open for 60 seconds after the unit is 20% smoke filled. This represents occupants escaping from the unit. The main door shall close thereafter. The main door shall open for 120 seconds if:

a The floor is served by a single exit staircase or

b The corridor under assessment is at the discharge floor

9.1.2 Acceptance criteria for the residential corridor

Acceptance criteria shall be met at 180 seconds after the main door open, at a height of 2m above the floor level. (Z = 2m). The criteria are:

a Visibility for the whole corridor shall exceed 10m and

b Temperature for the whole corridor shall be less than $60^{o}C$

See timeline below

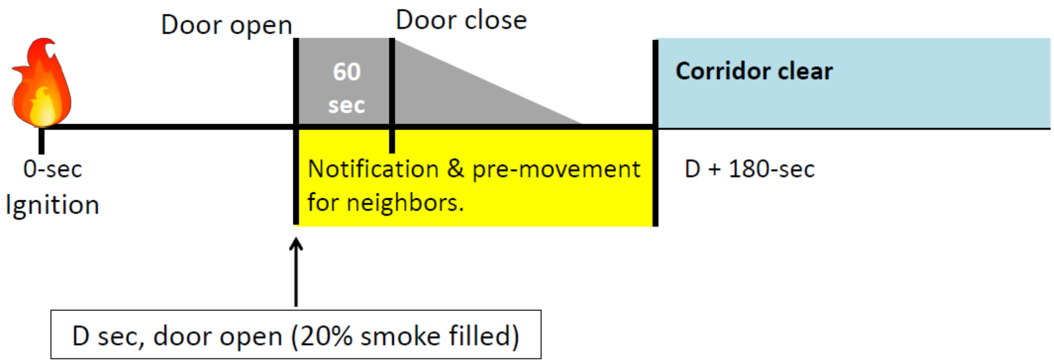

Figure 9.1 : Timeline for residential corridor assessment.

9.1.3 Fire size

The fire shall be a 13MW fast t^2 growing fire. This fire size shall be adopted for all fire engineering assessments involving non-sprinkler protected residential units.

9.1.4 Soot yield

The soot yield shall be 0.06 kg/kg. The soot yield shall be increased to 0.1 kg/kg if

a The floor is served by a single exit staircase or

b The corridor under assessment is at the discharge floor

9.1.5 Wind effects

FSE shall include wind effect study for applicable fire scenarios. FSE needs to determine and justify the wind direction and speed adopted.

9.1.6 Windows and glazing facade

Where there are windows in the unit on fire, the windows shall be modelled as closed at the start of the simulation. If the windows do break mid-way through the simulation, FSE needs to justify this timing based on the type of windows/glass used with technical data sheet for the glass. The time the window/glass breaks shall be shown clearly in the timeline of the fire scenario. FSE may also model the windows as closed for the duration of the simulation. This needs to be stated clearly.

9.2 Assessment of non-residential corridors(for relevant clauses listed in Annex K)

The assessment of non-residential corridors may be based on the methodology above for residential corridors with the following changes.

9.2.1 Main door of unit of fire origin

The opening of the main door shall be based on:

a If the main door is not a fire rated door, the door shall be modelled open throughout the simulation.

b If the main door is fire rated, it shall open

(1) When the detectors within the unit detect the fire, followed by suitable pre-movement time

(2) If there are no detectors within the unit, the main door shall open after the unit is 20% smoke filled

(3) The duration of door opening shall be determined by FSE. A safety factor of 2 shall be applied to the door opening time. If it is a sensitivity study, a safety factor of 1.2 shall be applied to the door opening time.

9.2.2 Acceptance criteria for the corridor

Acceptance criteria shall be met at all times at a height of 2.5m above the floor level. (Z = 2.5m).

9.2.3 Fire size

Fire size shall be determined and proposed by the FSE.

9.2.4 Soot yield

FSE may adopt a soot yield, which refers to mass of soot generated during combustion divided by the mass loss of the test specimen, not lower than 0.1, unless he/she has justification to adopt other values.

9.2.5 Wind effects

Where applicable, FSE shall include wind effect study for all fire scenarios. FSE needs to determine and justify the wind direction and speed adopted.

9.3 Assessment of exit staircases (for relevant clauses listed in Annex K)

The FSE shall propose suitable methodologies based on how the exit staircase may be affected by smoke. Separate fire scenarios are required if the exit staircase can be affected from smoke through the smoke stop lobby and smoke rising up through the air well from a unit that opens into the air well.

9.3.1 Acceptance criteria for staircases

Acceptance criteria shall be met at all times in the whole exit staircase

a Visibility shall be more than 10m. FSE needs to clearly show where the visibility slices are taken from.

b Temperature shall be less than 60°C. FSE needs to clearly show where the temperature slices are taken from.

c Fractional Effective Dose (FED) shall be less than 0.3 for the duration of the simulation. The duration of the simulation shall be determined based on total building evacuation. FED shall be measured at 1.7m above landing/ground where occupants may traverse. FSE to clearly show where FED is measure throughout the whole staircase.

9.3.2 Wind effects

Where applicable, FSE shall include wind effect study for applicable fire scenarios. FSE needs to determine and justify the wind direction and speed adopted.

9.4 Non fire rating of secondary steel beams (membrane action)

Where the structural design involves non fire rating of secondary steel beams in a sprinkler-protected building, the design shall comply to the Steel Construction Institute (SCI) Publications P288 and P390 for Fire Safety Design of Multi-storey Steel-framed buildings with Composite Slabs. The approach shall be used in conjunction with SCI Publication 390 titled "TSLAB v3.0 User Guidance and Engineering Update" and its accompanying software TSLAB v3.0. Refer to Annex M.

9.4.1 Waiver application

The approaches in P288 and P390 falls under the self-regulation framework and shall be regularised through a prescriptive waiver application.

9.4.2 Structural plans and calculations

The structural plans and calculations of the affected beams is to be prepared and endorsed by the PE(Civil) and submitted together with the BP plan by the Architecture QP. The affected beams need to be shown clearly.

9.4.3 Architectural plans

The Architecture (or BP) plans shall contain notes (similar to notes on waivers) to include a general statement indicating that there are structural plans based on

P288 and P390. The notes should be clear on whether there is a performance-based assessment (E.g. design based on parametric temperature time curve)

9.4.4 Should the designer choose to adopt standard ISO fire curve, this is deemed as a prescriptive submission. The PE (Civil) shall submit the report, calculations and drawings as an additional attachment to building plans via the architect QP to SCDF. The architect QP shall indicate on building plans for areas where the structural beams have fire protection omitted.

a Declaration by PE (Civil) on the submission plans

I, _______PE Registration number _________being a qualified person, hereby certify that the omission of fire protection to the structural steel as shown on these plans have been designed in accordance with the provisions of the Code of Practice for Fire Precautions in Building 2018, P288 - Fire Safe Design A New Approach to Multi-Storey Steel-Framed Buildings (Second edition) and P390 - TSLAB V3.0 User Guidance and Engineering Update

b The PE (Civil) shall clearly mark the beam(s) with omission of fire protection in the drawings. Any additional features such as increase thickness of fire protection shall be clearly described and marked up.

9.4.5 Use of parametric temperature time curve in the structural design

Should the parametric temperature time curve be used in the structural assessment, a Fire Safety Engineer is needed to establish the various fire scenarios based on varying fuel load densities and ventilation conditions. In this instance, the structural design shall be regularised through the full performance-based framework.

a The structural PE (FSE) shall submit the report, calculations and drawings as an additional attachment to building plans via the architect QP to SCDF. If the structural PE is not an FSE, he/she is allowed to work together with FSE and co-endorse on the submission documents. The same arrangement is applicable to the Peer Reviewer (i.e. FSE(PE) or FSE+PE).

The architect QP shall indicate on building plans for areas where the structural beams have fire protection omitted.

b Declaration on submission plans by PB (Civil).

I, _______ PE Registration number _________being a qualified person, hereby certify that the omission of fire protection to the structural steel as shown on these plans have been designed in accordance with the provisions of the <<Insert relevant Code of Practice for Fire Precautions

in Building >>, P288 - Fire Safe Design A New Approach to Multi-Storey Steel-Framed Buildings (Second edition) and P390 - TSLAB V3.0 User Guidance and Engineering Update

c Declaration on submission plans by FSE.

I, _______ FSE Registration number _________being a registered fire safety engineer, hereby certify that the parametric temperature-time curve has been designed according to BS EN 1991-1-2, Annex A, P288 - Fire Safe Design A New Approach to Multi-storey Steel-Framed Buildings (Second edition) and P390 - TSLAB V3.0 User Guidance and Engineering Update

d If the PB (Civil) is also a FSE, the declaration shall be as such.

I, _______ PE and FSE Registration numbers _________being a qualified person and a registered fire safety engineer, hereby certify that the omission of fire protection to the structural steel as shown on these plans have been designed in accordance with the provisions of the <<Insert relevant Code of Practice for Fire Precautions in Building >>,, Annex A P288 - Fire Safe Design A New Approach to Multi-storey Steel-Framed Buildings (Second edition) and P390 - TSLAB V3.0 User Guidance and Engineering Update, and the parametric temperature-time curve has been designed according to BS EN 1991-1-2

9.5 Ductless Jet Fan (DJF) system for carparks

Where the alternative solutions involve only issues pertaining to ductless jet fan design, the design team may apply for a waiver that is supported by a fire engineering assessment. The Fire Engineering Report shall be prepared by a Fire Safety Engineer.

9.5.1 Acceptance criteria

a Refer to Fire Code Cl. 7.4.4.g(1)(b) for acceptance criteria for carpark provided with ductless jet fan system (DJF).

b In the event ‘visibility ≥ 25m’ criterion cannot be achieved for spaces beyond the maximum allowable 1000 m2 smoke-logged area, FSEs can consider use of emergency illumination and subject to the following:

(1) the illumination shall have at least an average of 10.8 lux along the path of egress measured at floor level during hot smoke test on site.

(2) smoke temperature not more than 60ºC and visibility of at least 10 m at 1.7 m AFFL; and

(3) at least 1 viable route for firefighters within the smoke-logged area, where smoke temperature not more than 250ºC and visibility of at least 5 m at 1.7 m AFFL.

9.5.2 Soot yield

Soot yield shall not be lower than 0.1 kg/kg, unless FSE has justification to adopt other values. For vehicle fires, soot yield for general car parks shall not be lower than 0.07kg/kg.

9.5.3 Additional requirements for adopting emergency illumination approach

a FSE shall provide tabulation of designed lux level for the affected carpark floor(s) in the fire engineering report.

b FSE, RI and QP shall be jointly responsible for the outcome of the assessment of lux level measurements.

CHAPTER 10

10.0 METHODS OF ASSESSMENT FOR COMMON DEVIATIONS

This chapter recommends methods to assess common deviations. It covers:

a. Objectives to be achieved
b. Design fire scenarios
c. Tenability limits
d. Acceptance criteria
e. Sensitivity analysis

The methods of assessment listed serve as a guide and the FSE shall still be responsible for the design solution.

The root and sub objectives for the PB design to achieve are stipulated in Fire Code 2013 and can be found in SCDF website and Annex J.

10.1 EXAMPLE 1

Smoke Control [Enlarged smoke reservoir (Area, length), or Atrium design (Width, area)] or Enlarged Fire Compartment

10.1.1 Root objectives

The root objectives are:

a R2.1 - Occupants must be able to escape to a safe place, directly or through a protected exit, before untenable conditions are reached during a fire emergency.

b R2.2 - Fire-fighters must be provided with adequate means of access for firefighting and rescue operations within the building.

c R7.1 - Maintain tenable conditions for evacuation of occupants and protect them from injury arising from the effects of fire.

d R7.2 - Provide smoke management in the building for firefighting operations.

10.1.2 Sub objectives

The sub objectives are:

a S2.9 - Provisions for adequate ventilation for means of escape.

b S2.13 - Provisions for adequate time for occupant escape from building.

c S2.14 - Provisions for safe movement of people within the means of escape.

d S7.1 - Provisions for ventilation for life safety purposes such that in the event of a fire, evacuation routes are maintained: -

(1) below thermal threshold for human tenability; and

(2) at visibility levels adequate for occupant evacuation; and

(3) below toxicity threshold for human tenability for the period of time required for escape.

e S7.2 - Provisions for ventilation to maintain safe conditions in the means of escape for evacuees for the period of time required for escape.

Table 10.1 : Design fires (sprinkler protected building)

Usage	**Location**	**Size**	**Remarks**
Factory / warehouse / large space or compartment	Centre of space or credible location	Proposed by FSE (E.g. use of 2^{nd} ring sprinkler activation)	
	In-rack	Proposed by FSE	
	Loading / Unloading Bay	10 MW truck fire (as prescribed by the fire code) or higher (if deemed necessary by FSE)	
Atrium	Centre	Proposed by FSE	Axis-Symmetric plume
	Shop/unit	5MW (as prescribed by the fire code) or other appropriate fire size	Axis-Symmetric plume or spill plume.

		as proposed by FSE.	

Table 10.2 : Fire size proposed by FSE based on DETACT T2, FPETool or Firecalc

Usage	**Growth rate**	**Remarks**
Factory/warehouse	Ultra-fast	2nd ring sprinkler activation
Factory in-(rack sprinklers)	Ultra-fast	Next higher level of sprinkler activation
Usage other than industrial.	Fast/Ultra-fast	2nd ring sprinkler activate.

Table 10.3 : Tenability Limits

	Tenability Criteria
Smoke layer 2.5m above relevant Finished Floor Level (FFL)	Visibility > 10m Temperature < 200^{o}C
Smoke layer drops below 2.5m above relevant FFL	Temperature < 60^{o}C

Table 10.4 : Acceptance Criteria

Scenario	
Base case	≥ 2 Safety Factor (ASET/RSET)
Sensitivity analysis	≥ 1.2 Safety Factor (ASET/RSET)
	Base cases for healthcare occupancies or projects deemed appropriate by SCDF (e.g. of national and cultural importance such as airport, Large-scale indoor gardens, National Art Galleries/Museums, etc.) shall achieve perpetual tenability.

Table 10.5 : Determining RSET

Time for	Method
Detection	Refer to Section 4.1.
Notification time	Refer to Section 4.2.
Pre-movement	Refer to Section 4.3.
Movement	Refer to Section 4.4.

Table 10.6 : Sensitivity Analysis (ASET/RSET ≥ 1.2)

Sensitivity study	Affects	Remarks
Natural Ventilation : 1 MW fire	ASET	(i) Test buoyancy of smoke.
Natural ventilation: Design fire size is based on base case design fire.	ASET	1 side of exhaust vents fail. Side with most vents or adverse wind effect.
Mechanical ventilation: Design fire size is based on based case design fire.	ASET	(i)Fan failure (See Section 2.2) or increase fire size by 20%
Increase in fire growth rate	ASET	E.g. From fast to ultrafast
Delay in detection	RSET	Failure of main means of detection
1 exit blocked (or more)	RSET	The number of exits blocked depends on closeness of the exits
Extended pre-movement time	RSET	Value to be doubled

10.2 EXAMPLE 2

Extended 2-way travel distance or Inadequate egress capacity

10.2.1 Root objectives

The root objectives are :

a R2.1 - Occupants must be able to escape to a safe place, directly or through a protected exit, before untenable conditions are reached during a fire emergency.

b R2.2 - Fire-fighters must be provided with adequate means of access for firefighting and rescue operations within the building.

c R7.1 - Maintain tenable conditions for evacuation of occupants and protect them from injury arising from the effects of fire.

d R7.2 - Provide smoke management in the building for firefighting operations.

10.2.2 Sub objectives

The sub objectives are:

a S2.9 - Provisions for adequate ventilation for means of escape.

b S2.13 - Provisions for adequate time for occupant escape from building.

c S2.14 - Provisions for safe movement of people within the means of escape.

d S7.1 - Provisions for ventilation for life safety purposes such that in the event of a fire, evacuation routes are maintained: -

(1) below thermal threshold for human tenability; and

(2) at visibility levels adequate for occupant evacuation; and

(3) below toxicity threshold for human tenability for the period of time required for escape.

e S7.2 - Provisions for ventilation to maintain safe conditions in the means of escape for evacuees for the period of time required for escape.

Table 10.7 : Design fires (sprinkler protected)

Usage	Location	Size	Remarks
Factory / warehouse / large space or compartment	Centre of space or credible location	Proposed by FSE	
	In-rack	Proposed by FSE	
	Loading / Unloading Bay	10 MW truck fire (as prescribed by the fire code) or higher (if deemed necessary by FSE)	
Atrium	Centre	Proposed by FSE	Axis-Symmetric plume
	Shop/unit	5MW (as prescribed by the fire code) or other appropriate fire size as proposed by FSE	Axis-Symmetric plume or spill plume

Table 10.8 : Fire size proposed by FSE based on DETACT T2, FPETool or Firecalc

Usage	Growth rate	Remarks
Factory/warehouse	Ultrafast	2nd ring sprinkler activation
Factory in-(rack sprinklers)	Ultrafast	Next higher level of sprinkler activation
Usage other than industrial.	Fast/Ultrafast	2nd ring sprinkler activation

Table 10.9 : Tenability Limits

	Tenability Criteria
Smoke layer 2.5m above relevant FFL	Visibility > 10m Temperature < 200°C
Smoke layer drops below 2.5m above relevant FFL	Temperature < 60°C

Table 10.10 : Acceptance Criteria

Scenario	
Base case	≥ 2 Safety Factor (ASET/RSET)
Sensitivity analysis	≥ 1.2 Safety Factor (ASET/RSET)
	Base cases for healthcare occupancies or projects deemed appropriate by SCDF (e.g. of national and cultural importance such as airport, Large-scale indoor gardens, National Art Galleries/Museums, etc.) shall achieve perpetual tenability.

Table 10.11 : Determining RSET

Time for	Method
Detection	Refer to Section 4.1.
Notification time	Refer to Section 4.2
Pre-movement	Refer to Section 4.3.
Movement	Refer to Section 4.4.

Table 10.12 : Sensitivity Analysis (ASET/RSET ≥ 1.2)

Sensitivity study	Affects	Remarks
Natural Ventilation: 1 MW fire	ASET	Test buoyancy of smoke.
Natural ventilation: Design fire size is based on base case design fire.	ASET	1 side of exhaust vents fail. Side with most vents or adverse wind effect.

Mechanical ventilation: Design fire size is based on based case design fire.	ASET	Fan failure (See Section 2.2) or increase fire size by 20%
Increase in fire growth rate	ASET	E.g. From fast to ultrafast
Delay in detection	RSET	Failure of main means of detection
1 exit blocked (or more)	RSET	The number of exits blocked depends on closeness of the exits
Extended pre-movement time	RSET	Value to be doubled

10.3 EXAMPLE 3

Internal discharge of exit staircase

10.3.1 Root objectives

The root objectives are:

a R2.1 - Occupants must be able to escape to a safe place, directly or through a protected exit, before untenable conditions are reached during a fire emergency.

b R2.2 - Fire-fighters must be provided with adequate means of access for firefighting and rescue operations within the building.

c R7.1 - Maintain tenable conditions for evacuation of occupants and protect them from injury arising from the effects of fire.

d R7.2 - Provide smoke management in the building for firefighting operations.

10.3.2 Sub objectives

The sub objectives are:

a S2.9 - Provisions for adequate ventilation for means of escape.

b S2.13 - Provisions for adequate time for occupant escape from building.

c S2.14 - Provisions for safe movement of people within the means of escape.

d S7.1 - Provisions for ventilation for life safety purposes such that in the event of a fire, evacuation routes are maintained: -

(1) below thermal threshold for human tenability; and

(2) at visibility levels adequate for occupant evacuation; and

(3) below toxicity threshold for human tenability for the period of time required for escape.

e S7.2 - Provisions for ventilation to maintain safe conditions in the means of escape for evacuees for the period of time required for escape.

Table 10.13 : Design fires (sprinkler protected)

Usage	**Location**	**Size**	**Remarks**
Atrium	Centre	Proposed by FSE	Axis-Symmetric plume
	Shop/unit	5MW (as prescribed by the fire code) or other appropriate fire size as proposed by FSE	Spill plume.
Shopping Centre / Office / Mixed Use	Unit/s affecting egress path	5MW (as prescribed by the fire code) or other appropriate fire size as proposed by FSE	To determine impact of radiation on escaping occupants
All others	Area with deviation	Proposed by FSE	

Table 10.14 : Fire size proposed by FSE based on DETACT T2, FPETool or Firecalc

Usage	Growth rate	Remarks
All others	Fast/Ultrafast	2nd ring sprinkler activation

Table 10.15 : Tenability Limits

	Tenability Criteria
Radiation at egress path to external	Radiation < 2.5 kW/m^2
Smoke layer 2.5m above relevant FFL	Visibility > 10m Temperature < 200^{o}C
Smoke layer drops below 2.5m above relevant FFL	Temperature < 60^{o}C

Table 10.16 : Acceptance Criteria

Scenario	
Base case	≥ 2 Safety Factor (ASET/RSET) Radiation along evacuation route < 2.5 kW/m^2
Sensitivity analysis	≥ 1.2 Safety Factor (ASET/RSET)
	Base cases for healthcare occupancies or projects deemed appropriate by SCDF (e.g. of national and cultural importance such as airport, Large-scale indoor gardens, National Art Galleries/Museums, etc.) shall achieve perpetual tenability.

Table 10.17 : Determining RSET

Time for	**Method**
Detection	Refer to Section 4.1.
Notification time	Refer to Section 4.2.
Pre-movement	Refer to Section 4.3.
Movement	Refer to Section 4.4.

Table 10.18 : Sensitivity Analysis (ASET/RSET ≥ 1.2)

Sensitivity study	**Affects**	**Remarks**
Natural Ventilation: 1 MW fire	ASET	(i) Test buoyancy of smoke
Natural ventilation: Design fire size is based on base case design fire.	ASET	1 side of exhaust vents fail. Side with most vents or adverse wind effect.
Mechanical ventilation: Design fire size is based on based case design fire.	ASET	(i)Fan failure (See Section 2.2) or increase fire size by 20%
Increase in fire growth rate	ASET	E.g. From fast to ultrafast
Delay in detection	RSET	Failure of main means of detection
1 exit blocked (or more)	RSET	The number of exits blocked depends on closeness of the exits
Extended pre-movement time	RSET	Value to be doubled

10.4 EXAMPLE 4

Insufficient set back distance from notional boundary.

10.4.1 Root objectives

The root objectives are:

a R3.1 - Prevent the untimely collapse of buildings due to the effects of fire that would affect the safe egress of the building occupants.

b R3.2 - Prevent spread of fire to adjacent properties due to the effects of a fire in the building.

10.4.2 Sub objectives

The sub objectives are :

a S3.7 - Provisions for prevention of spread of fire to adjacent buildings.

Table 10.19 : Design fires (sprinkler protected)

Usage	**Location**	**Size**	**Remarks**
N.A.	Relevant compartment	Proposed by FSE. Could be based on : • Specific fuel load; • 2nd ring sprinkler activation ; • 10 MW heavy goods vehicle or • 84 kW/m² or 168 kW/m² depending on usage.	

Table 10.20 : Acceptance Criteria

Scenario	
Base case	Radiation receiving plane on site/notional boundary < 12.6 kW/m²

Table 10.21 : Sensitivity Analysis

Sensitivity study	**Affects**	**Remarks**
Increase in fire growth rate	Radiant heat flux from fire source	Increase fire size by 50%.

10.5 EXAMPLE 5

Omission or Reduction of Fire rating of element of structure. Structural engineer is to carry out structural analysis with thermal input from FSE. The PE(Civil) shall co-endorse with the FSE on all fire engineering reports/assessment involving structural assessment.

10.5.1 Root objectives

The root objectives are:

a R3.1 - Prevent the untimely collapse of buildings due to the effects of fire that would affect the safe egress of the building occupants.

b R3.3 - The building shall remain structurally stable to allow adequate time for fire-fighters to conduct their firefighting and rescue operations.

10.5.2 Sub objectives

The sub objectives are:

a S3.1 - Provision of elements of structure with appropriate fire resistance with respect to :-

(1) the fire severity; and
(2) firefighting and rescue operations; and
(3) the occupant evacuation time; and
(4) enclosure characteristics and configurations; and
(5) the height of building; and
(6) occupancy characteristics; and
(7) different fire risk levels.

b S3.2 - The construction and use of building materials should be of the type and method appropriate to the intended performance.

c S3.9 - Provisions for reasonable measures to prevent premature structural collapse of the building due to fire.

Table 10.22 : Design fires (sprinkler protected)

Usage	**Location**	**Size**	**Remarks**
Area of concern	Close to structural member in question	Proposed by FSE	Based on post flashover fires. Refer to Clause 3.2(b) on computation of post flashover fires.

Table 10.23 : Acceptance Criteria

Scenario		
Base case	(i)	Load-Capacity ratio ≤ 1. Structural engineer is to carry out structural analysis with thermal input from FSE. Annex I describe the steps to determine the load capacity ratio.
	(ii)	Smoke temperature less than limiting steel temperature.
Sensitivity	Structure shall not fail due to failure of two or more key structural member(s) and increase fire size by 50%	

10.6 EXAMPLE 6

Ductless Jet Fan (DJF) system for car parks.

Where the alternative solutions involve only issues pertaining to ductless jet fan design for car parks, the design team may apply for a waiver that is supported by a fire engineering assessment. The Fire Engineering Report shall be prepared by a Fire Safety Engineer.

10.6.1 Root objectives

The root objectives are:

a R7.2 - Provide smoke management in the building for firefighting operations.

10.6.2 Sub objectives – N.A.

Table 10.24 : Design fires (sprinkler protected)

Usage	**Location**	**Size**	**Remarks**
Vehicle/Car park	Least favourable location i.e. longest smoke path that is	20MW coach/bus parking area	Fire growth is instantaneous
		10 MW truck fire (as prescribed by the fire code) or higher if	Fire growth is instantaneous

	away from openings.	deemed necessary by FSE.	
		4MW car fire/forklift fire (as prescribed by the fire code) or higher if deemed necessary by FSE.	Fire growth is instantaneous

Table 10.25 : Acceptance Criteria

Scenario	
Base case	Refer to Section 9.5.
Sensitivity Analysis	Failure of a group of jet fans nearest to the fire

10.7 EXAMPLE 7 Mass Engineered Timber

A fire safety performance-based (PB) approach shall be adopted in the design of any engineered timber building where its habitable height exceeds 12m. The engineering timber building shall be fully protected by an automatic sprinkler system. Essential escape provisions such as staircase shafts and lift shafts of engineered timber building shall be constructed of non-combustible materials which achieve the necessary fire resistance rating.

10.7.1 Root objectives

The root objectives are:

a R3.1 - Prevent the untimely collapse of buildings due to the effects of fire that would affect the safe egress of the building occupants.

b R3.3 – The building shall remain structurally stable to allow adequate time for fire-fighters to conduct their firefighting and rescue operations.

10.7.2 Sub objectives

The sub objectives are:

a S3.2 – The construction and use of building materials should be of the type and method appropriate to the intended performance.

b S3.9 – Provisions for reasonable measures to prevent premature structural collapse of the building due to fire.

The performance-based approach shall adopt a quantitative analysis based on non-sprinkler-controlled fires. The roles and responsibilities of the FSE and PE (Civil) are shown in the flow chart below.

See the flowchart below for roles and responsibilities of FSE and PE (Civil).

Figure 10.1 : Flowchart for roles and responsibilities of FSE and PE (Civil)

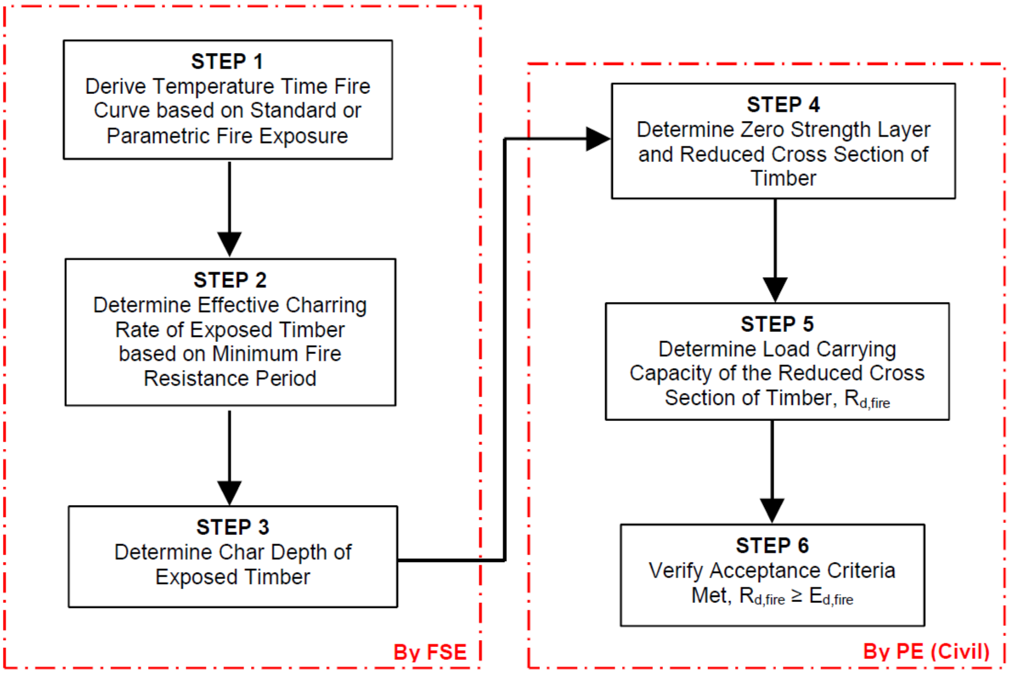

Table 10.26 : Determination of Time-Temperature Fire Curves

Scenario	**Type of Time-Temperature Fire Curve**	**Standard/Methodology**
Base Case	Standard time-temperature fire exposure.	ISO 834-1:1999
Sensitivity Analysis	Parametric time-temperature fire exposure. For timber that delaminates, cooling phase shall be ignored.	Eurocode 1 SS EN 1991-1-2:2008 EN 1991-1-2:2002

10.7.3 Base case and sensitivity analysis

Base case and sensitivity analysis using ISO 834 and Eurocode 1 standards to derive the temperature-time fire curves are compulsory. The largest charred depth from base and sensitivity analysis shall be used. When establishing charring rates for base case and in absence of literature, only test reports from SAC approved laboratories shall be used.

10.7.4 Limitations in Eurocode 1

When limitations in Eurocode 1 are exceeded (i.e. height of compartment > 4m, opening factor $0.02 \le O \le 0.2$ and/or fire load density: $50 \le X \le 1000$ MJ/m^2), the FSE shall justify that exceeding these limitations would result in a more onerous outcome. Otherwise, the FSE shall replace the sensitivity analysis with one of the alternative methodologies as shown in Table 10.27 to derive the time-temperature fire curves. The largest charred depth obtained from base, sensitivity or alternative method shall be used.

The limitations stated above are based on the current version of Eurocode 1. In future, if there are any updates to Eurocode 1 which affects these limitations, the FSE shall take those limitations into account.

Table 10.27 : Alternative methods for sensitivity analysis

Alternative Methods	**Type of Time-Temperature Fire Curve**	**Standard/ Methodology**
1	Methodologies from internationally recognised publications such as SFPE Handbook.	E.g. National Bureau of Standards NBSIR 83-2712
2	Derived from Computational Fluid Dynamics (CFD).	Software's such as FDS and Fluent could be used.

a National Bureau of Standards NBSIR 83-2712

Alternative method 1 using NBSIR 83-2712 could be used for predicting gas temperatures within a compartment. A few examples have been considered in the publication to show the versatility of the formulas and its general level of accuracy.

b Using CFD

For analysis using CFD simulations (i.e. alternative method 2), the FSE shall meet the general guidelines stipulated in Table 10.28.

Table 10.28 : General Guidelines for CFD Modelling

No	**General Guidelines for CFD Modelling**
1	Grid independence analysis shall be carried out and presented in the fire safety engineering report. The FSE shall justify the cell size to be used.
2	Appropriate CFD software shall be used which is able to model complex algorithms and reactions of non-sprinkler controlled, fuel controlled, ventilation controlled and/or flash over fires. FSE to review and consider whether the CFD software can model timber pyrolysis accurately.
3	All input parameters, type, locations and orientation of thermocouples and devices used in the CFD models shall be presented and justified in the fire engineering design brief (FEDB).
4	The CFD domain shall include the relevant fire compartment. CFD domain considering only the room of fire origin may not be adequate if the room of fire origin is not fire compartmented.
5	Materials of compartment shall be modelled to the actual building construction materials used.
6	The extent and choice of fuel bed and how fire spreads on the fuel bed shall be presented in the FEDB.
7	Fire spread via timber and other combustible materials shall be considered.
8	Fuel load contribution from charred timber, delamination of cross laminated timber and fire regrowth phase shall be considered.
9	Design fire size shall follow a non-sprinkler-controlled fire scenario. All factors adopted such as fuel load density, soot yield, effective heat transfer coefficient, duration of fire and added fuel from delaminated timber etc shall be justified.
10	For timbers that delaminate, the decay or cooling phase of the fire could be ignored.
11	The resultant heat release rate (HRR) shall be checked against ventilation controlled HRR hand calculations to ensure that the output HRR is in line with expectations.
12	The use of CFD modelling is ~~s~~ subject to SCDF's acceptance.

CFD results are to be supported by alternative method calculations or research to show applicability of results to the specific project.

c Other methodologies

Apart from NBSIR 83-2712 or CFD, FSE may propose other methodology from internationally recognised published documents (e.g. SFPE Handbook) to derive the time-temperature fire curve subject to SCDF's acceptance.

Table 10.29 : Acceptance Criteria

Scenario	Acceptance Criteria
Base and sensitivity cases	To adopt relevant structural codes, for example: $R_{d,fire} \geq E_{d,fire}$, where $R_{d,fire}$ is the resistance moment of reduced cross-section of timber after charring and $E_{d,fire}$ is the design bending moment on reduced cross-section of timber after charring. PE(Civil) to include any applicable safety factors from the structural codes.

The FEDB and FSER shall be endorsed by the FSE and PE (Civil).