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# **UK Team | SFPE PBD Case Study 2026**

Fire strategy Report for Existing Historic Building Adaptive Reuse

Simón Santamaria (Stantec), Gabriel Risco (Ashton Fire), Jun Heng Low (Ashton Fire), James McNay (Stantec) and Jose Torero (University College London).

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## Summary

This report presents the fire strategy developed for the 2026 SFPE Performance-Based Design Conference in Singapore. The building examined in this case study is conceptual; accordingly, the strategy is intended to demonstrate how performance-based fire engineering can be applied to a complex heritage refurbishment with significant constraints. The emphasis is on illustrating the reasoning process, the engineering assumptions, and the simple analytical tools that underpin a robust performance-based design. This case study combines heritage preservation, security-sensitive occupancies, and exposed mass timber construction, requiring a strategy grounded in simple, transparent engineering methods that rely on appropriate assumptions rather than complex modelling.

The strategy is informed by the project brief, but several assumptions and simplifications have been necessary where design information is incomplete or undefined. These assumptions are explicitly stated throughout the report, as their clarity is essential to the integrity of performance-based fire engineering. The report focuses on a set of key design decisions that reflect both the philosophy and methodology applied in developing the fire strategy.

A central objective of this work is to demonstrate that fire engineering competence lies not in the use of advanced modelling, but in the correct formulation of assumptions and the proper application of simple, transparent calculations. For this reason, the analysis relies wherever possible on methodologies and formulae presented in the SFPE Handbook of Fire Protection Engineering (5th Edition), with preference given to first-order calculations over computational tools such as Computational Fluid Dynamics (CFD) or Finite-Element Analysis (FEA).

This document has been prepared on a voluntary basis for educational purposes. It is not professional advice, and the authors disclaim all liability associated with its use or interpretation. Any application of the material presented herein is at the sole risk of the reader. An AI assisted writing tool was used to support the drafting and editing of this report, primarily to improve clarity, consistency of terminology, and readability across sections. The AI tool did not perform engineering judgement. All calculations, assumptions, scenario selection decisions, and technical checks were developed and verified by the human authors. The authors retain full responsibility and ownership for the content, conclusions, and any use of this document.

This report has been prepared as part of a teaching exercise and completed on a voluntary basis; accordingly, some elements of the assessment, including portions of the quantitative analysis, are intentionally incomplete and will be further addressed, explained, and discussed during the conference presentation and the associated question-and-answer session.

## Design Intent

The design of the building aims to maximise usable space, satisfy operational security requirements, and support the use of sustainable construction materials. The architectural and structural concept is therefore driven by minimising intrusive interventions to the existing structure and by enabling the new upper levels to be constructed from exposed mass timber.

The following constraints define the basis of the design:

- The existing building consists of two storeys that must remain largely unaltered. No additional structural protection, façade modifications, or new openings are permitted.
- Three additional storeys are to be constructed above the existing structure. These levels must be formed entirely in exposed mass timber and must not impose new loads onto the heritage fabric.
- The building will be used for cultural and diplomatic functions, resulting in a mixture of public access areas and secure staff-only spaces with sensitive information.
- The fire strategy must therefore rely on management measures, control of fuel load, and the inherent performance of the spaces rather than extensive compartmentation or added fire protection systems.

To support these constraints, the fire strategy adopts a staged evacuation approach and demonstrates, through simple, transparent calculations, that acceptable performance can be achieved provided the use of the building is managed appropriately. This includes careful control of fuel loading, maintenance of clear escape routes, and the preservation of the geometric and ventilation characteristics that underpin the design assumptions.

Changes to the building geometry or to the ventilation characteristics, including the size, openness, or configuration of façade openings, the lightwell, or internal voids, are not considered “minor alterations” for the purposes of this strategy. These features directly define the bounding assumptions used to control smoke movement and limit fire growth. Any modification that alters ventilation behaviour, whether through refurbishment, operational changes, or maintenance works, may invalidate the engineered fire envelope and therefore requires formal review by a competent fire engineer. Such changes are explicit triggers for re-evaluation under the FRA process described in Section 6.

The detailed fire safety design is presented in Section 3, where each performance requirement is defined, quantified, and linked to specific design assumptions. Throughout, the philosophy remains consistent: performance is demonstrated through the correct use of simple SFPE methods, supported by clearly stated engineering assumptions.

## Building management

The continued safety of this building depends as much on how it is managed as on how it is designed. Because the fire strategy relies deliberately on simple, transparent calculations rather than layers of added protection, the validity of those calculations rests entirely on the assumption that the building is operated within the boundaries that the strategy defines. In practice, this means that building management is not an administrative afterthought but a fundamental component of the fire safety design itself. If the building is not used as assumed, the design no longer represents the actual level of safety.

A central aspect of this strategy is the control of fuel load. The calculations that underpin each failure mechanism, untenable conditions, flashover, ignition of timber, and fire spread, depend on limiting both the quantity and the distribution of combustible materials. If fuel is introduced in locations or concentrations greater than those assumed, the predicted heat release rates may be exceeded, and the fire may develop faster or more intensely than the strategy allows. It is therefore essential that management actively enforces restrictions on furniture, storage, temporary installations, and operational materials. Stacking items in circulation spaces, placing rubbish bins or movable furniture adjacent to exposed timber columns, or allowing temporary displays to accumulate combustible content all create localised fire scenarios that fall outside the parameters used in the design.

Equally important is the preservation of clear means of egress. The evacuation analysis depends on corridors, stairs, and vertical exits always retaining their unobstructed width. Any narrowing of escape routes, whether by stored items, event equipment, or day-to-day operational clutter, will invalidate the egress times established through the Required Safe Egress Time (RSET) methodology. Maintaining these routes clear is therefore not a housekeeping preference but a performance requirement of the fire strategy.

Some architectural features introduce additional considerations. The green walls proposed for the building contribute to its cultural and aesthetic value but also introduce a fuel load that must be managed appropriately. If these elements are not properly treated, maintained, and inspected, they may undermine compartmentation or facilitate vertical fire spread in ways that were not accounted for in the design. Their maintenance becomes, therefore, another mandatory management responsibility.

Because so many aspects of the strategy rely on operational discipline, the building can only be considered to perform as expected by this strategy when trained staff are present. Whenever the building is open, staff must understand not only the evacuation procedures but also the assumptions underpinning the entire fire strategy: why fuel load matters, why exposed timber is vulnerable to ignition, why escape routes must remain clear, and how their day-to-day decisions influence the safety margins built into the calculations. Their role is not limited to reacting to emergencies but extends to continuously preserving the conditions that allow the design to function as intended.

Although this strategy relies on trained staff to preserve key conditions of use, it does not assume that human performance will be perfect or error-free. Reliance on people is acceptable in this case only because the management controls required by the fire strategy are deliberately simple, visible, and verifiable. Tasks such as maintaining clear egress paths, enforcing limits on fuel load, preventing storage beneath exposed timber, and ensuring the irrigation of the green wall do not require specialist judgement; they require consistent application of straightforward rules.

Finally, although the fire service provides an additional layer of redundancy, the strategy does not rely on their intervention for life safety. It has been formulated so that the fire service need only manage a single-floor fire, consistent with the design assumptions on fire containment and smoke movement. Even so, the building must still provide clear access and predictable conditions to support effective intervention, and these provisions are described in Section 5.

## Fire Risk Assessment

A Fire Risk Assessment (FRA) for this building must begin with a clear understanding that the fire strategy is entirely dependent on the assumptions, dependencies, and limitations established during the design process. The failure mechanisms that guided the development of the strategy, untenable conditions during egress, flashover, ignition of exposed timber, and fire spread beyond the floor of origin, are not abstract theoretical considerations. They are the fundamental criteria against which the performance of the building was engineered. The purpose of the FRA is to verify that the provisions intended to prevent these failure mechanisms remain effective throughout the building's lifecycle.

For untenable conditions during egress, the assessment must ensure that the conditions assumed when calculating egress times are still representative of actual use. This includes confirming that travel distances, escape route widths, and door configurations have not been compromised through operational changes. Any reduction in available width, any obstruction of corridors, or any alteration of the building layout has a direct effect on evacuation time and therefore on the first identified failure mechanism.

The second mechanism, prevention of flashover or structural failure, depends on maintaining strict control of fuel load and ensuring that spaces with high occupancy or high combustible content remain within the conditions used in the design calculations. The risk assessor must therefore examine not only the presence of combustible materials but also their distribution. Local accumulations of fuel or operational changes that increase fire load may create a flashover-capable scenario where the design assumed one would not occur. The task of the assessor is to identify these deviations before they erode the safety margin.

The third mechanism concerns the ignition of exposed timber. The strategy assumes that the mass-timber structure will not become involved in the fire. The FRA must therefore verify that the timber remains adequately protected by management controls, that no combustible items are stored against or near the structural timber, and that the environmental or architectural features, such as green walls, do not inadvertently increase the heat exposure to timber surfaces. If the building's daily operation creates conditions that bring ignition sources or fuel closer to the timber than was assumed, the core premise of the structural strategy is undermined.

The fourth mechanism relates to fire spread beyond the floor of origin. The strategy relies on the geometry of the building, the open-plan layouts, and the ventilation conditions to limit the fire to the floor where it starts. The risk assessor must therefore verify that any features which could facilitate vertical or lateral fire spread, changes in ventilation patterns, alterations to wall linings, new services penetrations, or the deterioration of existing passive measures, have not been introduced. Likewise, the maintenance of green walls must be assessed to ensure that they do not inadvertently provide a path for fire to bypass intended barriers.

Ultimately, the objective of the FRA is to ensure that every assumption made in the design still holds true, and that every provision or system relied upon by the strategy is still in place, fully functional, and adequately maintained. This includes management controls, detection systems, the configuration of escape routes, the treatment and upkeep of vegetated installations, and the conditions governing the

use of spaces and the placement of furniture. Given the strong dependence of the overall strategy on management, the assessor must be especially attentive to operational drift: small changes in practice that, over time, erode the assumptions on which the performance-based design depends.

Because the building's safety strategy is designed using simple SFPE-based calculations rather than multiple layers of engineered safety systems, the stability of these assumptions is paramount. If the assumptions are invalidated, the calculations no longer describe the behaviour of the real building. The risk assessor's responsibility is therefore not merely to identify hazards but to confirm, systematically and rigorously, that the foundation of the strategy remains intact.

## **Fire Service**

The building provides several measures intended to support safe and effective fire-service intervention. The protected stair shafts and their associated access lobbies are designed to remain tenable during the early stages of a fire, providing a secure vertical route for both evacuation and responder entry. The building includes evacuation lifts, allowing trained staff to support the movement of people with reduced mobility prior to fire-service arrival. Emergency lighting is provided throughout the escape stairs, helping to maintain visibility. In addition, dry risers are installed to ensure the fire service can supply water rapidly to the upper storeys, consistent with the requirement that responders be able to suppress a single-floor fire once they arrive.

It is essential for the fire service to understand the operational boundaries of this strategy. This building is explicitly designed on the assumption that the exposed mass-timber structure will not ignite and that the external green wall will not become involved in the fire. If responders observe ignition of mass timber, involvement of the green wall, or any other behaviour suggesting the fire is developing outside the bounds defined in the strategy, then the building is no longer operating within its engineered performance envelope. Under such circumstances, the reliability of protected stairs, smoke conditions, structural performance, and all supporting measures becomes uncertain, and responders must recognise that entering the building may expose them to hazards not accounted for in the design assumptions.

## **Failure**

When any of the identified failure mechanisms occurs, the building no longer operates within its engineered performance envelope and cannot be relied upon to achieve the intended fire-safety outcomes.

Faster-than-expected fire growth can trap occupants on the fire floor or compromise the stairs, requiring fire-service rescue. Structural failure conditions, usually signalled by flashover or localised element collapse, make internal operations hazardous and shift priorities toward completing evacuation and controlling the fire externally. If exposed timber ignites or delaminates, the building ceases to behave as a non-combustible structure, accelerating fire development and threatening multiple safety goals. Fire spread beyond the floor of origin, whether through façade ignition, void propagation, or compartmentation failure, transforms the incident into a multi-storey event that endangers evacuation, structural stability, and responder safety.

These failures generally arise from violations of key assumptions, such as increased or poorly arranged fuel loads, inadequate maintenance, or unapproved modifications, and once they occur, neither the building nor the strategy can assure safe performance.

## **Status and stage of design**

This fire strategy represents a concept-level, performance-based design developed to demonstrate engineering reasoning and methodological rigour rather than to define a fully resolved construction solution. It is aligned with an early design stage, equivalent to RIBA Stage 2 progressing towards Stage 3 in accordance with the RIBA Framework published by the Royal Institute of British Architects (RIBA),

where the objective is to establish the viability and limitations of a fire-safety concept rather than to finalise all technical details.

Several aspects of the design are therefore intentionally bounded rather than resolved. These include the detailed protection of mass-timber columns passing through the existing structure, the final configuration of façade openings, and the detailed integration of environmental control measures. These elements are identified explicitly as future design dependencies and must be addressed as the design develops.

# 1 Introduction

This section provides a brief overview of the building and the unique challenges associated with its adaptive reuse. It summarises the key characteristics, constraints, and contextual factors that shape the need for a performance-based fire safety approach, with full details developed in the sections that follow. Further information can be found [here](#).

## 1.1 The building

The building is an existing two-storey historic asset originally constructed as a chocolate factory and warehouse. It occupies the entire footprint of the site, bounded by a river at one end and a street at the other. The side walls are shared masonry walls with neighbouring properties, and no alterations may be made, or additional structural load may be placed upon the existing historic structure or its foundations.

The refurbishment proposes the addition of three new levels above the existing structure, creating a five-storey mixed-use building. The existing ground and first floors, formed from reinforced and unreinforced concrete, masonry, and stone, must remain exposed as part of the heritage expression of the building. These levels cannot be structurally altered, nor may new openings be formed in the retained façades.

The new upper levels must be constructed in exposed mass timber, not as an aesthetic choice alone but primarily due to its significantly lower weight, which reduces the load transferred to the poor underlying ground conditions and prevents additional stress on the existing building fabric.

A new lightwell, approximately 8 m by 14 m, will provide natural light to the internal spaces, extending from Level 2 up to the Level 4 terrace. This architectural feature reshapes the interior environment of the refurbished building and plays a significant role in the spatial and fire-safety characteristics of the upper levels.



Figure 1 Representation of building main elevation (left) and internal lightwell (right), reproduced from [1].

The building will have approximate dimensions of 60m x 34m and storey heights ranging between 5m and 3.8m. The lightwell will be used to provide access to the 4th level terrace. Indicative floorplans and sectional drawings are shown in Figure 2 to Figure 8.

The existing ground floor (Figure 2) will remain largely unchanged and will operate as a publicly accessible space containing an information centre, cultural display areas, and a meeting/function room accommodating up to 300 people. The first floor (Figure 3) above it, also part of the original historic structure, will function as an open access art gallery displaying valuable artefacts. Both levels retain their original reinforced and unreinforced concrete and masonry construction, which must remain exposed and unaltered, as part of the heritage requirements.

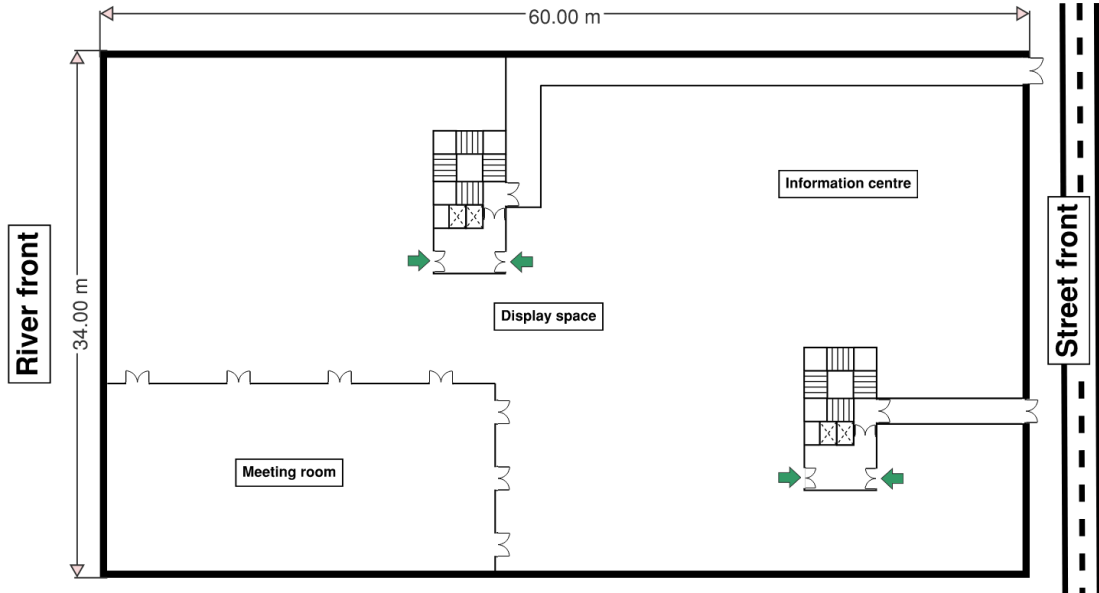


Figure 2 Ground floor plan

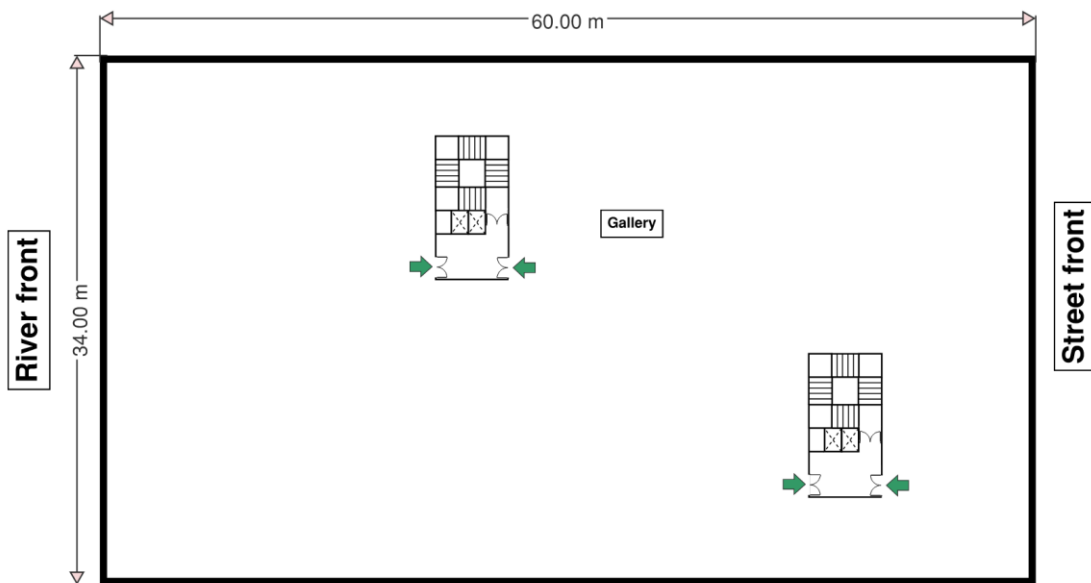


Figure 3 First floor plan

Levels 2 (Figure 4) and 3 (Figure 5) form the first two floors of the new extension above the retained building, providing office accommodation for diplomatic staff and embassy support personnel. A central lightwell, measuring approximately 8 m by 14 m, begins at Level 2 and brings natural light deep into these office spaces, strongly influencing the internal geometry and fire safety behaviour of the building.

Sensitive documents, diplomatic material, and confidential records will be stored across Levels 2 and 3. These floors therefore have additional security and continuity-of-operation requirements, including the need to protect such material from smoke infiltration and thermal damage during a fire. The fire strategy assumes that all sensitive material is housed in fire-resisting, smoke-tight storage units, as archive and document preservation is a core functional requirement of these levels.

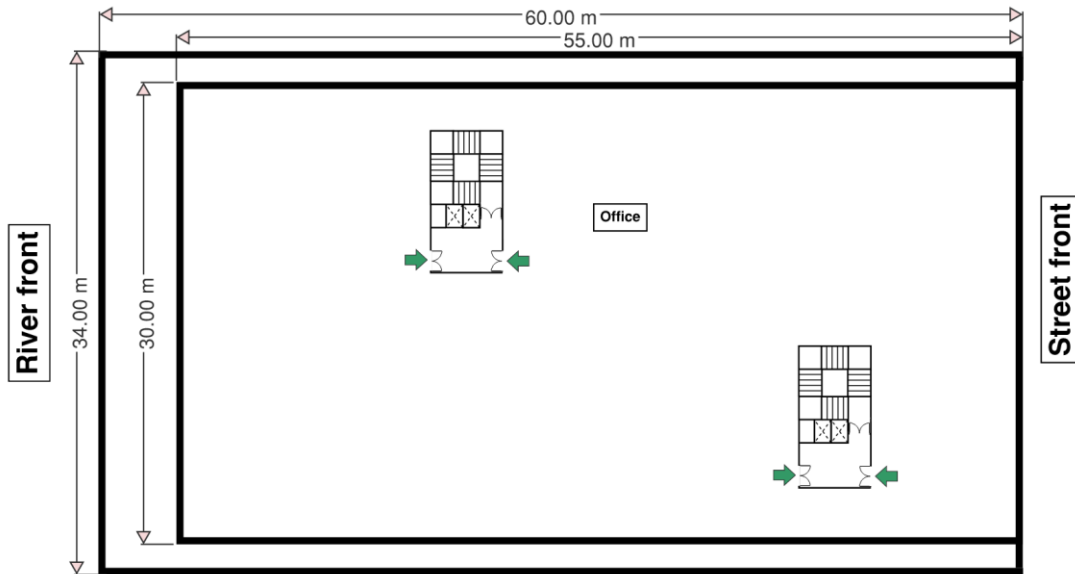


Figure 4 Second floor plan

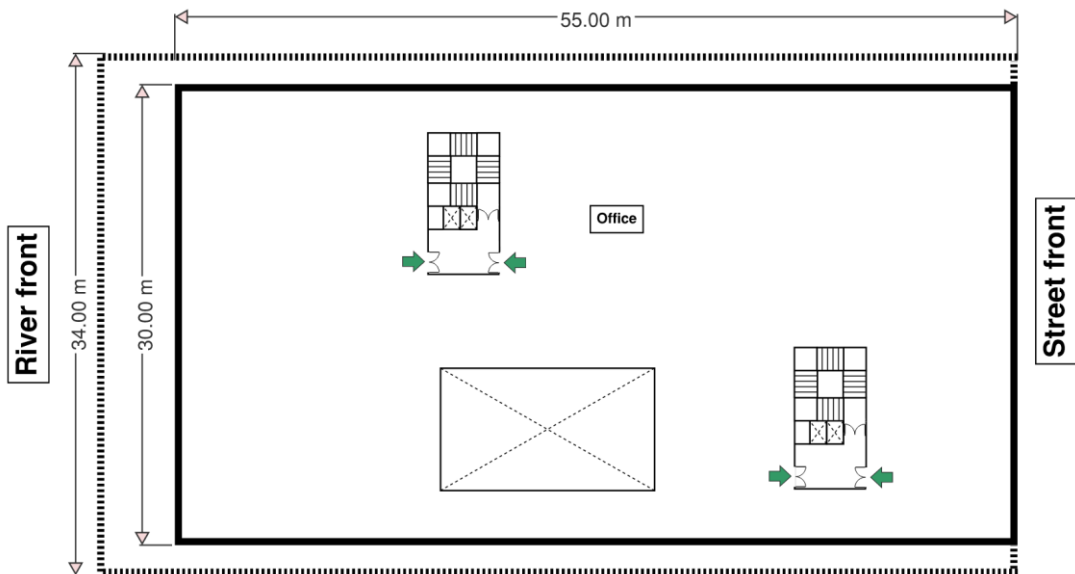


Figure 5 Third floor plan

Level 4 (Figure 6) comprises a combination of enclosed mass timber structure and open-air terrace space used for diplomatic functions. At peak operation, it must accommodate up to 800 guests and 120 staff, or up to 500 visitors during public open access hours. This level is also reached via the central lightwell, which provides vertical circulation and visual connectivity to the lower floors. Above Level 4, portions of the roof (Figure 7) may be used as an additional openair terrace.

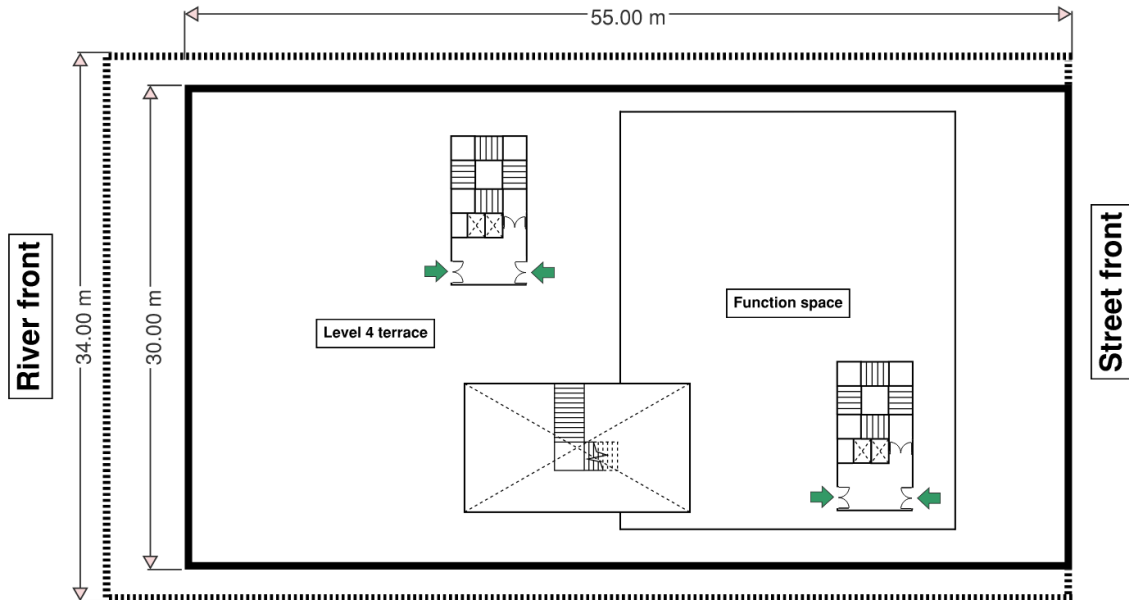


Figure 6 Fourth floor plan

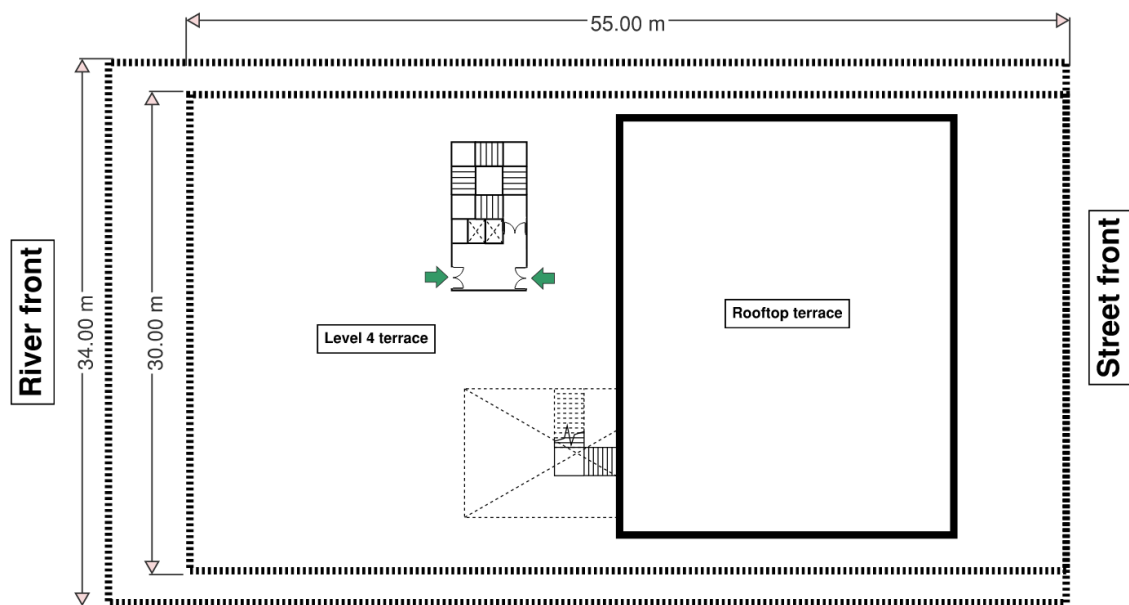


Figure 7 Rooftop terrace

Figure 8 illustrates a longitudinal section through the building, showing the central lightwell, the proposed mass-timber upper levels, and the arrangement of the outdoor and roof terraces.

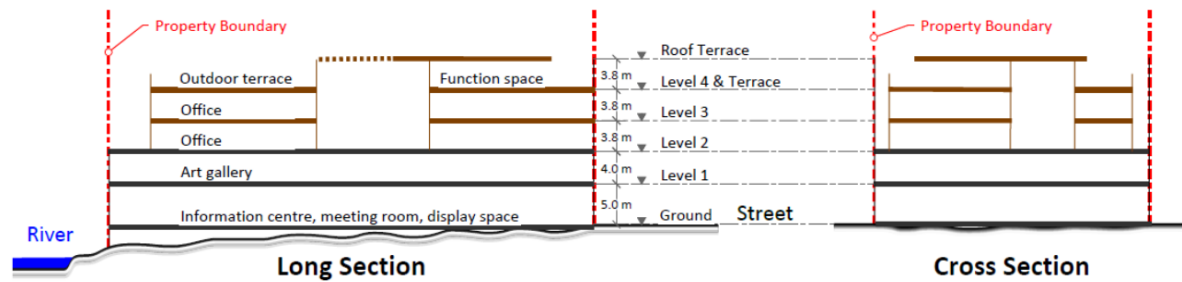


Figure 8 Indicative section plan

The new mass-timber structure is supported independently from the existing heritage building. To avoid imposing additional loads on the historic concrete and masonry, new foundations and piles are introduced beneath the footprint of the extension. Timber columns pass continuously through openings in the existing Ground and First floors and connect directly to these piles, maintaining uninterrupted vertical load paths for the upper levels.

Given that the fire-safety analysis and expected thermal exposures differ between the retained masonry/concrete structure and the exposed mass-timber floors above, the timber columns must not be exposed on the Ground or First floors. At these levels, the thermal environment cannot be guaranteed to remain below the timber ignition criteria, and exposure would invalidate the assumptions used for both structural stability and failure-mechanism prevention. The columns will therefore require protection, likely via encapsulation or an equivalent fire-resisting alternative, to be developed during later design stages. Above Level 2, where the design intent relies on exposed mass timber, the columns may remain visible consistent with the architectural concept and the performance-based fire strategy.

In addition to the column penetrations, the interface between the original concrete structure and the new mass-timber extension will require fire-resisting movement joints to accommodate differential thermal and moisture-related movements between the two structural systems. These joints are an unavoidable consequence of combining a historic masonry and concrete building with a lightweight timber superstructure and must be carefully addressed in later design stages to ensure they do not compromise compartmentation strategy or the structural response.

The building accommodates a wide range of public, cultural, office, and diplomatic functions, each with distinct occupancy characteristics and patterns of use. Table 1 summarises the expected occupancy profile for every level, based on the Case Study brief.

Table 1 Characteristics. Occupancy and use

Level	Occupancy Characteristics	Expected Use
<b>Ground Floor</b>	Open access to the public. Large numbers of shortstay visitors, plus periods with high, concentrated occupancy.	Information centre and arts/culture display space, including a meeting/function room for up to 300 occupants seated or standing.
<b>Level 1</b>	Open access to the public, with visitors moving at low to moderate density through display areas.	Art and artefacts gallery displaying valuable items from the visiting country, accessible to general visitors during opening.
<b>Level 2</b>	Primarily staff occupancy. Restricted access for diplomatic and support staff; presence of confidential material.	Office accommodation for diplomatic staff, with secure work areas and storage of sensitive documents and information.
<b>Level 3</b>	Primarily staff occupancy. Restricted access for diplomatic and support staff; presence of confidential material.	Office accommodation for diplomatic staff and embassy support staff, with secure work areas and storage of sensitive documents and information.
<b>Level 4</b>	Mixed, high-density assembly occupancy during events; controlled public access at other times.	Enclosed space and open-air terrace for diplomatic functions (designed for 800 guests and 120 staff) or up to 500 public visitors during open hours.
<b>Roof terrace</b>	Intermittent use with variable occupancy, linked to Level 4 activities.	Additional openair terrace above Level 4 that may be used as an extension of the diplomatic function space or public viewing area, as permitted by the brief. Access via the central lightwell.

## 1.2 Challenges

This section provides a brief overview of the main fire-safety challenges identified for this project and outlines early proposals for how these may be addressed within the constraints of the building's design and use. It is not intended to be comprehensive; rather, it highlights the key issues that shape the strategy, with the detailed analysis and justification for each challenge developed further in Section 3.

The first major challenge arises from the way people move through the building. Large numbers of occupants, many of whom will be unfamiliar with the layout, must evacuate without the support of active smoke management systems such as mechanical extraction. The strategy therefore relies entirely on early detection, clear and unambiguous alarm systems, well-maintained egress pathways, and the presence of trained staff who can direct occupants quickly and decisively.

A second challenge relates to the existing historic structure. Because the building fabric cannot be modified or provided with additional fire protection, and because active suppression systems capable of influencing fire development are not part of the design, the fire strategy must prevent conditions that would challenge the structural capacity of the original construction. This is achieved by careful control of fuel load and fuel arrangement, ensuring that potential fire sizes remain within the thresholds that the existing concrete and masonry can tolerate without severe thermal degradation.

The third challenge is inherent in the use of exposed mass timber in the new upper levels. If the timber were to ignite, the resulting fire could escalate rapidly due to the continuity and extent of exposed combustible structure, coupled with the absence of suppression. To address this, the strategy adopts the same principles applied to the existing structure: fire sizes are engineered by limiting and distributing fuel in such a way that the timber would not reach its ignition conditions. This maintains the mass-timber elements as passive, non-participating components in the fire dynamics.

The final challenge concerns the possibility of fire spreading beyond the space where it originates. While some smoke migration between areas is possible, the strategy ensures that fire itself remains contained to the floor of origin. This is achieved through the combined effect of passive measures, such as fire stopping, and strict management controls that limit fuel near openings, prevent exterior ignition, and maintain the spatial arrangement assumed in the fire scenarios. By controlling where fire can develop and how smoke can travel, the building maintains safe conditions for evacuation and prevents escalation to upper levels.

## 2 Methodology

The content in this section is based on the following chapters of the SFPE Handbook of Fire Protection Engineering [2]:

- Chapter 37, which provides an overview of the application of the performance-based approach to fire safety engineering.
- Chapter 38, which explains how design fire scenarios are identified and filtered to form the basis of a fire strategy.

In developing the methodology for this project, we have generally followed the general structure of the performance-based design process presented in Chapter 37, as illustrated in Figure 9. This process outlines the conventional sequence of defining the project scope, establishing goals and objectives, identifying performance criteria, developing fire scenarios, creating trial designs, quantifying design fires, and evaluating those designs against the agreed criteria.

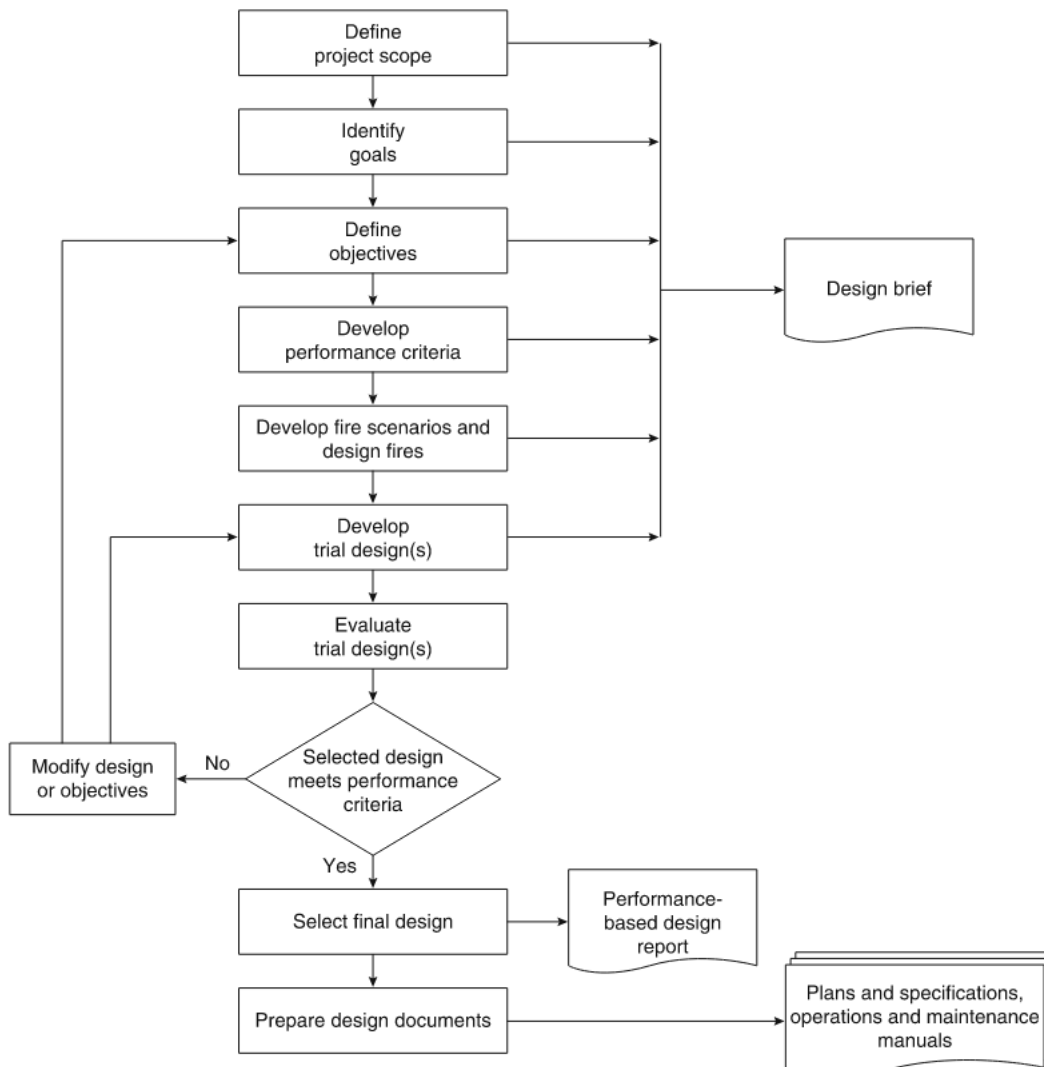


Figure 9 Performance-based design process. Reproduced from [2].

However, while our approach is informed by the SFPE framework, it intentionally diverges from it in a key respect: fire scenarios in our methodology are not an input to the design but an output. In a standard SFPE performance-based methodology, the development of design fire scenarios (Step 5) precedes

detailed engineering calculations. Scenarios are selected early and then used to test potential design strategies. In contrast, our project structure, driven by the nature of the case study and the underlying philosophy, requires that the fire scenario emerges from the design, not the other way around. This ensures that the engineered solution defines the credible fire, rather than relying on assumed or prescribed scenarios.

This departure is necessary because our strategy deliberately engineers the fire to remain within defined limits, preventing flashover or structural failure, restricting ignition of mass-timber elements, and maintaining the fire to a single storey, thus making the scenario itself a product of design constraints rather than a predefined condition. The implications of this methodological shift and its justification are explored in detail in Section 2.3, where the relationship between engineered fire behaviour and design performance criteria is fully articulated and, summarised in Table 2.

## **2.1 Goals**

Fire safety goals describe the overall desired outcomes of the strategy in qualitative terms and guide the development of the subsequent engineering objectives, criteria and analyses. The goals for this performance-based fire strategy are listed below:

### **2.1.1 Life safety**

- Safeguard occupants from injury due to fire until they reach a place of safety.
- Safeguard emergency responders while performing fire-fighting or rescue operations.

### **2.1.2 Property and heritage protection**

- Prevent damage to the existing heritage structure arising from a fire incident.
- Protect confidential documents and sensitive information from fire damage.

### **2.1.3 Mission continuity and security**

- Maintain security integrity during a fire event.

## **2.2 Objectives**

The objectives describe the maximum allowable levels of injury, damage, or operational impact and guide the development of performance criteria and limiting fire scenarios. They remain qualitative, but they clearly articulate what must be shown through analysis and simple calculations to demonstrate that the design meets the overarching goals.

All objectives seek to reflect the purpose of the strategy, which is to define the limiting fire conditions under which performance remains acceptable, and to ensure that those conditions cannot be reached.

### **2.2.1 Life safety**

- Demonstrate that occupants can remain in tenable conditions for the full duration required to reach a place of safety.
- Demonstrate that structural integrity is maintained for the time required to complete occupant evacuation and fire-fighting operations.
- Provide fire-fighters with operational conditions and built-in provisions that enable them to control the risks associated with suppression and rescue activities, ensuring that the fire develops and remains within the range of conditions they are trained and equipped to manage.

### **2.2.2 Property and heritage protection**

- Demonstrate that fire does not cause significant thermal or smoke damage to the existing heritage structure.
- Demonstrate that fire spread beyond the floor or compartment of origin is prevented under all limiting conditions.
- Demonstrate that smoke spread remains within acceptable limits that do not lead to secondary ignition or unacceptable property damage.

### **2.2.3 Mission continuity and security**

- Demonstrate that the building's security integrity is maintained throughout the fire event.
- Demonstrate that confidential documents and sensitive materials remain protected from heat, smoke, and fire exposure.

## **2.3 Design philosophy**

The goals (Section 2.1) and objectives (Section 2.2) describe what the fire strategy must achieve, expressed in qualitative terms that are understandable to all project stakeholders, including architects, clients, heritage specialists, security advisers, and building managers. They provide the shared language through which the intention of the fire strategy is communicated. However, these goals and objectives alone are not sufficient for engineering analysis. To evaluate whether the strategy truly achieves its intended outcomes, the fire engineer must translate these high-level statements into specific, quantifiable mechanisms of failure that can be rigorously assessed.

In a performance-based design framework, these failure mechanisms form the engineering bridge between the qualitative expectations of stakeholders and the quantitative assessments carried out by the fire engineer. They distil each goal and objective into the physical conditions under which that objective would no longer be met. For example:

- The goal of life safety is expressed quantitatively through the condition that ASET must not fall below RSET.
- The goal of protecting the existing heritage structure becomes a requirement to prevent flashover or any thermal condition that could compromise structural stability.
- The goal of preventing fire spread is understood through the engineering requirement that fire must remain strictly confined to the floor of origin.

By defining these mechanisms explicitly, the strategy makes clear exactly what must not happen for the building to remain safe, functional, and consistent with stakeholder expectations. This is central to the design philosophy adopted for this project, where the performance is verified by proving that failure cannot occur under the limiting fire conditions defined by the engineered design.

This methodological shift is essential to ensure that simple, first-order correlations remain valid. By engineering the fire to remain within defined limits, rather than modelling highly uncertain and complex scenarios, the strategy ensures that plume correlations, ASET/RSET calculations, ignition thresholds, and thermal criteria can be applied reliably and defensibly.

### 2.3.1 Design for failure

A central principle of our approach is to identify the conditions under which the fire strategy could fail and use these failure conditions to define the design limitations on space, materials, compartmentation, and allowable fuel load, that ensure such failures cannot occur. This approach requires explicit assumptions, an understanding of dependencies, and a definition of clear performance expectations rather than relying on occupant competence or prescriptive provisions. The failure mechanisms are therefore derived from an engineering analysis of how untenable conditions, structural or material failure, or uncontrolled fire spread could compromise the intended safety objectives.

In this framework, fire scenarios are the output of the quantitative design, emerging from the limits defined by these failure mechanisms rather than being assumed at the outset. Hence, the design fire is engineered by constraining its allowable growth, peak heat release, and extent so that the building performs within safe limits.

This approach stands in contrast to the traditional methodology described in Chapter 37 and Chapter 38 of [2], where design fire scenarios are selected early in the process and then used to assess the performance of trial designs. In the conventional framework, scenarios are identified through systematic methods assessing location, type of fire, hazards, system impacts, and occupant response, and reduced to a manageable set to evaluate building performance.

Our methodology reverses this flow: instead of selecting scenarios as inputs, we derive the credible fire scenario from the building's required performance, ensuring that conditions such as flashover, untenable egress environments, ignition of structural timber, or fire spread beyond the floor of origin cannot occur within the engineered limits. This ensures the fire strategy is anchored in quantitative performance objectives.

The four failure mechanisms identified for this building are:

1. Untenable conditions during egress, where occupants cannot evacuate before conditions become life-threatening.
2. Structural failure, primarily arising from flashover or thermal conditions capable of degrading the heritage structure or mass-timber elements.
3. Contribution of exposed timber to the fire, including ignition or delamination of mass timber, which would dramatically alter the fire dynamics and invalidate the engineered assumptions.
4. Fire spread beyond the floor of origin, internally or externally, which would compromise life safety, asset protection, and the fire service's ability to intervene predictably.

The subsections that follow describe each failure mechanism in turn, explaining the physical conditions that would constitute failure, the engineering reasoning behind those definitions, and how the strategy ensures that such conditions cannot occur.

### 2.3.2 Failure mechanism 1: untenable conditions during egress

This failure mechanism occurs when the Available Safe Egress Time (ASET) becomes shorter than the Required Safe Egress Time (RSET), meaning occupants can no longer evacuate safely before conditions become life-threatening. Untenable conditions arise when smoke obscuration, elevated temperatures, excessive radiation or toxic combustion products impair movement, reduce visibility, or render exit routes unusable.

To quantify this failure mechanism, the strategy requires an assessment of evacuation performance under different use conditions, considering variations in occupancy, activities, and occupant characteristics. This includes evaluating fire scenarios occurring on different storeys, as smoke movement, compartment geometry, and egress path vulnerabilities change with building level.

Although ASET is identified as the governing criterion for life safety, an explicit calculation of Available Safe Egress Time has not been carried out in this strategy. This is a deliberate choice. At this stage of

design, uncertainties associated with fire growth, smoke production, and ventilation conditions would dominate any calculated ASET value, potentially giving a false impression of precision.

Instead, the strategy adopts an engineering approach in which the fire is constrained such that untenable conditions are not expected to develop during the evacuation period. By preventing flashover, limiting heat release rate through fuel control, and preserving ventilation characteristics, the design ensures that ASET remains comfortably greater than RSET without relying on a numerically fragile ASET calculation.

### **2.3.3 Failure mechanism 2: structural failure**

This failure mechanism encompasses any condition in which the thermal environment becomes severe enough to compromise the load-bearing capacity of the existing concrete and masonry structure. Structural failure may result from several possible causes, including flashover, travelling fires, or intense localised heating.

Flashover represents the most critical of these causes, as fully developed fire conditions would generate temperatures far beyond what the heritage structure could tolerate. Travelling fires and localised fires, although different in behaviour, may also produce elevated or uneven heating that challenges structural performance even without full-compartment involvement.

The design therefore requires that flashover does not occur and, that travelling fire temperatures, or localised heating do not reach levels capable of impairing structural integrity. Fuel load, ventilation, and spatial arrangements are constrained accordingly so that the engineered fire remains below structural-failure thresholds.

Although similar considerations apply to the mass-timber elements, the conditions required for timber to contribute to the fire are more onerous than those required to challenge its structural response. For that reason, the structural performance of the timber elements is fully addressed within Failure Mechanism 3 (section 2.3.4) and not repeated here.

### **2.3.4 Failure mechanism 3: contribution of timber to the fire**

This failure mechanism concerns the risk that the exposed timber ceiling or timber columns could ignite or delaminate. Our design philosophy requires that the fire be constrained so that the thermal exposure, defined by smoke-layer temperature, flame height and incident heat flux, never reaches the conditions necessary to ignite or degrade the timber.

Because the report identifies limiting fire scenarios rather than assuming a set of credible scenarios, the assessment determines the threshold conditions (fire growth, size and plume characteristics) at which timber ignition or delamination would occur. These limiting conditions then define the constraints on acceptable fire behaviour.

To ensure that the fire remains strictly localised and incapable of igniting adjacent fuels, the strategy also requires that combustible items on the mass timber floors be spaced so that a single burning item or cluster cannot generate flame heights or radiant heat fluxes sufficient to ignite neighbouring combustibles. This spacing requirement is essential to demonstrate that lateral fire spread cannot occur and that the fire will not transition into a travelling fire type event across the open floor plate. These limits are addressed through fuel load and spatial distribution controls described in Sections 5.1 and 5.2.

### **2.3.5 Failure mechanism 4: fire spread beyond compartment of origin**

This failure mechanism addresses the risk of fire spread beyond the compartment of origin, recognising that while the strategy permits a controlled level of smoke spread, fire spread is not permitted under any circumstances.

Smoke may migrate under natural, open-ventilation conditions, and this smoke movement must be assessed to understand its potential impact. The distinction between allowable smoke spread and unacceptable fire spread is critical: as noted, ignition in adjacent spaces is a far more onerous condition than smoke migration, and the strategy makes this distinction explicit.

Both internal and external fire spread pathways are assessed in this strategy. Internally, we evaluate the potential for flames or hot gases to breach compartmentation, informed by the observations that even seemingly robust separations (e.g., small protrusions) may be insufficient to prevent spread. Externally, façade performance and separation distances are considered to ensure that neither flame extension nor radiation can ignite neighbouring systems or structures. These internal and external limiting conditions define the boundaries of acceptable fire behaviour and ensure that the fire remains confined to the floor of origin as required by the strategy

## **2.4 Performance criteria**

Performance criteria provide the quantitative conditions that distinguish acceptable from unacceptable fire behaviour. They translate each failure mechanism into a threshold that the design must not exceed. Performance criteria must be measurable, predictable using engineering tools, and directly linked to the mechanisms of harm affecting people, structure, materials and property.

In this strategy, performance criteria are set against the failure mechanisms, because the limiting fire scenarios that threaten failure define the boundary of acceptable performance. By demonstrating that these thresholds are not exceeded under the limiting fire conditions, we show that the objectives, life safety, property and heritage protection, mission continuity and security, are satisfied. The criteria below use values consistent with those identified in [2].

### **2.4.1 Criteria for failure mechanism 1: untenable conditions during egress**

- The ASET must remain greater than RSET on every floor.

### **2.4.2 Criteria for failure mechanism 2: structural failure**

- Flashover must not occur.
- The concrete reinforcement temperature must remain below 773 K (500 °C).

### **2.4.3 Criteria for failure mechanism 3: contribution of timber to the fire**

- Smoke layer temperature must remain below 523 K (300 °C).
- Glue-line temperatures must remain below 333 K (60 °C).

### **2.4.4 Criteria for failure mechanism 4: fire spread beyond compartment of origin**

- Flashover must not occur (addressed in failure mechanism 2).

- Incident heat flux from any external plume or internal void plume to the floor above must remain below 20 kW/m<sup>2</sup>.
- Ignition of the timber structure must not occur (addressed in failure mechanism 3).
- Neighbouring buildings are not exposed to a heat flux exceeding 12.5 kW/m<sup>2</sup>.

This strategy uses simple, transparent calculations, reinforcing that the engineer must choose suitable assumptions and justify them clearly. A summary of the relationship between goals, objectives and failure mechanisms is presented in Table 2.

Table 2 Relationship between goals, objectives, failure mechanisms and performance criteria.

Goal	Objectives	Failure Mechanism	Performance criteria
Safeguard occupants from injury due to fire until they reach a place of safety.	Demonstrate that occupants can remain in tenable conditions for the full duration required to reach a place of safety.	Failure mechanism 1: untenable conditions during egress	$ASET > RSET^*$ <i>*See discussion on Appendix A regarding the determination of ASET.</i>
		Failure mechanism 3: contribution of timber to the fire* <i>*Storeys with exposed mass timber</i>	$T_g < 300 C$ $T_{gt} < 60 C^*$ <i>*See discussion on Appendix C regarding the in-depth temperature estimation for the exposed timber.</i>
	Demonstrate that structural integrity is maintained for the time required to complete occupant evacuation and initial fire-fighting operations.	Failure mechanism 2: structural failure	$t_{FO} \rightarrow \infty$ $t_{reinf} < 500 C$
Safeguard emergency responders while performing fire-fighting or rescue operations.	Provide fire-fighters with operational conditions and built-in provisions that enable them to control the risks associated with suppression and rescue activities, ensuring that the fire develops and remains within the range of conditions they are trained and equipped to manage	Failure mechanism 1: untenable conditions during egress* <i>*Although tenability conditions do not apply to firefighting operations, a safe evacuation of the fire floor before firefighter intervention is essential, as responders rely on that floor being clear to work effectively and to avoid hazardous rescue operations.</i>	$ASET > RSET^*$ <i>*See discussion on Appendix A regarding the determination of ASET.</i>

Goal	Objectives	Failure Mechanism	Performance criteria
		Failure mechanism 2: structural failure	$t_{FO} \rightarrow \infty$
		Failure mechanism 3: contribution of timber to the fire	$T_g < 300 C$ $T_{gt} < 60 C^*$ <i>*See discussion on Appendix C regarding the in-depth temperature estimation for the exposed timber.</i>
		Failure mechanism 4: fire spread beyond compartment of fire origin	$q_{inc}^i < 12.5 \frac{kW}{m^2}$ <b>Internal fire spread*</b> <i>*See discussion on Appendix C regarding separation distances between cluster and discussion on Appendix D regarding other modes of internal fire spread.</i>
Prevent damage to the existing heritage structure arising from a fire incident.	Demonstrate that fire does not cause significant thermal or smoke damage to the existing heritage structure.	Failure mechanism 2: structural failure	$t_{FO} \rightarrow \infty$ $t_{reinf} < 500 C$

Goal	Objectives	Failure Mechanism	Performance criteria
Protect confidential documents and sensitive information from fire damage.	Demonstrate that fire spread beyond the floor or compartment of origin is prevented under all limiting conditions.	Failure mechanism 4: fire spread beyond compartment of fire origin	<p>Internal fire spread*</p> <p><i>*See discussion on Appendix C regarding separation distances between cluster and discussion on Appendix D regarding other modes of internal fire spread.</i></p>
	Demonstrate that smoke spread remains within acceptable limits that do not lead to secondary ignition or unacceptable property damage.	Failure mechanism 4: fire spread beyond compartment of fire origin	<p>Internal fire spread*</p> <p><i>*See discussion on Appendix C regarding separation distances between cluster and discussion on Appendix D regarding other modes of internal fire spread.</i></p>
Maintain security integrity during a fire event.	Demonstrate that the building's security integrity is maintained throughout the fire event.	<p>Failure mechanism 1: untenable conditions during egress*<sup>§</sup></p> <p><i>*Although tenability conditions do not apply to firefighting operations, a safe evacuation of the fire floor before firefighter intervention is essential, as responders rely on that floor being clear to work effectively and to avoid hazardous rescue operations.</i></p> <p><i><sup>§</sup>Failure mechanism 1: untenable conditions during egress also discusses segregation of the evacuation for floors with restricted access. See appendix A.</i></p>	<p><math>ASET &gt; RSET^*</math></p> <p><i>*See discussion on Appendix A regarding the determination of ASET.</i></p>

Goal	Objectives	Failure Mechanism	Performance criteria
	<p>Demonstrate that confidential documents and sensitive materials remain protected from heat, smoke, and fire exposure.</p>	<p>Failure mechanism 4: fire spread beyond compartment of fire origin</p>	<p>Internal fire spread*</p> <p><i>*See discussion on Appendix C regarding separation distances between cluster and discussion on Appendix D regarding other modes of internal fire spread.</i></p>

## 3 Conceptual fire strategy

The content in this section is based on the following chapters of the SFPE Handbook of Fire Protection Engineering [2]:

- Chapter 37, which provides an overview of the application of the performance-based approach to fire safety engineering.
- Chapter 38, which explains how design fire scenarios are identified and filtered to form the basis of a fire strategy.
- Chapter 49, which describes how fire strategies depend on the coordinated performance of passive and active system.

Section 2 defined the fire-safety goals, objectives, failure mechanisms, and performance criteria that establish the engineered limits of acceptable fire behaviour. Section 3 translates these to form the conceptual fire strategy. The limiting fire scenarios in Section 4 emerge as a direct consequence of this framework, rather than as predefined inputs.

The conceptual fire strategy establishes the fundamental logic by which the building is expected to perform in the event of a fire. This stage corresponds to the qualitative definition of system behaviour, including the assumptions, dependencies, design boundaries, and intended fire safety outcomes that will later be tested through calculation. This step is essential because the clear articulation of the conceptual strategy is required to ensure that all subsequent quantitative work is coherent, justified, and technically sound.

Consistent with the design-for-failure methodology adopted in Section 2.3, the conceptual strategy does not begin with predefined fire scenarios. Instead, it describes how the building must behave for the strategy to succeed and identifies the assumptions and system conditions that allow that performance to be achieved. The limiting fire scenarios that will ultimately be evaluated in Section 4 emerge directly from this conceptual strategy.

### 3.1 Scope

This fire strategy is issued for an assumed Concept Design stage (UK) as described by the Royal Institute of British Architects (RIBA) [3], where the architectural concept is developed and aligned with the brief and client requirements. This stage corresponds to Concept Design under the Architects' Council of Europe (ACE, Europe), Schematic Design under The American Institute of Architects (AIA, USA), and Feasibility under the Association for Project Management (APM, Global).

At this stage, design information is intentionally limited to the development of a coherent architectural concept supported by strategic engineering inputs rather than detailed analyses. The aim is to ensure the concept is robust and coordinated at a high level with engineering requirements. This avoids premature detail while ensuring the design can progress efficiently to later stages

At Concept Design level, the contribution of specialist consultants, such as fire engineers, focuses on shaping the strategic direction of the project. This stage establishes a clear conceptual framework and identifies the requirements that must be satisfied by later design stages and specialist disciplines.

This fire strategy demonstrates that the architectural principles and intended use of the building can be aligned with an effective fire safety approach. The strategy focuses on demonstrating feasibility, defining performance expectations, and clarifying the assumptions required to support concept-level decision-making.

Several project-specific details are not yet defined. These include:

- The distribution of functions and uses across floors.
- The identification and treatment of higher-risk areas (e.g., storage).
- System routing and services penetrations and their impact on compartmentation.
- The actual furniture, internal layouts, and final fuel loads.

This strategy uses transparent calculations supported by clear assumptions to demonstrate that the overarching fire safety objectives are achievable, provided those assumptions are satisfied in later design and construction phases. Therefore, this strategy forms a conceptual framework that justifies continuation of the design under an agreed fire safety intent.

## **3.2 Roles and responsibilities (fire safety)**

The role of this fire strategy is to:

- Define the expected performance of the building during a fire.
- Set the performance requirements for fire safety systems.
- Establish assumptions, dependencies, and required management practices, which must hold true for the strategy to remain valid.
- Identify the systems and building features that will need to be developed in detail during later design stages.

The primary recipients of this strategy, at this stage, are the design team members, particularly the architect and the developer, who must clearly understand the constraints on management, use, and operational expectations imposed by the strategy before progressing the design. Their decisions at this stage must be informed by the management-related assumptions embedded in the strategy, as these assumptions underpin the validity of the simple calculations and strategic approach being employed.

The strategy does not specify products or systems, as that will be the responsibility of specialist designers. These specialist designers must ensure their systems meet the performance requirements set out here and, they must consult with the fire engineer where system behaviour affects the assumptions underlying this conceptual strategy.

As the fire engineer in this project, we take responsibility for:

- Developing the conceptual fire strategy.
- Defining the relevant fire scenarios, assumptions, and performance expectations.
- Identifying how design, construction, management, and maintenance must support the intended performance, including the operational conditions and redundancies required for the strategy to remain valid over the building's lifecycle.
- Documenting the boundaries, conditions, and dependencies upon which the strategy relies, ensuring that all assumptions are clearly stated and that their implications are understood by the design team and downstream stakeholders.

While we set the performance requirements and conceptual framework, we do not take responsibility for:

- Designing or specifying products or systems (e.g., fire-stopping products or fire detection systems).
- Validating or certifying the detailed design of systems produced by other specialists.
- Overseeing installation quality or maintenance arrangements once products and systems are procured and installed.

These tasks fall under the remit of competent specialist designers, contractors, system suppliers, and ultimately the building management team.

### 3.3 Assumptions

This strategy relies on a defined set of assumptions that underpin all subsequent calculations and evaluations. These assumptions establish the conditions under which the building is expected to behave during a fire and form the basis for determining the limiting fire scenarios described earlier. The assumptions are summarised below:

- We assume that only a single fire occurs at any given time, that the fire is not the result of arson or multiple ignition sources, and that the fire remains confined to a single storey consistent with the design-for-failure philosophy.
- We expect occupants to react to alarms, staff to do their jobs, building management to follow operational rules including conducting first-aid firefighting and stairs, corridors, and key areas to stay clear of hazards and obstructions.
- We assume that the stair functions as a safe space forming part of the established hierarchy of protected areas, that internal ventilation and geometry remain unchanged from those used in the design calculations, and that the heritage and mass-timber elements perform in accordance with their expected thermal behaviour.
- We assume that the fire service will elect to intervene even though life safety does not rely on their actions, and therefore provisions must enable them to operate within conditions that are predictable, consistent with procedures, and within the bounds of the engineered fire behaviour.
- The ground floor meeting room is assumed to be open at high level and provided with acoustic baffles to increase crossflow ventilation and omit reliance on active ventilation systems.
- Ventilation conditions are assumed to remain equivalent to the open-façade arrangement shown in Figures 1–8. For the purpose of the calculations carried out in this report, it has been assumed that: 50% of the level 4 function space elevations are open, 70% of the levels 2 and 3 office space (including lightwell) are open and 50% of the ground and level 1 display space and gallery front and rear elevations are open. Any future design development that materially reduces, encloses, or obstructs façade or lightwell openings would require reassessment, as the natural-ventilation conditions form part of the limiting assumptions used in the fire-engineering analysis.
- A critical assumption of this strategy is that mass-timber columns are not exposed to post-flashover thermal conditions. Where timber columns pass through the existing Ground and First floors, they must be protected to prevent exposure to fire scenarios that cannot be reliably bounded using the methodologies adopted in this report. There is currently no accepted first-order methodology for assessing the structural response of exposed timber columns subjected to travelling fires within mixed-material buildings. Accordingly, the protection of these columns is a non-negotiable design requirement rather than an optimisation. The form of protection may be developed at later design stages, but the need for protection is fundamental to the validity of the strategy.

### 3.4 Building performance

In the event of a fire, the building is expected to operate in a predictable and controlled manner consistent with the assumptions and management constraints defined in this strategy. Although ignition cannot be fully prevented, the conditions that follow ignition can be controlled by limiting fuel load,

maintaining open and unobstructed spaces, and preserving the ventilation characteristics assumed throughout the design. Under these constraints, the size and growth rate of any fire are expected to remain within the engineered limits that prevent flashover, avoid ignition of exposed timber, and keep the fire confined to the floor of origin.

Two broad ignition contexts are considered: a fire occurring on a floor occupied primarily by visitors, and a fire occurring on a floor occupied primarily by staff. While pre-movement and response times may differ between these groups, both situations follow the same overall sequence. Upon smoke detection or confirmation of a developing fire, the alarm will be activated locally on the floor of fire origin. Occupants on that floor will begin to move once the alarm is activated, with staff assisting and directing evacuation where present. As smoke is detected on floors above, consistent with natural vertical spread driven by the building's open ventilation, the alarm will be extended to those floors to initiate their evacuation. After a reasonable period and following established procedures, the remainder of the building will be evacuated in a staged manner to avoid unnecessary congestion and to prioritise the areas at greatest risk.

For the secure Levels 2 and 3, this staged sequence is modified to preserve security integrity. These floors evacuate together only when the fire occurs on Level 2 or Level 3, or when all non-secure floors below have first cleared, as described in Section 3.6.3. This adjustment ensures that protected evacuation routes do not result in unauthorised mixing of occupants. Throughout this process, the stairs are assumed to remain a safe space, providing a protected vertical route for all building users. The strategy does not rely on fire-service intervention for life safety, but it does assume that fire-fighters may choose to intervene; therefore, the conditions within the building must remain consistent with those expected by standard fire-fighting procedures. This staged and controlled building response ensures that occupant movement, smoke behaviour, and the growth of the fire remain within the limits defined through the design-for-failure methodology, enabling the building to achieve the performance required by the goals and objectives set out in Section 2.2.

To achieve a sustainable design solution and minimise reliance on mechanical ventilation systems, a passive design approach is adopted. This approach promotes cross-ventilation through large openings on opposing facades supported by generous ceiling heights that enhance internal air movement.

This strategy is further facilitated by a central open lightwell which functions as a thermal chimney, permitting warm air to discharge at roof level through stack ventilation. However, given the tropical climate context, similar to Singapore, characterised by elevated humidity, high temperatures, heavy rainfall and seasonal monsoons, a fully open-sided building is not viable. Therefore, additional design measures are incorporated (as indicated in Figure 10), to enhance comfort, architectural features and enable natural smoke ventilation in case of a fire incident:

- Automated timber louvres and windows: motorised louvres and operable windows that respond dynamically to environmental conditions including temperature, humidity and precipitation. They are linked to the fire alarm system to provide full crossflow ventilation in case of a fire incident.
- Perforated screens, deep overhangs and verandas: Maintain constant natural ventilation while provide solar shading and protection from heavy rainfall.
- Green walls: Contribute to passive cooling by reducing the external surface temperature and lowering ambient air temperatures through evapotranspiration.
- Green roofs and sky gardens: Reduce heat gain and maintain lower overall roof temperatures, while improving the overall thermal performance of the building.

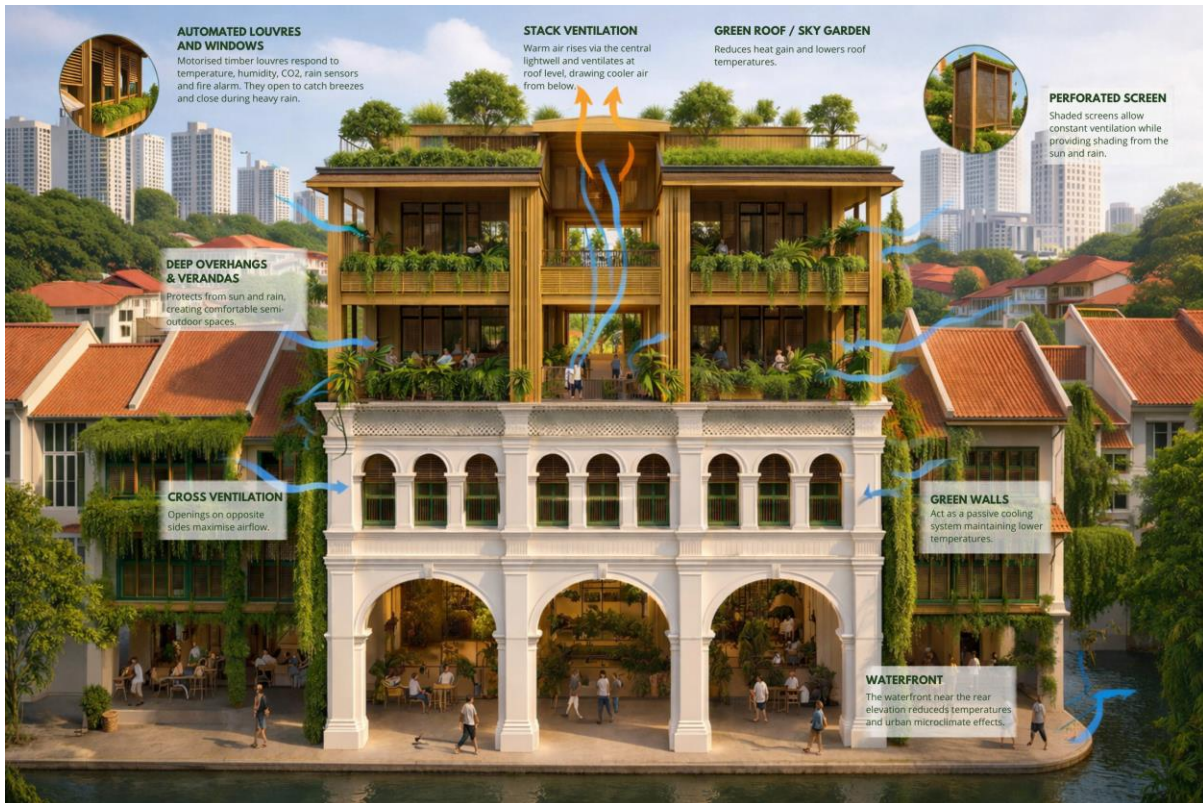


Figure 10 Passive ventilation design proposal

## 3.5 Fire safety measures

This section outlines the passive and active fire safety measures incorporated into the strategy. It focuses on the physical and system-level provisions only; management arrangements are addressed separately in Section 5. It is important for the reader to understand that management plays a role just as critical as passive and active systems, given that the assumptions, dependencies, and performance conditions of this strategy rely on effective operation and maintenance throughout the building's lifecycle.

### 3.5.1 Passive measures

#### 3.5.1.1 Compartmentation

Compartmentation is a core assumption of this strategy, but its function differs across the building. The non-negotiable requirement in all cases is that the protected stairs and lobbies remain tenable and free of smoke for the duration of evacuation. Fire must remain confined to the floor of origin. On the Ground and First floors, both fire and smoke are required to remain within the floor of origin. On Levels 2–4, smoke migration within the open floor plates may occur under natural ventilation, but the strategy prevents smoke from compromising the protected egress routes and prevents any thermal exposure capable of igniting exposed timber.

Although compartmentation is a core assumption of this strategy, it does not apply uniformly across the building. On the Ground and First floors, the retained heritage structure, compartmentation performs its traditional function: both fire and smoke are required to remain within the floor of origin, and these floors behave as true compartments forming critical horizontal fire separation boundaries. In contrast, the new mass timber Levels 2–4 do not rely on compartmentation to achieve performance. These floors operate as large, open, naturally ventilated volumes where only fire (not smoke) is required to remain confined to the floor of origin. On these levels, the strategy relies instead on engineered limits on fuel load, spatial distribution, and ventilation conditions to prevent flashover, ignition of timber, or lateral fire spread.

The continuity of the timber columns through the Ground and First floors creates unavoidable structural penetrations through what would otherwise be critical horizontal compartmentation boundaries. Because these heritage floors are required to contain any fire originating on these levels, the penetrations must be detailed and protected so that the full fire-separation performance of the slab is preserved. The fire-safety analysis on the Ground and First floors differ fundamentally from those on the exposed timber storeys above, and the thermal environment in these retained floors may exceed the ignition thresholds for mass timber. For this reason, the timber columns must not be exposed on these levels and will require encapsulation or equivalent protection to maintain the assumptions underlying the structural-failure and timber-ignition failure mechanisms.

In addition to the column penetrations, the junctions between the retained masonry structure and the new mass-timber extension require movement joints to accommodate differential thermal expansion, moisture-related movement, and structural deflection. These joints are structurally necessary but represent potential vulnerabilities within the building's compartmentation strategy and should therefore achieve a suitable level of fire resistance.

Under the design-for-failure philosophy, the performance requirement for both the annular gaps around timber-column penetrations and the broader movement joints is the same: they must not permit fire spread beyond the floor of origin. Fire-stopping and encapsulation measures must accommodate structural movement while maintaining integrity and insulation performance. The precise solutions will depend on detailed design considerations, including tolerances, joint widths, and connection arrangements. Regardless of the final detailing, the conceptual requirement is explicit: the introduction of movement joints and column penetrations must not compromise the compartmentation performance of the heritage structure or enable any deviation from the assumption that fire is contained to the floor of origin.

### **3.5.1.2 Downstands around the lightwell**

The central lightwell provides natural ventilation and daylight but also represents a potential vertical pathway for smoke and fire. As a passive mitigation measure, the use of downstands around the perimeter of the lightwell openings should be explored with the architect at detailed design stages.

The purpose of the downstands is not to prevent smoke movement entirely, which is an accepted condition on the upper mass-timber levels, but to limit direct flame projection and reduce the momentum of hot gases entering the void. By interrupting direct plume attachment at the lightwell edge, the downstands encourage lateral spill and discharge through the open façades, consistent with the cross-ventilation assumptions used in the fire-engineering analysis.

Downstands therefore support the design-for-failure philosophy by helping to:

- prevent fire spread beyond the floor of origin,
- limit thermal exposure to exposed mass-timber elements above the fire floor, and
- preserve the validity of the simple calculations used to demonstrate performance.

At this concept stage, no specific downstand geometry or fire-resistance rating is defined. The performance requirement is qualitative: the downstands must be sufficient to prevent direct flame projection into the lightwell and to delay vertical fire spread under the limiting fire conditions defined by fuel-load control and ventilation. The detailed geometry and integration with architectural intent should be developed collaboratively at later design stages.

### **3.5.1.3 Fire-fighting risers**

To ensure that the fire service can effectively suppress a one-floor fire, the strategy incorporates dedicated fire-fighting risers that allow crews to bring water directly into the building during an incident. The fire brigade represents one of the final layers of redundancy in the overall fire safety system.

#### **3.5.1.4 Protection of sensitive documents**

Levels 2 and 3 contain diplomatic work areas and stores of confidential documents that must remain protected during a fire. Because the performance-based methodology adopted for this building assumes that smoke may spread beyond the floor of fire origin, the protection of sensitive material cannot rely solely on spatial separation. Instead, the strategy requires that all sensitive documents, classified materials, and essential records be stored in fire-resisting, smoke-tight cabinets that provide protection from both thermal exposure and smoke infiltration under the limiting fire conditions defined in this design. These cabinets must achieve the temperature-rise and smoke-exclusion performance consistent with the preservation of sensitive paper-based or digital materials expected within diplomatic environments.

The requirement for fire-resisting storage ensures that mission-critical information remains protected even if smoke migration or localised heating occurs on Levels 2 or 3, and it preserves the validity of key assumptions used in the performance-based assessment. If these storage systems remain in place, the failure mechanisms related to fire spread or thermal exposure cannot compromise the operational continuity or security objectives associated with these floors. The precise specification, performance class, and distribution of storage units will be determined during later design stages, but the conceptual requirement is that sensitive material remains protected independently of smoke movement patterns, ventilation behaviour, or occupant-driven evacuation flows.

### **3.5.2 Active measures**

This strategy deliberately avoids reliance on systems that would materially control fire growth (e.g., automatic suppression) or require complex mechanical smoke-exhaust modelling at this concept stage. Active systems are used primarily as dependencies for early warning, clear communication, and controlled natural smoke ventilation, consistent with the design-for-failure philosophy and the goal of minimising embodied carbon. The design remains robust only if these dependencies are maintained through inspection, testing, and management controls.

#### **3.5.2.1 Detection and alarm system**

The strategy relies on automatic detection to minimise the time between ignition, system activation, and occupant response. The intention is that detection time will be significantly shorter than egress time. To meet this objective, the building incorporates:

- A comprehensive automatic detection system designed to initiate the alarm as soon as conditions indicate a developing fire.
- A multilingual alarm messaging system, delivering a clear, unambiguous announcement that the situation is not a drill and directing people to evacuate.

Messages are broadcast in the local language, the language of the diplomatic mission, and two additional widely spoken regional languages, ensuring that no occupant is required to interpret or reason through the situation. These provisions reduce both detection and pre-movement time and ensure that occupants receive direct, actionable instructions without ambiguity.

#### **3.5.2.2 Smoke management**

To maintain a tenable stair environment during an evacuation, the protected stair shafts are equipped with an automatic opening vent (AOV) at their head. This provides an additional layer of redundancy in safeguarding the means of escape. The AOV activates immediately upon detection of a fire in any floor.

The ventilation throughout the building will be managed by the automatic louvres and windows located on each side of the external elevations. These systems are integrated with the automatic fire detection and alarm system and will automatically open in the event of a fire to provide cross-ventilation.

### **3.5.2.3 Evacuation lifts**

The design incorporates evacuation lifts serving each stair core and enabling the safe and timely evacuation of people with reduced mobility (PRMs). This demonstrates that system design accounts for foreseeable evacuation needs. Evacuation lifts ensure that PRM occupants are not forced into untenable waiting positions or forced to rely on stair descent.

### **3.5.2.4 Emergency lighting**

The stair core and escape routes are equipped with emergency lighting to maintain visibility even under degraded or smoke-affected conditions.

### **3.5.2.5 First-aid firefighting**

Hose reels are installed throughout the building and can be used by trained members of staff. Due to the building's unique characteristics, including heritage elements and exposed timber construction, early firefighting is particularly important. Use of the hose reels during the incipient stage of a fire may enable a small fire to be extinguished quickly, preventing the ignition of the exposed timber and reducing the risk of the fire developing into a larger incident.

### **3.5.2.6 Fire service controls**

Upon arrival, the fire brigade can trigger a simultaneous building-wide evacuation if it has not already occurred. Providing responders with the ability to command the evacuation sequence ensures that fire-fighting and rescue protocols can be executed under predictable and controlled conditions, allowing the fire service to respond if the conditions deviate from the design premise.

### **3.5.2.7 Green walls**

Means of fire detection in the green walls will be provided, using linear heat detection (LHD), which takes form of sheathed cables threaded through the green wall. As a general principle, the LHD cables will need to extend to every floor level and extend across the full elevation where a green wall is present.

Irrigation pumps will also be provided as part of the green wall system to keep the plants watered, such that the moisture content is kept to a level which would not cause the reaction of fire classification to reduce and further propagate the spread of fire. The pumps will be monitored by the Building Management System (BMS) to prevent plants from drying out, any fault will be detected and rectified in short time period.

With the above provisions, the likelihood of a green wall becoming involved in a fire and spreading to other floors is minimised, where the risk of fire spreading across the façade can be reasonably disregarded.

## **3.5.3 Back-up power and essential building services**

The building incorporates a number of active systems that support the early detection of fire, the management of smoke within protected stairs and on the fire floor, and the safe evacuation of occupants. It is essential that the availability of these systems is fully understood. Consistent with the design-for-failure methodology, these systems are treated as dependencies whose correct operation underpins the assumptions used in the performance-based assessment.

With the exception of the evacuation lift, no active fire-safety system is provided with generator-backed secondary power. The fire detection system, alarm sounders, automatic window actuators and louvres, and the stair-head automatic opening vents (AOVs) should operate on independent battery backup units, and their continued reliability therefore depends on a rigorous maintenance and testing regime. The evacuation lift is the only system supported by a standby generator or UPS given the expected power demand in the event of power failure.

The strategy also requires clear coordination of building services in areas that support the fire-safety systems. Detector heads and alarm sounders must be located so that they operate effectively under the open-plan and cross-ventilated conditions of the building, and service routes must not compromise compartment lines.

Any backup power package or energy-storage system associated with building operations must be located within dedicated enclosures on the non-timber floors (i.e., ground or first). These enclosures must provide an appropriate level of compartmentation, including protection to the ceilings, to ensure that any failure or malfunction within these rooms cannot alter the fire behaviour assumed in the analysis. The exact fire-resistance requirements for these enclosures will be determined at later design stages once the specification, size, and hazard profile of the equipment are known.

## **3.6 Conflicts**

The conflicts described below do not undermine the viability of the strategy; rather, they highlight where boundary conditions must be recognised and controlled.

### **3.6.1 Egress and fire service intervention**

This strategy assumes that both stairs remain tenable throughout egress. However, fire service intervention may conflict with means of egress if responders enter via a stair that occupants are still using. No directional guidance is provided to the fire service indicating which stair to use and so there is a potential for operational conflict at the moment of arrival.

To mitigate this:

- The strategy immediately evacuates the fire floor on detection and subsequently evacuates any floor that receives an alarm activation.
- This staged sequence ensures that all occupants likely to be affected have already cleared the stairs by the time the fire service arrives.
- PRM evacuation inherently takes longer, raising the risk of overlap between their movement and the fire-service entry. This conflict is managed by trained staff assigned to assist PRMs, including coordination with arriving responders.

### **3.6.2 Design requirements and compartmentation**

The architectural concept includes exposed mass-timber, a central lightwell and green-wall features. However, this strategy requires that compartmentation must not allow fire spread until burnout, and that fuel must not contribute to vertical spread. There is therefore a conflict between aesthetic design intentions and the requirements to preserve floor-to-floor fire separation.

This conflict is addressed through:

- Explicit management controls on fuel load to ensure that vegetation and exposed timber surfaces remain within acceptable ignition-resistance boundaries.
- Provision of downstands around the lightwell to delay the vertical spread of fire and smoke via the lightwell and direct it outwards via the open elevations.

This ensures that compartment integrity remains intact.

### **3.6.3 Security requirements and controlled egress**

The building includes secure floors (Levels 2 and 3) that accommodate diplomatic and administrative functions, with access restricted to authorised personnel. Under normal operation, these floors are entered only through controlled-access lobbies incorporating fob-activated doors and supervised entry. These access constraints create a potential conflict with the requirement for rapid evacuation, and the

fire strategy therefore establishes a controlled egress sequence that preserves both life safety and security integrity.

To prevent unauthorised movement between secure and non-secure levels during an emergency, Levels 2 and 3 are treated as a single egress unit for fire safety purposes. A fire on either of these floors triggers the simultaneous evacuation of both, ensuring that occupants do not rely on passing through access-controlled doors into spaces where they would not normally be permitted. Conversely, a fire on the public floors (Ground or Level 1) initiates evacuation of those floors first, with Levels 2 and 3 evacuating immediately after the fire floor is cleared. For a fire on Level 4 or the rooftop terrace, the priority order is the fire floor, then the public floors, and finally the secure Levels 2 and 3. This sequence minimises the likelihood of unauthorised occupants entering restricted areas while still maintaining the staged, risk-based approach required to keep evacuation efficient and manageable.

All sensitive and classified material located on Levels 2 and 3 must be stored in fire-resisting, smoke-tight cabinets distributed across the secure office areas. These storage provisions ensure that documents remain protected from both thermal exposure and smoke migration during all stages of an evacuation, consistent with the objective of safeguarding confidential information under fire conditions.

### **3.6.4 Cross-ventilation and smoke spread**

The building incorporates large façade openings and an open internal void extending from Level 2 upward, creating a ventilated environment in which air can move freely both horizontally and vertically. This configuration reduces the likelihood of flashover, as well-ventilated fires tend to remain in the growth or localised-burning phase; however, it increases the potential for smoke to migrate between floors. The strategy therefore distinguishes clearly between smoke spread, which is expected and acceptable under the design assumptions, and fire spread, which must not occur under any circumstances.

On the Ground and First floors, where the existing heritage structure is retained and no mass-timber elements are present, the strategy requires that both fire and smoke remain confined to the floor of fire origin. These floors follow a conventional compartmentation-driven approach consistent with the limitations of the heritage structure. In contrast, on Levels 2 and 3, the mass-timber office floors, the partitions do not extend to the soffit, and the geometry is intentionally open to support environmental and architectural objectives. As a result, smoke spread beyond the room of fire origin is assumed on these levels. This assumption is directly addressed in the performance-based design: the strategy controls fuel load and fuel arrangement so that any resulting smoke layer temperatures remain well below the thresholds for timber ignition, and evacuation of Levels 2 and 3 is initiated immediately upon detection anywhere in those floors, ensuring that occupants can reach a place of safety.

Cross-ventilation and wind effects are considered qualitatively within this framework. Although varying wind conditions may alter smoke flow paths or influence plume behaviour, such variations do not affect the failure mechanisms provided that fuel loads and spatial arrangements remain within the limits defined by the strategy. Because the limiting conditions for timber ignition and fire spread are governed by local thermal exposure rather than large-scale smoke flow, management controls (Section 5) ensure that flames cannot reach the exposed timber and that clusters of combustibles cannot create ladder-fuel effects capable of igniting surfaces on higher floors or within the void. As long as these controls are preserved, wind-driven smoke movement may influence smoke deposition patterns but will not compromise the fire-safety objectives or lead to any of the identified failure mechanisms.

### **3.6.5 Climate, weather resilience and façade openness**

The building is assumed to operate in a tropical climate subject to high rainfall, strong winds, and storm events. The open façade strategy adopted for ventilation and smoke dilution must therefore be robust not only under fire conditions but also under adverse weather.

Fully open elevations may be vulnerable to wind-driven rain ingress during storms, potentially requiring temporary or permanent perimeter glazing with operable elements. Any such intervention would alter

ventilation characteristics, smoke accumulation, and fire growth rates, and therefore falls outside the assumptions of this strategy.

If operable façade systems are introduced, their default position, actuation logic, and failure modes must be assessed explicitly for fire conditions. Changes to façade permeability represent a fundamental modification to the engineered fire envelope and must trigger formal re-evaluation of smoke movement, tenability, and fire development assumptions.

## 3.7 Dependencies

Dependencies and the sequence of events (Section 4) must be explicitly understood, because the safety margin created by simple analytical methods only holds when the dependencies are preserved.

### 3.7.1 Evacuation

The safe evacuation of occupants depends on three primary factors:

- Detection and alarm performance: Early activation of the fire detection and alarm system is essential. If detection or alarm performance degrades, the sequence of events assumed in the RSET calculations is no longer valid.
- Tenable Conditions in the Stairs: The protected stair shafts must remain free of smoke for the duration of evacuation. Any loss of compartmentation around the lobby or stair compromises the assumed evacuation conditions.
- Fuel-Load Management: Evacuation calculations rely on fire-growth rates that are directly linked to assumed fuel loads and spatial distribution. If the fuel load increases beyond assumed values, fire development may exceed the predictions used in this strategy.

### 3.7.2 Structural response

The structural response depends on operational controls:

- Fuel-load control determines maximum fire size: Structural performance assumptions are based on bounding fire sizes derived from controlled fuel-load conditions. Excess fuel can increase heat-release rates beyond those used in the failure-mode calculations.
- Ignition prevention of exposed timber: A core assumption of the strategy is that mass timber does not ignite. If fuel or heat sources accumulate near timber surfaces, structural integrity cannot be guaranteed.
- Ignition prevention of the green wall: Similar considerations apply to the building's vegetated elements. The green wall is not expected to become involved in a fire; ignition would create a new vertical fuel path outside the modelled assumptions.

### 3.7.3 Fire service intervention

Fire-service operations represent the final redundancy in the overall safety strategy. Their ability to intervene safely depends on:

- Integrity of the protected shafts: A core dependency is the continued compartmentation of the stair shaft, which must remain clear of smoke long enough for responders to enter predictably.
- Smoke clearance via the stair-head AOV: Fire-fighting activities may introduce smoke into the stair, especially if doors are held open during hose deployment or rescues. In such cases, responders depend on the automatic opening vent (AOV) at the top of the stair to relieve smoke and restore visibility.
- Smoke clearance via the open facade: The automatically openable windows and louvres are essential to ensuring that smoke is dispersed through crossflow ventilation, further reducing strain on firefighters.

- Compartmentation to restrict fire spread: As with evacuation provisions, the fire service relies on the fire remaining confined to a single floor.

If these dependencies fail, the fire brigade may face unpredictable and hazardous conditions outside the engineered performance envelope.

## 4 Quantification of performance

This section translates the conceptual fire-safety strategy set out in Section 3 into a demonstration of performance. It explains how a combination of qualitative assessment, hazard elimination through design, and simplified first-order calculations has been used to evaluate whether the building meets the defined goals, objectives, and failure mechanisms.

A deliberate distinction is made throughout between situations where numerical analysis adds engineering value and situations where it would introduce misleading precision. Where key aspects of geometry, ventilation, fuel characteristics, or use remain undefined at concept stage, the strategy avoids producing numerical results that would obscure unacceptable uncertainty. In such cases, hazards are addressed by constraining the design or operational envelope, rather than by relying on calculations that imply a level of knowledge that does not yet exist.

Conversely, where the physical behaviour is sufficiently well understood and the assumptions can be stated clearly, simple first-order calculations from the SFPE Handbook [2] are used to test limiting conditions and validate the proposed approach. The intent is not to optimise the design numerically, but to demonstrate that, under the engineered constraints, the identified failure mechanisms cannot credibly occur.

The detailed calculations and scenario-specific considerations that support this assessment are provided in Appendices A–D. This section therefore presents the overarching analytical framework: how fire scenarios were derived, how performance criteria were tested, and how uncertainty was explicitly considered in defining the building’s engineered fire envelope.

### 4.1 Analysis

This section summarises how the building’s fire performance has been assessed. The analysis is organised around the four identified failure mechanisms and reflects a conscious choice of method appropriate to the level of design definition available.

In some areas, performance is demonstrated primarily through qualitative assessment and design decisions rather than numerical calculation. For example, hazards such as fire exposure at protected stairs or excessive thermal exposure of egress routes are addressed by design measures that remove or constrain the hazard, including fuel-free zones, protected lobbies, and the treatment of stairs as places of safety. In these cases, providing a numerical result would not increase confidence in the outcome and could obscure the underlying dependency on management and layout assumptions.

In other areas, simplified first-order calculations are used to validate that the proposed constraints are effective. This includes, for example, the assessment of evacuation demand and stair capacity, screening calculations for timber ignition based on convective and radiative heating, and the evaluation of structural response using travelling fire concepts. These calculations are intentionally simple, transparent, and bounded by clearly stated assumptions, ensuring that their use remains within the limits of their validity.

Where uncertainty is high and dominant parameters are not yet defined, such as the detailed smoke movement behaviour in large, open, naturally ventilated spaces, explicit numerical values (e.g. ASET) are not calculated. Instead, the analysis focuses on identifying the mechanisms that could compromise performance and demonstrating how the strategy prevents those mechanisms from developing.

All numerical work, scenario-specific assumptions, and supporting sensitivity considerations are provided in the appendices. The purpose of this section is not to reproduce calculations, but to explain how engineering judgement has been applied to decide what to calculate, what to constrain by design, and what to defer to later design stages, while still demonstrating that the strategy achieves the required level of fire safety performance.

#### **4.1.1 Failure mechanism 1: untenable conditions during egress. Appendix A.**

The number of occupants has been estimated based on the project brief, floor areas and floor space factors. This ensures that sufficient exits of appropriate capacity have been provided for means of egress purposes.

With the specified number of occupants and available exit provisions, required safe egress time (RSET) calculations have been undertaken to determine total time required for each floor to complete an evacuation, this is calculated up to the storey exits of each floor only based on the assumption that the staircases remain a place of safety. The RSET calculation is based on a first order, simplified hydraulic model as explained in Chapter 59 of SFPE Handbook [2]

#### **4.1.2 Failure mechanism 2: structural failure. Appendix B**

##### **4.1.2.1 Flashover fires**

The likelihood of flashover occurring was assessed for each compartment / floor of the building. However, experimental data is based on measurements in compartments up to 100 m<sup>2</sup> and the Eurocode parametric fire curves associated to flashover fires, are limited to maximum compartment areas less than 500 m<sup>2</sup>. On this basis, flashover is unlikely to occur, as all compartments range between 450-1860 m<sup>2</sup> in area.

Notwithstanding the above, a calculation was carried out based on Chapter 30 of the SFPE Handbook to determine the heat release rates required for a flashover to occur for each floor. This resulted in significantly large heat release rates, which are unrealistic for this building.

##### **4.1.2.2 Travelling fires**

In order to represent a more realistic fire scenario in the existing storeys, travelling fire curves have been calculated based on the methodology developed by Stern-Gottfried and Rein [4], [5] and other relevant research.

Based on the compartment characteristics, fire properties and an iterative process to determine an acceptable fire load, a time-temperature curve was plotted for different fire scenarios which may occur in each compartment. The temperature was calculated at a given point in the far end of the compartment, where the highest heat transfer is expected to occur within a structural slab or beam.

##### **4.1.2.3 Existing concrete structure**

Several assumptions have been made for the reinforced concrete slab, such as the type of concrete and reinforcement depth. Further non-intrusive investigations should be conducted on site (such as ground penetrating radar) to determine whether reinforcement is present, bar spacing and depth. Additional destructive testing (core sampling) may provide information on aggregate type and cement composition to further validate the fundamental assumptions in the following assessments.

Based on the travelling fire time-temperature curves, the resulting temperature was calculated at the face of the concrete and the assumed reinforcement bar location within the concrete element. As a simplification, the steel temperature was assumed to be identical to the concrete temperature the interface.

##### **4.1.2.4 Existing masonry walls**

Masonry and natural stone generally perform very well at elevated temperatures. Fired clay (ceramic) bricks in particular, can retain a substantial portion of their strength after exposure to temperatures as

high as 1000 °C [6]. Unlike reinforced concrete, masonry walls do not contain embedded steel reinforcement that would significantly degrade under fire conditions; however, the mortar joints may experience strength loss and cracking when subjected to elevated temperatures.

The existing masonry party walls are assumed to be substantially thick, consistent with typical historic loadbearing construction, and therefore likely to possess significant inherent fire resistance and thermal mass. It is expected that by controlling the fuel loads and subsequently restricting the fire size and resulting temperatures as discussed throughout this report, it would be sufficient not to warrant a detailed assessment for the loadbearing masonry walls.

#### **4.1.3 Failure mechanism 3: contribution of timber to the fire. Appendix C.**

The contribution of exposed timber to the fire is treated as an explicit failure mechanism because any ignition or delamination of the mass-timber elements would fundamentally alter the fire dynamics and invalidate the engineered fire envelope. The strategy therefore requires that the fire be constrained such that the thermal exposure experienced by exposed timber surfaces never reaches conditions capable of causing ignition or heat-induced delamination.

The quantification of this failure mechanism is provided in Appendix C, where first-order screening calculations are used to establish limiting fire sizes and fuel arrangements. Using simple correlations from the SFPE Handbook, the assessment considers the dominant heat-transfer mechanisms relevant to exposed timber: convective heating from hot gases beneath the ceiling, flame height and flame impingement, and, where relevant, radiative heat transfer. Rather than attempting to predict detailed fire behaviour, the analysis identifies the threshold conditions at which timber ignition or delamination would become credible and then demonstrates that these conditions cannot be reached if the building is operated within the defined management constraints.

The outcome of this assessment is not a single “design fire”, but a set of engineering limits on fire size, fuel-cluster dimensions, fuel elevation, and separation distances. These limits ensure that localised fires remain small, well ventilated, and spatially separated, such that the exposed timber ceiling and columns remain non-participating in the fire. In this context, ignition of timber is not mitigated by material performance or suppression, but by engineering the fire itself through control of fuel load and arrangement.

The analysis in Appendix C recognises the uncertainty associated with real three-dimensional fuel arrangements. Where uncertainty remains significant, it is managed by restricting the operational envelope rather than by introducing additional analytical complexity.

#### **4.1.4 Failure mechanism 4: fire spread beyond compartment of origin. Appendix D.**

The compartment of fire origin is defined as the full storey. This reflects the architectural and environmental intent of the building: internal compartmentation is deliberately avoided to satisfy natural-ventilation and spatial requirements. As a result, the strategy distinguishes clearly between allowable smoke spread, which may occur within (all storeys) and between floors (timber storeys only) under natural ventilation, and unacceptable fire spread, which must not occur beyond the floor of origin.

The assessment of this failure mechanism is presented in Appendix D and considers internal and external fire-spread pathways separately, recognising that different physical mechanisms govern each.

For the non-timber storeys (Ground and First floors), internal fire spread within the floor is assessed using a travelling fire framework, as documented in Appendix B. These storeys are treated as conventional compartments bounded by the existing masonry and concrete structure.

For the mass-timber storeys (Levels 2–4), the approach is fundamentally different. Internal fire spread within the floor, in the sense of fire propagating from one fuel package to another, is not allowed. Rather than relying on compartmentation, the strategy prevents internal fire spread by engineering the fire to remain localised. As described in Appendix C and applied in Appendix D.1, combustible items are arranged in discrete fuel clusters with enforced separation distances derived from first-order ignition screening calculations. These separations ensure that neither flame contact nor radiative heat transfer from a burning cluster can ignite adjacent fuel packages.

Vertical fire spread between floors is addressed through a combination of fuel-load control, geometric separation, and protection of critical interfaces. Fire stopping at slab penetrations, including those associated with timber columns passing through the lower storeys, is treated as a non-negotiable dependency of the strategy. Any failure of fire stopping that would allow flames or hot gases to bypass the floor separation would constitute a direct breach of the assumed compartment boundary and therefore a failure of the fire strategy. The protection of these interfaces is therefore essential.

External fire spread is assessed in Appendix D.2, recognising the presence of large façade openings, terraces, and vegetated external wall systems. The assessment adopts bounding radiative heat-flux criteria consistent with failure mechanism<sup>4</sup> and demonstrates that, under the limiting fire sizes established elsewhere in the strategy, flames or radiation from an internal fire cannot ignite elements on floors above, adjacent façades, or neighbouring buildings. Particular attention is given to the external wall system, including the green walls, where ignition would represent a direct pathway for vertical fire spread. To prevent this, the strategy requires clear separation between combustible fuel loads and the external walls, combined with plant selection, irrigation, and maintenance measures that limit the combustibility of the vegetated system.

## 4.2 Summary of fire scenarios

The fire scenarios considered in this report are derived directly from the identified failure mechanisms and are intended to represent the limiting conditions under which the fire strategy could fail. Consistent with the design-for-failure philosophy adopted throughout, these scenarios are not selected arbitrarily or to represent worst-conceivable events, but rather to test whether credible, localised fires could challenge life safety, structural stability, or the non-participation of exposed timber elements. The scenarios are therefore defined as outputs of the engineering constraints imposed on fuel load, fuel arrangement, geometry, and ventilation, rather than as prescriptive inputs.

Several scenarios address the potential ignition of exposed mass-timber elements on the upper levels. Localised fires are considered beneath timber ceilings to assess whether convective heating from hot gases could lead to ignition under plausible fire sizes and fuel configurations. These scenarios assume fires limited in footprint and growth rate by management controls and examine whether ceiling-level gas temperatures and flame heights remain below ignition-capable conditions. Direct flame impingement is treated as a bounding condition, recognising that flame contact provides the most rapid heating pathway, while convective heating is assessed as the more credible mechanism in open, ventilated spaces.

Additional localised scenarios are considered for exposed timber columns on the mass-timber levels. These scenarios focus primarily on radiative heating from nearby fuel packages, combined with the possibility of elevated fuels typical of office environments. The intent is to verify that, with appropriate separation distances and fuel-free zones, radiative heat fluxes to column surfaces remain below critical thresholds. Direct flame impingement onto columns is avoided by design and management and is therefore not treated as a credible scenario within the assumed operating envelope.

Localised external fire scenarios are also considered at the perimeter of the mass-timber levels. These address the potential for fire spread to or from adjacent façades and openings, recognising that the upper storeys incorporate exposed timber and rely on openness and cross-ventilation. The scenarios examine whether fires within the building could plausibly lead to external flame spread to neighbouring surfaces, or whether external fires could threaten exposed timber internally, given the assumed limits on fuel placement, façade geometry, and separation.

The presence of vegetated green walls introduces an additional localised fire scenario. Fires originating adjacent to or within the green wall system are considered to assess the potential for ignition, vertical fire spread, or increased thermal exposure to adjacent timber elements. These scenarios are addressed through assumptions on plant selection, irrigation, maintenance, and separation from other combustible materials, with the objective of ensuring that green walls do not provide a pathway for fire spread beyond the floor of origin.

Specific localised scenarios are also considered in relation to the means of egress. These include fires occurring near stair entrances or within circulation spaces that could compromise access to protected stairs. Rather than quantifying untenability through explicit ASET calculations, these scenarios are addressed by design measures that prevent their occurrence or limit their impact, including the provision of fire-resisting lobbies, exclusion of fuel in critical egress zones, and management controls that maintain clear escape routes.

Finally, travelling fire scenarios are considered for the assessment of structural response of the existing concrete structure. These scenarios represent spatially non-uniform fires that move across large compartments, producing localised peaks in thermal exposure rather than uniform compartment conditions. The travelling fire framework is used to assess whether the structure can tolerate these localised thermal demands without loss of stability, while remaining consistent with the assumption that fire remains confined to a single storey.

Collectively, these scenarios cover the mechanisms by which fire could challenge the strategy: ignition of exposed timber, compromise of egress, external fire spread, and structural failure. They are deliberately limited in number and complexity, reflecting the intent to use simple, transparent calculations applied within clearly defined assumptions. Where detailed modelling would require information not yet available at concept stage, the strategy instead constrains the design so that such scenarios cannot credibly develop, preserving the validity of the simplified engineering approach adopted in this report.

### **4.3 Uncertainty**

Performance-based fire safety engineering is unavoidably affected by uncertainty. Fire behaviour, human response, system reliability and structural performance cannot be predicted exactly. In this context, the role of the fire engineer is not to eliminate uncertainty, but to choose valid assumptions that allow simple calculations to be applied within their validity limits, so that the residual uncertainty is compatible with the redundancy built into the design.

We identified the variables that most strongly influence the failure mechanisms, including heat release rate, fuel distribution, human response times, ventilation conditions, and timber ignition, and we manage the uncertainty by treating these variables explicitly while keeping less influential details at a consistent and simplified level. Hence, we seek to maintain a consistent level of crudeness [7], avoiding situations where one part of the analysis is highly refined while others remain coarse.

We have not carried out a full probabilistic risk analysis. However, we make use of published probabilistic insights, from design-fire studies [8], HRRPUA distributions [9], and ASET/RSET uncertainty analyses [10], to select bounding or representative values. The subsections below summarise the main uncertainty domains and explain how they are managed in this project.

Uncertainty in fire engineering cannot be eliminated by increasing analytical complexity. In many cases, additional modelling introduces new uncertainties that exceed those it seeks to resolve. In this strategy, uncertainty is managed by constraining design freedom and operational variability rather than by attempting to predict fire behaviour in detail.

The reliability of the analysis therefore depends less on numerical precision than on the stability of the assumptions. Maintaining these assumptions through design development, construction, and operation is the primary mechanism by which uncertainty is controlled.

### **4.3.1 HRR, HRRPUA and fire growth**

HRR, HRRPUA and fire-growth rate are major contributors to uncertainty in ASET calculations. Variations in peak HRR or growth rate can produce large shifts in predicted tenability. In this strategy we use deterministic design fires but, as already explained, these design fires are the output of our assessment and not the input to the calculations. Therefore, the uncertainty is not associated with the HRR and fire growth values, as these are not design choices, but to the relationship that is established in Section 5 between these fire engineering parameters and modern fuel load characteristics.

HRRPUA introduces further uncertainty because widely cited values in design guidance originate from a small number of historic tests and have been repeatedly adapted across documents. These values span wide ranges, e.g. 250-650 kW/m<sup>2</sup> for offices [2], [11], [12], [13], [14], because they depend strongly on occupancy, fuel configuration, and ventilation, and are therefore better treated as ranges than fixed constants.

### **4.3.2 Fuel load and fuel composition**

Fuel-load density and fuel composition also carry substantial uncertainty, as shown in probabilistic design-fire studies where fuel loads and item-level HRR data follow broad distributions, often triangular or log-normal for fuel load and growth factor, and normal for peak HRR [15]. To manage this uncertainty, the strategy adopts floor-by-floor fuel-load limits such that the resulting fire sizes and durations remain within the bounds used in Appendices B–D, and these limits are tied directly to operational controls in Section 5.

Because detailed item-level fuel data are not available for this conceptual case study, we rely on literature ranges for HRRPUA and fuel behaviour to confirm that our assumptions fall within conservative bounds for the relevant occupancies, and we enforce spatial-distribution rules to prevent large continuous burning areas that could otherwise drive the fire toward flashover or travelling-fire conditions. This ensures that uncertainty in fuel characteristics does not undermine the core requirement of keeping the fire within the domain where simple engineering calculations remain valid.

### **4.3.3 Human behaviour**

Uncertainty in human response is the largest source of variability in fire-safety engineering. The SFPE Handbook [2] emphasises that human behaviour cannot be predicted with precision and must therefore be treated as a major design dependency rather than a fixed input. Pre-evacuation time, recognition of the alarm, decision-making, and movement speeds vary widely between individuals and contexts, meaning that any single value or narrow range inevitably masks significant behavioural diversity. Because of this, the accuracy of the engineering calculations must be matched to the level of uncertainty inherent in human response. Over-refined numbers would give a false sense of confidence when the underlying variability is so large, and it is therefore the responsibility of the engineer to ensure that the level of robustness built into the RSET assessment is appropriate to this dominant uncertainty.

Behavioural assumptions, such as how quickly people perceive risk, how they prioritise actions, and how efficiently they move are not properties of the building but outcomes of management, training, and operational conditions that must be explicitly stated and continuously verified in use.

### **4.3.4 Fire-fighter operations**

Fire-service intervention introduces uncertainty because arrival times, operational tactics, water supply, and on-scene decision-making cannot be predicted deterministically. Experience-based actions are inherently variable and are not treated as primary safety barriers. Accordingly, this strategy assumes a traditional approach in which the fire service operates from a safe location, uses the dry risers for water supply, and prioritises rescue and confirmation of conditions. Their intervention is treated as a redundancy rather than a necessary element for achieving tenable egress or preventing any of the defined failure mechanisms.

Although we make simple, explicit assumptions, such as arrival during or shortly after the completion of evacuation of the fire floor, none of these assumptions are used to justify reductions in fuel-load limits, structural protection, or evacuation capacity. This is deliberate, because real-world firefighting involves dynamic risk assessments that can lead to changes in tactics, withdrawal, or defensive operations, especially if any part of the strategy fails. Such dynamic decision-making cannot be meaningfully quantified within performance-based calculations and is therefore excluded from the primary demonstration of performance. Instead, fire-service intervention is used only as a robustness check.

#### **4.3.5 Response of exposed mass timber**

The thermal and structural response of mass-timber elements is sensitive to adhesive performance, moisture content, and the interaction between local heating and global structural restraint. These areas have significant uncertainty for modern engineered-timber products. To manage this uncertainty, our strategy deliberately assumes that timber behaves under ideal, dry, and stable material conditions, with no moisture-induced modification and no adhesive degradation beyond the temperature limits explicitly identified in Appendix C. Because the behaviour of exposed mass timber under fire remains an active research domain, the strategy treats the timber's contribution to the fire as unacceptable; ignition of the timber surface or heat-induced delamination of lamellae is defined as a failure mechanism, not a design variable.

## 5 Building Management

The content in this section is based on the following chapters of the SFPE Handbook of Fire Protection Engineering [2]:

- Chapter 49, which describes how fire strategies depend on the coordinated performance of passive and active system.
- Chapter 74, which explains how reliability, availability, and maintainability methods are used to predict failures, optimise inspections and maintenance, and quantify the performance of fire protection components.

Effective building management is a foundational pillar of this fire strategy. The performance of the building in a fire is governed by the continued accuracy of the design assumptions and, the reliability and coordinated operation of its systems. Inspection, testing, and maintenance activities, explicitly identified as the dominant means by which failures are discovered, directly influence system performance and therefore constitute essential management responsibilities.

Good building management ensures that all assumptions underpinning the fire strategy remain valid throughout operation. Maintaining these assumptions requires continual control of fuel loads, spatial arrangements and maintenance schedules. These operational factors influence reliability (likelihood of functioning), availability (probability of being operational at the time of fire), and maintainability (the building's capacity to return systems to service following inspections or failures). These elements must be quantitatively understood and proactively managed because system performance degrades with time unless management actions explicitly preserve it. Building management therefore becomes a continuous process of ensuring that the building performs as intended in a fire, making it a core structural element of the overall fire strategy

### 5.1 Fuel load characteristics

Table 3 summarises the limitations imposed on the fuel load characteristics, both the type of combustible materials permitted and their spatial arrangement, derived from the quantitative analysis presented in Section 4 and detailed in Appendices A through D.

The inclusion of engineering limits in Table 3 serves a practical purpose: it provides building managers, designers, and future fit-out teams with the underlying quantitative constraints that must remain satisfied if the use and occupant characteristics of the space remain unchanged. These engineering limits represent the maximum fuel load and fire growth parameters that the building's fire strategy can safely accommodate without compromising the performance objectives established earlier. Presenting these limits explicitly ensures that future changes in occupancy or furniture specification can be assessed against a clear engineering baseline, allowing the management limits to be reconstructed in a transparent and repeatable manner. The reader is referred to Appendices A-D for a full explanation of how these limits were derived.

A clear zone shall be maintained around all exposed timber columns on mass-timber floors. The minimum radius of this zone shall be consistent with the ignition-screening distances derived in Appendix C and shall not be encroached upon by furniture, storage, or temporary installations.

Table 3 Requirements imposed on the fuel load for storeys with exposed timber

Engineering limit Max fire size (MW)	Engineering limit Assumed Heat Release Rate Per Unit Area $\left(\frac{kW}{m^2}\right)$	Management limit Maximum size of fuel cluster (m <sup>2</sup> )
Fuel load closer to floor (1.9)	Conservative limit (500)	7
	Non-conservative limit (250)	3.5
Fuel load at 1 m height (0.8)	Conservative limit (500)	3
	Non-conservative limit (250)	1.5

### 5.1.1 Rooftop amenities and non-combustible substrates

The rooftop terrace is expected to support a variety of public and diplomatic activities, and the use of amenities in this space must be consistent with the fire-safety assumptions that underpin the performance-based strategy. Because the rooftop sits directly above exposed mass-timber floors and is supported by exposed mass-timber columns, any activity on this level must not increase the likelihood of heating, ignition, or flame impingement on the structural timber elements or on the external walls and parapets, also assumed to be exposed mass timber. In addition, all rooftop activities must preserve safe and unobstructed egress routes for occupants on both Level 4 and the rooftop terrace, ensuring that evacuation performance remains consistent with the RSET calculations.

Amenities such as saunas, barbecues, and hangi pits may be included, provided they are installed over non-combustible slabs that prevent heat transfer to the timber structure below and are arranged in a manner that maintains safe separation from timber columns, parapets, and external walls. Their design must ensure that flame height, radiant heat flux, and hot-gas temperatures remain well below the conditions that could cause timber ignition or delamination, with specific requirements to be determined at a later stage of design when more specific information regarding amenities is available to the fire engineer.

All such amenities must be operated under staff supervision, and their fuel loads must comply with the limits defined in this strategy. By contrast, no plant equipment, machinery, or energy-intensive installations are permitted on the upper storeys or rooftop terrace. These systems often introduce additional ignition hazards, energy-storage components, or thermal loads that are incompatible with the assumptions used to prevent fire spread and the involvement of mass timber. Provisions for permitted amenities must therefore rely on passive, non-combustible construction and must not create new pathways by which heat or flame could compromise the limits defined by the strategy.

## 5.2 Fuel load distribution

Table 4 summarises the specific limitations on the spatial distribution of fuel across each storey, ensuring that fuel packages are placed only in locations that remain consistent with the assumptions embedded in the quantitative assessment presented in Section 4. These spatial restrictions must therefore be applied in conjunction with the fuel-load limits described in Section 5.1 so that the overall fire growth, heat-release behaviour, and compartment performance evaluated in the analysis remain valid for any future fit-out.

Table 4 Requirements imposed on the fuel load (spatial distribution)

Floor	Notes
Ground	n/a
First	n/a
Second	Fuel clusters to be discrete, separated in accordance with Appendix C; no combustible items within column clear zones
Third	Fuel clusters to be discrete, separated in accordance with Appendix C; no combustible items within column clear zones
Fourth	Stricter enforcement due to assembly occupancy; no temporary clustering or decorative fuel beneath timber ceilings or adjacent to columns
Roof Terrace	As determined in 5.1

### 5.2.1 Fuel spread and prevention of fire spread

On the mass-timber floors (Levels 2–4), the performance-based strategy assumes that any fire will remain localised to its point of origin and will not propagate laterally across the floor plate. Because the strategy does not permit the mass-timber ceiling or columns to become involved in the fire, it is essential that the arrangement of combustible items prevents a single burning cluster from igniting adjacent fuels. To achieve this, management must ensure that combustible items are spaced sufficiently apart so that flame height, plume temperature and incident radiant heat from one cluster remain below the ignition thresholds of all neighbouring fuels. Restriction on fuel distribution are summarised in Table 4.

This requirement directly supports Failure Mechanism 3 (see section 2.3.4) by ensuring that the thermal exposure at ceiling level remains below the timber-ignition and delamination criteria. It also prevents the formation of a travelling-fire-type event, consistent with the assumption that fire behaviour on these floors will be limited to localised burning. More detailed minimum separation distances for typical furniture clusters and combustible items will be defined during later design stages using the limiting fire-size correlations established in the analysis (e.g., flame-height limits, allowable heat-release rates). Operationally, management must ensure that furniture layouts, temporary displays, and storage practices do not create continuous combustible pathways capable of enabling lateral fire spread.

### 5.3 Means of egress

Management must ensure that all systems supporting safe evacuation remain reliable, available, and free from preventable failure. This includes routine inspection, testing, and maintenance of the alarm and detection systems.

Further, access to the stairs and the stair enclosures must be kept completely free of fuel or obstructions. Staff must be trained to support evacuations under different scenarios, including maximum occupancy conditions, ensuring occupants are guided rather than expected to make competence-based decisions. The AOV at the top of the stair and other automatic opening windows or louvres around the building elevation must be tested and maintained to ensure it performs as expected during a fire. Staff must also be trained in the correct use of evacuation lifts and associated procedures, and signage throughout the building must be kept clear, legible, and consistent so that users understand precisely what to do during an emergency.

## 5.4 Green walls

For the green walls, building management must ensure that the system operates under the same assumptions used in the fire-engineering analysis (see Section 4), specifically the moisture content and fuel characteristics that control the likelihood of ignition and subsequent fire spread.

Likewise, the plant species, substrate, and overall fuel type must remain consistent with the design specification, as even small deviations can significantly change the heat-release properties and undermine the performance criteria upon which the strategy is based. Regular inspections, preventative maintenance, and coordination with the green-wall specialist are therefore required.

To reduce the risk of externally located fire spreads to the green walls, an appropriate Fire Safety Management Strategy should be implemented, and the area adjacent to the living wall should be kept free of fire load, including vehicles parked for prolonged periods of time. Service vehicles who will be parked in the layby for a short period of time will be allowed. Any hot-works, fireworks, Chinese lantern or similar should not be permitted near the green walls without appropriate risk assessment.

A crucial element is ensuring that it is kept well maintained and irrigated. If the wall is not kept well irrigated, then it increases the likelihood of the living wall becoming involved in a fire and spreading significantly across the façade. This would create a hazard for occupants in the building and also in neighbouring buildings. It is therefore essential that the living wall is kept watered, such that the moisture content is kept to a level which would not cause the reaction to fire classification to reduce, and that the automatic watering system is continuously monitored for faults.

As the irrigation pumps will be monitored by the Building Management System (BMS) to prevent plants from drying out, any fault will be detected and rectified in short time period. Therefore, a secondary power supply to the pumps is not considered necessary.

In addition, the growth of the living wall needs to be kept monitored. External planters should not grow beyond the areas specified as being allowed to have a living wall and additionally, any dead foliage should be removed regularly as part of the maintenance programme.

## 5.5 Provisions for the fire service

From a management perspective, supporting the fire service means ensuring that all systems and information they rely on remain available, reliable, and immediately usable when an incident occurs.

This includes maintaining the AOV at the top of the stair, automatic opening windows and louvres around the building perimeter and the dry risers so that they operate as intended. As with any safety-critical component, failures must be discovered during routine inspection and testing rather than during an emergency.

Management must also maintain accurate, real-time information on building occupancy, both who is in the building when the alarm activates and, where possible, who has already evacuated, as this can significantly improve the effectiveness and safety of fire-service operations.

Access control procedures must guarantee that the fire service can take control of the evacuation lifts without delay, with keys, override systems, and lift-lobby routes kept fully functional and unobstructed.

Finally, the full fire strategy, including all assumptions, limitations, and performance requirements, must be readily available to the fire service on arrival if they do not already hold a copy. This transparency ensures that the fire service understands the design intent and can operate within the same assumptions that underpin the building's performance-based strategy.

## 6 Fire Risk Assessment

The FRA is a core component of the building's ongoing fire-safety management, acting as the mechanism through which the assumptions underpinning the performance-based strategy are continuously verified as the building ages and its use evolves. Unlike a one-off design exercise, the FRA provides a structured process for checking that the conditions, limitations, and dependencies defined during the engineering analysis still hold true in day-to-day operation. Because the fire strategy is supported by clearly stated assumptions, the stability of those assumptions over time is fundamental to ensuring the strategy remains valid.

A second and equally important function of the FRA is to identify when changes to the building such as its layout, systems, or use, may alter the basis on which the fire strategy was developed. As discussed later in Section 6.2, any such change, whether physical (e.g., new partitions, increased fuel loads, altered ventilation paths) or operational (e.g., new occupancy patterns, revised management procedures), may invalidate key design assumptions.

When this occurs, the FRA must not attempt to resolve the issue; instead, it should prompt a formal review and, if necessary, a redrafting of the fire strategy by a competent fire engineer. The FRA therefore serves as both a monitoring tool and an early-warning mechanism, ensuring the strategy remains aligned with the actual building throughout its lifecycle.

### 6.1 Carrying out the FRA

Carrying out the FRA for this building requires a rigorous and disciplined process that begins with a complete understanding of the fire strategy. Before assessing any aspect of the building, the fire risk assessor must read this strategy in full and be able to clearly articulate the reasoning behind each of the limitations imposed, particularly those governing fuel load and fire growth ((see Sections 5.1 and 5.1.1), which are central to preventing the identified failure mechanisms. Without this understanding, the assessor cannot meaningfully judge whether the building continues to operate within the design envelope.

The FRA must treat the management controls set out in Sections 5 as primary life-safety provisions. These include limitations on fuel load and arrangement, preservation of the ventilation geometry, protection against ignition of mass timber, restrictions on combustibles near façade openings, and maintenance of the green wall. These items are not operational preferences; they are engineered boundary conditions. The FRA must therefore verify them systematically during every assessment.

The assessor must then review all relevant management information, including procurement records, commissioning certificates, testing reports, and maintenance documentation. This is essential for verifying three things:

- That the correct systems were installed, as required by the strategy.
- That they were installed correctly, in accordance with manufacturer guidance.
- That they have been subject to appropriate inspection and maintenance, ensuring reliability and availability in line with the assumptions underpinning the fire-engineering calculations.

A physical inspection of the building is mandatory. The assessor must visit every floor to confirm that the fuel load is being managed as required, both in quantity and spatial distribution. This includes verifying compliance with limits on furniture, storage, combustibles near timber, and the condition and irrigation of green walls. Any deviation in fuel management directly affects the probability of flashover, ignition of exposed timber, and fire spread beyond the floor of origin, and therefore must be identified immediately.

The FRA must also include a review of operational performance. The assessor should examine records of evacuation drills and training exercises to ensure that staff understand their duties under all expected

use scenarios and can execute them confidently in practice. This includes familiarity with evacuation lifts, wayfinding and signage, and procedures for assisting visitors, PRMs, or large crowds.

Another key responsibility is to assess whether previous FRA actions and recommendations have been closed out effectively. Unresolved actions may represent systemic weaknesses or indicate persistent management drift.

The assessor must also verify that management has engaged appropriately with the fire service, that the fire service is aware of the building's unique challenges, and that the information the strategy relies upon, including occupancy data, access arrangements, and system interfaces, remains accurate and readily available during an emergency.

Ultimately, carrying out the FRA means confirming not just that hazards are controlled, but that the building is still operating on the assumptions used to design it. Any deviation from those assumptions must be documented and evaluated, and where deviations exceed tolerances, the assessor must recommend a review of the fire strategy by a competent fire engineer before the FRA can be considered complete.

## 6.2 Review of the fire strategy

The fire strategy for this building is only valid as long as the assumptions, dependencies, and limitations established during design remain true in practice. The FRA must therefore identify any circumstance under which the strategy may no longer represent the real behaviour of the building. When such circumstances arise, the fire strategy must be formally reviewed and, where necessary, redrafted by a competent fire engineer.

The following events constitute explicit triggers for such a review:

- Changes in use or occupancy: Any modification to how spaces are used, the number of people occupying them, or the characteristics of those occupants may invalidate key assumptions regarding egress times, fuel load, and fire growth. A change of use (e.g., converting office space into exhibition or storage areas) must always be treated as a trigger for reassessment.
- Changes to occupancy levels or patterns: Increases in maximum occupancy, new crowd-forming activities, or the introduction of vulnerable populations alter evacuation performance and may move the building outside the design envelope. These changes require a re-evaluation of untenable-condition timelines and egress capacity.
- Replacement, alteration, or degradation of fire-critical systems: If systems such as detection, alarms, AOVs, automatic opening windows or louvres, dry risers or evacuation lifts are replaced with products that do not meet the required specifications, or if existing systems deteriorate such that their reliability and availability no longer align with assumptions, the strategy must be revisited.
- Deviations in fuel load or its distribution: If the quantity, type, or arrangement of fuel in any space no longer matches the limits defined in the strategy, the fire growth calculations, flashover assumptions, and the expected suppression conditions may no longer be valid. This includes changes to furniture, storage practices, green-wall maintenance, or added combustibles near mass-timber elements.
- Observations indicating that underlying design assumptions are incorrect: If the FRA identifies operational realities that contradict the design assumptions (e.g., egress routes frequently obstructed, staff not meeting expected evacuation performance, green walls not maintained, or ventilation behaving differently than predicted), the strategy must be reviewed to determine whether its premises still hold.
- Introduction of new building features or penetrations: New partitions, openings, services, enclosures, or alterations to the building geometry may change compartmentation performance, smoke movement, or structural fire exposure. Any such modification must be evaluated against the strategy assumptions.
- Emerging research, updated standards, or authoritative guidance: If new evidence or guidance challenges the validity of assumptions used in the design, particularly regarding mass-timber

ignition, fuel-load modelling, smoke movement, or human-behaviour characteristics, the strategy must be reconsidered in light of the updated understanding.

- Repeated or unresolved findings from previous FRAs: If persistent deficiencies are identified, or if multiple FRAs highlight the same unmanaged risks, this may indicate systemic failure of the strategy's management dependencies and therefore requires reassessment.
- Requests or observations from the fire service: If the fire service expresses concern about access conditions, system reliability, or the practicality of suppression tactics based on their understanding of the building, this constitutes a trigger for review.
- Any change affecting façade openings, the lightwell, the size or continuity of voids, or any element that modifies natural ventilation patterns. Because the fire strategy depends on fixed geometrical and ventilation assumptions to constrain fire growth and smoke movement, such changes cannot be treated as minor works and must prompt formal review.

## 7 Fire service

The fire service plays a limited role within this fire strategy. The design has been developed to meet all fire-safety goals without requiring intervention by the fire service, ensuring that life safety, protection of the existing structure, and the containment of the fire to a single floor are achieved through the building's own performance and management controls. The fire service is therefore treated as a redundancy rather than a primary component of the strategy, consistent with performance-based design principles and the expectation that the building must perform safely under foreseeable conditions before responders arrive.

While intervention is not relied upon for life safety, it is recognised that the fire service may still choose to enter the building to suppress the fire or support evacuation. For this reason, the building incorporates features intended to enable safe and effective responder operations so long as the fire remains within the engineered performance envelope (see Section 8). These provisions include protected stair shafts, access lobbies, evacuation lifts, dry risers, emergency lighting, and clear access routes throughout the building. These measures support safe entry and establish predictable operational conditions under the assumption that the fire remains confined to a single floor and that neither the exposed mass timber nor the external green wall become involved in the fire.

### 7.1 Expectations on the fire service

Under design conditions, the fire service is expected to encounter a controlled, single-floor fire with clear access via protected stair shafts and predictable internal smoke behaviour. Their early priority is expected to be verification: confirming that the fire is behaving within the limits defined by the strategy, including the absence of ignition in the mass-timber structure and the external green wall. If these assumptions hold, responders should be able to advance safely to the fire floor, operate from protected lobbies, and apply water from the dry riser to suppress the fire. Evacuation should be nearly complete by the time the fire service arrives, with all occupants from the fire floor clear and only residual flow in the stairs from upper floors.

If responders observe conditions outside the engineered assumptions, such as flame spread to upper storeys, ignition of timber elements, involvement of the green wall, or failure of the protected stairs to remain tenable, this must be treated as an indication that the building is no longer operating within its designed performance envelope. In such cases, internal intervention becomes significantly more hazardous, and operations should shift toward safeguarding life, assisting with any remaining evacuation, and preventing external fire spread by attacking the fire externally via the open elevations. Responders must recognise that structural behaviour, smoke movement, and compartment conditions may be unpredictable once these failure indicators are present and should adjust tactics accordingly. Further information is provided in Section 8.

### 7.2 Assumed fire service response

The strategy assumes that the fire service will arrive during or shortly after the completion of evacuation from the floor of fire origin. Their response is expected to follow standard operational procedures for a single-floor fire: staging at the building entrance, verifying building management information, accessing the nearest protected stair, and preparing hose lines using the dry riser to enter the fire floor. The design anticipates that responders may also activate a simultaneous building-wide evacuation if appropriate once they arrive, using the building's alarm controls.

If conditions remain within the design assumptions, the fire service can conduct interior attack operations from protected positions, using the stair-head AOV to manage any smoke introduced into the stair during hose deployment. Their actions at this stage serve primarily as a final layer of redundancy, reinforcing the building's performance rather than compensating for its failure.

If, however, responders encounter flashover, multi-storey involvement, ignition of structural timber, or compromised protected stairs, they should adopt defensive tactics. In such cases, the priority becomes life safety: locating any remaining occupants, assisting with final evacuation, and controlling the fire from the exterior to limit further spread. These conditions indicate a failure of one or more design assumptions, and the fire service must recognise that the building can no longer be approached as a predictable, single-floor event.

## 8 Failure of the fire strategy

A core principle of this performance-based fire strategy is the explicit identification of the fundamental failure mechanisms that could prevent the building from achieving its fire-safety goals. The strategy has therefore been developed with specific design, operational, and management provisions that prevent each failure mechanism from being reached. These provisions, limits on fuel load, controls on spatial arrangement, assumptions on ventilation, reliance on early detection, and preservation of compartmentation, are all intended to ensure that the building remains within the engineered fire envelope.

However, the prevention of failure depends on assumptions that may be violated during the building's life. As highlighted in the design-for-failure methodology, safety depends not only on the initial design but also on the continued accuracy of its assumptions, the integrity of its dependencies, and the discipline of its management practices. When any of these degrade, the building may transition into conditions that were never intended in the engineered design. This section therefore describes what occurs if a failure mechanism is reached, how such a failure may arise, and the consequences for the building's ability to meet its fire-safety goals.

In the subsections that follow, each failure mechanism is considered individually. For each, we describe how the failure may arise and what would be the expected consequences. This ensures that both building management and the fire service understand the significance of each mechanism, why its prevention is essential, and what conditions indicate that the building has moved beyond its engineered fire-safety limits.

### 8.1 Failure mechanism 1: untenable conditions during egress

If this failure mechanism occurs, the fire grows faster than expected and conditions on the floor of fire origin deteriorate before all occupants can escape. This may lead to delayed or incomplete evacuation, with some people becoming trapped or requiring rescue. In most cases, the impact would be limited to occupants on the floor of fire origin, but if the stairs become compromised, the failure can extend to occupants elsewhere in the building. Once this occurs, the fire service becomes the primary means of life safety, as the strategy can no longer guarantee safe, independent evacuation.

This type of failure typically arises when the assumptions controlling fire growth are violated. Changes in use, increased or different fuel loads, or the introduction of combustible storage can all produce faster-growing fires or larger quantities of smoke. Stacking combustible items, introducing new furniture types, or allowing fuels to accumulate near ignition sources can shift fire behaviour beyond the limits assumed in the design. On timber floors, early ignition of the exposed timber ceiling due to excess fuel or proximity of combustibles can drastically accelerate conditions. Similarly, placing combustible materials in stair enclosures can allow smoke or fire to compromise the protected route, directly undermining the conditions required to maintain  $ASET > RSET$ .

## 8.2 Failure mechanism 2: structural failure

If this failure mechanism occurs, the thermal conditions within the fire compartment exceed those assumed in the strategy, potentially leading to localised or general structural compromise. Given that the existing concrete and masonry structure was designed to remain outside flashover-level heating, or excessive temperatures, the most visible indicator of this failure will be the onset of flashover or localised element failure. At that point, temperatures and heat fluxes may rise above the limits required to protect structural stability. By the time this occurs, all occupants on the floor of fire origin should already have evacuated, and occupants elsewhere should be close to completing their evacuation. However, once flashover occurs or localised failure commences, internal fire-service intervention carries increased risk, and efforts may need to shift to supporting evacuation and preventing fire spread from the exterior of the building. Although the stairs are expected to maintain protection, conditions within the fire floor will be far outside the engineered design envelope.

This failure typically arises when fire growth exceeds the limits assumed in the strategy. Such an increase may stem from changes in building use, the introduction of additional or more combustible fuels, or the accumulation of fuel packages in patterns that allow larger or faster-growing fires. Increased fuel loads can also generate more severe plume temperatures or radiant heat fluxes, which may push the compartment closer to flashover conditions. While assumptions in the strategy are conservative, once fuel loads or spatial arrangements exceed those limits, the ability of the strategy to prevent structural failure no longer exists.

## 8.3 Failure mechanism 3: contribution of timber to the fire

If this failure mechanism occurs, the exposed timber begins to participate in the fire, either through direct ignition or through heat-induced delamination of the first lamellae. Ignition is the clearest indicator of failure, as flames spreading across the ceiling significantly increase the heat release rate and change the fire dynamics from a fuel-controlled event to one driven partly by the building fabric itself. Heat-induced delamination is harder to detect during an emergency, but it similarly increases burning surface area and can cause sudden changes in fire intensity. Because the strategy treats the building as a non-combustible structure, any contribution of timber to the fire undermines the ability to meet multiple goals by accelerating fire growth, reducing available egress time, and increasing the risk of vertical fire spread. While self-extinction might be possible in low fuel-load conditions, this has not been demonstrated and cannot be relied upon operationally.

This failure usually arises when the assumptions limiting thermal exposure to the timber are violated. Increased or redistributed fuel loads can raise plume temperatures and radiant flux to ignition-capable levels. More commonly, failure could be triggered by the stacking or placement of combustible items directly beneath the exposed timber, creating ladder-fuel conditions that allow flames to impinge on the ceiling earlier than predicted. Any such change enables faster heating of the timber surface and increases the likelihood of delamination. Effective management of fuel arrangement, particularly in areas with exposed timber, is therefore essential to prevent this failure mechanism.

## 8.4 Failure mechanism 4: fire spread beyond compartment of origin

If this failure mechanism occurs, fire extends beyond the floor of fire origin, either through ignition of the external wall system or through flames appearing on multiple storeys via the façade or internal void. This compromises evacuation, structural stability, and the fire service's ability to operate within safe and predictable conditions. The presence of fire on more than one floor is a clear indication to the fire service that the building has exceeded its engineered performance envelope. At that point, internal intervention becomes significantly riskier, and operations should shift toward protecting life, assisting evacuation, and controlling the fire externally. Because the strategy is explicitly built on containing fire to a single floor, any multi-storey fire spread means that the assumptions on which all goals and objectives rest are no longer valid.

This failure typically occurs when compartmentation or façade performance no longer behaves as intended. Poor maintenance of the external wall, improper installation or deterioration of fire stopping, or unapproved modifications to the building can create pathways that allow flames or hot gases to breach floor separations. Fire spread may also result from fuel being stored too close to façade openings or the internal void, allowing flames to project upward and ignite elements on higher levels. In all these cases, the strategy's dependence on preventing ignition in adjacent spaces is violated, and the building transitions from a controlled, single-floor event to a condition that cannot be managed through the simple, engineered limits on which the design is based.

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## Appendix A Untenable conditions for egress

The content in this section is based on the following chapters of the SFPE Handbook of Fire Protection Engineering [2]:

- Chapter 56, which outlines the core components of egress design, detection, notification, pre-movement, travel and flow, and how they combine to determine RSET.
- Chapter 58, which explains key human behaviour factors, especially recognition and response delays that shape pre-evacuation time
- Chapter 59, which presents the hydraulic model for estimating movement speeds, bottlenecks and flow, forming the basis for travel and congestion time calculations.

### A.1 ASET vs RSET

In performance-based fire safety engineering, the fundamental life-safety requirement is that the Available Safe Egress Time (ASET) exceeds the Required Safe Egress Time (RSET). This principle underpins the methodology adopted in the SFPE Handbook and is fully acknowledged in this strategy, demonstrating that occupants can evacuate before conditions become untenable.

However, at this stage of design, an explicit numerical calculation of ASET has not been carried out. This is a deliberate and reasoned engineering decision rather than an omission. The authors' judgement is that, given the current level of design definition, any calculated ASET value would be highly sensitive to assumptions that are not yet fixed and would therefore risk being misleading and inappropriate.

ASET depends fundamentally on the development of untenable conditions, which in turn are governed by factors such as fire size and growth, fuel characteristics and arrangement, enclosure geometry, ventilation conditions, and the interaction between smoke movement and the means of egress. In this case study, several of these parameters remain intentionally undefined at concept stage. The building comprises large, open, cross-ventilated spaces with significant façade openings and a central lightwell. Under such conditions, commonly used ASET proxies, such as smoke layer height or uniform smoke filling times, are not physically representative. Calculating a smoke layer descent time in a space that is not expected to stratify in a conventional manner would give a number that appears rigorous but does not reflect the actual behaviour of the space.

More sophisticated approaches, such as Computation Fluid Dynamics (CFD) modelling of smoke movement, would imply a degree of certainty about the final geometry, ventilation openings, wind effects, fuel package characteristics, and fire location that does not yet exist. Similarly, radiation-based tenability checks near exits would require assumptions about the precise location of fires, exits, and occupant movement patterns that would be arbitrary at this stage. In all such cases, the resulting ASET would be a function of the modeller's assumptions rather than a reliable representation of safety, creating an artificial margin that could be mistaken for robustness.

Rather than producing a numerically precise but conceptually fragile ASET, this strategy adopts an alternative, first-principles approach that is consistent with the design-for-failure philosophy set out in Section 2. The fire is constrained so that the mechanisms that typically drive ASET reduction are explicitly prevented. This includes limiting fire growth through fuel-load control; preventing fire spread beyond the floor of origin; protecting the stairs with fire-resisting lobbies and treating them as places of safety; ensuring that stair capacity exceeds demand; and excluding combustible fuel in critical zones adjacent to the means of escape. Under these conditions, untenable conditions are not expected to develop in the egress system during the evacuation period, and ASET is therefore expected to remain comfortably greater than RSET.

This approach does not diminish the importance of ASET. On the contrary, it reflects the authors' view that ASET should only be quantified when the physical conditions that govern it are sufficiently well defined for the result to be meaningful. At later stages of design, once geometry, ventilation, fuel characteristics, and management arrangements are fixed, an explicit ASET assessment may be both

appropriate and necessary. At the current concept stage, however, providing a single ASET value would risk conveying a level of certainty that is not justified and would detract from the clarity of the underlying engineering assumptions.

Accordingly, this appendix focuses on a transparent calculation of RSET and on identifying, qualitatively and quantitatively, the mechanisms that could compromise evacuation performance. These mechanisms are then addressed directly through design constraints and management requirements, ensuring that life safety is demonstrated through robust control of fire behaviour rather than through the presentation of a misleading numerical margin.

## A.2 Occupancy numbers

The total occupancy for the building is estimated to confirm whether the means of escape are suitably sized and to determine permissible fire loads which will not adversely impact the evacuation.

Table 5 Estimated occupancy numbers

Floor	Use	Area (m <sup>2</sup> ) (Note 1)	Density (m <sup>2</sup> /pers.)	Occupancy (pers.)
Roof	Rooftop terrace	518	-	920 / 500
Level 4	Diplomatic function / public access	1421	-	
Level 3	Office	1373	6.0 (Note 2)	228
Level 2	Office	1486	6.0 (Note 2)	248
Level 1	Gallery	1867	2.0 (Note 2)	934
Ground level	Conference room	300	1.0	300
	Public access	1467	2.0	734
<b>Total:</b>				<b>3364</b>
<b>Note 1: The occupancy is based on the total floor area excluding any obstructions such as stairs, lifts, corridors and lightwell openings.</b>				
<b>Note 2: Office occupant densities are generally specified as 10m<sup>2</sup>/person (US), 9m<sup>2</sup>/person (AU) or 6m<sup>2</sup>/person (UK). The most conservative number has been adopted for increased flexibility.</b>				

In accordance with the project brief, Level 4 has been designed to accommodate up to 920 persons consisting of 800 guests and 120 staff for diplomatic functions. Alternatively, it may accommodate up to 500 persons when open to access for the public. The ground floor will also contain a conference room which will sit up to 300 persons.

The occupant numbers in all other areas were determined based on floor space factors adopted from International Guidance or the Fire Engineering Design Guide [16].

### A.3 Required safe egress time (RSET) calculation

#### A.3.1 Introduction

The RSET calculation is based on a first order, simplified hydraulic model as explained in Chapter 59 of SFPE Handbook [2].

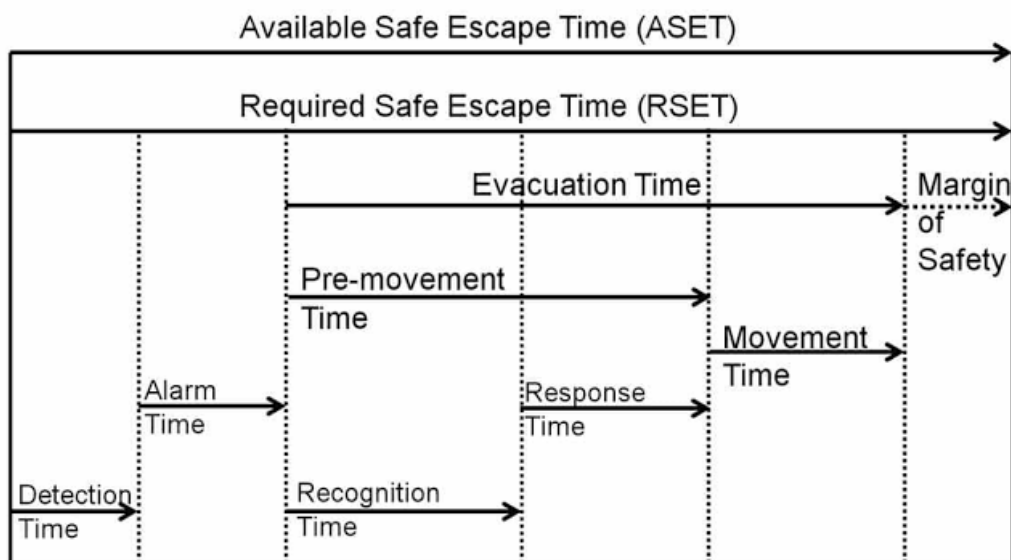


Figure 11 Diagram representing RSET components

This can also be characterised by equation below:

$$RSET = t_d + t_n + t_{p-e} + t_e \quad \text{Equation 1}$$

where:

$t_d$  = Time from fire ignition to detection; that is, the detection phase

$t_n$  = Time from detection to notification of occupants of a fire emergency; that is, the notification phase

$t_{p-e}$  = Time from notification (or cue reception) until evacuation commences; that is, the pre-evacuation phase

$t_e$  = Time from the start of purposive evacuation movement until safety is reached; that is, the evacuation phase

The RSET can be reduced into two sets of components: the phase prior to evacuee involvement, made up of  $t_d$  and  $t_n$ , and the escape phase ( $t_{esc}$ ) where:

$$t_{esc} = t_{p-e} + t_e \quad \text{Equation 2}$$

There are two scenarios to be considered for the escape phase,  $t_{esc}$ . The first scenario considers a congestion dominant evacuation, where a significant proportion of time is composed of the flow time for occupants to pass through the exits. This can be calculated as:

$$t_{esc} = t_{p-e1} + t_{trav} + t_{flow} \quad \text{Equation 3}$$

where:

$t_{p-e1}$  = The pre-evacuation time associated with the first people to respond

$t_{trav}$  = The time taken to traverse the average distance to a place of safety.

$t_{flow}$  = The time of total occupant population to flow through the most restrictive components

The second scenario is to consider a situation where the evacuation is dominated by the time required for the last remaining occupants to leave and their walking time to the exits. In this instance, the occupant density will be low and walking to exits is expected to be unimpeded with no congestion at the exits. This is calculated using:

$$t_{esc} = t_{p-e99} + t_{trav} \quad \text{Equation 4}$$

where:

$t_{p-e99}$  = The pre-evacuation time for the last few occupants to respond

Of the two calculated scenarios, the one with the longest evacuation time will be adopted for calculating the final RSET.

### A.3.2 Estimating RSET

The RSET will be calculated for each floor based on the horizontal egress time only, this is based on the assumption that the staircases remain a place of safety. This assumption, that both staircases remain available, forms an essential part of the evacuation strategy. It is therefore mirrored in the management and Fire Risk Assessment (FRA) sections (Section 5 and 6), which explicitly require both protected lobbies and both stair enclosures to remain operational and unobstructed at all times.

The different components of the RSET and assumptions for each value are further discussed in the following sections.

### A.3.3 Detection time

It is expected that the building will be provided with smoke detectors according to the local code. To determine detection time for a smoke detector, a large number of factors must be evaluated. These include smoke aerosol characteristics, aerosol transport, detector aerodynamics, and sensor response.

For the purpose of this assessment, a simplified method has been adopted whereby the smoke detection time is estimated based on the required fire size at detection,  $\dot{Q}_{cr}$ . The  $\dot{Q}_{cr}$  can be calculated based on the relationship of stratification effects in the detection of low-energy fires and fires in rooms or volumes with very high ceilings:

$$\dot{Q}_{cr} > 0.352H^{5/2}T^{3/2} \quad \text{Equation 5}$$

where:

$\dot{Q}_{cr}$  = Required fire size at detection, which can be taken as convective heat release rate in W

$H$  = Distance from the top of the fuel package (base of the fire) to the ceiling level in m

$T$  = Difference in ambient gas temperature in °C between the fuel location and ceiling level

Given the climate and ventilation conditions of the building,  $T$  is not expected to be greater than 10 °C between the floor and ceiling. For the greatest storey height of 5 m on the ground floor, the  $\dot{Q}_{cr}$  is determined to be 622 W. This is equivalent to a total heat release rate of 900 W, considering a convective factor of 0.7.

With a medium fire growth rate of  $0.012 \text{ kW/s}^2$ , the estimated time to reach a fire size of 900 W is around 9 seconds. For conservatism, the detection time has been taken as 30 s universally across the building.

### **A.3.4 Notification time**

Notification time is assumed to be zero, whereby the detection of a fire will immediately raise a fire alarm to the entire floor via the emergency voice/alarm communication systems.

### **A.3.5 Pre-evacuation time**

Pre-evacuation time distributions depend primarily upon the behavioural scenario and the fire safety management level, with some effect from building complexity. Data on pre-evacuation time distributions for a range of occupancies are available from Chapter 64, Table 64.4 of the SFPE Handbook, which were derived from major studies.

However, as PD 7974-6:2019 has discussed, there are significant factors that might have affected how these data were collected, the user has to exercise judgement in the use of pre-evacuation times reported in the table.

As an alternative, Table E.2 of PD 7974-6 [17] has been adopted as it provides generic pre-evacuation activity time data that have been summarised from the data reported in Table 64.4 of the SFPE Handbook. The behavioural scenario categories expected fire safety management level and building complexity of each floor is tabulated in Table 6.

Table 6 Pre-evacuation times for each floor

Floor level	Behavioural scenario	Fire safety management level (Note 1)	Building complexity (Note 2)	$t_{p-e1}$ (seconds)	$t_{p-e99}$ (seconds)
Level 4 / Roof	Awake and unfamiliar	M2	B2	90	270
Level 3	Awake and familiar	M2	B2	60	180
Level 2	Awake and familiar	M2	B2	60	180
Level 1	Awake and unfamiliar	M2	B2	90	270
Ground level	Awake and unfamiliar	M2	B2	90	270

**Note 1:** A management level M2 expects the normal occupants to be trained to a high level of fire safety management with good fire prevention and maintenance practice, a well-developed emergency plan and regular drills. It is also expected that it has a lower staff ratio and floor wardens might not always be present.  
**Note 2:** Building complexity level B2 is appropriate as it represents a simple multi-storey with simple internal layouts.

### A.3.6 Travel time

The travel time is the time taken for an occupant to traverse the average distance to an exit. For conservatism, the maximum direct travel distance to the stair exit has been taken, along with an unimpeded walking speed of 1.2 m/s. The travel time for each floor is calculated in Table A.1.

Table A.1 Travel time for each floor

Floor level	Maximum travel distance	$t_{trav}$ (seconds)
Level 4 / Roof	42.3 m	35
Level 3	23.7 m	20
Level 2	23.7 m	20
Level 1	27.9 m	24
Ground level	44.2 m	37

### A.3.7 Flow time

The stairs are considered the most restrictive components of the exits (e.g., two stairs vs. four storey exits per floor). As such, the flow times for each upper floor have been determined based on two no. of 1800 mm stair width and a boundary layer deduction of 150 mm per side, with a flow rate of 0.94 persons/m/s down the staircase (the worst-case flow rate in Table 59.5 of SFPE handbook).

None of the staircases have been discounted in calculating the flow time, this is on the basis that both stairs have been provided with a protected lobby. Each protected lobby has two separate entrances from the floor plate.

For ground floor, it has been assumed that at least 4 no. of final exits will be available to escape onto street level. The flow time has been determined based on three no. of 1500 mm exit widths (assuming one is discounted due to fire) and a boundary layer deduction of 150 mm per side, with a flow rate of 1.3 persons/m/s.

The flow time for each floor is calculated in Table A.2.

*Table A.2 Flow time for each floor*

<b>Floor level</b>	<b>Occupancy</b>	<b>Available exits</b>	<b>Specific flow (persons/m/s)</b>	<b><math>t_{flow}</math> (seconds)</b>
Level 4 / Roof	920	2 × 1800 mm stairs	0.94	327
Level 3	228	2 × 1800 mm stairs	0.94	81
Level 2	248	2 × 1800 mm stairs	0.94	88
Level 1	934	2 × 1800 mm stairs	0.94	331
Ground level	1034	3 × 1500 mm doors	1.3	221

### A.3.8 Calculating the final RSET

Based on sections A.3.3 to A.3.7, the RSET can be calculated by adding all the time components discussed. The total RSET for each floor is documented in Table A.3.

Table A.3 Calculated RSET for each floor

Floor level	Detection time, $t_d$ (seconds)	Notification time, $t_n$ (seconds)	1 <sup>st</sup> percentile pre-evac time, $t_{p-e1}$ (seconds)	99 <sup>th</sup> percentile pre-evac time, $t_{p-e99}$ (seconds)	Travel time, $t_{trav}$ (seconds)	Flow time, $t_{flow}$ (seconds)	RSET (seconds)
Level 4 / Roof	30	0	90	270	35	327	482
Level 3	30	0	60	180	20	81	230
Level 2	30	0	60	180	20	88	230
Level 1	30	0	90	270	24	331	475
Ground level	30	0	90	270	37	221	378

## Appendix B Structural failure

The content in this section is based on the following chapters of the SFPE Handbook [2].

- Chapter 30, which summarises methods to quantify the evolution of the fire behaviour in a compartment.

### B.1 Flashover

Flashover is defined as the transition from a growing fire to a fully developed fire, in which the entire volume of contents within a compartment is involved. It is generally characterised by a radiation at which all combustibles within a room will ignite and is often accompanied by temperatures ranging between 300-600 °C.

**Fig. 30.1** General description of room fire in absence of fire control

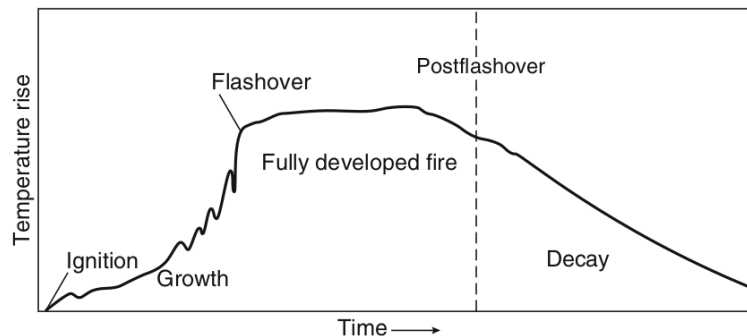


Figure 12 Representation of compartment fire curve (reproduced from Figure 30.1 of [2])

However, traditional compartment design fires assumed in fire engineering are based on observations of fire dynamics from relatively small experimental compartments, less than 100m<sup>2</sup> in area. The Eurocode EN 1991-1-2 limits the use of parametric fire curves in compartments with an area up to 500 m<sup>2</sup>.

Each floor of the building is designed with a generally open-plan layout, incorporating a minimal number of partitions across the floorplate. Large openings are provided at the front and rear elevations of the existing structure, as well as on all elevations of the proposed new storeys to permit cross-flow ventilation. Considering the very large compartment dimensions (floor areas ranging between 450-1,860m<sup>2</sup>), relatively low fire load densities and open-sided nature, a flashover fire is highly unlikely to occur.

The ground floor meeting room will be open to the wider ground floor areas, as discussed in Section 3.3. Therefore, a flashover fire is considered unlikely.

Notwithstanding the above, a calculation was carried out to determine the required heat release rate in different areas of the building for flashover to occur, using Thomas' equation, reproduced in Equation 6 below.

$$\dot{Q} = 7.8A_T + 378A_o\sqrt{H_o} \quad \text{Equation 6 (30.75 in [2])}$$

Where  $Q'$  is the heat release rate (kW),  $A_T$  is the area of all exposed surfaces ( $m^2$ ),  $A_0$  is the area of the openings ( $m^2$ ) and  $H_0$  is the height of the openings (m).

Table 7 Required HRR for flashover to occur

Floor	Use	Compartment height (m)	Exposed area ( $m^2$ )	Opening area ( $m^2$ )	Heat release rate (kW)
Level 4	Function space	3.6	1,191	182.7 (Note 1)	140,323
Level 3	Office	3.6	3,176.9	530.8 (Note 2)	405,463
Level 2	Office	3.6	3,355.9	419.3 (Note 2)	326,920
Level 1	Gallery	3.8	4,523.5	125.8 (Note 3)	127,964
Ground level	Display space	4.8	4,797.7	33.1 (Note 3)	64,834

Note 1: 50% of external elevations assumed to be open.  
 Note 2: 70% of elevations including lightwell assumed to be open.  
 Note 3: 50% of front and rear elevations assumed to be open.

The results indicate that very large, unrealistic heat release rates would be required, therefore flashover is unlikely to occur. However, further consideration should be given to other design fire models such as travelling fires or localised fires and how they may impact the structure.

## B.2 Travelling fires

Buildings with large compartments are generally less susceptible to flashover fires but may be prone to alternative fires behaviours where parts of the compartment do not burn simultaneously. Travelling fires are fires which are characterised by a movement across the floorplate as the flames spread, burning over a limited area at any one time.

Therefore, a separate assessment was conducted for the existing ground and first floor levels to estimate the maximum temperatures expected at ceiling levels and to evaluate how these conditions may impact the structure.

The methodology developed by Stern-Gottfried and Rein [4], [5] was adopted to define the travelling fire behaviour.

The fire-induced thermal field is divided into two regions, namely the near field and the far field, represented in Figure 13.

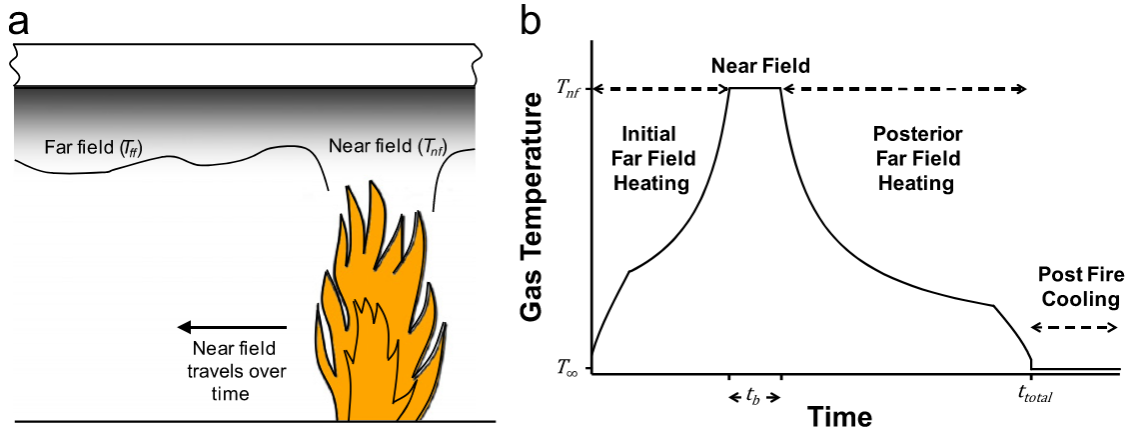


Figure 13 – (a) Illustration of a travelling fire and (b) Near field and far field exposure at an arbitrary point within the compartment (reproduced from [5])

Burning regions of the compartment tend to range between 5% and 25% of the compartment floor areas, however, some of the most severe conditions for concrete reinforcement were observed to be travelling fires accounting for 10% of the floor, which has been adopted in this study.

The fire model assumes a uniform fuel load across the fire path that will burn at a constant heat release rate  $\dot{Q}$  for a local burning time  $t_b$ , determined by Equation 8.

$$\dot{Q} = A_f \dot{Q}'' \quad \text{Equation 7 (1 in [5])}$$

$$t_b = \frac{q_f}{\dot{Q}''} \quad \text{Equation 8 (2 in [5])}$$

where:

$\dot{Q}$  = Total heat release rate in kW

$A_f$  = is the floor area of the fire in m<sup>2</sup>

$t_b$  = burning duration at one location in s

$\dot{Q}''$  = the heat release rate per unit area in kW/m<sup>2</sup>

$q_f$  = the fuel load density in MJ/m<sup>2</sup>

A HRRPUA of 400 kW/m<sup>2</sup> was adopted, for the ground and first floor levels.

The near field temperature assumes that the structure is in direct contact with the flames, therefore peak flame temperatures have been adopted. Various measurements indicate that in case of small fires these range between 800-1000°C and up to 1200°C in large fires. However, in other relevant studies on travelling fires significantly lower flame temperatures were observed at ceiling level ranging between 400-500 °C [18]. Considering the controlled fire load expected in the gallery and display space, a reduced near field temperature of 500°C was adopted in this study. The far field temperatures are calculated based on Alpert's ceiling jet plume from Equation 9 where the far field is characterised by Equation 10 below.

$$T_{max} - T_{\infty} = 5.38 \frac{(\dot{Q}/r)^{2/3}}{H} \quad \text{Equation 9 (4 in [5])}$$

$$r/H > 0.18 \quad \text{Equation 10}$$

where:

$T_{max}$  = maximum ceiling jet temperature in °C

$T_{\infty}$  = ambient temperature in °C  
 $r$  = the distance from the centre of the fire in m  
 $H$  = the floor ceiling height in m

The far-field temperature is assumed to be uniform along the width of the building, but varies across its length. The fire is assumed to travel at a constant spread rate, determined by Equation 11.

$$s = \frac{L_f}{t_b} \quad \text{Equation 11 (5 in [5])}$$

Where:

$s$  = the spread rate in m/s  
 $L_f$  = length of the fire in m

By separating the building length into multiple nodes, each with a fixed width of 1m, the fire location can be tracked throughout the building. The distance from the fire starting point (far-left of the floorplan) and a specific node, and the fire movement time step are calculated based on Equation 12 and Equation 13 respectively.

$$x_i = (i - 0.5)\Delta x \quad \text{Equation 12 (6 in [5])}$$

$$\Delta t^* = \frac{\Delta x}{s} \quad \text{Equation 13 (7 in [5])}$$

Where:

$x_i$  = the position relative to the end of the structure in m  
 $x$  = the grid size in m

The time the fire spends at one node location is equal to the sum of travel time across one node plus one burning time and can be calculated using Equation 14.

$$t_i = \frac{\Delta x}{s} + t_b \quad \text{Equation 14 (8 in [5])}$$

The total burning duration can then be determined by Equation 15.

$$t_{total} = t_b \left( \frac{L - \Delta x}{L_f} + 1 \right) \quad \text{Equation 15 (9 in [5])}$$

The parameters adopted for each compartment assessed are summarised in *Table 8*. The resulting time-temperature curves for the individual fire scenarios are reproduced in Figure 14 and Figure 15.

Different fire load densities have been assessed with the largest being 300 MJ/m<sup>2</sup>. For context, the SFPE Handbook indicates 285 MJ/m<sup>2</sup> as typical for classrooms.

*Table 8 Compartment characteristics for travelling fires*

Floor	Use	Compartment height (m)	Fire load density (MJ/m <sup>2</sup> )	Burning region (m <sup>2</sup> )	Fire spread rate (mm/s)	Total burning time (min)
Level 1	Gallery	3.8	300	204	8.0	135.4
Ground level	Display space	4.8	300	204	8.0	135.4

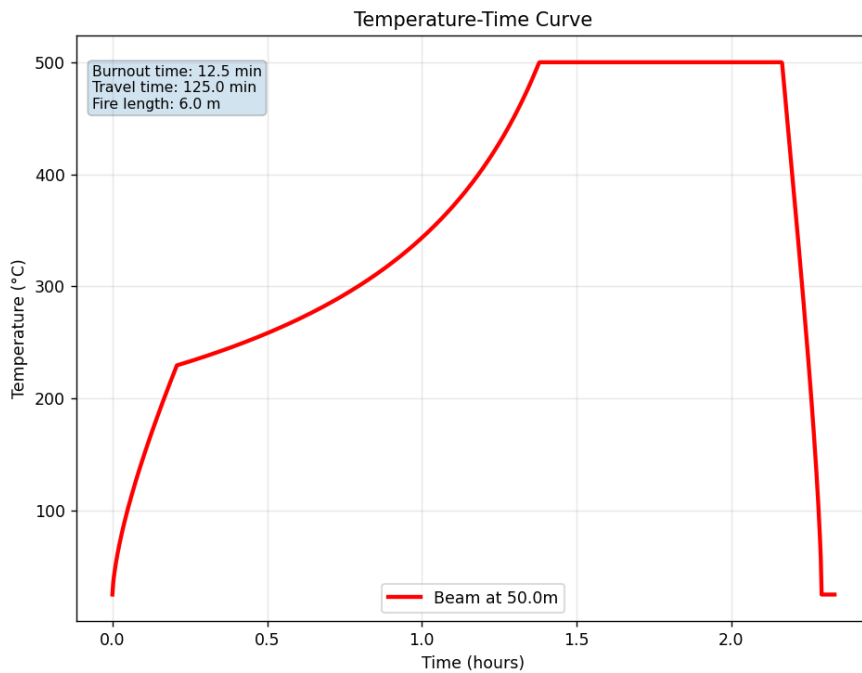


Figure 14 Travelling fire time-temperature curve in first floor gallery space (beam located at 50m)

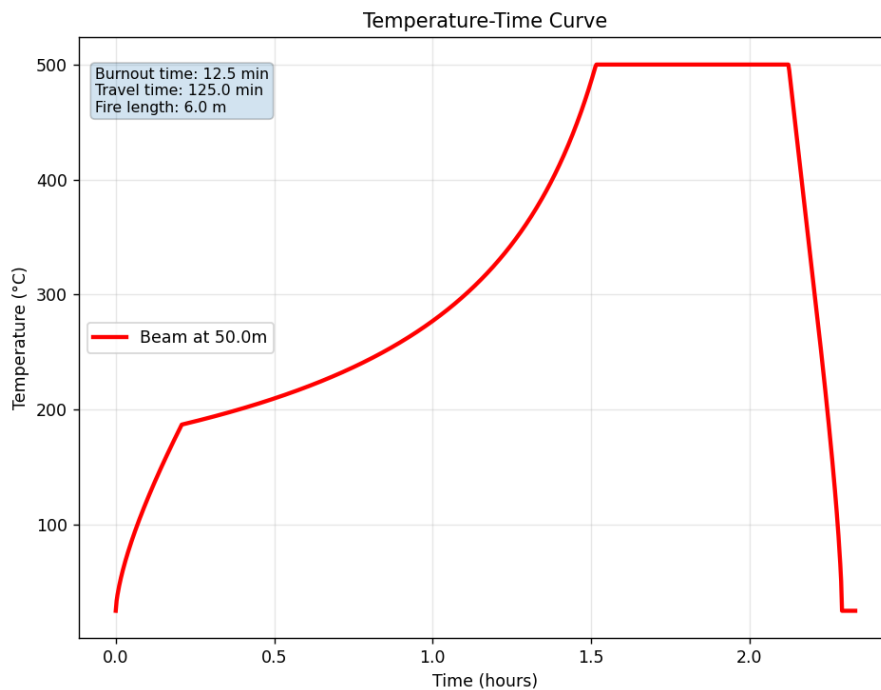


Figure 15 Travelling fire time-temperature curve in ground floor display space (beam located at 50m)

Several locations were analysed to determine which would result in the largest temperature increase in the beam/slab reinforcement. As discussed in the following section, elements located in the furthest bays (e.g. 50m from the starting location of the fire) were observed to reach the highest internal temperatures.

### B.3 Maximum concrete temperatures

In accordance with the project brief, the existing concrete structure is expected to provide adequate loadbearing capacity during normal use. However, there is no information regarding the structural fire resistance rating likely to be achieved.

This section of the report aims to establish whether the proposed fire loading would adversely impact the existing concrete structure. Due to time constraints, sections of the reinforced concrete slab have been assessed based on the temperature-time curves that determined in the previous section of this appendix. Similar calculations should be conducted for individual beam or column structural elements and the existing masonry walls.

As the existing construction detailing is unknown, several key assumptions have been made, summarised in *Table 9* below. The floor build-up is assumed to comprise a calcareous reinforced concrete. These assumptions should be further confirmed on site as per the recommendations in Section 4.1.2.3 of this report.

*Table 9* – Assumptions of the concrete detailing

Concrete slab thickness (mm)	Reinforcement concrete cover (mm)	Concrete specific heat (J/kgK)	Concrete density (kg/m <sup>3</sup> )	Convective heat transfer coefficient (W/m <sup>2</sup> K)	Thermal conductivity (W/mK)	Emissivity
200	30	1000	2300	35	1.3	0.7

The temperature at different depth within the concrete slab were calculated based on the equations given in Incropera et al. [19] and modified to include a radiative term as per in [5]. Three different equations are used to determine the temperatures of the surface node (Equation 16), an interior node at a certain depth (Equation 17) and the backside surface node (Equation 18).

$$T_0^{t+1} = \frac{2t}{\rho_c c_c \Delta z} \left[ h_0 (T_g - T_0^t) + \sigma \varepsilon (T_g^4 - T_0^{t4}) + \frac{k_c}{\Delta z} (T_1^t - T_0^t) \right] + T_0^t \quad \text{Equation 16 (A.1 [5])}$$

$$T_i^{t+1} = Fo(T_{i+1}^t + T_{i-1}^t) + (1 - 2Fo)T_i^t \quad \text{Equation 17 (A.2 [5])}$$

$$T_n^{t+1} = \frac{2t}{\rho_c c_c \Delta z} \left[ h_n (T_\infty - T_n^t) + \sigma \varepsilon (T_\infty^4 - T_n^{t4}) + \frac{k_c}{\Delta z} (T_{n-1}^t - T_n^t) \right] + T_n^t \quad \text{Equation 18 (A.2 [5])}$$

Where:

$T_i^t$  = concrete temperature at time t and location i (subscript 0 indicates exposed surface, while n indicates backside surface), in K

$T_g$  = gas temperature in K

$T_\infty$  = ambient temperature in K

$\rho_c$  = density of concrete in kg/m<sup>3</sup>

$c_c$  = specific heat of concrete in J/kgK

$h$  = convective heat transfer coefficient in W/m<sup>2</sup>K

$\sigma$  = Stefan-Boltzmann constant in W/m<sup>2</sup>K<sup>4</sup>

$\varepsilon$  = radiative emissivity

$k_c$  = thermal conductivity of concrete in W/mK

$\Delta_t$  = time step in s

$\Delta_z$  = element length in m

Steel reinforcement bars experience significant degradation of properties between 500-600 °C [20]. Therefore, a limiting temperature of 500 °C was adopted as the limiting factor to ensure that failure does not occur.

The maximum temperatures for each scenario are presented in *Table 10* below.

*Table 10* – Calculated maximum temperatures in concrete slab

Floor	Use	Maximum concrete surface temperature (°C)	Maximum reinforcement temperature (°C)
Level 1	Gallery	434	296
Ground level	Display space	426	278

The calculated reinforcement temperatures for the assessed travelling-fire scenarios remain well below the adopted limiting temperature of 500 °C, indicating that the proposed fire loading does not challenge the load-bearing capacity of the existing concrete slabs under the assumed conditions. Given the concept-design nature of this study and the absence of detailed construction information, this level of assessment is considered sufficient to demonstrate that Failure Mechanism 2 (structural failure) is not credible for the existing concrete structure, provided that the fuel-load limits and ventilation assumptions defined elsewhere in this report are maintained.

## B.4 Localised heating

Localised heating of individual structural elements, such as beams, slab regions adjacent to concentrated fuel packages, or elements exposed to near-field flame contact, represents a potential refinement of the structural fire assessment. In this report, localised thermal effects are not assessed through separate, dedicated calculations. This is a deliberate choice, consistent with the concept-design nature of the study and the design-for-failure methodology adopted throughout.

The travelling-fire framework used in Appendix B inherently captures localised heating effects by representing non-uniform fire exposure that moves across the compartment, producing peak thermal demands at specific locations rather than uniform compartment temperatures.

At later design stages, or for specific boundary cases where fuel arrangements, element geometry, or construction detailing indicate an elevated sensitivity to localised exposure, additional localised heating assessments could be undertaken for selected members. Such assessments would not alter the overall strategy but would serve to confirm that the assumptions adopted here remain valid once detailed design information becomes available.

## Appendix C Contribution of exposed timber

The content in this section is based on the following chapters of the SFPE Handbook of Fire Protection Engineering [2]:

- Chapter 11, which introduces the fundamental heat-transfer mechanisms relevant to fires, including convection, radiation, and conduction, and provides the physical basis for assessing thermal exposure of materials.
- Chapter 13, which presents correlations for fire plumes and flame geometry, including flame height and ceiling interaction, forming the basis for first-order assessment of flame impingement and convective heating.
- Chapter 14, which describes the behaviour of ceiling jets, including correlations for ceiling-level gas temperature and velocity beneath flat ceilings, and provides first-order tools for assessing heat transfer to targets.
- Chapter 26, which discusses heat release rate, heat release rate per unit area (HRRPUA), and fuel characteristics, and how these parameters govern fire size and growth in compartment fires.

### C.1 Objective

The objective of this appendix is to demonstrate, using simple first-order methods, that the exposed mass-timber ceiling (and timber columns on the timber floors) can be kept outside ignition and delamination conditions by constraining the credible fire size and fire location through fuel-load management and fuel arrangement. In this strategy, the design fire is treated as an output of the engineered constraints: if the fuel is controlled and arranged as assumed, the resulting fire cannot generate the thermal exposure required for timber ignition.

For this building configuration (open, cross-ventilated, large floor plates) the intent is not to predict every possible fire in detail, but to show that reasonable use conditions can be managed so that a localised fire does not transition into a timber-involved event. The analysis therefore focuses on the thermal exposures that govern whether timber becomes involved in the fire, using simple relationships applied with explicit assumptions.

For a fire originating within the occupied space, timber may fail in this context through the following mechanisms:

- Ignition of the exposed timber ceiling, driven by direct flame impingement (flame height reaching the ceiling) or convective heating from hot gases (gas temperatures at the ceiling reaching an ignition threshold).
- Heat-induced delamination of timber lamellae, which can expose fresh timber and introduce additional fuel to the fire, potentially changing fire dynamics and increasing the likelihood of subsequent ignition.

Although radiative heating can be relevant for ceiling ignition in some configurations, this assessment screens radiation as a secondary mechanism and does not quantify it at this stage, since convective heating is considered the dominant mode of heat transfer. This is a deliberate choice given the uncertainties in fuel arrangement, HRRPUA, and ventilation. A detailed radiative exchange calculation would imply a level of precision that is not supported by the available design information.

For ignition of the timber columns, radiation is considered a dominant mode of heat transfer and considered in this assessment.

Two assumptions dominate the usefulness and limitations of the first-order ignition screening adopted in this appendix.

- Heat Release Rate per Unit Area (HRRPUA): HRRPUA varies significantly with fuel type, configuration, and ventilation. Bounding values consistent with SFPE Handbook guidance and those used elsewhere in this report are adopted to test define limiting conditions.
- Fuel elevation: In practice, office fuels are often elevated above floor level (e.g. desks, shelving, stacked items), which can increase effective flame height and lead to earlier ceiling contact. As a result, the first-order calculations presented here cannot be treated as proof unless the assumed fuel arrangement is maintained. This reinforces the need for management controls and further fuel-load characterisation at later design stages including specific testing to understand the deviations between the expected and predicted fuel behaviour.

The intent of these calculations is therefore to demonstrate that, for plausible HRRPUA values and controlled fuel heights, a practical operational envelope exists in which flames do not reach the ceiling and ceiling-level gas temperatures remain below ignition-capable conditions. Under these constraints, the exposed timber remains non-participating in the design fire.

This appendix is intentionally first-order and concept-design level. At later design stages, the expected fuel load and arrangement should be characterised more precisely, including typical item heights and credible clustering, using available empirical datasets and, where appropriate, targeted testing. This work would confirm that the derived limiting fire sizes and flame heights remain consistent with the strategy assumptions and that credible ignition and fire-spread pathways remain excluded by design and management.

## C.2 Ignition of exposed ceiling

To prevent ignition of the exposed mass-timber ceiling, combustible items (e.g. desks, chairs, soft furnishings and temporary displays) are assumed to be arranged in discrete, separated fuel clusters, rather than as continuous fuel beds. This is to ensure that any single ignition produces a localised fire that cannot grow into a large, ceiling-involving event. A first approximation to the maximum size of an individual cluster is developed below, recognising that this is a screening calculation, using Alpert's ceiling-jet correlation in the turning-region limit ( $r = 0$ , see Equation 19 below), intended to translate a thermal ignition criterion into a practical management constraint on furniture grouping and spacing.

We use an assumed ignition temperature of 300 °C and take the nominal ceiling height above the fuel package as  $H = 3.8$  m. To explore the influence of a more realistic three-dimensional fuel arrangement, we also repeat the calculation using a reduced clearance of  $H = 2.8$  m.

The resulting maximum allowed HRR is then converted into a maximum burning area using representative values of HRRPUA of 250 and 500 kW/m<sup>2</sup> (see Equation 20 below) as bounding ranges for this occupancy type. The maximum burning area can then be translated into practical constraints on the maximum plan area of any single furniture grouping. Results are shown in *Table 11*.

	$T - T_{\{\infty\}} 5/3 = 16.9 \frac{\dot{Q}^2}{H^{5/3}}$	Equation 19 (SFPE 14.2)
	$A = \frac{\dot{Q}}{\dot{q}''}$	Equation 20

Table 11 Indicative maximum fire (fuel arrangement) sizes based on simple correlations and assumed values for Heat Release Rate per Unit Area (HRRPUA)

Heat Release per Unit Area (kW/m <sup>2</sup> )	Height (m)	Maximum Heat Release Rate (MW)	Maximum fire size (m <sup>2</sup> )
<b>250</b>	3.8	~ 1.9	~ 7
	2.8	~ 0.8	~ 3
<b>500</b>	3.8	~ 1.9	~ 3.5
	2.8	~ 0.8	~ 1.5

This screening calculation carries significant uncertainty. This uncertainty is not primarily about life safety (which is addressed through early evacuation, protected stairs, and the broader design-for-failure framework), but about property protection and business continuity, because the credibility of the strategy’s heritage-/asset-protection narrative depends on our ability to robustly exclude ignition (or sustained involvement) of the exposed timber.

Alpert’s correlations were developed from a broad set of fire tests and are intentionally simple. Even though ceiling-jet behaviour is fundamentally linked to the convective component of heat release rate, the correlations are expressed in terms of the actual heat release rate because fuel-specific convective fractions were not consistently available at the time, and convective fractions can vary by fuel type. This was later revised, with improved correlations obtained by Alpert, but given the uncertainty around the fuel load arrangement in this report, there is not expected value to be gained in using a more precise version of the correlation to obtain an equally uncertain result.

We adopt 250–500 kW/m<sup>2</sup> as convenient bounding values to obtain an early cluster size; however, because the strategy relies on aggressive fuel-load and fuel-distribution management, these HRRPUA values may be overly conservative for the actual intended contents and layouts. At the same time, real furniture groups are not idealised pool fires: they are three-dimensional, may be elevated, and may produce different flame/plume behaviour than the simplified representation implied by a single HRRPUA and a single “burning area”. These competing effects mean that we cannot, at this stage, defend a single maximum cluster size with high confidence and this will be a core question to be explored in the detailed design stages.

Third, and most importantly, the consequence of being wrong is asymmetrical. If the true credible clusters can be larger than estimated, we may be imposing unnecessarily strict operational limits. But if the true behaviour permits larger flames, higher ceiling-jet temperatures, or earlier ceiling interaction than assumed, as experimental data can show [21] [22], the strategy’s property-protection and continuity objectives could be undermined even if life safety remains robust. Therefore, to progress with this design philosophy, experiments need to be carried out during the detailed design stages to characterise the expected flame heights and smoke temperatures to be produced in well-ventilated scenarios by a variation of expected fuel cluster arrangements.

For these reasons, this report treats the above as a screening step only. During later (detailed) design, the appropriate next step would be to benchmark the adopted HRRPUA and cluster assumptions against the actual furniture and fit-out proposals (testing) to adopt a more robust evidence base. The purpose of further work would be to reduce uncertainty where it matters most by directly establishing the behaviour of the proposed fuel arrangement relative to the failure mode (timber ignition).

Finally, it is worth noting that the building’s intended characteristics, very low managed fuel loads, ceiling-only exposed timber, large open volumes, and large façade openings and voids, could plausibly promote an environment where ignition, if it occurred, may not necessarily lead to sustained timber involvement (i.e. conditions may favour limited involvement or self-extinction). However, that would require careful, case-specific evidence and is beyond the scope of this first-order approach. The present report therefore does not rely on self-extinction and instead frames timber ignition as an unacceptable

failure mechanism that should be prevented by design and management, with further validation required at later stages.

### **C.2.1 Delamination**

A further potential failure mechanism associated with exposed mass timber is heat-induced delamination, whereby layers of timber separate under thermal exposure and expose fresh, uncharred material to the fire [23]. While the timber is not expected to ignite under the limiting fire scenarios defined in the previous sections, delamination could introduce additional fuel into the compartment, alter fire dynamics, and potentially increase the likelihood of timber ignition. For this reason, delamination is recognised as a relevant mechanism that must be considered, even where ignition is not expected.

A first-order assessment of delamination would have been undertaken using a one-dimensional heat-transfer model, consistent with the simplified approaches adopted elsewhere in this report. The heating regime established in the previous section (based on bounding fire exposure and gas-temperature histories) would be applied at the exposed timber surface, and in-depth temperatures would be calculated as a function of time. The assessment objective would be to verify that temperatures at a defined depth within the timber remain below a threshold, taken here as approximately 60 °C.

It is recognised that this approach represents a first-order approximation. Delamination behaviour is subject to significant uncertainty and is influenced by a wide range of factors, including moisture content, loading conditions, adhesive type, lamella thickness, heating rate, duration of exposure, and restraint conditions. Experimental and analytical studies [23], [24], [25] have shown that both the likelihood and extent of delamination can vary substantially depending on these parameters, and there is no single deterministic criterion that can be applied universally. The recent research literature, including the studies referenced in this appendix, demonstrates the complexity of delamination phenomena and the sensitivity of outcomes to material and boundary conditions.

Notwithstanding this uncertainty, the use of a simplified one-dimensional heat-transfer check is considered an appropriate level of crudeness for this conceptual assessment. The intent is not to predict delamination in detail, but to confirm that, under the engineered fire scenarios and management-controlled fuel loads assumed in this strategy, thermal penetration into the timber remains limited and does not create conditions conducive to significant delamination. This is consistent with the overall philosophy of the report, which prioritises the correct formulation of assumptions and the disciplined use of simple methods within their domain of validity.

The detailed modelling required to assess delamination rigorously has not been completed as part of this report. This reflects the educational nature of the case study and the time constraints of the exercise. In a real project, further assessment would be undertaken at later design stages if exposed timber were to be relied upon for fire performance, with material-specific data and testing evidence used to refine assumptions and confirm robustness.

## **C.3 Ignition of exposed columns**

On the mass-timber floors, ignition of exposed timber columns is prevented primarily through fuel separation and fuel-arrangement controls. Combustible items are required to be arranged such that localised fires cannot generate radiative heat fluxes capable of igniting the column surfaces. These spacing and arrangement rules are essential to prevent escalation from a localised fire to larger, continuous burning areas involving structural timber.

Where timber columns pass through the existing lower storeys, they are required to be protected. Exposed timber in these levels falls outside the scope of the simple, first-order methods used in this report; these areas are therefore excluded from the present assessment.

Radiative ignition of timber columns is screened using a point-source radiation model, consistent with the simple methods adopted elsewhere in this appendix. The incident radiative heat flux at the column surface is estimated using:

	$\dot{q}'' = \frac{\dot{Q}_r}{4 \pi R^2}$	<i>Equation 21 (SFPE 14.2)</i>
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where  $\dot{Q}_r$  is the radiative component of the fire heat release rate and  $R$  is the distance from the effective source to the column surface. In applying this relationship, a radiative fraction of 0.3 is assumed. The distance is measured from the edge of the column, such that the calculated value defines a clear radius around the column within which combustible items must not be placed.

Fire sizes of 1900 kW (1.9 MW) and 900 kW (0.8 MW), corresponding to the maximum permitted localised fire sizes established in Section C.2 are used. For these fire sizes, the resulting clear radius is found to lie in the range of approximately 0.5 m to 2.0 m, depending on the assumed fire size. This distance is used both to protect the timber columns directly and, by extension, to inform minimum separation distances between fuel clusters, thereby reducing the likelihood of fire spread through radiative ignition.

The application of a point-source radiation model to represent heat transfer from a flame is subject to significant uncertainty, particularly at short distances and for complex, three-dimensional fuel arrangements. However, given the substantial effort elsewhere in this appendix to characterise and bound the many uncertainties associated with the credible fire size, growth, and configuration, the use of this approach is considered appropriate for a first-order screening assessment. The intent is not to predict radiative exposure with precision, but to demonstrate that a practical operational envelope exists within which ignition of the timber columns is unlikely.

As with other elements of this appendix, these assumptions would need to be revisited at later design stages once the actual fuel types, arrangements, and fire dynamics are better defined, for example through targeted testing.

## Appendix D Fire spread

For the purposes of this failure mechanism, the term compartment must be understood in the context of the building's hybrid construction. The Ground and First floors function as true compartments with the expectation that both fire and smoke remain within the room of origin.

Above these levels, however, the mass-timber floors (Levels 2–4) are not designed as compartments in the traditional sense, and the strategy does not rely on compartmentation to limit fire development. On these floors, the strategy depends on fuel-load limitations, ventilation characteristics, and thermal-exposure constraints to ensure that the fire cannot ignite the exposed timber or spread vertically or laterally. This distinction ensures that the failure-mechanism definition aligns with the actual physical and operational behaviour of each part of the building.

### D.1 Internal fire spread

No explicit calculations are performed in this section. Internal fire spread is addressed through a combination of building geometry, passive fire-safety measures, fuel-load management, and operational controls that together prevent fire from spreading beyond the floor of origin. Given the conceptual stage of design and the nature of the spaces considered, a qualitative assessment is considered more appropriate and more transparent than numerical analysis.

The assessment of internal fire spread is directly informed by the ignition screening calculations presented in Appendix C. In particular, the clear distances derived for ignition of exposed timber ceilings and columns are adopted here as the minimum separation distances between fuel clusters. By enforcing these separations, the incident radiative heat flux and convective exposure at adjacent fuel packages remain below ignition-capable conditions, preventing lateral fire spread across the floor plate for the exposed-timber storeys.

Vertical fire spread between floors is prevented primarily through the use of compartment floors with appropriate fire resistance. These floors provide the principal barrier to fire spread and define the fundamental assumption that fire remains confined to a single storey. Where services, structural elements, or movement joints penetrate compartment boundaries, fire-stopping is required to maintain the integrity of the compartmentation and prevent the formation of concealed fire paths.

On the mass-timber levels, additional measures are adopted to prevent fire spread via open internal geometry. Fuel-free zones are required adjacent to the central lightwell to prevent flame projection or sustained heating at the void edge. These zones limit the potential for fire to interact with the void in a manner that could promote vertical spread. The use of downstands around the lightwell further supports this objective by interrupting direct plume attachment and delaying the upward movement of hot gases, encouraging lateral spill and discharge through the open façades rather than vertical propagation.

Internal fire spread involving exposed timber elements is prevented by ensuring that timber does not ignite under the engineered fire scenarios. The strategy relies on limiting fire size through fuel-load control, fuel arrangement, and separation distances, such that convective and radiative heating of timber surfaces remains below ignition-capable conditions. Heat-induced delamination, which could introduce additional fuel and alter fire dynamics, is recognised as a potential mechanism and is discussed separately in Appendix C, with the strategy ensuring that the conditions that could lead to significant delamination are avoided.

The presence of green walls introduces a further internal fire-spread consideration. The strategy assumes that green walls are designed, installed, and maintained to prevent ignition and fire propagation. This includes appropriate plant selection, continuous irrigation, avoidance of dry or dead vegetation, and separation from other combustible fuel sources. Fuel-free zones are also maintained between green walls and exposed timber elements, particularly near façades and openings, to prevent localised fires from escalating or spreading internally.

Fire spread within circulation spaces and towards the means of egress is addressed by design rather than calculation. Protected lobbies and stair enclosures are treated as places of safety, and combustible fuel is excluded from areas immediately adjacent to stairs and critical egress routes. By removing fuel from these locations, the strategy prevents internal fire spread from compromising escape routes, rather than relying on time-based tenability calculations that would be highly sensitive to uncertain assumptions.

Overall, internal fire spread is controlled by constraining the conditions under which fire can develop, rather than by predicting fire growth in detail. This approach is consistent with the design-for-failure philosophy adopted throughout the report: where the mechanisms that would enable fire spread are removed or limited by design and management, detailed calculations are neither necessary nor appropriate at this stage. The resulting strategy is robust, transparent, and aligned with the level of design definition available.

## D.2 External fire spread

The external fire spread assessment adopts the same limiting incident heat-flux criteria defined in Section 2.4 for failure mechanism 4, namely that external surfaces and adjacent structures are not exposed to heat fluxes exceeding 12.5 kW/m<sup>2</sup>.

### D.2.1 External fire spread between adjacent buildings

The external fire spread considered in this section mainly refers to a scenario where fire can spread from one building to another located some distance away. As in accordance with Chapter 86 of SFPE Handbook, two main mechanisms of external fire spread between buildings are:

- The burning of combustible contents involves the whole compartment in a building causing the failure of weaker areas in the external walls (e.g., combustible façade, non-fire-rated windows or openings). These areas emit thermal radiation to adjacent buildings.
- Burning brands (burning debris from the fire) which could provide a pilot ignition source for materials on an adjacent building that has been heated by thermal radiation from the fire.

To assess potential radiation transfer through the external walls, the guidance from BRE Fire Research Station's document titled External Fire Spread: Building Separation and Fire Distances (BR 187) has been adopted for addressing fire spread between adjacent buildings.

BR 187 consider that radiation can cause fire spread when there is direct line-of-sight from the radiating building to an exposed building (see *Figure D.1*). The total area of the external walls (those areas that are radiating due to failure) and the distance from adjacent buildings directly impact the risk of fire spread since.

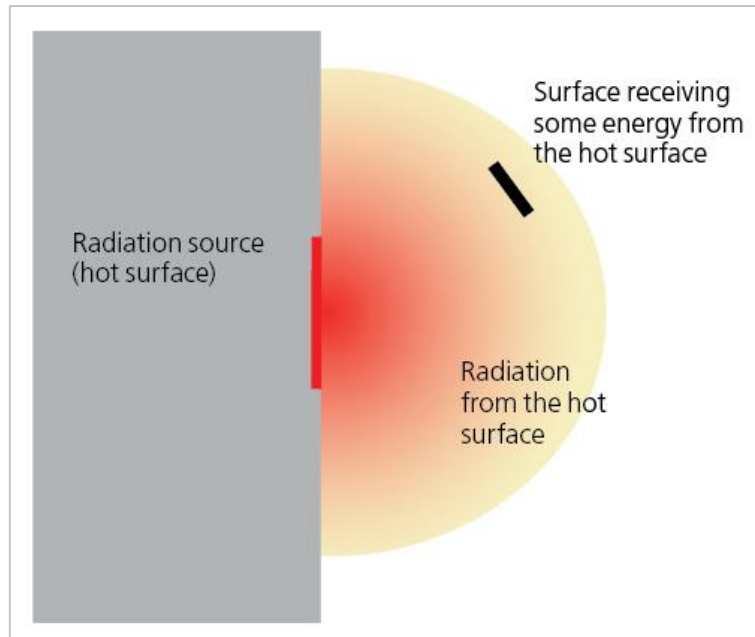


Figure D.1 Radiation from an emitter surface (taken from BR 187)

To determine whether the adjacent buildings will be exposed to a radiation intensity above a specified threshold, it is essential to calculate the size and distance to determine the configuration factor, and the heat flux received to the exposed building. The following equation is used to calculate the thermal radiation to the exposed building,  $I_R$  (kW/m<sup>2</sup>).

$$I_R = \theta \varepsilon \sigma (273 + T_e)^4$$

where:

$\theta$  = configuration factor

$\varepsilon$  = emissivity of the emitter (generally assumed to be 1)

$\sigma$  = Stefan-Boltzmann constant,  $56.7 \times 10^{-12}$  (kW/m<sup>2</sup>K<sup>4</sup>)

$T_e$  = Temperature of the emitting surface (°C)

The radiation intensity needed to cause ignition of a distant exposed building has been taken to be the intensity needed for pilot ignition of wood materials, which is 12.5 kW/m<sup>2</sup>.

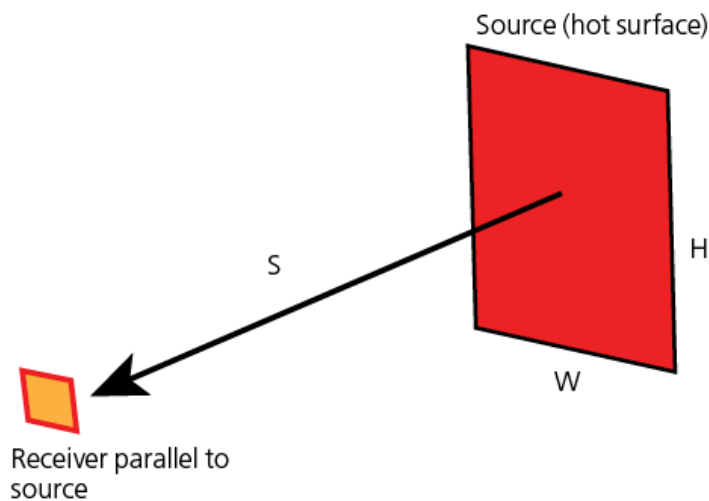


Figure D.2 Parallel source and receiver (taken from BR 187)

The configuration factor,  $\theta$  depends on the orientations of the source and the receiver. The basic equation used for this analysis for the configuration factor is for an emitter parallel to the receiver as seen from the centre as shown in *Figure D.2*, which can be found from:

$$\theta = \frac{2}{\pi} \left[ \frac{X}{\sqrt{1+X^2}} \tan^{-1} \left( \frac{Y}{\sqrt{1+X^2}} \right) + \frac{Y}{\sqrt{1+Y^2}} \tan^{-1} \left( \frac{X}{\sqrt{1+Y^2}} \right) \right]$$

where:

$$X = \frac{W}{2S}$$

$$Y = \frac{H}{2S}$$

$W$  = Width of the emitter (m)

$H$  = Height of the emitter (m)

The rear elevation to the river front has been excluded from this assessment as there is no building facing this side of the building and therefore no risk for external fire spread. Given that the side walls are shared structural masonry walls with the neighbouring buildings on either side on the ground and first floor, these side walls have been fully protected without any openings.

The elevations that have been assessed are:

- The street front elevation, where the results are recorded in *Table D.1*.
- The side elevations (Level 2 to 4), where the results are recorded in *Table D.2*

*Table D.1 The received heat flux at a distance from the street front elevation*

Floor level	Temperature of the emitter, $T_e$ (°C)	Width of emitter, $W$ (m)	Height of emitter, $H$ (m)	Separation distance, $S$ (m)	Configuration factor, $\theta$	Received heat flux (kW/m <sup>2</sup> )	Accepted?
Level 4	741	30	3.6	8	0.2089	12.5	Yes
Level 3	741	30	3.6	8	0.2089	12.5	Yes
Level 2	741	30	3.6	8	0.2089	12.5	Yes
Level 1	724	34	3.8	8	0.2229	12.5	Yes
Ground level	670	34	4.8	8	0.2770	12.5	Yes

*Table D.2 The received heat flux at a distance from the side boundaries*

Floor level	Temperature of the emitter, $T_e$ (°C)	Width of emitter, $W$ (m)	Height of emitter, $H$ (m)	Separation distance, $S$ (m)	Configuration factor, $\theta$	Received heat flux (kW/m <sup>2</sup> )	Accepted?
<b>Level 4</b>	506	6	3.6	2	0.2089	12.5	Yes
<b>Level 3</b>	506	6	3.6	2	0.2089	12.5	Yes
<b>Level 2</b>	506	6	3.6	2	0.2089	12.5	Yes

## Appendix E List of acronyms / abbreviations

Table 12 List of acronyms and abbreviations

Acronym	Definition
<b>ACE</b>	Architects Council of Europe
<b>AIA</b>	The American Institute of Architects
<b>AOV</b>	Automatic Opening Vent
<b>APM</b>	Association for Project Management
<b>ASET</b>	Available Safe Egress Time
<b>BMS</b>	Building Management System
<b>CFD</b>	Computational Fluid Dynamics
<b>FEA</b>	Finite Element Analysis
<b>FRA</b>	Fire Risk Assessment
<b>HRR</b>	Heat Release Rate
<b>HRRPUA</b>	Heat Release Rate Per Unit Area
<b>LHD</b>	Linear Heat Detection
<b>PRM</b>	Person of Reduced Mobility
<b>RIBA</b>	Royal Institute of British Architects
<b>RSET</b>	Required Safe Egress Time