RESEARCH

High Rise Buildings with Combustible Exterior Wall Assemblies: Fire Risk Assessment Tool

FINAL REPORT BY:

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ABSTRACT

Based on a number of recent fires in high rise buildings clad with combustible wall insulation systems, global enforcement authorities are revisiting their existing building inventories to assess potential risks. There are a number of risk factors which may impact the level of risk and the consequent priority for inspection and/or remediation. Authorities are seeking a means to make these assessments and decisions based on them, using a risk informed methodology.

Such a risk informed methodology involves: the identification of key variables (e.g., component materials, connection systems, installation techniques and geometries, occupancy type, age of application, proximity to other structures, external factors such as weather, building fire protection systems, etc.); characterization of those variables in terms of risk or mitigation potential; and incorporation of them into an engineering based risk model whose output will be a means for authorities to prioritize mitigation. Because there is limited test data or statistics to further inform a quantitative approach to risk ranking or scoring, a qualitative assessment is being utilized based on engineering judgement.

The goal of this project has been to develop and make available a risk assessment methodology to assist global authorities to assess the risks and prioritize inspection/remediation efforts for the high-rise building inventory in their jurisdiction with exterior wall assemblies containing combustible components. The methodology is qualitative rather than quantitative and follows internationally recognized risk assessment approaches. The method does not recommend specific mitigation measures, but rather prioritizes the need for mitigation based on risk factors and provides suggestions for possible mitigation to be assessed on a project by project basis.

This report provides the baseline approach and information to support a larger effort to separately develop and implement an electronic tool and user guide (based on the information in this report) to directly support Authorities who are attempting to address this topic in their respective jurisdiction.

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Keywords: High Rise Buildings, Combustible Exterior Wall Assemblies, Fire Risk Assessment Tool, façade fire, fire tests, NFPA 285, Cladding, Insulation

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FOREWORD

Based on a number of recent fires in high rise buildings clad with combustible wall insulation systems, global enforcement authorities are revisiting their existing building inventories to assess potential risks. There are a number of risk factors which may impact the level of risk and the consequent priority for inspection and/or remediation. Authorities are seeking a means to make these assessments and decisions based on them, using a risk informed methodology.

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PROJECT SPONSOR

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High rise buildings with combustible exterior façade systems: Fire risk assessment tool

Background and development of the tool

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1 Introduction

This report is the final deliverable for the NFPA Research Foundation Project *High Rise Buildings with Combustible Exterior Façade Systems: Fire Risk Assessment Tool.* It documents the background, development, beta testing and refinement of the fire risk assessment (FRA) tool. It also provides the final version of the FRA tool and a detailed user's guide to accompany the tool.

At the request of NFPA, the FRA tool focuses on life safety only. Business continuity or property protection are not addressed.

The FRA tool is applicable in any geography but is currently limited to residential (hotel, apartments) or business (office) or a mix of both occupancies that are over 18m high where height is measured as the total vertical distance from fire department access level to the finished floor level of the top most occupied floor of the building. NFPA selected these occupancies for the FRA tool as the majority of high rise buildings internationally are these types of occupancy.

The FRA tool is intended to be used by Enforcers or Authorities Having Jurisdiction (AHJ) to assess a portfolio of buildings across a town or city where there is a concern that the exterior facade systems are built-up from combustible materials. The FRA tool is intended to provide a framework to aid the AHJ to prioritize buildings in their jurisdiction and to conduct fire risk assessments of each building, assessing the highest priority buildings first. A range of possible mitigation measures are suggested to help the AHJ and building owner to begin reducing the fire risk where necessary. The tool can be used to measure the success of the mitigation by revisiting the risk assessment.

The mitigation measures suggested provide a means of reducing risk but will not eliminate risk unless the combustible façade materials are removed from the system and replaced by non-combustible materials.

In some instances this assessment will highlight the need for a more detailed risk assessment by a qualified engineering team of façade and fire engineers. This could be because of the complexity of the building, complexity of the façade patterns (combustible cladding/insulation is randomly arranged or non-uniform) across the building or difficulties in identifying the façade systems/materials.

It is important to note that the FRA tool is for existing buildings with combustible façade systems only. It assumes there is the potential for fire spread to multiple stories of the building via the façade system. The guidance is not appropriate for the risk assessment of buildings without a combustible façade, other published tools are widely available for this. None of the guidance is applicable to the design of new buildings and therefore should not be used in this context.

The FRA tool has been developed by Arup with peer review and technical input from Jensen Hughes. The Arup team comprised a core team of three fire engineers in Dubai to develop the tool with support and input from two fire engineers in each of Australia, Asia, UK, Europe and USA to address the global nature of the tool. The Arup façade engineering team have provided input in terms of the façade systems that could be present in each geography and they have developed guidance to help the end user of the FRA tool in identifying and understanding the various facade systems and in particular the combustible materials within these systems. The Jensen Hughes team provided peer review and advice based on their understanding of risk assessments and experience of witnessing fire testing and identifying combustible materials through forensic testing. A panel of experts and interested parties was formed by NFPA to further peer review and comment upon the development of the FRA tool at key stages of the project. Input from the peer review teams has been addressed and incorporated.

The project team would also like to acknowledge the fire testing and consulting team of Thomas Bell-Wright International Consultants (TBW), Dubai. TBW provided invaluable input in terms of their experience of fire testing of façade systems which allowed the project team to estimate the likely fire hazard of a range of potential existing façade systems and incorporate this within the FRA tool.

1.1 Navigating this Report

The following table summarizes each section of the report to help navigate the document.

Section	Title	Summary
2	Objective	This section sets out the objective of the report
3	Background	This section looks at the history of combustible materials in facade systems to help inform the age of buildings or the age of facade systems that may contain combustible insulation or cladding. Note: Facade systems are replaced over the life of a building therefore the age of the building may not reflect the age of the façade. It also provides a brief summary of some of the high rise fires internationally involving combustible facades, with reference to other documents which provide more detail.
4	Assumptions and Limitations	This section states the assumptions made in developing the FRA tool and the limitations of the FRA tool.
5	Challenges	This section states the project challenges.
6	Literature Review	This section looks at available fire risk assessment approaches and tools in the fire industry and other industries. It also looks at methods developed by various industries for weighting of risk variables. It concludes with the proposed approach for the FRA tool.
7	Variables Associated with Combustible Façade Systems and High Rise Buildings Fire Safety	This section outlines the variables to be assessed in the FRA tool.

Section	Title	Summary
8	AHP	An analytical hierarchy process (AHP) is used in a number of industries to rank the relative importance of variables to each other. This section outlines the application of AHP to this project.
9	Methodology	This section described the FRA tool methodology for - Sleeping risk and total evacuation strategy (which may occur in phases); - Sleeping risk and remain-in-place evacuation strategy; and - No sleeping risk, i.e. Office premises and all out evacuation strategy (which may occur in phases)
10	Mitigation Measures	This section lists potential mitigation measures, their likely impact and how to assess their impact using the FRA tool.
11	Data Gathering	This section provides guidelines for gathering information about existing façade systems on buildings. It describes the information to look for in as-built drawings and what other methods there are to identify façade systems and component materials if as-built information is not available or deemed unreliable. These include visual non-destructive inspections, destructive inspections and laboratory testing of façade component materials.
12	Conclusion	Concluding statements
13	Further Work and Suggested Next Steps	This section suggests further work and next steps for development of the FRA tool for consideration by NFPA
14	References	This is a list of the papers, codes and standards referenced in this report.
Appendix A	Fire Risk Assessment Tool	This is the FRA tool in excel form for development by NFPA as an online application with Graphical User Interface
Appendix B	Users Guide	This is the user's guide for NFPA to circulate along with the FRA tool

1.2 Acronyms

A number of acronyms are used in the report. These are defined as follows:

ACP	Aluminium Composite Panel
ASTM	American Society for Testing and Materials
AHJ	Authority Having Jurisdiction
AHP	Analytical Hierarchy Process
AHU	Air Handling Unit
BCA	Building Code of Australia
BS	British Standard
EIFS	Exterior Insulation and Finishing System
ETICS	External Thermal Insulation Composite Systems
EN	European Standard
EPS	Expanded Polystyrene
FRA	Fire Risk Assessment
GFA	Gross Floor Area
GRC	Glass Reinforced Concrete
GRP	Glass Reinforced Plastic
GUI	Graphical User Interface
HPL	High Pressure Laminate
IBC	International Building Code
ISO	International Standards Organization
LDPE	Low Density Polyethylene

LPG	Liquid Propane Gas
MCM	Metal Composite Material
NFPA	National Fire Protection Association
PAS	Publically Available Specification
PE	Polyethylene
PIR	Polyisocyanurate
PUR	Polyurethane
SIP	Structural Insulated Panel
SNG	Synthetic Natural Gas
SPF	Spray Polyurethane Foam
XPS	Extruded Polystyrene
VA	Vinyl Acetate

1.3 Definitions

Definitions taken directly from NFPA 5000 (2015 Edition) are in italics. Definitions taken from the Merriam-Webster Dictionary are underlined.

All-out evacuation strategy	An “all-out” evacuation can only be assumed if there is the ability to sound the alarm throughout all areas of the building using an “all-out” or “all-call” button at the main fire alarm panel. As most high rise buildings adopt a phased evacuation strategy, an all-out alarm would usually be activated manually by the fire department or building management
Cavity barrier or fireblocking	*A material, a barrier, or construction installed in concealed spaces to prevent the extension of fire for an unspecified period of time.* In some countries the cavity barrier of fireblock may be specified for a particular fire resistance period such as 15 minutes.
Combustible material	*A material that, in the form in which it is used and under the conditions anticipated, will ignite and burn; a material that does not meet the definition of non-combustible or limited-combustible.*
Façade system	The assembly of framing and materials used to envelope a building. NFPA 5000 treats a façade system as a load bearing exterior wall or non-loadbearing exterior wall
Flame spread	*The propagation of flame over a surface*
Flame spread index	*A comparative measure, expressed as a dimensionless number, derived from visual measurements of the spread of flame versus time for a material tested in accordance with ASTM E 84, Standard Test Method for Surface Burning Characteristics of Building Materials or UL 723, Standard for Test for Surface Burning Characteristics of Building Material*
Fire resistance	The time, in minutes or hours, that materials or assemblies have withstood a standard fire exposure as determined by standard testing to ASTM E119 or equivalent.
Ignition	The process or means of igniting fuel; the starting of a fire
Limited-combustible material	*A material shall be considered a limited-combustible material where both of the following conditions are met:* *(1) The material does not comply with the requirements for a non-combustible material.* *(2) The material, in the form in which it is used, exhibits a potential heat value not exceeding 8141 kJ/kg (3500 Btu/lb),when tested in accordance*

	with NFPA 259, Standard Test Method for Potential Heat of Building Materials. *And* *7.1.4.2.1 The material shall have a structural base of non-combustible material with a surfacing not exceeding a thickness of 3.2 mm where the surfacing exhibits a flame spread index not greater than 50 when tested in accordance with ASTM E 84, Standard Test Method for Surface Burning Characteristics of Building Materials, or ANSI/UL 723, Standard for Test for Surface Burning Characteristics of Building Materials.* *or* *The material shall be composed of materials that in the form and thickness used, neither exhibit a flame spread index greater than 25 nor evidence of continued progressive combustion when tested in accordance with ASTM E 84 or ANSI/UL 723 and are of such composition that all surfaces that would be exposed by cutting through the material on any plane would neither exhibit a flame spread index greater than 25 nor exhibit evidence of continued progressive combustion when tested in accordance with ASTM E 84 or ANSI/UL 723.* Or A material that is classified as A2 by the EN 13501-1 test series.
Non-combustible material	*A material that complies with any one of the following shall be considered a non-combustible material:* *(1)*The material, in the form in which it is used, and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat.* *(2) The material is reported as passing ASTM E 136, Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750 °C.* *(3) The material is reported as complying with the pass/fail criteria of ASTM E 136 when tested in accordance with the test method and procedure in ASTM E 2652, Standard Test Method for Behavior of Materials in a Tube Furnace with a Cone-shaped Airflow Stabilizer, at 750 °C.* or A material that is classified as A1 by the EN 13501-1 test series.
Perimeter fire stopping or perimeter fire barrier joint systems	A listed opening protective in the joint between the perimeter of a fire rated floor slab and the façade (exterior wall) of a building
Smoke developed index	*A comparative measure, expressed as a dimensionless number, derived from measurements of smoke obscuration versus time for a material tested in accordance with ASTM E 84, Standard Test Method for Surface Burning Characteristics of Building Materials or UL723, Standard for Test for Surface Burning Characteristics of Building Materials.*
Spandrel	A spandrel beam is the edge beam on the perimeter of a structure, spanning between adjacent perimeter columns. In this FRA tool, a spandrel is used to define the area of opaque façade system covering this structural beam and floor slab.
Stay-put evacuation strategy	A stay put (defend in place) evacuation strategy assumes that building occupants not affected by a fire directly in their apartment, remain in their apartment. Only the apartment affected by a fire/smoke would be in alarm and only these occupants would be expected to evacuate. If fire/smoke spreads then the smoke detector and fire alarm in further smoke affected units would be expected to automatically activate but there is no ability to simultaneously raise the alarm in all areas of the building. The fire alarm system is not networked to a main fire alarm control panel at the entry or other designated area in the building.
Substrate	The structural wall, frame and/or floor that the façade system is fixed to
Structural Insulated Panel	For the purposes of this guide a structural insulated panel (SIP) is two layers of metal (often steel) with a foam or mineral wool insulation layer between. These are also commonly called insulated metal panels or sandwich panels
Thermal barrier	A material, product, or assembly that prevents or delays ignition of an unexposed surface by limiting the temperature rise and by acting as a flame exposure barrier. NFPA 5000 and the International Building Code (IBC) would require this between a combustible façade system that achieves compliance with NFPA 285 and the interior of the building

1.4 Project Team

The project team comprises Arup and Jensen Hughes as follows.

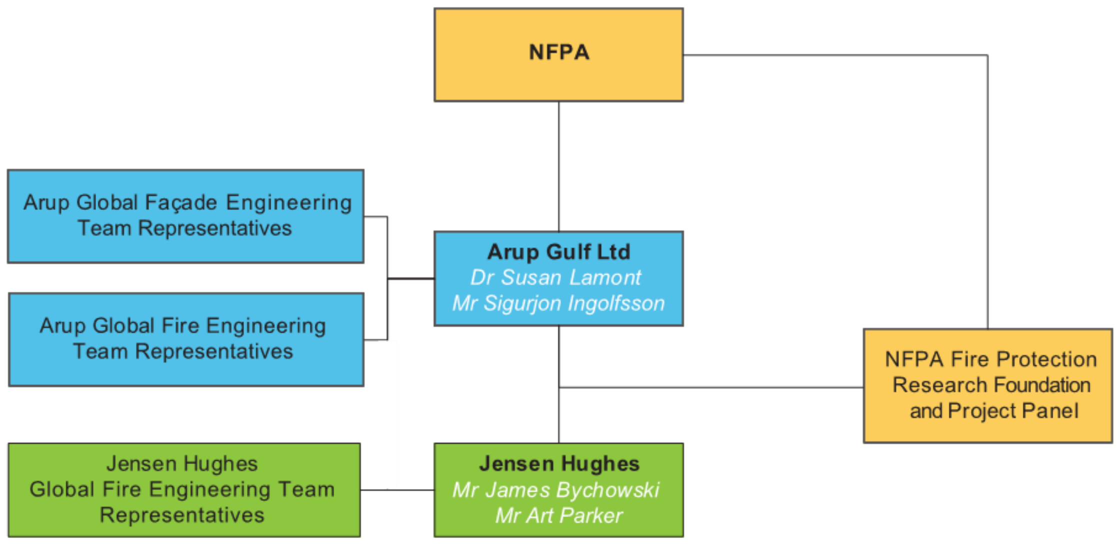


Figure 1 Project Team

The FRA tool has been developed by Arup with peer review and technical input from Jensen Hughes. A panel of experts and interested parties was formed by NFPA to further peer review and comment upon the development of the tool at key stages of the project. Input from the peer review teams has been addressed and where appropriate incorporated.

2 Objective of this Report

The objective of this report is to document the background and development of the fire risk assessment tool for future reference by NFPA and users of the FRA tool.

3 Background

3.1 Legislation

Most countries or cities globally legislate against significant combustible materials in facade systems of high rise buildings. The applicable fire safety codes for high rise buildings internationally typically mandate that materials of construction are non-combustible or at least limited combustible.

Non-combustible means a material will not ignite or burn. A limited combustible material is one that will ignite and burn but has passed certain code mandated fire tests such that ignition and combustion is substantially more difficult.

This means that facade assemblies in high rise buildings generally have to be entirely non-combustible or pass a series of fire tests to show that the proposed façade system assembly is acceptable per code. Where combustible content is proposed it is limited and generally must pass small-scale fire tests of the component materials and large scale fire tests of the actual proposed façade system for the project. Naturally legislation varies from country to country and these statements may not apply to every jurisdiction. Details of some of this legislation and required tests can be found in the relevant codes and are summarized by White and Delichatsios[29].

3.2 Combustible Materials in Facade Assemblies

Façade systems on most high rise buildings fall into three main categories

a) Curtain wall facade systems that are essentially hung from the upper floor slab with an anchor system at each floor line.

b) Built-up wall facade systems with cavities that sit on and are supported from floor slab below e.g. Rain screen

- Traditional masonry (e.g. brick) construction with a cavity is a form of rainscreen

c) Built-up wall facade systems without cavities that sit on and are supported from the floor slab below e.g. pre-cast concrete panels

-Exterior insulation and finish system (EIFS) or External thermal Insulation Composite Systems (ETICS) and Structural Insulated Panels (SIPs) are also a form of built-up façade usually without a cavity.

The various façade systems prevalent on high rise buildings are discussed in the User's Guide in Appendix B.

Combustible materials have been used in the past and are used today in façade assemblies or systems to improve energy performance, reduce water and air infiltration, and allow for aesthetic design flexibility. As stated above, combustible materials are either not permitted or restricted by national fire codes but a lack of understanding or enforcement or other issue in the construction industry supply chain has meant that some building façade systems globally have combustible material content that has not been restricted.

Foam insulations and/or metal composite materials (MCM) with combustible low density polyethylene cores tend to be the most prevalent combustible materials in any given high rise façade system. The most common type of MCM is Aluminum Composite Panels (ACP).

3.2.1 Aluminium composite panels (ACPs)

Aluminium composite panels were first introduced to the market in the 1970s. ACP panels consist of two thin layers of aluminium sheet with a core of low density polyethylene or a mixture of polyethylene, non-combustible minerals and/or fire retardants.

ACPs, are pre-fabricated panels consisting of two thin sheets of aluminium bonded to a non-aluminium core. The total thickness of the panel is usually between 4-6mm with the core between 2-4mm. Some panels can be up to 10mm total thickness. When ACP was first developed it comprised 100% polyethylene (PE) core. Aluminium melts at relatively low temperatures and the PE core ignites and burns very readily. It is the PE material which allows fire to propagate over large areas of ACP façade systems on high rise buildings.

ACPs were patented in the late 1960's [13] which as consequence of the patent restriction meant they were not extensively used. Once the patent expired in the 1980's other companies produced similar products and it became widely used in the late 1980's to the present day.

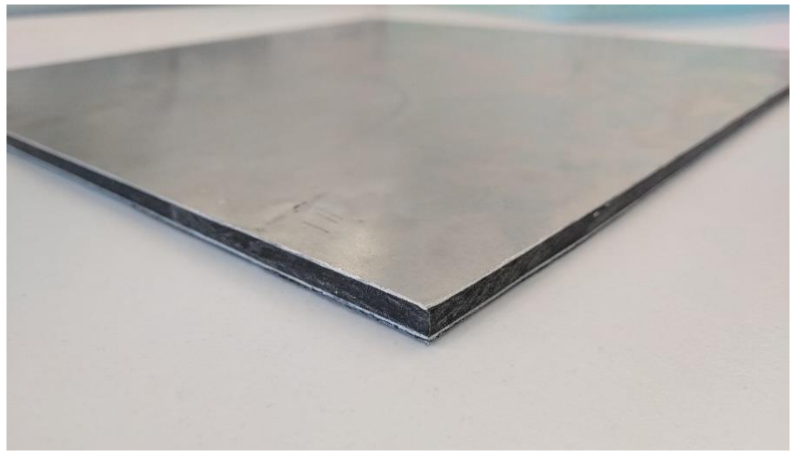


Figure 2 – Sample piece of an Aluminium Composite Panel (© Courtesy of Arup).

ACPs are widely used for high-rise construction projects due to their uniform aesthetic appearance and finish, durability, low maintenance requirements and ease of installation.

The reaction of ACP suppliers to concerns regarding the fire performance of their products has been to focus on providing panels that can pass standardized large scale fire tests.

For full scale façade assembly tests the ACP's performance is also influenced by the properties of the other materials used in the façade build-up and the configuration of all of these materials in the façade design. Typically ACP suppliers replace the 100% PE core with a mix of non-combustible mineral, fire retardants and PE binder.

Dependent upon the required fire performance, and the proprietary mixtures developed by individual manufacturers the percentage of PE is reduced to between 10 and 30% of the total core.

Visually ACP panels look the same because the core is not exposed.

This means that once installed it is difficult to distinguish between those ACPs that are designed to limit fire spread and those which do not achieve any fire performance. However, they behave very differently in a fire test situation as illustrated in the image below.

ACP use became widespread during the booms in construction in the 1990s and 2000s when high rise towers were built quickly to meet the growing demand in parts of China, Russia, Australia and The Middle East. Other countries like the UK and USA have a mix of new and older building stock but ACP panels have been retrofitted to some façade systems on to older buildings.

3.2.2 Other Cladding Materials

High pressure laminate panels [25], [29] are a decorative cladding similar to an MCM. They comprise layers of a cellulosic material (e.g. papers) impregnated at high temperature and pressure with a phenolic resin. The end product is dense and weather resistant typically 3-14 mm thick. A wide range of decoration is possible on the exterior surface. These are combustible.

Timber cladding [25], [29] has also become popular because it is a renewable material. Timber is combustible.

Glass reinforced polymers (GRPs) are another form of combustible cladding.

There are also a host of non-combustible cladding materials such as ceramic, stone, terracotta, glass reinforced concrete, cement board, concrete panels, brick, pre-cast concrete panels etc.

Some modern facades will be made to look like a traditional brick but may be comprised of thin pieces of brick stuck to another cladding material ("brick-slip"), made to look like traditional brickwork. The "brick-slip" may use pieces of brick or can be made from another material such as mortar or a combustible material, such as acrylic.

Cladding does not usually provide any insulation properties.

3.2.3 Insulations

Insulations provide the thermal and acoustic performance required of façade systems. They are usually installed behind the decorative cladding. Highly insulating plastic foams are more prevalent in cold climates where environmental legislation may have strict requirements for energy losses. All foam plastic insulation materials are combustible.

Non-combustible mineral wools are a more traditional form of insulation and are still prevalent in the Middle East and other countries where the climate is warm and energy losses are less of an issue.

Common insulations are as follows:

- Expanded polystyrene (EPS) foam
- Polyurethane (PUR) foam
- Polyisocyanurate (PIR) foam
- Modified Phenolic foam
- Spray Polyurethane Foam (SPF)
- Cellular glass insulation (CG), fiberglass or glass wool
- Mineral wool

3.2.4 Other Façade Insulation Systems

Exterior Insulation and Finishing Systems (EIFS) or External Thermal Insulation Composite Systems (ETICS) [1][25][29] are fixed to the exterior wall substrate for insulation, weather tightness and aesthetic reasons. EIFS/ETICS comprises an expanded foam (commonly EPS) and usually a fiber glass mesh and cement based polymer render to encapsulate the foam.

Insulated metal panels or insulated sandwich panels [25], [29], [19] provide the decorative finish as well as the insulation in one proprietary system. They comprise thin metal, typically steel or aluminium, skins and a foam insulation or mineral wool core. They are more common on low rise warehouses, laboratories, food processing facilities etc. but can be found on high rise. These are also sometimes called Structural Insulated Panels (SIPs).

White and Delichatsios [29] and O'Conner[25] provide more details on this subject.

3.3 High Rise Fires involving the Exterior Facade Assembly

There have been several high-rise fires internationally in the last 20+ years involving the combustible façade system on the exterior of the building. They have primarily occurred in residential buildings, with some incidences also in hotels and office buildings. The fires have spread rapidly over the façade system and have sometimes broken into the building at multiple floors causing fire spread both through the interior and exterior of the building. The materials burning within the façade system have been predominantly low density polyethylene as the core of decorative ACPs or foam insulation and in some instances foam insulation behind the decorative ACP panel.

Figure 3 and Figure 4 provide an illustrative map and a non-exhaustive list of the fires that have happened internationally as a result of combustible facade systems. Façade fires which have not been reported in English globally may not have been found by the project team. Similarly, older fire incidents and smaller fire incidents that do not make it into print media will also not have been noted.

These fire events are documented elsewhere in the press, social media and in papers, books and other reference material[29].

Country	City	Fire incidents involving the façade assembly on the exterior of a building							
UAE	Dubai	2017	2016	2016	2015	2012	2012	2008	2007
	Ajman		2016						
	Abu Dhabi		2016						
	Sharjah		2015	2012	2010				
Qatar	Doha		2010						
Russia	Grozny		2013						
Australia	Melbourne		2014						
	Fairfield		2002						
China	Shenyang		2016						
	Beijing		2011	2010	2009	2008			
Azerbaijan	Baku		2015						
Turkey	Istanbul		2012						
Thailand	Bangkok		2012						
Bangladesh	Dhaka		2016	2012					
USA	Atlantic City		2007						
	Reno		1997						
	Philadelphia		1991						
Hungary	Miskolc		2009						
France	Dijon		2010						
	Epinay-sur seine		2016						
	Lille		2016						
	Roubaix		2012						
Belgium	Neder-over-Heembeck		2016						
Germany	Berlin		2016						
	Munich		2005						
Spain	Ovideo		1996						
Canada	Winnipeg		2016						
S. Korea	Busa		1990						
UK	Liverpool		2010						
	Irvine		1991						
	Hereford		1999						
	London	2017	1993						
Japan	Hiroshima		1996						
Indonesia	Jakarta		2015						

Figure 3 List of fire incidents involving exterior façade systems globally (© Courtesy of Arup)

Figure 4 Map of fire incidents involving exterior façade systems (© Courtesy of Arup)

As a result of these fires, NFPA has initiated this project to develop a specific fire risk assessment tool.

3.4 High Rise Fire Safety

High rise fire safety relies on layers of fire safety provisions to act together to provide the level of life safety required by international codes. If any one of these layers is compromised, then the fire safety provided to the building starts to reduce. This concept is illustrated in the images in Figure 5. The degree to which safety is reduced depends upon which provision the design relies on the most. Building codes generally assume a single fire scenario interior or exterior to the building. The fire is generally assumed to be contained to one or two stories. Where the façade system is combustible a fire can spread to multiple stories via the façade system.

The fire safety provisions provided to contain an interior fire to a single story may not be as appropriate as provisions such as raising means of warning and escape for a façade fire over multiple stories.

For this reason, the existing quantitative or semi-quantitative fire risk assessment methodologies available in the market are unlikely to be suitably weighted for a façade fire scenario.

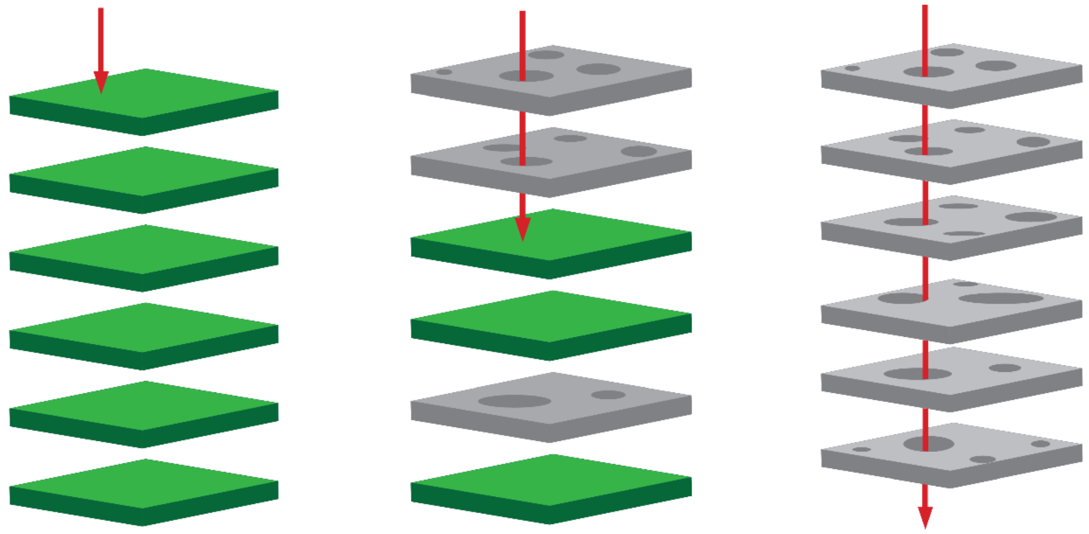


Figure 5 – Layers of fire safety provisions for high rise fire safety (© Courtesy of Arup).

4 Assumptions

The FRA tool is based on the following assumptions:

- The scope of the FRA tool is for high rise buildings comprising residential or business occupancies or a mix of both. Where the building is a mix of residential and business, it should be treated as a residential building due to the greater life safety risk associated with sleeping occupants.
- High rise is defined as a building over 18m in height, measured from fire department access level to the topmost occupied floor.
- It is assumed that there will be ignition risks throughout the high rise building interior, possibly within the facade system cavities and possibly on the exterior of the building (parked vehicles, cabling, electrics, lights, PV panels, balconies, BBQs, adjacent buildings etc.). The likelihood of a fire is reviewed in the context of ignition sources within the vicinity of the exterior combustible façade system, within the façade system itself and from a fire breaking out from the interior of the building.
- The tool is intended to have global applicability with minor geographical variations. The tool is not a code compliance check although it is based on the first principles of fire safety to, as far as practicable, meet the intent of life safety codes.
- The tool is distributed by NFPA as a risk assessment tool for use by an Authority Having Jurisdiction (AHJ). While other parties (owners, facilities managers, fire safety engineers, fire risk assessors) may also use the tool it is developed with the NFPA specified end users in mind.

5 Limitations

The development of the FRA tool is based on the following limitations:

- The tool is limited to three occupancy types:
  1. Sleeping risk and all out evacuation strategy (which may occur in phases);
  2. Sleeping risk and stay put (defend in place) evacuation strategy; and
  3. No sleeping risk, i.e. Office premises and all out evacuation strategy (which may occur in phases).
- The tool is not applicable to timber frame buildings. The structural frame should be steel or concrete. Timber frame buildings should be assessed by a qualified team of façade and fire engineers.
- The risk rankings produced by the tool are intended to err on the side of caution.
- The tool cannot address all possible combinations of façade system and building characteristics. In some instances the assessment will highlight the need for a more detailed risk assessment by a qualified engineering team of façade and fire engineers. This could be because of the complexity of the building, complexity of the façade patterns across the building and difficulties in identifying the façade systems/materials/components.
- The FRA tool addresses life safety only. The building owner or their insurer may have wider reaching objectives around business continuity or property protection.
- Issues such as business continuity, property protection, loss of belongings, loss of a place to stay are secondary and while important are not addressed by this FRA tool.
- The life safety of fire fighters is not explicitly addressed although mitigation measures for the life safety of the occupants can also be expected to reduce the risk to fire fighters. It is assumed that the Commanding Officer would risk assess the building's access and egress routes as well as the structural stability of the building before entering the structure for prolonged periods of time.
- The tool is for use in assessing existing buildings with a possible combustible façade system. It is not a design tool and should not be used for design of new buildings.
- The internal fire safety provisions that are important for a fire starting and remaining in the room or compartment of fire origin are different than those required for a fire spreading through several stories of the building predominantly via the façade system. This tool recognizes this and therefore should not be used for a fire risk assessment of building fire safety provisions for a building without a combustible façade system.
- There is limited statistical data on fires involving the exterior façade system. Test data is largely proprietary and therefore generally not available to inform this study with the exception of test data explicitly cited by this work.
- The adopted risk ranking approach is based on the available literature and the engineering judgment of the global Arup and Jensen Hughes teams and the NFPA advisory panel.
- The tool assesses buildings in their completed state; i.e. it does not assess "temporary risks" that arise from construction work or partially occupied buildings; there are clear guidelines and tools available to assess those.
- This guide is not exhaustive and variations on the information presented may exist on specific buildings.
- The following façade types are not included in this guide as they are generally non-combustible and are not an extensive proportion of the external envelope of high rise residential and office buildings:
  - Shop front glazing systems & glazed atrium screens.
  - Structural glazing systems.
  - Glazed skylights/roof lights.
  - Concrete wall with applied finish e.g. paint, tiling, render etc.
  - Heritage facades of loadbearing masonry.
- The FRA tool does not address membranes within the façade system and does not take any benefit from perimeter fire stopping, cavity barriers or thermal barriers. The reasons for this are as follows:
  - Membranes are provided to resist water vapor and are an essential part of the façade system. Vapor barriers (rubber, bituminous materials) are combustible by their nature but are generally thinner than insulation or cladding
  - It will be difficult for a user to establish if perimeter fire stopping and cavity barriers have been installed properly.
  - Ignoring the benefits of perimeter fire stopping and cavity barriers is conservative.
  - Thermal barriers between a combustible façade system and the interior of the building are a requirement of the codes in the USA but are not required in all jurisdictions globally.
  - Thermal barriers can get damaged over time as services and other items are fixed back to the interior walls.
  - For these reasons any benefit of thermal barriers is ignored.
- The FRA tool references ASTM, NFPA, EN and the equivalent ISO reaction to fire tests only. Other National fire test standards are not considered. This is because:
  - The abovementioned test standards are the most prevalent internationally and most suppliers test to these standards.
  - Addressing all National test standards was not possible within the scope of this project. This is because they are not directly comparable to each other.
  - If a façade material is found to have as-built information that references other reaction to fire test properties then the advice of a fire engineer should be sought.
  - Similarly, large scale exterior wall fire test standards recognized by the FRA tool are NFPA 285 and BS 8414 parts 1 and 2 with performance criteria from BR 135.

6 Literature Review

6.1 Risk Assessment Tools

6.1.1 General

Risk is defined as likelihood x consequence.

The process of risk assessment is to identify the hazard(s) and then assess the likelihood (likelihood) and consequence of the hazard occurring (see Figure 6).

The likelihood of a fire occurring is linked to the hazards that may cause ignition combined with the presence of fuel and oxygen. Larger buildings, whether they are taller or have greater footprint have a greater risk of fire occurrence as there are more potential ignitions sources. The likelihood of a large fire is linked to the fire load available to burn, including construction materials used and whether the fire safety provisions can contain the fire to the room or floor of origin.

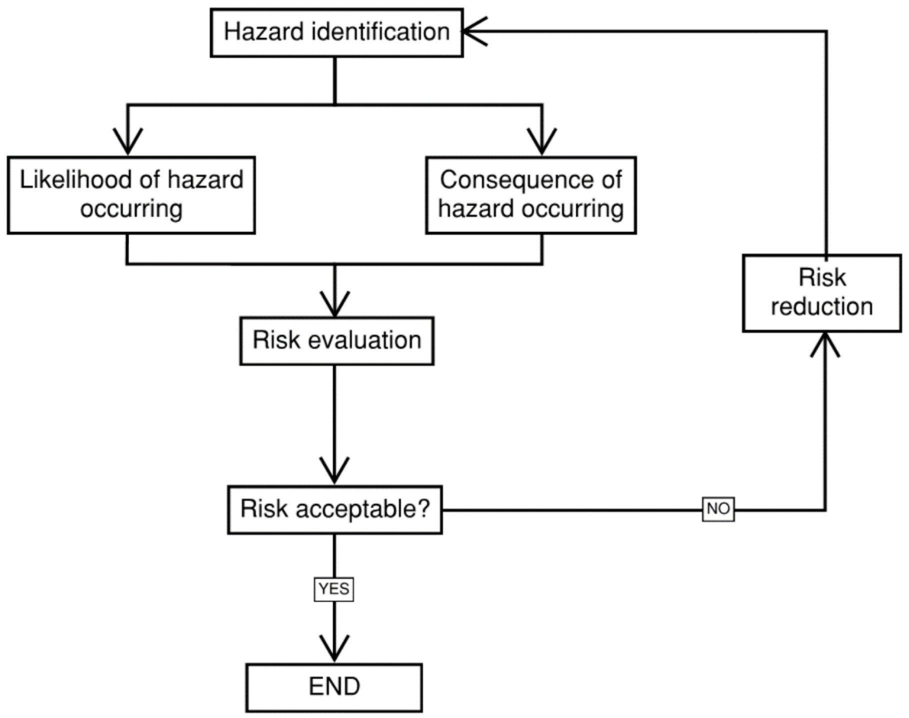


Figure 6 General approach to risk assessment

In the context of buildings with combustible façade systems, there are no active fire protection systems to contain the fire from spreading over the facade system beyond firefighter hose streams. If the fire breaks into the building then sprinklers may control a fire from spreading further inside the building but if a fire breaks into multiple floors the sprinkler system is likely to become overwhelmed as it would not have been designed for multiple fires on multiple floors simultaneously. There may be passive systems within the design of the façade assembly such as cavity barriers which may delay fire spread through a cavity or insulation layer but these do not act as fire breaks on the exterior face of decorative cladding systems.

6.1.2 Fire Safety Industry

In the literature [29], risk ranking is described:

"as the process of modelling to produce a rapid and simple estimate of relative fire risk. The incentive for risk ranking techniques is to provide decision makers with a transparent and defensible way of arriving at decisions."

Fire risk assessment approaches generally follow one of three approaches:

- Qualitative,
- Quantitative or
- Semi-quantitative.

All of these approaches are used in the fire safety industry but quantitative analysis is only possible if there is statistical data. There is no statistical data linking all of the variables of a combustible facade system on a high rise building with the likelihood or consequence of a fire. There are a number of reported fire incidents in the last 20 years which provide evidence of how fires have spread and how fire safety provisions have reacted but the actual impact of each fire safety provision or the combination of fire safety provisions cannot be quantified in this context within the timeframe (6 months) of this project.

There are a number of risk assessment tools available for use in the fire industry. Meacham *et al* [18] discuss many of these including quantitative, semi-quantitative and qualitative approaches. Quantitative approaches available include fault tree analysis, event tree analysis, FN curves based on frequency of events, probabilistic methods, cost benefit analyses and computer based risk assessment models using Monte- Carlo simulations of a large number of possible fire events and outcomes. These methods require statistical data (frequency of fires and number of deaths or extent of damage) of real fire events and the skills of a qualified fire engineer with the relevant experience in these types of analyses.

Four of the most widely used and most well documented semi-quantitative fire risk assessment tools or fire risk ranking methods are:

- US Fire Safety Evaluation System (FSES), published in NFPA 101A [22]
- Swiss Gretener method [9]
- UK Edinburgh scheme (A continuation of the FSES system) [17], [29]
- FRAME, Fire Risk Assessment Method (for) Engineering [http://www.framemethod.net/indexen.html, Nov 2017]

The FSES is a scoring method for developing equivalencies to the NFPA 101 Life Safety Code. The FSES and Edinburgh model are based on scoring and ranking of the risk variables. The scores are based on collective engineering judgment that is built-in to the methodology. The collective engineering judgments were collated using a Delphi method (a process which draws from the opinions of identified experts to develop relative rankings of variables) [29]. These methods are useful to inform the variables to be assessed by this project but the weighting or ranking of the variables does not explicitly address potentially large fires over several stories of a building involving combustible façade systems. Any scoring system proposed for this project would need to be re-evaluated in this context. For example, a detection system is important to detect a fire interior to the building for early warning and means of escape. In a facade fire, the fire alarm maybe more important because the detectors may not see the fire if it does not break inside the building.

The Swiss Gretener method [9][29] gives parameters associated with hazards (e.g. ignition sources) and protection measures (e.g. sprinklers) empirically derived numerical values. The product of these values gives a measure of potential hazard and protective measures. The ratio of these products is taken as a measure of expected fire severity.

The FRAME method is based on mathematical formulas of potential risk (R), acceptance and protection level. R must me less than 1 for a compartment to be adequately protected. It was developed for compartment fire scenarios in the interior of the building and while it is relatively easy to use, the theory behind it does not address a fire spreading over multiple stories of a building via the exterior façade system. The mathematical equations and justifications would have to be revisited for the fire scenarios of concern in this study. The author describes the method as follows "w*ith the FRAME - method one can calculate the fire risk in buildings for the property and the content, for the occupants and for the activities in it. A systematic evaluation of all major influence factors is given, and the final result is a set of values which express in numbers, what otherwise has to be said by a long description of positive and negative aspects. The method is not suitable for open-air installations*"

Qualitative approaches define hazard and consequence and therefore risk in words based on engineering judgment. An example of this is PAS 79 [26] adopted in the United Kingdom.

The inputs for a qualitative risk assessment are typically:

a) Identification of the premises and people at risk;

b) Identification of the fire hazards;

c) Assessment of the fire hazard likelihood; and

d) Assessment of the fire hazard consequence.

The PAS 79 approach defines 9 steps to a qualitative risk assessment. Annex B of PAS 79 proposes risk rankings in ascending order: Trivial, Tolerable, Moderate, Substantial and Intolerable. Risk is a function of the likelihood of a fire hazard and the consequence of that fire hazard occurring. Annex B of PAS 79 suggests a matrix to combine these two parameters to determine the risk category (see Figure 7).

	Likelihood of fire hazard *(definition in PAS 79)*		
Potential consequences of fire hazard ***(definition in PAS 79)***	**Low (***Unusually low likelihood of fire as a result of negligible potential sources of ignition***)**	**Medium** *(Normal fire hazards (e.g. potential ignition sources) for this type of occupancy, with fire hazards generally subject to appropriate controls (other than minor short comings)*	**High***(Lack of adequate controls applied to one or more significant fire hazards, such as to result in significant increase in likelihood of fire)*
Slight harm *(Outbreak of fire unlikely to result in serious injury or death of any occupant (other than an occupant sleeping in a room in which a fire occurs)*	Trivial risk	Tolerable risk	Moderate risk
Moderate harm *(Outbreak of fire could foreseeably result in injury (including serious injury) of one or more occupants but unlikely to involve multiple fatalities)*	Tolerable risk	Moderate risk	Substantial risk
Extreme harm *(Significant potential for serious injury or death to one or more occupants)*	Moderate risk	Substantial risk	Intolerable risk

Figure 7 PAS 79 matrix (figure extracted from [26])

PAS 79 also provides guidance and corresponding examples of documentation of risk assessments. Definitions of risk levels and associated action timescales from PAS 79 Annex B are given in Figure 8.

Risk level	Action and timescale
Trivial	No action is required and no detailed records need to be kept.
Tolerable	No major additional fire precautions required. However, there might be a need for reasonably practicable improvements that involve minor or limited cost.
Moderate	It is essential that efforts are made to reduce the risk. Risk reduction measures, which should take cost into account, should be implemented within a defined time period. Where moderate risk is associated with consequences that constitute extreme harm, further assessment might be required to establish more precisely the likelihood of harm as a basis for determining the priority for improved control measure.
Substantial	Considerable resources might have to be allocated to reduce the risk. If the premises are unoccupied, it should not be occupied until the risk has been reduced. If the premises are occupied, urgent action should be taken.
Intolerable	Premises (or relevant area) should not be occupied until the risk is reduced.

Figure 8 – PAS 79 risk level definitions (figure extracted from Annex B of [26])

Similarly, the National Health Service (NHS) in the UK have a risk matrix (5x5) of fire hazards versus consequence for risk managers to rank fire safety in hospitals from low to extreme risk[20].

Meacham et al report on the guidelines for risk assessments available from international organizations such as NFPA 551 [23], SFPE [28], BS PD 7974-7[4], ISO 16732-1[12]. These provide useful insight for users of a risk assessment methodology as well as those responsible for reviewing them. They help evaluate the appropriateness and execution of a fire risk assessment.

6.1.3 Seismic Industry

The seismic engineering industry can be required to assess a large number of existing buildings or structures against a level of seismicity and required level of performance. This could be because of a seismic event or new data on seismicity for a particular geography.

The American seismic industry has established a tiered system as part of ASCE 41-06[2] for evaluating the seismic resistance of buildings which can be summarized as follows:

- Tier 1 – Screening Phase (see Figure 9)
- Tier 2 – Evaluation and retrofit phase
- Tier 3 – Detailed evaluation and retrofit phase.

The level of assessment and evaluation increases with each tier. This approach allows a large number of buildings across a city or client portfolio to be studied relatively quickly and prioritized for further assessment in Tier 2 and 3.

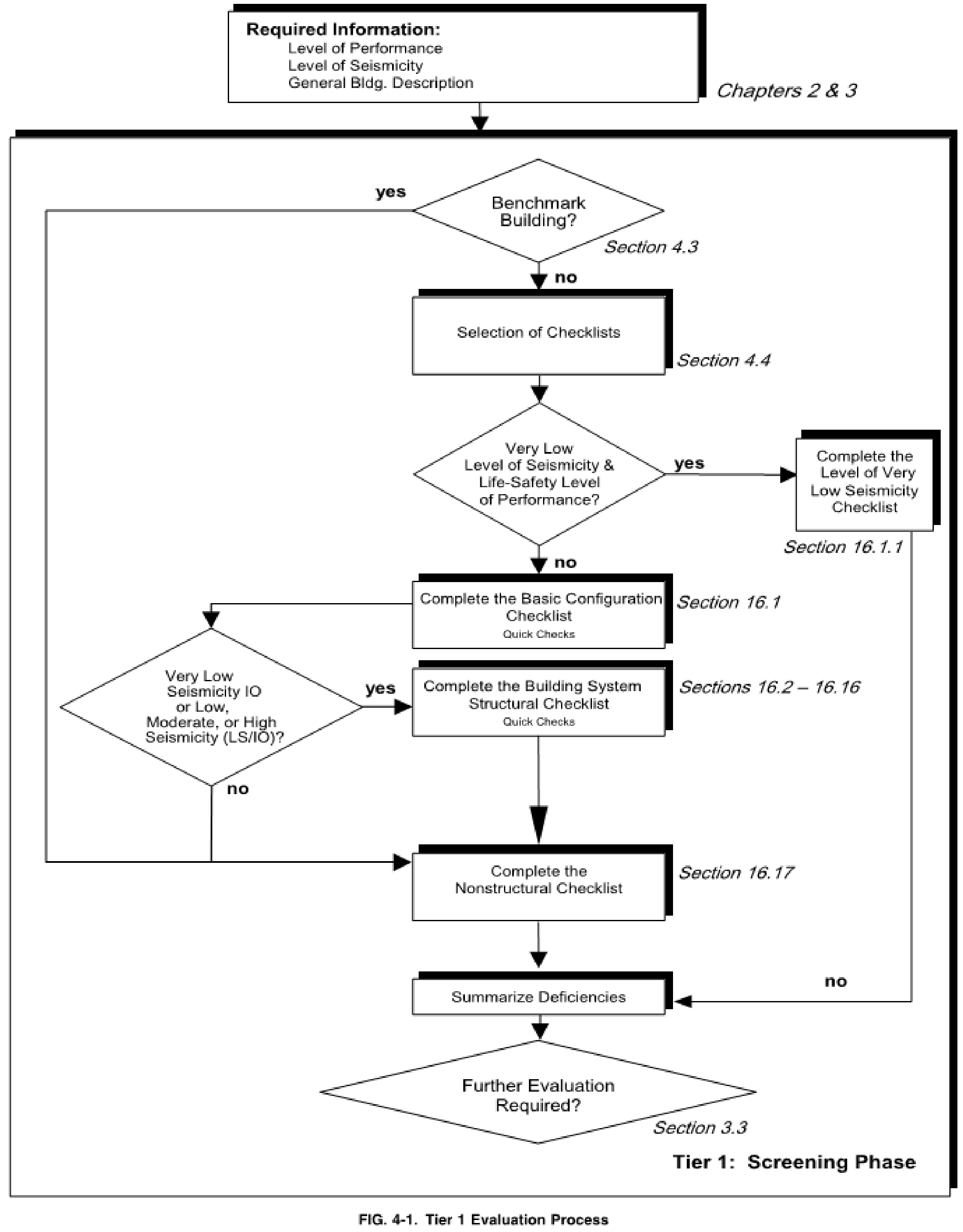


Figure 9 Tier 1 screening phase flowchart extracted from ASCE 41-06 [2]

6.1.4 Process Industry

The bowtie method [3] (Figure 10) is one of the risk assessment methods used in the process industry and is based around a visualization diagram that displays proactive and reactive risk management in the shape of a "bowtie". The "top event" (e.g. ignition sources near a combustible facade) is at the center of the diagram. The threats are on the left hand side and the consequences are on the right hand side. The diagram also has "preventive and reactive barriers" to mitigate the "top event".

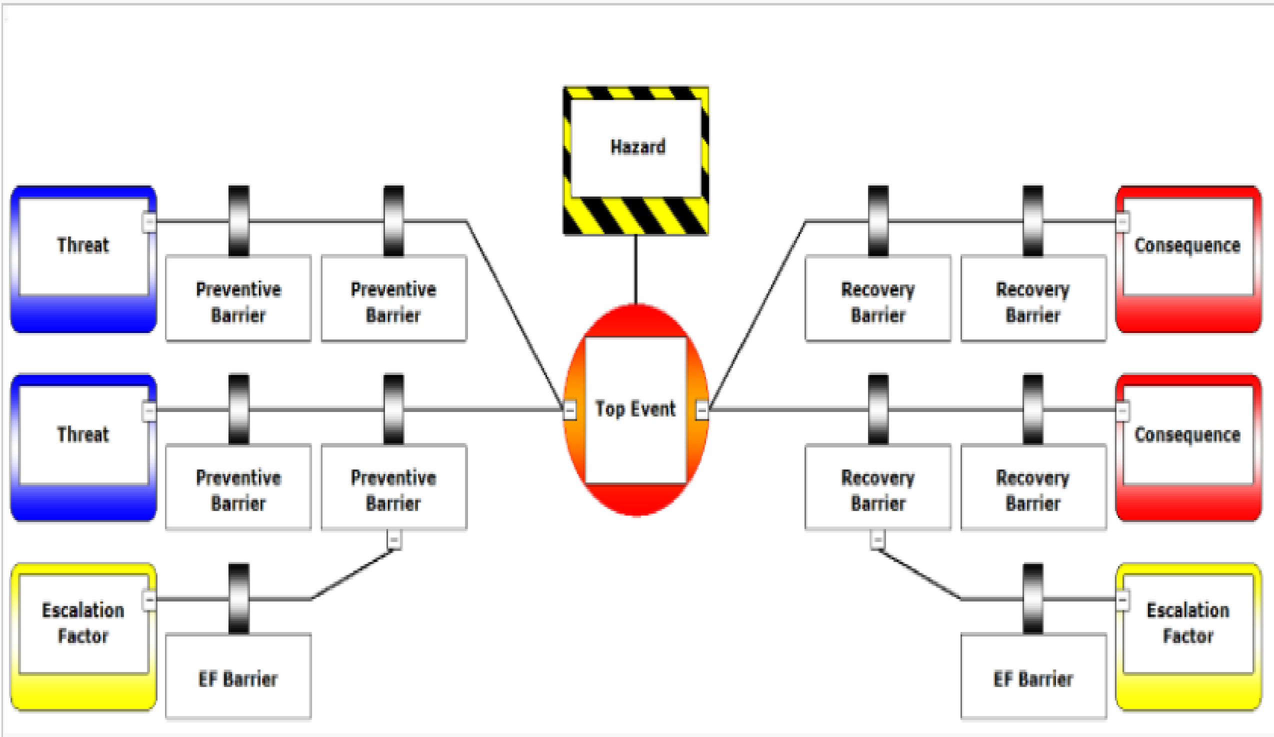


Figure 10 Bowtie method (figure extracted from [3])

6.1.5 Wildfires

Ignition of property as a result of wildfires and mitigation measures associated with the same have some parallels with the risk to facade systems in an urban environment. NFPA 1144 [24] provides a methodology for assessing wildland fire ignition hazards around existing buildings and guidance on mitigation measures. It also provides minimum requirements for new construction to reduce the potential of structure ignition from wildland fires. This document will be referred to again in the context of mitigation measures.

6.1.6 Occupational Health & Safety

BS 18004 *Guide to achieving effective occupational health and safety performance [5]*, has a basic outline for a risk assessment process. It acknowledges "*Whereas complex numerical methods are required for the assessment of some major hazards activities, in many circumstances OH&S risk can be addressed using simpler methods, which are either qualitative or semi-quantified. These approaches typically involve a greater degree of judgment, since they place less reliance on hard numerical data. In some cases such methods will serve only as initial screening tools, to identify where more detailed assessment is needed, or where measurements are needed*."

BS 18004 compares examples of risk assessment tools and methodologies in terms of strengths and weaknesses in Table E.1 of the standard (see Figure 11).

Table E.1 of BS 18004 concludes that checklists/questionnaires, risk matrices and ranking or voting tables are relatively easy to use while other methods require specialist knowledge.

Table E.1 **Comparisons of some examples of risk assessment tools and methodologies**

Tool	Strengths	Weaknesses
Checklists/ Questionnaires	• Easy to use • Use can prevent "missing something" in initial evaluations	• Often limited to yes/no answers • Only as good as the checklist used – it might not take into account unique situations
Risk matrices	• Relatively easy to use • Provides visual representation • Does not require use of numbers	• Only 2-dimensional – cannot take into account multiple factors impacting risk • Predetermined answer might not be appropriate to the situation
Ranking/ Voting tables	• Relatively easy to use • Good for capturing expert opinion • Allows for consideration of multiple risk factors (e.g. severity, probability, detectability and data uncertainty)	• Requires use of numbers • If the quality of the data is not good, the results will be poor • Can result in comparison of incomparable risks
Failure modes and effects analysis (FMEA); Hazard and operability studies (HAZOP)	• Good for detailed analysis of processes • Allows input of technical data	• Needs expertise to use • Needs numerical data to input into analysis • Takes resources (time and money) • Better for risks associated with equipment than those associated with human factors
Exposure assessment strategy	• Good for analysis of data associated with hazardous materials and environments	• Needs expertise to use • Needs numerical data to input
Computer modelling	• If relevant and sufficient data are available, computer modelling can give good answers • Generally uses numerical inputs and is less subjective	• Significant time and money needed to develop and validate • Potential for over-reliance on the results, without questioning their validity
Pareto analysis	• A simple technique that can assist in determining the most important changes to make	• Only useful for comparing similar items, i.e. is unidimensional

Figure 11 Table E.1 from BS 18004, comparing strengths and weaknesses of different risk assessment tools (figure extracted from [5]).

6.2 Weighting of Variables in Risk Ranking Tools

6.2.1 Fire Risk Index Method

Fire risk indexing is described by Watts[29] in the SFPE Handbook. He defines risk indexing "*as heuristic models of fire safety. They constitute various processes of analyzing and scoring hazard and other system attributes to produce a rapid and simple estimate of relative fire risk. They are also known as rating schedules, point schemes, ranking, numerical grading, and scoring. Using professional judgment and past experience, fire risk indexing assigns values to selected variables representing both positive and negative fire safety features*". He describes various techniques some of which are also described in the following sections of this report.

6.2.2 Delphi Method

The Delphi method [29] is a way of obtaining a collective view from individuals about issues with no quantitative data. The process can also create group ownership and enable consensus among professionals or experts with differing backgrounds and therefore views.

It is an iterative questionnaire exercise with controlled feedback to a group of experts who are anonymous. The experts are therefore not swayed by group dynamics and the process allows individuals to re-evaluate their answers to the questionnaires in the light of the responses of the group as a whole.

The Delphi method has been used in many fields or industries. The FSES in NFPA 101a is based on a Delphi method[21].

Researchers in Lund University have developed a fire risk index method for multi-story apartment buildings of timber construction[10],[14],[15],[16]. The method is based on risk ranking to permit timber construction when the risk is acceptable. The risk ranking was developed using a Delphi method with 20 panel members from each of the 5 Nordic countries.

6.2.3 Analytical Hierarchy Process

The analytical hierarchy process (AHP) is used in a number of industries to rank the relative importance of variables to each other [27]. Figure 12 shows a typical AHP where several individuals are asked to rank the relative importance of excellence, cost and location when selecting a school. Each criteria is ranked against each other. A maximum of six variables should be compared for the methodology to be reliable [16].

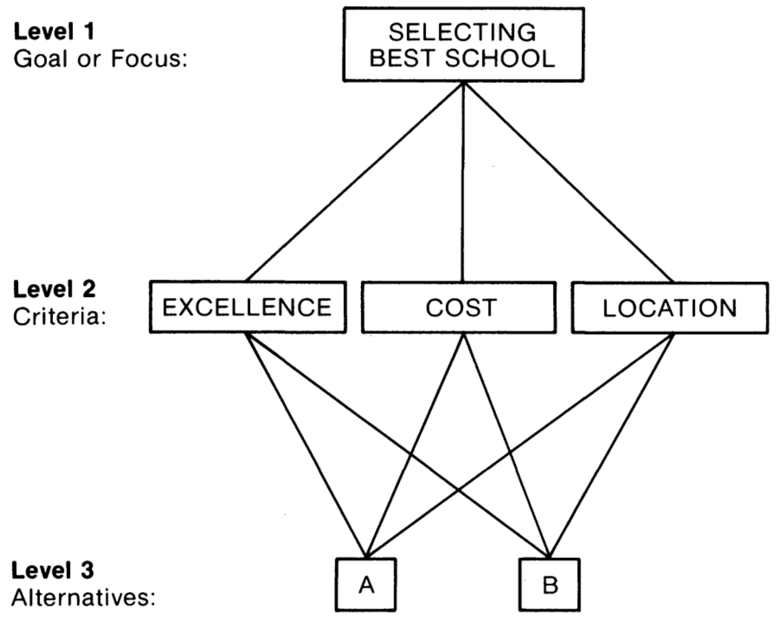


Figure 12 AHP process as applied to selecting a school (figure extracted from [27]).

Figure 13 shows a similar image for variables associated with fire safety and particularly means of escape and warning.

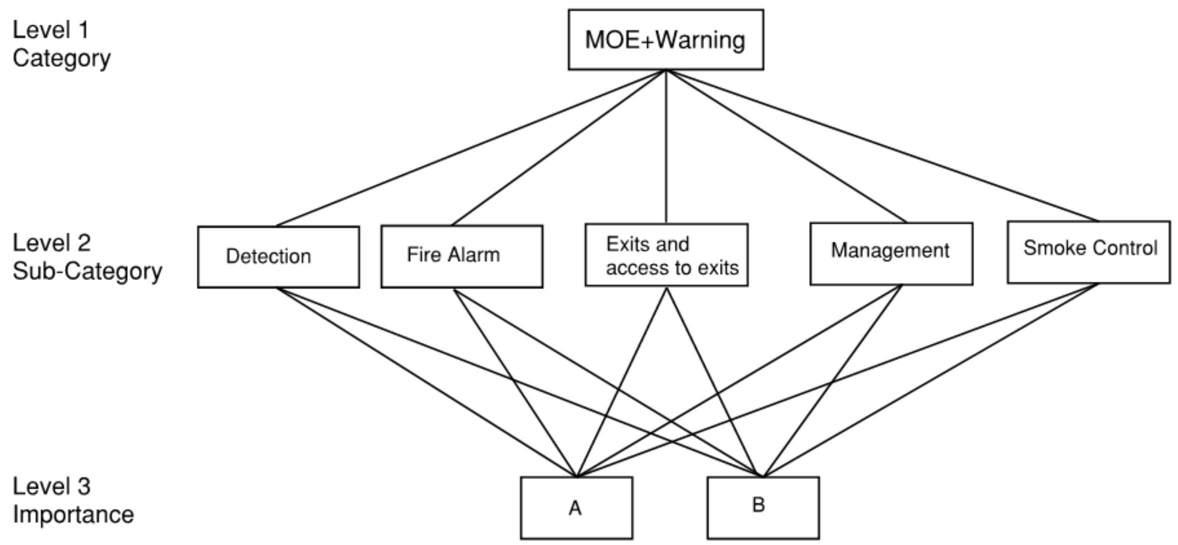


Figure 13 AHP process as applied means of escape (MOE) and warning (© Courtesy of Arup)

Figure 14 shows an excerpt from a spreadsheet where the AHP process has been embedded to assess the hierarchy of the means of escape and warning sub-categories (criteria) in Figure 13. In this example, a participant assesses the relative importance of detection, fire alarm, exit paths, fire safety management and smoke control. A score of 1 means that "A" is equally important to “B”. A score of 2 means that “A” would be twice as important as B and 3 would be three times as important and so on.

		Criteria		more important ?	Scale
i	j	A	B	A or B	(1-3)
1	2	Detection	Fire Alarm	B	3
1	3		Exit and access to	B	3
1	4		Management	A	2
1	5		Smoke Control	A	2
1	6				
1	7				
1	8				
2	3	Fire Alarm	Exit and access to	A	1
2	4		Management	A	3
2	5		Smoke Control	A	3
2	6				
2	7				
2	8				
3	4	Exit and access to exits	Management	A	3
3	5		Smoke Control	A	3
3	6				
3	7				
3	8				
4	5	Management	Smoke Control	A	1
4	6				
4	7				

Figure 14 AHP process as applied to means of escape (MOE) and warning using the spreadsheet software by Goepel[10] and verified by Arup

Figure 15 is a summary of the AHP after several participants (8no.) have assessed the relative importance of the sub-categories in Figure 13. The sheet ranks each of the 5 sub-categories from 1-5, weights each of the rankings and provides information on the consensus of all participants. In this example, the participants were advised that they should rank these sub-categories in terms of importance for a high rise building with a combustible exterior facade. The exits and exit access ranked 1st with a weighting of 29% followed by fire alarm and then detection. Management and smoke control were considered less important with weightings of about 12% each.

The AHP method is relatively simple to use when there are a limited range of variables to assess. It does not rely on a questionnaire but asks participants to score the relative importance of variables, in this case fire protection hazards and fire safety provisions. The expertise of the participant will have an impact on the outcomes but his is true of all of the risk ranking approaches.

AHP Analytic Hierarchy Process (EVM multiple inputs)

K. D. Goepel Version 04.05.2016 | Free web based AHP software on: http://bpmsg.com

Only input data in the light green fields and worksheets!

n= 5 Number of criteria (2 to 10) Scale: 1 AHP 1-9

N= 8 Number of Participants (1 to 20) α: 0.1 Consensus: 92.1%

p= 0 selected Participant (0=consol.) 2 7 Consolidated

Objective: Life safety during egress

Author: SI

Date: 3-Aug-17 Thresh: 1E-07 Iterations: 5 EVM check: 2.1E-08

Table	Criterion	Comment	Weights	Rk
1	Detection		21.0%	3
2	Fire Alarm		24.4%	2
3	Exit and access to exits		29.3%	1
4	Management		12.0%	5
5	Smoke Control		13.3%	4
6			0.0%	
7			0.0%	
8			0.0%	
9		for 9&10 unprotect the input sheets and expand the	0.0%	
#		question section ("+" in row 66)	0.0%	

Result: Eigenvalue lambda: 5.013

Consistency Ratio 0.37 GCI: 0.01 CR: 0.3%

Figure 15 AHP process as applied means of escape (MOE) and warning using the spreadsheet software by Goepel[10] and verified by Arup

6.2.4 PIRT

Diamond [6] describes the phenomena identification and ranking technique (PIRT) in relation to nuclear technology issues. Diamond explains that it is *a “systematic way of gathering information from experts on a specific subject, then ranking the importance of the information in order to meet a decision-making objective”.* It is used to prioritize the way nuclear analysis is undertaken. The ranking technique uses a matrix approach combining knowledge with importance. Issues of high importance but limited knowledge are then prioritized for further research. This approach could be used to prioritize research in the field of façade fires but has limited applicability to this scope of work.

		Importance		
		H	M	L
Knowledge Level	K			
	P	*		
	U	*	*	

*** Research in this area is suggested**

Figure 16 PIRT matrix of knowledge versus importance, (extracted from [6]).

6.3 Global Survey of High Rise Fire Safety Provisions

The Arup global fire practice was asked to answer a series of questions about the fire safety provisions required for office or residential buildings in their respective countries. The questions also asked about current practice and the fire safety provisions that might be expected in existing buildings.

6.3.1 Survey Findings

6.3.1.1 Building Height and Fire Safety Provisions

As building height increases, the fire safety codes require more fire safety provisions. The height at which additional fire safety provisions are required varies slightly but not significantly from country to country or region to region. In modern codes, high rise buildings are typically defined as being over about 25m high. The introduction of fire-fighting elevators starts at 18m in the UK. Sprinklers are required in new buildings by most jurisdictions in buildings over 23-30m high.

However, based on the survey, a large number of existing residential buildings globally are likely to be unsprinklered so linking sprinkler protection to building height i.e. assuming a building over 30m is sprinkler protected is not proposed. Sprinklers should be considered in the context of ignition risk inside the building or on balconies. Sprinklers have some benefit in protecting escape routes by delaying a fire from growing once it has broken into a building but this benefit will reduce if the fire breaks-in on multiple floors as the pressure and water supply are not expected to cope with the demand of multiple fires.

Most towns and cities have high-reach ladder appliances to assist fire fighters in reaching high rise buildings but very few have the most modern appliances with ladders of 100m in length. For this reason it is assumed that fire fighters will not be able to fight a facade fire from the exterior if the building is over 30m high.

It is proposed that the ranges for building height will be 18<h<30m, 30<h<50m, h> 50m.

6.3.1.2 Evacuation and Fire Alarm Approach

Based on the answers to the survey, there are three main approaches to evacuation, defend in place (stay-put), phased (fire floor/floor above and below) or simultaneous evacuation. In some countries, the defend in place strategy includes a fire alarm that can be raised in all common corridors.

If there is no "all out" fire alarm option where an alarm sounds in every room/space in the building then it shall be treated as "stay-put" even if common corridors have a fire alarm system that can sound on all floors. This is because the occupant of the apartment may not hear an alarm in a common corridor.

The defend-in place evacuation strategies all rely on fire rated compartmentation to apartment units. Phased evacuation strategies rely on compartmentation floor by floor although apartments will also be constructed in fire rated compartments.

6.3.1.3 Material and Façade Assembly Test Methods

Most countries either prohibit combustible materials on the façade system entirely or permit them if the actual façade assembly proposed for the building passes a large scale fire test (e.g. NFPA 285).

Not all countries have a large scale test and where they do, they differ from country to country.

This does not impact upon the FRA tool but it does mean that material data sheets including fire testing and certification of façade cladding, insulation or the entire façade system found in as built-information will differ from country to country and the user's guide for this FRA tool will need to address this.

6.4 Summary of Literature Review

Based on the literature review and the scope of the proposed fire risk assessment tool it is proposed that the methodology should be qualitative or semi – quantitative as these approaches are simpler to use. This is appropriate for the intended end-users.

A tiered approach to risk assessment as adopted by ASCE 41 would allow the tool to prioritize buildings for detailed assessment when there is a city or large portfolio of buildings to assess. If a building does not have a combustible facade system then it can be eliminated from further assessment at the first tier. This approach does not address any issues with other fire protection systems within the building when there is a non-combustible façade system. The purpose of this tool is to address the risk posed by combustible facade systems.

While there are existing fire risk assessment ranking systems such as FSES, FRAME etc. these were not developed considering the potential for a multi-story fire in the façade system on the exterior of the building, with the possibility of fire breaking into multiple levels of a building. A new scoring or weighting system for the risk variables will need to be developed using a Delphi method or similar.

The AHP approach to developing risk ranking or weightings of variables is relatively easy to use and does not rely on questionnaires. It should be used within its limitations and only rank up to 6 variables at a time.

It is proposed that buildings will be assessed based on building height (h) with break points at 18<h<30m, 30<h<50m, h> 50m and evacuation strategy either "all-out" or "stay-put".

If there is no "all out" fire alarm option where an alarm sounds in every room/space in the building then it shall be treated as "stay-put" even if common corridors have a fire alarm system that can sound on all floors. This is because the occupant of the apartment may not hear an alarm in a common corridor.

As existing buildings of any height may or may not have sprinklers, the presence of sprinklers should be considered separately and independent of building height. Sprinklers should be considered in the context of controlling an interior fire and reducing the likelihood of ignition of a façade system from an interior initiating fire.

7 Variables Associated with Combustible Façade Systems and High Rise Building Fire Safety

7.1 Façade System

The common variables associated with facade systems are described in Table 1. They are grouped into categories and sub-categories to help organize them within the FRA tool. Sub-categories highlighted in grey are not proposed to be considered by the FRA tool. The reasons for this are briefly described within the Table and then further in Section 9 of this report.

Category	Sub-category	Variables
Components of façade system	Framing	Aluminium, occasionally steel if facade is also fire rated or supporting heavy cladding materials such as stone panels. Framing is non-combustible therefore is not proposed to be considered by the FRA tool.
	Exterior cladding	Combustible materials or composites such as ACPs, MCMs, timber, EIFS/ETICS, SIPs, HPLs, GRP. Non-combustible cladding such as natural stones, glass, masonry, brick, terra cotta, ceramics, GRC, solid metals (e.g. aluminium, steel, stainless steel, copper, titanium), factory painted (<0.3mm thick) metals, mineral wool, cement plaster and concrete. Combustible cladding can be expected to contribute to a façade fire. Surface area of combustible cladding may contribute to the rate of fire spread.
	Insulation	Combustible insulation such as, XPS, EPS, PUR, PIR, SPF, Phenolic, encapsulated (EIFS/ETICS) or not. Non-combustible insulation such as mineral wool or glasswool. Combustible insulation can be expected to contribute to a façade fire.
	Location of insulation in facade system	Attached to substrate or cladding or as part of EIFS/ETICS or SIP system.
	Cavities in facade system	Size of air gap (50mm is common but it can range from 0-150mm or more). In rainscreen systems, good quality façade construction would have cladding attached to the structure using façade runners (framing). Poor construction fixes it back to the wall directly. The runners create a greater air gap (usually 50mm+). The air gap may be filled with insulation or not. Cavities provide a path for flames and hot gases to readily travel inside the facade system as well as on the outside.
	Membranes (e.g. Impermeable vapor barrier / permeable breather membrane)	Membranes in facade systems are typically impermeable vapor barriers and permeable breather membranes. They are important to the overall performance of the façade system as the envelope to a building. Vapor barriers (rubber, bituminous materials) are combustible by their nature but are generally thinner than insulation or cladding. For this reason and because they cannot be removed from the facade system they are ignored by the FRA tool.
Façade system joints	Joints	Joints can be filled or unfilled. Joints provide a route for flames to ignite combustible materials but they are present in all façade systems and do not contribute significantly fire load therefore are not considered by the FRA tool.
	Joint sealant	Silicone or other combustible joint sealing material Combustible joint seals are common but form a small part of a facade system when compared to insulation or cladding therefore are not considered by the FRA tool.
Façade system arrangement	Vertical or horizontal strips of combustible façade system	Façade systems can comprise any pattern of vertical or horizontal connections. Office buildings tend to have horizontal spandrels at slab level. Residential buildings tend to have more cladding and smaller windows although full height glass walls are also possible. Vertical strips will aid vertical fire spread over the height of the building compared to horizontal strips, with no vertical connection.
	Balconies	Balconies can be cantilevered from the building or partially enclosed on up to 5 sides. They provide horizontal and vertical surfaces which may hinder or help fire spread respectively. They will provide ignition sources to a façade system. They may not be sprinklered even if the rest of the building is sprinkler protected.
	Corners in façade system	Fire spread over a façade system is expected to be more rapid when two walls form a corner to each other i.e. at 90 degrees[8]. This is true but is not proposed to be assessed by the FRA tool. This may be considered by a FRA conducted by a team of engineers but is too detailed for this FRA tool.
Passive fire safety measures associated with a façade system	Fireblocking, window lintels, cavity barriers	Could be present or not depending upon code requirements and design. Properly installed fireblocking or cavity barriers are expected to delay fire spread in the insulation and air gap between cladding and insulation or main structure.
	Perimeter fire stopping	Could be present or not. Perimeter fire stopping is intended to delay fire and smoke spread via the gap between the edges of a fire rated floor slab and a façade system.

Category	Sub-category	Variables
Other	Age of façade system	It is likely that ageing of a façade system will expose the cores of ACPs at the joints of the system therefore making ignition easier. An EIFS/ETICS system may also be damaged over time. Damage of an EIFS/ETICS system is considered as the outer skin is essential to the fire performance of the system. Damage to other materials is not addressed.

Table 1 Variables associated with a façade system

7.2 Facade Ignition Sources

Façade system fires can occur as a result of a range of ignitions sources. They can be characterized by their location relative to the façade as shown in Figure 17.

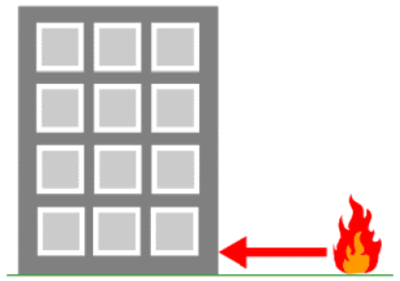
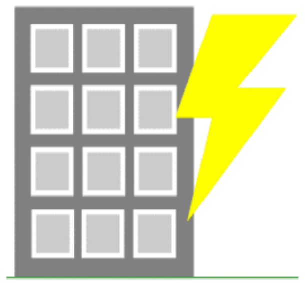
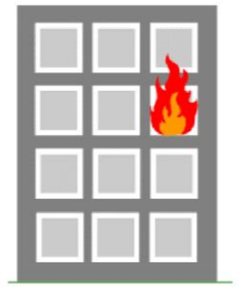
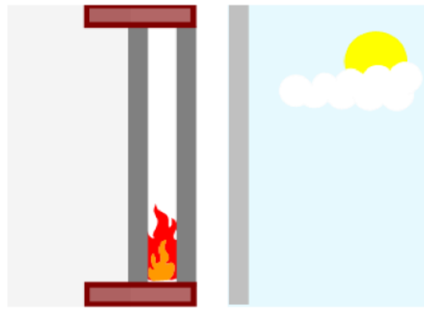
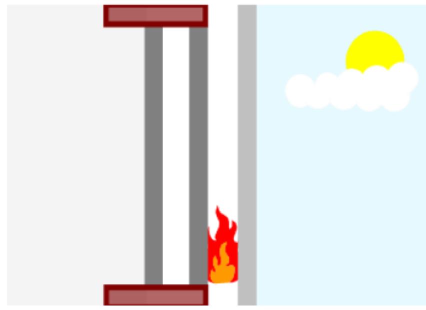
No.	Scenario	Description of ignition sources
1a		Fire external to the building but not impinging on the façade – e.g. fire in an adjacent building or a nearby vehicle
1b		Fire external to the building and impinging on the façade at the base of the building– e.g. fire in a parked vehicle or trash container at the base of the building
		Fire external to the building and impinging on the façade at any height over the building – e.g. fire on a balcony, in a photovoltaic panel, lighting system, automated shading system or green façade system. Ignition sources could be overheating of electrical components, cigarettes, lighting strikes, BBQs, Shisha pipes etc.
2		Fire internal to the building which breaks out via a window or other opening to reach the façade system – e.g. fire in an apartment. If the building is sprinkler protected throughout and the sprinkler system is maintained then the likelihood of this interior fire breaking-out to the facade is reduced. High hazard rooms with unprotected walls to the exterior (e.g. generator rooms, sub-stations) also pose a potential ignition risk to the façade system
4a		Fire within an internal cavity of the façade system between cavity barriers or fireblocking. Electrical wiring can be found in wall cavities therefore overheating of electrical components within the cavity could pose an ignition source.
4b		Fire within an internal open cavity of the façade system. Ignition source as above but in this case there are no cavity barriers or fireblocking to delay fire spread.

Figure 17 Fire Hazards in the vicinity of façade systems (© Courtesy of Arup)

7.3 Other Variables

Other variables associated with fire safety in high rise buildings have been taken from other fire risk assessment methods such as the FSES. These are listed Table 2 and also grouped into categories and sub-categories to help organize the FRA tool.

Table 2 Variables associated with fire safety in high rise buildings except façade systems

Category	Sub-category	Description of other variables
Building characteristics	Construction Type	Construction type (structural steel, concrete etc.).
	Evacuation Strategy	Simultaneous evacuation of the entire building, phased evacuation by evacuation zone (typically the fire floor, floor above and below) or "stay-put"/defend-in place which means the occupant of the fire affected apartment only would be alerted to evacuate, all other occupants remain inside the building.

Category	Sub-category	Description of other variables
	Building height	Building height is measured from fire department access level to the top most occupied floor as this gives an indication of the height occupants must travel to each grade.
	Floor Area	This is the gross floor area of the building and is linked to the amount of fire load and ignition risks present as well as the number of people in the building.
	Occupants at Risk	Are occupants sleeping or awake, familiar or unfamiliar with the building. How many people are inside the building and at what height, for example is there a bar or restaurant near the top of the building.
Means of Escape and Warning	Detection	Manual, automatic smoke, automatic heat, automatic via sprinkler flow switch.
	Fire Alarm	In apartment only Phased over 3 floors Simultaneous activation possible automatically and/or manually
	Exits and access to exits	Number of stairs. Are stairs remotely located? Fire rating of stairs. Corridor fire rating. Lining materials on walls/ceilings along escape routes. Fire stopping to stairs/corridors present or not. Fire doors present or not, condition? Exits open or locked. Façade fire exposure to stairs (windows or glazing on stairs). External stairs beside facade. Façade fire exposure to exit discharge routes. Façade debris falling to the ground above exit discharge.
	Management	Housekeeping Maintenance of all passive/active fire safety systems (reliability)
	Smoke Control	Smoke control present in exit routes open to atria or similar. Smoke control/pressurization to stairs or corridors. Is it maintained (reliability)?
Containment and Extinguishment	Sprinklers	Extent of system (none, partial, throughout). Quick or standard response. Maintained (reliability)? Supplied by public mains or dedicated tank. Fire pumps (duty or duty/standby). Maintained?

Category	Sub-category	Description of other variables
	Fire Service access	Perimeter access to building? Street hydrants? How easy is it to access the façade if it was on fire Fire station location/proximity/response time. Internal firefighting measures (standpipes, firefighting shaft with protected elevators/stair/lobby) Communication systems
	Compartmentation	Fire stopping, fire doors etc. in fire rated walls between apartments or other rooms (e.g. storage etc.)
	Atrium	The presence of atria or not. How many floors connected? Exit access through atrium or not. While this variable is important for a fire starting on the interior of the building, due to smoke spread vertically through the building, it is not considered further here. Fire and smoke spread via the façade system is assumed to be the dominant means of fire spread in which case multiple stories of the building are already involved.

8 AHP

As the existing fire risk assessment tools in the industry do not address the likelihood and consequence of a multi-story facade fire explicitly, the relative importance of the categories and sub-categories discussed in Section 7 have been weighted using an analytical hierarchy process (AHP) survey of Arup/Jensen Hughes and the NFPA project panel. The background to AHP is documented in the literature review (see Section 6.2.3).

The AHP results are assumed to apply equally to both high rise residential and high rise business use. This is because the answers to the AHP should inform the relative importance of common fire safety measures. For example, if the AHP states that means of warning and escape is relatively more important than containment and extinguishment then a residential building with a "stay-put" evacuation strategy, relying on containment will pose a higher life safety hazard than an office or residential building with an "all-out" evacuation strategy.

The categories and sub-categories assessed using the AHP are listed in Table 3. A total of 34 participants (20 from Arup, 10 from Jensen Hughes and 4 from the NFPA project panel) from different global locations (Asia, Europe, Australia, UK, USA, Middle East) and each having a minimum 5 years of experience have taken the questionnaires. Most participants have been working on projects or risk assessments tackling the issue of combustible façade systems.

Table 3 – Categories and sub-categories proposed to be assessed by the FRA tool

Category	Sub-category	Variables
Façade System (fuel) and Ignition Sources – A combustible façade system that could ignite due to the presence of external or internal ignition sources.	Façade ignition sources	Likelihood of a fire due to ignition sources in the vicinity of the façade (in the façade cavity, at the base of the building and over the façade e.g. balconies). This also includes uncontrolled, i.e. non-sprinklered, internal ignition sources which can affect the facade.
	Façade Component Materials	The presence of combustible insulation and/or cladding materials in the façade system.
	Combustible vertical connections	Vertical connectivity of a combustible façade system over the height of the building and the path it may provide for fire spread.
	Perimeter fire-stopping	Reliable fire-stopping system between each floor slab and the façade to prevent internal fire spread from one floor to another via the gap between the façade and the floor slab.
	Cavity barriers/fireblocking	Cavity barriers installed to limit fire and smoke spread in the cavities of a façade system.
Means of Escape and Warning - Availability of protected exit routes and the ability to initiate evacuation.	Detection	Automatic and manual detection provided throughout the building.
	Fire Alarm	The capability to sound the alarm throughout the building simultaneously by pressing an "all-out" button at the fire command center.
	Exits and access to exits	The availability of at least one exit stair for egress, its construction, access control and the construction of routes leading to the exit stair.
	Management	Management and maintenance employed to keep escape routes clear and to maintain fire safety systems (active and passive) associated with means of egress and warning.
	Smoke Control	Active smoke control (e.g. pressurization) in egress routes to keep them clear of smoke.
Containment and Extinguishment - Fire safety provisions to delay or prevent fire and smoke spread throughout the interior of a building.	Sprinklers	Reliability of the sprinkler system installed throughout the building interiors but not on balconies or other external areas.
	Fire Service facilities	Presence of firefighting facilities such as fire appliance access, access to exterior and interior fire-fighting water and fire-fighting elevators.
	Compartmentation	Adequacy of compartmentation between floors and between apartments / tenancies and corridors / shafts. This is about spread of fire throughout the building. Compartmentation of exit routes is covered separately in the exits category of "means of egress and warning".

8.1 Weighting of Categories

The results (see Table 4) of the AHP survey have been divided into four columns, one that represents the outcome of the assessment from representatives of Arup, one from Jensen Hughes, one from the NFPA project panels and the other shows the overall results of all three parties.

The percentage scores indicate how each group has weighted the relative importance of each category and sub-category. A higher percentage score indicates a greater relative importance.

Table 4 Results of AHP

Comparison of Categories							
	ARUP	**#**	**JH**	**#**	**NFPA**	**#**	**Overall**
Façade Hazard	36%	20	31%	10	41%	4	35%
Means of Escape and Warning	38%	20	37%	10	32%	4	37%
Containment and Extinguishment	27%	20	33%	10	27%	4	29%

Category: Means of Escape and Warning							
	ARUP	**#**	**JH**	**#**	**NFPA**	**#**	**Overall**
Detection	19%	20	18%	10	17%	4	18%
Fire Alarm	26%	20	22%	10	22%	4	24%
Exit and access to exits	29%	20	30%	10	29%	4	29%
Management	15%	20	15%	10	17%	4	15%
Smoke Control	12%	20	16%	10	15%	4	13%

Category: Containment and Extinguishment							
	ARUP	**#**	**JH**	**#**	**NFPA**	**#**	**Overall**
Sprinklers	40%	20	36%	10	31%	4	38%
Fire Service Facilities	21%	20	31%	10	37%	4	26%
Compartmentation	40%	20	33%	10	31%	4	37%

Category: Façade Hazard							
	ARUP	**#**	**JH**	**#**	**NFPA**	**#**	**Overall**
Façade ignition sources	20%	20	17%	10	22%	4	20%
Component materials	30%	20	25%	10	30%	4	29%
Combustible connections	20%	20	22%	10	19%	4	21%
Perimeter fire stop	14%	20	19%	10	14%	4	16%
Cavity barriers	15%	20	17%	10	16%	4	16%

The results of the AHP are broadly the same for Arup/Jensen Hughes and the NFPA project panel.

All parties agreed that fire alarm and availability of exits are most important in the means of escape and warning category. Detection ranks third with management and smoke control fourth and fifth respectively. This is to be expected as the fire is assumed to be predominantly on the exterior of the façade making interior detection less important than fire alarm.

All parties placed equal importance on sprinklers and compartmentation in the containment category. NFPA scored fire service facilities slightly higher than Arup or Jensen Hughes. Sprinklers reduce the likelihood of an interior fire igniting a combustible façade. Sprinklers have also been shown to slow a fire breaking into a building but if the fire breaks-in on multiple stories then the demand on the water pressure and water source can be expected to outweigh the supply. Compartmentation delays fire and smoke spread interior to the building (but not via the façade) and can be expected to be available for longer than a sprinkler system, provided the compartmentation is installed properly. Compartmentation between apartments and the exit corridors also adds another barrier between the fire on the facade and the interior escape stairs, provided the stairs are interior to the building and not exterior.

For the category of Facade Hazard, the weightings assigned to perimeter fire stopping/cavity barriers are considered to be relatively more important by Jensen Hughes than Arup or NFPA but this is marginal. However, all parties agreed they were the least important variables when the facade system is combustible. All parties agreed that the component materials are the biggest hazard followed by ignition and connectivity of the materials over the vertical height of the facade system. This is to be expected as cavity barriers may delay fire spread via the cavity but if the exterior cladding is combustible they cannot delay fire spreading on the front of the cladding. Perimeter fire stopping is intended to prevent an interior fire breaking into the floor above but if the fire enters the façade cavity or starts on the cladding these are likely to become ineffective.

In terms of AHP weightings for each of the three main categories, means of escape and warning and façade hazard score higher than containment. This indicates that where there is a combustible façade system with ignition hazards that evacuation of the building is more important than containment measures interior to the building. This in turn implies that a residential “stay-put” strategy for protecting occupants from a fire is not an appropriate strategy for a fire spreading over multiple stories of the building via the façade.

These results have been used to inform the FRA tool methodology as explained in Section 9 of this report.

9 Methodology

9.1 General

In general, the FRA tool is intended to be used AHJ's to assess a portfolio of buildings across a town or city where there is a concern that the exterior facade systems are built-up from combustible materials. The FRA tool is intended to provide a framework to aid the AHJ to prioritize buildings in their jurisdiction and to conduct initial fire risk assessments of each building, assessing the highest priority buildings first. A range of possible mitigation measures are suggested to help the AHJ and building owner to begin reducing the fire risk where necessary. The tool can be used to measure the success of the mitigation by revisiting the risk assessment.

Figure 18 and Figure 19 illustrate the proposed methodology for the FRA tool. The methodology relies on a two-tier process, which has been adopted to help the user refine the inspection need when confronted with large building portfolios:

- Tier 1 – Desktop study of a portfolio of buildings to establish a priority ranking for further assessment. This could be by a building owner, facilities manager or the AHJ. A small number of questions with clearly pre-defined answers are posed of the users for the Tier 1 assessment to inform the ranking of buildings that then require further detailed assessments.
- Tier 2 – A FRA evaluation by the AHJ, prioritized by the ranking in Tier 1, involving on-site inspections, review of as built information and maintenance records, sampling and laboratory testing of unknown façade materials.

In some instances the Tier 2 assessment will highlight the need for a more detailed risk assessment by a qualified engineering team of façade and fire engineers. This could be because of the complexity of the building, complexity of the façade patterns (combustible cladding/insulation is randomly arranged or non-uniform across the building), difficulties in identifying the façade systems/materials or because the owners objectives are wider reaching than life safety only e.g. business continuity or upgrading the façade system to achieve better aesthetics, acoustics, thermal performance etc. This more detailed FRA would be Tier 3 of this methodology and is outside the scope of this document.

Tier 1 and 2 are further sub-divided into two parallel processes, "A" and "B", which focus on A) facade fire hazards and ignition sources, and B) internal fire safety provisions, respectively. The two parallel processes have been introduced for the following reasons:

- If the building does not have a combustible façade system then no further assessment is required using this tool. This may be established at Tier 1A or if it is unknown or in doubt at this early stage it may be determined in Tier 2A.
- It allows the AHJ to identify deficiencies interior to the building which should be rectified regardless of the situation with the façade system e.g. if the fire pumps are OFF or the fire alarm panel has multiple faults etc. These changes can be identified through the "B" processes at each Tier.
- Separating the two subjects provides more visibility of the results to the enforcer/AHJ and simplifies the tool as the "B" process should be familiar to most AHJs.

The tool is limited to three occupancy types:

- Sleeping risk and all out evacuation strategy (which may occur in phases);
- Sleeping risk and stay put evacuation strategy; and
- No sleeping risk, i.e. Office/retail premises and all out evacuation strategy (which may occur in phases)

An "all-out" evacuation can only be assumed if there is the ability to sound the alarm throughout all areas of the building using an "all-out" or "all-call" button at the main fire alarm panel. As most high rise buildings adopt a phased evacuation strategy, an all-out alarm would usually be activated manually by the fire department or building management.

A stay put (defend in place) evacuation strategy assumes that building occupants not affected by a fire directly in their apartment, remain in their apartment. Only the apartment affected by a fire/smoke would be in alarm and only these occupants would be expected to evacuate. If fire/smoke spreads then other alarm bases would be expected to automatically activate but may be no ability to simultaneously raise the alarm in all areas of the building.

Questions with clearly pre-defined answers will be posed of the users in both the Tier 1 and Tier 2 assessments. Tier 1 will include a small number of questions that could be answered though a questionnaire by a Facilities Management team to initially screen a large number of buildings.

In Tier 2, additional questions will be posed of the users. These questions are more detailed in nature and require additional input. It is envisaged that Tier 2 is completed by a more experienced user (code official, authority having jurisdiction, certifier, building control) however specialist expertise in facade design or construction is not required.

The purpose of Tier 2 is to confirm or amend the priority risk ranking assigned to the building in Tier 1 due to a greater understanding of each variable and to identify areas for mitigation to reduce the risk ranking to an agreed acceptable level. Mitigation measures can be tested by using the tool to check the impact of the proposed mitigation measures on the risk ranking.

The tool is designed to be conservative and widely applicable. Some variables identified in Section 7 of this report are not assessed in Tier 1 or 2. They would likely be considered in a Tier 3 type assessment and are further discussed in Sections 9.3.12 and 9.4.9 of this report. Additional detailed assessment (Tier 3) beyond the scope of this tool, conducted by a team of qualified fire and façade engineers may be required to provide a more tailored approach for an individual building.

Note: The internal fire safety provisions that are important for a fire starting and remaining in the room or compartment of fire origin are different than those required for a fire spreading through several stories of the building predominantly via the façade system. This tool recognizes this and therefore should not be used for a fire risk assessment of building fire safety provisions for a building without a combustible façade system.

9.2 User Guide

This report sets out the methodology of the tool and the theoretical underpinnings of the outputs. An overall user guide has been prepared to accompany the tool. The user guide is intended to clearly and simply explain the variables chosen and how the tool is proposed to be used, including its limitations. The user's guide is in Appendix B of this report.

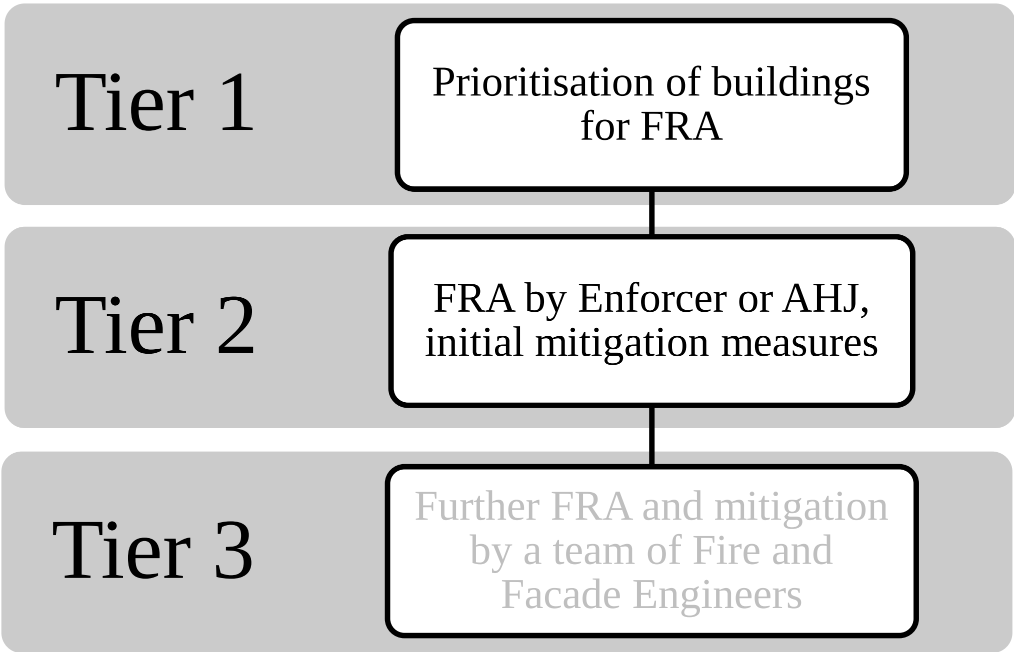


Figure 18: Proposed methodology (© Courtesy of Arup)

The outcome categories (as shown in Figure 19) for the tool at Tier 2 are based on the risk rankings, actions and timescales suggested in Annex B of PAS 79 (see Table 5).

Table 5: Outcomes – Prioritization of Actions and associated timescales (extracted from [26])

Outcome Ranking	PAS 79	Action & Timescale
A	Trivial	No action is required.
B	Tolerable	No immediate action is required. No major additional fire precautions are required. However, there might be a need for reasonably practicable improvements that involve minor or limited cost which can be considered in the longer term.
C	Moderate	Action is required in the medium term. It is essential that efforts are made to reduce the risk. Risk mitigation measures, which should take cost into account, should be implemented within a defined time period.
D	Substantial	Action is required. The risk could be substantial. Considerable resources might have to be allocated to reduce the risk. If the premises are unoccupied, it should not be occupied until the risk has been reduced. If the premises are occupied, urgent action should be taken.
E	Intolerable	Urgent action is required. It may be that premises (or relevant area) should not be occupied until the risk is reduced.

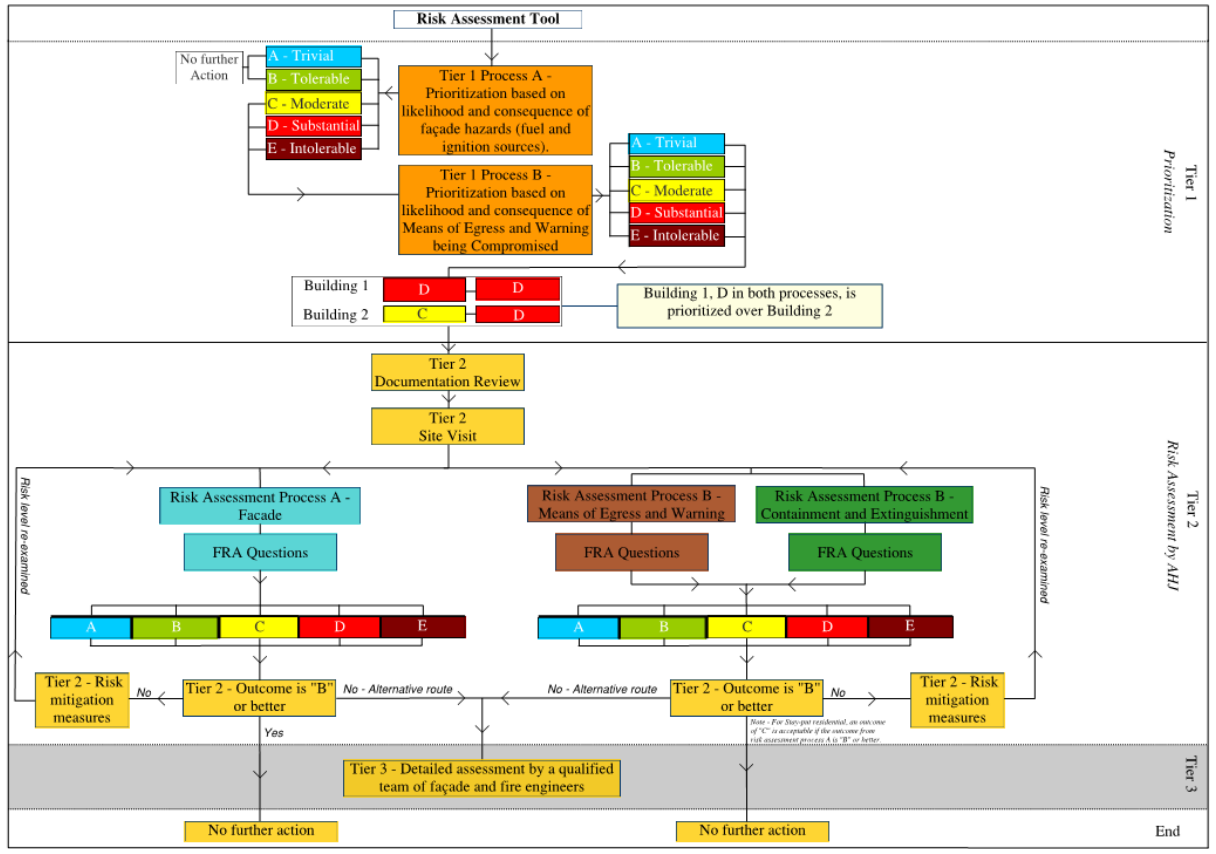


Figure 19: Proposed methodology using PAS 79 terminology represented by A-E (© Courtesy of Arup)

9.3 Tier 1 Prioritization

9.3.1 General

The inputs and steps in a PAS 79 assessment to arrive at an outcome are:

a) Identification of the people at risk;

b) Identification of the fire hazards;

c) Assessment of the fire hazard likelihood; and

d) Assessment of the fire hazard consequence.

The following sections describe these four steps.

9.3.2 Tier 1 – Identify Building Characteristics and People at Risk

This section outlines the questions and pre-defined answers (see Table 6) used to determine the characteristics of the building and the people at risk.

Table 6: Tier 1 questions and answers in relation to building characteristics and people at risk

Category	Sub-category	Question	Answer and Commentary
Building characteristics	Construction type	I) Is the structural frame of the building non-combustible (e.g. concrete and/or steel)?	Yes – building can be assessed using the FRA tool No – this results in a flag to the user as the building could be timber frame construction and may need to be assessed at a Tier 3 level.
	Evacuation strategy	II) Is there residential (sleeping) accommodation within the building? III) Is the evacuation strategy for the building simultaneous (i.e. the fire alarm sounds automatically throughout the building)? IV) Can the fire alarm alert occupants of the entire building to evacuate simultaneously by manual activation (all-out) from the fire alarm panel?	a) No – Office/business Yes – proceed to part (b) b) No – Residential "stay-put" Yes – Residential "all-out" In a residential building (apartment or hotel) occupants may be asleep at the time of a fire leading to a delayed response time during a fire alarm. The building should always be classified as residential if there is any sleeping accommodation within. For example, a mixed use office and hotel building would classify as residential. The ability to sound the fire alarm throughout the building ("all-out") means that an evacuation can be started quickly. Some residential buildings are designed based on a "stay-put" strategy where the fire alarm will only sound if smoke is in the apartment and has activated the detector. The fire alarm may be powered based on local batteries or through the main's electrical power. As the system is not networked to a main fire alarm control panel, a fire alarm cannot be raised throughout the building. As a result of this approach to fire alarm, occupants may be unaware of a fire on the exterior of the building for a considerable length of time, delaying evacuation. The FRA tool assumes "stay-put" if an "all-out" fire alarm is not possible.
	Building Height	V) What height (m.) is the building from fire department access level to the top most occupied floor?	H < 18m 18m < H < 30m 30m < H < 50m H > 50m The height of the building will increase evacuation time. For very tall buildings the fire and rescue service are unable to fight fires externally as fire service appliances have a limited reach (up to circa 30m for most aerial platform appliances). The height of the building is also related to the fire safety provisions required within the building (i.e. the code fire safety requirements typically increase with height). The range in the pre-defined answers to this question represent the heights at which firefighting techniques and evacuation strategies begin to change, e.g.: Between 18-30m external firefighting is usually possible; Between 30-50m, high reach ladder appliances are generally ineffective. Phased evacuations of high rise buildings are more likely; Above 50m, there is greater reliance on internal firefighting provisions and phased evacuation is common.
	Occupants at risk	VI) Is there an assembly use (bar, restaurant, pool deck, nightclub) in the building? If so, what is it, where is it located and what is the approximate floor area?	Yes – this results in a flag to the user as this implies a higher occupant load No –the expected occupant load of the building is within the range assumed by the developers of this tool. While office and apartment buildings usually have a well-defined occupant load a hotel may contain large Assembly areas. It is proposed that these are not a significant problem at the lower levels of a building because escape times will be short, but they can pose an increased consequence if the assembly space is at the top of the building. If there is a large Assembly area then this would mean there are more people at risk and an increased consequence if there is a fire on the exterior of the building. This issue will be raised as a "flag". The flag will mean the user has to consider this increased hazard and its height within the building when prioritizing the inspections.

9.3.3 Tier 1, Process A – Identify Fire Hazards Associated with the Façade

This section outlines the questions and pre-defined answers (see

Table 7) used to determine the hazards associated with the façade in Tier 1 Process A. The questions are intended to be answered very simply and do not go into any detail about different types of façade systems, patterns of facade on each side of a building or proximity of ignition sources and combustible facade. These issues are dealt with in Tier 2A.

There is a pre-defined answer for each of the questions. The hazards generally score as low or high.

Table 7: Tier 1 Process A questions and answers in relation to the hazards associated with the façade system.

Category	Sub-category	Question	Answer and associated hazard in terms of fuel or ignition source (low to high)
Façade Fire Hazard	Insulation	Is the insulation provided within the building façade made of a combustible material, e.g. foam insulation?	Don't know – High Yes – High No – Low
	Cladding	Are the outer cladding panels of the façade system of the building made of a combustible material?	Don't know – High Yes – High No – Low
	Façade Vertical Connectivity	In terms of the façade system pattern over the building, is there continuity in the combustible insulation and/or the combustible cladding vertically across more than one story?	Yes – High No – Low
	External Ignition Sources/Fire Hazards	Are there any external ignition sources/fire hazards near the building envelope; for example: refuse areas or parked vehicles adjacent or below the façade; restaurants with full kitchens in the building or below the façade; photovoltaic panels or light fittings in the façade; balconies; or other buildings that are in close proximity (<6m)? If yes, proceed to part (b) Are the ignition sources/fire hazards restricted to ground level only?	a) No – Low Yes – proceed to part (b) b) Yes – Medium No – High
	Internal ignition sources	Is a sprinkler system provided throughout the building? If yes, proceed to part (b) Is the sprinkler system fully operational, reliable, and being tested and maintained regularly?	a) No – High Yes – proceed to part (b) b) No – High Yes – Low

There are a large amount of facade component products available on the market which can be difficult to identify without specific knowledge of these materials or façade systems. Therefore, the pre-defined answers to each of the variables in Tier 1A are intended to capture a broad range of façade types to simplify the toolset in prioritizing further assessment. At Tier 1, the user just needs to report whether the insulation is a combustible? or not and if the cladding is combustible or not.

9.3.4 Tier 1, Process B – Identify Hazards Associated with Deficient Fire Safety Provisions

Once fire occurs, one of the first requirements of an appropriate fire strategy is to warn occupants, who can then use suitably designed means of escape to leave the building. Harm to occupants might also be mitigated and safe escape facilitated by appropriate measures to contain, control or extinguish the fire.

Tier 1B is intended to capture the most important fire system components to allow occupants to become aware of a fire, be notified to evacuate and do so safely.

The intention is not to interrogate all possible fire safety precautions that may be installed in a building at this first stage as there are concerns that the responses may not be sufficiently reliable for the prioritization when undertaken as a desk top exercise.

If any of these systems are deficient then this poses a hazard to occupants as they may be impeded in their escape.

This section outlines the variable questions and pre-defined answers (see Table 8) used to determine the hazards associated with deficient fire safety provisions. There is a pre-defined answer for each of the questions. The hazards generally score as low or high.

Table 8: Tier 1 process B questions and answers in relation to the hazards associated with deficient fire safety provisions

Category	Sub-category	Question	Answer and associated hazard in terms of reduced fire safety provisions (low to high)
Containment and Extinguishment	Compartmentation	Is compartmentation in the building maintained and reliable?	Don't know – High No – High Yes – Low
Means of Escape and Warning	Fire Alarm	Is a fire detection and alarm system provided within the building? If yes, proceed to part (b) Is the fire alarm system fully operational and reliable, and tested and maintained regularly?	a) No – High Yes – proceed to part (b) b) No – High Yes – Low
	Means of Escape	Do the occupants within the building have more than one escape route available? If yes, proceed to part (b) Are all the escape routes within the building unlocked and protected with fire rated construction?	a) No – High Yes – proceed to part (b) b) No – High Yes – Low

9.3.5 Tier 1, Process A - Assessment of the Likelihood of the Fire Hazard

In order to assess the likelihood of a fire over multiple stories of a building, the fuel, ignition sources and vertical connectivity of the fuel have been combined. This is explained in the following sections.

The individual hazards are firstly scored as follows:

HAZARD		SCORE
Non-combustible insulation and cladding	No fuel	Low
Combustible insulation	Fuel from insulation	High
Combustible cladding	Fuel from cladding	High
Sprinklered building with no balconies and no ignition source at base of building or in façade cavity or on facade.	None or very few ignition sources	Low
Ignition source at base of building and/or in cavity and/or lights/PV panels/etc. on facade	Limited ignition sources	Medium
Balconies or unsprinklered building	Multiple ignition sources	High
No vertical connections between combustible facade	Fuel is connected over building height	Low
Vertical connections between combustible facade	Fuel is connected over building height	High

When these hazards are combined then the likelihood of a fire over multiple stories of a façade system can be defined:

HAZARD			LIKELIHOOD OF A FIRE OVER MULTIPLE STORIES (CLADDING NOT VERTICALLY CONNECTED)	REASON
FUEL		IGNITION SOURCE		
INSULATION	CLADDING			
Low	Low	Low	**Very Low**	No fuel and no ignition source
Low	Low	Medium	**Very Low**	No fuel
Low	Low	High	**Very Low**	No fuel
High	Low	Low	**Low**	No ignition source but fuel from insulation
High	Low	Medium	**Medium**	Some ignition sources and fuel from insulation
High	Low	High	**High**	Multiple ignition sources and fuel from insulation
Low	High	Low	**Low**	No ignition source but fuel from cladding
Low	High	Medium	**Medium**	Limited ignition source and fuel from cladding
Low	High	High	**High**	Multiple ignition sources and fuel from cladding
High	High	Low	**Low**	No ignition source but cladding and insulation as fuel
High	High	Medium	**High**	Limited ignition source with cladding and insulation as fuel
High	High	High	**High**	Multiple ignition sources with cladding and insulation as fuel

If the fuel is then vertically connected over the height of the façade then the likelihood of a fire over multiple stories of a façade system is increased:

FUEL		IGNITION SOURCE	LIKELIHOOD OF A FIRE OVER MULTIPLE STORIES (CLADDING NOT VERTICALLY CONNECTED)	REASON	LIKELIHOOD OF A FIRE OVER MULTIPLE STORIES (CLADDING VERTICALLY CONNECTED)	REASON
INSULA-TION	CLADD-ING					
Low	Low	Low	**Very Low**	No fuel and no ignition source	**Very Low**	No fuel so vertical connection is irrelevant
Low	Low	Medium	**Very Low**	No fuel	**Very Low**	
Low	Low	High	**Very Low**	No fuel	**Very Low**	
High	Low	Low	**Low**	No ignition source but fuel from insulation	**Medium**	Vertical connection increases fuel and connects it over building height
High	Low	Medium	**Medium**	Limited ignition sources and fuel from insulation	**High**	
High	Low	High	**High**	Multiple ignition sources and fuel from insulation	**Very high**	
Low	High	Low	**Low**	No ignition source but fuel from cladding	**Medium**	
Low	High	Medium	**Medium**	Limited ignition source and fuel from cladding	**High**	
Low	High	High	**High**	Multiple ignition sources and fuel from cladding	**Very high**	
High	High	Low	**Low**	No ignition source but cladding and insulation as fuel	**Medium**	
High	High	Medium	**High**	Limited ignition source with cladding and insulation as fuel	**Very high**	
High	High	High	**High**	Multiple ignition sources with cladding and insulation as fuel	**Very high**	

9.3.6 Tier 1, Process A - Prioritization Based on Likelihood and Consequence

The priority (risk) is then scored as Trivial (A), Tolerable (B), Moderate (C), Substantial (D) or Intolerable (E) based on Likelihood and Consequence.

Consequence is linked to building height and occupancy. Three matrices are produced, one for each occupancy and evacuation strategy in the scope of this FRA tool.

The matrix is based on the PAS 79 matrix but expanded to include "very low" and "very high" on the likelihood scale and "slight-moderate harm" and "moderate-extreme harm" on the consequence scale. For residential occupancies the lowest consequence is "slight-moderate" versus "slight" for offices. The highest consequence is "moderate-extreme" for offices and "extreme" for residential.

OFFICE - TIER 1A			LIKELIHOOD OF A FIRE ON MULTIPLE STORIES				
BUILDING HEIGHT		CONSEQUENCE	Very Low	Low	Medium	High	Very High
<18m	Slight harm	*External firefighting attack to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water. Search and rescue times inside the building short. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Pre-movement time relatively short as occupant's awake, time to evacuate relatively short due to building height. Risk to life from a fire on the exterior facade is low.*	A	A	B	C	C
18>30m	Slight-moderate harm	*External firefighting attack to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water. Search and rescue times inside the building relatively short. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Pre-movement time relatively short as occupants awake, time to evacuate relatively short as building height is increasing but still comparatively low. Risk to life from a fire on the exterior façade is low but increasing.*	A	B	B	C	D
30>50m	Moderate harm	*External firefighting attack to upper levels of the building likely to be difficult or not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high. Search and rescue times inside the building relatively long. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Pre-movement time relatively short as occupant's awake, time to evacuate comparatively longer due to increased building height. Risk to life from a fire on the exterior façade is increasing.*	A	B	C	D	E
>50m	Moderate-Extreme harm	*External firefighting attack to upper levels of the building not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high. Search and rescue times inside the building long. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Pre-movement time relatively short as occupant's awake, time to evacuate is comparatively long due to increased building height. Risk to life from a fire on the exterior façade is high.*	A	C	D	D	E

RESIDENTIAL "ALL-OUT" - TIER 1A			LIKELIHOOD OF A FIRE ON MULTIPLE STORIES				
BUILDING HEIGHT		CONSEQUENCE	Very Low	Low	Medium	High	Very High
<18m	Slight-moderate harm	*External firefighting to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water.* *Search and rescue times inside the building short.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement longer than an office as occupants could be asleep, time to evacuate relatively short due to building height.* *Risk to life from a fire on the exterior facade is low but higher than for an office building of same height.*	A	B	B	C	D
18>30m	Moderate harm	*External firefighting attack to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water.* *Search and rescue times inside the building relatively short.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement longer than an office as occupants could be asleep, time to evacuate relatively short as building height is increasing but still comparatively low.* *Risk to life from a fire on the exterior façade is increasing.*	A	B	C	D	E
30>50m	Moderate-Extreme harm	*External firefighting attack to upper levels of the building likely to be difficult or not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high.* *Search and rescue times inside the building relatively long.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement longer than an office as occupants could be asleep, time to evacuate comparatively longer due to increased building height.* *Risk to life from a fire on the exterior façade is high.*	A	C	D	D	E
>50m	Extreme harm	*External firefighting attack to upper levels of the building not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high.* *Search and rescue times inside the building long.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement longer than an office as occupants could be asleep, time to evacuate is comparatively long due to increased building height.* *Risk to life from a fire on the exterior façade is very high.*	A	C	D	E	E

RESIDENTIAL "STAY-PUT" - TIER 1A			LIKELIHOOD OF A FIRE ON MULTIPLE STORIES				
BUILDING HEIGHT		CONSEQUENCE	Very Low	Low	Medium	High	Very High
<18m	Moderate harm	*External firefighting attack to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water. Search and rescue times inside the building short. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Increased recognition and response time for occupants due to sleeping risk. Occupants can stay put until such time that they choose to evacuate or are manually alerted by the fire service to do so. The time required for manual notification of each occupant to evacuate can be relatively short. Overall evacuation time will be delayed, but can be completed in a comparatively short time frame due to the limited height of the building. Risk to life from a fire on the exterior façade is higher than for office or residential "all-out" in the same building height.*	A	B	C	D	D
18>30m	Moderate-Extreme harm	*External firefighting attack to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water. Search and rescue times inside the building relatively short. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Increased recognition and response time for occupants due to sleeping risk. Overall evacuation time will be delayed. Occupants can stay put until such time that they choose to evacuate or are manually alerted by the fire service to do so. The time required for manual notification of each occupant to evacuate is likely to be extended, and occupants will take an extended period of time to evacuate due to the height of the building. Risk to life from a fire on the exterior façade is high.*	A	C	D	D	E
30>50m	Extreme harm	*External firefighting attacks to upper levels of the building likely to be difficult or not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high. Search and rescue times inside the building relatively long. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Increased recognition and response time for occupants due to sleeping risk. Overall evacuation time will be delayed. Occupants can stay put until such time that they choose to evacuate or are manually alerted by the fire service to do so. The time required for manual notification of each occupant to evacuate is likely to be long, and occupants will take a long period of time to evacuate due to the height of the building. Risk to life from a fire on the exterior façade is very high.*	B	D	D	E	E
>50m	Extreme harm	*External firefighting attack to upper levels of the building not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high. Search and rescue times inside the building long. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Increased recognition and response time for occupants due to sleeping risk. Overall evacuation time will be delayed. Occupants can stay put until such time that they choose to evacuate or are manually alerted by the fire service to do so. The time required for manual notification of each occupant to evacuate is likely to be very long, and occupants will take a very long period of time to evacuate due to the height of the building. Risk to life from a fire on the exterior façade is very high.*	B	D	E	E	E

9.3.7 Tier 1, Process B - Likelihood of Means of Egress and Warning Being Compromised

In order to assess the likelihood of the means of egress and warning being compromised, the exit stairs, detection and fire alarm system and compartmentation have been combined. This is explained in the following sections.

The individual hazards are firstly scored as follows:

HAZARD	SCORE
Two or more fire rated and enclosed stairs available	Low
One fire rated and enclosed stair available per design or because second stair is compromised (locked or poor compartmentation)	Medium
No fire rated/enclosed stairs available due to locks or poor compartmentation	High
All-out detection and fire alarm available	Low
Stay-put detection and fire alarm available	Medium
No detection and fire alarm available	High
Good compartmentation to apartments, corridors and between floors	Low
Poor compartmentation to apartments, corridors and between floors	Medium

When these hazards are combined then the likelihood of a fire over multiple stories of a façade system can be defined:

Means of Escape	Detection and Fire Alarm	LIKELIHOOD OF MEANS OF EGRESS AND WARNING BEING COMPROMISED	REASON
Low	Low	Very Low	All multiple means of escape available and "all-out" fire alarm possible
Medium	Low	Medium	A single or reduced means of escape available and "all-out" fire alarm possible
High	Low	Very High	No means of escape
Low	Medium	Medium	All multiple means of escape available and "stay-put" local alarm possible
Medium	Medium	High	A single or reduced means of escape available and "stay-put" local alarm possible
High	Medium	Very High	No means of escape
Low	High	High	All multiple means of escape available but no fire alarm
Medium	High	Very High	A single or reduced means of escape available but no fire alarm
High	High	Very High	No means of escape

If compartmentation to apartments, corridors and between floors is also poor then the likelihood of means of egress and warning being compromised is increased:

Means of Escape	Detection and Fire Alarm	LIKELIHOOD OF MEANS OF EGRESS AND WARNING BEING COMPROMISED	REASON	LIKELIHOOD OF MEANS OF EGRESS AND WARNING BEING COMPROMISED IF COMPARTMETATION ALSO POOR	REASON
Low	Low	Very Low	All multiple means of escape available and "all-out" fire alarm possible	Low	All multiple means of escape available and "all-out" fire alarm possible but smoke spreading to corridors and up through floors
Medium	Low	Medium	A single or reduced means of escape available and "all-out" fire alarm possible	High	A single or reduced means of escape available and "all-out" fire alarm possible. Smoke spreading to corridors and up through floors may compromise means of escape.
High	Low	Very High	No means of escape	Very High	No means of escape
Low	Medium	Medium	All multiple means of escape available and "stay-put" local alarm possible	High	All multiple means of escape available and "stay-put" local alarm possible. Delayed alarm may mean escape stairs are blocked by smoke spreading to corridors and up through floors before evacuation happens.
Medium	Medium	High	A single or reduced means of escape available and "stay-put" local alarm possible	Very High	A single or reduced means of escape available and "stay-put" local alarm possible. Delayed alarm may mean escape is blocked by smoke spreading to corridors and up through floors before evacuation happens.
High	Medium	Very High	No means of escape	Very high	No means of escape
Low	High	High	All multiple means of escape available but no fire alarm	Very high	All multiple means of escape available but no fire alarm. No alarm and compromised compartmentation may mean escape stairs are blocked by smoke before evacuation happens
Medium	High	Very High	A single or reduced means of escape available but no fire alarm	Very High	A single or reduced means of escape available but no fire alarm. No alarm and compromised compartmentation may escape is blocked by smoke before evacuation happens
High	High	Very High	No means of escape	Very high	No means of escape

9.3.8 Tier 1, Process B - Prioritization Based on Likelihood and Consequence

The priority (risk) is then scored as Trivial (A), Tolerable (B), Moderate (C), Substantial (D) or Intolerable (E) based on Likelihood and Consequence.

Consequence is linked to building height and occupancy. Three matrices are produced, one for each occupancy and evacuation strategy in the scope of this FRA tool.

The matrix is based on the PAS 79 matrix but expanded to include “very low” and “very high” on the likelihood scale and “slight-moderate harm” and “moderate-extreme harm” on the consequence scale. For residential occupancies the lowest consequence is “slight-moderate” versus “slight” for offices. The highest consequence is “moderate-extreme” for offices and “extreme” for residential.

For residential “stay-put” the likelihood of means of egress and warning being compromised can never be “very low” or “low” as the fire alarm system does not sound throughout the building..

OFFICE - TIER 1B			LIKELIHOOD OF MEANS OF EGRESS AND WARNING BEING COMPRIMISED				
BUILDING HEIGHT		CONSEQUENCE	Very Low	Low	Medium	High	Very High
<18m	Slight harm	*External firefighting attack to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water.* *Search and rescue times inside the building short.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement time relatively short as occupant's awake, time to evacuate relatively short due to building height.* *Risk to life from a fire on the exterior facade is low.*	A	A	B	C	E
18>30m	Slight-moderate harm	*External firefighting attack to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water.* *Search and rescue times inside the building relatively short.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement time relatively short as occupants awake, time to evacuate relatively short as building height is increasing but still comparatively low.* *Risk to life from a fire on the exterior façade is low but increasing.*	A	B	C	C	E
30>50m	Moderate harm	*External firefighting attack to upper levels of the building likely to be difficult or not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high.* *Search and rescue times inside the building relatively long.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement time relatively short as occupant's awake, time to evacuate comparatively longer due to increased building height.* *Risk to life from a fire on the exterior façade is increasing.*	A	B	C	D	E
>50m	Moderate-Extreme harm	*External firefighting attack to upper levels of the building not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high.* *Search and rescue times inside the building long.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement time relatively short as occupant's awake, time to evacuate is comparatively long due to increased building height.* *Risk to life from a fire on the exterior façade is high.*	A	C	D	E	E

RESIDENTIAL "ALL-OUT" - TIER 1B			LIKELIHOOD OF MEANS OF EGRESS AND WARNING BEING COMPRIMISED				
BUILDING HEIGHT		CONSEQUENCE	Very Low	Low	Medium	High	Very High
<18m	Slight-moderate harm	*External firefighting attack to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water.* *Search and rescue times inside the building short.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement longer than an office as occupants could be asleep, time to evacuate relatively short due to building height.* *Risk to life from a fire on the exterior facade is low but higher than for an office building of same height.*	A	A	B	C	E
18>30m	Moderate harm	*External firefighting attack to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water.* *Search and rescue times inside the building relatively short.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement longer than an office as occupants could be asleep, time to evacuate relatively short as building height is increasing but still comparatively low.* *Risk to life from a fire on the exterior façade is increasing.*	A	B	C	D	E
30>50m	Moderate-Extreme harm	*External firefighting attack to upper levels of the building likely to be difficult or not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high.* *Search and rescue times inside the building relatively long.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement longer than an office as occupants could be asleep, time to evacuate comparatively longer due to increased building height.* *Risk to life from a fire on the exterior façade is high.*	A	C	C	D	E
>50m	Extreme harm	*External firefighting attack to upper levels of the building not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high.* *Search and rescue times inside the building long.* *Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris.* *Pre-movement longer than an office as occupants could be asleep, time to evacuate is comparatively long due to increased building height.* *Risk to life from a fire on the exterior façade is very high.*	A	C	D	E	E

RESIDENTIAL "STAY-PUT" - TIER 1B			LIKELIHOOD OF MEANS OF EGRESS AND WARNING BEING COMPRIMISED				
BUILDING HEIGHT		CONSEQUENCE	Very Low	Low	Medium	High	Very High
<18m	Moderate harm	*External firefighting attack to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water. Search and rescue times inside the building short. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Increased recognition and response time for occupants due to sleeping risk. Occupants can stay put until such time that they choose to evacuate or are manually alerted by the fire service to do so. The time required for manual notification of each occupant to evacuate can be relatively short. Overall evacuation time will be delayed, but can be completed in a comparatively short time frame due to the limited height of the building. Risk to life from a fire on the exterior façade is higher than for office or residential "all-out" in the same building height.*			C	D	E
18>30m	Moderate-Extreme harm	*External firefighting attack to some or all of the building elevations possible from the exterior. Some falling debris can be extinguished. Adjacent buildings can be cooled with water. Search and rescue times inside the building relatively short. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Increased recognition and response time for occupants due to sleeping risk. Overall evacuation time will be delayed. Occupants can stay put until such time that they choose to evacuate or are manually alerted by the fire service to do so. The time required for manual notification of each occupant to evacuate is likely to be extended, and occupants will take an extended period of time to evacuate due to the height of the building. Risk to life from a fire on the exterior façade is high.*			D	E	E
30>50m	Extreme harm	*External firefighting attack to upper levels of the building likely to be difficult or not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high. Search and rescue times inside the building relatively long. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Increased recognition and response time for occupants due to sleeping risk. Overall evacuation time will be delayed. Occupants can stay put until such time that they choose to evacuate or are manually alerted by the fire service to do so. The time required for manual notification of each occupant to evacuate is likely to be long, and occupants will take a long period of time to evacuate due to the height of the building. Risk to life from a fire on the exterior façade is very high.*			D	E	E
>50m	Extreme harm	*External firefighting attack to upper levels of the building not possible. Some falling debris can be extinguished. Adjacent buildings can be cooled with water unless they are also > 30m high. Search and rescue times inside the building long. Fire fighters can assist occupants at the point of discharge and guide them to safety away from falling debris. Increased recognition and response time for occupants due to sleeping risk. Overall evacuation time will be delayed. Occupants can stay put until such time that they choose to evacuate or are manually alerted by the fire service to do so. The time required for manual notification of each occupant to evacuate is likely to be very long, and occupants will take a very long period of time to evacuate due to the height of the building. Risk to life from a fire on the exterior façade is very high.*			E	E	E

9.3.9 Tier 1 - Outcomes

The Tier 1 assessment will result in two outcomes for a building in process A and process B. Prioritization is based on the combination of these two outcomes. The outcome of Tier 1A has a higher weighting in the context of this fire risk assessment tool.

For example, a building with a combined outcome of E-E would be the top priority, followed by E-D, D-D and D-C etc. A building with A-F or B-F would have lower priority due to the non-combustible façade system. However, the condition of the fire safety systems inside the building (Tier 1, process B) when the façade system is non-combustible should still be checked and addressed through the normal AHJ process for this situation. See Figure 20.

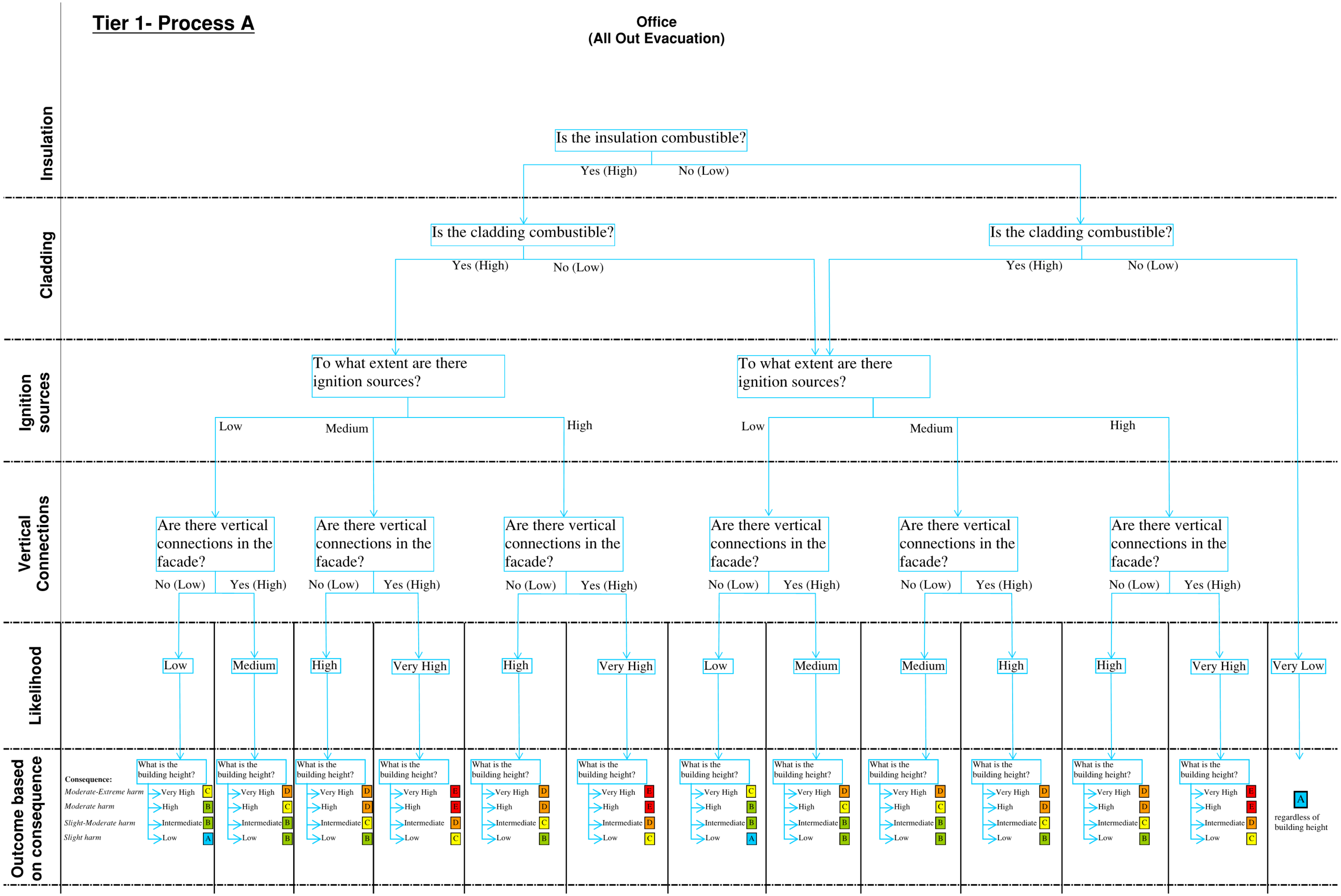
Buildings which have been identified at Tier 1A as C and above (see Table 5), will need to be further evaluated in Tier 2, in order of priority.

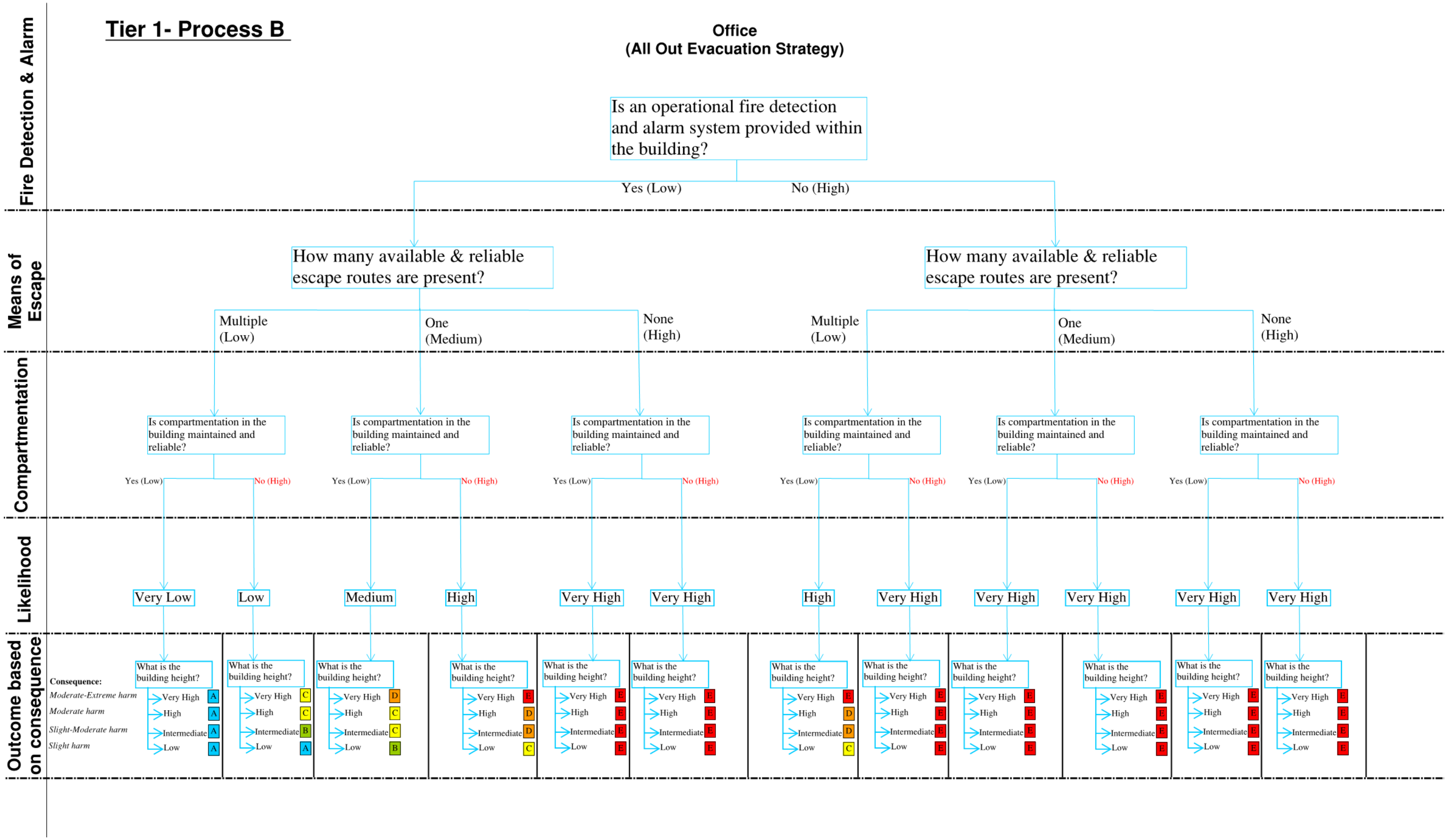
	Tier 1 Prioritization		
Building	**Process A**	**Process B**	**Action**
1	E	C	Tier 2 assessment required as process A prioritization > Tolerable
2	E	B	
3	D	C	
4	D	B	
5	C	D	
7	C	A	
8	C	A	
9	B	B	No action
10	B	D	Fire safety provisions to be assessed using alternate tool
11	A	D	
12	A	C	
13	A	B	No action
.			
etc.			

Figure 20 Theoretical example of prioritized buildings from Tier 1

9.3.10 Tier 1 Prioritization Flowcharts

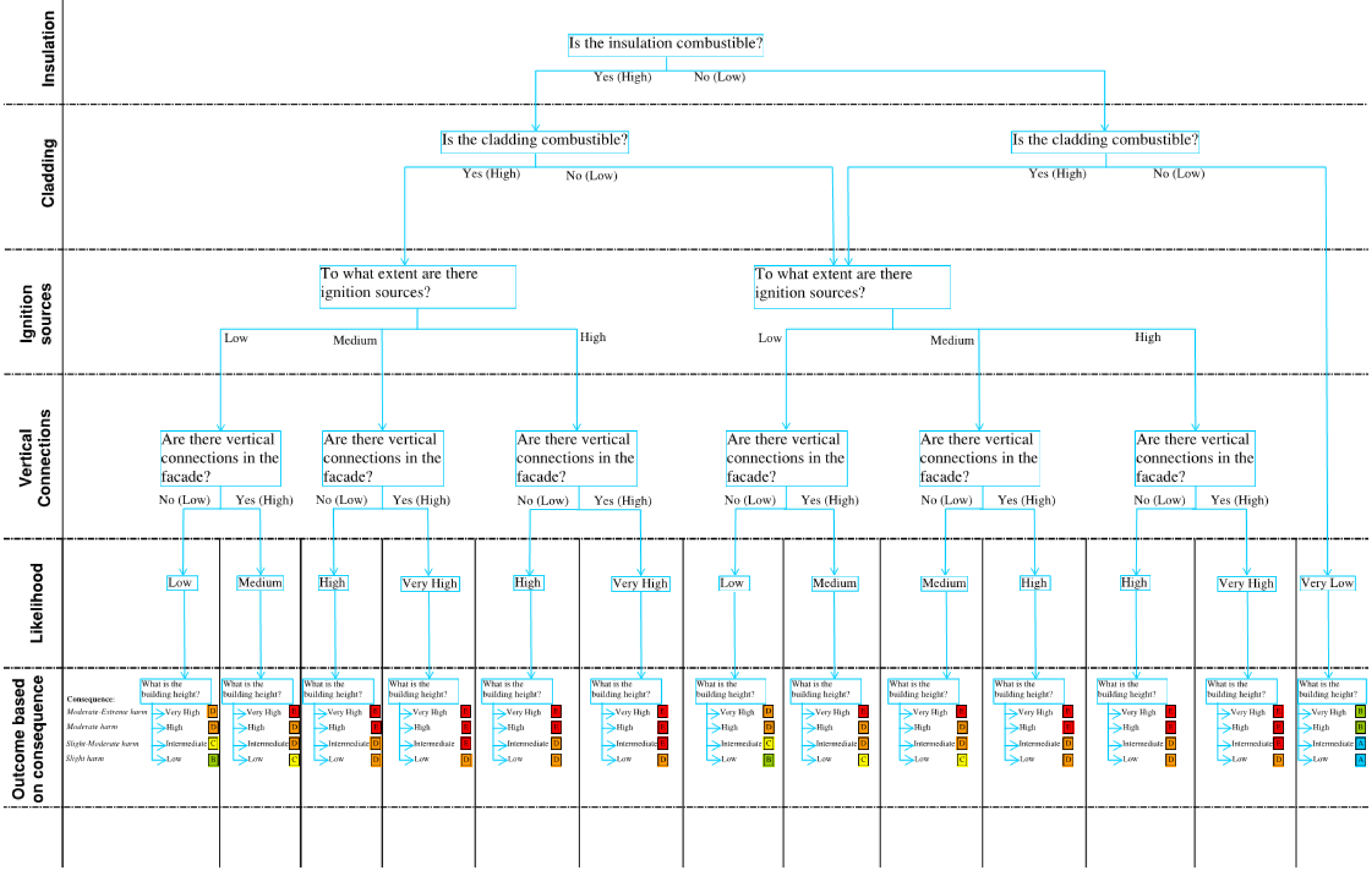
To aid understanding, another way of presenting the information above is provided in the flow charts in this section:



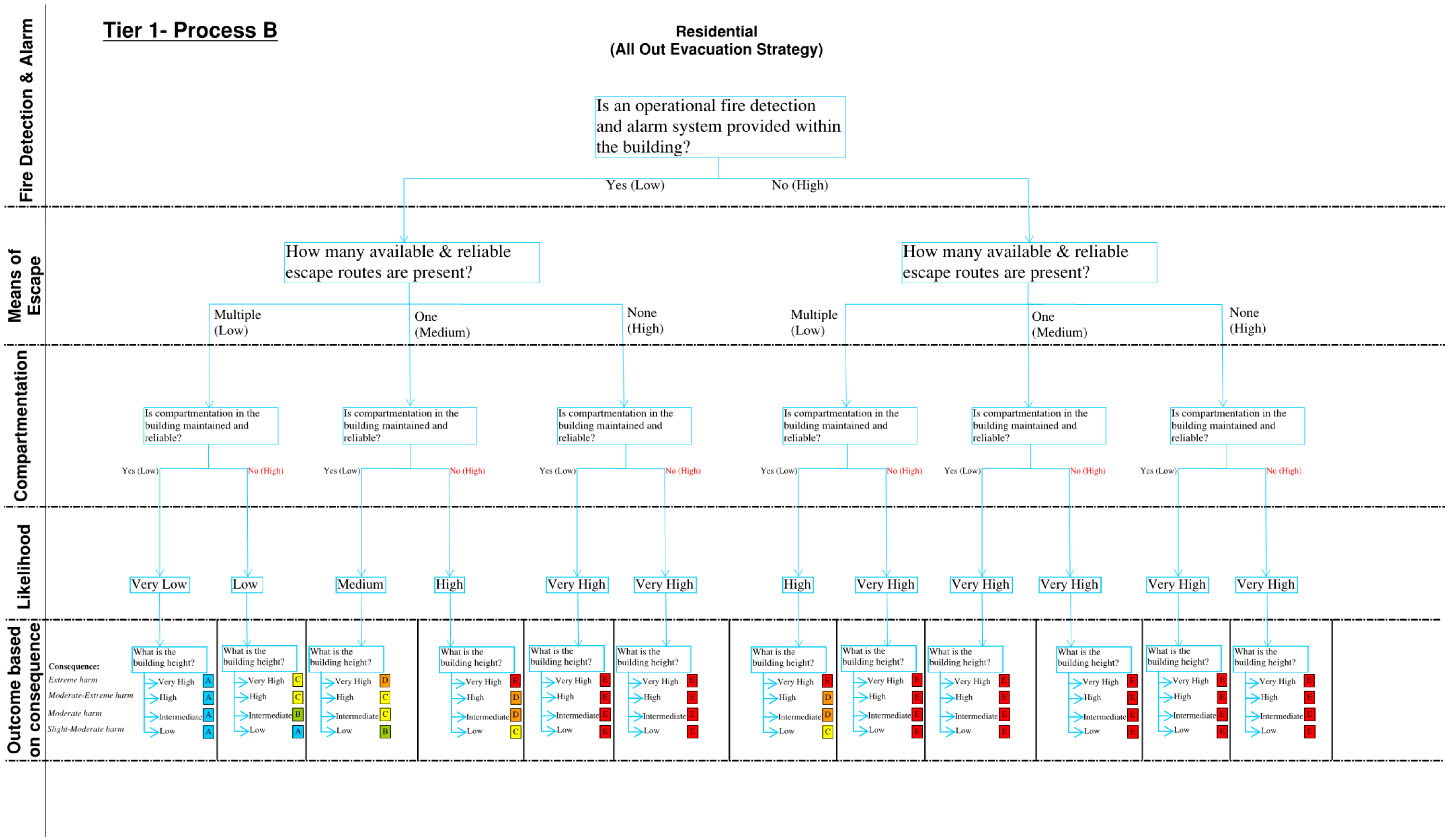

Tier 1- Process B
Office
(All Out Evacuation Strategy)
Fire Detection & Alarm
Means of Escape
Compartmentation
Likelihood
Outcome based on consequence
Is an operational fire detection and alarm system provided within the building?
Yes (Low)
No (High)
How many available & reliable escape routes are present?
Multiple (Low)
One (Medium)
None (High)
Is compartmentation in the building maintained and reliable?
Yes (Low)
No (High)
Very Low
Low
Medium
High
Very High
What is the building height?
Consequence:
Moderate-Extreme harm
Moderate harm
Slight-Moderate harm
Slight harm
Very High
High
Intermediate
Low
A
B
C
D
E

Tier 1- Screening Process A

Residential
(All Out Evacuation)

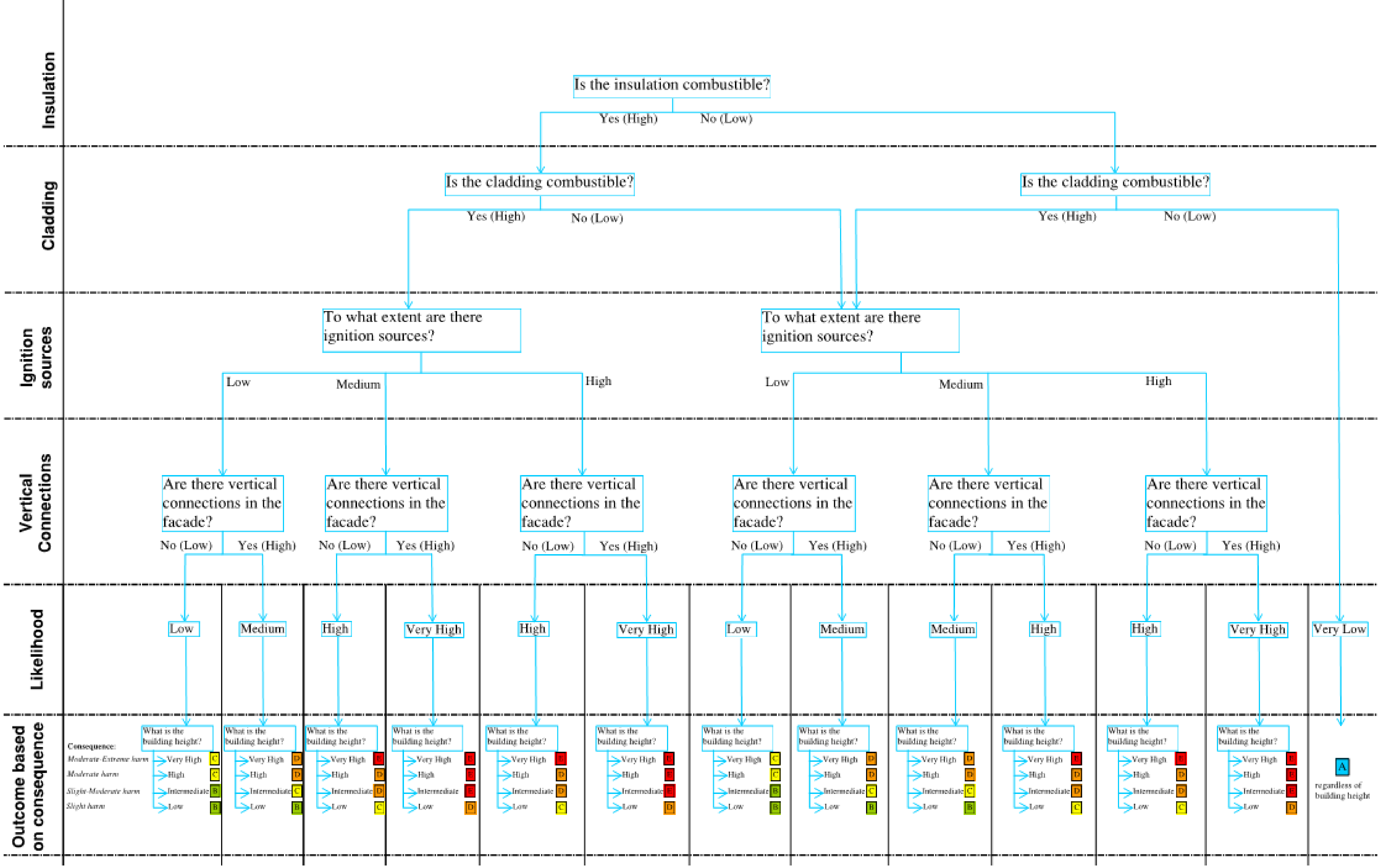


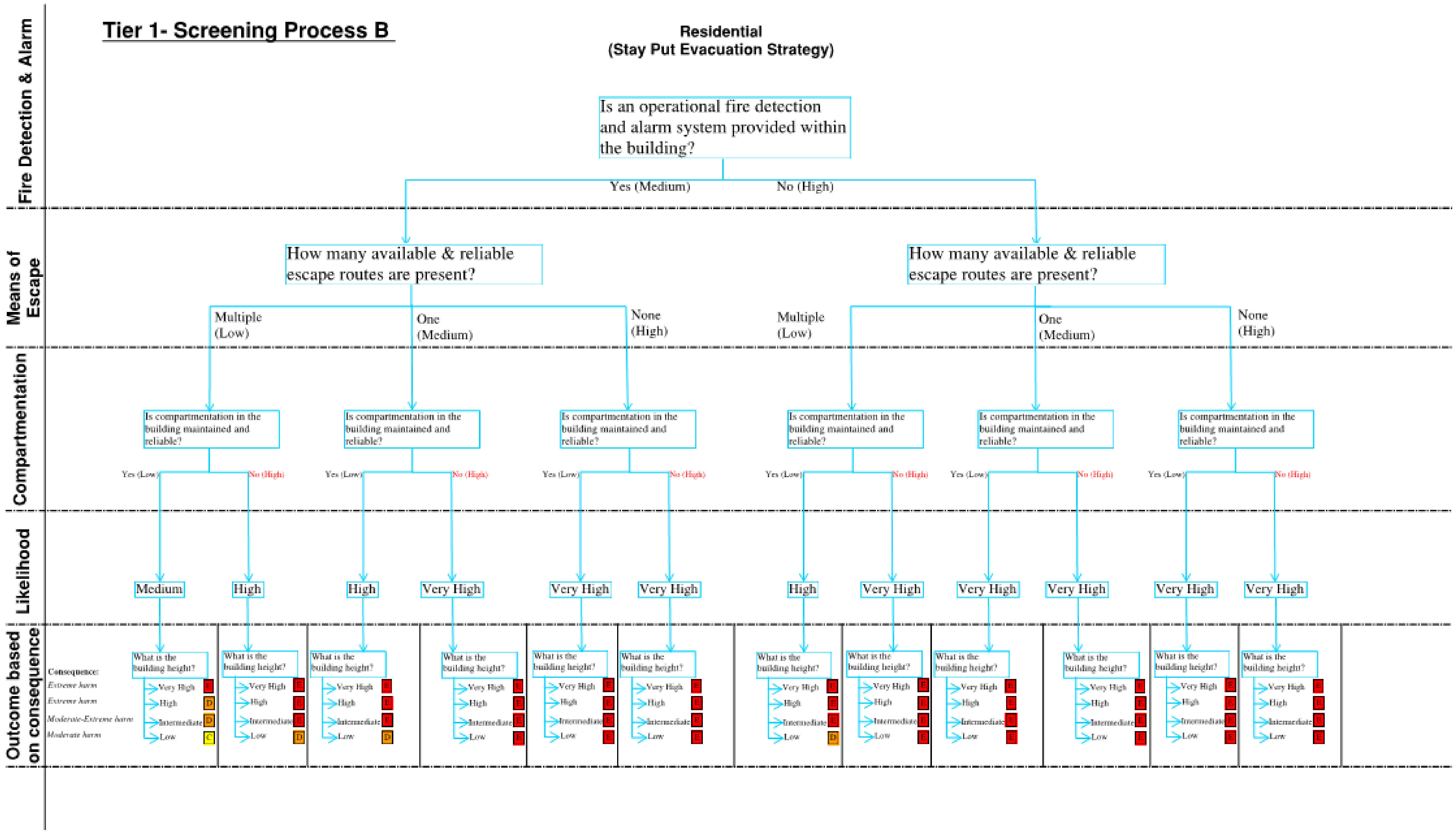
Tier 1- Process B



Tier 1- Screening Process A

Residential
(Stay Put Evacuation)




Tier 1- Screening Process B
Residential
(Stay Put Evacuation Strategy)
Fire Detection & Alarm
Means of Escape
Compartmentation
Likelihood
Outcome based on consequence
Is an operational fire detection and alarm system provided within the building?
Yes (Medium)
No (High)
How many available & reliable escape routes are present?
Multiple (Low)
One (Medium)
None (High)
Is compartmentation in the building maintained and reliable?
Yes (Low)
No (High)
Medium
High
Very High
What is the building height?
Consequence:
Extreme harm
Extreme harm
Moderate-Extreme harm
Moderate harm
Very High
High
Intermediate
Low

9.3.11 Assessed Variables in Tier 1

9.3.11.1 General Variables

Construction Type

What is the question and what are the answers?	Is the structural frame of the building non-combustible (e.g. concrete and/or steel)? Yes/No
Why this variable?	If no, this would indicate that the frame of the building is timber which is outside the scope of this tool. The building would require a Tier 3 assessment by a team of façade and fire engineers.

Occupant Characteristic

What is the question and what are the answers?	Is there residential (sleeping) accommodation within the building? Yes/No Any residential accommodation, i.e. sleeping risk, in the building requires a "Yes" answer.
Why this variable?	Building use dictates the fire safety measures provided within the building as well as being an indicator of the time needed for persons to commence their evacuation (i.e. occupants that are sleeping may need longer to get become aware of a fire, to then ready and commence an evacuation than those that are awake).
Why this range?	The two occupant characteristics (residential and non-residential) chosen are distinct and are considered to represent a significant portion of the high-rise building stock internationally. Residential use represents a different risk when compared to other occupancies due to people potentially being asleep when a fire occurs and therefore the delayed occupant response time.

Evacuation strategy

What is the question and what are the answers?	Is the evacuation strategy for the building simultaneous (i.e. the fire alarm sounds automatically throughout the building)? Yes/No Can the fire alarm alert occupants of the entire building to evacuate simultaneously by manual activation (all-out) from the fire alarm panel? Yes/No
Why this variable?	The ability to sound the fire alarm throughout the building ("all-out") means that an evacuation can be started quickly. Some residential buildings are designed based on a "stay-put" strategy where the fire alarm will only sound if smoke is in the apartment and has activated the detector. The fire alarm may be powered based on local batteries or through the main's electrical power. As the system is not networked to a main fire alarm control panel, a fire alarm cannot be raised throughout the building. As a result of this approach to fire alarm, occupants may be unaware of a fire on the exterior of the building for a considerable length of time, delaying evacuation. The FRA tool assumes "stay-put" if an "all-out" fire alarm is not possible.

Height

What is the question and what are the answers?	What height (m) is the building from fire department access level to the top most occupied floor? • 18 m < H ≤ 30 m • 30m < H ≤ 50m • H > 50m
Why this variable?	The height of the building will also increase the evacuation time, should occupants be required to leave the building. Furthermore as the building height increases, there are usually additional provisions required for the fire and rescue operations to avoid delay in commencing their operations internally. For very tall buildings the fire and rescue service are unable to fight fires externally as fire service appliances have a limited reach (up to circa 30m for aerial platform appliances and approximately 60m for very high reach with few jurisdictions owning these or the newer ladders at 100-150m reach). The height of the building is also related to the fire safety provisions required within the building (i.e. the code fire safety requirements increase with height).
Why this range?	The range represents the heights at which evacuation strategies and firefighting techniques begin to change, e.g.: • Between 18-30m external firefighting is usually possible; • Between 30-50m, high reach ladder appliances are generally ineffective. Phased evacuations of high rise buildings are more likely; • Above 50m, there is greater reliance on internal firefighting provisions and phased evacuation is common.

Additional Occupants at Risk

What is the question and what are the answers?	Is there an assembly use (bar, restaurant, pool deck, nightclub) in the building? Yes/No If so, what is it, where is it located and what is the rough floor area?
Why this variable?	While office and apartment buildings usually have a well-defined occupant load a hotel may contain large Assembly areas. It is proposed that these are not a significant problem at the lower levels of a building because escape times will be short, but they can pose an increased consequence if the assembly space is at the top of the building. If there is a large Assembly area then this would mean there are more people at risk and an increased consequence if there is a fire on the exterior of the building. This issue will be raised as a “flag”. The flag will mean the user has to consider this increased hazard and its height within the building when prioritizing the inspections.

9.3.11.2 Tier 1A Variables

Insulation

What is the question and what are the answers?	Is the insulation provided within the building façade made of a combustible material, e.g. foam insulation? Answer options: Don’t know / Yes / No Any potentially combustible insulation requires a yes answer. If the answer is unknown, it would be treated as a ‘yes’ for the purpose of the assessment.
Why this variable?	Where insulation is combustible it can pose a significant fire load to the exterior of the building, and needs further investigation.
Why this range?	The range represents the upper and lower bound of the variants on the market in terms of combustibility. The most common non-combustible insulation is mineral wool. There are a large amount of foam insulation products available. All foam plastic insulation is considered to be combustible. Differentiating between types (e.g. phenolic, PIR, PUR, XPS, EPS) is not required at Tier 1 because it is a prioritization phase.

Figure 21: Examples of combustible insulation (© Thinkstock)

Figure 22: Example of non-combustible insulation (mineral wool and glass wool (© Courtesy of Knauf Insulation)

Cladding panels

What is the question and what are the answers?	Are the outer cladding panels of the façade system of the building made of a combustible material? Answer options: Yes / No / Don’t know Any potentially combustible cladding panels require a yes answer. A ‘don’t know’ answer would be treated as a yes answer.
Why this variable?	Where cladding panels are combustible they can contribute a significant fire load to the exterior of the building and potentially contribute to rapid external fire spread.
Why this range?	The range represents the upper and lower bound of the variants on the market. Cladding panels which fall into the non-combustible range include but are not limited to: • Stone; • Masonry; • Ceramic; • Solid steel or aluminium or other metal; • Glass. • Cement board • Glass reinforced concrete (GRC) • Terra-cotta Cladding panels which fall into the combustible range include but are not limited to: • Timber • Glass reinforced plastics (GRP) • Any composite material comprising of one combustible component. • Aluminium composite panels (ACPs)* • High pressure laminates (HPL) All ACPs are considered to be combustible for the purpose of this tool. Differentiating between types (e.g. 100% LDPE core, ~30% LDPE core, ~10% LDPE core) is not required at Tier 1.

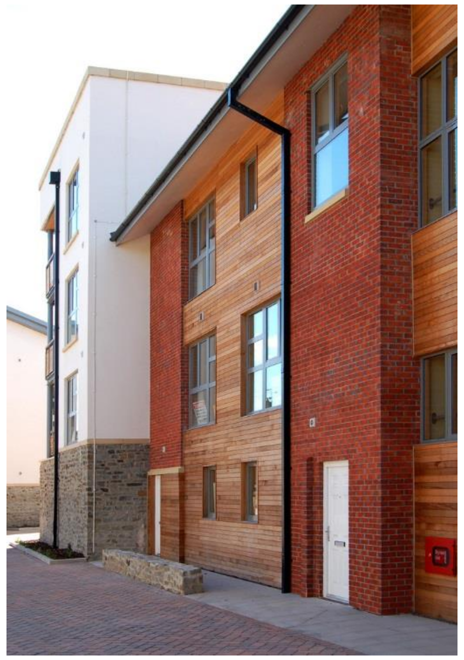


Figure 23: Timber Cladding (Combustible) (© Courtesy of Arup)

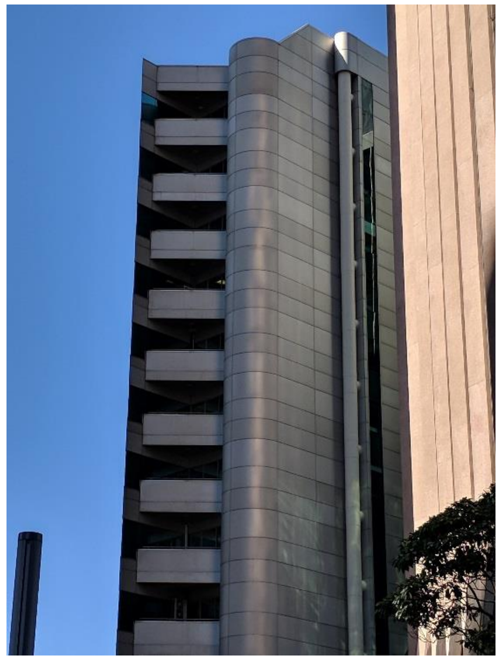


Figure 24: Aluminium Composite Panel (ACP) Rainscreen Cladding (Combustible) (© Courtesy of Arup)

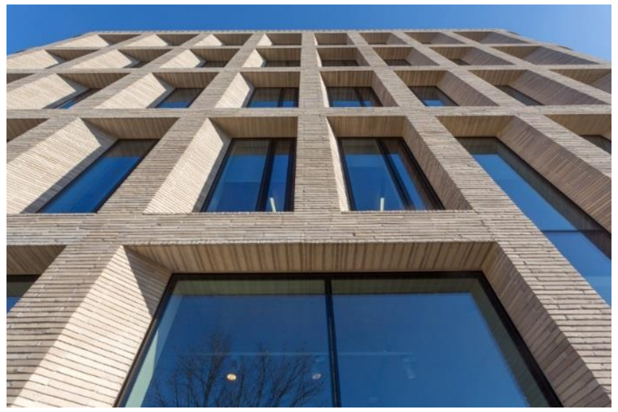


Figure 25: Masonry (non-combustible) (© Courtesy of Arup)

Figure 26: Glazing (non-combustible) (© Courtesy of Arup)

External Ignition Sources

What is the question and what are the answers?	Does the building have balconies within 6m of the combustible façade system? Does the building have PV panels or external lights fixed to the facade system (or similar)? Are there ignition sources (e.g. vehicles or trash cans or similar) within 6 m of the ground level facade? Yes/No for each
Why this variable?	Where an external ignition source is located in close proximity (<6m) to a building, this increases the likelihood that a fire will ignite the façade, where it has combustible elements, i.e. cladding and/or insulation.
Why this range?	External ignition sources can range from a ground level refuse area to photovoltaic panels over the entire façade building. Where external ignition sources are widespread across the building façade this represents a greater likelihood that a fire will occur in comparison to ground only sources or hazards. A fire starting inside the building or in an adjacent building also pose hazards but these are addressed separately and are not the subject of this question.

Figure 27: Presence of balconies on external façade (© Courtesy of Arup)

Figure 28: Lights on external façade (© Courtesy of Arup)

Internal Ignition Sources

What is the question?	Is a sprinkler system provided throughout the building? Yes/No If the answer is yes, the following question should be answered. Is the sprinkler system fully operational, reliable, tested and maintained regularly? Yes/No/Don't know
Why this variable?	Sprinklers are widely accepted to help control the intensity and size of a fire within the initial growth period. In some cases, it may extinguish the fire, but at the very least will contain the fire for a period of time and reduce the likelihood of an internal fire spreading externally to the building envelope. Answer "yes" if the building is sprinkler protected throughout. Note: Balconies, the top of an atrium or 2 hour fire rated electrical rooms are commonly unsprinklered. If only these spaces are unsprinklered then answer "yes". Otherwise answer "no".
Why this range?	This range is limited to whether or not the building is provided with a fully operational sprinkler system that is also tested and maintained.

Cladding Vertical Connectivity

What is the question and what are the answers?	In terms of the façade system pattern over the building, is there continuity in the combustible insulation and/or the combustible cladding (opaque, non-glazed portion) vertically across more than one story? Answer options: Yes / No Any vertical connections require a yes answer. Fire stopping and cavity barriers within the façade (as a potential mitigation measure) should not be taken into account when answering this question.
Why this variable?	Vertical connections of the cladding and/or insulation, i.e. non-glazed part of the exterior surface of the building could provide a means for rapid fire spread if the façade components are combustible.
Why this range?	Vertical connections can range from having no connections, i.e. spandrel panels only or fully glazed, to connecting the entire elevation. Grading or distinguishing between e.g. the number of vertical connections or the % of the elevation that is connected requires user interpretation and access to detailed information and is therefore subjective and less reliable as an answer. This is addressed in Tier 2.

Figure 29: Building with no vertical connection across the façade between stories (© Courtesy of Arup)

Figure 30: Building with vertical connections across the façade between stories (© Courtesy of Arup)

9.3.11.3 Tier 1B Variables

Detection and Fire Alarm

What is the question and what are the answers?	Is a fire detection and alarm system provided within the building? Yes/No If Yes: Is the fire alarm system fully operational, reliable, tested and maintained regularly? Yes/No/Don't know
Why this variable?	The provision of a maintained fire alarm system is important such that detection of a fire in the early stages, allows occupants to be alerted to afford their escape.
Why this range?	This range is limited to whether or not the building is provided with a fully operational detection and fire alarm system that is also tested and maintained. Differentiating between types of fire alarm requires a level of understanding which the users of the tool may not have. Note, while the fire alarm system is linked to the evacuation strategy, the choice of evacuation strategy is distinct and is considered as a separate variable, as described earlier.

Compartmentation

What is the question?	Is compartmentation between apartments, rooms and floor-by-floor in the building maintained and reliable? Yes / No / Don't know.
Why this variable?	Compartmentation is a key component in developing a fire strategy for a building such that it limits fire growth and restricts fire spread beyond the compartment of fire origin, which could trap building occupants; and reduces the chance of fires becoming so large that they become dangerous not only to occupants and fire and rescue service personnel but also to people in the vicinity of the building.

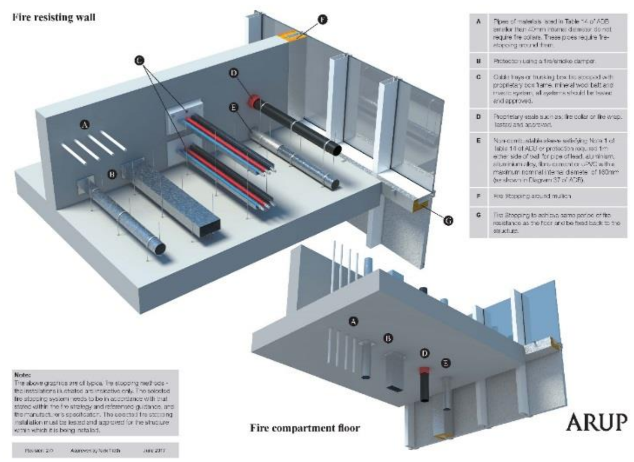


Figure 31: Fire Doors (© Courtesy of Arup)

Figure 32: Examples of fire stopping of service penetrations through fire resistant construction (© Courtesy of Arup)

Means of Escape

What is the question and what are the answers?	Do the occupants within the building have more than one escape stair available? Yes/No Is the escape stair(s) unlocked and enclosed in fire rated construction?
Why this variable?	The provision of a clear and available escape routes is essential to permit occupants to escape from a building. If doors are locked or the stair is not protected by fire doors and fire rated construction then the stair may not be available for means of escape during a fire involving the exterior façade system. Access control doors that open on fire alarm are not considered to be locked.
Why this range?	This range is one or more stairs and whether or not these are available for use.

	The building will have been designed assuming that the majority of escape routes are available, and therefore the restriction and unavailability of one or more escape routes may impede the evacuation of occupants.

9.3.12 Variables NOT chosen for Tier 1

These variables are not included in Tier 1 for the reasons given but will be revisited for Tier 2.

9.3.12.1 Façade related variables

Membranes (e.g. Impermeable vapor barrier / permeable breather membrane)

Why not this variable?	Membranes in facade systems are typically impermeable vapor barriers and permeable breather membranes. Vapor barriers in particular are often combustible as they are made from rubber or bituminous paints however they are also important to the performance of the façade system. The materials chosen and thickness of membrane can also vary. There are commonly 4 types of membrane -foil, rubberized, bituminous paint and woven textile. A facilities manager is unlikely to be able to identify the membrane materials and locations at Tier 1. This variable will not be a useful or reliable differentiator at Tier 1.

Size of Cavity

Why not this variable?	While the size of the cavity may contribute to the height of the flaming as the combustible façade is consumed a facilities manager is unlikely to be able to identify the cavity size at Tier 1. This variable will not be a useful or reliable differentiator at Tier 1.

Cavity Barriers

Why not this variable?	This variable scored relatively low in the AHP exercise of Section 8.1. Assessing the provision of cavity barriers which have been correctly installed in line with the fire strategy and code for the building, is out-with the scope of the Tier 1 assessment. This would also require a level of understanding which the users of the tool at Tier 1 are unlikely to have, without detailed drawing reviews and very likely opening up works on site.

Perimeter Fire Stopping

Why not this variable?	Similar to cavity barriers, this variable scored relatively low in the AHP exercise of Section 8.1.

Operable windows

Why not this variable?	Operable windows have not been treated any differently than fixed shut. This is because an unsprinklered fire is expected to break a window. The smoke temperatures from a sprinkelred fire (~100°C) are not expected to cause ignition of most façade materials.

Thermal barrier

Why not this variable?	In the USA, the IBC and NFPA 5000 require a thermal barrier between a façade system with combustible content and the interior of the building. This is not mandated globally so has not been included as a variable.

9.3.12.2 Other variables

Building Age

Why not this variable?	Building age may indicate the type and build-up of the façade, specifically as foam type insulation gained popularity in the late eighties, and in addition may indicate whether the building façade has been refurbished. However, these are assumptions, and do not reliably provide a benchmark of the increased fire risk associated with the building.

Building address

Why not this variable?	Building location would indicate the likely proximity to the fire and rescue service, should a fire occur. However, it not related to likely fire risk within or out-with the building nor how the building functions in order to ensure life safety, as the building should be designed to allow all occupants to escape prior to the attendance of the fire and rescue service. In addition it does not allow a direct assessment of the perimeter access for a fire appliance. Therefore building location is unlikely to be a significant differentiator in this assessment. Also fire service attendance times is greatly dependent on traffic conditions on the day, so this is not a reliable factor to take into consideration.

Proximity to other buildings

Why not this variable?	The proximity to other buildings may provide an indication of possible external fire spread from or to a neighboring building if the design of the respective buildings does not address this risk. However this risk factor is assessed in Tier 2 of the tool.

Perimeter access for fire appliances

Why not this variable?	Vehicle access to the building for the fire and rescue service forms part of the fire strategy for a building; for high rise buildings the firefighting access strategy is usually to provide facilities for firefighting from the interior, in combination with controlling the risk of fire spread on the exterior of the building. In addition there possibility that access may be blocked and fire service access not available, so for the purposes of this tool providing a conservative estimate of fire risk, the mitigating factor of fire service intervention reducing the likelihood of a fire was not included. It is included in the consequence side of the matrices for buildings up to 30m high as search and rescue and fighting fires with an aerial appliance is easier at these lower building heights. Good fire service access is assumed in Tier 1 but further assessed in Tier 2.

Smoke Control in Escape Routes

Why not this variable?	This variable scored relatively low in the AHP exercise of Section 8.1.

Management

Why not this variable?	This variable scored relatively low in the AHP exercise of Section 8.1.

9.4 Tier 2 Fire Risk Assessment

9.4.1 General

Tier 2 follows the same steps as PAS 79 also used in Tier 1. Tier 2 entails detailed desktop studies of plans, and as built information as well as on-site studies and testing, as necessary, to inform a more detailed building specific fire risk assessment to identify the materials in the façade system, ignition sources and any deficiencies in the fire safety provisions.

The buildings should be assessed based on the priority ranking assigned to them in Tier 1.

It should be noted that the outcomes established through Tier 1 are intended to be conservative and err on the side of caution, and it may be possible that no risk reduction measures are necessary upon further review of the buildings which have an outcome of C or greater (C-E) in Tier 1. On the other hand, due to the more detailed nature of Tier 2, other hazards which were not identified in Tier 1 may come to light.

The following sections describe the more detailed assessment of the likelihood and consequence of fire hazards in Tier 2.

The inputs and steps in a PAS 79 assessment to arrive at an outcome are:

a) Identification of the people at risk;

b) Identification of the fire hazards;

c) Assessment of the fire hazard likelihood; and

d) Assessment of the fire hazard consequence.

The following sections describe these four steps.

9.4.2 Facade Assemblies with Possible “Medium” likelihood score

Questions drafted for Tier 2 can give three different results Low, Medium or High. Medium results are not proposed unless they can be justified. If a medium result is not an option, then this is because further research or information is considered required to judge if the risk factor is less than high.

Façade systems that are expected to pass large scale testing (e.g. NFPA 285, BS 84114) have been scored as “low” or “medium” based on the experience of Arup/ Jensen Hughes, references to publically available test reports and interviews with testing laboratories. The façade build-ups as currently evaluated are shown in Figure 33 and Figure 34.

Specifically, Arup have liaised with the accredited fire testing laboratory Thomas Bell Wright (TBW) in Dubai to gather further evidence for these proposed scores. Over 140 NFPA 285 test reports were reviewed to establish patterns of behavior, supplier and product names were made anonymous:

- ACP panels with a core of Euroclass B/ASTM E84 Class A in combination with mineral wool insulation consistently pass NFPA 285 up to a maximum cavity size of 75 mm. Some tests passed at up to 90 mm cavity size.

- ACP panels of Euroclass A2 in combination with mineral wool insulation consistently pass NFPA 285.
- ACP panels with a 100% LDPE core do not pass NFPA 285.
- There were often no cavity barriers installed in the façade system. The three points above are independent of cavity barriers.

The conclusions above are similar to the results of the testing regime undertaken by the Building Research Establishment (BRE) for Department For Communities And Local Government (DCLG) [6] although these were carried out to BS 8414 with the acceptance criteria documented in BR 135 and all tests had cavity barriers.

There is less tests data available for façade systems involving GRP, timber panels etc. therefore the scoring for these are based on smaller cavity sizes and do not score "low" even with non-combustible insulation. This is deemed to be conservative (see Figure 34) based on current knowledge.

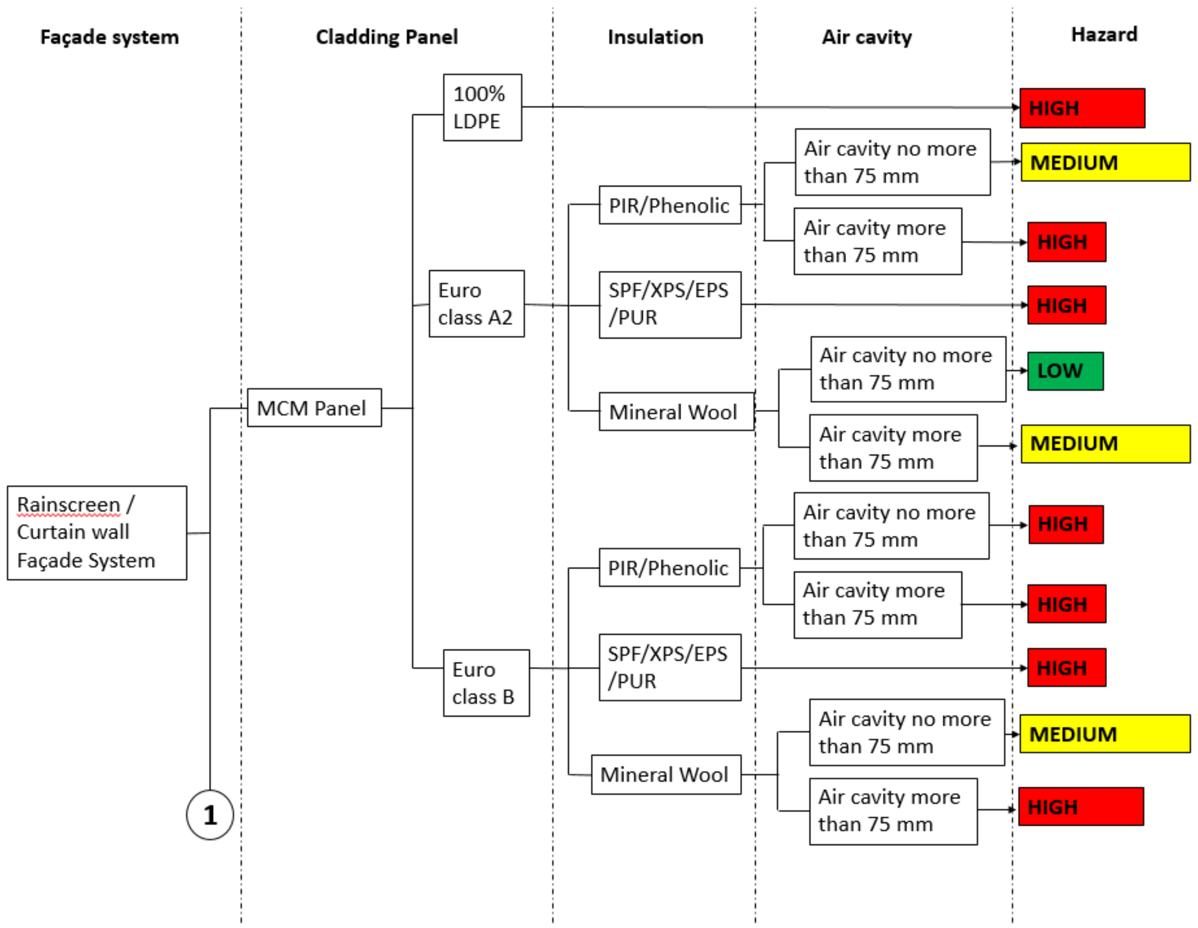


Figure 33 – Façade system hazards (fuel), Part 1, (© Courtesy of Arup)

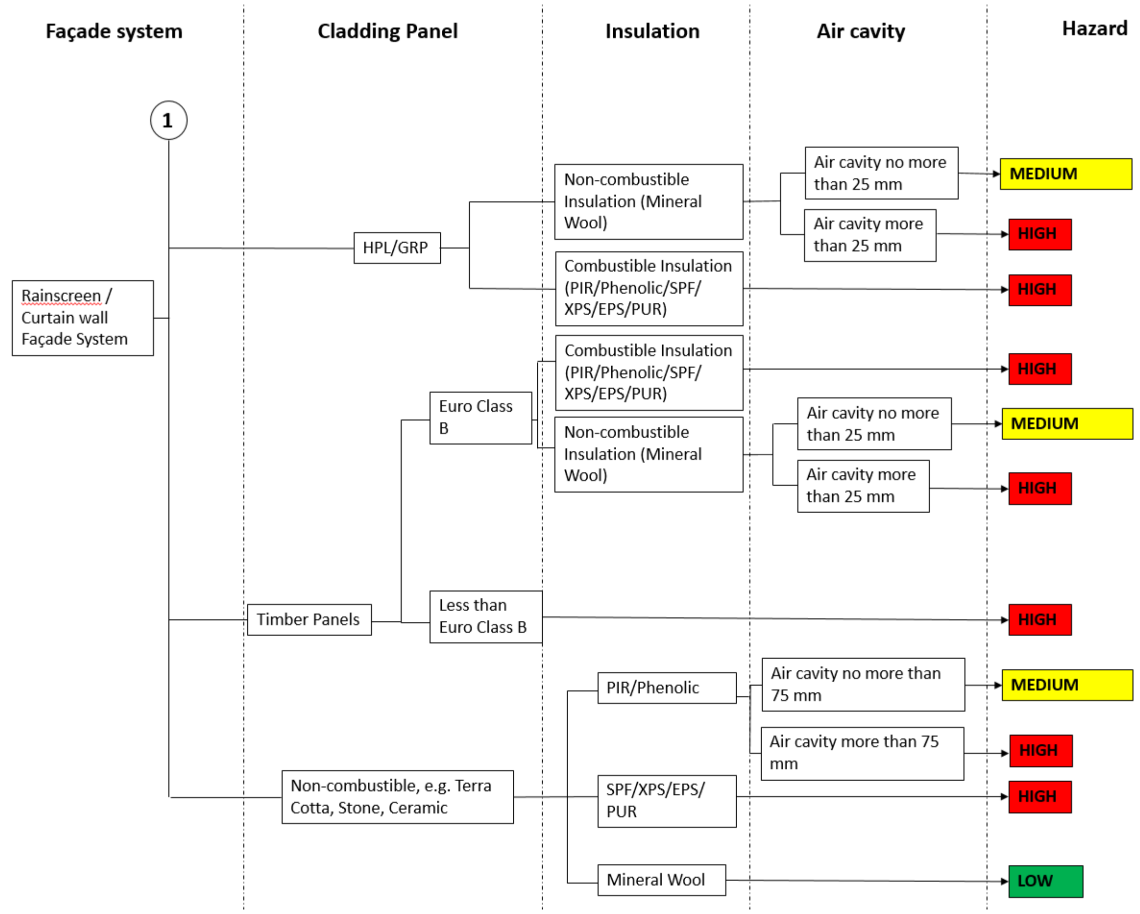


Figure 34 – Façade system hazards (fuel), Part 2, (© Courtesy of Arup)

9.4.3 Tier 2, Process A – Identify Fire Hazards Associated with the Façade

The hazards for Tier 2, Process A are the same as for Tier 1, with the following additions/changes:

Table 9: Tier 2 Hazards associated with the façade system

	Variable	Identified hazard in terms of fuel or ignition source (low to high)
Tier 2, process A	Insulation	Facade systems per Figure 33 and Figure 34
	Cladding	Facade systems per Figure 33 and Figure 34
	Façade Vertical Connectivity	Vertical connectivity has been defined as connecting more or less than 3m of a façade system. 3m is a typical story height. More than 3 m connected – High Less than 3 m connected – Low If the combustible façade system is on spandrels only and spandrels are less than 20% of the floor to floor height then the tool ignores this fuel. Further commentary is given on this issue in the User's Guide in Appendix B where all of the Tier 2 questions are discussed.
	External ignition Sources/Fire Hazards	In addition to the hazards in Tier 1 the proximity of adjacent buildings and presence of ignition sources in the façade cavity have been included in Tier 2. Further commentary is given on this issue in the User's Guide in Appendix B where all of the Tier 2 questions are discussed.

9.4.4 Tier 2, Process B – Identify Hazards Associated with Deficient Fire Safety Provisions

The hazards for Tier 2, Process B are the same as for Tier 1, Process B.

9.4.5 Tier 2, Process A - Assessment of the Likelihood of the Fire Hazard

In order to assess the likelihood of a fire over multiple stories of a building, the fuel, ignition sources and vertical connectivity of the fuel have been combined as follows.

The individual hazards are scored as follows:

HAZARD		SCORE
Facade systems per Figure 33 and Figure 34	No fuel	Low
Facade systems per Figure 33 and Figure 34	Limited Fuel	Medium
Façade systems per Figure 33 and Figure 34	Significant Fuel	High
Sprinklered building with no balconies and no ignition source at base of building or in façade cavity or on facade.	Very few ignition sources	Low
Ignition source at base of building and/or in cavity and/or lights/PV panels on façade and/or proximity of adjacent building with non-combustible facade	Limited ignition sources	Medium
Balconies or unsprinklered building or proximity of adjacent building with combustible facade	Multiple ignition sources	High
No vertical connections between combustible façade, less than 3m of façade system vertically connected	Fuel is not connected over building height	Low
Vertical connections between combustible façade, more than 3m connected	Fuel is connected over more than 3 m of building height	High

When these hazards are combined then the likelihood of a fire over multiple stories of a façade system can be defined:

HAZARD			LIKELIHOOD OF A FIRE OVER MULTIPLE STORIES (CLADDING NOT VERTICALLY CONNECTED)	REASON
FUEL		IGNITION SOURCE		
INSULATION	CLADDING			
Low	Low	Low	Very Low	No fuel and no ignition source
Low	Low	Medium	Very Low	No fuel
Low	Low	High	Very Low	No fuel
High	Low	Low	Low	No ignition source but fuel from insulation
High	Low	Medium	Medium	Significant ignition sources and fuel from insulation
High	Low	High	High	Multiple ignition sources and fuel from insulation
Low	High	Low	Low	No ignition source but fuel from cladding
Low	High	Medium	Medium	Significant ignition source and fuel from cladding
Low	High	High	High	Multiple ignition sources and fuel from cladding
High	High	Low	Low	No ignition source but cladding and insulation as fuel
High	High	Medium	High	Significant ignition source with cladding and insulation as fuel
High	High	High	High	Multiple ignition sources with cladding and insulation as fuel
Medium	Low	Low	Very Low	No ignition source but limited fuel from insulation

HAZARD			LIKELIHOOD OF A FIRE OVER MULTIPLE STORIES (CLADDING NOT VERTICALLY CONNECTED)	REASON
FUEL		IGNITION SOURCE		
INSULATION	CLADDING			
Medium	Low	Medium	Low	Significant ignition source and limited fuel from insulation
Medium	Low	High	Medium	Multiple ignition sources and limited fuel from insulation
Low	Medium	Low	Very Low	No ignition source but limited fuel from cladding
Low	Medium	Medium	Low	Significant ignition source and limited fuel from cladding
Low	Medium	High	Medium	Multiple ignition sources and limited fuel from cladding
Medium	Medium	Low	Low	No ignition source but fuel from insulation and cladding
Medium	Medium	Medium	Medium	Significant ignition source and fuel from insulation and cladding
Medium	Medium	High	High	Multiple ignition sources and fuel from insulation and cladding
High	Medium	Low	Low	No ignition source but fuel from insulation and cladding
High	Medium	Medium	Medium	Significant ignition source and fuel from insulation and cladding
High	Medium	High	High	Multiple ignition sources and fuel from insulation and cladding
Medium	High	Low	Low	No ignition source but fuel from insulation and cladding
Medium	High	Medium	Medium	Significant ignition source and fuel from insulation and cladding
Medium	High	High	High	Multiple ignition sources and fuel from insulation and cladding

If the fuel is then vertically connected over the height of the façade then the likelihood of a fire over multiple stories of a façade system is increased:

HAZARD			LIKELIHOOD OF A FIRE OVER MULTIPLE STORIES (CLADDING NOT VERTICALLY CONNECTED)	REASON	LIKELIHOOD OF A FIRE OVER MULTIPLE STORIES (CLADDING VERTICALLY CONNECTED)	REASON
FUEL		IGNITION SOURCE				
INSULATION	CLADDING					
Low	Low	Low	Very Low	No fuel and no ignition source	Very Low	No fuel so vertical connection is irrelevant
Low	Low	Medium	Very Low	No fuel	Very Low	
Low	Low	High	Very Low	No fuel	Very Low	
High	Low	Low	Low	No ignition source but fuel from insulation	Medium	Vertical connection increases fuel and connects it over building height
High	Low	Medium	Medium	Significant ignition sources and fuel from insulation	High	
High	Low	High	High	Multiple ignition sources and fuel from insulation	Very High	
Low	High	Low	Low	No ignition source but fuel from cladding	Medium	
Low	High	Medium	Medium	Significant ignition source and fuel from cladding	High	
Low	High	High	High	Multiple ignition sources and fuel from cladding	Very High	
High	High	Low	Low	No ignition source but cladding and insulation as fuel	Medium	
High	High	Medium	High	Significant ignition source with cladding and insulation as fuel	Very High	
High	High	High	High	Multiple ignition sources with cladding and insulation as fuel	Very High	
Medium	Low	Low	Very Low	No ignition source but limited fuel from insulation	Low	
Medium	Low	Medium	Low	Significant ignition source and limited fuel from insulation	Medium	
Medium	Low	High	Medium	Multiple ignition sources and limited fuel from insulation	High	

HAZARD			LIKELIHOOD OF A FIRE OVER MULTIPLE STORIES (CLADDING NOT VERTICALLY CONNECTED)	REASON	LIKELIHOOD OF A FIRE OVER MULTIPLE STORIES (CLADDING VERTICALLY CONNECTED)	REASON
FUEL		IGNITION SOURCE				
INSULATION	CLADDING					
Low	Medium	Low	Very Low	No ignition source but limited fuel from cladding	Low	Vertical connection increases fuel and connects it over building height
Low	Medium	Medium	Low	Significant ignition source and limited fuel from cladding	Medium	
Low	Medium	High	Medium	Multiple ignition sources and limited fuel from cladding	High	
Medium	Medium	Low	Low	No ignition source but fuel from insulation and cladding	Medium	
Medium	Medium	Medium	Medium	Significant ignition source and fuel from insulation and cladding	High	
Medium	Medium	High	High	Multiple ignition sources and fuel from insulation and cladding	Very High	
High	Medium	Low	Low	No ignition source but fuel from insulation and cladding	Medium	
High	Medium	Medium	Medium	Significant ignition source and fuel from insulation and cladding	High	
High	Medium	High	High	Multiple ignition sources and fuel from insulation and cladding	Very High	
Medium	High	Low	Low	No ignition source but fuel from insulation and cladding	Medium	
Medium	High	Medium	Medium	Significant ignition source and fuel from insulation and cladding	High	
Medium	High	High	High	Multiple ignition sources and fuel from insulation and cladding	Very High	

9.4.6 Tier 2, Process B - Likelihood of Means of Egress and Warning Being Compromised

Tier 2, Process B is the same as Tier 1, Process B.

9.4.7 Tier 2, Process B - Risk Based on Likelihood and Consequence

Tier 2, Process B is the same as Tier 1, Process B.

9.4.8 Tier 2 Questions and Answers

As stated previously, the purpose of Tier 2 is to confirm or amend the prioritization assigned to the building in Tier 1, due to a greater understanding of each variable, and to identify areas for mitigation to reduce the risk ranking or identify the need for a Tier 3 assessment.

The questions in Tier 2 are intended to be applied to each of the building elevations as required to assess the hazard (fuel and ignition sources) on each elevation.

As the Tier 2 questions are answered some of the façade systems may be identified as having no combustible insulation or cladding. If the elevation(s) has no combustible insulation or cladding then the user can stop answering questions for that elevation.

Ignition hazards on the elevation that could affect other façade systems may still need to be considered (e.g. kitchen hood exhaust points or smoke extract points from basements etc.).

All of the Tier 2 questions and commentary are provided in the User's Guide in Appendix B.

9.4.9 Variables NOT Chosen for Tier 2

9.4.9.1 Façade Related Variables

Operable windows

Why not this variable?	Operable windows have not been treated any differently than fixed shut. This is because an unsprinklered fire is expected to break a window. The smoke temperatures from a sprinklered fire (~100°C) are not expected to cause ignition of most façade materials.

Thermal barrier

Why not this variable?	In the USA, the IBC and NFPA 5000 require a thermal barrier between a façade system with combustible content and the interior of the building. This is not mandated globally so has not been included as a variable.

Membranes (e.g. Impermeable vapor barrier / permeable breather membrane)

Why not this variable?	Membranes in facade systems are typically impermeable vapor barriers and permeable breather membranes. Vapor barriers in particular are often combustible as they are made from rubber or bituminous paints however they are also important to the performance of the façade system. Membranes are provided to control the direction of flow of vapor. The air seal location is what changes based on climate. The cold side of the facade system should always have the lower vapor resistivity. In countries with a hot climate the impermeable membrane is on the outside of the insulation .In areas with a hot climate all year round, the system only needs one membrane layer on the outside of the insulation. In countries with a cold climate the problems of too much fuel arise when a designer has two membranes and one is thicker than the other to control the vapor flow. The materials chosen and thickness of membrane can also vary. There are commonly 4 types of membrane -foil, rubberized, bituminous paint and woven textile. If a designer uses a rubber product as the membrane(s) it could be 1-2 mm thick in two locations. There have been no publically recorded instances of a façade fire involving the membranes only. If the façade system is to be removed and redesigned the new design should incorporate the minimum combustible content to achieve the necessary water resistive barriers. Guidance on this matter is provided in international codes such as NFPA 5000 and the International Building Code. This variable should be considered in a Tier 3 assessment. If upon removal of parts of the façade system there is one or two thick water resistive barriers of a rubber or combustible material then a Tier 3 assessment should be carried out.

Condition of the Facade

Why not this variable?	While physical holes or gaps in the façade system are likely to provide a route for ignition sources and flames it is difficult to quantify the impact of this in a risk assessment. An inspector could be faced by a façade system that has very localized damage/ deterioration or only one side may have aged due to prevailing weather conditions. The combustible content is proposed to be a bigger issue than age or condition. Condition of the façade is likely to factor into a Tier 3 assessment.

Perimeter Fire Stopping

Why not this variable?	This variable scored relatively low in the AHP exercise of Section 8.1.

Cavity Barriers

Why not this variable?	This variable scored relatively low in the AHP exercise of Section 8.1.

9.4.9.2 Other variables

Building Age

Why not this variable?	Building age may indicate the type and build-up of the façade, specifically as foam type insulation gained popularity in the late eighties, and in addition may indicate whether the building façade has been refurbished. However, these are assumptions, and do not reliably provide a benchmark of the increased fire hazard associated with the building facade. Furthermore, the facade system may have been replaced or upgraded since the building was first built.

Building Address

Why not this variable?	Building location would indicate the likely proximity to the fire and rescue service, should a fire occur. However, it is not related to likely fire hazard within or out-with the building nor how the building functions in order to ensure life safety, as the building should be designed to allow all occupants to escape prior to the attendance of the fire and rescue service. In addition, it does not allow a direct assessment of the perimeter access for a fire appliance. Therefore, building location is unlikely to be a significant differentiator in this assessment. Also fire service attendance times is greatly dependent on traffic conditions on the day, so this is not a reliable factor to take into consideration.

Smoke Control in Escape Routes

Why not this variable?	This variable scored relatively low in the AHP exercise of Section 8.1.

Management

Why not this variable?	This variable scored relatively low in the AHP exercise of Section 8.1.

10 Mitigation Measures

A risk score of more than trivial as established in Tier 2 will indicate that mitigation measures are recommended.

This tool is intended to assess the fire risk associated with combustible façade systems that have, for whatever reason, been installed on high rise buildings. Where there are deficiencies in pre-existing fire safety provisions such as sprinklers, fire alarm or passive fire protection that were required by the original design or applicable code, then these should be rectified as a matter of course.

The mitigation options that will reduce the risk rankings assigned by this tool can be classified as follows:

Management solutions;

Repair and regular testing/maintenance of existing fire safety provisions

Installation of additional fire safety provisions (active or passive);

Facade system remediation.

The arrow in the diagram above generally indicates that the mitigation options increase in their effectiveness to reduce risk.

Table 10 – Possible mitigation measures and a discussion of their possible impact

Mitigation options	Examples	Impact on risk ranking
Management solutions	Management procedures to eliminate occupancy of balconies or at least prohibit BBQs, shisha pipes and other similar ignition risks from balconies. This would need to be monitored daily or more often	This will reduce the ignitions risks sub-category and is a suitable short-term solution but will not give significant gains long-term. It may be appropriate where immediate action needs to be taken because a building is classified as "substantial (D)" or "intolerable (E)"
	Management procedures to eliminate fire load near the base of the building e.g. no parking, no trash containers etc. This would need to be monitored daily or more often	
	Remove or de-energize PV panels and lighting systems including any associated low voltage transformers to reduce ignition risks. Removal of kitchens and their associated kitchen exhausts or removal of the façade system above and in the vicinity of the exhaust.	
Repair and regular testing/maintenance of existing fire safety provisions	Repair of a faulty fire alarm system and initiation of a code compliant testing/maintenance regime.	Any repair or introduction of a maintenance regime will impact the categories associated with Means of Escape and Warning/ Containment and Extinguishment. This will generally have a positive effect on the risk ranking in all cases. However, these should be carried out regardless to protect occupants against other fire scenarios interior to the building. In the context of this tool, changes which improve means of escape routes, fire alarm and compartmentation have the greatest impact on the risk ranking in Tier 2B. Introducing sprinklers reduces the likelihood of a fire in a building in Tier 2A.
	Initiation of a code compliant testing/maintenance regime for any of the passive or active systems that have not been looked after over the life of the building.	
Installation of additional fire safety provisions (active or passive)	Upgrade of a fire alarm system from a "stay-put" type system to "all-out" i.e. the fire alarm will sound simultaneously throughout the building and not just in the apartment of fire origin.	The risk rankings for residential "all-out" are lower than for the same building height, façade risk and fire safety provisions as residential "stay-put". This means upgrading the fire alarm system will have some benefit in reducing the risk ranking. It will not remove the fire risk but it will mean occupants are likely to leave the building more quickly.
	Addition of sprinklers interior to the building	This will help reduce the likelihood of ignitions sub-category. Sprinklers do not offer a guarantee that fire will not break out through the window into the facade but they reduce the risk.
	Addition of sprinklers to balconies	This will help reduce the likelihood of ignitions sub-category. Sprinklers on balconies do not offer a guarantee that fire will not spread to the façade but they reduce the risk.

Mitigation options	Examples	Impact on risk ranking
Facade system remediation	Replacement or removal of vertical connections in the façade system.	This will reduce the "façade hazards" category as the likelihood for flame spread up the building facade is reduced. This option does not offer a guarantee that fire will not spread up the building as flames could leap from one portion of combustible façade to another or flaming debris could ignite the façade at lower levels but it would reduce the risk.
	Removal of combustible façade cladding/insulation near the base of the building.	This could be an option if the ignition risks are at the base of the building only and the interior of the building is sprinkler protected. This option does not offer a guarantee that fire will not spread up the building as flames could break-out from an interior fire but it would reduce the risk.
	Removal of combustible façade cladding/insulation in the vicinity of ignition sources.	This could be an option if the ignition risks are limited and the interior of the building is sprinkler protected. This option does not offer a guarantee that fire will not spread up the building as flames could break-out from an interior fire but it would reduce the risk.
	Replacement of the combustible cladding and/or insulation system in its entirety	This is the only way of mitigating the risk of a façade fire and reducing the risk to "tolerable (B)" or trivial (A)"

11 Data Gathering

11.1 General

The user's guide provides a step by step guide for the user to each Tier and question in the FRA tool. For example, there is commentary and guidance on each of the questions and pre-defined answers in Tier 1 and Tier 2.

Gathering of information on the façade system is a significant task that needs to be undertaken to be able to answer the questions in Tier 2A.

For the two tiers of the FRA tool, there two distinct methods of gathering data proposed:

- Tier 1 – Simple questionnaire from the AHJ/Enforcer to the facilities manager/owner for them to answer based on their knowledge of the building and possible access to as-built information.
- Tier 2 – Review of as-built information (if available), interviews with facilities management, on site assessment, visual inspection and some destructive testing of the façade system for better visual access or to take samples of materials for laboratory testing. A rigorous Tier 2 assessment requires information related to the combustibility of the cladding and insulation within the façade system. Figure 35 and the following sections provide some guidance on gathering information about the façade system and its insulation/cladding materials.

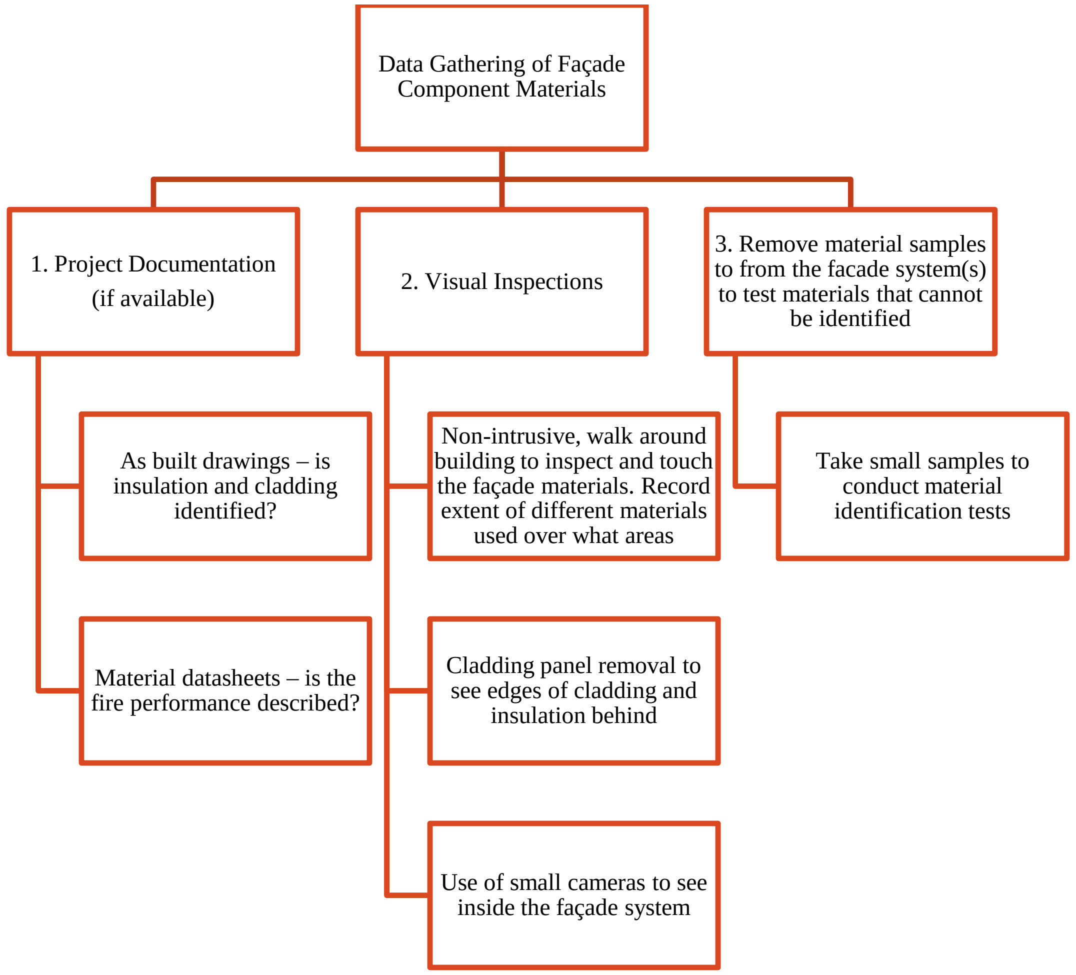


Figure 35 Options for gathering data on façade systems (© Courtesy of Arup)

11.2 Suggested Process for ID of Façade Systems and Combustible Component Materials

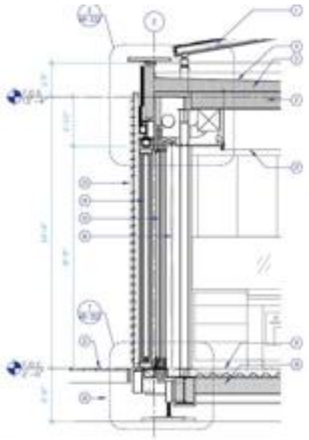
Step 1 Review as built drawings (if available)	
Step 2 Review as built material submittals (If available)	
Step 3 Visual inspection of façade at the building.	
Step 4 Visual inspection with removal of façade elements.	
Step 5 Destructive sampling and laboratory testing of component façade materials (insulation and cladding) if necessary	

Figure 36 Flowchart outlining a process to identify the façade type and combustible materials in the façade system, to be read in conjunction with Table 11 and Table 12 (© Arup and Thinkstock)

Table 11 Steps to identify (ID) combustible materials in a façade system

Steps	Activity	Where to look	What to look for?
Step 1	Review as built drawings (if available)	Drawings of cross-sections through the façade system. Operating and Maintenance (O&M) manuals describing the façade systems. The owner or facilities manager should be able to provide these although they may have been lost if the building is older and the ownership has changed several times	Compare the drawings to the façade systems in the user's guide. If possible, identify the likely façade typology but most importantly identify the presence or not of insulation, cavities and cladding materials. Make a note of these materials and cavity sizes for each elevation and area of facade system.
Step 2	Review as built material submittals (if available)	Material submittals can be very large documents comprising 100s of pages but many are not relevant to this task. The material submittal may not be for the façade system but for the component materials only. An EIFS/ETICS or insulated metal panel façade assembly should come in one material submittal. The component parts of a curtain wall or rainscreen system may be in separate documents.	Look for the specification requirements, the data sheet from the supplier and any fire test certificates. Has the façade system as installed been tested as an assembly to NFPA 285 or BS 8414 or similar? Have the façade materials been tested to NFPA 285 or BS 8414 in a standard façade system (not the same as the project). Have the component materials been tested for their reaction to fire properties e.g. flame spread, ignitability etc.? There could be engineering judgments in support of the façade system installation. Please be cautious of these as they may not provide sufficient justification for the combustible materials in the system. Collect this information.
Step 3	Visual inspection of façade at the building	Look at each elevation of the building in turn. Some buildings may have the same façade system and ignition sources on every elevation while others will have different façade systems or different aesthetic patterns of the same façade system or different ignition sources. All of these differences need to be documented. The FRA tool prompts this through questions in Tier 2A.	Does the installation look like the as-built information? Do the patterns of glass and opaque façade system match the drawings? If there is no as-built information, try to identify the likely façade typology and cladding materials by using the user's guide. If a cavity and insulation is expected behind the cladding then use a small camera and light to see inside the system. Look for access hatches in the façade system to see into the wall depth. These could be provided at fuel filling points if there are diesel or gas tanks in the building. It may not be possible to see insulation or cavities without removing parts of the façade. See the user's guide for information on what to check and look out for.
Step 4	Visual inspections with removal of façade elements	With assistance from the owner/facilities manager and a qualified contractor, remove portions of the facade to gain access to see the insulation or cavities. Where possible, do this in non-obtrusive locations. This may need to be from the exterior or from the interior of the building. If there are different façade system or materials installed across the building then this exercise has to happen for each area of the façade.	See guidance for different materials in Table 12. Measure and note the insulation thickness. Measure and note the cavity depth.
Step 5	Destructive sampling and laboratory testing of component façade materials (insulation and cladding)	If the insulation or cladding materials cannot be identified with certainty in Steps 1-4, then small samples will need to be removed for laboratory testing and identification. Samples of combustible components may be removed during a building inspection for further forensic analysis to document reaction to fire properties as well as identify the presence (or not) of fire-retardant compounds and or non-combustible minerals	See guidance for different materials in Table 12.

Table 12 Suggested laboratory tests for further forensic analysis of materials to document material properties, the presence (or not) of fire-retardant compounds and/or non-combustible minerals and reaction to fire properties

Materials	Characteristics and visual appearance				Laboratory testing	Reaction to fire testing recognized by FRA tool
	Color	Texture	Appearance of cross-section	Sound when tapped with a metal object		
Glass	See-through, opaque white or colored.	Hard and smooth	Uniform throughout	A sharp sound	Not required	Not required
Stone	A range of colors depending upon the geology of the stone.	Hard but could be smooth or rough	The material is uniform through its cross-section although the colors may vary.	A thud	Not required	Not required
Ceramic	Ceramic is usually clay-based and hardened through heating. Various colors	Hard and usually smooth	Uniform throughout	A sharp sound	Not usually required. Material is clay based so could be identified through FTIR.	Not required
Terracotta	Terracotta is a clay based, unglazed ceramic, typically brown or red in color.	Hard and usually quite smooth	Uniform throughout	A sharp sound	Not usually required. Material is clay based so could be identified through FTIR.	Not required
Metals e.g. steel, aluminium, copper	Copper is usually brown or green due to oxidation. Steel and aluminium are silver but an aluminium will not attach to a magnet whereas steel will.	Hard and smooth	Uniform throughout. There may be evidence of welds at joints or bends.	A sharp sound, can be hollow if cavity behind	Not required	Not required
Brick	Brick is usually orange or cream with grey mortar	Hard and quite smooth	Uniform throughout	A thud	Not required	Not required
Brisk-slip	Brick is usually orange or cream with grey mortar	Hard and quite smooth	Uniform throughout	A dull thud if plastic.	Required if the brick-slip feels and looks like a plastic such as acrylic. X-ray diffraction will identify materials and quantities. Cone calorimeter will identify quantity (mass loss) of combustibles.	
GRC	Usually grey or cream/off-white.	GRC is a very smooth concrete as the aggregate (sand and glass) is fine and the pores are very small.	Uniform throughout	A thud	Not usually required. Material could be identified through FTIR.	Not required
GRP	GRP can be formed to almost any shape and be colored with a variety of pigments.	Plastic look and feel	Uniform throughout	They will sound like plastic when tapped.	Microscopic testing can be conducted to identify the presence of glass fibers. FTIR testing can be used to detect and identify the presence of polymer materials.	ASTM E 84 or EN 13501-1 series of tests.
MCM e.g. ACP	Various as outer metal skins can be painted or made to look like timber, stone etc.	Hard and smooth like metal	Composite material with a plastic core and two outer metal skins. Typically 4-6mm thick	Some metallic “twang” but also a dull thud due to plastic core	X-ray diffraction of the core will identify materials and quantities. Cone calorimeter will identify quantity of combustibles (mass loss).	ASTM E 84 or EN 13501-1 series of tests
HPL	HPL panels can have many different types of finishes, from a timber looking finish to brightly colored panels.	Hard and smooth but less hard than a metal	Layers of thin glued Kraft paper	A dull thud due to paper build-up	Microscopic analysis can be used to reveal multiple layers within the panel, indicative of the individual Kraft paper layers.	ASTM E 84 or EN 13501-1 series of tests

Materials	Characteristics and visual appearance				Laboratory testing	Reaction to fire testing recognized by FRA tool
	Color	Texture	Appearance of cross-section	Sound when tapped with a metal object		
Timber	Natural wood or painted	Hard but less than metal/stone. Grain visible.	Grain structure and sawdust from cutting	A dull thud	Not usually required	ASTM E 84 or EN 13501-1 series of tests
Mineral wool	Light brown/tan or grey in color.	Scratchy due to fibers and binders	Fibrous strands with binder. Fibrous and "scratchy" or "sharp"	None as soft	Not usually required. Microscopic inspection will confirm the presence of fibers and binders. . In this FRA tool mineral and glass wool are treated the same way so the key is to differentiate between a foam or a mineral.	Not required
Glass wool	Often yellow.	Scratchy due to fibers and binders	Fibrous strands with binder. Fibrous and "scratchy" or "sharp"	None as soft	Not usually required. Microscopic inspection will confirm the presence of fibers and binders. In this FRA tool mineral and glass wool are treated the same way so the key is to differentiate between a foam or a mineral.	Not required
Foams (PUR,PIR,Phenolic)	Tan	PUR, PIR and Phenolic foams come in boards. Smooth, foam like	Uniform, foam like texture Foil facers may be included on one or both of the faces and manufacturer information could be printed on the facers to provide identifying information.	A quiet thud	FTIR analysis can be used to refine the foam identification. The FTIR will provide a chemical fingerprint for the foam which can be compared to available chemistry database information for these common classes of foam products.	ASTM E 84 or EN 13501-1 series of tests
Foams (EPS)	White although other colors may be present due to variations in the formulation, particularly additives such as carbon black.	Pre-expanded polystyrene beads which can be seen	Bead structure	"Squeak" of metal against plastic	For EPS, microscopic analysis will support the presence of the small polystyrene beads and FTIR testing will identify the polystyrene chemical formulation.	ASTM E 84 or EN 13501-1 series of tests
Foams (XPS, SFI)	XPS can be many colors depending on the manufacturer, especially in the USA. Can be blue, pink, green, or black (for products with carbon black added to mixture).	XPS comes as a board and is smooth, foam like. SFI is just sprayed into a cavity so is not a board.	Smooth, foam like	"Squeak" of metal against plastic	FTIR analysis can be used to refine the foam identification. The FTIR will provide a chemical fingerprint for the foam which can be compared to available chemistry database information for these common classes of foam products.	ASTM E 84 or EN 13501-1 series of tests

11.2.1 Test Samples and Removal

Sample selection sites should be representative of the installed materials on the building. Multiple sample locations may be needed in order to obtain confidence that the materials being removed are representative of the building exterior wall construction. Depending on the building, only one sample typically needs to be removed from each location, however, multiple samples or larger samples may be removed to ensure acceptable testing results will be obtained. The location of the sample removal sites needs to be documented on drawings and through photographic means.

A competent contractor should be hired to remove the samples and make any necessary repairs to the existing exterior wall, as needed. If samples are taken from unobtrusive areas then repairs may not be needed. A method statement and health & safety procedures should be adhered to. Repair of the façade system should be undertaken, to close any opened areas and reduce the likelihood of ignition of exposed insulation or similar.

Samples should be packaged appropriately to ensure no damage occurs between the removal and the testing. Care to keep samples dry should also be taken as added water to a sample may alter the testing results.

Forensic testing typically does not require large amounts of material. However, since coordinating and performing destructive testing necessary to obtain samples is difficult, slightly more material than may be initially needed is always preferred to be obtained from any project. Samples of material should be approximately 300-mm x 300-mm (12-inches x 12-inches) in size. If the amount of accessible material is limited, 100-mm x 100-mm (4-inches x 4-inches) in size is suitable.

11.2.2 Forensic Laboratory Testing Referenced by the FRA Tool

11.2.2.1 Cone Calorimeter Testing

Testing using an Oxygen Consumption Calorimeter, (commonly referred to as the Cone Calorimeter) provides useful fire performance parameters, including peak heat release rate (HRR) values for the product being tested as well as the amount of energy contained in the plastic (heat of combustion), and a relative measure of the mass of the sample consumed i.e. the combustible mass of the sample.

For example, a solid LDPE sample from an MCM panel core will exhibit very high peak HRR values, a heat of combustion exceeding approximately 45 MJ/kg, relatively quick times to ignition, and little material remaining at the end of the test.

In contrast, MCM panel plastic core materials containing fire retardant compounds would be expected to have lower peak HRR values, low heat of combustion values, and percentage of mass remaining in the range of 30 to 40 percent of the original sample mass.

An exact determination of the type of plastic material cannot be determined by the Cone Calorimeter testing without known reference samples. However, the relative fire performance parameters gathered by the Cone Calorimeter testing will provide an indication as to the type of plastic core material being evaluated (pure polyethylene core or a core with polyethylene and mineral or fire retardants) and the quantity of combustible material (mass loss).

11.2.2.2 Microscopic Testing

High powered microscopic testing can provide another means for determining the presence or not of fire retardant chemicals in a material. Common microscopic testing techniques include using a scanning electron microscope with an energy dispersive spectrometer (SEM/EDS) and a SEM, back scattered electron mode (SEM-BSE). Both methods allow for producing a greyscale image with high contrast between organic and inorganic phases of materials. Images can be included in reports for positive identification evidence.

The SEM/EDS analysis can detect the presence and relative quantities of elements commonly used in various types of fire retardant additives, including magnesium, antimony, boron, aluminum, phosphorous, chlorine, and bromine. The exact amount of these elements in MCM panels and combustible insulation materials is typically not determined, simply the presence, or not. In MCM panels, a relatively pure sample of LDPE would not be expected to contain measureable amounts of these elements, so the presence of these common fire retardant elements could indicate a fire-retardant treated plastic core material. This test would need to be conducted alongside a cone calorimeter test to establish the quantum of combustible materials as the FRA tool asks questions about the percentage of combustible content in the MCM core and or if the core has achieved a Euroclass B or A2.

11.2.2.3 Fourier Transform Infrared Spectroscopy (FTIR)

A small sample of any combustible material can be evaluated by conducting a Fourier Transform Infrared Spectroscopy (FTIR) analysis to identify the presence of chemicals in the test sample. The FTIR analysis uses infrared light to scan the test sample and develop a "fingerprint" of the material present based on the absorbed radiation at specific wavelengths unique for each element or material. Standard chemistry databases can be referenced for various common compounds and polymers for identification purposes.

The FTIR analysis can identify the foam insulation material, confirm the presence of LDPE, minerals and fire retardants in the cores of MCM panels.

11.2.2.4 Thermogravimetric Analysis (TGA)/X-Ray Diffraction

A thermogravimetric analysis (TGA) with X-ray Diffraction analysis can be used to evaluate the thermal decomposition process of a sample and the percent of materials remaining after the decomposition process. The TGA measures the mass of the sample with time while the temperature of the sample is changed (representative of combustion).

X-ray diffraction techniques can then be used to identify the relative percentage of plastic core materials by weight as well as other organic and inorganic materials contained in the test sample. The results are similar in nature to the cone calorimeter testing results whereby relative amounts of known materials can be identified to determine the plastic material composition products (plastic, filler materials, and common fire retardant elements).

11.2.2.5 Testing Laboratory Accreditation and Capability

All samples should be sent to an experienced testing laboratory which is accredited per ISO 17025, *General Requirements for the Competence of Testing and Calibration Laboratories*, or equivalent. Laboratories should have the capabilities to perform the above described forensic testing and it is recommended that the sample testing program be discussed with the testing laboratory to ensure the expected results will be delivered.

For this type of inspection, the laboratory should be capable of identifying the particular general chemical nature of the foam plastic insulation materials as well as possess a general understanding of the cladding materials composition to properly evaluate the exterior wall samples.

11.2.3 Common Reaction to Fire Tests and Façade Assembly Fire Tests Referenced by the FRA Tool

Most countries test to American, British, European or ISO test standards. The following is a non-exhaustive list of the test standards referenced in the section of the report.

ASTM D 1929, Standard Test Method for Determining Ignition Temperature of Plastics, 2012.

ASTM E 84, Standard Test Method for Surface Burning Characteristics of Building Materials, 2013.

BS 8414-1:2015 Fire performance of external cladding systems. Test method for non-loadbearing external cladding systems applied to the masonry face of a building was published in 2015. It was then amended by BS 8414-1:2015+A1:2017 in June 2017.

BS 8414-2:2015 Fire performance of external cladding systems. Test method for non-loadbearing external cladding systems fixed to and supported by a structural steel frame was published in 2015. It was then amended by BS 8414-2:2015+A1:2017 in June 2017.

Colwell S. and Baker T., BR 135 Fire performance of external thermal insulation for walls of multistory buildings, Third edition, 2013.

NFPA 268, Standard Test Method for Determining Ignitability of Exterior Wall Assemblies Using a Radiant Heat Energy Source, 2012.

NFPA 285, Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components, 2012 edition.

NFPA 286, Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth, 2011.

ASTM E1354, Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter, 2017.

ISO 1716, Reaction to fire tests for building products -- Determination of the heat of combustion (bomb calorimeter), 2010.

ISO 1182 - Reaction to fire tests for products - Non-combustibility test, 2010.

ISO 11925-2 - Reaction to fire tests -- Ignitability of products subjected to direct impingement of flame - Part 2: Single-flame source test, 2010

EN 13501-1, Fire classification of construction products and building elements. Classification using test data from the following reaction to fire tests, 2007:

EN ISO 1182 - Reaction to fire tests for products - Non-combustibility test.

EN ISO 1716 - Reaction to fire tests for products - Determination of the gross heat of combustion (bomb calorimeter).

EN 13823 - Single burning item (SBI) test,

EN ISO 11925-2 - Reaction to fire tests -- Ignitability of products subjected to direct impingement of flame - Part 2: Single-flame source test.

12 Conclusion

This report presents the proposed methodology for the NFPA risk assessment tool for high rise buildings with combustible facade systems as it applies to the global building market.

The methodology proposes a two tier approach to the risk assessment tool. Tier 1 is a prioritization stage based on a qualitative assessment to PAS 79[26] to be used where an AHJ has a large number of buildings to review and needs to prioritize those at highest risk. Tier 2 is a more detailed fire risk assessment, also based on PAS 79[26], on a building by building basis looking at those of highest priority first.

Potential mitigation measures are discussed and in particular those that have the greatest impact on the risk ranking.

13 Further Work and Suggested Next Steps

The following points are a non-exhaustive list of suggestions for future work:

- Update EFFECT to include FAQs once users start to use the FRA tool and ask questions.
- Develop EFFECT to include data collection to inform future iterations of the FRA tool.
- Investigate further methods of gathering information about a facade system using simple non-destructive tests.
- Increase the applicability of the Tier 1 and 2 assessments to other occupancies such as schools, ambulatory care homes, hospitals, assembly buildings etc.
- Development of a framework for a Tier 3 risk assessment.
- Conduct further fire testing of common façade systems to inform the scoring of cladding, insulation and cavity size combinations in the FRA tool.
- Conduct further research on the likelihood of ignition of common façade system materials from common but relatively small ignition sources such as electrical equipment, cigarettes etc.
- The impact of smoke toxicity as a result of burning plastics in a facade system is being debated especially in the context of a residential occupancy with sleeping risk and stay-put evacuation strategy. This needs further research to establish whether or not this is a key factor that should be incorporated into this FRA tool.

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Appendix A

Fire Risk Assessment Tool can be found at: www.nfpa.org/exteriorwalls

A1

Appendix B

Users Guide
can be found at:
www.nfpa.org/exteriorwalls

B1

B2