Fire Safety: Property Protection

CPD/004/121/138

Research into approaches intended to reduce property damage in the event of a fire – an international review

November 2022

Final report

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Glossary

ABCB	Australian Building Codes Board
ABI	Association of British Insurers
ADB	Approved Document B
AFAC	Australasian Fire and Emergency Services Council
BBA	British Board of Agreement
BBR	Boverket's building regulations
BCA	Building Code Australia
BCA	Building Construction Authority
BRE	British Research Establishment
BS	British Standards
BSL	Building Standards Law
CFPA	Confederation of Fire Protection Associations
CLT	Cross-laminated timber
DCSF	Department for Children Schools and Families
DLT	Dowel laminated timber
EML	Estimated minimum loss
ERM	Enclosing Rectangle Method
EV	Electric vehicle
FPA	Fire Protection Association
FPZ	Fire Protection Zones
FRP	Fibre reinforced polymer
FRS	Fire and Rescue Service
FSA	Fire Safety Audit
Glulam	Glue laminated timber
IBC	International Building Code
ICC	International Code Council
IRC	International Residential Code
LPC	Loss Prevention Council
LSL	Laminated strand lumber
LVL	Laminated veneer lumber
MBA	Modern Building Alliance
MBO	The Model Building Regulations Musterbauordnung
NCC	National Construction Code
NFPA	National Fire Protection Association
NLT	Nail laminated timber
NZBC	New Zealand Building Code
PV	Photo-voltaic
QFPZ	Quazi-Fire Protection Zones
SCDF	Singapore Civil Defence Force
SIP	Structured Integrated Panel
WFSC	World Fire Statistics Centre

Executive Summary

Background and Methodology

Background

The Department for Levelling Up, Housing and Communities (DLUHC) is a UK Government Department charged with supporting communities across the UK to thrive, making them great places to live and work. A key part of the Department's remit is to maintain 'Approved Documents' which describe ways to meet building regulations in England.

In England and Wales, the legal requirements for fire safety in buildings are described in Schedule 1, Part B of the Building Regulations. Statutory guidance on how to meet the fire safety requirements of the building regulations in England are set out in Approved Document B (ADB).

In response to Dame Judith Hackitt's independent Review of Building Regulations and Fire Safety, which resulted from the Grenfell Tower tragedy of July 2017, the government committed to a full-scale technical review of ADB. The review started with a call for evidence which invited views on the technical issues and improvements that could be made to ADB. While the primary objective of the regulations and ADB is life safety, the call for evidence uncovered concerns from respondents that insufficient attention is given to protection of buildings in fire safety regulations.

Methodology and scope

The aim of this work is to conduct a review of literature and evidence on approaches intended to reduce property damage in the event of a fire, including how other countries approach the issue of property protection through building regulations or equivalent industry guidance.

The main methodological approach is a structured and systematic Rapid Evidence Assessment (REA) of the most relevant and up to date academic literature (published since 1st January 2015) and different countries' legislation, codes, standards and industry guidance. This was combined with liaison and interviews with key stakeholders within the UK and in each of the comparator countries.

Countries were selected on the basis of covering a broad geographical spread and a range of different approaches to fire regulations (prescriptive vs. performance-based). While prescriptive frameworks define the mechanisms by which the final output must be produced, performance-based frameworks – rather than defining the specific ways in which a building must be constructed – set out functional statements about how a building must perform in the event of a fire.

The countries included within this review, and their approach to fire regulation, is illustrated in the table below.

Country	Prescriptive	Performance-based
England and Wales	✔	✔
Northern Ireland	✔	✔
Scotland	✔	✔
USA	✔	
Germany	✔	
Sweden	✔	✔
New Zealand		✔

Australia		✔
Japan		✔
Singapore	✔	

In addition, a high-level review of **Switzerland**'s approach is included to illustrate an alternative to the typical prescriptive and performance-based approaches.

Property Protection

The fire protection of buildings and property involves both the protection of buildings as physical assets from fire, but also measures to ensure continuity of building operations and to minimise disruption to building functions. Property protection also encompasses measures to reduce the social and environmental consequences of fires.

The insurance industry plays an important role in promoting measures to protect buildings and property from fire. Insurance companies will often insist on higher design specifications or property protection systems for buildings deemed to be higher risk. The industry has recently highlighted the insurance challenges posed by modern construction methods such as mass timber construction.

The protection of properties and buildings from fire relies on both passive and active fire protection measures. Typical measures designed to protect property from fire include: longer fire resistance durations for compartmentation; limitations on the use of combustible materials; provision of automatic fire suppression systems (such as sprinklers); use of early automatic fire detection and alarms systems, and; measures to minimise arson and intentional ignition of fires.

International Regulatory Approaches and Building Typologies

Domestic buildings

The primary objective of national building and fire safety regulations for residential buildings, in all of the countries reviewed, is life safety.

In some countries – such as Australia, Japan, New Zealand, Sweden and the USA – a degree of property protection is achieved through the principle of limiting fire spread, both between and within buildings. This principle is historically rooted in these countries' building legislation and applies equally to high-rise domestic buildings and to individual dwellinghouses.

However, this review found no empirical evidence to link any of these strategies focused on limiting fire spread to a higher level of property protection or stronger building resilience.

Industrial buildings

Warehouses are often afforded a higher level of property protection as these buildings are usually subjected to stricter requirements in national building regulations.

These stricter requirements reflect both the unique nature of hazards typical to warehouses, where stored goods have the potential to act as fire load, but also the high potential economic losses associated with warehouses fires, resulting from destruction of commercial stock and loss of jobs. This review found that – of the countries studied – sprinklers are almost always mandatory. Furthermore, warehouse size thresholds, which place limits on the size of un-sprinklered warehouses, are also generally much lower than in England.

Commercial buildings

Fire safety requirements for commercial buildings in most countries rarely exceed the minimum provisions necessary to secure life safety. Requirements for additional fire protection – such as automatic sprinkler systems or high levels of fire resistance – are generally specified only for larger commercial buildings, such as shopping centres, or multi-storey department stores which exceed the building design allowances specified in national regulations.

Schools

Several countries have building regulations with stricter requirements for schools. In some cases, such as Scotland and New Zealand, these requirements are explicitly described as measures intended to protect the physical fabric of the school buildings. Mandatory sprinklers in schools are also commonplace.

Stricter requirements reflect the fact that schools are often seen as important service providing-buildings and community resources. These requirements are designed to minimise disruption to education and ensure continuity of function as an amenity to the community.

Historic buildings

Historic buildings often have unique fire safety requirements, as these buildings, along with their contents, typically have social and cultural value. However, historic buildings are rarely assigned specific building categories in building regulations and so fire safety provisions for these types of buildings are often no different to domestic buildings.

In some countries – such as the USA and Germany – there is specific guidance on fire safety for historic buildings. In this case of the USA, fire codes for historic buildings focus on measures designed to minimise the likelihood of fire ignition, rather than on passive and active fire protection. This is both to minimise the impact of fire protection features on the character of the building, but also to ensure that important cultural resources are not damaged by mechanisms such as water-based fire suppression systems.

Thematic analysis

Robustness and Resilience of Buildings

Academic research into the fire resilience of buildings is scarce. The few studies which have been undertaken tend to focus on active fire protection measures, most notably sprinklers, as the most effective means of enhancing building resilience and protecting property from fire.

Research which examines the contribution of structural elements of buildings, such as fire resisting construction, to fire resilience is scarcer still. The paucity of research in this area is most likely a consequence of methodological approaches to assessing building behaviour in fire, which tend to focus on the responses of individual structural elements to fire, rather than whole building structures.

Buildability

The shift towards modern, low-carbon and sustainable construction materials and techniques in recent decades arguably has consequences for the fire resilience of buildings. Recent research suggests that the sustainability agenda in construction – and the drive to construct 'green' buildings with low embodied carbon – has the potential to conflict with fire safety and resilience. In particular, research has highlighted critical vulnerabilities in certain building methods such as mass timber construction and modular construction. For mass timber buildings, questions remain over the achievability of 'self-extinguishment', while for modular construction, concerns centre on the existence of internal voids and cavities, which have the potential to act as pathways for fire spread, as well as the use of combustible materials.

Competence

Issues relating to competence in property protection tend to overlap with broader competency issues in the building regulation sector more generally. Findings from recent research and stakeholders suggest that many of those working in the building regulatory system in the UK do not possess the level of skills or competence needed to implement greater fire safety provisions aimed at protecting buildings and property.

Competence is seen as lacking both at the building design stage, but also at the building control and planning stage, as well as in the construction and installer industries more broadly.

Societal and Environmental Impacts

The destruction of a whole building by fire can have a devastating impact on the environment (through CO_2 release and water run-off from firefighting activities) and on the economy and society (through dislocation of businesses and residents).

While the environmental impacts of fire are well documented in published literature, especially relating to the impact of gaseous emissions and the environmental benefits of active fire protection, considerably less research has been conducted into the economic and societal impacts of building fires. Statistics on fire incidents compiled by Fire Safe Europe suggest that the economic impact of fire accounts for up to 1% of GDP each year in most advanced countries.

This review identified no empirical research into the cost of disruption caused by fire to key services, nor any studies into societal benefits of strengthening the fire protection of buildings and property.

Key Messages

To what extent is property protection explicit in international building regulations and codes?

The primary objective of all national building and fire safety regulations reviewed here is life safety. Some countries have strategies through which protection of property is achieved via the principle of limiting fire spread, as well as stricter requirements for certain types of buildings (such as warehouses and schools). However, this review found that most of the guidelines designed specifically to protect buildings and property from fire are non-statutory in nature (such as businesses and residents).

What are the drivers for property protection internationally?

Drivers for property protection in international codes and regulations are not always clear. For industrial and commercial buildings, the overarching driver for property protection is likely the need to ensure business continuity, driven by the insurance industry, through measures intended to minimise economic losses and environmental damage. For schools, property protection is most likely driven by the desire to minimise disruption to education.

The drivers for protection of historic buildings can be argued to be a combination of the two: continuity of business (e.g., in the case of a museum or gallery) and preservation of a structure which may hold cultural significance to a community.

To what extent is which property protection achieved through life safety?

Life protection measures will, by default, protect property and vice versa. Several of the countries reviewed here have fire safety requirements which go above and beyond the guidance set out in Approved Document B, and which, in some cases, also offer a higher level of protection to buildings and properties. However, in most cases these requirements are intended principally as life safety mechanisms and any protection they afford to buildings is an unintended consequence of the life safety function.

A key finding of this review is that there is no empirical evidence to indicate the extent to which property protection is achieved through life safety.

How can property protection be achieved?

While there are a range of measures (both active and passive) which can help to protect buildings and property from fire, this review has found that active fire protection measures – most notably automatic fire sprinkler systems – are especially prominent in literature about property protection and building resilience.

Mandatory sprinklers are common in international fire safety regulations, especially for buildings deemed to require additional protection (such as warehouses and schools), and sprinklers feature heavily in non-statutory guidelines for the fire protection of buildings and property. Research into the fire resilience of buildings also tends to emphasise sprinklers as the primary method of protecting buildings from fire and ensuring resilience, a point which is also underlined by numerous stakeholders. However, the rationale for sprinkler use is not always explicitly set out in international building regulations.

Empirical research examining the impact of fire resisting construction on building resilience is relatively scarce. However, findings from the Japanese Building Standard Law, which emphasises more passive fire protection through the provision of 'fire resistive buildings', would indicate that effective fire resilience can also be achieved through higher durations of fire resisting construction.

1. Background and Methodology

1.1 Introduction

1.1.1 Background

An independent Review of Building Regulations and Fire Safety was announced by government in July 2017, in response to the Grenfell Tower tragedy. Led by Dame Judith Hackitt, the review examined building and fire safety regulations and related compliance and enforcement issues with the focus on multi-occupancy high-rise residential buildings. The purpose of the review was to make recommendations that will ensure a sufficiently robust regulatory system for the future and to provide further assurance to residents that the complete system is working to ensure the buildings they live in are safe and remain so.[1]

An interim report was published on 18 December 2017 and the final report was published on 17 May 2018. The final report sets out a regulatory framework designed to:

- Create a more simple and effective mechanism for driving building safety
- Provide stronger oversight of duty-holders with incentives for the right behaviours, and effective sanctions for poor performance
- Reassert the role of residents

A key part of the report focuses on roles and responsibilities, with the framework enhancing the current responsibilities of those who produce, design, create and maintain buildings; government; the regulator; residents.[2]

1.1.2 Building regulations in England

The Department for Levelling Up, Housing and Communities (DLUHC) is a UK Government Department charged with supporting communities across the UK to thrive, making them great places to live and work.

A key part of the Department's remit is to maintain 'Approved Documents' which describe ways to meet building regulations in England. The Approved Documents contain:

- general guidance on the performance expected of materials and building work in order to comply with the building regulations
- practical examples and solutions on how to achieve compliance for some of the more common building situations[3]

Statutory guidance on building regulation in England covering fire safety matters within and around buildings is published in Approved Document B (ADB)[4], with provisions for property protection signposted to the RISCAuthority Design Guide for the Fire Protection of Buildings by the Fire Protection Association (FPA).[5]

In response to the Hackitt Review, the government committed to a full-scale technical review of Approved Document B. The review started with a call for evidence which invited views on the technical issues and improvements that could be made to ADB.[6]

Whilst the primary objective of the regulations and ADB is life safety, the call for evidence uncovered concerns from respondents that insufficient attention is given to protection of buildings in fire safety regulations. The call for evidence specifically sought views on property protection, as one of the considerations states:

> *"For non-domestic buildings, there is a view that businesses should be making their own decisions on commercial property protection in conjunction with their insurers. However, for housing there is a question as to whether fire safety measures in Part B should seek to address not only life safety, but also whether a building is sufficiently resilient to fire, for example, by it being constructed in a way that seeks to resist disproportionate loss of housing.*
>
> *There are arguments that the current guidance provided should go further and property protection should be considered in addition to life safety. Including property protection from fire, and therefore avoidance of economic loss, within the scope of Part B would be a significant change and could have a significant impact on the cost effectiveness of some measures. This raises a broader question about the scope of Building Regulations than can be addressed in this technical review, but the Government would welcome evidence on this question."*[7]

Several respondents to the call for evidence suggested that the regulations and ADB should give additional consideration to property protection, namely:

- Protection of the nations' built assets
- Helping to ensure business, employment and profit continuity
- Avoiding housing disruption and the displacement of residents
- Ensuring the continuity of social and public services, particularly health and education
- Sustainability/climate change considerations
- Prevention of pollution
- Avoiding remediation costs
- Prevention of unmanageable building fires[8]

Whilst property protection is not the intent of building regulations or ADB, The RISCAuthority Design Guide is signposted in ADB, as many insurers use it as a basis for providing guidance to the building designer on what they require. Property protection often requires additional requirements and insurers may set higher standards before accepting the insurance risk. However, compliance with the guide is not a requirement of ADB.

Building regulations in the UK also have an explicit, in-built limitation in the form of Regulation 8, which stipulates that Schedule 1 of the building regulations 'shall not require anything to be done except for the purpose of securing reasonable standards of health and safety for persons in or about buildings.' This limitation places a statutory disincentive to implement elements of property protection into building design.

In parallel to the review of ADB, a Building Safety Bill is being considered by Parliament. The Bill seeks to *"improve provisions about the safety of people in or about buildings and the standard of buildings, to amend the Architects Act 1997, and to amend provision about complaints made to a housing* *ombudsman*."[9] The Bill also includes further provisions around fire safety which, amongst other things, includes requirements about competency, record keeping and cooperation.[10]

1.1.3 International response to Grenfell Tower fire

The events of the Grenfell Tower fire reverberated around the world and prompted action in many countries. Several other EU countries followed the UK's lead by reviewing construction fire regulations. Countries include Ireland, France, Belgium, The Netherlands, Greece, Denmark, Finland, and Bulgaria,[11] all committing to roll out new initiatives, as well as Italy and South Korea.

The events and lessons of the tragedy have been reflected on as far afield as Australia and the United States and prompted government responses and academic research focused on fire safety in high-rise multi-occupancy buildings.

Over recent decades evidence from the Modern Building Alliance suggests that Europe has achieved substantial improvements in fire safety due to the continuous adjustment and implementation of fire safety strategies. According to their data[12] fire fatalities have fallen by 65% in Europe over the last 30 years. However, in Europe around 5,000 fatalities per year are still attributed to building fires.

1.1.4 Fire occurrence and prevention

Incidence and causes of fires

In England, the UK government records the incidence of fires attended by the fire and rescue service and their cause.[13] According to the latest figures for the financial year 2020-2021, there were 24,496 dwelling fires attributed to an accidental cause. The most common accidental causes were identified as being the misuse of equipment or appliances, or faulty appliances and leads.

The main material responsible for the development of the fire in 23% of dwelling fires was textiles, upholstery and furnishings. Fires involving these materials accounted for 60% of all fire-related fatalities in dwellings. Fires involving food accounted for 18% of dwelling fires but resulted in 4% of all fire-related fatalities in dwelling fires.[14]

In the context of fires attended by the fire and rescue service, most fire-related fatalities occur in dwellings. In the financial year 2020-21 these accounted for 78% of all fire-related fatalities. The most common cause of death is being overcome by gas or smoke. This year recorded the lowest financial year figure for fatalities since comparable data became available in 1981-82.[15]

Although the primary focus on fire statistics is related to impact on life safety, some data are available and are published on **damage to property**; however, this data is not measured in economic terms, but in the area (m^2) of damage. In financial year 2020-21 the average area of damage to dwellings (excluding those over 5,000m^2) in England was 14.8m^2, a decrease of nine per cent compared with the previous year and a decrease of 32% from ten years ago.[16]

Spread of fire is also recorded: in financial-year 2020-21 7% of fires in purpose-built high-rise (10+ storeys) flats or maisonettes spread beyond the room of origin, compared with 7% of fires in purpose-built medium-rise (4-9 storeys) flats or maisonettes, 10% in purpose-built low-rise (1-3 storeys) flats or maisonettes and 12% of fires in houses, bungalows, converted flats and other dwellings combined. [17]

Fire prevention

Fire and rescue services (FRSs) undertake prevention activities, which provide information and advice and aim to encourage fire safety behaviours. These activities educate people on the steps to be taken to prevent the occurrence of a fire and increase the survivability when involved in a fire. This work became a statutory duty for FRSs in 2004 with the introduction of the Fire and Rescue Services Act. The Homes Office collects data on the number of Homes Fire Safety Checks (HFSCs) and Safe and Well Visits (SWVs) carried out by FRSs.[18] Although these are not primarily focused on property protection, fire prevention has benefits for property protection and insurance liabilities.

Fire and Rescue Services are also responsible for carrying out Fire Safety Audits (FSA) in the wider built environment including, for example; shops, care homes, hotels, purpose-built flats, schools and hospitals. In the decade to 2020, there has been a steady decline in the number of FSAs undertaken in England. It is not clear from the data why the number of FSAs has declined, but some variation year on year is expected depending on local need, targeting strategies and the complexity of the buildings being audited.[19]

International statistics

The International Association of Fire and Rescue Services Center of Fire Statistics[20] publishes information on fires world-wide.

To put this current research into context, Table 1 and Table 2 compare these data for each of the countries within scope of this study. This is based on the latest figures (for 2019).

As per the UK fire statistics, the data does not include information on property protection.

Table 1: Common indicators of fire statistics in comparison countries, 2019 data

Country	Population 1000s	Number of Fires	Number of Fire deaths	Number of Fire injuries	Fires per 1,000 inh.	Fire deaths per		Fire injuries	
						100,000 inh.	100 fires	100,000 inh.	100 fires
USA	328,240	1,291,500	3,704	16,600	3,9	1,1	0,3	5,1	1,3
Japan	126,167	37,683	1,486	5,865	0,3	1,2	3,9	4,6	15,6
Great Britain	*64,903*	*222,511*	*317*	*8,750*	*3,4*	*0,5*	*0,1*	*13,5*	*3,9*
Sweden	10,328	26,445	78	882	2,0	1,1	0,3	8,5	3,3
New Zealand	4,748	23,258	33	-	4,9	0,7	0,1	-	-
Singapore	5,612	2,862	1	142	1,8	0,3	0,1	-	-
Australia	-	-	-	-	-	-	-	-	-
Germany	-	-	-	-	-	-	-	-	-

Data are not published for Australia and Germany.

Table 2: Distribution of fires in structures in comparison countries

Country	Population 1000s	Structure fires					
		Residential	In%	Others	In %	All	In %
USA	328,240	361,500	28,0	120,000	9,3	481,500	37,3
Japan	126,167	-	-	-	-	2 103	11,2
Sweden	10,328	7,191	26,9	3,963	14,8	11 154	41,7
New Zealand	4,748	5,588	24,0	11,670	50,2	17 258	74,2
Singapore	5,612	1,168	41,1	496	17,5	1 664	58,6
Australia	-	-	-	-	-	-	-
Germany	-	-	-	-	-	-	-

Data are not published for Australia, Germany or Great Britain.

1.2 Methodology

1.2.1 Aims and objectives

This current project forms part of the broader review of ADB.

The main aim of this work is to conduct a review of literature and evidence on approaches intended to reduce property damage in the event of a fire including how other countries approach the issue of property protection through building regulations or equivalent, industry guidance, and evidence on the benefits of property protection and different regulatory approaches.

The objectives of this research, as stated in the specification are to:

- Review of international approaches to regulation on property projection;
- Review available studies, statistics and evidence regarding property protection and how policy questions on this subject are being addressed internationally;
- Review literature on benefits in relation to property protection regulations and guidance;
- Identify ongoing relevant work and research internationally;
- Review relevant literature and studies to assess the effectiveness of the current regulatory system in England in restricting property damage across building types. Where possible, comparisons should be made to other regulatory systems.

In addition to reviewing literature on international approaches to fire regulation focused on property protection, this review will also:

- Review literature and data into potential tensions between sustainable/green building design and fire safety compliance and how this could create risk e.g., balance between acoustic insulation and fire performance (requirements can be in conflict)
- Consider any additional considerations for Modern Methods of Construction (MMC)
- Review the evidence in relation to product/material testing framework/approaches undertaken internationally, in addition to the regulatory and policy framework

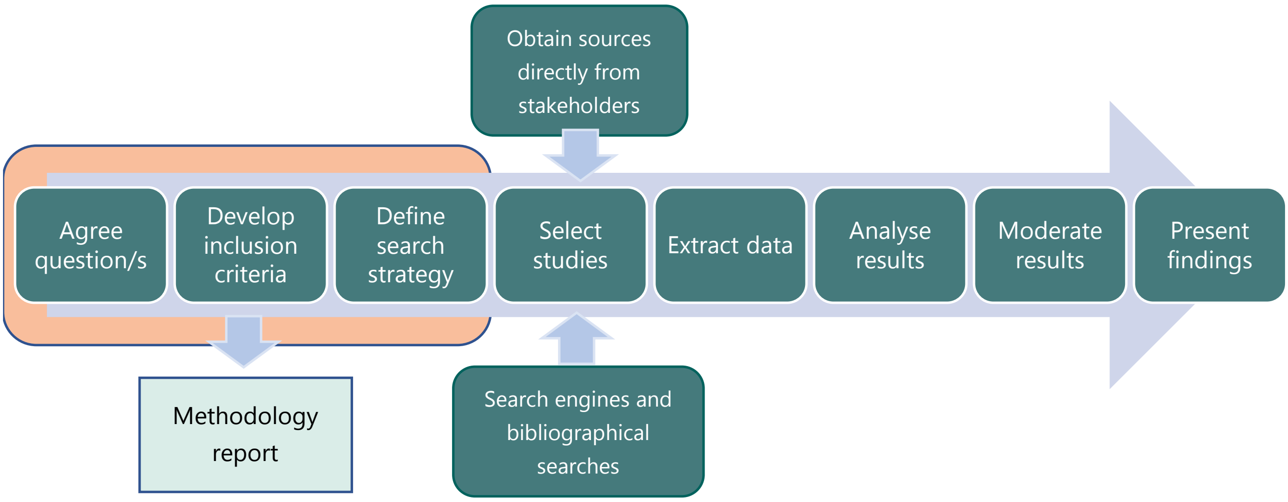
Following on from an initial inception meeting, it was also agreed that the review would explore literature paying attention to following themes:

- Robustness and resilience of buildings
- Distinctions made in international regulations between commercial and domestic buildings and discussion of the arguments for and against property protection in the different property types
- Any consideration given in international regulations to disproportionate damage
- Buildability – how achievable are tolerances and how realistic is it to build to specification?
- Consideration given to the competence of installers
- Consideration given to societal impacts of fire, such as the impact on air quality and other environmental impacts.

1.2.2 Approach

The approach to this commission is a structured and systematic Rapid Evidence Assessment (REA) to produce the necessary rigour and reliability for this important study. This was combined with liaison and interviews with key stakeholders – including regulators – within the UK and in each of the comparator countries, to ensure all relevant literature is discovered and included within the timescales. In total, 25 interviews were completed, each lasting between 45 minutes and two hours.

Figure 1: Desk research - approach to the Rapid Evidence Assessment (REA)



Inclusion criteria

The inclusion criteria are a critical element of the REA as they set the entire scope of the study (Table 3).

Table 3: Inclusion/exclusion criteria for the evidence review

Inclusion Criteria	Exclusion Criteria
English language	Papers not in English
• International regulatory approaches • Industry guidance/Standards • Academic literature: peer-reviewed journal articles, conference presentations; PhD theses/dissertations • Government reports, policy papers • Research reports from stakeholder organisations	Books, PowerPoint presentations and posters, press articles, other media
For academic literature: Published 1 January 2015 – 31st July 2021	**For academic literature**: Published prior to 2015

To ensure that the review captured and synthesised only the most relevant and up-to-date academic knowledge on the topic within the tight timescales of the project, attention was focused on academic literature published after 1st January 2015. However, a limited number of exceptions were made for significant publications which were found to be cited extensively in the academic literature reviewed.

The chronological exclusion criterion was not applied to standards, codes or industry guidance. In many cases, standards for fire safety were published before 2015.

Search terms

Search terms were based around the following formulations. These search terms were used in various combinations to ensure that all published literature relevant to property protection from fire within the countries in scope (and within the inclusion criteria, above) are captured.

The list below serves as an indicative example. It is not exhaustive as search terms were developed and refined as sources were identified and as new terminology became apparent.

- "Fire regulations property protection" AND [country]
- "Fire regulations building protection" AND [country]
- "Fire regulations building resilience" AND [country]
- "Fire regulations disproportionate collapse" AND [country]
- "Fire regulations disproportionate damage" AND [country]
- "Fire regulations building protection" AND "Modern Methods of Construction" AND [country]

Simple, Boolean and wildcard search were employed– as well as bibliographic, snowballing and back-and-forth approaches – using the following search engines:

- Google Scholar
- CORE
- Semantic Scholar
- JSTOR

1.2.3 Stakeholder engagement

Key industry stakeholders were engaged with to access any potentially unpublished studies and to identify any sources which may not have been discoverable via conventional internet searches. These discussions were also used to gather further contextual information about the rationale for the regulatory approach, priorities and challenges. These conversations were also used to establish any potential forthcoming reviews of, or consultations on, the respective regulations.

Stakeholders included representatives from government agencies (such as building standards departments) and, fire safety organisations and code-publishing bodies (such as NFPA), as well as academics and fire security experts and consultants.

1.2.4 Scope

An initial scoping stage was undertaken to identify potential comparator countries. Countries were selected on the basis of covering a broad geographical spread and a range of different approaches to fire regulations (prescriptive vs. performance-based). Countries were prioritised where it was considered they *may* prioritise property protection OR which have a strong record in green/sustainable design. A 'primary' and a 'reserve' list was collated (Table 4).

In order to identify countries which may prioritise property protection, countries were selected which consistently score high on FM Global's Resilience Index for Fire Risk[21]. This index offers a composite measure of countries' relative enterprise resilience to disruptive events, including fire risk, using measures such as the quality and enforcement of a country's building code with respect to fire-based design. Since FM Global's Index emphasises the resilience of enterprises, it is considered likely that countries which rank at the top of the list are those with regulations in place to protect building integrity and, as such, ensure business continuity.

Please note: these suggestions were the result of superficial appraisals based on initial desk research. This list of countries/territories evolved slightly as the research progressed and as gaps and clusters were identified within the research landscape.

Table 4: Preliminary list of countries/territories within scope

Primary list	Reserve list
USA	South Korea
New Zealand	Hong Kong
Singapore	Turkey
Japan	Dubai
Sweden	France
Germany	Italy
UK	Australia

This list was kept under review throughout the research and Australia was added to the primary list (Table 5) as a result of the scoping review.

Table 5: Final list of countries within scope

USA
New Zealand
Singapore
Japan
Sweden
Germany
UK
Australia

In addition, a high-level review of Switzerland's approach is included in section 3.1 to illustrate an alternative to prescriptive and performance-based approaches which are typical, internationally.

2. Property protection

2.1 Fire protection of buildings and property

'Buildings' tend to refer to physical assets. 'Property', on the other hand, is a broader term which encompasses the buildings themselves but also includes the building's contents, its internal operations and associated business activities, as well as intangible assets such as corporate image and reputation.[22]

The fire protection of buildings and property involves a range of associated aims and objectives. Chief among these is the protection of buildings as physical assets from the effects of fire. However, property protection also involves ensuring the continuity of building operations and minimising disruption to building functions. In the case of commercial and industrial buildings, such as shops and warehouses, this is about maintaining business continuity and resilience, ensuring that business activities are not unduly disrupted by fire. For service providing buildings, such as hospitals and schools, continuity of building operations is about minimising interruptions to important services, such as education or healthcare provision. For residential buildings, continuity of building functions contributes to housing security.

The fire protection of buildings and property also has broader advantages and objectives, including minimising the social and environmental consequences of fires. The destruction of a whole building by fire can have a devastating impact on both the environment (through CO_2 release and water run-off from firefighting activities) and on society (through dislocation of businesses and residents). The provision of greater fire protection of properties and buildings minimises damage to the environment by aiming to contain fires (or extinguish them in their early stages), thus limiting carbon emissions and the need for extensive water discharge by firefighters. Protecting the integrity of building structures also means that residents will not need to be relocated and businesses will not have to find new premises. This ensures more resilient and sustainable communities and businesses.

The insurance industry plays an important role in promoting measures to protect buildings and property from fire. By protecting individuals and companies from financial loss, insurance companies take on the financial responsibility of risks to buildings and building operations (including business activities). This includes the risk posed by fire beyond the time required to ensure safe evacuation of building occupants. Insurance companies therefore have a financial interest in ensuring that buildings and properties as physical assets are protected from losses caused by fire. Insurance companies will often insist on higher design specifications or property protection systems for buildings deemed to be higher risk, and the UK insurance industry has also recently highlighted the insurance challenges posed by modern construction methods such as massive timber construction.[23] (see section 5.2.2)

RISCAuthority[24] Design Guide for the Fire Protection of Buildings proposes the following property protection aims:

- reduce the likelihood of fire, either accidental or malicious;
- minimise the spread of fire and smoke;
- minimise the effect of fire on a business and the consequential loss;
- protect the buildings within a business;
- maintain the health and safety of those in and around the building (including firefighters); and
- protect the environment from the consequences of fire and firefighting.[25]

The RISCAuthority Design Guide is a non-statutory guide which offers design recommendations for the protection of buildings and property from fire. It has been developed by the Fire Protection Association (FPA) and is supported by a large number of UK insurance companies. Many insurers also use the Design Guide as a basis for providing guidance to building designers on insurers' requirements for building performance.

RISCAuthority Design Guide also lays down the following 'essential principles' (Table 6) to ensure adequate property and business protection in the event of a fire.

Table 6: RISCAuthority Design Guide for the Fire Protection of Buildings: Essential Principles[26]

RISCAuthority Essential Principles	Measures to ensure compliance with principle:
Principle 1: *The building shall be constructed and protected in such a manner that if a fire starts, the extent of fire and smoke damage will be minimised and confined as close to the source of fire outbreak as is practical/feasible.*	• The building is fully **sprinkler protected** • The building is **subdivided by fire-resisting compartment** walls and/or floors which have a minimum fire resistance of not less than **90 minutes** • Hidden voids are adequately protected **by cavity barriers** • Glazing in compartmentation and fire separation barriers is classified for integrity and insulation fire resistance, for at least a minimum 30-minute tested performance.
Principle 2: *With the exception of non-structural joinery products, the building shall be constructed from building materials/products that will not make a significant contribution to the early stages of a fire or contribute to the spread of fire.*	• Materials/products used are **non-combustible**, Euro-class A1 or A2 or are approved by LPCB to the requirements of the appropriate part of LPS 1181 • No more than 10% of the construction products used in the construction of the building are combustible • **Provision of sprinklers** to control fire in its early stages and reduce contribution to fire spread made by combustible construction materials.
Principle 3: *Suitable measures will be taken for the prevention of premature structural collapse and excessive deflection.*	• The building structure shall have fire resistance sufficient to prevent collapse or partial collapse and shall ideally exhibit restricted deflections
Principle 4: *Consideration should be given at the design stage regarding potential damage from firefighting water and to ensure as far as practical that the effect on the environment of the fire effluent will be minimised.*	• Use of **products** and **materials** that **do not give off** • **toxic fumes** in a fire situation • **Good standard of fire safety management** • Provision of **sprinklers** • Convenient **drainage for sprinkler water** should be provided if possible.
Principle 5: *As a minimum, all fire protection products shall be third party certified to an appropriate product-or performance-based standard.*	• Designers should ensure that **the scope of certification** granted by the certification body **is appropriate for the end use application** in the specific building, taking due regard of processes, fire load and anticipated fire inception hazards (fire risk assessment). • Where a change in use occurs, the suitability of the **fire protection product/system** shall be **re-assessed** • Penetration that breaches compartmentation should be fire stopped by appropriate • products/systems installed by competent personnel or third-party contractor.

Principle 6: *All fire protection products/systems shall be installed by appropriately trained specialist installers.*	• Installers shall be **third party certified** to install the specific product/system when an appropriate scheme is available (e.g., FIRAS, LPCB, BM Trada, BAFE etc).
Principle 7: *The building shall be fitted with an appropriate automatic fire alarm system that should suitably reduce/prevent false alarms such as high-integrity detectors.*	• Design of a fire alarm system must **reduce the chances of a false fire alarm** to as near to zero as possible to increase the confidence of the fire and rescue service. • Sprinkler systems are also considered to give highly reliable notification of fires (rarely activating in non-fire scenarios) • High-integrity detectors can differentiate effectively between false and real fire signatures and can communicate real fire alarms to the fire services.
Principle 8: *The fire protection systems shall be regularly inspected and maintained by a competently trained person so that they are able to perform their intended function throughout the life of the building.*	• Designers to ensure that the **building owner is provided with all necessary listings** of both **passive and active fire protection measures**, details of the manufacturer and installer and recommendations for maintenance. • **Maintenance** and service to be undertaken by **companies that are third party certified** for the specific product/system (e.g., FIRAS, BAFE, LPCB, BM Trada, NSI, SSAIB etc).
Principle 9: *There shall be adequate provision to prevent an arson attack.*	This may be achieved by a combination of: controlled access to the external fabric and fittings of the building; • perimeter security; • specific provisions being made in the fire safety management system; • security alarms; • security cameras; • external storage being kept well clear of the building; • the external fabric (including the eaves) being capable of resisting an arson attack; • external ground floor glazing made up of minimum anti-burglar or anti-vandal specifications.
Principle 10: *The building shall be so constructed that fire cannot spread into the premises from an adjoining building or other external fire source.*	• for **compartment walls separating** adjoining **buildings** of different occupancy, the fire resistance shall not be less than **120 minutes** • provision shall be made to house skips etc in enclosures well away from the external fabric of a building
Principle 11: *The building owner shall ensure an adequate standard of fire safety management throughout the life of the building.*	• Building owners to maintain documented fire risk management procedures and provide adequate proof that such systems are being complied with. • The mandatory fire risk assessment carried out for life safety under national regulations must also include a suitable fire risk assessment that addresses property protection. • In a fire engineered building, the appropriate frequency and depth of life safety and property protection fire risk assessments must be described in the fire engineering strategy.

Principle 12: *All building services (including all forms of renewable energy), e.g., heating, lighting and power, shall be designed, constructed, installed in a manner that reduces their potential as an accidental source of ignition.*	• **Fuel burning appliances** such as fixed and moveable space heaters, dryers, etc shall be **maintained in good working** order by appropriately trained people in line with manufacturer's specifications.

It is important to note that the life safety requirements in the Building Regulations for England and Wales cover *some* of the principles of property and business protection outlined in the RISCAuthority Design Guide. For example, Schedule 1, part B of the Building Regulations (2010) for England and Wales has stipulations concerning overall structural stability in the event of a fire, as well as requirements around inhibiting the spread of fire through effective sub-division of the building and fire-resisting construction (see requirement B3). These requirements overlap to some extent with Principles 1 and 3 of the RISCAuthority Design Guide.

However, fire safety regulations in England and Wales are also subject to Regulation 8 which limits the statutory performance of buildings to 'securing reasonable standards of health and safety for persons in or about buildings.' This means that, while some of the statutory requirements of Building Regulations may offer some protection to property, they are intended only to protect property in so far as it is necessary to protect life safety. Furthermore, even where there are overlaps between the statutory requirements of the Building Regulations and the principles of the RISCAuthority Design Guide, the performance requirements set out as in the RISCAuthority Design Guide generally exceed those in the Building Regulations. This is especially true of fire-resistant construction, where the RISCAuthority Design guide specifies a minimum fire resistance rating of 90 minutes, for all compartment walls throughout the building.[27]

The recommendations in the RISCAuthority's Design Guide therefore go beyond the requirements of the Building Regulations in several, significant ways:

1) Longer fire resistance durations for compartmentation.
2) The provision of sprinklers throughout the whole building as an effective means of controlling a fire in its early stages and limiting the contribution to fire spread made by combustible construction materials.
3) Limitations placed on the use of combustible materials in structural elements of the building.
4) Consideration at design stage of ways of mitigating environmental damage of fires and impact on the environment of water run-off from fire fighter activity.
5) Alarm systems which provide early warning, but which are also reliable, and which reduce incidence of false alarms.
6) Provisions to minimise arson and intentional ignition of fires.
7) Fire protection products that are certified and installed by competent, appropriate installers.

2.2 Typical property protection mechanisms

Fire safety measures intended to protect buildings and property from the effects of fire fall into categories of:

- Passive fire protection measures, and;
- Active fire protection measures.

Passive fire protection measures focus on containing and inhibiting the spread of fire. Active fire protection measures, however, aim to detect fires, alert occupants, and potentially extinguish a fire before it develops. Examples of the former include compartmentation and fire-resistant design, while examples of the latter include fire suppression systems such as sprinklers. Passive fire protection measures are an integral part of UK Building Regulation Guidance and as such function as an important means of meeting statutory requirements. However, passive measures designed for property protection have requirements and specifications which go above the minimum requirements for life safety, such as longer fire resistance durations or smaller compartment sizes.

While there are a range of measures (both active and passive) which can help to protect buildings and property from fire, this review has found that active fire protection measures – most notably automatic fire sprinkler systems – are often recommended in literature about property protection and building resilience. Mandatory sprinklers are also common in international fire safety regulations, especially for buildings deemed to require additional protection (whether for life safety or for property protection). Sprinklers also feature heavily in non-statutory guidelines (such as the RISCAuthority Design Guide, above) for the protection of buildings and property from fire. Numerous stakeholders also emphasised the importance of sprinklers as the primary method of protecting buildings from fire.

Thus, while this review has presented findings on the full range of approaches and mechanisms to protect buildings and properties from fire, it must be noted that sprinklers carry noticeable importance as a property protection mechanism in the fire safety community and literature. As such, this review reflects the evidence found.

The measures listed below were informed by discussions with stakeholders as well as by relevant publications.[28]

N.B. Manual fire service intervention can be seen as an 'active fire protection measure', as fire services aim to suppress and extinguish building fires. The Fire Services Act also places a duty on fire services to protect property as well as life. However, the focus of this section is on the measures, features and systems that can be integrated into the design or function of a building, and which provide an immediate, in-situ solution designed to protect buildings and properties from fire.

2.2.1 Passive fire protection measures

Passive fire protection is one method of protecting buildings and people from fire with the purpose of limiting the effects of fire within a building. This is achieved by protecting structural components from fire that may cause early collapse and is achieved by installing fire resistance-rated elements of construction and controlling the flammability of construction materials.[29]

Compartmentation: The purpose of compartmentation is to use fire resisting construction to restrict the spread of fire and smoke around a building. By confining fire and smoke to the area of fire ignition, compartmentation acts as a means of limiting the extent of damage to the building fabric and mitigating against disproportionate damage.

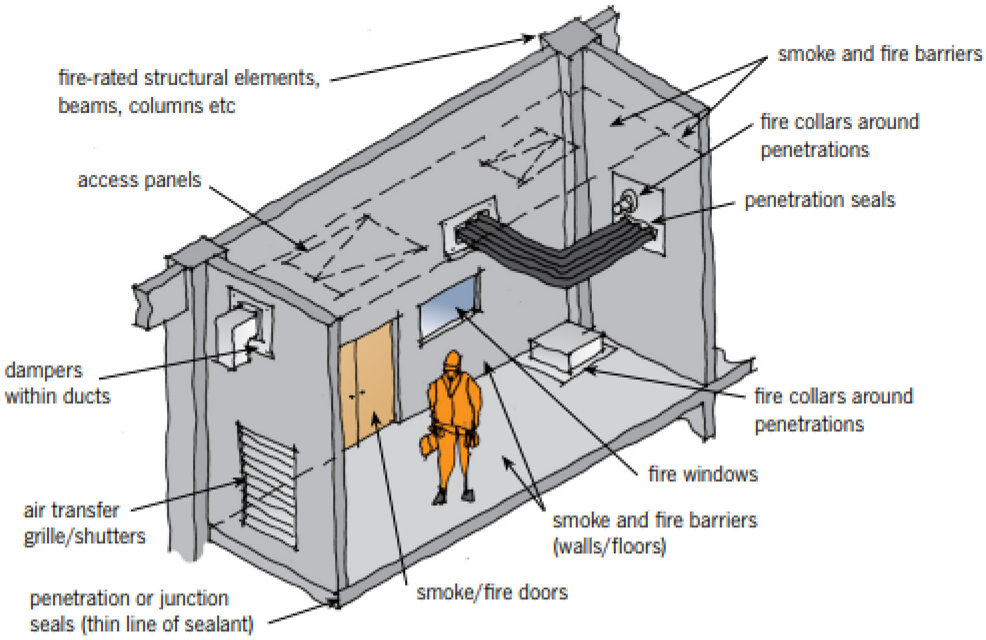
Measures to inhibit internal fire spread within a building through compartmentation and fire resistance are contained in the Building Regulations for England and Wales. This may include the provision of fire doors, as detailed in ABD. However, statutory measures for England and Wales are intended only to preserve building stability for 'a reasonable period', sufficient to allow occupants time to escape. As such, recommended minimum periods of fire resistance in ADB for England are lower than those stipulated in design guides for property protection. For instance, RISCAuthority Design Guide recommends fire-resisting compartment walls and floors with a minimum fire resistance of 90 minutes, in order to ensure adequate property protection. In ADB, however, a block of flats up to 11 metres high (with or without sprinklers) need only have compartments with a fire resistance rating of 60 minutes, whereas 90-minute fire resistance is only recommended for blocks of flats between 18 and 30m high.[30] What we can infer from this is that compartmentation can act as a property protection measure, but requirements around fire resistance performance of compartment walls are generally higher than the minimum required by building regulations to ensure life safety.

Non-combustible materials: The provision of non-combustible materials, for both structural and non-structural elements, prevents building components from contributing to the fire fuel load and increasing the intensity of the fire. Use of combustible building materials has been shown to be equated with accelerated fire development and higher total heat release rate, compared to non-combustible materials.[31] The use of non-combustible materials therefore helps to protect the building by limiting the intensity and extent of impact of the fire on the building.

Fire-stopping: Fire-stopping mechanisms help to impede the spread of fire and smoke around the building by maintaining the fire resistance of the fire separating elements. This is achieved primarily by sealing apertures and gaps in joints between fire separating elements in the building structure. Fire-stopping acts as a physical barrier which limits the impact of fire on the building.

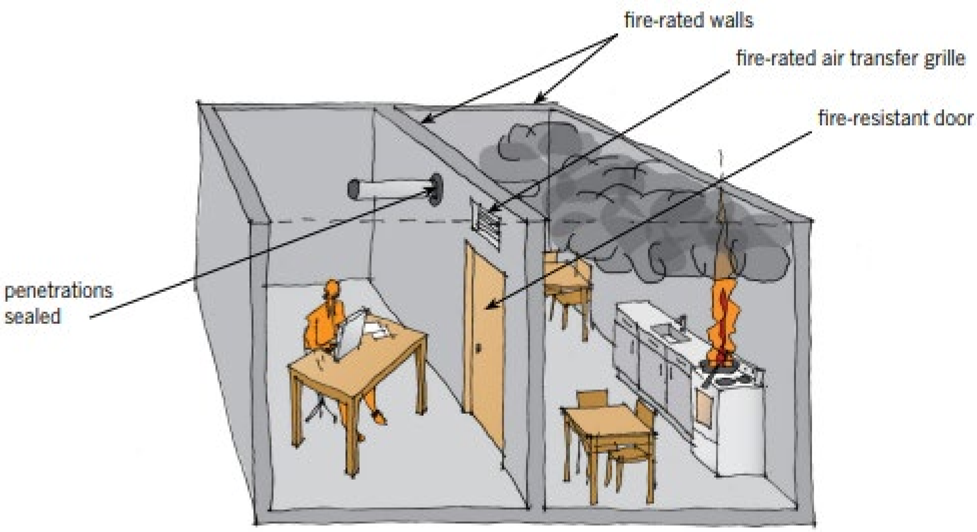
Examples are provided below of measures used to protect building components (Figure 2), and to control the spread of fire (Figure 3). Both of these illustrations are taken from the Branz Guide to Passive Fire Protection in Buildings.

Figure 2: Passive fire protection building components



Source: Branz, *Guide to Passive Fire Protection in Buildings*

Figure 3: Fire spread control using passive fire protection



Source: Branz, *Guide to Passive Fire Protection in Buildings*

2.2.2 Active fire protection measures:

Automatic fire suppression systems: The two main automatic fire suppression systems are:

- **Automatic sprinkler systems**
- **Water mist systems**

An **automatic sprinkler system** consists of a water supply, which is fed via pipework to a series of sprinkler heads. Sprinklers are typically thermally operated: a sprinkler head will activate when the air temperature around it reaches a predetermined temperature (the 'operation temperature'). Sprinkler systems are also designed so that, in the event of a fire, only those sprinkler heads which have reached the operation temperature (i.e., only those in the vicinity of the fire) will activate.[32]

The advantage of sprinklers is that they operate at an early stage. Their purpose is to control the fire while it is still small, or else contain and control the fire so that the fire service can manage it. By containing or extinguishing the fire, sprinklers prevent fires from spreading from the point of origin and so limit the extent of fire damage on the building and its contents.[33] Water from sprinklers can, however, cause damage to the internal fabric of the building as well as to contents.

According to the FPA,[34] sprinkler systems intended for the protection of both people and property should be designed, installed and maintained in accordance with the *LPC Rules for Automatic Sprinkler Installations 2009 incorporating BS EN 12845*.[35] This document contains the text of BS EN 12845: 2015, a design standard for automatic sprinkler systems which has been developed over many years to ensure performance reliability. This standard includes an extensive set of design considerations for suppression systems designed to protect people and property, including the need for sprinklers to cover all areas of the building, including roof voids where necessary.

In contrast to LPC Rules, BS 9251 design standard for residential sprinkler systems is primarily concerned with the design of sprinklers 'for life safety purposes with additional benefits for property protection.' Its scope is also residential buildings and so does not cover non-domestic premises.[36]

Water mist systems are also water-based fire suppression systems, some of which are thermally operated. In contrast to sprinklers, however, water mist systems are designed to extinguish high temperature surface fires using a smaller volume of water than an equivalent sprinkler system. Water mist systems generate smaller droplets with larger surface areas that have a greater ability to absorb the heat from a fire. The main advantage of water mist systems is their ability to extinguish high temperature surface fires, such as flammable fuels and deep fat fryers, using less water than a sprinkler system.[37] Disadvantages are that they are less effective at suppressing fires in large open areas or in highly ventilated spaces subject to air movements.[38]

Water mist systems are bespoke solutions and each manufacturer's product is distinctly different. BS 8489-1 covers the design and installation of industrial and commercial water mist systems. However, this design standard does not contain prescriptive design rules but instead provides 'a structured approach and guidelines for designing and installing fixed water mist systems.'[39]

Early automatic fire detection and alarm systems: Automatic detection systems serve an important life safety function by alerting building occupants at the earliest possible moment, thus facilitating early escape. Early automatic fire detection systems can also be designed to serve a property protection function, enabling fire services to be alerted sooner and prompting more rapid intervention, which is intended to reduce the damage to the fabric and contents of the buildings.

BS 5839-1 specifies three categories of fire detection and alarm system. Category 'M' are manual alarm systems which depend on manual call points. Category 'L' systems are automatic fire detection and alarm systems intended primarily for the protection of life, designed to be installed in areas of a building which are frequently occupied. Category 'P' systems are fire detection and alarm systems intended to protect property. The main difference is that 'P' systems are designed to be installed throughout all areas of a building, including in areas typically unoccupied, or in high fire hazard areas.[40]

First-aid and fire-fighting equipment: Hand-held and portable firefighting equipment, such as fire extinguishers, serve an important life safety function. Provision of fire-fighting equipment also plays an ancillary role in property protection; in that it allows a fire to be tackled before it becomes too large. Like sprinklers and water mist systems, firefighting equipment has the potential to limit the impact of fire on the fabric of the building, but it depends on human intervention.

Smoke ventilation and exhaust systems: Controlling the spread of smoke is important for life safety, limiting exposure of occupants to harmful substances. However, when used in combination with other active fire protection measures, such as fire sprinklers or interlinked alarms, smoke control systems can also minimise smoke damage to the contents and fabric of the building. This is particularly important in buildings where contents may become easily damaged by smoke, such as warehouses, or schools and offices with sensitive information and communications technology (ICT) equipment. Smoke control can therefore be considered as a property protection system, but research suggests that such systems are most effective in protecting building resilience only in combination with other systems.[41]

3. Overview of regulatory approaches to protection of buildings from fire

3.1 Prescriptive v performance-based approach

This chapter presents an overview of the building regulations of each of the countries within scope of this research.

Regulations are typically categorised as either prescriptive or performance-based. A description of each is provided below (Table 7).

The comparator countries within the scope of this review have been selected to represent a range of different approaches on the prescriptive/performance spectrum. Some countries can easily be categorised, whereas some fall midway between the two, or offer a hybrid approach. For example, Germany adopts a prescriptive approach, whereas Australia uses a performance-based approach. In Sweden, either approach can be followed.

Table 7: Description of prescriptive and performance-based frameworks (taken from the Hackitt Review)

Prescriptive frameworks: Prescriptive regulatory frameworks define the mechanisms by which the final output must be produced. These frameworks tend to assume that compliance with the rules is equivalent to what is considered to be safe. Regulatory frameworks that are overtly reliant on prescription may fail to provide the expected level of safety, because if this assumption is incorrect, the output will be compliant with the prescription, but not safe. Prescriptive frameworks use necessarily simplified design tools and can risk becoming a box-ticking exercise. These frameworks may not be able to keep pace with innovation in design and construction, and detailed and recurring empirical feedback and technical review is absent. Prescriptive frameworks can therefore result in high compliance costs.
Performance-based frameworks: Performance-based or 'outcomes-based' frameworks define the outcome that is required. They measure the key functional requirement, namely that buildings are safe, rather than that they are compliant with prescriptive requirements. Outcomes-based regulation can also be seen to play an enabling function, as it is often used to encourage the use of innovative designs[42,43]. However, such frameworks are dependent on the competence of those within it.[44] Functional requirements should provide a backstop for any omissions from prescriptive guidance in frameworks that offer outcomes-based solutions.

Performance-based frameworks are typically based on a series of 'functional' statements. These statements describe how a building should perform in the event of a fire, rather than defining how a building should be designed and constructed. These functional requirements are then supported by a series of 'performance standards': a statement about performance which, if achieved, would ensure that the functional requirement is met. Finally, the performance standards are reinforced by a series of 'deemed-to-satisfy' clauses which are assumed to provide an acceptable standard of performance, if complied with. The overall purpose of this approach is to enable building legislation to be suitably flexibly to accommodate new materials and methods, while at the same time ensuring that basic standards are upheld.[45]

3.2 Overview of countries

This section summarises the regulatory approaches of the eight comparator countries:

- UK (England, Wales, Scotland and Northern Ireland)
- USA
- Germany
- Sweden
- New Zealand
- Australia
- Japan
- Singapore

Table 8 illustrates whether each of the countries adopts a prescriptive or a performance-based approach.

Table 8: Comparator countries - prescriptive or performance-based approach

Country	Prescriptive	Performance-based
England and Wales	✔	✔
Northern Ireland	✔	✔
Scotland	✔	✔
USA	✔	
Germany	✔	
Sweden	✔	✔
New Zealand		✔
Australia		✔
Japan		✔
Singapore	✔	

The primary objective of all of the international fire safety regulations summarised below is life safety.

Very few of the regulations reviewed here contain requirements which are explicitly linked to the goal of protecting property. However, while property protection is rarely mentioned as an overt objective in international regulations, in many cases, the principle of property protection is implicit in the historical development and design of codes. In some cases, national fire safety regulations contain requirements which go above and beyond those embedded in England's Building Regulations, and which offer a higher degree of protection to property and buildings. Similarly, several of the countries reviewed here (such as the USA, Japan, Singapore, Australia and New Zealand) have codes with a historic background in limiting the spread of fire between buildings. These codes can be seen as having the principle of protecting property implicitly written into their design (even if they don't have requirements specifically linked to property protection).

A brief overview of the approach to fire safety in Switzerland is included here as a counterpoint to the prescriptive versus performance-based approaches adopted in the comparator countries.

Switzerland

In Switzerland, the Association of Cantonal Fire Insurance Companies (Vereinigung Kantonaler Gebäudeversicherungen, or VKF) is the umbrella organisation for building insurers which is responsible for setting the country's fire protection standards. The standards published by the VKF are legally binding, but it is the task of the individual cantons to promulgate fire safety regulations, based on the standards published by the VKF.

The VKF standards are revised every 10 years. The latest standards came into effect on 1st January 2015. The VKF deem the Swiss standards to be among the most advanced in Europe. The primary objective of the Swiss fire regulations – as set out in Brandschutznorm, the Swiss Fire Protection Standard – is to 'protect people, animals and property from the dangers and the effects of fire and explosions.'[46] Fires with two or more fatalities are extremely rare in Switzerland.[47]

The approach[48] combines fire protection, natural hazard prevention and training in both areas. All fire protection products are published in a fire protection register, detailing technical information and approvals to ensure that all fire protection products are installed correctly, in accordance with fire safety regulations. This means that there is no need to check documents at an individual fire protection authority level; this centralised approach provides a guarantee that all products on the register meet fire protection requirements.

The VKF also provides training and administers examinations for fire protection specialists and experts.

The VKF standards regulate the use of flammable materials in structures, fire compartments, exterior wall cladding, roofing, and interior applications. Documentation published in 2015 comprises the fire protection standard and 19 fire protection guidelines, supplemented by various explanations, directories, working aids and leaflets.

The Swiss regulatory system of fire classification is dictated by building height. There are three categories:

- Buildings of low height (up to 11m)
- Buildings of medium height (up to 30m)
- Skyscrapers (more than 30m)

Minimum measures are defined for quality assurance, which must be regularly reviewed and amended if required. There are four quality assurance levels, which are applied to buildings based on their use, height, construction methods and any other specific fire risks:

- **Category 1:** Small and simple buildings, limited number of different units for use and no increased fire risk as a result of their use or mode of construction

- **Category 2:** Small or medium-sized buildings, with several different or extensive uses which may present increased fire risks as a result of their use or mode of construction

- **Category 3:** Medium to large-sized buildings, with many different or extensive uses and increased fire risks as a result of their use or mode of construction

- **Category 4:** Large buildings, with many different or extensive uses and high fire risks as a result of their use or mode of construction

Categories 2, 3 and 4 must have a certified VKF-approved fire protection specialist responsible for quality assurance.

The VKF provides a list of generally approved building products. The construction products listed can therefore be used without needing further proof of verification or VKF approval. Building materials are classified by the VKF into different categories based on their behaviour in the event of a fire, and their corrosivity.

3.2.1 UK

England and Wales:

In England and Wales, the legal requirements for fire safety in buildings are described in Schedule 1, Part B of the Building Regulations. Since 1991, building regulations in England and Wales have been fully performance-based. Part B of Schedule 1 contains a list of goal-oriented, functional statements which describe how buildings should perform in the event of a fire. These **functional** regulations set out the minimum requirements for the design, construction and refurbishment of buildings to ensure life safety in England and Wales. The building regulations are backed up by supporting guidance documents (Approved Document B – the Welsh Government publishes its own version) which set out performance standards describing how to comply with the building regulations. These guidance documents carry statutory weight: following them provides assurance that compliance with the regulations has been achieved.[49]

Building regulations in England and Wales focus solely on the protection of life safety in the event of a fire; they are not intended as a means of protecting buildings and property from fire. Approved Document B sets out clearly that property protection is beyond the remit of building regulations:

"The Building Regulations are intended to ensure a reasonable standard of life safety in a fire. The protection of property, including the building itself, often requires additional measures. Insurers usually set higher standards before accepting the insurance risk."

Northern Ireland:

Northern Ireland publishes its own building regulations. However, requirements for fire safety in buildings (Part E of Northern Ireland's building regulations) broadly mirror those in place in England and Wales. Northern Ireland also publishes its own guidance documents (Technical Handbook E) which provide advice on how compliance with the building regulations can be achieved. Like in England and Wales, the primary objective of regulations in Northern Ireland is the protection of life safety.

Scotland:

Scotland also publishes its own version of the building regulations. The current building standards system in Scotland was established by the Building (Scotland) Act 2003, which gave ministers in Scotland power to establish their own building regulations and set building standards. Like in England, Wales and Northern Ireland, regulations in Scotland are **functional** standards. The section of the Scottish building regulations which covers fire safety (section 2 of Schedule 5) contains functional statements, rather than detailed prescriptive requirements, describing how buildings should perform. Scotland also publishes its own guidance to ensuring compliance with the building regulations (Technical Handbooks).

Unlike England, Wales and Northern Ireland, Scotland's Building Regulations contain a legislative requirement for 'automatic life safety fire suppression systems' to be installed in certain types of building (shopping centres, residential care buildings, high-rise domestic buildings, sheltered housing complexes). The purpose of this mandatory requirement is, however, to ensure life safety, rather than to protect buildings and properties.

While the primary objective of Scotland's building regulations is life safety, the Technical Handbook for non-domestic buildings in Scotland sets out a series of requirements for ensuring the protection of property and building infrastructure in schools.

3.2.2 USA

The regulatory approach to fire safety in the USA is unique compared to other countries. As in Germany, fire safety legislation is enacted and enforced by individual states or, in some cases, local jurisdictions. However, unlike Germany, the federal government has no responsibility in the publication of building codes. Instead, each state bases its building regulations to some extent on a number of 'model codes' which are written and published by private-sector, not-for-profit membership organisations. The two main code-publishing bodies in the USA are the International Code Council (ICC) and the National Fire Protection Association (NFPA). The model codes written by these bodies are adopted by each state and enacted as building legislation. However, model codes are not adopted equally (and some are not adopted at all), as states follow their own legislative processes and typically tweak the model codes in accordance with their own geographic conditions.[50]

The principal model code, on which most states' building and fire regulations are based, is the International Building Code (IBC). The IBC is a highly prescriptive set of requirements which describe in detail how buildings should be constructed in order to ensure safety. While the ICC and the NFPA have both published performance-based codes since 2000, these codes have not been taken up by many states and the principal approach to fire safety regulation in the USA remains a prescriptive one.[51]

One stakeholder notes that the USA regulatory environment is heavily prescriptive, as those involved in fire safety standards are resistant to wholesale change, i.e., a transition to performance-based design.

The objective of the IBC is to protect both life safety and property from fire. Its purpose, as set out in its 'Scope and General Requirements', is to provide:

> 'a reasonable level of life safety and property protection from the hazards of fire, explosion or dangerous conditions, and to provide a reasonable level of safety to fire fighters and emergency responders during emergency operations.'[52]

The IBC has its origins in the municipal fire codes published by American cities in the late nineteenth century, which were written primarily with the aim of limiting the spread of fire between buildings and preventing city-wide conflagrations (such as the Chicago fire of 1871).[53] The principle of protecting buildings by limiting the spread of fire has since been inherited by the American national model codes, including the IBC. Stakeholders point out that it is precisely this historic background in codes which attempted to restrict fire spread which gives the modern-day IBC its implicit, ingrained focus on protecting buildings and property from fire. Unfortunately, this review found no empirical, non-anecdotal evidence to suggest a link between the historical antecedents in the principle of limiting fire spread on the one hand, and the objective of property protection in the current IBC, on the other.

The IBC also works by setting allowances for building design based on:

1. use and occupancy of buildings,
2. building heights and areas, and
3. construction types.

These criteria are used to determine 'equivalent risk' for buildings and prescribe limitations on building design: i.e., the greater the potential fire hazards associated with a particular occupancy, the smaller the height and area allowances for a particular construction type. Building design allowances can, however, be exceeded with the inclusion of additional fire safety design features, such as fire suppression systems: the code permits designers to increase the height and areas of their buildings if they install sprinklers. Sprinklers, therefore, are important in the IBC – and the USA building regulatory system more generally – as they permit designers to exceed prescribed building allowances, enabling them to construct bigger or taller buildings, or buildings made from different materials (such as cross-laminated timber). As a result, sprinklers are highly prevalent in the USA built environment.

3.2.3 Germany

In Germany – in contrast to most European countries, but in common with the USA – it is the responsibility of the federal states to set fire regulations, rather than these being set by the national government.

Each states' regulations are based on a national framework – Musterbauordnung – however, each state is permitted some flexibility in setting their own Landesbauordnungen. Overall, the model is a highly prescriptive one although, anecdotally, the approach to industrial buildings is becoming more performance based, employing computer-based modelling.

In Germany, building fire regulations are set at three levels:

1. The Building Code of the 16 federal states, each of which are based on the national model building code. Many of the states specify different provisions, such as permissible area of fire compartment or minimum required size of opening in the external wall.
2. Regulations for special types of buildings such as high-rise and industrial buildings (please see section 4 for examples of these).
3. Technical building regulations that are 'bindingly implemented by the building authority of federal states e.g., Euro-codes' as well as German DIN standards.[54]

There are also requirements on the performance of building components including the behaviour of building materials in fire using building material classes. For example, federal states set administrative technical building regulations that are based on the national model administrative technical building regulations. In addition, European standards for building components are also observed.[55] There are also rules regarding the structure's division into fire compartments and provision of access routes for the fire service.[56]

The Model Building Regulations Musterbauordnung (MBO)
The Model Building Regulations offer a 'prototype' on which each state can issue its own building regulations. The MBO is published by the Argebeau[57]. In the course of a previous revision to the MBO, in 2016, the technical rules for design and execution of structural works, construction techniques and construction products were thoroughly amended and merged into one document, the Model Administrative Provisions – Technical Building Rules (MVV TB). These Technical Building rules are published by the Deutsches Institut für Bautechnik (DIBt) on behalf of the federal states.[58]

As well as the model administrative regulation technical building rules (Jan 2022) and a 'model architects act' (2006) there are a range of papers relating to specific building types under the heading 'special buildings, furnaces and garages'. These include models, ordinance and directives on different types of buildings such as operating rooms, garages, high-rise buildings, sales outlets and schools.[59]

The primary objective of the model regulations is life safety:

Model Building Regulation MBO §14 "Fire Protection"

"Buildings and structures must be designed, constructed and maintained in such a way that the development of a fire and the spread of smoke and fire is prevented and that in case of fire the rescue of humans and animals as well as an effective extinguishing are guaranteed."

To obtain a building permit (Baugenehmigung), a construction project must comply with all planning and building regulations and all other relevant regulations.[60] Fire protection is included in the first stages of the design process during which a fire protection concept is devised by the Sachverständige, a qualified private fire expert. This is then checked by the building regulator or certified experts. Following completion of the building, checks on the structure and fire safety are performed by a private contractor and basic checks by the building regulator. Post-completion, regular fire safety checks are carried out by the local fire department.[61]

As of 2016, smoke detectors were required for new buildings and renovations in all 16 states, starting with the most populous state of North Rhine-Westphalia. This brought the requirements for new builds in line with an obligation for smoke detectors to be fitted in existing buildings (Saxony was exempt until 31st December 2020). The smoke detector obligation is regulated in the building codes of the individual federal states. It appears the primary motivation to make smoke detectors compulsory is for life safety. There is anecdotal evidence that smoke detectors have accounted for a 50% reduction in 'fire victims', but this research has been unable to find any evidence in relation to property protection.

3.2.4 Sweden

Sweden offers an interesting comparator approach to fire protection in that the requirements of the building regulations can be met through either prescriptive or performance-based design. A premise of the regulations is that buildings should be designed with the assumption that a fire will occur at some point in the building's life.

Fire safety is regulated by the **Boverkets byggregler (2011:6) – föreskrifter och allmänna råd**, The National Board of Housing, Building and Planning's building regulations (2011:6) – regulations and general advice.[62] In Swedish law, 'regulations' is an umbrella term for what is prescribed in Acts and Ordinances as well as in the mandatory provisions and general recommendations of government agencies. Not all regulations are binding. General recommendations state what can or should be done to meet the binding regulations that must be met. Binding regulations are Acts, Ordinances and mandatory provisions.

The National Board of Housing, Building and Planning's building regulations – regulations and general advice, contain guidelines, as well as mandatory requirements. The Planning and Building Act and the Planning and Building Ordinance set out legally binding requirements for the planning of land and water areas and on construction.[63]

Boverket's building regulations (BBR) consists of mandatory provisions and general recommendations that state how the mandatory provisions may be fulfilled. Developers are free to use solutions other than those suggested in the general recommendations, but the verification process will need to ensure that the mandatory provisions are met, as a minimum. Hence, either a prescriptive or performance-based approach can be adopted by developers. BBR is divided into nine parts, one of which includes specific provision for fire safety:

1. Introduction
2. General rules for buildings
3. Accessibility, dwelling design, room height, and utility rooms
4. Mechanical resistance and stability
5. **Safety in case of fire**
6. Hygiene, health and environment
7. Protection against noise
8. Safety in use
9. Energy management

In addition to the BBR, Sweden stipulates compliance with Eurocodes and 'national choices in the Boverket Series of Provision on the Application of European Construction Standards (EKS)' in the structural design of building works.

BBR sets out how compliance may be achieved through either pre-accepted solutions (prescriptive approach) or by deviating from the pre-accepted solution and using fire safety engineering – referred to as analytical design – to verify that the solutions fulfil the mandatory provisions in BBR (performance-based approach).[64]

Prescriptive design cannot be used if an automatic fire suppression system is used to meet the requirements in either:

- More than two mandatory provisions
- More than one mandatory provision, where an automatic fire suppression system is used

In this case an analytical approach must be used and will be verified through a variety of means including qualitative assessment, scenario analysis, quantitative risk analysis, 'equivalent methods' or a combination of methods.[65]

The BBR includes definitions of occupancy classes (e.g., offices, places of assembly, dwellings, healthcare environments) as well as building classes, based on their need for protection. Various factors should be taken into account when assessing the need for protection, including probable fire progress, potential consequences of a fire and the complexity of the building. Structural elements of a building are all assigned to different classes (e.g., load-bearing capacity, integrity, mechanical impact). Other prescriptive aspects of the BBR include permissible smoke emittance from building materials and permissible levels of 'burning drops or particles'.

Many of the provisions are outcomes-focused. Detection and evacuation systems are not mandated but 'shall be installed where this is necessary for the fire protection's design'. The approach to automatic fire suppression systems is also outcomes-focused, with the BBR stating that if such a system 'is essential for fire protection, the design shall be such that it has the capacity to extinguish or control a fire over the appropriate time with high reliability.' There is a similar requirement for smoke ventilation. The BBR provides for an element of property protection in terms of prevention of fire spread, however, property protection is not overtly mentioned.

Boverket's general recommendations on the analytical design of a building's fire protection describes broadly the scope of analysis for analytical design, how to identify the need for verification and how to clarify deviation from prescriptive design (Table 9). The table is taken from: Boverket's general recommendations on the analytical design of a building's fire protection[66]

Table 9: Matrix for identifying deviations from prescriptive design (PD) (Sweden)

Fire protection element		Deviations from prescriptive design							
		Deviation				Addition			
		1	2	3	4	1	2	3	4
5.2	Fire resistance classes and other conditions								
5.3	Ability to escape in case of fire								
5.4	Protection against outbreak of fire								
5.5	Protection against the development and spread of fire and smoke in buildings								
5.6	Protection against the spread of fire between buildings								
5.7	Possibility of rescue responses								
Section C, Ch. 1.1.2. in EKS	Load-bearing capacity in case of fire								

As with the provisions in BBR, the only aspects of the general recommendations on analytical design relating to property protection are regarding preventing spread of fire and building resilience. Therefore, property protection is implicit in the regulations (it is not stated as an objective).

3.2.5 New Zealand

Fire safety regulations are stipulated in The Building Code (Regulation 6 of the Building (Building Code: Fire Safety and Signs) Amendment Regulations 2012): the NZBC.

Fire protection is specified in Section C of the Building Code, with Clause C1 stating the objectives of Clauses 2 to 6 (Table 10).

Table 10: Section C of the New Zealand Building Code

C1	Objectives of Clauses C2 to C6
C2	Prevention of fire occurring
C3	Fire affecting areas beyond the source
C4	Movement to a place of safety
C5	Access and safety for firefighting operations
C6	Structural stability

The stated intention of the NZBC, as specified in Clause C1, is primarily life safety but it includes as a secondary objective to protect other property from damage caused by fire. The third objective is to facilitate firefighting and rescue operations.[67] As with Sweden, property protection is implicit in New Zealand's approach.

All buildings (whether new build, existing or refurbishment) must meet the requirements of the NZBC.

Clause C2 specifies the performance requirements for buildings in terms of the prevention of fire occurring. This covers the design, construction and installation of fixed appliances using controlled combustion and other fixed equipment in buildings. The Clause states that these must reduce the likelihood of illness or injury due to fire occurring. It also sets the maximum surface temperature of combustible building materials.[68]

Minimising spread of fire is covered specifically in sub-cause C3 of the NZBC which states that buildings must be designed and constructed so there is a low probability of fires spreading via external vertical fire spread in buildings higher than 10m where the upper floors contain sleeping uses. There are also requirements around the design and construction of buildings so that there is a low probability of fire spread to other property, vertically or horizontally.

The NZBC also sets performance criteria for materials used as internal surface linings (Table 11). The differentiating factor is whether or not automatic fire sprinkler systems are used.

Table 11: Performance criteria of material used as internal surface linings (New Zealand)

	Performance determined under conditions described in ISO 9705:1993	
Area of building	**Buildings NOT protected with an automatic fire sprinkler system**	**Buildings protected with an automatic fire sprinkler system**
Wall/ceiling materials in sleeping areas where care or detention is provided	Material Group Number 1-S	Material Group 1 or 2
Wall/ceiling materials in exitways	Material Group Number 1-S	Material Group 1 or 2
Wall/ceiling materials in all occupied spaces in importance level 4 buildings	Material Group Number 1-S	Material Group 1 or 2
Internal surfaces of ducts for HVAC systems	Material Group Number 1-S	Material Group 1 or 2
Ceiling materials in crowd and sleeping uses *except household units* and where care or detention is provided	Material Group Number 1-S or 2-S	Material Group 1 or 2
Wall materials in crowd and sleeping uses *except household units* and where care or detention is provided	Material Group Number 1-S or 2-S	Material Group Number 1, 2 or 3
Wall/ceiling materials in occupied spaces in all other locations in buildings, including household units	Material Group Number 1, 2 or 3	Material Group Number 1, 2 or 3
External surfaces of ducts for HVAC systems	Material Group Number 1, 2 or 3	Material Group Number 1, 2 or 3
Acoustic treatment and pipe insulation within air-handling in sleeping uses	Material Group Number 1, 2 or 3	Material Group Number 1, 2 or 3

Table taken from: The Building Code, Clause C1 – Objectives of clauses C2 to C6 (protection from fire)[69]

Sprinklers are the only protection measure called out in the NZBC; passive measures such as fire stops and compartments are not specified as a fire protection measure in Clause C3.

Whilst the NZBC offers a performance-based approach, certain stipulations – or mandatory performance requirements – are made regarding spread of fire. For example:

- Fire should not spread more than 3.5m vertically from the fire source over the external cladding of multi-level buildings
- In the event of fire building received radiation at the relevant boundary of the property does not exceed 30kW/m^2 and at a distance of 1 m beyond the *relevant boundary* of the property does not exceed 16 kW/m^2

Property protection is implicit in the requirements for **structural stability** during fire. As well as buildings being constructed so there is a low probability of illness or injury to occupants or the fire service, they should also be constructed so there is *"a low probability of direct or consequential damage to adjacent household units or other property."*[70] Evidence from stakeholders confirmed that property protection is not explicitly addressed, with any implicit provision being for the purpose of protecting neighbouring properties.

Disproportionate collapse is also considered under a requirement that *"collapse of building elements that have lesser fire resistance must not cause the consequential collapse of elements that are required to have a higher fire resistance."*

Clause A3 of the NZBC 'Building Importance Levels' defines three importance levels to buildings, based on the consequences of a building failure after a major disaster. Property protection and other impacts are explicitly considered here:

1. **The risk to human life**
2. **The economic impacts**
3. **The ability for the building to continue to function or be repaired after a disaster**[71]

The requirements of the NZBC may be achieved by:

- Compliance with an Acceptable Solution (previously called 'Compliance documents')
- Following a Verification Method
- An Alternative Solution
- An 'as near as reasonably practicable (ANARP) solution for change of use or alterations in existing buildings'[72]

The Code provides the regulatory, performance-based requirements for achieving fire safety. These are mandatory by law. The ways in which the requirements of the NZBC may be met are not mandatory. 'Alternative solutions' and 'verification methods' are 'deemed to comply', but they don't have to be used. The same is true of New Zealand Standards. Stakeholders interviewed stated that when alternative standards can be used, there is freedom to choose whichever standard is deemed appropriate.

This is broadly similar to the Swedish model where a prescriptive or performance based ('analytical design') approach may be adopted.

For Clause C 'Protection from Fire', there are three sets of Acceptable Solutions and Verification Methods. C/AS2 explicitly separates the minimum fire resistance ratings (FRRs) for life and property; again, a differentiating factor here is whether or not the property contains sprinklers (Table 12). The ratings are based on the respective risk group of the property. Table 12 is taken from: C/AS2 Acceptable Solution for Buildings other than Risk Group SH, For New Zealand Building Code Clauses C1-C6 Protection from Fire.[73]

Table 12: Life and Property ratings in minutes (New Zealand)

Risk Group	Unsprinklered		Sprinklered	
	Life	Property	Life	Property
SM	60	60	30	30
SI	n/a	n/a	60	60
CA	60[1]	120	30[1]	60
WB	60[1]	120 (180[2])	30[1]	60 (90[2])
WS	n/a	n/a	60[1]	180
VP	60[1]	60	30[3]	30[3]

[1]When the escape height is greater than 10 m the exitways shall have fire separations with an FRR meeting the property rating (refer to Paragraph 4.9.2)
[2]Where the building is less than 15m to the relevant boundary and the storage height is greater than 3.0 m the FRR shall be 90 minutes where sprinklered and 180 minutes where unsprinklered.
[3]The sprinkler system can be substituted for cross ventilation in accordance with Paragraph 4.1.3

For risk group SH 'Buildings with Sleeping (residential) and Outbuildings', separate ratings for life and property are specified, although the ratings are identical. The fire resistance rating for life and for property is 30 minutes.[74] C/VM2 Verification Method: Framework for Fire Safety Design for New Zealand Building Code Clauses C1-C6 Protection from Fire sets out in detail specific requirements for protection of 'other property' with regard to horizonal fire spread and external vertical fire spread.

Various standards are also available for helping developers achieved Building Code compliance; the Ministry of Business Innovation and Employment (Building System Performance) has funded 15 standards published by Standards New Zealand.[75] One of which specifically relates to fire: 'Fire detection and alarm systems in buildings.' Other relevant standards include:

- NZS/BS 476: Fire tests on building materials and structures
- NZS 4515: 2009 Fire sprinkler systems for life safety in occupancies of less than 2000 m^2
- NZS 4517: 2010 Fire sprinkler systems for houses
- NZS 4520: 2010 Fire resistant doorsets
- NZS 4541: 2013 Automatic fire sprinkler systems[76]

NZS 4541 was written 'partially with property protection in mind'.

There are also various Guides published by the MBIE, relating to different building types. Section 4 of this report contains information on the guidance for different buildings.

3.2.6 Australia

The Australian Building Codes Board (ABCB) sets the National Construction Code (NCC): a performance-based code specifying the minimum required level for 'safety, health, amenity, accessibility and sustainability of certain buildings.' The NCC is produced and maintained by the Australian Building Codes Board (ABCB) together with each State and Territory government.[77]

The NCC does not specifically call out the objectives fire safety – i.e., life and/or property protection – but simply states the requirements for preventing fires and fire spread.

Volumes 1 and 2 of the NCC constitute the Building Codes of Australia (BCA). Volume 3 constitutes the Plumbing Code of Australia (Table 13).

Table 13: Volumes of the National Construction Code (Australia)

Volume of the NCC	Content
Volume 1	Technical design and construction requirements for all Class 2 to 9 buildings and their associated structures: • multi-residential • commercial • industrial • public assembly buildings This Volume consists of several components, Section C covering 'Fire resistance'.
Volume 2	Technical design and construction requirements for certain residential and non-habitable buildings and structures.

Volume 3	Possible methods of demonstrating compliance with the NCC. This also covers plumbing and drainage requirements for buildings of all classifications.

Within the BCA, property protection is addressed but from the point of view of limiting the spread of fire to adjacent properties.

Protection of other property

The BCA is principally designed to maximise (within reasonable bounds) the safety, health and amenity of people in and around buildings. Protection of property, either the subject building or what is termed "other property", is not generally a primary aim of the BCA – although it may sometimes be a consequence of the provisions of the BCA.

However, there are some exceptions to this rule, and the inclusion of "other property" in CO1(e) is one of these. In this context, a building is expected to maintain the level of structural sufficiency necessary to prevent it causing damage to any other property as a result of fire. The reason CO1(e) concerns itself with the protection of other property is primarily because fire from a building should not pose a serious risk to the health, safety and amenity of the public or occupants of another building...[78]

Importantly, the NCC groups buildings and structures by the purpose for which they are designed, constructed or adapted to be used, rather than by the function or use they are put to. A building may have more than one purpose and may be assigned more than one classification.[79]

Part C of Volume 1 contains requirements on passive fire protection, specifically compartmentation and separation. General floor area and volume limitations are set out according to the construction type. The table below (Table 14) illustrates the compartment sizes stipulated for most building types (e.g., residential, multi-occupancy, schools, healthcare, restaurants, laboratories and other public buildings).

Table 14: Maximum size of fire compartment or atria (Australia)

Classification	Type A construction	Type B construction	Type C construction
5, 9b or 9c	Max – 8,000m^2 Max volume – 48,000m^3	Max – 5,500m^2 Max volume – 33,000m^3	Max – 3,000m^2 Max volume – 18,000m^3
6, 7, 8 or 9a (except for patient care areas)	Max – 5,000m^2 Max volume – 30,000m^3	Max – 3,500m^2 Max volume – 21,000m^3	Max – 2,000m^2 Max volume – 12,000m^3

Table taken from: NCC Volume 1, C2.2 General floor area and volume limitations[80]

Requirements on vertical separation of openings in external walls are specified based on building type, rather than classification. Requirements for separation by fire walls do not appear to differentiate based on classification or type but are general obligations relating to their construction and separation from buildings.

For certain types of buildings, exemptions are permitted. For example, in 'large, isolated buildings' the fire compartment may be exceeded if other provisions are in place such as limits on the number of storeys, there is open space surrounding the building and if the building is protected with a sprinkler system. Similarly, the requirements for separation of buildings may not apply (i.e., a building may be classed as a separate building) if the fire wall extends through all storeys and is carried through to the underside of the building, other provisions relate to roof construction and if the lower part of the roof has a sprinkler system.[81] Similarly, sprinklers are a differentiating factor when it comes to the separation of lift shafts.

The NCC is updated every three years, based on required regulatory practices, industry research, public feedback and policy directions from Governments. Updated content is then consulted on.[82]

The ABCB is in the process of updating the National Construction Code (NCC). Proposed changes include guidance for accessible housing, lead plumbing products, egress for schools, requirements for bushfire protection and quantification of performance requirements.

Whilst the NCC sets the minimum performance-based outcomes that must be achieved for compliance, it also specifies the standards that must be met. These standards are developed and published by Australian Standards. Standards relevant to fire safety are listed in Table 15.

Table 15: Australian Standards relevant to fire safety

AS 1670:2018 Fire detection, warning, control and intercom systems — System design, installation and commissioning
AS 1905:2015 Components for the protection of openings in fire-resistant walls
AS 2444-2001 Portable fire extinguishers and fire blankets — Selection and location
AS 2441-2005 Installation of fire hose reels
AS 3786:2014 Smoke alarms using scattered light, transmitted light or ionization
AS 1530:2014 Methods for fire tests on building materials, components and structures
AS 2118:2017 Automatic fire sprinkler systems
AS 2941-2013 Fixed fire protection installations
AS 1682:2015 Fire, smoke and air dampers
AS 4072-2005 Components for the protection of openings in fire-resistant separating elements

In addition to the NCC and Australian standards, each state has its own standards.

3.2.7 Japan

In Japan, fire safety regulations for buildings are set by the Building Standard Law (BSL), administered by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), which establishes the minimum standards for the construction of buildings.[83] The purpose of the BSL is to safeguard the life, health, and property of people by setting minimum standards around the construction, equipment, and use of buildings.

The BSL functions in a similar way to the IBC, in that the potential fire risk and resulting fire performance requirements of buildings are calculated based on a combination of the building's occupation, floor area and height. Fire risk is also determined by the fire zone the building is located in. Buildings located in designed 'Fire Protection Zones' (FPZ) or 'Quasi-Fire Protection Zones' (QFPZ) are subject to stricter rules in the BSL. These zones are designated in urban areas of all major cities in Japan. The purpose of both designations FPZ and QFPZ is to impose limitations on buildings in densely populated urban areas, to prevent fire spreading from one building to another, with stricter rules applying in the FPZ, compared to the QFPZ.[84]

Like the IBC, the Japanese BSL also has its origins in the principle of limiting the spread of fire between buildings. Given the high level of seismic activity in Japan, combined with the large number of old wooden buildings in many urban areas, large-scale conflagrations have been known to occur in Japanese history. The BSL was designed largely to minimise the destruction caused by large urban fires by limiting fire spread between buildings in densely populated areas.[85] The BSL therefore has provisions which arguably afford a higher level of protection to buildings and properties, especially in densely populated urban areas. One of the most effective ways by which fire spread is restricted is through provisions surrounding 'fire resistive buildings.' Fire resistive buildings are defined in the BSL as buildings which have 'principal building parts' (namely, walls, columns, beams, roofs, and stairways) made of fire resistive construction, or which have been constructed using a method that has been confirmed to be capable of withstanding fire and heat until the end of a fire (Figure 4). Larger buildings (e.g., above 3 storeys, or with total floor area exceeding 100m2) constructed in a FPZ or QFPZ are required by the BSL to be fire resistive buildings.[86]

Provisions around 'fire-resistive buildings' in the BSL can be seen as providing greater protection to property and buildings by stipulating requirements that ensure the physical structure of the building can withstand the duration of the fire. This is very different from regulations in England and Wales, which stipulate merely that building stability should be maintained 'for a reasonable period' in order to facilitate the escape of inhabitants.

Japan was also one of the first countries in Asia-Pacific to embrace performance-based fire engineering solutions in the design of new buildings. Since 1983, the BSL has developed to include a performance-based approach, leading in 1998 to the publication of a new version of the BSL, which made greater allowance for a performance-based approach. In 2000, a new verification method for the fire resistance performance of buildings (known as the Fire Resistance Verification Method (FRVM)) was added to the BSL. Specially qualified and licenced Japanese architect-engineers (or *Kenchikushi* as they are known)[87] are now permitted to make use of new, innovative construction materials and methods, provided that they evaluate the fire resistance of their buildings – and demonstrate their fire safety – using the FRVM.[88]

Figure 4: Fire-Resistive Buildings in the Japanese Building Standards Law[89]

Fire-resistive buildings are defined as buildings of which the 'principal building parts' (namely walls, columns, beams, roofs, stairways) are either:

a) Constructed using a solution that has been confirmed to be **capable of withstanding fire and heat until the end of a fire**, using the Fire Resistance Verification Method (FRVM), or
b) Can be categorised as '**fire resistive construction**'.

'Fire resistive construction' means that 'principal building parts' must conform to the following technical criteria for fire resistive performance.

Technical criteria of fire-resistive performance required on the building parts of fire resistive construction:

Storey / Building part	Uppermost storey and second to fourth stories from the uppermost storey	Fifth to fourteenth stories from the uppermost storey	Fifteenth storey or more from the uppermost storey
Load bearing walls	1 hour	2 hours	2 hours
Columns	1 hour	2 hours	3 hours
Floors	1 hour	2 hours	2 hours
Beams	1 hour	2 hours	3 hours
Roofs	0.5 hour		
Stairs	0.5 hour		

Building parts designated as 'fire-resistive construction' must not incur any deformation or damage detrimental to structural integrity of the building during the times listed in the table when subjected to heat produced by a normal fire.

Quasi Fire-Resistive Buildings in the Japanese Building Standards Law

The 'principal building parts' of 'quasi fire-resistive buildings' are subjected to more lenient fire resistance performance criteria:

Building part	Fire resistive performance
Load-bearing walls	45 minutes
Columns	45 minutes
Floors	45 minutes
Beams	45 minutes
Roofs	30 minutes
Stairs	30 minutes

Source: T. Hasegawa, (2019), *Building Control in Japan - Introduction to the Building Standard Law - Part D Technical Requirements for Building Safety and Amenity*

3.2.8 Singapore

In contrast to many countries, in Singapore, the legislation which regulates fire safety provision in buildings is separate from the primary building legislation. Fire safety regulations in buildings are determined by the Code of Practice for Fire Precautions in Buildings (Fire Code), administered by the Singapore Civil Defence Force (SCDF). This is separate from the Building Control Act, which is primarily concerned with structural safety in buildings, and which comes under the authority of the Building and Construction Authority (BCA).

Evidence from stakeholders states that the regulatory system has separated the Building Code from the Fire Code: passive systems are in the building code, but sprinkler systems and active fire suppression are in the fire code. The Building Code focuses on prevention by design of building which translates into better protection of the building, in terms of enabling the building to be re-used.

Singapore's Fire Code is a highly prescriptive set of regulations, consisting of detailed requirements around means of escape, structural fire precautions, firefighting systems (covering provision of portable extinguishers and fire sprinkler systems), smoke control and external firefighter access.

Stakeholders note that there is very strong enforcement of regulations in Singapore, with penalties for non-compliance. There is focus on collection of relevant data: for example, statistics on electric or battery fires. A strong driver is the dominance of large cities with many high-rise buildings; consequences in the event of a fire would be severe.

Although a more performance-based approach has been integrated into the Singaporean building control system (overseen by the BCA) since 2004, enabling designers to explore alternative design solutions for building structural safety,[90] the fire safety regulations, overseen by SCDF, remain quite prescriptive in nature.

The opening clause of Singapore's Fire Code states that its purpose is to ensure both life safety and property safety from fire:

> *"The Code of Practice for Fire Precautions in Buildings, hereinafter called "the Code" or "this Code", serves to establish the minimum requirements for fire safety provisions in all buildings. It takes into account the function, design, management, operation, and maintenance of buildings to secure the life safety of occupants and property safety in the event of a fire."*[91]

The Fire Code also operates in a similar way to the IBC in that it allows for trade-offs to be made and prescribed building allowances to be exceeded if additional active fire suppression systems are included. For instance, the Fire Code sets out rules on maximum fire compartment sizes and building heights for all occupancy types. These sizes and heights can be exceeded, but only if building designers specify automatic fire sprinkler systems. As such, sprinklers are mandatory in:

- All rooms and on all floors of any building where the size of fire compartments exceeds the allowable limits.
- Every floor of buildings over 24 metres in habitable height (excluding high-rise domestic buildings, but including hotels, boarding houses, serviced apartments and hostels).

Sprinkler provision is particularly strict in large atria within buildings. Atria up to 18m in height must be fitted with a sprinkler system. Additional fire suppression measures are needed for atria with ceiling height exceeding 18m (in whole or in part). These include water monitor, deluge and/or extended-throw sprinkler systems to ensure coverage of the entire atrium space.[92]

Although the rationale for sprinklers is not explicitly set out in the Singapore Fire Code, the fact that sprinklers are used as a mechanism through which prescribed building allowances can be surpassed –

much in the same way as in the IBC – suggests that sprinklers are seen as a means of adding further protection to occupants and the building.

3.3 Summary of international approaches

Property protection is not typically stated at an overarching level within regulations but may feature in underpinning codes/guidance, which are not always mandatory. In the case of many of the countries reviewed here (USA, Japan, Singapore, Australia, New Zealand), the protection of buildings and property is addressed where codes have a historical background in limiting the spread of fire, either within buildings or between buildings. In other countries, property protection can be seen as a built-in consequence of life safety provisions which go above and beyond those in England (such as in the provision of mandatory sprinklers for life safety in certain buildings in Scotland, and in Wales). One stakeholder emphasised the difficulty of prescribing what is needed in relation to property protection, as this can depend greatly on different building types, heights, materials and how they are used. Another consideration is the local environment, for example the likelihood of seismic activity or woodland/bush fires. This can make it challenging to undertake a cost-benefit analysis.

Furthermore, making direct comparisons between regulations is a challenge because of the various ways in which different countries regulate fire protection. For most, fire protection is included as an intrinsic part of building regulations, but this is not the case in all countries – i.e., Japan. Additionally, whether a country adopts a prescriptive or a performance-based approach adds another dimension of complexity. For example, in some countries, specific requirements for the size of compartments or fire resistance are stipulated as part of building regulations, or in Standards; in others these are recommended in Guides. The various requirements for different building types, uses or classifications are an additional complicating factor making comparisons challenging.

4. International regulatory approaches: building typologies

This section examines international regulatory approaches to fire safety in different types of building. The purpose of this section is to identify fire protection measures which go over and above the minimum requirements necessary to secure life safety and which conceivably offer protection to buildings and properties. As such, this section is not a synopsis of every country's approach to fire safety in each of these building categories. An overview of every country for each building type would risk becoming repetitive as many buildings are considered in national regulations merely from the point of view of life safety. However, given that few national regulatory frameworks explicitly link fire safety requirements to property protection (or any other objective beyond life safety), attention is given throughout this section to regulatory requirements and measures which notably surpass England's fire safety regulations and the guidance given in ADB.[1] Examples would be mandatory sprinklers in certain building types, or an expectation that buildings must be able to survive the duration of a fire event.

This section also summarises non-statutory guidance and codes which specifically aim to protect buildings and properties from fire.

4.1 Domestic

4.1.1 High-rise, multi-occupancy buildings

For high-rise domestic buildings, the primary objective of building and fire safety regulations is the protection of life safety. None of the national regulations reviewed here make any explicit mention of the need to protect property for these kinds of buildings.

However, some countries have strategies for the protection of residential buildings which can be seen as providing additional protection to buildings and properties over and above life safety. In the case of Australia, Japan, New Zealand, Sweden and the USA modern-day building legislation is historically rooted in the principle of limiting fire spread between buildings, which consequently gives building regulations in these countries an implicit focus on property protection.

In other countries, such as Scotland, the overarching strategy for fire safety in residential buildings is focused on ensuring safe evacuation. While the principle of evacuation arguably sits in conflict with property protection, as a strategy which prioritises occupant egress it typically ensures protection of the building only for as long as is required to ensure occupants can safely escape. In Scotland, additional requirements based on active fire protection are mandatory for certain categories of residential housing (including those housing vulnerable residents, such as social housing, care homes). The purpose of these active fire protection measures is to ensure that residents have sufficient time to escape, but the provision of measures such as sprinklers can be seen as providing greater protection to the property.

N.B. Although the strategies described here can arguably be seen to afford greater protection to buildings and properties, in comparison to the statutory fire safety regulations in England, it must be

[1] It is worth noting at this point that ADB is one route to ensure compliance with the building regulations. Other approaches include BS9991, BS9999 or a fully fire engineered design.

noted that this review found no empirical evidence which actively links any of these strategies to more robust property protection. Furthermore, the rationales for different strategies are rarely set out in detail in national fire safety legislation. Many of the ideas reported here – about different countries' regulations offering more property protection to residential buildings – are based on the interpretations of stakeholders and inferences based on national fire safety legislation.

Regarding residential buildings, several stakeholders also noted the need to consider changing fire risks, especially those associated with electric car charging points in underground car parks below high-rise buildings, or with storage that may contain electric bikes or scooters. Stakeholders note that there is not enough research and testing to fully understand the potential risks and impacts. This also applies to houses with electric charging points. One stakeholder pointed out that fires caused by electric batteries can be spontaneous, burn hotter and with greater intensity.

In **Scotland**, since March 2021, automatic fire suppression systems have been mandatory in the following residential buildings:

- Any building containing flats or maisonettes (including shared multi-occupancy residential buildings)
- All social housing
- Dwellings which form part of a sheltered housing complex
- Residential care homes

However, the rationale for automatic fire suppression systems in these buildings in Scotland is unambiguously one of life safety. Fire suppressions systems in domestic buildings are not intended as a property protection measure, although the Technical Handbooks acknowledge additional benefits such as reduction in damage and disruption caused by fire:

> *"Automatic fire suppression systems installed in domestic premises are primarily designed for life safety purposes. Successful activation can provide occupants, including vulnerable occupants, with additional time to escape following the outbreak of fire. The added benefit of automatic fire suppression in domestic buildings means that the damage and disruption caused by fire is greatly reduced."*[93]

In the case of care homes and sheltered housing complexes, automatic fire suppression systems are designed to offer additional life safety protection for vulnerable residents, giving more time for occupants of such buildings to make a safe escape. In the case of social housing, the Technical Handbooks note that there is a greater prevalence of fires in social housing dwellings. Thus, *"in order to help contain a fire and to protect occupants, every house, flat and maisonette that is a social housing dwelling should be fitted with an automatic fire suppression system."*[94]

In all cases, in residential properties, the primary objective of mandatory fire suppression systems is life safety. This is consistent with the requirement, in Scottish building regulations, for 'automatic life safety fire suppression systems' to be installed in certain buildings (shopping centres, residential care buildings, high-rise domestic buildings, sheltered housing complexes).

Evidence from cost benefits analyses suggests that active fire suppression systems are cost effective in multi-occupancy residential buildings, in particular care homes, although they are not cost effective in individual dwelling-houses. A recent review of cost benefit analyses of residential sprinklers – which applied the life quality index (LQI) concept to assess the extent of risk reduction compared against costs – found that the installation of sprinklers, while not cost-beneficial in single family homes, is often found to be cost-effective in buildings where the installation and maintenance costs of sprinklers can be split across a number of properties per installation, such as multi-occupancy residential buildings.[95]

Similarly, a cost benefit analysis undertaken by BRE Global for Welsh Government in 2013[96] concluded that sprinklers are a cost-effective measure in certain types of multi-occupancy residential properties, specifically care homes and halls/dormitories. This is mainly because the average monetised cost of property damage in these types of residential buildings was deemed to be considerably higher than that for individual dwellinghouses. Care homes, for instance, are larger than domestic accommodation units and would also incur losses due to business interruption. Thus, the reduction in financial losses from damage to the building, its contents and business interruption would make sprinklers cost effective. The analysis also found sprinklers to be marginally cost effective (that is, not statistically significant) in new blocks of flats, blocks of sheltered flats (not including sheltered houses) and 'traditional HMOs' (on average six accommodation units per building).

In the **USA**, the International Building Code (IBC) is centred on the principle of limiting fire spread between buildings. This is a principle which the IBC has inherited from the original municipal codes which American cities published in the nineteenth century to limit fire damage in urban areas and prevent city-wide conflagrations.[97]

The IBC works by establishing design allowances for buildings based on the following variables:

1. Use and occupancy of buildings,
2. Building heights and areas, and
3. Construction types. (See above, section 3.2.2)

However, the IBC also has a mechanism whereby building designers are permitted to exceed prescribed allowances if they install fire suppression systems such as automatic sprinklers. The provision of fire sprinklers, therefore, allows designers to build taller buildings – and make use of different construction materials, such as timber – as the fire suppression system is seen as offering an additional layer of safety both to the life of the occupants and to the fabric of the building.

Designers are also permitted to exceed prescribed allowances by greater margins if they use sprinkler design standards intended to ensure both life safety and property protection. **NFPA 13** (described in IBC section 903.3.1.1) is a standard for the installation of sprinkler systems designed to **protect both life and property**. Its objective is “to provide a reasonable degree of protection for life and property from fire.”[98] **NFPA 13R** (IBC section 903.3.1.2), by contrast, is a standard for sprinkler installation designed primarily with the intention of **ensuring life safety**, by increasing the time occupants have to escape a burning building.[99] Its purpose is “to prevent flashover (total involvement) in the room of origin, where sprinklered, and to improve the chance for occupants to escape or be evacuated.”[100] **The IBC allows designers to build taller buildings if they employ NFPA 13.**

Table 16 shows the maximum allowable heights of residential buildings with different sprinkler standards.

Table 16: Allowable building height in feet above grade plane for occupancy group R (residential), according to the IBC

Sprinkler standard	Type of Construction								
	Type I		Type II		Type III		Type IV		
	A	B	A	B	A	B	A	B	C
NFPA 13R	60	60	60	60	60	60	60	60	60
NFPA 13	UL	180	85	75	85	75	270	180	85

UL = Unlimited

Table adapted from Table 504.3 of IBC: https://codes.iccsafe.org/content/IBC2021P1/chapter-5-general-building-heights-and-areas

Table 17: Construction types according to the IBC[101]

Construction Type		Description
Type I	A	Fire resistive construction: All materials used in construction must be non-combustible and the structural frame and exterior walls must have fire ratings of at least 3 hours and floors and ceilings of at least 2 hours.
	B	Fire resistive construction: All the materials used in construction must be non-combustible and the structural frame and exterior walls must have fire ratings of at least 2 hours and floors and ceilings of at least 1 hours.
Type II	A	Non-combustible: All the structural elements in Type II buildings must be made of non-combustible materials however it is not necessary to treat them with fire-resistive coatings or otherwise protect them (as in Type I).
	B	Non-combustible: All the structural elements in Type II buildings must be made of non-combustible materials however it is not necessary to treat them with fire-resistive coatings or otherwise protect them (as in Type I).
Type III	A	Ordinary Construction: Exterior walls are of non-combustible materials, while internal floors and roofs may be of combustible materials that have been rated as fire resistant for up to one hour.
	B	Ordinary Construction: Buildings have non-combustible exterior walls, while the floors and roofs may be of wood that has not been rated as fire resistant.
Type IV[102]	A	Mass Timber Construction: All structural elements must have at least a 3-hour fire resistance rating and floors must have 2-hour rating. All timber surfaces encapsulated with non-combustible material.
	B	Mass Timber Construction: Structural elements and floors must have a 2-hour fire resistance and only a 'calculated percentage' of the building may be exposed timber.
	C	Mass Timber Construction: 2 hour rated structure and floors, but all timber surfaces can be exposed.

As Table 16 shows, residential buildings of all building types are limited to 60' if sprinkler standard NFPA 13R (designed primarily to protect life safety) is used. However, buildings can be considerably taller if NFPA 13 (designed for both life safety and property protection) is used. Other variables, such as the extent of fire resistance, also affect maximum allowable building heights. In the case of mass timber buildings (Type IV), variations in maximum allowable heights of buildings, designed in accordance with NFPA 13, are determined by the amount of exposed wood.

The maximum allowable height, prescribed by IBC, for a multi-occupancy residential building made of non-combustible construction materials with the highest fire resistance rating (Construction Type 1A), designed in accordance with sprinkler standard NFPA 13R, is 60'. However, with sprinkler standard 13, the height of the building is unlimited.

For a multi-storey residential building of timber construction (construction type IV), designed in accordance with NFPA 13R, the maximum allowable height is 60'. With NFPA 13, the height limit for mass timber buildings is between 85' and 270', depending on the amount of exposed timber.[103]

These provisions within the IBC have permitted more innovative building design in USA in recent years, including use of mass timber in taller buildings. In 2016, Hines' T3 North Loop, located in Minneapolis, became the largest mass timber building in USA, with a height of 85 feet.[104] This 7-storey, 220,000-square-foot building, which uses wood for its structure and interior, was constructed using 8-foot-by-20-foot panels of wood that were stacked across beams of glue laminated timber.[105]

Thus, while sprinkler systems are not presented explicitly in IBC as a property protection mechanism, the use of sprinkler standards designed to offer greater property protection allows designers to surpass prescribed building allowances for building height.

Although this review identified no empirical evidence which specifically links the provision of sprinklers within the framework of the IBC to more effective property protection or greater fire resilience of buildings in the USA, evidence exists to suggest that sprinklers are effective at containing fires and limiting property damage due to fire[106,107] (see section 5.1.2). Furthermore, stakeholders from the USA emphasise that sprinklers are highly effective at protecting the physical fabric of the building and supporting continuity of building functions. One such stakeholder pointed out that the provision of sprinklers in high-rise buildings means that most buildings in the USA can now survive burnout.

Stakeholders interviewed for this research suggest sprinkler use in the US is linked to the aim of keeping fires small, and also emphasise the importance of having multiple layers of protection. Notably this includes control over the materials used in the structure due to the risk of introducing combustible materials. For example, timber can be used for construction as the inclusion of sprinklers provides reassurance (also timber can take a long time to actually burn). Other elements of protection may include a protective layer of plasterboard over the timber but adding more protective materials also increases the cost of construction.

Like the IBC, the Building Standards Law (BSL) of **Japan,** is also based on a historic principle of limiting fire spread between buildings and preventing large-scale urban fires. Unlike the IBC, however, the BSL places greater emphasis on passive fire protection methods to protect buildings and occupants in high-rise domestic buildings. This strategy of limiting fire spread through increased fire resistance in urban buildings can be seen as offering a higher level of protection to high-rise residential buildings in densely populated urban centres.

The BSL imposes stricter building requirements on all buildings constructed in designed 'Fire Protection Zones' (FPZ) or 'Quasi-Fire Protection Zones' (QFPZ). Buildings in these areas above a specified height and area must be constructed as 'fire-resistive buildings', meaning they must be capable of withstanding fire and heat until the end of a fire, or they must have 'principal building parts' made of fire resistive construction. (For information on 'fire-resistive buildings' and 'fire resistive construction', see above, p. 43) The purpose of these requirements is not specifically to protect buildings per se, but rather to minimise the spread of fire from building to building and prevent city-wide conflagrations.[108]

According to the BSL, in FPZs, buildings with three or more storeys, or with total floor area exceeding 100 m^2, must be fire-resistive buildings. This means they must have key structural elements which can either withstand the duration of a fire or resist structural deformity for an extended period specified by BSL (see p. 44, above). All other buildings must be 'quasi fire-resistant buildings' at a minimum.

In QFPZs, buildings with four or more storeys, or with total floor area exceeds 1500 m^2, must be fire-resistive buildings. Buildings with three storeys, or with a total floor area between 500 m^2 to 1500 m^2 must be 'quasi-fire-resistive buildings.'[109]

BSL also has specific requirements around 'special buildings', which are defined as:

- Buildings that are intended to be used by many and unspecified people, such as theatres, grandstands and department stores; and
- Buildings where many people sleep, such as apartment houses, hotels and hospitals

Multi-occupancy residential buildings (or buildings where many people sleep, such as apartment blocks, hotels, boarding houses, dormitories) must be constructed as a fire-resistive building if three storeys or higher.

Three-story apartment houses, however, can be of quasi fire-resistive construction if they are not located in a Fire Protection Zone and the structure has a 1-hour (or greater) quasi fire-resistive performance and all other necessary fire prevention measures are implemented.[110]

As with many national building regulations, the BSL does not link measures around fire resistance explicitly to property protection. The purpose of fire-resistive construction is ultimately to protect life by minimising fire spread between buildings and reducing the chance of large-scale urban fires. However, since fire-resistive construction specifies a need for buildings to withstand the duration of a fire, these requirements can conceivably be seen as offering greater protection to buildings than in some countries (notably England).

The strategy for residential buildings contained in the **Singapore** Fire Code – which is focused on residents seeking refuge on a protected floor of the building until fire service intervention – can also be seen as affording a higher level of property protection in high-rise residential buildings.

In 2006, the Singapore Civil Defence Force amended the Fire Code to include additional fire protection measures for residential high-rise buildings with more than 40 storeys (defined as 'super high-rise buildings'). These measures included:

- The creation of refuge floor/holding area at 20-storey intervals, where evacuees from surrounding floors can temporarily take refuge in the event of a fire.
- Provision of a larger capacity fire-lift to ferry men and equipment, thus facilitating the rapid deployment of firefighting personnel in super high-rise buildings.[111]

According to the Fire Code, the refuge floor of super high-rise buildings must be made of masonry construction, having at least 2-hour fire resistance rating. This is double the required fire resistance rating of fire compartments separating individual dwellings within a high-rise building. At least 50% of the accessible floor area of the refuge floor must be designated as an evacuee holding area, and all equipment placed within the evacuee holding area must be constructed of non-combustible materials. The evacuee holding area must also be separated from other areas of the refuge floor by compartment walls with at least 2-hour fire resistance rating and is linked by a smoke-free lobby (which is itself separated from adjoining areas of the building by a wall of 1-hour fire resistance and an access door with 0.5 hours fire resistance and an automatic self-closing device). A sprinkler system must also be provided for the refuge floor if there is any non-residential room located on the same floor.[112]

The primary purpose of the refuge/holding floor is to ensure life safety in tall residential buildings, by providing a safe place for residents to shelter as firefighting services tackle the fire and coordinate escape. However, provisions of the refuge/holding floor arguably give 'super high-rise buildings' a degree of additional property protection, by enabling the building (or at least the area of the refuge floor) to withstand the effects of fire for longer than the prescribed minimum fire resistance rating of fire compartments separating individual dwellings.

Like the IBC, Singapore's Fire Code also has a mechanism whereby prescribed allowances can be surpassed if fire suppression systems are added. The provision of automatic fire sprinkler systems allows building designers to exceed maximum fire compartment sizes permitted in the Fire Code. Furthermore, all hotels, boarding houses, serviced apartments and hostels over 24m in habitable height must have a sprinkler installed on every storey of the building.[113] Sprinkler systems must also be designed and installed in compliance with Singapore Standard CP52 Code of practice for automatic fire sprinkler system.[114]

Singapore's Fire Code also stipulates that fire sprinklers are to be provided in nursing or care homes which have more than one storey, or which have non-compartmented areas greater than 750m^2. The same requirements are also made of hospitals. Every upper storey of care homes and hospitals used for accommodation of patients must also have at least one refuge area. The size of the area of refuge must be sized adequately to accommodate the number of beds of minimum dimension 2.55m (length) by 1.1m (width) and computed based on occupant load factor of 2.8m^2 per person for the ward served by the area of refuge.[115]

In **Germany**, minimising the spread of fire is a principal objective underpinning German fire regulations. For external walls and facades, this is achieved by specifying the use of walls and fire protective panels as fire resistant components and sprinklers.

The code for high-rise buildings does not define what a high-rise building is, but this is defined in other documents as a building higher than 22m.

The code permits fire protection measures to be balanced and alternatives specified if these still meet the required fire performance standard. For example, reductions in compartment fire resistance are permitted if sprinklers are fitted:

> *"Automatic fire extinguishing and fire alarm systems are an essential part of the concept and permit a reduction in the requirements for the compartmentation construction components within the floors from the current 90 minutes to 30 minutes." (Unofficial translation)*

It appears that – because automatic fire suppression systems have been proven to reliably prevent the spread of fire from floor to floor and internal fires from facades – requirements for construction components to prevent the spread of fire can be removed and all types of facades permitted. The code states that:

> *"High-rises must have automatic fire extinguishing systems, which prevent fire spread within floors and from floor to floor for a sufficiently long time."*

However, there are relaxations for high-rises less than 60m and with occupancies less than 200m^2, whereby automatic fire extinguishing, alarm and detection systems are not required if:

- the 'occupancies' have fire resistant walls and ceilings;
- fire spread from floor to floor is prevented by a 1m high wall of a 1m protruding plate;
- automatic pressure ventilation system and control of lifts in the event of fire;
- occupancies are fitted with hard-wired smoke detectors.[116]

As in the case of Singapore, above, the Code provides no discernible rationale for the need for sprinklers, other than for limiting the spread of fire. However, the main cornerstones of the fire protection concept under MHHR 2005 are:

- early detection of fire;
- automatic alerting of the floor on fire;
- automatic forwarding of the fire report to the fire brigade;
- rapid self-rescue from the building;
- limiting of the spread of fire for a sufficiently long time and;
- rapid attachment by the fire brigade on the fire floor.

The **New Zealand** Building Code is contained in Schedule 1 of the Building Regulations 1992. As it is a performance-based code it doesn't specify how buildings should be designed and built. Fire safety design is a key component of the Code, with an overarching strategy being means of escape and protection of other properties.

The 'Design Guide, Fire Safety, Residential Community Housing' covers three types of housing including:

1. Single-storey or two-storey dwellings providing accommodation for no more than 10 residents;
2. Multi-unit dwellings containing residential community housing that provide accommodation for no more than 10 residents per unit, with no more than one unit above another, where each unit has an escape route independent of all other units;
3. All garages or carports that are associated with the residential community housing.

For 1 and 2, residents are characterised into four groups depending on the level of support they might need to exit the building.

As is the case in some other countries 'trade-offs' can be made between some measures (such as with firecells) if an automatic fire-suppression system is used.

Depending on the building type, different building features and minimum fire safety systems are specified. For type A – buildings up to two storeys – a single firecell and interconnected smoke and heat alarms to NZS 4514 are required. Housing type B (a maximum of two storeys) also specifies interconnected smoke and heat alarms and either a minimum of two firecells or a domestic sprinkler system to NZS 4517. The two other categories of housing (with an escape height of less than 2m – categories C and D) also specify the same domestic sprinkler system requirements as well as a minimum of two firecells and either interconnected smoke and heat alarms, or smoke detectors.

Fire resistance ratings are specified for both life and property - both are 30 minutes. An insulation rating is not required where sprinklers are provided.

Methods of protecting a lower roof in multi-unit dwellings from the spread of fire are specified:

> *"Fire spread from a roof close to, and lower than, an external wall of an attached sleeping unit or attached building on either property shall be prevented by providing an FEE of 30/30/30 to either a) the part of the roof within 5.0m horizontally of the wall, or b) any part of the wall within 9.0m vertically of the roof."*

In **Australia**, the Australasian Fire and Emergency Services Council (AFAC) includes **property protection** as an objective, with its 'capstone doctrine' setting out what is 'practical, realistic and possible in terms of protecting life, property and the environment.' The AFAC advocates the use of automatic fire suppression in residential buildings, noting the effectiveness of sprinklers in life safety:

> *"Innovative fire safety technology is increasingly evident in commercial buildings, driven by insurance premiums, the high cost of property damage and regulatory changes.*
>
> *In the residential sector, innovative technology in the form of sprinkler systems, smoke control, smoke and fire detection has had significant success in mitigating fire deaths and injuries in residential buildings over 25 metres in height, and in other high-risk classes, such as residential aged care facilities."*
>
> *"Residential sprinklers lead to reduced spread and intensity of the fire through the structure enabling firefighters to work safer and quicker to extinguish the fire and remove any remaining occupants to safety. Fires controlled or extinguished by sprinklers also resulting (sic) reduced exposure to firefighters of physical and psychological risks."*[117]

The BCA allows the use of sprinklers in place of relaxations in other methods of fire protection in various residential settings, such as residential care homes. For example, a 2019 amendment to Volume 1 allows a concession *"for the fire protection of certain building elements in residential care buildings when a suitable sprinkler system is used to achieve an adequate level of occupant safety."* This concession was introduced in response to concerns around the requirements for fire separation of individual sole-occupancy units imposing unwarranted development costs. Specifically, the installation of door closers was considered impractical, day to day.[118]

Other guidance:

Fire safety in apartment buildings, CFPA-E Guidance No 27:2021 F[119]: This guidance is overtly focused on life protection; property protection is not mentioned. As stated in the scope 'the objective of this guideline is to provide a reasonable safe environment for the occupants of apartment buildings and mainly to give them the opportunity to safely escape a fire.' The guide provides examples of solutions that can be implemented but states they can be replaced by others that give the same level of safety.

Specific features of the guidance:

- Apartment buildings must be divided into fire resistant compartments to avoid fire and smoke spread; they should be separated by fire resistant barriers (walls and floors).
- A minimum separation distance may be required between unprotected or partially protected exterior walls or facades (and should have the required fire resistance and reaction to fire rate according to national regulations).
- In basements there should be one or more smoke outlets for ventilation.
- In garages and covered car parks (in addition to the requirements above for basements), care should be taken to provide fire resistance compartmentation. Attention is also given to LPG, methane, hydrogen and electric vehicles as potential fire risks, particularly the presence of electric cars, scooters or bicycles with lithium-ion batteries

In addition, the guidance states that 'approved and supervised' residential sprinkler systems should be fitted in apartment buildings.

4.1.2 Individual dwelling – houses

Several of the countries reviewed here follow a similar approach to the UK for fire safety in dwelling-houses, based on the principle that a fire in one house should not affect a neighbouring property. However, this review identified no empirical evidence linking any of these strategies to improved property protection.

In the **USA**, fire safety in individual dwelling-houses is covered as part of the International Residential Code (IRC). This code establishes the minimum performance requirements for one- and two-family dwellings and townhouses, up to three storeys high, using prescriptive provisions.

Like the IBC, fire safety requirements in the IRC are predicated on the principle of limiting fire spread and preventing a fire in one dwelling affecting a neighbouring dwelling. This is achieved primarily through a combination of fire-resistant construction (passive fire protection measures) and the installation of fire suppression systems (active fire protection measures).

For instance, the minimum fire separation distance for exterior walls without a fire protection rating, for all dwellings in the US, is 5 feet. However, for exterior walls with a fire resistance rating of 1 hour (tested in accordance with ASTM E119, UL 263 or Section 703.3 of the IBC with exposure on both sides), the minimum fire separation distance is 0 feet.

For projections (elements of the building which project beyond the building's exterior wall), the minimum fire separation distance for those without fire resistance rating is 5 feet or greater. However, for projections with a fire resistance rating of 1-hour, minimum distance may be between 2-5 feet. No projections are permitted at less than 2 feet.

In a similar manner to the IBC, the IRC has a mechanism whereby limitations on building design requirements can be exceeded if buildings are fitted with sprinklers. In residential dwellings with sprinklers, the minimum fire separation distance for exterior walls (and projections) without fire resistance rating is 3 feet, compared to 5 in non-sprinklered houses.[120]

A combination of passive and active fire protection measures is therefore used in the USA to ensure containment of fire to one dwelling and prevent fire from spreading between houses. There is, however, no empirical evidence to suggest that this approach is any more effective at ensuring property protection of building resilience to fire.

In **Japan**, fire safety requirements around individual houses are also based on the principle of preventing fire spread between dwellings. The BSL defines as 'parts liable to catch fire' any part of the building exterior which falls within 3m for the first floor, or 5 m for the second or higher floors, from any of the following:

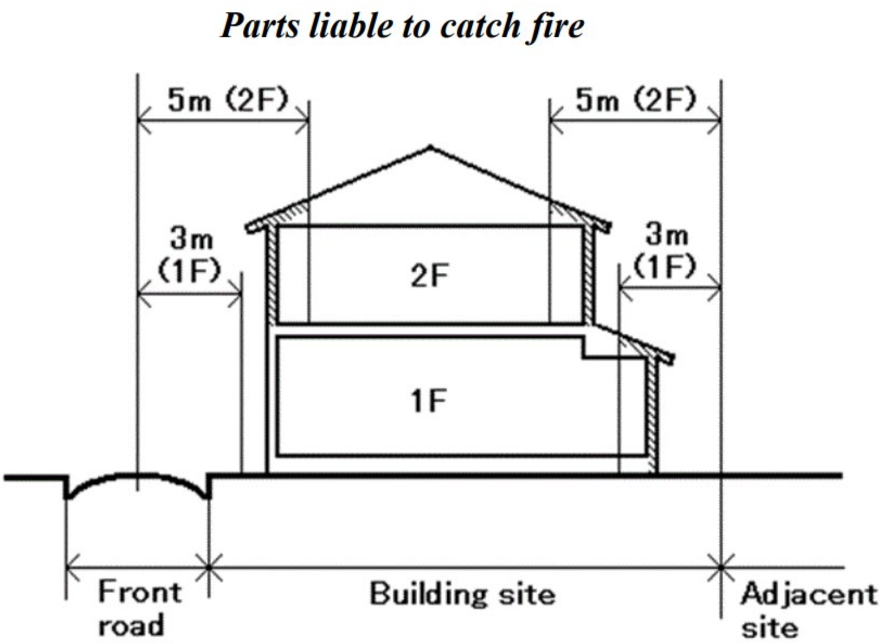
- The boundary line with the adjacent land lot;
- The centre line of the road;
- The centre line between exterior walls of two or more buildings on the same site (two or more buildings with an aggregate total floor area not exceeding 500 m2 are regarded as one building).[121]

This is represented in Figure 5, below.

Elements of the building located in the areas defined as 'parts liable to catch fire' are subjected to strict regulations as part of the BSL, in order to prevent fire spreading between neighbouring buildings. According to Article 64 of the BSL, in the FPZ and QFPZ, all openings in exterior walls in the ''parts liable to catch fire'', in any building constructed in a Fire Protection Zone (FPZ) or a Quasi Fire Protection Zone (QFPZ) must have fire performance or flame-blocking duration for 20 minutes or more, when exposed to the ISO 834 curve.[122]

However, any part of a building facing an open space or a body of water, or facing walls of fire-resistive construction, are not considered parts liable to catch fire.[123]

Figure 5: Parts of the building liable to catch fire, as defined by the Japanese BSL



Source: T. Hasegawa, (2019), Building Control in Japan - Introduction to the Building Standard Law - Part D

As with IRC, this review did not identify any empirical evidence to link this approach to fire safety to a higher level of property protection or stronger building resilience to fire.

A strategy centred on limiting fire spread between buildings is also following in **New Zealand**. Guidance describes provisions for residential community housing – this includes dwellings up to two storeys. This guidance is described in 4.1.1 High-rise, multi-occupancy buildings. A key principle of this guidance is to limit the spread of fire and smoke within buildings and the spread of fire between buildings.

Although **Wales** is subjected to the same legislative limitations as England, in the form of Regulation 8, since 2016, Wales has made automatic fire suppression systems mandatory in all new:

- Houses
- Flats
- Care home
- Rooms for residential purposes (not including rooms in a hostel providing temporary accommodation to those who are ordinarily resident elsewhere; hotels; hospitals; prisons and young offender institutions.[124]

The rationale for mandatory sprinkler systems in all new housing in Wales is, however, one of life safety, rather than property protection. ADB for Wales states that 'any automatic fire suppression system installed to satisfy the requirements of Part B of the Building Regulations should be regarded as a life safety system.'[125]

The law regarding mandatory residential sprinklers was introduced in Wales in spite of the findings of a cost benefit analysis, undertaken by BRE Global for Welsh Government in 2013,[126] which concluded that the provision of automatic fire sprinklers in all residential properties in Wales would not be cost effective. This analysis found that the monetised costs of sprinkler installation and maintenance in all new residential buildings (over 40-to-50-year period) would greatly outweigh the monetised benefits, such as reduced risk of deaths and injuries, and reduced property damage.

Other guidance:

Fire safe homes, CFPA-E No 24:2016 F[127]: This guidance applies to all types of dwellings, including multi-storey buildings (as covered above). As per the guidance on apartment buildings, this guidance for homes does not incorporate aspects of property protection. The guidance sets out a 'base level' for fire safe homes which includes:

- Smoke alarms or a fire detection system (both of which should be mains operated)
- Portable fire extinguishers
- Devices for fire prevention and suppression for electric hobs
- Fire blankets
- Fire safety information and a checklist for occupants
- The owner/tenant having basic knowledge about fire safety (which includes protection of the building)

4.2 Industrial

4.2.1 Warehouses

Most of the countries reviewed have very specific fire safety requirements to reduce the risk of fires in warehouses and storage facilities. This is because warehouses and storage facilities have their own set of quite unique fire risks. Warehouses are typically large, cavernous spaces with a large quantity of stored goods. The contents of warehouses, especially packaging materials and protective coverings for stored goods, constitute an immediately available fire load and means of propagation, creating the ideal environment for the development of fire once ignited. For this reason, once a fire starts in a warehouse, it has the potential to escalate into a large fire which firefighters struggle to extinguish.

In the UK, many major fires occur in warehouses and storage buildings every year. With the growth of e-commerce and online shopping, the number and size of warehouses in the UK is likely to increase. Many warehouse buildings also have undivided floor areas of 2000m^2 and often exceed 20,000m^2. Such buildings may need to accommodate mezzanine floors and gallery levels, or have high-bay racking systems, some of which may also call for automated goods retrieval.[128]

However, since warehouses have until recently contained only small concentrations of staff,[2] fires in warehouses can be considered to pose only a small risk to life. As such, in UK regulations, requirements for fire protection of warehouses are quite light. In England and Wales, warehouses which have a top floor 5 metres from the ground need to have a fire resistance rating of 60 minutes. Automatic sprinkler systems are only required in warehouses exceeding 20,000m^2.[129]

Yet, fires in warehouses, while presenting low risk to life, have the potential to cause considerable financial losses through the destruction of property (both in terms of the warehouse building and stored goods) and disruption to business continuity.

FPA's *Design Guide for the fire protection of warehouses and storage buildings*[130] provides guidelines for the design of warehouses intended to minimise loss prevention and property damage by fire.

FPA recommends the following maximum floor areas for warehouses and storage buildings, based on contents and risk level (Table 18). Multi-storey warehouses should always be regarded as high risk.

Table 18 is taken from: FPA Design Guide for the Fire Protection of Buildings: Warehouses and storage buildings[131]

[2] This situation is, however, changing, with warehouses increasingly becoming big employers of personnel. The number of people employed in warehousing and storage in England alone has increased from 215,000 in 2015 to 322,000 in 2020. ONS, (2020), *Business Register and Employment Survey.*

Table 18: Maximum floor areas for specific applications in warehouses and storage

Application (Roof height less than 10m)[1]	Recommended floor areas (m^2)[2]		
	High Risk	**Medium Risk**	**Low risk**
Warehouses with high rack storage	2,000	4,000	8,000
Storage building connected to factory/production area without high rack storage	4,000	8,000	10,000
Areas containing hazardous processes, equipment or other critical areas, including quarantine areas	250	500	-

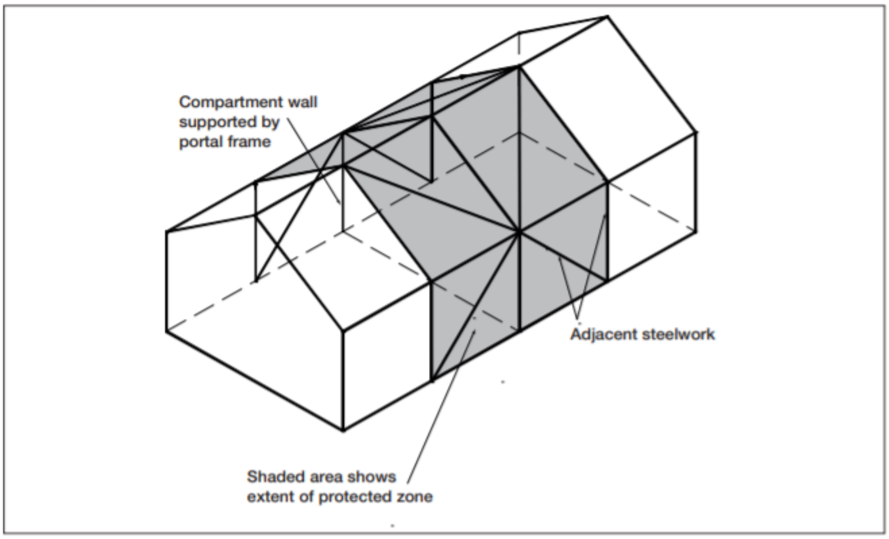
[1] Warehouses with a ceiling height to eaves greater than 10m present a particular risk. Proposals for such buildings should be referred to the insurer for specific guidance on requirements.
[2] Recommended floor areas may be increased if a suitable automatic extinguishing system is provided. Whether or not an increase is allowable, and the amount of increase, will be subject to the insurer's individual risk assessment.

Compartmentation in accordance with these specifications will prevent excessive damage caused by fire and smoke spread and limit the spread of fire to protect valuable materials and reduce business interruption caused by fire.

In addition to limits on compartment size, the FPA also recommend that warehouses should have 'protected zones' to add a further layer of fire security to compartment walls which abut external walls. The protected zone is comprised of sections of the roof, external walls and supporting frame of the building, adjacent to and within a specified distance on each side of a compartment wall. Its purpose is to prevent fire from bypassing the compartment wall at a junction with an external wall or roof.[132]

The concept of the 'protected zone' is illustrated in Figure 6.

Figure 6: Fire Protected Zone[133]



Source: FPA (2004), *Design Guide for the Fire Protection of Buildings: Protected Zone[134]*

The FPA's guide also recommends the following measures:

- Fire stopping in all wall and ceiling cavities, as well as in openings around service ducts, pipework and conduits, where they pass across or penetrate compartment boundaries.
- Fire venting to limit the spread of fire and smoke and facilitate firefighting.

- Sprinkler systems throughout the whole building, designed and installed in accordance with the *LPC Rules for automatic sprinkler installations incorporating BS EN 12845*.

Research conducted by BRE Global[135] in 2013 has shown sprinklers to be cost-effective fire suppression mechanisms in warehouses above 2,000m^2 in size.

BRE's cost benefit analysis, which examined the associated costs and benefits of installing sprinklers in three sizes of warehouses in England, found that for 'medium' buildings (that is, those between 2,000m^2 and 10,000m^2 in area), the whole life costs of warehouses with sprinklers are between 2.2 and 4.8 times smaller than the whole life costs of warehouses without sprinklers. The greatest benefits of sprinklers were found to be reductions in direct property losses. For a warehouse of between 2,000m^2 and 10,000m^2, the total cost of fire damage was estimated to be £36,333 in a warehouse with sprinklers, compared to £1,511,289 in a warehouse without sprinklers. The research also reported other benefits from installing sprinklers including:

- Reductions in the costs of injuries and fatalities
- Reductions in the CO_2 released in fires
- Reductions in CO_2 embodied in replacement of building contents and reconstruction of the building
- Reductions in water used in firefighting
- Reduction in unemployment caused by fires.

All of the above benefits had associated cost savings and minimised environmental harm. Costs savings associated with reductions in people rendered unemployed by warehouse fires are particularly striking: BRE's analysis found that the cost of unemployment for a medium sprinklered warehouse is £1,655, compared to £196,268 in a warehouse of the same size without sprinklers.

Many of the countries reviewed have fire safety regulations for warehouses which are stricter than those in place in England. Active fire protection systems, especially sprinklers, are a common requirement in many countries. Furthermore, warehouse size thresholds, which place limits on the size of un-sprinklered warehouses, are also generally much lower than in England (20,000m^2).

In **Scotland**, the maximum compartment size for warehouses without sprinklers is 14,000m^2 (reducing to 1,000m^2 for warehouses containing hazardous goods). Any warehouse with compartments exceeding these thresholds must be protected by an automatic fire suppression system (up to an absolute threshold of 28,000m^2).[136]

In the **USA**, the IBC prescribes that automatic fire sprinkler systems must be installed in all storage buildings (used for the storage of non-hazardous substances) if the following conditions exist:

- The fire area (that is, the area bounded by external walls or by fire barriers) exceeds 12,000 square feet (1,115m^2).
- The fire area is located more than 3 storeys above ground level.

- The combined area of all fire areas on all floors, including any mezzanines, exceeds 24,000 square feet (2,230m^2).

Sprinkler systems should be installed in any warehouse used for the storage of commercial motor vehicles where the fire are exceeds 5,000 square feet. (465 m^2).[137]

In **Singapore**, sprinklers are mandatory in all warehouses which have fire compartments with floor space exceeding 3,000m^2 (or volume greater than 12,000m^3). Furthermore, warehouses with compartment sizes between 700m^2 and 5000m^2 must also be fitted with a 'smoke purging system', while those with compartments greater than 5,000m^2 must have an engineered smoke control system.[138]

In **Japan**, the BSL emphasises passive fire protection and places stringent requirements on the fire resistance performance of warehouse building structures. The BSL stipulates that warehouses must be constructed as fire-resistive buildings if the third floor (or higher) exceeds 200m^2.[139] This means these warehouses must have key structural elements which can either withstand the duration of a fire or resist structural deformity for an extended period specified by BSL (see p. 40, above).

In **Germany**, The Model Directive on structural fire protection in industrial buildings (Model Construction Industry Directive, German designation: - MIndBauRL) June 2014, adopts a very prescriptive approach and sets specific requirements for storage buildings and for buildings with connected storage area. For those *"without an automatic extinguishing system, the surface area of each fire compartment or storage area on each floor shall be divided by open spaces into storage areas with a maximum area of 1,200 m^2. The open spaces must be at least 3.5 m in width with a height of stored goods (top) of up to 4.5 m, and a width of at least 5.0 m with a height of stored goods (top of the stored goods) of 7.5 m. The minimum widths of the open spaces for a height of stored goods between 4.5 m and 7.5 m result from interpolation."*

For storage buildings and buildings with storage areas, *"automatic fire extinguishing systems shall be installed where the height of stored goods exceeds 7.5m."*

Stakeholder evidence also highlights German regulations which add that there must be measures in buildings that make it possible for fire services to extinguish fire, by contrast with other approaches which focus on ensuring the fire service has access.

Germany's Model Directive also specifies general requirements for industrial buildings which include 'extinguishing water demand' which assumes extinguishing water demand for a period of two hours:

- of at least 96 m3/h in compartment areas up to 2,500 m2 and
- of at least 192 m3/h in compartment areas over 4,000 m2.

In industrial buildings with an automatic fire suppression system, an amount of extinguishing water for extinguishing the fire of at least 96 m^3/h for one hour.

Further stipulations cover location and accessibility (including buildings with a total area of >5000m^2 having an access road around them for firefighting vehicles), compartmentation of floors and levels below ground (load-bearing and supporting walls and supports of ceilings must be fire resistant); fixtures; escape routes; smoke extraction (production and storage spaces and levels of more than 200m^2 must be able to extract smoke in order to support the firefighting); fire extinguishing systems (only automatic universal fire extinguishing systems that are suitable for the existing flammable material may be considered); fire alarm systems; fire walls and walls separating firefighting compartments; fire spread path; external walls and external wall cladding (non-supporting outer walls may be of semi-flammable building materials); roofs (connected roof surfaces over 2.500 m^2 shall be designed so that the spread of fire within a fire compartment or firefighting compartment over the roof is restricted).

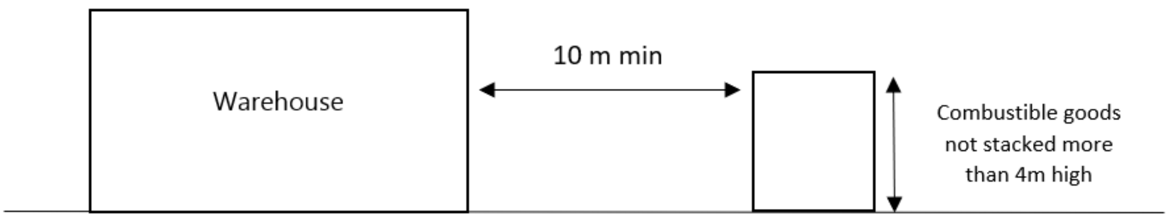
Table 19: Example of prescription for load-bearing and supporting walls in industrial buildings (Germany) - Maximum size of the fire compartment in m2

Safety Category	Number of above-ground floors of the building								
	Ground floor		2nd floor			3rd floor		4th floor	5th floor
	Fire resistance of load bearing and supporting components								
	From incombustible materials	Fire retard-ant	Fire retard-ant	Highly fire retardant and of incombustible materials	Fire retardant and of incombustible materials	Highly fire retardant and of incombustible materials	Fire retardant and of incombustible materials	Fire retardant and of incombustible materials	Fire retardant and of incombustible materials
K1	1,800	3,000	800	1,600	2,400	1,200	1,800	1,500	1,200
K2	2,700	4,500	1,200	2,400	3,600	1,800	2,700	2,300	1,800
K3.1	3,200	5,400	1,400	2,900	4,300	2,100	3,200	2,700	2,200
K3.2	3,600	6,000	1,600	3,200	4,800	2,400	3,600	3,000	2,400
K3.3	4,200	7,000	1,800	3,600	5,500	2,800	4,100	3,500	2,800
K3.4	4,500	7,500	2,000	4,000	6,000	3,000	4,500	3,800	3,000
K4	10,000	10,000	8,500	8,500	8,500	6,500	6,500	5,000	4,000

Other guidance:

Fire safety in warehouses, CFPA-E Guideline No 35:2017 F: the guidance gives specific instruction on storage of materials for fire prevention as well as combustible materials being kept at least 2m from boundary walls or fences and external storage sited at least 15m from hazardous installations.

Figure 7: Ideal external storage arrangements in warehouses



Source: CFPA Europe, CFPA-E Guideline No 35:2017 F

Regarding property protection, automatic fire detection and alarm systems specifically call out property protection, stating they 'should be designed to take into account the need for property protection' and that 'serious consideration should be given to the installation of a water sprinkler installation when the facility is as design stage.'

The guidance points out that automatic fire suppression systems are often a requirement from insurance companies and recommends that 'consideration should be given to installing local fire suppression system where they may be beneficial, such as to protect the electric motors of auto-stacker systems.'

In addition, compartmentation is highlighted with a recommendation of enclosing areas such as packaging operations, plant rooms, IT facilities etc. with elements of structure providing at least 120 minutes of fire resistance.

Other aspects of fire safety include specific guidance on:

- the use of heat sealing and shrink wrapping
- heating, electricity, gas and other services
- smoking
- lift trucks
- hazardous goods
- arson prevention

4.3 Commercial

Fire safety requirements for commercial buildings in most countries tend to focus on provisions necessary to secure life safety. Requirements for additional fire protection – such as automatic sprinkler systems or high levels of fire resistance – are generally specified only for larger commercial buildings, such as shopping centres, or multi-storey department stores which exceed the building design allowances specified in national regulations (such as in the case of IBC and BSL).

In **Scotland**, the Technical Handbook for non-domestic buildings stipulates that enclosed shopping centres should be fitted with an 'automatic life safety fire suppression system.'[140] Although the Technical Handbooks do not explain explicitly the rationale behind this requirement, the fact that such systems are described specifically as 'automatic life safety suppression systems' would suggest that the primary objective is to ensure the protection of life.

In the **USA**, requirements for active fire protection mechanisms in commercial premises are similar to those in place for storage and warehouse facilities. The IBC prescribes that automatic fire sprinkler systems must be installed in all commercial properties if the following conditions exist:

- The fire area (that is, the area bounded by external walls or by fire barriers) exceeds 12,000 square feet (1,115 m^2).
- The fire area is located more than 3 storeys above ground level.
- The combined area of all fire areas on all floors, including any mezzanines, exceeds 24,000 square feet (2,230 m^2).

The IBC also stipulates that sprinklers are to be installed in any commercial property where merchandise is stored in high-piled or rack storage arrays. Sprinklers are also to be installed in any shop with areas used for the display and sale of upholstered furniture or mattresses exceeding 5,000 square feet (465 m^2).[141]

In **Japan**, emphasis is on passive fire protection. The BSL stipulates that department stores taller than two storeys must be designed as fire resistive buildings.[142] This means these buildings must have key structural elements which can either withstand the duration of a fire or resist structural deformity for an extended period specified by BSL (see p. 43, above).

In **Germany**, the Model Ordinance for the Construction and Operation of Shopping Centres (Shopping Centre Law) version July 2014, stipulates requirements for shopping centres in Germany with 'a sales and aisle area including construction members totalling more than 2,000m^2.'

The model states that: **Shopping centres must have sprinkler systems**. However, this does not apply to:

- Ground floor shopping centres (without sprinkler systems no more than 3,000m^2)
- Other shopping centres (no more than 1,500m^2 if the sales outlets do not extend over more than three floors and the total area of all floors within a fire compartment does not exceed 3,000m^2)

Specific requirements cover:

- **Load-bearing walls, pillars and columns:** which must be fire resistant, or at least fire-retardant in the case of ground-floor sales outlets without sprinkler systems
- **Exterior walls:** must be made of non-flammable building materials, if they are not fire-resistant, in sales outlets without sprinkler systems; at least flame-retardant, if they are not fire-resistant, in sales outlets with sprinkler systems; at least flame-retardant building materials, provided they are not fire-retardant, in the case of sales outlets on the ground floor
- **Partitions:** must be fire resistant; in outlets without sprinkler systems, storage rooms with an area of more than 100m^2 each and workrooms with an increase of risk of fire must be separate from other rooms by fire-resistant walls.
- **Fire compartments:** outlets are to be divided by fire walls, with specific requirements for different building storeys. Distinctions are reliant on whether or not sprinkler systems are used.
- **Ceilings: must be fire-resistant and made of non-combustible materials.** Ceilings above storeys, whose floor is at no point more than 1m below ground level, are only required to be either: 1) fire-retardant and to be made of non-combustible building materials in ground floor sales outlets without sprinkler systems; 2) made of non-combustible building materials in ground-floor sales outlets with sprinkler systems.
- **Roofs:** The supporting structure of roofs that form the ceiling of rooms in the sales outlets or that are not separated from these rooms by fire-resistant components must: 1) consist of non-combustible building materials in sales outlets with sprinkler systems, except in ground-floor

sales outlets; 2) be at least fire-retardant in ground floor sales outlets without sprinkler systems; 3) be fire-resistant in other sales locations without sprinkler systems.

- **Linings, insulating materials:** External wall cladding including the insulating materials and substructures must consist of: 1) at least flame-retardant building materials for sales areas with sprinkler systems or inground-floor sales areas; 2) non-combustible building materials at other sales areas without sprinkler systems.

Other requirements relate to evacuation: routes, the shopping street, corridors, main aisles; doors in escape routes.

4.4 Schools

Schools are considered in many countries to be important social and community resources. Schools are foundational to children's education, but school buildings also serve additional functions as community hubs and meeting points. The loss of a school building to fire, therefore, has a disruptive impact on children's education, but it also deprives communities of an important resource and impacts on community sustainability. As such, building regulations and statutory guidance in some countries – such as those in Scotland and New Zealand – have additional requirements specifically designed to protect physical infrastructure of school buildings.

In **England and Wales**, *Building Bulleting 100: Design for fire safety in schools* (BB100),[143] published by the Department for Education (DfE), is a non-statutory design guide for fire safety in schools. Its primary objective is to advise how the life safety requirements contained in the Building Regulations can be achieved in new schools. However, BB100 also offers guidance on property protection, including how to ensure that the fabric of the school building is adequately protected from the effects of fire. BB100 was first published by the Department for Children, Schools and Families in 2007, but was updated in draft form for consultation in 2021 by DfE.

However, it is important to emphasise that the statutory limitations imposed by Regulation 8 – which limits UK building regulations to 'securing reasonable standards of health and safety for persons in or about buildings' – means that BB100, as a voluntary standard, has little legislative traction. As such, the property protection measures proposed for schools in BB100 have not been integrated as part of national guidance for England and Wales.

The updated, draft version of BB100 recommends that automatic fire suppression systems should be installed in all:

- New school buildings that have a storey with a finished floor level over 11m above ground level
- New special schools
- New boarding accommodation

At the heart of BB100 is the recognition that schools are important community resources, and that the loss of a school building can have significant social consequences in causing disruption to children's education. The 2007, DCSF version of BB 100 states:

"While the primary concern is for the safety of the users of school buildings, a fire can have a serious impact on children's education due to disruption and loss of course work. The important roles that schools play in the community mean that losses incurred as a result of fire can have particularly severe social consequences. As such, it is important that property protection be considered during the design and throughout the working life of these buildings. This guide therefore gives advice on property protection as well as life safety issues."[144]

The updated, draft version of BB100 also emphasises disruption to education as a consequence of property damage caused to a school building by fire:

"A large fire will have a significant effect on a school, disrupting continuity of education and lowering morale in addition to the more obvious financial losses, not all of which will be covered by insurance. Disruption to education may be caused by loss of coursework and teaching material as well as loss of time in school."

BB100 recommends fire suppression systems as an effective means of protecting property from the effects of fire. Fire suppression systems help to control a fire while it is still small, which buys time before the arrival of the Fire and Rescue Service, as well as creating less hazardous conditions for the fire fighters.

The two main fire suppression systems proposed are:

- Sprinklers (designed, installed and maintained in accordance with BS EN 12845)
- Water mist systems.

While sprinklers will operate at an early stage, with typically less than three heads operating to suppress and control the fire, the advantage of water mist systems is that (in theory) they require less water to fight a fire than an equivalent sprinkler system. In practice, this benefit is mainly seen in applications to extinguish high temperature surface fires, such as flammable fuels and deep fat fryers.

In addition to fire suppression systems, BB100 also recommends the following fire safety features designed to minimise the impact of the fire on the physical structure of the school building:

- **External walls:** External walls often contain 'flammable' polymer materials used as insulation. While compliant with Building Regulations, such materials, when ignited, may contribute or act as fuel to a fire. BB100 therefore recommends the use of **'insulation materials with better fire performance' in external walls**.
- **Cladding** on a school building with a storey above 18 metres should achieve Class A2-s1,d0 or better. Schools below that height must use cladding which achieves Class B-s1,d0 or better. Where school buildings are prone to vandalism, however (as determined by a security risk assessment at feasibility stage), any cladding to ground floor external walls should achieve Class A2–s1,d0 or better. Residential areas in boarding schools boarding schools should have external walls constructed of materials achieving Class A2-s1,d0 or better
- All floors in schools without sprinklers should be constructed as compartment floors.

To reduce the risk of deliberate fires in schools, BB100 also recommends strengthening security in school grounds.

Approved Documents B in both England and Wales refer to BB100 for the design of fire safety in schools. However, ADB for England says that BB100 'contains fire safety provisions that are outside the scope of the Building Regulations.' ADB for Wales advises that 'Part B of the Building Regulations will typically be satisfied where the life safety guidance in that document is followed.' Thus, the property protection measures proposed for schools in BB100 have not been integrated as part of national guidance for England and Wales. Sprinklers are, however, made mandatory in all new school buildings through Welsh government funding.

Sprinklers are also mandatory in school buildings in **Scotland**. As set out in the Technical Handbook for non-domestic buildings, mandatory sprinklers in schools are linked to both life safety but also to property protection and to community sustainability goals.

A primary objective of the building standards system in Scotland is to 'further the achievement of sustainable development.' Since schools are recognised as an important social asset and components in the local economic network, protection of school buildings from fire is seen as a means of promoting the sustainability of communities:

> *"A school building should have an automatic fire suppression system installed for asset protection to further the achievement of sustainable development."*[145]

The Technical Handbook recommends that, to ensure the suppression system is robust, the automatic fire suppression system should be designed, installed and maintained in accordance with the *LPC Rules for Automatic Sprinkler Installation*. The suppression system should cover the entire building including roof voids where necessary.

In the **USA**, the IBC sets requirements around the use of automatic sprinkler systems in schools. According to the IBC, sprinkler systems must be installed in all educational buildings in the following areas:

- In all fire areas (an area bounded by external walls or by fire barriers) greater than 12,000 square feet in area.
- In all fire areas located on floors without fire escapes.
- In all fire areas with an occupant load of 300 or more.[146]

In **Japan**, the BSL stipulates that schools with three storeys or more must be constructed as 'fire resistive buildings.' They must be quasi fire-resistive buildings if the total floor area is 2000 m^2 or more.[147]

In **Germany**, schools and universities are regulated special buildings, also known as special constructions ('Sonderbauten'). Model regulations exist for these types of buildings, published by the Conference of Building Ministers. The MSchulbauR (sample school construction guideline) applies to fire protection in general and vocational schools, but not universities and technical colleges, academies, adult education centres or comparable school types.

The guideline sets out various stipulations:

- The requirements of the MBO for building class (GK) 3 must be met for load-bearing and bracing components in school buildings of building class (GK)1 and 2
- Internal fire walls are to be arranged at intervals of no more than 60m (in some circumstances highly-fire retardant walls are permitted instead of firewalls)
- In buildings of building classes (GK) 1 and 2, the walls of necessary stairwells must be fire-retardant
- Halls extending over several floors are permitted according to Section 2.4. The walls of the halls – with the exception of the outer walls – must meet the requirements for the ceilings of the building

The sample school construction guideline, in contrast to the approach to industrial buildings, for example, does not stipulate the use of automatic fire protection systems but relies on passive fire protection.

In **New Zealand** fire safety requirements are published in the 'Fire and Safety Design Requirements for Schools (2008)', published by the Ministry of Education. The fire policy covers building design as well as passive and active fire protection systems: fire alarms, use of sprinklers, minimum separate distances between Ministry buildings and maximum allowable firecell size.[148] Addendums were added to the guidance in 2017 and 2018 to cover the adoption of the Enclosing Rectangle Method[149] (ERM) and requirements for sprinklers, compartmentation and fire alarm systems, respectively.

- The addendum for the adoption of the ERM stemmed from a need to provide sufficient flexibility for the wide variety of school building types and 'specific circumstances that may be encountered.' Thus, introducing a more performance-based approach which is also still in line with the Ministry's overall property protection objectives. The Requirement specifically calls out concerns with horizonal fire spread and a desire to mitigate this to 'manage risk and costs of fire damage.'
- The addendum for sprinklers, compartmentation and fire alarm systems was in response to a staged review of the Ministry's fire policy. Specifically, this addendum includes a requirement that sprinklers are used in certain circumstances in new buildings. But the use of sprinklers is not mandated.

The design requirements include specific provision for fire and smoke separation for property protection which is dependent on whether or not a sprinkler system is installed. Buildings shall be sub-divided to create firecells comprising a maximum of 800m^2 except where the building is sprinklered. Un-sprinklered assembly halls and gyms are permitted *"to have a maximum area greater than 800m^2 if fire separations will disrupt the intended use of the building."* This requirement was included as an addendum in June 2018.

"…additional property protection guidelines have been provided, to help protect the high capital investment in schools and reduce the risk of loss through arson."[150]

The installation of sprinklers is highlighted as a specific measure to minimise property damage in the event of a fire. The 'Fire and Safety Design Requirements for Schools' states that sprinkler systems can be a cost-effective choice as they can reduce the need for other fire protection measures in some circumstances. Property protection is also featured as a reason for installing smoke detectors.

This differs markedly from the requirements of the Building Code which places obligations on building owners to protect other people's property:

> *"There is no provision in the Building Act 2004 or the Building Code requiring property owners to protect their own property."*

Other guidance:

CFPA Europe publishes a Guideline of 'Fire protection in schools.' According to the CFPA, "Most European countries have national or local codes concerning the fire safety of schools, but the legislation can be very different between countries."[151] As well as to maximise life safety, and reduce the intervention by external fire fighters, the guidelines are also intended to reduce the probability of a fire and to 'reduce, in case of fire, the consequences of the fire on people and on properties.' The Guidelines provide information on aspects such the necessary fire resistance of the bearing structure, fire compartments, the choice of materials (including furniture) as well as technical systems for fire protection which 'must be designed, installed and maintained following the applicable national or local regulations.' These include:

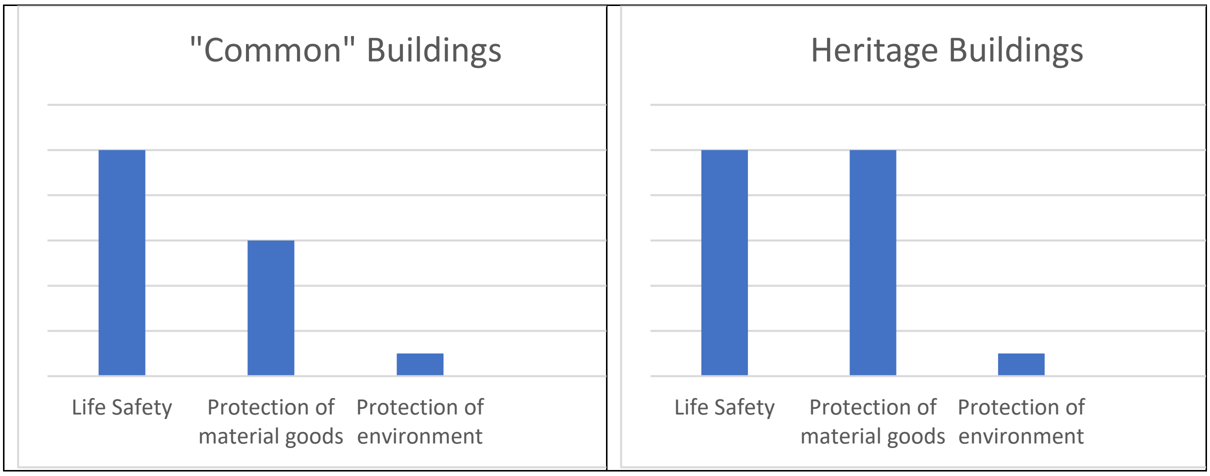
- Fire detection and alarm systems
- Fire extinguishers
- Water hose systems
- Emergency lighting
- Smoke ventilation
- Other fixed fire safety systems (e.g., carbon monoxide detectors and fire blanket, or a sprinkler system when required by a specific fire risk assessment)
- Safety signage
- Lifts

4.5 Historic buildings

Historic buildings are a fairly unique proposition, in that the building itself, as well as its contents (for example, in the case of a museum or gallery) have social and cultural value. Whilst that is also true of schools and other public buildings, arguably one of the greatest impacts of the loss of such a building is inconvenience to the users. In the case of historic buildings, they have an intrinsic value *"that not only must be preserved, but the way in which this can be done must be explicitly selective so as not to compromise the architectural values of the building."*[152]

As such, the fire safety objectives for cultural buildings are often different than for other types of buildings. However, historic buildings are not always given assigned specific building categories or types and therefore fire safety provisions for these types of buildings can be no different to a domestic residence. In some countries – such as the USA and Germany – there is specific guidance on fire safety for historic buildings. In some examples, the fire safety objectives for historic buildings differs to those for other types of building (Figure 8).

Figure 8: Fire safety objectives in heritage buildings



Graphs adapted from: 3 lecture: Marija Jelčić Rukavina: Fire Protection of Cultural Heritage Buildings[153]

However, according to the literature the primary focus on fire safety of historical buildings remains on life safety. As discussed by Torero, means of quantifying the importance of the building and its contents in a comparative manner to life safety is not discussed. This is likely because the cultural, societal and historical value of historic buildings is extremely difficult to measure. As Torero points out, a good example of this a review by Bernardini which found *"after a detailed explanation of the issues, the focus is placed back on effective means of wayfinding as a mechanism to aide egress without major modifications to the building fabric."*[154]

The challenge in retrofitting both passive and active fire suppression methods in historic buildings is substantial and can sometimes be impossible without altering the structure or fabric of the building.

In the USA, Historic buildings tend not to be treated as a discrete building category in building legislation, instead they are categorised under different building types or occupancy categories. In ADB, for instance, museums fall under the category of recreation. In IBC, they fall under occupancy type A, 'Assembly'. As such, the specific fire safety and property protection requirements of historic buildings are often overlooked in statutory building regulations.

There are a number of non-statutory US codes, published by NFPA, designed to protect historic buildings and buildings housing historic collections from fire.

Fire codes for historic buildings and buildings with historic collections tend to focus more on property protection than on mandatory building regulations. The purpose of these codes is to protect the fabric and distinctive characteristics of culturally significant buildings and ensure operational continuity of such buildings, while at the same time ensuring the life safety of occupants.

Fire codes for historic buildings also tend to focus more on measures designed to minimise the likelihood of fire ignition, rather than on extensive passive and active fire protection measures, designed to control fire spread. This is both to minimise the impact of fire protection features on the character and distinctive architectural elements of the building, but also to ensure that important cultural resources are not damaged by mechanisms such as water-based fire suppression systems. As such, sprinkler usage is heavily controlled (restricted to certain areas) and use of fire doors is also limited, to ensure adequate ventilation needed to protect historic building features.

NFPA 909: *Code for the Protection of Cultural Resource Properties - Museums, Libraries and Places of Worship (2021)*[155] has the following objectives:

- **Building Preservation**: *"to provide a reasonable level of protection for a building, their unique characteristics, and their fabric against conditions or physical situations with the potential to cause damage or loss, including, fire."*
- **Continuity of operations**: *"to provide a reasonable level of protection against disruption of facility operations consistent with the organisation's mission and protection goals."*

However, the impact of fire protection measures on the building fabric and aesthetics are to be kept to a minimum:

> *"Removal or alteration of any distinctive architectural features for the purpose of improving fire protection of life safety shall be minimised."*

NFPA 914: *Code for the Protection of Historic Structures*[156] has a similar scope. Its purpose is to ensure the protection of historic structures and historic districts (and their occupants), along with the elements, spaces, and features that make the structures historically or architecturally significant and allow for continuity of operations. This includes the following objectives:

- *"To provide reasonable safeguards for the protection of property and the preservation of historic finishes, spaces and architectural elements from the damaging effects of fire."*
- *"To maintain the historic fabric and integrity of the building."*

As with NFPA 909, fire safety solutions need to be sensitive to the distinctive historic building features and preserve its historic character:

> *"Fire safety, fire protection features, and security measures shall be designed, approved, implemented and maintained to preserve the original qualities or character of a building, structure, site or environment."*
>
> *"Removal or alteration of any historic material or distinctive architectural feature for the purpose of improving fire protection, security or life safety shall be minimised."*

Both NFPA 909 and NFPA 914 emphasise fire prevention measures designed to minimise fire ignition and spread. These include:

- **Restrictions around decorations**: Decorations, such as hanging draperies, should be made of non-combustible materials and kept at least 1m away from all ignition sources, including light fittings and radiators.
- **Fire spread control**: All doors to be closed when the building is unoccupied, except where doors are to remain open for interior ventilation to ensure conservation of historic building fabric, or where doors are themselves part of historic fabric. In such instances, the fire codes recommend that *"professional analysis of the open doors' impact shall be performed and documented alternative methods to control fire spread shall be implemented."*
- **Strict house-keeping regimes**: Combustible packing materials to be stored in metal containers with self-closing covers. Where this is not possible, dedicated crating and packing areas will be enclosed by fire barriers with a fire resistance rating of not less than 1 hour or shall be equipped with sprinklers.

  External refuse bins should be located at least 4.6m away from all parts of the building exterior. Refuse bins stored inside the building shall be confined to designated 'trash rooms' with both sprinklers installed and a 1-hour resistance rating.
- **Restrictions on hot works and open flames**.

Legislators in Germany have developed comprehensive fire safety and heritage protection regulations with the specific purpose of property protection and a stated objective of keeping historic buildings operational, *"to show their beauty and to preserve them and the interior for posterity. The difficulty is to link the conservation of architectural spaces to needs of people who use the spaces*."

In keeping with the federation approach to building regulation, there are consequently 16 separate heritage protection acts – one for each of the German Federal States and in Saxony property protection is given particularly high importance because of the number of heritage protections in the state.

German heritage protection law specifically requires owners of historic buildings to protect them from damage such as fire, including sufficient fire safety provisions.

Other guidance:

CFPA Europe publishes:

- Guideline No 7:2016 S Developing evacuation and salvage plans for works of art and heritage buildings
- Guideline No 30:2021 F Basic principles of fire safety of historic buildings

Guideline No 30:2021 F Basic principles of fire safety of historic buildings: This guideline was proposed by the Slovenian Professional Firefighters Association. As stated in this guide 'national guidelines prescribe how to protect lives, environment and property from fire. Protecting historic buildings is often more complex. The level of protection should be high without destroying the historical value.' The guideline focuses on fire protection and fire prevention. In terms of fire protection, the guide lists basic recommendations including risk assessment, the need for comprehensive documentation (including a fire safety handbook and a fire safety logbook), an evacuation and salvage plan.

Throughout, the guideline underlines the importance of good housekeeping and places emphasis on the appropriate use of manual firefighting equipment and active fire protection measures to minimise damage to the building. For example, 'it is essential to choose fire extinguishers that have sufficient extinguishing effectiveness for the expected fire and not give irreversible damage to the building and its content.' With regard to active fire protection measures, consideration is given to the invasiveness of suppression systems such as sprinklers and mist systems which may seem invasive, 'but in certain situations (can be) a very effective way to deal with a fire before it spreads too much.' Other protection systems are also introduced, such as inert air systems which prevent ignition, initial smoke and fire spread.[157]

5. Thematic analysis

This section presents a thematic analysis of issues relating to the fire protection of buildings and property. These themes were agreed at project inception and findings for this section draw on a combination of stakeholder discussions and recent published literature (the latter having many gaps).

This section also contains a number of case studies to exemplify the themes discussed. These case studies – some of which are from countries other than the comparator countries selected for this study – were suggested by stakeholders.

5.1 Robustness/resilience of building (and disproportionate damage)

5.1.1 Definitions of building resilience:

Although there exists expansive literature exploring the concept of 'resilience' in building and infrastructure design, the majority of this literature assesses building resilience in relation to natural disasters (earthquakes, hurricanes, wildfires); there has been very little specific research on building resilience to fire.[158]

Definitions of resilience in the context of the built environment tend to focus on the ability of a building or system to recover from – and return to a state of operational and functional normality following – a disaster or unexpected disturbance.

Canadian researchers Smith and Gales define resilience as:

> *"The ability for an operation to withstand shocks or stresses and return to normal operating capacity in a desired timeframe. A stress is a prolonged disturbance to the operation, such as labour shortage or reduced water supply, while a shock is a sudden and short disturbance such as an earthquake or a fire. The operation within a building may be commercial, residential, or institutional in nature, among others."*[159]

For Japanese researchers Himoto and Suzuki, the concept of fire resilience in buildings can be equated with functional continuity:

> *"Functional continuity is the ability of a fire-affected building to quickly recover by minimizing the extent and degree of the damage, even though the occurrence of the damage may be unavoidable."*[160]

For Himoto and Suzuki, in order for a building to be truly fire resilient, all components of the building, including non-structural members and equipment systems, must remain undamaged in a fire event. By their analysis, building components can be categorized into 4 main types:

- Structural members (columns, beams, walls, floors, etc.)
- Non-structural members (partitioning walls, interior finishes)
- Equipment systems (electricity, sanitation, air conditioning, lighting)
- Stored items (fixtures, fittings, goods, electronic devices)

Of these, the fire resistance of non-structural members, equipment systems and stored items is calculated as significantly lower than structural members. While structural members have a critical temperature of 773˚C, below which functional continuity is maintained, the remaining 3 component types have a critical temperature of 373 ˚C. The researchers argue that damage to any one component

– including non-structural ones which have much lower fire resistance – will affect the speed with which the building can recover from fire and impact on its functional continuity.

Gernay et al.,[161] in their overview of fire in the urban environment, propose that the resilience of urban infrastructure to fire can be evaluated using a three-stage analysis, exploring the system's resistive, absorptive and restorative capacities:

- The **resistant capacity** is the ability of the infrastructure to prevent the occurrence of fire or limit initial damage in the event of a fire. Examples of measures to increase resistant capabilities include limitations of fire load, use of active fire protection systems (sprinklers) or application of passive protection (insulation) to key structural elements.
- The **absorptive capacity** focuses on limiting the cascading effects of fire damage within a system, aiming to limit the maximum impact of fire to maintain the largest possible level of residual functionality. This can be achieved through robust structural design and enhancing fire resistance of materials.
- **Restorative capacity** is equated with the time needed to recover after a fire. A resilient system can be repaired quickly and efficiently.

Guay, in her article on fire resilient cities, proposes a similar set of 'technological' solutions to improve the fire resilience of buildings:

> *"Several solutions are available and so if brought together, they can make a difference on the level of resilience reached. For example, assure that there are sprinklers in the building so that small fires can be quickly extinguished, or have an alarm system that can alert first responders so they can rapidly respond. Another measure would be the use of non-combustible materials for high-rise and high-risk buildings."*[3]

In the case of both Guay and Gernay, a combination of both active and passive fire protection methods (such as sprinklers and fire-resistant construction) is seen as critical to improving fire resilience of buildings.

[3] F. Guay, (2019), *Fire Resilient Cities: The Impact of Fire Regulations, Technological and Community Resilience*, International Journal of Urban and Civil Engineering

Case study: Top Mountain Crosspoint Motorcycle Museum, Austria, 2021

The Top Mountain Crosspoint Motorcycle Museum opened in 2016 and contained one of the largest and most valuable collections of motorcycles in Europe. The building was constructed of timber and did not have a sprinkler system.

The fire, having been discovered in the early hours, could not be contained, and the building was burned to the ground. There were no casualties, but the museum's 230 classic motorcycles spanning over 100 manufacturers - including classic models from Brough Superior, Vincent, Matchless, Sunbeam and Zündapp – were all destroyed. The museum also had a number of rare cars which were also destroyed in the blaze.

Image credit: Top Mountain Motorcycle Museum

Source material: https://www.hagerty.co.uk/articles/fire-destroys-austrias-prized-motorcycle-museum/; https://www.eurosprinkler.org/unsprinklered-austrian-motorbike-museum-destroyed-by-fire/

5.1.2 Fire suppression systems and fire resilience of buildings

Several recent studies of building resilience have emphasised fire sprinkler systems as one of the most effective means of improving the fire resilience of buildings.

A recent computational study[162] conducted in Japan employed a multi-layer zone model as a methodology to assess the fire resilience of buildings. The multi-layer zone model represents a more advanced form of the classical one-layer and two-layer zone models. It works by dividing the rooms of a building into multiple horizontal control volumes, called zones, which are used to predict the behaviour of fire inside a building. Using the case study of a 5-storey office building in Japan, the multi-layer zone model suggests that, although fire resistance of structural elements is an important factor in minimising the cost and time for buildings to recover from fires, extinguishment in the early stage of a fire was particularly important to improve the fire resilience of buildings. This is because early extinguishment serves to protect all building components, including non-structural parts (non-structural members, equipment systems, items stored within the building), from fire. The protection of all building parts, including non-structural ones, is critical in securing the functional continuity of the building.

Of the individual fire protection systems assessed as part of this study, sprinkler systems were found to be the most effective in improving the fire resilience of buildings. This was followed by provision of an indoor fire hydrant (second most effective), then fire extinguisher (third most effective). The model found that sprinklers were associated with the greatest reductions in burned floor area, total building loss and recovery time. A combination of all fire protection systems, however, had greatest impact on improving resilience. The study also found that the effect of a mechanical smoke exhaust system on fire resilience was negligible in a situation without the other systems.

The results of the study detailed above are confirmed by another recent Japanese study,[163] which employed a conceptual approach using a simple fire hazard model (assuming uniform temperature distribution inside a room) to quantify the fire resilience of fire-affected buildings. This study concluded that, of all the design specifications tested, installation of a sprinkler system was the most effective in enhancing the fire resilience of buildings.

Statistical research also suggests that sprinklers are effective at limiting the damage caused by fire to the fabric of a building. An analysis of data[164] on fires in UK buildings with sprinkler systems, between 2011 to 2016, found the following:

- Fires in dwellings where sprinkler systems operated had an average area of fire damage of under $4m^2$. This compares to an average area of fire damage of 18 to $21m^2$ for all dwelling fires in England between 2011/12 and 2015/16.
- The average area of fire damage in a non-residential building where a sprinkler system was present was $30m^2$ which is half the average area of fire damage of in comparable "other building" fires in England between 2011/12 and 2015/16.

The same research also found that sprinkler systems were both highly reliable and effective at containing and extinguishing fires. Out of 879 fire cases where a sprinkler system was present but did not operate, only 57 of these cases were due to sprinkler system failure (that is, the system could have been expected to work but did not). This indicates that the operational reliability of the systems was 94%.

In terms of effectiveness of sprinkler performance against fire, across all fires for which data were available, the sprinkler systems contained or controlled the fires in 62% of incidents and extinguished the fire in 37% of incidents. Hence, the performance effectiveness of sprinkler systems was 99% across all building types.

5.1.3 Structural elements and fire resilience of buildings

While there exists a handful of studies which link fire suppression systems to building resilience, research into the contribution of key structural elements to the overall fire resilience of buildings is comparably scarcer.

The dearth of research into the structural resilience of buildings in fire is most likely a consequence of methodological approaches to assessing building behaviour in fire. The most common approach to fire safety design of structures is a member-level approach, which involves quantifying the behaviour of individual structural elements or members (such as beams, columns) during a fire. The main limitation with this approach is that it does not examine the response of the building structure as a whole and fails to predict the responses of combinations of structural elements to a fire event.[165]

In recent years, researchers have proposed a new methodology for modelling whole building structural responses to fire events. This methodology uses the concept of 'fragility curves' (taken from the seismic engineering community) to quantify structural damage to the building. Fragility curves are an analytical tool used to calculate the probability of structural elements exceeding acceptable damage states (e.g., column failure, excessive beam deflection, connection failure) following fire ignition. The damage states are generally related to the structural performance level and can be grouped in different categories such as 'no damage', 'slight', 'moderate', 'extensive', and 'complete'. By combining multiple fragility curves at different compartment locations, this new methodology is able to generate a fire fragility curve for the entire building system. This can, in turn, be used to estimate the probabilistic structural damage for the whole building in the event of a fire.[166,167]

However, this methodology is still relatively new, and more research is required to fully understand the influence of different parameters on the fire fragility function. For instance, in order to use the fire curve function to accurately quantify building resilience to fire, it is necessary to take into account other factors such as fire load and the likelihood of fire ignition.[168] Furthermore, the fire fragility methodology has been developed primarily based on steel structures; the applicability of the methodology to other structures (such as concrete ones) is lesser known.[169] There are, therefore, limitations in methodologies for assessing the resilience of whole building structures.

These limitations may also explain the lack of empirical research into disproportionate damage caused by fires. Assessments of disproportionate damage – and probabilistic estimations of the likelihood of fire causing disproportionate damage – depend on analyses which consider the response of the whole building structure to fire.

A small number of researchers have taken a more holistic approach towards assessing the performance of whole building structures and their contribution to building resilience. Canadian researchers Smith and Gales carried out a review of literature on fire performance of key elements of steel-framed buildings.[170] From this review, they proposed a series of structural design criteria which, they argue, would maximise the operational resilience of steel-framed buildings.

Smith and Gales propose 3 different levels of performance:

- Life safety level (LOP-L): occupants can safely egress in time; damage state and repair scope unknown; fire effected area will likely require extensive repair and rebuilding
- Occupancy level (LOP-M): occupants can safely egress; fire effected zone requires repair, the scope of which may interfere with adjacent units
- Operational level (LOP-H): occupants can safely egress; fire effected zone requires only aesthetic clean-up and repair; adjacent units can be occupied immediately following the fire

Using the results of their literature review, the researchers then propose a series of performance criteria, for each performance level, encompassing:

- Performance of structural members (i.e., the maximum gross member steel temperature);
- Compartmentation (deflection limits of partition walls);
- Performance of structural connections, informed by the concept of Demand Capacity Ratio

Smith and Gales suggest the following performance criteria, for steel-framed building structures, for each performance level (Table 20).

Table 20: Performance criteria for steel-framed buildings

Performance level		Deflection	Gross member steel temperature	Connection DCR: Flexible	Connection DCR: Rigid
LOP-L	Life Safety	0.75m	650℃	4	1
LOP-M	Occupancy	0.3m	500℃	2	1
LOP-H	Operational	0.1m	315℃	1	1

The criteria necessary to ensure 'operational continuity' are the strictest: structural steel members must not exceed a gross temperature of 315 degrees, while partition walls have a deflection limit of 0.1m. The demand placed on structural connections is informed using the concept Demand Capacity Ratio (DCR), which is used to calculate acceptable limits of tensile forces exerted on connections during the fire event. Building structures which exceed these limitations in a fire event would result in structural damage greater than permissible to ensure operational resilience of the building.

Research undertaken by Kotsovinos et al.,[171] has suggested a structural design to mitigate the likelihood of structural collapse of tall buildings in the event of fire. Their research involved modelling the fire behaviour of transfer beams in a 3- and 7-storey building. Their results show that beam deflections in a fire event can lead to inwards pull-in of columns and deflection of non-fire affected storeys under both single-storey fires and multi-storey fires. This means that deflected transfer beams can act as a collapse mechanism within the building. However, analysis of the 7-storey building showed that adequate load redistribution between the columns, bracing and beams on the upper storeys of the structure can assist in preventing the mechanism from occurring.

5.2 Challenges of new methods of construction

The methods and materials used to construct buildings have changed considerably in recent decades. The shift towards a performance-based approach to building regulations in the UK has acted as an impetus to the use of different kinds of modern, low-carbon and sustainable construction materials and techniques. This includes increased use of combustible materials, many of which offer advantages such as strength to weight ratio. However, the fire performance of many of these new construction products and processes has not been rigorously tested and their resilience is little known.

The question marks around the fire resilience of many modern building materials and methods could potentially cause problems within a building regulatory context which places little emphasis on property protection. The UK Building Regulations were developed when non-combustible materials were the dominant building material and the only legal requirement around property protection is to ensure structural integrity only for as long as is necessary to allow occupants to escape. With the increased use of modern, combustible materials, it's possible that buildings could legally comply with the requirements of the Building Regulations (i.e., retain structural stability for a 'reasonable period' to allow occupants to escape), but offer limited resilience to fire beyond the period necessary to ensure safe evacuation.

5.2.1. Tensions between building sustainability and resilience

The desire to promote more sustainable buildings with lower embodied carbon and minimal environmental impact is one of the key drivers for the use of innovative construction materials and techniques. However, recent research suggests that the sustainability agenda in the building sector has the potential to conflict with fire safety and fire resilience. The concept of 'sustainability' has traditionally been equated with environmental safety, but also encompasses economic and social aspects of sustainability. However, views of sustainability often fail to embrace fire safety, in particular fire resilience in buildings. Fire incidents in buildings with 'green' attributes provide evidence to suggest that the adoption of sustainable building materials, features and systems can have unexpected consequences when fire safety is not considered early in the development phase, or where unexpected combinations of materials are used to create and install systems outside of the original specifications. Sustainable and green features may, therefore, create accidental fire safety vulnerabilities if fire safety is not integrated into the early stages of design.[172]

Meacham and McNamee[173] have compiled a comprehensive register of the potential fire risks associated with green building materials, features and technologies, based on an extensive literature review of fire events involving green and sustainable building materials.

Many of the risks relate to structural elements of green buildings. For instance, use of mass timber as a structural component can lead to delamination, causing the timber to contribute to the fuel load.

Other risks relate to exterior materials and systems. For instance, the Structural Integrated Panel (SIP) can fail allowing the insulation to contribute to flame spread, smoke production and fuel load, which can in turn impact on the structural integrity of the building.

Modern building systems can also increase fire risks: cavities in modular construction can provide pathway for spread of flame, smoke and toxic POC. Furthermore, natural ventilation can also impact ability to control smoke.

Other risks relate to the energy sources used in sustainable buildings: PV roof panels and EV charging points, for instance, both present ignition hazard and contributes to fuel load.

5.2.2. Mass timber construction

Timber has been used as a building material for centuries. Recently, however, the drive to build more sustainable buildings has led to an increased focus on timber buildings, with a new generation of engineered 'heavy' timber systems (broadly referred to as 'mass timber') becoming more widely used. Mass timber systems include glue laminated timber (glulam), cross laminated timber (CLT), nail laminated timber (NLT), dowel laminated timber (DLT), laminated veneer lumber (LVL) and laminated strand lumber (LSL), along with wood and concrete composite systems and construction.[174]

The potential to use timber as a sustainable building material has triggered an abundance of research into the behaviour of timber in fire, and fires in timber-framed buildings has been a focus of enquiry for the UK government for over a decade.[175] Recent research has demonstrated good fire performance of timber structures under defined scenarios. While unprotected timber structures are known to burn and contribute to the fuel load, various studies and experimental tests have suggested that self-extinguishment of cross-laminated timber can be achieved if the timber is sufficiently encapsulated or treated to prevent fall-off of charred layers. This prevents the CLT structure from contributing to the fuel load, reducing heat release rates and minimising the chance of total building collapse.[176, 177]

However, research into the fire safety performance of timber is ongoing and there is still a lot that is not known about the behaviour of mass timber structures in fire. Concerns remain around the achievability of self-extinguishment, especially in fire compartments with large areas of exposed timber. Furthermore, while the contribution of encapsulated timber to building fires has been shown to be negligible, failure of encapsulation can lead to timber acting as a fuel to fire which can eventually lead to a second flash-over.[178] Even where CLT is adequately protected, studies show that some of the internal surface of an enclosure can be exposed whilst still achieving adequate fire performance. The types of adhesives used to bond lamellae can also affect fire performance, which can lead to delamination and secondary flashovers.[179]

Timber is also susceptible to structural collapse even at relatively modest temperatures. A temperature increase of just 100°C can reduce the load bearing capability of wood by as much as 50%.[180] These properties of timber have serious implications both for the safety of fire fighters, who enter fire-affected buildings after occupant evacuation, but also for overall building structural resilience.

The increased use of timber as a main structural element in buildings, especially in the residential and commercial sectors, creates significant insurance challenges. RISCAuthority, in their recent white paper on the insurance challenges of mass timber construction, argue that the uptake of mass timber construction has the potential to introduce residential buildings which will sustain enormous structural loss (Estimated Minimum Loss (EML) as much as 100%) as a result of a fire. While the provision of insurance for 100% EML situations is not uncommon in the industrial sector, these provisions typically require strict rules around fire protection systems and premium levels unfamiliar to the office or residential sectors. The advent of many non-industrial buildings at 100% EML will create new challenges and engender a situation in which 'insurers will seek to place their available capacity where economic pricing can be achieved for customer and insurer.' The paper appears to suggest there is a risk, therefore, that some mass timber residential buildings may become uninsurable.[181]

RISCAuthority have suggested hybridisation of traditional and modern building methods as a shorter-term means of mitigating the fire risks posed by mass timber structures. This involves using traditional, non-combustible materials for critical elements of building structure within timber-framed buildings, to minimise building vulnerability to fire and susceptibility to disproportionate collapse.

- Ground floor structure – The susceptibility of even timber framed buildings under construction to arson can be cut if the ground to 1st floor level is built of concrete. The through life benefit to ground level fire raising and flood challenges persist for the life of the building.
- Core structure – Building designs that incorporate a non-combustible core can benefit from increased structural stability, improved fire service confidence and response, and a means of routing services vertically via non-combustible, fire resistant, cavities.

5.2.3. Modular volumetric construction

One of the greatest dangers associated with the increased uptake of modular volumetric construction is the lack of robust data on the fire performance of modular structures. Fire safety in modular buildings is still a relatively new area of research and studies into the behaviour of prefabricated modular structures in fire are limited.[182]

Stakeholders highlight cavities and voids within modular buildings as a critical structural vulnerability, which make modular buildings more susceptible to disproportionate fire damage. Modular buildings are constructed with individual modules connected using inter-component connections. This arrangement typically introduces cavities in between modules, which create potential pathways for the unimpeded spread of fire and smoke throughout the building.[183] Voids can run both laterally and vertically throughout the building, even connecting with the external envelope. Modular components often have limited fire resistance, commonly employing plasterboard as the primary material separating the fire compartment from the combustible void. Plasterboard is easily damaged, and fire can easily spread into voids once the period of fire resistance on protective coverings is surpassed.[184]

In order to prevent the spread of fire through internal voids, it is essential that each module is fitted with fire resistant walls and that adequate fire stopping measures are installed in voids between modules. Inadequate fire barriers or insufficient compartmentation of modular components can allow fire to spread into the inter-modular voids, which in turn invites the possibility of fire spreading throughout the whole building. This increases the chances of disproportionate damage or whole building collapse.

The use of combustible materials is an additional fire risk associated with modular construction techniques. Modular structures typically make use of lightweight composite materials such as fibre reinforced polymer (FRPs). While such materials have advantages for modular construction (they are lightweight, yet offer high strength and stiffness), composite materials often have low fire resistance and their performance as a building envelope is not well known.[185] Research into the fire behaviour of lightweight composites is also relatively scarce. Nguyen et al., have shown that the fire performance of lightweight FRCs, used for both structural and non-structural elements, can be improved through the addition of resin additives. These additives can help to reduce the ignition risk of FRCs, as well as reducing flammability, heat release, smoke generation, oxidation, and shrinkage of FRPs composites. However, resin additives can create variations in the mechanical properties of composites under fire. More research is therefore required on the effect of additives on the mechanical properties of FRCs.[186]

Case study: Fire in timber-framed residential building, UK, 2015

The effects of improperly fitted cavity barriers is aptly demonstrated in a fire which took place in a timber-framed residential building, in the South-East of England in 2015.

The fire in this building broke out in the front cavity wall, most likely the result of an electrical fault. The absence of adequate cavity barriers and sufficient compartmentation allowed the fire to spread to neighbouring buildings via the timber-framed walls. The extent of damage to the property meant that Building Control had to carry out a partial demolition of the building, to avoid the risk of collapse of a three-storey high section of wall. Remedial works also had to be carried out to fire damaged properties, along with inspections and some remedial works to undamaged properties. Residents of fire-damaged properties had to be temporarily relocated.

It is estimated that the cost of the damage to the building would have been significantly reduced if the building had been made of standard construction, as the fire would most likely have been contained to the flat in which the fire ignited.

Moorfield Hotel, Shetland, Scotland, 2020

The structural vulnerabilities of modular buildings to fire are also highlighted by a fire which took place in Moorfield Hotel in Shetland, in July 2020. The hotel was constructed using prefabricated modular components constructed in a factory in Northern Ireland. The fire which broke out was particularly severe, spreading rapidly throughout the whole building with fire fighters unable to stop the spread. Although all occupants escaped the hotel and there was no loss of life, the hotel suffered extensive damage and all residents (mostly oil and gas workers) had to be relocated.

The hotel was built in 2013 from structural insulated panels (SIPs). The panels were built into fully furnished hotel rooms in a factory in Northern Ireland before being shipped to the Shetlands and assembled on site.

According to a fire service report obtained through freedom of information, while the cause of the fire is most likely to have been an electrical fault, it is believed that the "rapid and unchecked" spread of fire was made possible by cavities in the walls and roof. The fire is thought to have started on the top floor, before spreading externally along the flat roof behind the false pitched roof.

Voids in the building design had been highlighted as a potential fire safety risk at the design stage of the Moorfield hotel. Stewart Douglas, who worked as case officer for Shetland Islands Council, raised concerns about the possibility of fire spreading from a bathroom into a service void.

Cavities and voids are not the only issues identified in the design of Moorfield. The SIPs used as the principal structural component in the hotel were made of combustible polyurethane insulation held between two sheets of oriented strand board (a product made from compressed wood flakes). These products were given a 'Class 3' rating for surface spread of flame, which ranks only one grade above the worst rating (Class 4), according to a BBA certificate for the product and is considered a 'high risk' rating by building guidance in Scotland. However, the BBA certificate also says: "With adequate protection, panels used in external walls and separating walls will meet the required fire resistance periods given in the relevant national building regulations."

It is likely, therefore, that a combination of structural factors contributed to the rapid fire spread in Moorfield hotel. The cavities, which appear not to have been adequately protected with cavity barriers, may have permitted the unimpeded spread of fire and smoke while the combustible materials used in the SIPs may also have allowed fire to spread.

There is no evidence that Moorfield was not designed according to regulations and agreed plans. What this means is that fire safety issues are likely to have resulted from vulnerabilities inherent to MMC by the building standards system. This incident highlights how buildings constructed using modern methods – even those which comply with building regulations – can present fire dangers which threaten both life and property.

5.3 Competence

> **Note:**
>
> The points discussed in this section about competence relate equally to life safety and property protection. Findings from literature and stakeholder discussions suggest that a lack of competence introduces risks which are pertinent to both and so it is not possible to disaggregate discrete competencies which relate specifically to property protection and those which relate specifically to life safety.
>
> The only competencies that could be considered specific to property protection are those relating to installation of automatic fire suppression measures and passive fire protection measures. Discussion of skills around installation of such systems are discussed here as these are measures identified as being most effective in protecting property from fire.

The provision of property protection in buildings necessitates levels of skills and competencies above and beyond the minimum levels required for life safety systems in buildings. Additional competencies are required by both building designers, who must be competent and knowledgeable enough to design a building that can meet property protection design principles, as well as builders and installers, who must be sufficiently skilled (and ideally certified) in the installation of property protection features which are typically not required by statutory life safety requirements.

However, findings from recent research and stakeholder discussions suggest that many of those working in the building regulatory system in the UK do not possess the level of skills or competence needed to implement greater fire safety provisions aimed at protecting buildings and property. Competence is seen as lacking both at the building design stage, but also at the building control and planning stage, as well as in the construction and installer industries more broadly. One stakeholder noted particular concerns about the absence of the Clerk of Works, and the risk of delegation of responsibility and accountability. This links to a lack of continuity: one stakeholder stated that, in the UK, a fire engineer can submit a report and can then effectively exit the process. By contrast, in Australia, the engineer needs to go onsite to see the building.

5.3.1 Design and specification

The provision of property protection measures in buildings arguably places greater demands on the competency and knowledge of building designers. When following a design guide for property protection, designers need to be aware of a broader range of systems and features than when simply following life safety requirements. This includes considering relevant product certifications as well as the interaction of different property protection systems at the building design stage. These systems may include fire sprinkler systems, fire stopping measures, smoke ventilation systems and high integrity alarm systems.

Principle 5 of the RISCAuthority *Design Guide for the Fire Protection of Buildings (Essential Principles)*[187] states that designers must be aware of appropriate certification for fire protection products intended to protect property. Designers must ensure that 'the scope of certification granted by the certification body is appropriate for the end use application in the specific building, taking due regard of processes, fire load and anticipated fire inception hazards.'

The RISCAuthority Design Guide also recommends designers consider means of mitigating environmental damage caused by firefighting water, such as measures to capture water runoff for safe disposal (principle 4), as well as ensuring that building owners are provided with all necessary listings of both passive and active fire protection measures, including details of the manufacturer and installer and recommendations for maintenance (principle 8). These recommendations place considerably more responsibility on the building designer than when conforming to life safety requirements. This even includes ensuring that the building owner understands requirements for maintenance of the fire protection measures once the building is complete.

Recent evidence[188] also suggest that sprinkler systems, in particular, should be considered at the building design stage and integrated into the early design of the building. The need to consider sprinkler systems at the outset of building design serves to augment the responsibility, knowledge and competence expected of building designers. According to the findings of a sprinkler pilot scheme run by the Welsh government in 2014, which trialled the introduction of mandatory sprinklers in residential buildings, input from specialist sprinkler installers is recommended in the early design stages. This was to ensure that 'sprinkler factors affecting the building design or having impact on other building services, and vice versa, are taken into account as early as possible to give the best outcome.' Sprinkler factors to consider at design stage include:

- *'Voids to accommodate the sprinkler pipe need to be designed to be of sufficient size'*
- *'In timber framed constructions, types of floor joists have been specified which can readily accommodate the sprinkler pipe'*
- *'The location, space and structure requirements for any tank and the locations and spaces for any pumps and control valve arrangements need to be planned'*
- *'Allowance and coordination needs to be made for siting the different types of pipework and components under the kitchen sink unit.'*[189]

However, stakeholders have suggested that the building design sector lacks the competence and skills necessary to design fire-safe, resilient buildings which incorporate property protection measures. Stakeholders point out that the design of resilient buildings and provision of property protection measures, within a performance-based regulatory system, necessitates a holistic, risk-informed approach to building design, which involves looking at the fire safety of a building as a whole system and deciding how the building, as a whole integrated structure, should perform. To design a building with adequate property protection, the designer must take into account all elements of building design including how such systems fit together, rather than making decisions based purely on individual fire safety systems (such as fire sprinklers or compartmentation) and relying on the guidance documents to provide assurance of compliance. To judge the fire safety of a building holistically, however, requires significant understanding of fire safety, as well as an understanding of the routes to compliance. It also involves understanding where appropriate trade-offs can be made between individual systems – i.e., knowing which fire safety measures can be reduced if sprinklers are installed.

Stakeholder evidence from the US suggests a wholly performance-based approach strongly relies on competence, which must be assured throughout the whole lifecycle, from designer, engineer through to installer.

As the Hackitt report highlights, there is evidence of a critical problem of competence within the building regulatory system. Typical of this is the tendency for people within the system to work in silos, making decisions about materials and installations without understanding the broader implications of their actions on the whole building system. Specifically, the Hackitt review identifies:

"An existing approach to competence which is fragmented, encompassing a range of disciplines and different competence frameworks even within one discipline and without reference to other interacting disciplines. This results in people working within the system focusing on their individual specialism without giving due consideration to how their work may interact with the work of others and failure to see a building as a single entity or system."[190]

The absence of a holistic, joined-up way of thinking means that a risk-informed building design, needed to meet the requirements of property protection design, may be difficult to achieve. One stakeholder emphasised the importance of holistic design, with fire safety just one part of the broader equation in building design.

A related problem (as highlighted in the Hackitt report) is that many people working in the building regulatory systems do not use the regulatory guidance documents appropriately. Many builders tend to use ADB as a prescriptive system. However, given the technical content of the document in relation to fire, a lack of expertise in those interpreting the document can equally cause issues in relation to fire safety provision.[191]

A lack of competence in design, specification and delivery of fire protection systems is not unique to the UK. In New Zealand, evidence exists – and our stakeholder interviews confirm – that, in a large proportion of buildings, passive fire protection is not being effectively designed, specified and delivered. This potentially poses a serious life safety risk for building occupants and firefighters in the event of a fire occurring, as well as increasing risk of fire spread and subsequent property damage. There is an overwhelming need for comprehensive guidance on how to design, specify, install, inspect, certify and maintain effective and resilient passive fire protection in New Zealand buildings.[192]

In Australia, similar concerns have been raised about minimum competence levels for certain tasks. Whilst there are competency requirements for tasks such as developing a performance solution for fire protection, requirements for more routine tasks – such as installing fire protection equipment or occupancy separations – differ between States. In 2019, the chief executive officer of the Fire Protection Association of Australia (FPA Australia) expressed concerns about the lack of minimum competency requirements.[193]

As well as a lack of competence on the design side, research suggests that there are systematic failings on the part of building control and planning in the UK in securing relevant fire safety expertise when assessing new buildings. A recent analysis of responses to freedom of information (FOI) requests submitted to 50 local authority governments across England and Wales has revealed that local authorities have no guidance from central government regarding the fire safety expertise they should consult with when assessing planning applications for new buildings. Furthermore, although the Regulatory Reform (Fire Safety) Order (RRFSO) 2005 states a fire safety assessment must be performed for occupied buildings, there is no definition of what is required in terms of qualifications or experience to perform this task. This lack of advice or qualification is unusual in the building industry where competent person schemes are common and recommended by central government.[194]

The analysis of FOI requests also found that the extent to which local authorities engage fire authorities and consult fire safety expertise varies considerably. From this, the analysis concludes that 'there does not appear to be any guarantee that fire expertise is being employed for the purpose of fire safety in building/planning processes.'[195] This means that the planning and building control systems are contributing to the lack of expertise and competence in the building regulatory system.

Case study: Torre dei Moro - residential tower block fire, Milan, 2021[1]

The design of a residential tower block and use of combustible cladding were critical factors in a fire in Milan which was likened to the Grenfell Tower fire, due to the speed with which the fire spread through the building's cladding. The tower was constructed in 2011, comprising a rectangular structural core and lightweight steel curved *sails* which were attached to the long sides of the building, with balconies in between the sails and the core. The 60-metre-tall building was designed to resemble the keel of a shop and included an aluminium sail on the roof.

The fire took hold rapidly after spreading to the balcony due to the Aluminium Composite Material (ACM) cladding, which extended to the full height of the building around the four structural columns. The cladding on the sails was made from an aluminium skin and polyethylene (PE) core – similar to that in the Grenfell tower. There was additional combustible material at the roof level. The cladding contributed to the vertical spread of the fire. The walls at the ends of the building were not covered in ACM cladding, but an insulated render system containing limited combustibility mineral wool insulation – without this the fire may have been even worse.

Other design elements inadvertently created conditions for the fire to quickly take hold; the design and positioning of the sails created recesses for the fire to spread, and gaps occurred at the first floor where sails were built around a podium – helping to create a chimney effect.

Image credit: Sky News

Source material: https://www.dezeen.com/2021/08/31/milan-apartment-block-fire-torre-del-moro-grenfell/; https://news.sky.com/story/milan-fire-firefighters-tackle-blaze-as-flames-engulf-high-rise-block-of-flats-12394856

5.3.2 Installation

As well as imposing higher competency expectations on designers, property protection design guides also require higher competency levels amongst installers. Principle 6 of the RISCAuthority *Design Guide for Fire Protection of Buildings* states that '*all fire protection products/systems shall be installed by appropriately trained specialist installers. Installers shall be third party certified to install the specific product/system when an appropriate scheme is available (e.g., FIRAS, LPCB, BM Trada, BAFE etc.).*' Similarly, the FPA's Technical Guidance on Residential Sprinkler systems recommends that building designers should only use sprinkler installers who are third-party accredited. Clients/designers should also make sure to employ installers trained in the use of specific products. In particular, clients should choose those trained in the use of proprietary piping systems used in sprinkler systems (preferably training offered by manufacturers of such piping systems). All equipment and products should also be certified as being fit for purpose for performing their specific roles as part of the sprinkler system.[196]

The use of suitably skilled, accredited sprinkler contractors is essential to ensure that sprinklers are fitted correctly. Although research tends to suggest high sprinkler operational reliability – activating around 94% of the time when they are expected to[197] – incorrectly fitted sprinklers introduce the danger of operational failure and sprinkler heads not activating in the event of a fire. Improperly fitted sprinkler systems can also lead to water leakage which can damage the internal fabric of the building walls.

However, some stakeholders point out there are critical skills shortages in the installation sector in the UK, especially for active fire protection systems, such as automatic sprinklers. The sprinkler installation sector in the UK is small and anecdotal feedback proposes that any increase in mandatory usage of sprinklers has the potential to create demand which the sector may struggle to meet. It is difficult to quantify the size of the fire sprinkler installation sector in the UK, as official statistics are not sufficiently granular to identify fire sprinkler installation as a distinct sector.[4] However, the register of FIRAS-certified companies which specialise in fire sprinklers offers a possible proxy for the size and shape of this specialist industry. FIRAS's register contains fewer than 100 active certified installers of fire sprinkler systems across the UK.[198]

The absence of Competent Person Schemes relating to the installation and certification of many property protection systems also gestures to possible skills gaps in these critical areas. Competent Person Schemes exist for cavity and solid wall insulation (BBA, Blue Flame Certification, CERTASS, Certsure, NAPIT, Stroma), but no such schemes yet exist for the installation of systems such as fire stopping and cavity barriers.

The prevalence of skills gaps in these critical areas of installation have consequences for property protection. Not only does this mean the installation sector may struggle to meet increased demand for property protection, the shortage of key skills also introduces the possibility of incorrect installation which may lead to critical system failure, which would endanger both life and cause more damage to buildings and property.

[4] Sprinkler installation forms part of SIC 43.22: Plumbing, heat and air-conditioning installation.

5.4 Societal and environmental impacts

The Environmental Protection Act 1990 contains the legal definition in the UK of what constitutes the environment:

"All, or any, of the following media, namely, the air, water and land; and the medium of air includes the air within buildings and the air within other natural or man-made structures above or below ground."

"Pollution of the environment" *means pollution of the environment due to the release (into any environmental medium) from any process of substances which are capable of causing harm to man or any other living organisms supported by the environment."*

"A substance is "released" into any environmental medium whenever it is released directly into that medium whether it is released into it within or outside Great Britain and "release" includes—

a) *In relation to air, any emission of the substance into the air;*

b) *In relation to water, any entry (including any discharge) of the substance into water;*

c) *In relation to land, any deposit, keeping or disposal of the substance in or on land."*[199]

Fires have broader impacts than just the loss of buildings; building fires can have devastating impacts on the environment, the economy and society. Fires cause environmental damage through the release of pollutants into the atmosphere. The loss of buildings to fire also has broader social consequences such as dislocation of residents and businesses and disruption to critical services. This is especially true of important service-providing buildings such as schools, care homes or hospitals. The loss of a building to fire affects the lives of all those who use the building: children, residents or patients would have to be relocated, and there could be trauma related effects as well.[200]

5.4.1 Environmental impacts of fire

The environment impacts of fire are well documented in published research. Most of the research into the impact of fire on the environment, however, is about the emission of toxic gases, especially carbon dioxide. Research has been conducted into the production of carbon monoxide (CO) and carbon dioxide (CO_2) in fires, including the transport of CO on a global scale. Considerable work has also been undertaken on the effects of common gaseous products of fire, such as nitrous oxide, sulphur dioxide, Polycyclic Aromatic Hydrocarbons, and the toxicology impact of many of these compounds on humans and wildlife is well known.[201]

Far less is known about the impact of emissions from fire on aquatic environments or on soil.[202] Environmental studies conducted in the aftermath of catastrophic building fires give an insight into the extent of soil contamination by fire. A study led by the University of Central Lancaster found evidence of high concentration of toxins and potential carcinogens in soils and residue around Grenfell Tower. Similarly, another UK study found elevated concentrations of benzene – a proven carcinogen – in 140m away from the Grenfell Tower in quantities 25-40 times higher than those typically found in urban soils.[203]

Stakeholders consulted for this project are very conscious of the environmental damage of fire. Stakeholder evidence from the US highlights the importance of considering environmental impacts of a fire, such as the effect of the fumes on air quality. However, stakeholders perceive that there is not enough consideration of societal impacts, specifically in relation to the environmental damage arising from a fire.

Fire-fighting interventions can also have a detrimental impact on the local environment, especially through water run-off. Although it is assumed that the benefits of firefighting will usually outweigh the disbenefits of allowing fires to run a natural course, chemicals used in firefighting foams and powder can cause considerable harm to the environment. Water run-off from firefighting activities can cause contamination of groundwater and land and can have a toxicological impact on both animals and humans.[204]

Evidence suggests that active fire suppression systems, which help to contain and control fires, can have a positive impact on the environment by limiting fire emissions and requiring firefighting services to use less water to extinguish the fire. Automatic fire sprinkler systems, in particular, are associated with numerous environmental benefits.

Research conducted by FM Global[205] has shown that use of automatic fire sprinklers can reduce the environmental impact of building fires, as well as reducing the embodied carbon of a building over its whole lifecycle, for all building occupancy types. This research was based on large-scale fire tests conducted on identically constructed and furnished residential living rooms. In one test, fire extinguishment was achieved solely by fire service intervention. In the other test, a single residential fire sprinkler controlled the fire until final extinguishment was achieved by the fire service.

The results of the tests showed that total greenhouse gas emissions for the sprinklered rooms were lower than those for the non-sprinklered rooms. The tests also showed that the combination of sprinklers and hose stream discharge required around 50% less water to extinguish a fire compared to hose stream alone. Fewer pollutants were detected in the wastewater sample from the sprinklered test compared to that of the non-sprinklered test, while the pH value of the wastewater from the non-sprinklered test exceeded the parameters allowed by most environmental agencies. The study stated that non-sprinklered test wastewater represents a serious environmental concern.

FM Global's research also suggests that sprinkler systems are associated with reductions in embodied carbon linked to reconstruction of the building and replacement of furnishings. This is because in the sprinklered test, flashover never occurred (whereas in the non-sprinklered test, flashover occurred within five minutes of ignition). The prevention of flashover meant that the sprinkler limited the damage caused to the building structure and furnishings. This in turn lowered the embodied carbon associated with the building materials necessary for reconstruction and those associated with the manufacturing of furnishings and contents.

BRE's *Environmental Impact and Cost Benefit Analysis for Fire Sprinklers in Warehouse Buildings*[206] confirmed many of FM Global's findings. BRE's analysis found evidence of numerous environmental benefits to installing sprinklers in warehouses. These include:

- Reduction in CO2 emissions from fire
- Reductions in embodied CO2 from replacement of building contents and warehouse rebuild
- Reduction in fire size
- Reductions in quantities of water used to fight the fire

5.4.2 Societal impacts of fire

In contrast to the environmental impact of fire, there is noticeably less research available on the societal impact of building fires. Part of the reason is possibly the difficulty in establishing quantifiable metrics with which to measure the impact of fire on society: while environmental damage can be quantified relatively accurately by measuring carbon emissions, it is much more difficult to calculate the extent of business disruption.

At the first EU Fire Safety Day, the Croatian fire safety association and the University of Zagreb address the topic of cultural heritage in buildings and the importance of focusing on other types of fire damage, apart from human safety. The topics discussed included property protection and the costs of fire to society, which they acknowledge in many cases cannot be calculated in monetary value.[207]

Fire Safe Europe compiles statistics on fire incidents and highlights the societal, environmental and economic impact of fires. Although statistics on the economic impact of fires are hard to find, the World Fire Statistics Centre (WFSC) estimates that the economic impact of fires equates to 1% of GDP each year in most advanced countries. Furthermore, statistics published by FSEU suggest that 5,000 full time jobs were lost in the UK between 2009 and 2014 due to warehouse fires (Figure 9).

Figure 9: Economic Impacts of Building Fires

Infographic taken from Fire Safe Europe, 'Fire Safety: Know the Facts'.

Case study: ASOS warehouse fire, UK, 2014

The impacts of a warehouse fire for online retailer ASOS were far-reaching, causing significant damage to stock, affecting sales and ability to fulfil orders in the immediate aftermath, and affecting the share price in the medium to longer-term.

The fire spanned four floors and was thought to have been started deliberately, spreading from the second floor upwards. Around 20% of stock, worth £22million, was damaged by smoke and water from the sprinkler systems.

Although ASOS was able to re-start orders 48 hours after the fire, its share price dropped by more than three per cent in the immediate aftermath. ASOS confirmed it had lost sales in its final quarter of 2014, of between £25million and £30million.

Despite experiencing loses, the fire protection was successful in limiting damage and the spread of fire.

Image credit: @mathew_hanley (published on Sky News)

Source material: https://news.sky.com/story/asos-warehouse-fire-cost-up-to-30m-10389648; https://www.cityam.com/asos-share-price-drops-3pc-after-barnsley-warehouse-fire/

Case studies: Gardman warehouse fire, UK, 2018

This case study demonstrates significant impacts which resulted in major financial and operational pressure. Fire broke out at Gardman's Daventry warehouse in March 2018, destroying large volumes of its seasonal stock of products supplied to the garden sector. The 400,000 square foot warehouse was ultimately damaged so badly that the building had to be demolished. The fire was thought to have been caused by arson.

Gardman's ability to fulfil its orders was severely obstructed as a direct consequence of the fire. While some progress was made to re-build sales, additional investment was essential for the business to fully recover.

As no funding was available to Gardman, it went into administration in October 2018.

Image credit: South West News Service

Source material: https://www.bbc.co.uk/news/av/uk-england-northamptonshire-43391451; https://www.pwc.co.uk/services/business-restructuring/administrations/gardman.html

Quantifying the impact of building fires on service provision, such as healthcare and education is much more difficult. This review identified no published research which empirically examines the cost of disruption caused by fire to key services, nor any studies into the societal benefits of strengthening the fire protection of buildings and property.

Some indication of the societal cost of fire can, however, be gleaned through data presented by FSEU, which reveals that the education of 90,000 children is disrupted by fire each year in the UK.[208]

World Fire Statistics publish some data (Table 21) on the costs of 'indirect fire losses' but, as stated in the 2014[5] report, *"these figures are always difficult to calculate reliably and need to be treated with major reservations."*

Table 21: Published figures for claims/losses

Country	Currency	Claims/Losses			% of claims/losses
		2008	2009	2010	
Finland	EUR	77	57	88	50
France	EUR	-	-	-	50 (2005-2007)
Germany	EUR	308	287	-	216[1] (1989)
Japan	Yen	58	57	53	Unknown
Sweden	Krona	300	350	300	115
UK	GBP	187	83	153	165

[1] The adjustment figure of 216% was calculated for West Germany for 1989 and its application to the whole of Germany for more recent years must therefore be regarded with great caution.

Note: the data are in millions, except for Japan – billions)

[5] This research was unable to source any more recent data from this source

Case study: Millard Place, Arborfield – low rise flats, UK, 2021

A fire which broke out at a newly built block of flats left nearly 40 residents without homes in 2021.

Multiple fire crews were required to get the fire under control, which took more than seven hours, but the flats were left badly damaged. The building had a smoke detection system in the communal areas which is to activate smoke ventilations systems. No alarms were sounded as the building fire plan had a "stay put" fire policy.

The residents who were displaced as a result of the fire, had to be housed in temporary accommodation which was paid for by the owners of the building.

According to Google Earth satellite imagery, (accessed June 2022) the site appears to still be severely damaged.

Image credit: Tim Pritchard (published on BBC News)

Source material: https://www.bbc.co.uk/news/uk-england-berkshire-56760776

Case study: Weybridge Community Hospital, UK, 2017

A fire within a community hospital in 2017 had major repercussions for the provision of medical care. The three-storey building provided a walk-in centre, two GP practices and other NHS services including imaging and physiotherapy.

The fire took hold rapidly by spreading into the roof compartment, weakening the roof structure as the underfelt burnt away. The timber roof void was a source of oxygen to the combustion process which then increased the rate of burning. There were several explosions, and the fire fighter crews were compelled to adopt defensive rather than offensive firefighting measures, due to the risk and danger of further explosions of oxygen cylinders. The resulting damage meant that the entire building was destroyed.

A large number of local residents were evacuated temporarily for their own safety, and roads were closed for some time after the fire. NHS services were severely affected, with the need to house the two local GP practices elsewhere and closure of the walk-in centre. Temporary buildings had to be in place for several years following the fire, but it was not possible to temporarily house the walk-in centre due to its infrastructure requirements to offer services such as X-ray facilities. In consequence, walk-in centres in surrounding towns at Woking and Ashford were expected to take on additional patients.

An investigation into the fire concluded that it started in a server room on the second floor of the hospital, most likely caused by an air conditioning unit.

Image credit: Surrey Fire and Rescue Service

Source material: https://www.bbc.co.uk/news/uk-england-surrey-40578016; https://www.getsurrey.co.uk/news/surrey-news/most-probably-cause-weybridge-hospital-14777563; https://www.getsurrey.co.uk/news/surrey-news/weybridge-hospital-fire-what-changed-14135201

6. Key messages

The place of property protection in international building regulations and codes

The primary objective of all national building and fire safety regulations reviewed here is **life safety**. In England this strategy is explicitly stated in Regulation 8 which states that Schedule 1 of the building regulations *"shall not require anything to be done except for the purpose of securing reasonable standards of health and safety for persons in or about buildings."* This review has not identified an approach commensurate with this in any of the comparator countries.

Property protection is rarely set out in international fire safety regulations as an overt objective. However, while requirements linked to property protection are not always explicitly set out in international fire codes, the principle of protecting buildings and property from fire is **implicitly embedded** in a number of countries' codes. Given that the rationales which sit behind fire regulations are rarely laid out in detail – and measures designed to protect property are seldom described explicitly – the challenge becomes one of interpreting different codes and reading the notion of property protection in the code's historical development. Thus, while some fire regulations may contain a property protection element, this is hardly ever signposted unambiguously in the regulations.

For instance, in some countries, the protection of buildings and property is addressed in codes or regulations which have a **historical background in limiting the spread of fire**, either within buildings or between buildings. This is a strategy found in various countries, including Australia, Japan, New Zealand, Sweden and the USA. In most cases, however, property protection is not explicitly written into the requirements of published codes. All of these countries, with the exception of the USA, are regarded as having a performance-based approach to fire safety.

The only guidelines, identified by this review, which explicitly and unambiguously set the objective of protecting buildings and property from fire are **non-statutory** in nature. In most cases, these non-statutory guides are specific to the requirements and fire hazards of individual building types, such as FPA's Design Guide for Warehouses and storage buildings, or the NFPA's *Code for the Protection of Historic Structures* (NFPA 914). These design guides are often recommended by insurance companies and may provide useful frameworks for improving the fire protection of property for specific building types. This reflects the approach in England, where property protection is approached from the perspective of insurance, with property protection measures dealt with in the RISCAuthority Design Guide, rather than in Approved Document B.

The findings from this review also suggest that some buildings are afforded more fire safety protection, in national building and fire safety regulations, than others. Warehouses and schools are often subject to stricter requirements in **national building regulations**.

- In the case of **warehouses**, this reflects the unique fire hazards typical to these buildings. A related concern is the scale of warehouse fire incidents and the number of firefighting resources needed to control and extinguish a large warehouse fire. Sprinklers are almost always mandatory. Furthermore, warehouse size thresholds, which place limits on the size of un-sprinklered warehouses, are also generally much lower than in England.

- In schools, mandatory sprinkler systems are also commonplace internationally. Stricter requirements reflect the fact that schools are seen as important service providing-buildings and community resources.

  A good example of this is schools in Scotland. Although the principal function of the Scottish Building Regulations is the protection of life, Scotland's Technical Handbooks for non-domestic buildings contain fire protection measures designed specifically to protect school buildings as physical assets. This is also the case in New Zealand, in the Fire and Safety Design Requirements for Schools, where property protection is an explicit requirement to minimise disruption to education and to manage risk and costs of fire damage.

- In the case of residential buildings, stricter fire safety regulations are in place only for higher-risk, multi-occupancy buildings, such as high-rise domestic buildings above certain heights, or care homes. In part, these stricter requirements are based on life safety. However, these requirements also reflect the higher financial losses, as well as the broader social impact on the large number of dislocated occupants, which could result from fire damage to property, or interruption to business continuity, in these buildings (compared to individual dwellinghouses).

What are the drivers for property protection internationally?

The drivers for property protection are not always clear. This is perhaps linked to the implicit nature of property protection in many countries' fire safety regulations, along with the fact that there is no universal definition or consistency, internationally, in how property protection is defined. This is further complicated by the question 'how much damage is acceptable for a property to have been considered protected from fire?'.

For industrial and commercial buildings, the greater protections are most likely to minimise economic costs – stock destroyed, jobs lost – and environmental damage in terms of air pollution from smoke and other chemical pollutants. Here, the over-arching driver will be to preserve business continuity, driven for the most part by the insurance community, but also by businesses themselves.

Similarly, property protection for schools is driven by the desire to minimise disruption to education, which would have knock-on effects for parents should their child need to stay at home or travel to another setting to be educated. Another consideration is preserving the amenity that the school building provides to the local community, such as acting as polling stations, evening education centres, community refuges in the case of accidents and emergencies (e.g., flooding).

The drivers for protection of historic buildings can be argued to be a combination of the two; continuity of business (e.g., in the case of a museum or gallery) and preservation of a structure which may hold cultural significance to a community.

There are also social and environmental drivers for property protection. This is especially true of measures designed to protect large, multi-occupancy residential buildings. While measures such as sprinklers, refuge floors and higher fire resistance ratings for compartmentation are invariably linked to life safety, they also afford greater protection to buildings which have social and environmental benefits. The social benefits of such measures are that they mitigate the risk of mass dislocation (residents and businesses having to relocate after a fire), while environmental benefits include reduced carbon emissions and fire fighter intervention.

To what extent is property protection achieved through life safety?

Life safety and property protection are not mutually exclusive. Measures to protect property will, by default, protect life but life protection measures will also, to some extent, protect property. However, a key finding of this review is that there is no empirical evidence to indicate the extent to which property protection is achieved through life safety. This is a fundament gap research gap that that would benefit from further investigation.

Fire safety measures will often serve a dual or overlapping purpose in fire safety legislation. While the primary objective of most mandatory measures is to ensure life safety, many also have ancillary property protection impacts. However, it is difficult to objectively identify measures which have beneficial impacts for property protection because – as stated previously – rationales for fire safety regulations are not always articulated explicitly and in many instances property protection is implicitly embedded as the legacy of historic codes which had as their main objective limiting the spread of fire between buildings. What can be observed, however, is that several countries have fire safety regulations with requirements which go above and beyond the guidance set out in Approved Document B. In some cases, these requirements also offer a higher level of protection to buildings and properties.

An example of this would be the use of mandatory sprinklers in social housing and care homes in Scotland, which is proposed as a life safety measure, but which gives the physical infrastructure of the property greater protection from fire. Similarly, in Japan, 'fire-resistive construction' for buildings above a certain height in designated Fire Protection Zones is a measure designed primarily to protect life, driven by increased seismic activity, but which gives certain structural elements fire resilience to survive the duration of a fire.

However, discussions about the residual property protection benefits of measures designed primarily to address life safety must also consider the changing risks associated with the development of the built environment. The current UK Building Regulations can be seen as predicated on the inherent fire resilience of non-combustible materials, which have for a long time been dominant building materials. In this context, life safety requirements – such as the need for a building to withstand fire for a 'reasonable period' to allow occupants to escape – afforded a level of property protection because mainstream building materials (such as concrete) have high fire resistance credentials. However, the increased uptake of more modern materials and methods, which do not provide the same level of fire resilience, may introduce deeper levels of risk. Current regulations, which emphasise only the minimum requirements needed to ensure life safety, may no longer be sufficient to ensure the protection of buildings which offer limited resilience to fire.

How can property protection be achieved?

While there are a range of measures (both active and passive) which can help to protect buildings and property from fire, this review has found that active fire protection measures – most notably automatic fire sprinkler systems – are especially prominent in literature about property protection and building resilience.

Mandatory sprinklers are also common in international fire safety regulations, especially for buildings deemed to require additional protection (whether for life safety or for property protection, as described above). Sprinklers also feature heavily in non-statutory guidelines (such as the RISCAuthority Design Guide) for the protection of buildings and property from fire. Numerous stakeholders also emphasised the importance of sprinklers as the primary method of protecting buildings from fire. However, the rationale for their use is not explicitly set out. For instance, in the USA, the IBC mandates that sprinklers should be used in buildings where designers exceed the prescribed building allowances. In other words, the provision of fire sprinklers allows designers to build taller buildings or use combustible materials, such as timber and smaller compartment sizes. Or, to put it another way, unless the design includes enhanced measures to limit potential damage, the potential impacts of building on a larger run contrary to the principles of the Code.

Thus, while this review has presented findings on the full range of approaches and mechanisms to protect buildings and properties from fire, it must be noted that sprinklers carry noticeable importance as a property protection mechanism in the fire safety community and literature and accordingly feature prominently in this review.

However, sprinklers come with their own set of practical challenges. They are often deemed not cost-effective, especially in smaller residential properties (although they have been shown to be cost-effective in warehouses and some multi-occupancy residential buildings). However, this review has found very few instances of formal cost-benefit analyses being undertaken for the domestic market. An exception is in Wales, prior to the introduction of changes to ADB and new regulations requiring automatic fire suppression systems to be installed in residential buildings (new and converted). The assumption that sprinklers are a costly proposition likely stems from the currently small market and economies of scale not being realised. Sprinkler systems can also create challenges at the building design and installation stage; they impose demand on water mains supply which often cannot be sustained (and so require provision of water tanks); and installation and maintenance requires skills which are in short supply in the UK.

Research into fire resilience of buildings (although limited) tends to link active fire protection measures, especially sprinklers, to enhancements in building resilience. Research suggests that automatic fire sprinkler systems are highly effective at containing and controlling fires, which in turn limits the extent of fire spread and fire damage to property and buildings.

Research which examines the contribution of fire resisting construction to building resilience is scarce. However, the Japanese Building Standard Law, which emphasises more passive fire protection through the provision of ‘fire resistive buildings’, would indicate that effective fire resilience can also be achieved through higher durations of fire resisting construction. It can also be achieved through smaller compartment sizes, which have (anecdotally) become a more popular design solution as a means of minimising the damage to contents, vis. the larger the compartment the more contents at risk of damage.

Stakeholder evidence points to challenges in prescribing what is needed in relation to property protection, as this can depend greatly on different building types, heights, materials and how they are used. Another consideration is the local environment, for example the likelihood of seismic activity or woodland/bush fires.

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