Business Sprinkler Alliance

The Impact of Automatic Sprinklers on Building Design

COMMERCIAL SECTOR APPLICATION – OFFICES

JUNE 2018

A fire engineering review

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The Impact of Automatic Sprinklers on Building Design – Commercial Sector: Offices

Literature

Business Sprinkler Alliance
(11568)

Date: June 2018 Certificate No: A011647

CERTIFIED
The CPD Certification Service

About this Report

This independent report, produced by WSP, is a comprehensive and authoritative document which aims to provide those involved in the design and construction supply chain – including contractors, developers, architects and consultants - with useful and helpful information on the design implications of automatic sprinklers.

There are many positive benefits from the introduction of automatic sprinklers including improving life safety, business protection and sustainability and this document outlines in detail how automatic sprinklers can add value to building design.

Through robust research and by looking at different building types and design options, the report identifies the capital and lifestyles costs, design benefits and flexibility as well as the potential to reduce the construction programme. It also supports the view that automatic sprinklers should be considered early in the design process and dispels many myths about cost and design freedom.

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1. Executive Summary

The main purpose of producing this guide is to raise awareness in the industry of the beneficial impact that incorporating automatic sprinkler systems can have. It is reviewed in terms of cost (capital and lifecycle), aesthetics, design flexibility and construction programme for an intended audience including contractors, developers, architects and investors in new building developments.

This document is different from other reference sources because it focuses on the commercial and design impacts of automatic sprinklers rather than fire safety.

In building design, attaining an adequate level of fire safety is a statutory requirement. However, it is up to the designer to decide what design features and fire safety services are required to achieve this. Standard fire safety guidance offers concessions for a variety of building types if automatic sprinklers are incorporated whilst fire engineering techniques can derive further value. The first section of the report discusses these concessions generally whilst Section 6 onwards provides a review of office building types. It is intended that the reader will be able use the guide by referring to the building type and key objectives relevant to them.

The intended outcome of this report is to give the reader an appreciation of whether the inclusion of automatic sprinklers for a particular scheme is worthy of further consideration. For some schemes, whilst there may be other benefits, the inclusion of automatic sprinklers will not add value in terms of all of the objectives set out above. However, for other schemes the reader may be surprised as to how they will be able to add value and understand that there is merit in investigating further.

2. Introduction

About BSA

The BSA advocates greater business resilience by enhancing protection against fire through the increased acceptance and use of automatic sprinklers in commercial and industrial premises.

The BSA aims to:

- Deliver robust information and insight into the benefits of fire sprinklers and the critical importance of fire prevention
- Increase consideration of fire sprinklers with those who design, construct and approve new business buildings
- Ensure business decision makers appreciate the role that fire sprinklers can play in physical and commercial resilience
- Continue dialogue with regulators and legislators to review existing evidence and law, support the sprinkler case
- Drive widespread awareness of fire sprinklers to effect a culture change for their acceptance and adoption.

About WSP

WSP is one of the world's leading engineering professional services consulting firms.

They are technical experts and strategic advisors including engineers, technicians, scientists, architects, planners, surveyors and environmental specialists, as well as other design, programme and construction management professionals. With 36,000 talented people in more than 500 offices across 40 countries, we engineer projects that will help societies grow for lifetimes to come.

We know that without our clients, there would be no WSP, no great projects, and no big ideas. So we invest considerable time in building relationships – to understand our clients' aspirations and their needs.

It means we do more than deliver the obvious. We seek constant improvements. We are motivated to exceed expectations and to find ways of solving problems that are more effective, more exciting and more sustainable.

We draw on our expertise to find effective, efficient and sustainable ways of meeting our clients' needs. We work to be outstanding in everything we do, for the public and private sectors, in the UK and overseas.

We also understand the financial imperative. So we bring our creativity and our innovation to bear as we seek to reduce costs and add value in every way we can.

2. Introduction

2.1 OBJECTIVE

The objective of this document is to raise awareness in the construction industry of how and where the incorporation of automatic sprinklers in a new building development can add value that stakeholders such as contractors, developers, architects and investors can appreciate.

Standard fire safety design guidance offers relaxations on other fire precautions if automatic sprinklers are incorporated, whilst fire engineering can be used to tailor a package of fire protection measures around a specific building.

This is not a document about the fire and life safety or the fire protection benefits of automatic sprinklers; it is to explore the key ways that automatic sprinklers can add value to building design.

These are summarised as follows:

- Net capital cost saving of the construction project;
- Increasing the net internal area / building efficiency;
- Improving design flexibility and creating architectural freedom;
- Reducing the construction programme and/or simplifying site works.

Whilst other positive impacts can be realised from the introduction of automatic sprinklers into the building such as improving the level of life safety, business protection and sustainability credentials, they are not explored in depth here. This is a document that supports the view that automatic sprinklers should be considered during the design stage as part of establishing and developing the client's brief during the early stages of the project.

To this end the report is intended to give the reader an appreciation of whether the inclusion of automatic sprinklers for a particular scheme is worthy of further consideration. For some schemes, whilst there may be other benefits, it is likely that the inclusion of automatic sprinklers will not add value in terms of the objectives set out above. However, for other schemes the reader may be surprised as to how they will be able to add value and understand that there is merit in investigating the inclusion of automatic sprinklers.

2.2 WHO'S THIS DOCUMENT FOR AND ITS INTENDED USE?

The target audience is for those involved in the specification, design and construction of building works. Therefore this includes clients/end users, developers, engineers, architects and contractors.

It is intended that the reader will be able use the guide by referring to the building type and key objectives relevant to them.

2.3 REPORT LAYOUT AND METHODOLOGY

The content herein first presents general information, followed by a discussion of how automatic sprinklers can affect building design before presenting how and where automatic sprinklers relate to the typical project objectives listed in Section 2.1 for a range of building types. This includes but is not limited to: offices, hotels, warehouses, industrial premises, healthcare facilities, commercial facilities, places of assembly, transportation hubs and places of detention.

Subsequently, these building types are broken into separate sections so that the reader can gain an appreciation of how the information presented may apply to a particular project / sector they are involved with. This includes commentary on how best to realise the added value and design options that can be created by the inclusion of an automatic sprinkler system when using standard fire safety design guidance documents (namely Approved Document B and BS 9999) or when more advanced fire engineering solutions are developed. Case studies are presented within these sections to illustrate how the options have been applied.

2.4 EVIDENCE AND REFERENCES

Design options are based on project experience, standard guidance and fire engineering principles.

Standard guidance is referenced as:

- Approved Document B (Fire safety) – Volume 2: Buildings other than dwellinghouses (2006 edition incorporating 2010 and 2013 amendments) – ADB.
- BS 9999:2017. Code of practice for fire safety in the design, management and use of buildings, BSI – BS 9999.

Fire engineering is the work undertaken using the framework given in:

- BS 7974:2001 Application of fire safety engineering principles to the design of buildings. Code of practice.

Costs and values are fully referenced with key references being:

- Spon's Mechanical and Electrical Services Price Book 2012 (Spon's Price Books 2012), AECOM
- Spon's Architects' and Builders' Price Book 2015 (Spon's Price Books 2015) – 9 Sep 2014, AECOM

The Architects' and Builders' Price Book (2014) lists the costs of the materials and equipment required for fire protection in various building types. The Mechanical and Electrical Services Price Book 2012 is a comprehensive services engineering price book that provides detailed pricing information across the full range of mechanical and electrical services, together with higher-level costs for a diverse range of systems and different building applications.

2.5 LIMITATIONS AND APPLICABILITY

The technical content will be predominantly directed to property in England and Wales because of the functional nature of the Building Regulations 2010 that support the use of alternative solutions based upon fire engineering.

The design solutions presented are always required to meet the life safety (fire) requirements of the Building Regulations 2010. This is achieved through the application of standard design guidance (ADB, BS 9999) or fire engineering principles (BS 7974).

Fire engineering solutions are project specific. Therefore the applicability of the solutions discussed may not readily transfer onto another project. A review by a competent fire engineer would always be required.

Whilst this document focuses on buildings in England and Wales, the principles contained within could be applied to those in Scotland despite the difference in the underpinning legislation. Part 2 of the Building (Scotland) Regulations do make certain allowances where sprinklers are provided, including relaxation on external fire spread criteria in certain building types, provision of fire mains and increase in compartment sizes. Any benefits from the provision of sprinklers would need to be determined by a competent person.

The pricing information is applicable for contracts typically exceeding £3,500,000 in value (as recommended by Spon's price books).

The guidance given herein is based on new buildings. Whilst retrofitting of automatic sprinklers can be undertaken, the associated costs are hugely variable and have not been considered further.

2.6 NEXT STEPS

After reading this report you will understand how an automatic sprinkler system can impact on building design and whether your particular objective (i.e. cost saving, design flexibility etc.) is likely to benefit from their inclusion. The next step is to challenge those on the design team responsible for the fire protection design to ensure that automatic sprinklers have been at least considered.

2.7 PROJECT BACKGROUND

The Business Sprinkler Alliance (BSA) advocates greater business resilience by enhancing protection against fire through the increased acceptance and use of automatic sprinklers in commercial and industrial premises. The organisation is working with credible third parties to communicate to industry that the consideration of automatic sprinklers in every building should be part of a robust design development process. It is central to this objective that the BSA contributes sufficient robust information and insight to those within industry to inform the decision-making process.

The BSA approached WSP | PB in spring 2016 to prepare a document on how and where the incorporation of automatic sprinklers within a building design can bring a variety of benefits. These benefits are based on our experience of working in the industry with a variety of stakeholders including those involved in the development, construction, design and management of property. The question being asked is:

> 'What building design benefits can be generated from the fire safety and fire protection benefits of automatic sprinklers?'

2.8 INDEPENDENCE AND INTEGRITY

Whilst this guide is sponsored by the BSA, it has been written with editorial independence.

The content presented herein is our unbiased view gained from our experience of working within the construction industry and our knowledge of what is permissible under the Building Regulations. It is important to note that we are not promoting that automatic sprinklers should be provided in all buildings. What we are promoting is that each project should benefit from a robust evaluation of all fire safety/protection systems, of which automatic sprinklers are one available option.

3. OVERVIEW OF AUTOMATIC SPRINKLER SYSTEM DESIGN AND OPERATION

3.1 GENERAL

Automatic sprinkler systems extinguish or control fires by discharging water locally. Detection is handled mechanically by heat sensitive elements which can be constructed from soldered links or glass bulbs containing oil based liquids. The thermal element holds in place a plug which prevents water from flowing from the sprinkler head. The thermal elements respond to localised heating which acts to release the plug and allow water to flow. Key facts about their operation are:

- Automatic sprinklers will typically only operate in areas where fire is present allowing adjacent rooms or areas to remain unaffected;
- Discharge in the presence of fire is extremely reliable (98 to 99.8%) and discharge in the absence of fire is rare;
- They have an 80-95%[1] probability of being successful;
- Generally the cost and design complexity increases with fire risk. Offices which are considered lower risk have a lower water demand compared to high-bay warehousing that requires sprinklers to operate at a higher water demand;
- Systems can be designed to conceal pipes, and the availability of decorative sprinkler heads allows them to be matched with the interior of the space.

An automatic sprinkler system consists of water supply (tank, pump and valves) and sprinkler installation (pipes and heads). The specifications of the design depend primarily on the hazard classification of the occupancy of the building. The specifications include head spacing dimensions, assumed area of maximum operation (number of heads in-operation), design density (water discharge), water supply period, and tank volume.

AUTOMATIC SPRINKLER SYSTEM DESIGN

- Maximum area of coverage per sprinkler head depends on hazard classification and sprinkler mounting orientation (i.e. sidewall or overhead);
- Design density is the water discharge required in litres per minute over the assumed area of maximum operation. This can be summarised as the flow of water required which increases proportionally with the occupancy risk category;
- Area of operation is the design assumption for the maximum area over which the sprinklers will operate in a fire delivering the design density. This addresses the nature of the fire risk and recognises that some fires will grow faster than others;
- Water supplies are required to be capable of supplying the required flow (depending on the system design) for a minimum duration that varies from 30 to 90 minutes depending on the hazard classification;
- Minimum water volume requirement (water tank size) also depends on the hazard classification and the system type (wet, pre-action or dry).

[1] PD 7974-7: 2003 Application of fire safety engineering principles to the design of buildings — Part 7: Probabilistic risk assessment

3.2 DESIGN STANDARDS

The automatic sprinkler standards applicable at the time of writing this document are:
BS EN 12845:2015 – Fixed firefighting systems: Automatic sprinkler systems.
BS 9251:2014 – Fire sprinkler systems for domestic and residential occupancies.
LPC Rules for Automatic Sprinkler Installations 2015 incorporating BS EN 12845 (inc. TB229).

3.3 ALTERNATIVE SYSTEMS

Automatic sprinkler system designs can be adopted to suit a specific fire safety objective. Sprinklers are typically installed throughout a building, whereas drenchers are placed to address a specific risk such as on glazing as an alternative to fire rated glass, or on a structure as an alternative to passive fire protection. The principle was applied at a Hong Kong Air Cargo Handling Facility[2] where hollow structural members were water-cooled internally to reduce maintenance requirements and cost associated with passive fire protection. The design was justified using fire engineering methodologies. A performance-based approach to fire engineering design allowed fire safety to be addressed to meet clear performance requirements rather than the traditional prescriptive approach.

[2] Water-Cooled Roof Incorporating Sprinklers into the Structure: Hong Kong Air Cargo Handling Facility, Lovell, T. and Bressington, P. (2001)
http://ascelibrary.org/doi/abs/10.1061/40558%282001%2987

4. AREAS OF DESIGN IMPACT

4.1 GENERAL

The installation of an automatic sprinkler system can reduce the risk to life and the degree of damage caused in a fire event. As a result, to achieve the same level of fire safety, other fire protection measures can be reduced such as:

- Fire resistant construction;
- Compartmentation;
- Fire resistance of the external façades and glazed elements;
- Fire-fighting access and facilities.

The level to which other fire protection measures can be reduced requires an assessment of a variety of factors including building size, use and fire safety risk. Automatic sprinklers can permit freedom of design which in turn can create savings in the initial capital costs, lifecycle costs and the construction programme, such as:

- Larger compartment sizes;
- Reduced structural fire protection requirements;
- Increased travel distances leading to possible design freedoms such as the removal of stairs;
- Reduction in fire-fighting shafts;
- Reduced circulation areas leading to increased useable area.

This document fully discusses how and where such design impacts may be realised.

4.2 STATUTORY REQUIREMENTS

In England and Wales, fire safety requirements associated with building works are given in Part B of Schedule 1 to the Building Regulations 2010. It specifies requirements that are divided into five different areas:

B1: Means of Warning and Escape
B2: Internal fire spread (linings)
B3: Internal fire spread (structure)
B4: External fire spread
B5: Access and facilities for the fire service

These five requirements are termed 'functional' which means that the method of compliance is not dictated. To support the fire designer other publications provide recommendations for best practice to satisfy the functional requirement. There are 3 key references:

- General approach – Approved Document-B (ADB) is issued by the Secretary of State and provides practical guidance on how to satisfy the requirements of the Building Regulations 2010 schedule 1 part B. However, ADB is intended for most common/simple buildings. For complex buildings ADB guidance may not be suitable and other approaches may be required.

- Advanced approach – BS 9999 titled "Code of practice for fire safety in the design, management and use of buildings" is a British standard published by BSI. BS 9999 provides a more transparent and flexible approach to fire safety design.

- Fire engineering approach – BS 7974 titled "Application of fire safety engineering principles to the design of buildings" provides a framework for the application of scientific and engineering principles to the design of buildings to achieve adequate protection of people, property and the environment from fire. This is supported by series of Published Documents (PD 7974 1 – 8) that contain guidance on undertaking detailed analysis of specific aspects of fire safety engineering.

Building Control bodies are responsible for checking compliance with the requirements of the Building Regulations.

4.3 DESIGN BENEFITS GRANTED UNDER APPROVED DOCUMENT – B

INTRODUCTION

Approved Document – B (ADB) has been approved and issued by the Secretary of State for the purpose of providing practical guidance with respect to the fire safety requirements of Schedule 1 and Regulation 7 of the Building Regulations 2010 for England and Wales.

ADB recommends automatic sprinklers for most building types with a storey above 30m high. A notable exception to this rule is hotels which do not require automatic sprinklers regardless of height.

The sections below detail how automatic sprinklers can affect building design.

BUILDING LAYOUT / MEANS OF ESCAPE

ADB offers limited concessions when automatic sprinklers are incorporated, but the following options can create some flexibility in the building layout as detailed below:

Multi-storey flats with a floor above 4.5m are recommended to have the following unless automatic sprinklers are provided:

- An alternative exit should be provided from each habitable room that is not on the entrance floor of the flat;
- One alternative exit from each floor should be provided, with a protected landing that is entered directly from all habitable rooms on that floor;
- Additional smoke alarms in all habitable rooms.

When an automatic sprinkler system is provided in residential care homes, ADB permits the following:

- Fire doors to bedrooms need not be fitted with self-closing devices;
- Protected areas may contain more than ten beds;
- Bedrooms may contain more than one bed.

COMPARTMENTATION AND FIRE PROTECTION

Fire severity, building height and its occupancy all have an effect on the necessary fire resistance. The provision of automatic sprinklers can reduce the required fire resistance as highlighted in blue in Table 4-1.

Table 4-1 shows that due to the installation of automatic sprinklers, an office not more than 18 m tall can reduce its fire resistance from 60 minutes to 30 minutes and an office not more than 30 m tall can reduce its fire resistance from 90 minutes to 60 minutes. In certain tall buildings, more than 30m high, automatic sprinklers are required regardless and in small buildings no concessions are offered.

Raised storage areas which are frequently erected in industrial and storage buildings are not subject to the minimum periods of fire resistance displayed in Table 4-1 if they meet certain conditions including limits on the area of the floor, no more than 100m^2. This limit can be removed if automatic sprinklers are installed.

Table 4-1 ADB recommended minimum periods of fire resistance (reductions with sprinkler provision are highlighted in green)

		Minimum FR periods [min.]	
Building type/use	Height [m]	Non-Sprinklered	Sprinklered
Offices	≤5m	30	30
	≤18m	60	30
	≤30m	90	60
	>30m	Not permitted	120
Hotels	≤5m	30	30
	≤18m	60	60
	≤30m	90	90
	>30m	120	120
Shop and commercial Inc. restaurants, bars, auction halls, banks, bookshops	≤5m	60	30
	≤18m	60	60
	≤30m	90	60
	>30m	Not permitted	120
Assembly and recreation e.g. schools, gyms, cinemas, libraries, dance halls	≤5m	60	30
	≤18m	60	60
	≤30m	90	60
	>30m	Not permitted	120
Industrial e.g. factories, workshops, power stations, garages	≤5m	60	30
	≤18m	90	60
	≤30m	120	60
	>30m	Not permitted	120
Warehouses	≤5m	60	30
	≤18m	90	60
	≤30m	120	60
	>30m	Not permitted	120

Compartments should be limited in size according to the height of a building and its intended use. Automatic sprinklers either remove limits on compartment sizes, or increase them in the following situations:

- Single-storey shops: 2,000 m^2 to no limit
- Multi-storey assembly, recreational and commercial building: 2,000 m^2 to 4,000 m^2
- Multi-storey industrial building not more than 18 m: 7,000 m^2 to 14,000 m^2
- Multi-storey industrial buildings more than 18 m: 2,000 m^2 to 4,000 m^2

- Single-storey storage building not more than 18 m: 20,000 m^2 to no limit
- Single-storey storage building more than 18 m: Not permitted to no limit
- Multi-storey storage building not more than 18 m: 20,000 m^3 to 40,000 m^3 (compartment volume)
- Multi-storey storage building more than 18 m: 4,000 m^3 to 8,000 m^3 (compartment volume)

ACCESS TO BUILDINGS FOR FIRE-FIGHTING PERSONNEL

Buildings must be designed so that fire-fighting personnel have access without delay and with a sufficient operating base which allows effective action to be taken. The installation of automatic sprinklers allows the number of firefighting shafts and fire mains to be reduced:

- If the building is not fitted with sprinklers, then sufficient firefighting shafts should be provided such that every part of every qualifying story is no more than 45 m from a fire main outlet in a protected stairway.
- If the building is fitted with sprinklers, then sufficient firefighting shafts should be provided such that every part of every qualifying story is no more than 60 m from a fire main outlet in a firefighting shaft.

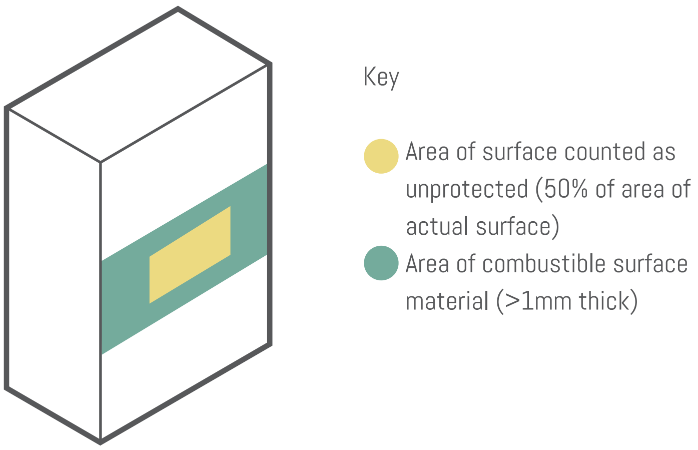
Smoke extraction and venting can benefit firefighters in performing their duties whilst also benefiting those evacuating a building. This is enhanced in basements where there is less opportunity for the heat and smoke to be vented outside via the windows as would happen above ground. Accordingly standard guidance recommends that sufficient ventilation is provided for large basement areas (larger than 200m^2). This can be achieved via openable natural vents but this can be difficult to achieve on a congested site due to the large vent discharge area required at ground floor. Alternatively automatic sprinklers can be used in tandem with a mechanical ventilation system. This has the advantage of requiring a smaller vent discharge area reducing the impact the chosen solution has on the building layout at ground level[3].

[3] In this scenario, it is not considered necessary to install sprinklers on the storeys other than the basement unless they are needed for other reasons.

EXTERNAL FIRE SPREAD / FIRE-RATED FAÇADES

To prevent fire spread between buildings ADB recommends that a portion of the building's façade should be fire-resistant or adjacent buildings be sufficiently separated. The amount of the façade required to be fire-rated is proportional to the distance between the façade and the site boundary. Automatic sprinklers are recognised as a significant inhibitor of fire size and therefore fire spread. ADB accordingly states that radiation from a sprinklered building on fire can be assumed to be halved and allows the separation distances required between buildings to be halved or the proportion of the façade that can be unprotected / non-fire-resistant to be doubled.

Figure 4-1 Defining non-fire-rated/unprotected façade area



4.4 BS 9999: AUTOMATIC SPRINKLER COMPENSATION BENEFITS

BS 9999 provides an advanced and flexible approach in building design; it describes a risk-based approach where designers can take into account design benefits such as the inclusion of automatic sprinklers.

Within BS 9999, buildings are rated on their risk to life in the event of a fire by assigning risk profiles to classify the building in terms of occupant characteristics (Table 4-2) and fire growth rates (Table 4-3).

Table 4-2 BS 9999 occupant characteristics

Occupancy characteristic	Description	Examples
A	Occupants who are awake and familiar with the building	Office and industrial premises
B	Occupants who are awake and unfamiliar with the building	Shops, exhibitions, museums, leisure centres, other assembly buildings, etc.
C	Occupants who are likely to be asleep:	
Ci [A)]	Long-term individual occupancy	Individual flats without 24 h maintenance and management control on site
Cii [A)]	Long-term managed occupancy	Serviced flats, halls of residence, sleeping areas of boarding schools
Ciii	Short-term occupancy	Hotels
D [B)]	Occupants receiving medical care	Hospitals, residential care facilities

[A)] Categories Ci and Cii are included for completeness within this table but are covered in more depth in BS 9991.

[B)] Currently occupancy characteristic D, medical care, is dealt with in other documentation and is outside the scope of this British Standard.

Table 4-3 BS 9999 fire growth rates

Category	Fire growth rate [A)]	Fire growth parameter [C)] kJ/s³	Description	Typical examples [B)]
1	Slow	0.003	Evenly distributed low level fire load, small discrete packets of fuel or material of limited combustibility [D)]	Reception areas, concourses (without concession outlets) and halls with limited fire load such as sports stadia and foyers
2	Medium	0.012	Evenly distributed low to mid-level fire load comprising a mix of combustible materials	Offices, lounges, classrooms, auditoria, seating areas, galleries and car parks [E)]
3	Fast	0.047	Stacked combustibles (on or off racking and shelving but excluding high rack storage), some small quantities of materials other than materials of limited combustibility [D)] (or where larger quantities are stored in separate fire resisting enclosures), process, manufacturing or storage of combustible materials	Shop sales areas[F)], workshops, factories and small storage buildings
4 [G)]	Ultra-fast	0.188	Medium to large quantities of materials other than materials of limited combustibility [D)], high racked storage, flammable liquids and gases or where rapid uncontrolled fire growth could occur	Warehousing [H)], processing plants and car parks [E)] utilizing a car stacker or similar method where there is no fire separation between stacked cars

[A)] These categories are related to the fire growth rate and not the ultimate potential fire size.

[B)] These are examples only and may be varied according to the specifics of the building/room contents.

[C)] This is discussed in PD 7974-1.

[D)] Limited combustibility is defined in 3.77 and includes for this purpose materials also defined in 3.85 as non-combustible.

[E)] Includes both open and non-open sided car parks.

[F)] Includes covered shopping complexes and department stores as well as high street shops and premises for personal services, delivery and collection of goods for cleaning/repair/treatment either carried out by staff or by members of the public themselves. Combustibility, quantity and how goods are displayed should also be taken into account and the risk category amended accordingly.

[G)] See Table 4. This category is unacceptable unless a sprinkler system is installed.

[H)] This is a worst case assumption. Combustibility, quantity and the way in which goods (including packaging) are stored should be taken into account and the risk category amended accordingly.

Automatic sprinkler systems can provide an efficient means of fire control within a building compartment. Consequently, the installation of an automatic sprinkler system throughout a building allows the fire growth rates that are determined to be reduced by one category. E.g. an industrial premises containing stacked cardboard boxes and wooden pallets, and occupants who are familiar with the building receives a risk profile of A3. The inclusion of an automatic sprinkler system reduces the risk profile to A2. The extent of fire safety measures and design features required in a building is proportional to the risk profile. By reducing the risk as a result of installing an automatic sprinkler system, fewer additional safety measures are required.
Where only part of a building contains automatic sprinklers, only the areas that are covered may be subject to a risk category reduction. Corridors and linking spaces from sprinklered rooms should also be covered by sprinklers, or separated by fire resisting construction.

BUILDING LAYOUT / MEANS OF ESCAPE

Reducing the risk profile (by incorporating automatic sprinklers) allows more time for escape by occupants. Consequently longer travel distances (Table 4-4), narrower door widths (Table 4-5) and narrower stair widths (Table 4-6) are allowed to achieve the same level of fire safety.

Table 4-4 BS 9999 maximum permissible travel distances

Travel distance when minimum fire protection measures are provided[A)]		
Risk profile	Travel distance, in metres (m)	
	Two-way travel	One-way travel
A1	65	26
A2	55	22
A3	45	18
A4[B)]	Not applicable[B)]	Not applicable[B)]
B1	60	24
B2	50	20
B3	40	16
B4[B)]	Not applicable[B)]	Not applicable[B)]
C1	27	13
C2	18	9
C3[B)]	14	7
C4[B)]	Not applicable[B)]	Not applicable[B)]
Where exact travel distances are not known, direct distances should be taken as two thirds of the travel distance.		

E.g. A building rated B3 has a maximum permissible one-way travel distance of 16 m and two-way travel distance of 40 m. The provision of automatic sprinklers reduces the risk profile to B2, allowing one-way travel distances up to 20 m and two-way travel distance up to 50 m.

Table 4-5 BS 9999 Minimum permissible door widths

Door widths when minimum fire protection measures are provided	
Risk profile	Minimum door width per person (mm)
A1	3.3
A2	3.6
A3	4.6
A4[A)]	Not applicable[B)]
B1	3.6
B2	4.1
B3	6.0
B4[A)]	Not applicable[B)]
C1	3.6
C2	4.1
C3[A)]	6.0
C4[A)]	Not applicable[B)]

E.g. A building with a risk profile B2 must contain doors with a minimum width of 4.1 mm per person. The installation of automatic sprinklers reduces the risk profile to B1 allowing minimum door widths of 3.6 mm per person.

Table 4-6 BS 9999: minimum permissible stair widths

Door widths when minimum fire protection measures are provided										
Risk profile	1 floor	2 floors	3 floors	4 floors	5 floors	6 floors	7 floors	8 floors	9 floors	10+ floors
A1	3.90	3.40	2.95	2.45	2.15	2.00	1.80	1.70	1.50	1.40
A2	4.50	3.80	3.25	2.75	2.45	2.20	2.00	1.90	1.70	1.60
A3	5.40	4.60	4.00	3.50	3.10	2.80	2.60	2.30	2.10	2.00
A4 A)	–	–	–	–	–	–	–	–	–	–
B1	4.20	3.60	3.10	2.60	2.30	2.10	1.90	1.80	1.60	1.50
B2	4.80	4.00	3.40	2.90	2.60	2.30	2.10	2.00	1.80	1.70
B3	7.00	6.00	5.30	4.60	4.20	3.70	3.40	3.10	2.80	2.60
B4 A)	–	–	–	–	–	–	–	–	–	–
C1	4.20	3.60	3.10	2.60	2.30	2.10	1.90	1.80	1.60	1.50
C2	4.80	4.00	3.40	2.90	2.60	2.30	2.10	2.00	1.80	1.70
C3 A)	7.00	6.00	5.30	4.60	4.20	3.70	3.40	3.10	2.80	2.60
C4 A)	–	–	–	–	–	–	–	–	–	–

E.g. a two-storey building in planning is to have a risk profile of A2, but the designers decide to include an automatic sprinkler system throughout. The risk profile is reduced to A1, either allowing an increase in the number of occupants permitted to use the stair or a reduction in the overall stair size (from 3.8mm/person to 3.4mm/person). The impact of this on a scheme will vary case-by-case.

Where two or more stairways are provided, it should be assumed that one of them might not be available due to fire or smoke and must be discounted unless:

- The stairs are protected by a lobby; or
- The stairs are protected by a smoke control system designed in accordance with BS EN 12101-6; or
- Automatic sprinklers are installed throughout the building.

For phased evacuation, two floors are used for the stair width calculations; the following table compares the improvements for different risk profiles:

Table 4-7 Impact of sprinklers on the variation of stair widths in BS 9999

Risk profile	Min. stair width factor (2 floors) [mm/ppl]		Reduction [%]
	Non-Sprinklered	Sprinklered	
A2: Offices	3.80	3.40	11%
A3: Teaching Labs	4.60	3.80	17%
B2: Restaurants	4.00	3.60	10%
B3: Libraries	6.00	4.00	33%
C2: Hotels	4.00	3.60	10%

For example; a seven-storey office building (risk profile A2) with open-plan area of 1,200m^2 per floor (200 ppl/floor).

- Non-sprinklered – Simultaneous evacuation strategy: the minimum width of the stairs would be 1,200ppl x 2.2mm = 2,640mm
- Sprinklered – The risk profile reduces to A1. Simultaneous evacuation strategy: the minimum width of the stairs would be 1200ppl x 2.0mm = 2,400mm.
- A reduction of 9% (240mm) in the width of stair is achieved when sprinklered. If multiplied by 10m (typical staircase length per storey) this gives an additional 2.4m^2/floor of useable floor space.

Another example is a six-storey library building (risk profile B3) with floor area of 1,400m^2 per floor (200 ppl/floor).

- Non-sprinklered – Simultaneous evacuation strategy: the minimum width of the stairs would be 1,000ppl x 4.2mm = 4,200mm.
- Sprinklered – The risk profile reduces to B2. Simultaneous evacuation strategy: the minimum width of the stairs would be 1,000ppl x 2.6mm = 2,600mm.
- A reduction of 38% (1,600mm) in the width of stair is achieved when sprinklered. If multiplied by 10m (typical staircase length per storey) this gives an additional 16m^2/floor of useable floor space.

FIRE FIGHTING ACCESS

BS 9999 provides the same concession as ADB in regards to the impact of providing automatic sprinklers on the number of firefighting shafts and basement smoke ventilation discussed earlier (see section 4.3)

PASSIVE STRUCTURAL FIRE PROTECTION

Elements of structure should have a minimum period of fire resistance to maintain the integrity and insulation of the building so that occupants can escape. The resistance required depends on the risk profile of the building but principally provides the same guidance as ADB.

FIRE SPREAD AND COMPARTMENTATION

BS 9999[4] states that radiation emitted from a building is halved by the action of automatic sprinklers and allows separation distances to be halved and unprotected areas to be doubled if automatic sprinklers are installed.

Compartments should be limited in size according to the risk profile of the building (Table 4-8). The provision of automatic sprinklers reduces the risk profile by one category and reduces the limits on compartment sizes.

Table 4-8 BS 9999 – maximum permissible building height and floor area

Maximum dimensions of compartments			
Risk profile	Single storey		Multi storey
	Maximum floor area m²	Height of top floor m	Maximum area of any floor m²
A1	No limit	No limit	No limit
A2	No limit	<30 ≥30	No limit 4,000
A3	No limit	<18 18 to 30 ≥30	14,000 4,000 Not acceptable
A4[A)]	Not applicable[A)]	Not applicable[A)]	Not applicable[A)]
B1	No limit	No limit	No limit
B2	No limit	<18 No limit	8,000 4,000
B3	2,000	<30 ≥30	2,000 Not acceptable
B4[A)]	Not applicable[A)]	Not applicable[A)]	Not applicable[A)]
C1	No limit	No limit	No limit
C2	No limit	No limit	No limit
C3[B)]	No limit	Not applicable	Not applicable
C4[A)]	Not applicable[A)]	Not applicable[A)]	Not applicable[A)]

A) These categories are outside the scope of the standard.
B) Risk profile C3 is unacceptable under many circumstances unless special precautions are taken.

4 For larger buildings BR187 External fire spread: building separation and boundary distances provides more detailed guidance.

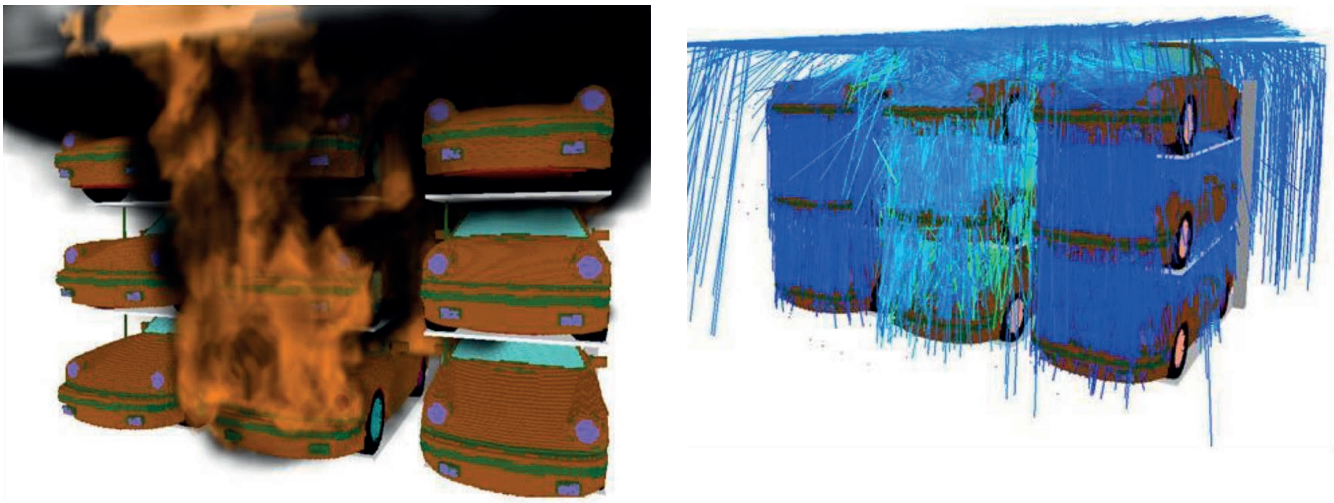
4.5 FIRE ENGINEERING

Fire engineering (also referred to as performance-based design) is defined as tailoring the fire systems and design features to a specific building and the risks within it. One of the key ways fire engineering is employed is to improve the efficiency of the design solution achieved when compared to the standard fire safety guidance (i.e. Approved Document B and BS 9999).

Standard guidance such as ADB or BS 9999 recognises the value of a fire-engineered approach (e.g. BS 7974 and PD 7974 series), particularly for large or complex buildings or where specific features of a building require a unique solution.

Fire engineering often utilises cutting-edge tools that have undergone rigorous processes of validation and verification by different parties/stakeholders (governmental bodies, insurance sector, construction industry, and academia). These tools range from CFD simulation models that allow interrogation of real-time fire and smoke production in 3D simulations (see Figure 4-2) to probabilistic risk-based models, and detailed analysis of structural behaviour in fire.

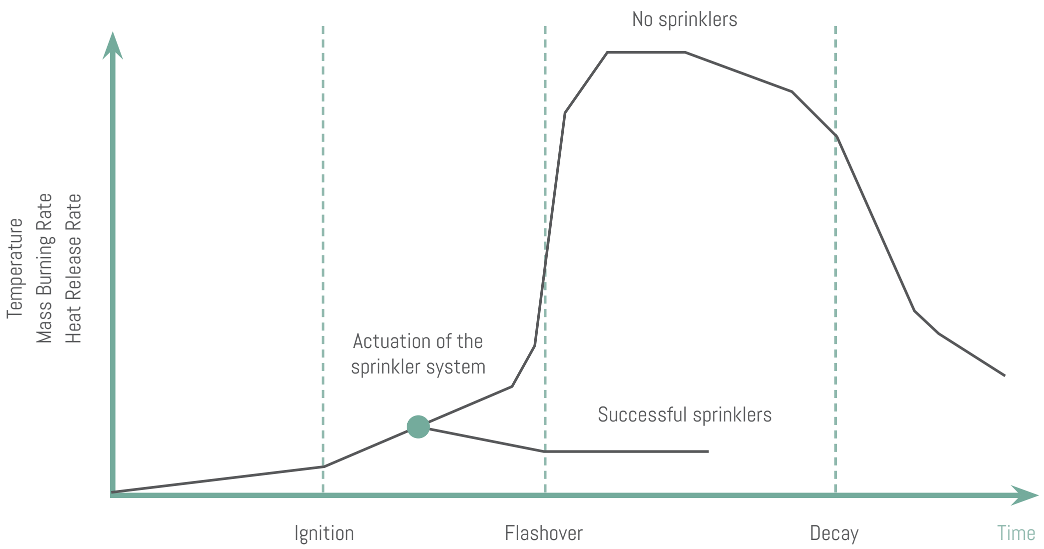
Figure 4-2 Example of output from CFD model: Car stacker fire without and with sprinklers



The main objective of CFD simulations of fire scenarios is to predict the development of the fire while taking into account building layout, fire management measures, occupant profile, etc. This then allows the designer to assess if the design satisfies the fire safety objectives defined for the project.

The impact of an automatic sprinkler system on a typical compartment fire is demonstrated in Figure 4-3 where a comparison is made between the development of fire in an enclosure with and without automatic sprinkler systems in terms of the fire growth rate and size. By limiting these characteristics (or by extinguishing a fire) other fire protection measures can be altered accordingly, such as reducing stair numbers and passive fire protection. Other important fire characteristics (e.g. smoke production, flame size, etc.) follow the same pattern shown in Figure 4-3.

Figure 4-3 Sprinklers' typical impact on the development of a compartment fire



The impact of automatic sprinklers on the evacuation process is subject to the complexity of the building. In a high-rise building with phased evacuation automatic sprinklers can have a major impact on extending the time allowed for evacuation, but for small or simple buildings with simultaneous evacuation, the impact is much lower.

Table 4-9 Impact of sprinklers on various elements of fire strategy

FIRE STRATEGY ELEMENTS	SPRINKLERS IMPACT
Building characteristics	Medium
Design fire	High
Occupant characteristics	None
Evacuation strategy	High – for complex geometry Low – for simple geometry
Environmental influences	High – for buildings with high fire load with potential harmful emission
Rate of smoke production	High
Flame size	High
Smoke and hot gas temperature	High
Fire spread from enclosure	High
Structural failure	High
Detection and warning systems	None – Low
Fire service intervention	High

Automatic sprinklers are used to mitigate risks in industrial and storage premises that have high fire loads with harmful material content (e.g. oil tanks/wells and wood manufacturing facilities). Automatic sprinklers have heat detection mechanisms implemented in their design; in certain situations (where the fire objective does not rely on early detection) sprinkler heads can aid in detecting a fire therefore reducing the necessity to install automatic fire detection and alarm systems.

However, there are areas where fire protection measures can delay or interfere with the operation of one another. For example natural smoke control systems that rely on the buoyancy of the smoke layer will be impaired by the cooling effect of automatic sprinklers whilst the cooling effect of smoke ventilation systems can delay the activation of the sprinkler heads. Therefore careful design specification that accounts for these effects is required.

These elements (shown in Table 4-9) collectively inform the impact of automatic sprinklers on the fire design strategy. Fire engineering solutions can then be developed and tailored to achieve specific project requirements such as functionality, efficiency and improved aesthetics.

For example, sufficiently large warehouses / manufacturing facilities may pose a national environmental risk if they are involved in a fire because of the large amount of smoke that would be released from uncontrolled burning of the building's contents (e.g. a fire at the Hanbury Plastics factory in Milton, Stoke-on-Trent in Feb 2017 produced smoke that could be seen from about five miles away as residents were asked to stay indoors [5]). Therefore, elements of the fire strategy may require enhancing to mitigate the special risk presented by the building. These enhancements can be fire protection measures like automatic sprinklers, smoke control, compartmentation etc. that can be tailored to the specific risks identified.

An example is presented in Section 6.5 where financial efficiency was achieved via a fire engineering solution that relied on the control of the fire at the source using a suppression system. Eventually, the structural fire protection for the building was completely eliminated after analysing the enhancement measure of incorporating an automatic sprinkler system into the building and showing that it can compensate for the required level of fire protection.

[5] The smoke produced from the fire was intense and affected the nearby residential area. https://www.thesun.co.uk/news/2788471/firefighters-tackle-huge-fire-at-plastics-recycling-centre-in-stoke-as-thick-plume-of-smoke-is-visible-for-miles/

5. FIRE PROTECTION COSTS

5.1 INTRODUCTION

This section provides background information on the pricing used within this document to determine the cost efficiency of different combinations of fire protection measures. It has been compiled based on our knowledge of building design with support provided by a qualified quantity surveyor to ensure a reasonable level of reliability in the figures quoted. The main references used here are Spon's price books and the figures should be seen as indicative. Variations will occur for local reasons (e.g. central location means difficult access and parking) and, regional variations to building costs quoted here are estimated to be between +6% (in central London) and -10% (in Wales).

To enable comparison between different fire protection measures and the impact of different design features, costs are typically converted to a unit cost per m^2 of floor area.

Further financial savings through reduced insurance premiums may also be realised although they are not considered further in this report.

5.2 COSTS OF WATER AUTOMATIC SPRINKLER SYSTEMS

An approximate estimate of installing automatic sprinkler systems to establish viability is given as follows:

- Sprinkler infrastructure: equipment installation, pipework, valve sets, booster pumps and water storage = £60,000 - £80,000
- Price per sprinkler head; including pipework valves and supports = £180 per head

Whilst the infrastructure cost (£60,000-£80,000) does vary depending on the building size, it only does so in a minor fashion due to fact that automatic sprinklers are designed to operate a fixed number of heads independent of floor area. Therefore as the building grows in size, the cost associated with the infrastructure does not vary significantly. This means that the cost efficiency of automatic sprinklers generally increases with building size.

The number of sprinkler heads required varies depending principally on the type of risk to be protected (i.e. category of building type) and layout. For most building types, automatic sprinklers are orientated on a 4m x 3m ceiling grid which gives 1 sprinkler head per $12m^2$ but as noted above, that is an ideal situation and further heads will be required to suit internal partitions and different building footprints. Therefore 15% has been added to the above figure to give a £/m^2:

- £180 per head;
- 3m x 4m coverage from a single head;
- 15% layout allowance.
- Total = £17.25/m^2 GIA[6] + Sprinkler infrastructure (£70,000)

[6] Gross Internal Area that includes; all areas occupied by internal walls and open-sided covered areas, but excludes; open balconies, open fire escapes, and open-sided covered ways. It is the total floor area of all storeys, not the building footprint area.

Other factors may influence the area of coverage such as whether a building has deep ceiling voids which may need protection or sterile areas such as stairs and toilets that may not.

For a comparison the rates shown in Table 5-1 are "Shell and Core" costs for installing automatic sprinkler systems (including the water supply) for Offices with GIA between 3,000 – 15,000 m^2 and hotels (2 to 5 stars). These rates highlight the variability in costs between building types.

Table 5-1: Generic pricing – sprinkler system installation

Building use	Installed as part of building shell Rate /m^2	Installed as part of building fit-out Rate /m^2
Office – central London	£16.37	£21.21
Office – regional (average)	£14.73	£19.08
Warehouse (fitted racking installed)	£42.32	n/a
Hotels (2 – 5*)	£20 – 30	n/a

To ensure these generic rates shown above (Table 5-1) are reasonable, specific cases of cost analyses provided by Spon's price book (shown in Table 5-2) are reviewed;

1. Installing a sprinkler system in the office building example shown in Table 5-2 costs £316k and averages to £16.37/m^2 GIA. This rate is within the generic ranges quoted earlier (i.e. £17.25/m^2 + £70k and £15-20/m^2).

2. In another example, the costs of providing automatic sprinkler system and dry risers to a 4* hotel were £596k and averaging to £36.12/m^2. In order to compare this figure (£36.12/m^2) with £20-30/m^2 from Table 5-1 the cost of dry risers has to be discounted leaving the rate as £26.12/m^2. This rate £26.12/m^2 falls almost in the middle of the generic price range shown in Table 5-1 and confidence can be placed in the values presented.

These examples demonstrate that the actual cost of installing automatic sprinkler system for each building depends on many factors, however the rates quoted in Table 5-1 can be used as a guide for estimating costs based on GIA.

Table 5-2: Real examples of installing sprinkler system costs in different types of buildings

Case study	Total Sprinkler Cost	Cost / m^2 GIA
Office building located in Central London, 15 floors, GIA = 19,300 m^2	£316,000	£16.37/m^2
4* Hotel, 200 bedrooms, located in Central London, 10 floors, GIA = 16,500 m^2	(inc. dry risers) = £596,000	(inc. dry risers) = £36.12/m^2
Airport terminal building located in the South East, GIA= 25,000 m^2	£790,000	£31.60/m^2
Shopping mall located in the South East comprised;		
Two storey retail area, GIA = 33,000 m^2	£415,000	£12.57/m^2
Covered car park, GIA = 13,000 m^2	£270,000	£20.76/m^2
Distribution centre (Warehouse), located in outer London, GIA = 75,000 m^2 (inc. refrigerator area GIA=17,500m^2)	(inc. racking protection)= £3,174,000	£42.32/m^2

5.3 COSTS OF DRY RISERS

The incorporation of automatic sprinklers into building design can be used to justify a reduction in the number of dry risers required in a building. All-in rates for approximate estimates of installing dry risers are as follows:

- 100mm dry riser + 2-way breeching valve and box (65mm landing valve + padlock + leather strap + automatic air vent + drain valve) = £1,500 per landing

The number of risers required depends on the layout of the building, as the minimum requirement is reported as "reach" from the dry riser outlet to completely cover the floor plate.

Different estimates for costing the installation of dry risers per GIA for offices and hotels are also quoted in Spon's (see table 5-3). If an automatic sprinkler system is installed, a reduction of the number of dry risers by up to 33% (based on the 33% increase in reach from 45m to 60m) is theoretically possible. This is tabulated below.

Table 5-3: Generic pricing – "Shell and Core" installation of dry risers

Building type	Dry risers cost £/m^2 GIA	Potential savings £/m^2 GIA
Offices (3,000 – 15,000 m^2)	3 – 5	1
Hotels	8 – 12	2-4

5.4 COSTS OF STAIRCASES

One of the impacts of incorporating automatic sprinkler systems on the capital cost is to use the increased fire protection offered to look at the possible removal of escape staircases. The cost associated with constructing a staircase in an office building in central London with 13 floors is estimated at £200k with an average of c. £15k per floor. Stairs may also require secondary fire protection measures such as fire-rated lobbies and smoke ventilation systems. An example of the latter is a stair pressurisation system for which a rate of £6/m^2 GIA is applicable.

5.5 COSTS OF GLAZING

Prices for fitting different types of glazing internally for compartmentation purposes (inclusive of labour costs) are as follows:

- 60min fire-resisting glazing = £600/m^2
- 30min fire-resisting glazing = £426/m^2
- Standard non-fire-resisting glazing = £40/m^2

The above prices are for glass that can be used within the building interior, i.e. protected corridors, atriums etc. For external glazing, a self-conducted market survey yielded the following for rates for fire-rated façade systems. These have additions such as fire treatment on the glass itself, increased robustness of the frame and intumescent sealing of the edges:

- Non-FR glazed façade (£500/m^2 – £700/m^2)
- 30-min FR glazed façade (£900/m^2 – £1,000/m^2)
- 60-min FR glazed façade (£1,600/m^2 – £1,800/m^2)
- 90-min FR glazed façade (£2,000/m^2 – £2,400/m^2)
- 120-min FR glazed façade (£3,000/m^2 – £3,400/m^2)

5.6 COSTS OF STRUCTURAL FIRE PROTECTION

Prices for providing fire protection to steel structures expressed as cost per m^2 rate of surface area of the steel:

- Spray
  - 60min-FR range (£8.55/m^2 – £12.30/m^2)
  - 90min-FR range (£14.30/m^2 – £20.00/m^2)
- Intumescent coating
  - 30min-FR range (£8.70/m^2 – £11.10/m^2)
  - 60min-FR range (£11/m^2 – £23.50/m^2)
  - 90min-FR range (£32/m^2 – £39/m^2)
  - 120min-FR range (£48/m^2 – £59/m^2)
- FR boarding
  - 30min-FR range (£29/m^2 – £45.50/m^2)
  - 60min-FR range (£41/m^2 – £62/m^2)

This can be converted (approximately) to a more practical rate per floor area. Typical steel structure in buildings is 50 kg/m^2 GIA (gross internal floor area). Typical steel mass per surface area in a structural element is 40 kg/m^2. Therefore a price in (£ per painted surface area) can be converted to the conventional cost unit of £/m^2 GIA;

£/m^2 GIA = (£/m^2 surface area) x (50 kg/m^2 GIA) ÷ (40 kg/m^2 surface area)

- Spray
  - 60min-FR range (£10.69/m^2 GIA – £15.38/m^2 GIA)
  - 90min-FR range (£17.88/m^2 GIA – £25.00/m^2 GIA)
- Intumescent coating
  - 30min-FR range (£10.88/m^2 GIA – £13.88/m^2 GIA)
  - 60min-FR range (£13.75/m^2 GIA – £29.38/m^2 GIA)
  - 90min-FR range (£40/m^2 GIA – £48.75/m^2 GIA)
  - 120min-FR range (£60/m^2 GIA – £73.75/m^2 GIA)
- FR boarding
  - 30min-FR range (£36.25/m^2 GIA – £56.88/m^2 GIA)
  - 60min-FR range (£51.25/m^2 GIA – £77.5/m^2 GIA)

5.7 SUMMARY OF CAPITAL COSTS

Total cost of sprinkler system installation (ordinary hazard classification)	= £70k + (GIA x £17.25/m^2)
Total cost of dry risers	= £1,500 x number of floors x number of risers
Cost of a staircase	= £15k x number of floors x number of staircases

Total cost of façade glazing per façade area:

- Non-FR glazed façade (£500/m^2 – £700/m^2)
- 30-min FR glazed façade (£900/m^2 – £1,000/m^2)
- 60-min FR glazed façade (£1,600/m^2 – £1,800/m^2)
- 90-min FR glazed façade (£2,000/m^2 – £2,400/m^2)
- 120-min FR glazed façade (£3,000/m^2 – £3,400/m^2)

Table 5-4 Cost of sprinklers vs. potential savings

Sprinkler system cost (OH) = £70k + (GIA x £17.25)	
Potential savings on	
Dry risers	= £1-3/m^2 GIA
Staircases	= £15k/floor/staircase removed
Façade FR glazing system	= up to £2,700/m^2 x wall area
Structure FP	= £10.88-77.50/m^2 GIA

5.8 LIFECYCLE COSTS

The values given above are those associated with capital costs. The lifecycle cost associated with each measure varies although it should be factored in when considering the lifespan of a building. For this report, lifecycle costs are not explicitly considered because they will be project-specific and complex to estimate.

6. COMMERCIAL SECTOR APPLICATION (OFFICES)

6.1 INTRODUCTION

This chapter deals specifically with commercial offices. For most building types, including offices, standard fire safety guidance (ADB / BS 9999) recommends that where there is a storey above 30m in height it should be fitted throughout with an automatic sprinkler system. The life safety benefit of automatic sprinklers is valued highly by the approval authorities (i.e. local Fire and Rescue Service, Building Control) such that derogating from this particular recommendation would be a major fire engineering challenge and the project would be unlikely to get approval. Therefore the focus herein will be on buildings where installing an automatic sprinkler system is optional (i.e. below 30m / 8 storeys).

This chapter is broken down into 4 sections based on the objectives considered:

- Capital cost;
- Lifecycle cost;
- Construction programme;
- Aesthetics / designer freedom.

6.2 COST OF OFFICE SPRINKLERS

Automatic sprinklers have a cost that scales with an office size, although there is also a non-scalable cost associated with the infrastructure, i.e. storage tanks, pumps and power supplies. This cost can be offset by rationalising other aspects of the fire safety design as previously described. This section details how and where this can be achieved specifically for new-build office developments.

6.3 COST OF OFFICE BUILDING CONSTRUCTION

To aid cost comparisons made in this section the cost of constructing offices requires identifying. Current 2016 rates are £1,800-£2,500/m^2 subject to location and internal specification.

6.4 CAPITAL COST IMPACTS: FAÇADE SPECIFICATION

For offices, glazed facades are now very common offering impressive and visually impactful features. They are desirable since they provide natural lighting, are aesthetically pleasing and provide a visual connection between the inside and outside of a building. The external glazed façades / cladding typically account for 15 to 25% of the construction cost.

Figure 6-1 Commercial façades help create a landmark building

Wall to floor ratios of between 0.40 and 0.50 are good but a variation of 0.1 can change the overall construction costs by 4 to 5%. Extensive party walls will result in reduced external wall costs whilst floor-to-floor heights have a marginal impact on overall cost. Plan and elevation complexity, curves, setbacks and other features will have a significant impact on design, buildability and cost, including the loss of economies of scale associated with standard construction.[7]

[7] (http://www.building.co.uk/cost-model-office-design/3044443.article)

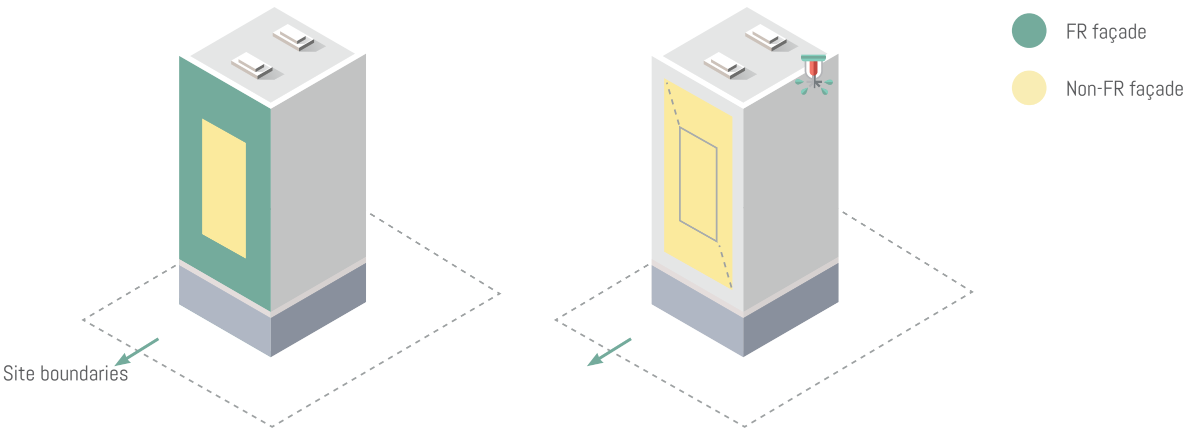
In summary, a building's façade, particularly for an office, is a sensitive part of building design both in terms of capital cost and aesthetics. It is one of the more common areas where automatic sprinklers can be used to gain an advantage even though standard guidance does not necessarily recommend them.

The link between façade specification and automatic sprinklers arises because there is a need to ensure that the risk of external fire spread between buildings is controlled. This is done either by, or through a combination of, fire rating the façade of buildings or providing adequate separation.

In cities space is limited and therefore expensive so there are obvious gains from maximising the building footprint within a site boundary / plot and building density is increasing. The combination of the above factors therefore leads the designer to desiring a glazed façade whilst building close to the site boundary. Standard guidance would recommend large amounts of fire-rated glazing being required for a building for the purpose of preventing fire spread between different buildings.

Fire-rated glazing is readily available from variety of suppliers but comes with two drawbacks; cost and weight. The heavier fire-rated glass has to remain in place during a fire and therefore a steel frame is required rather than aluminium. Automatic sprinklers provide a positive impact on the required fire rating since they reduce the thermal radiation emitted from a fire. Approved Document B and BS 9999 recognise this and permit the separation between buildings to be halved or the area of the fire-rated façade to be halved. It is considered that the rule of thumb presented within standard guidance is conservative and that a fire engineering approach can achieve greater dispensation when tailored to a specific project.

Figure 6-2 Effect of sprinklers on non-fire-rated facades



MAXIMISING VALUE ADDED

As shown in the following sections, incorporating an automatic sprinkler system in an office building could yield sufficient savings on the cost of the façade to fully offset the cost of the automatic sprinkler system through the difference between the cost of fire-rated and non-fire-rated glazing. The key factors to whether these savings can be realised on a specific building are:

- The distance between the building and the site boundary;
- The ratio of floor area vs. length of relevant façade, i.e. a rectangular building with the longest side facing the site boundary will yield the greatest benefit;
- Desirability of a fully-glazed façade, i.e. could a solid fire-resisting façade be used instead?

FAÇADE AREA VS. BOUNDARY DISTANCE

Figure 6-3 shows the relationship between the percentage of allowable non-fire-rated façade and the distance to the site boundary. This is based on the recommendations given within BR187[8] to prevent external fire spread. For a site with a fixed distance to the boundary[9] it shows that the amount of fire-rated façade increases proportionally to the size of the building / façade (i.e. the larger the building the greater % of the façade that must be fire-rated). The figures are presented for a single storey (4m slab to slab height) and multi-storey (27m building height) where the façade length is fixed at 30m. The exercise is repeated allowing for automatic sprinklers showing that the percentages of allowable non-fire-rated façade or separation distance are approximately doubled when they are provided.

Figure 6-3 Variation of the required façade fire rating depending on building size, site boundary distance and sprinkler provision

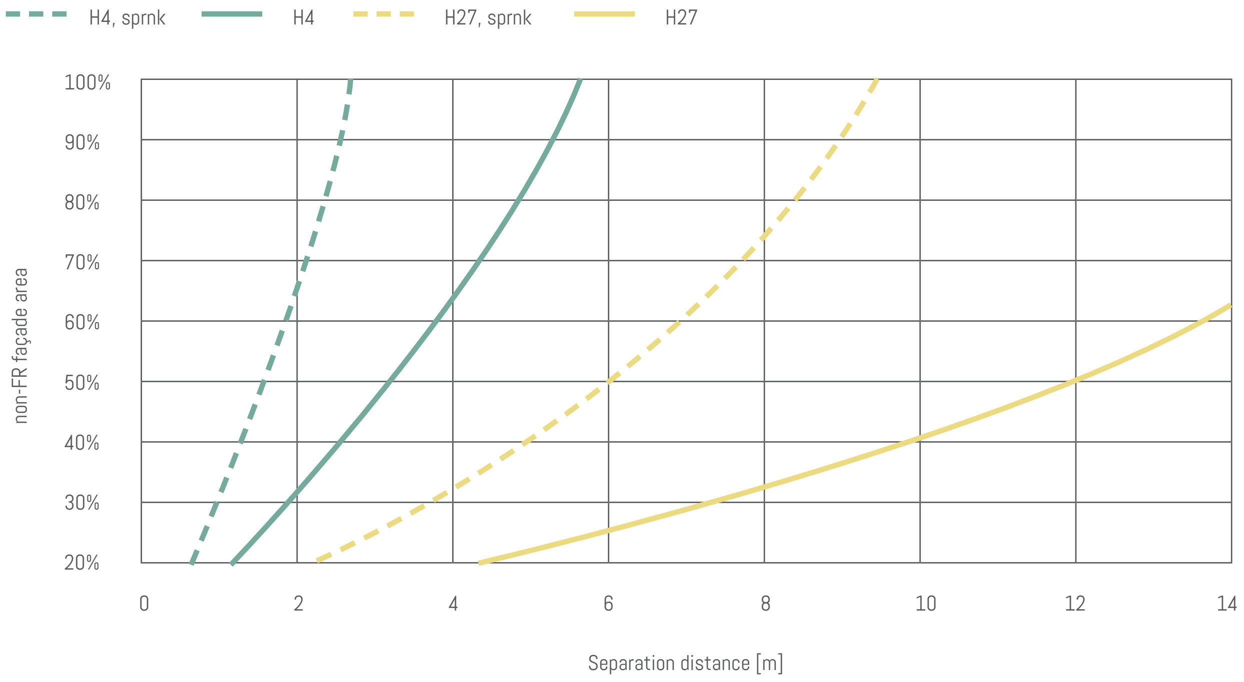


Figure 6-4 presents the reduction in the area of fire-resisting facade required for the two example building sizes when installing an automatic sprinkler system. It shows how for each building size there is a 'sweet spot' in terms of boundary distance and building size where automatic sprinklers provide the greatest reduction in the required facade fire protection.

[8] Chitty, R. (2014) BR 187: External fire spread: Building separation and boundary distances (BR 187). Second edition. Watford, United Kingdom: IHS Building Research Establishment Press.

[9] In most projects, the building location within the site is chosen based on commercial factors and will not be altered to satisfy a fire safety objective.

Figure 6-4 Reduction of required façade fire rating achieved by sprinkler provision

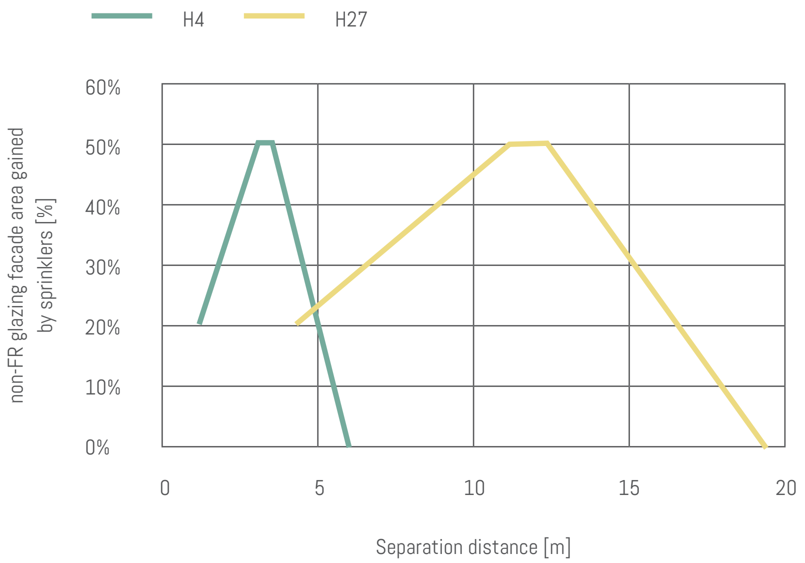
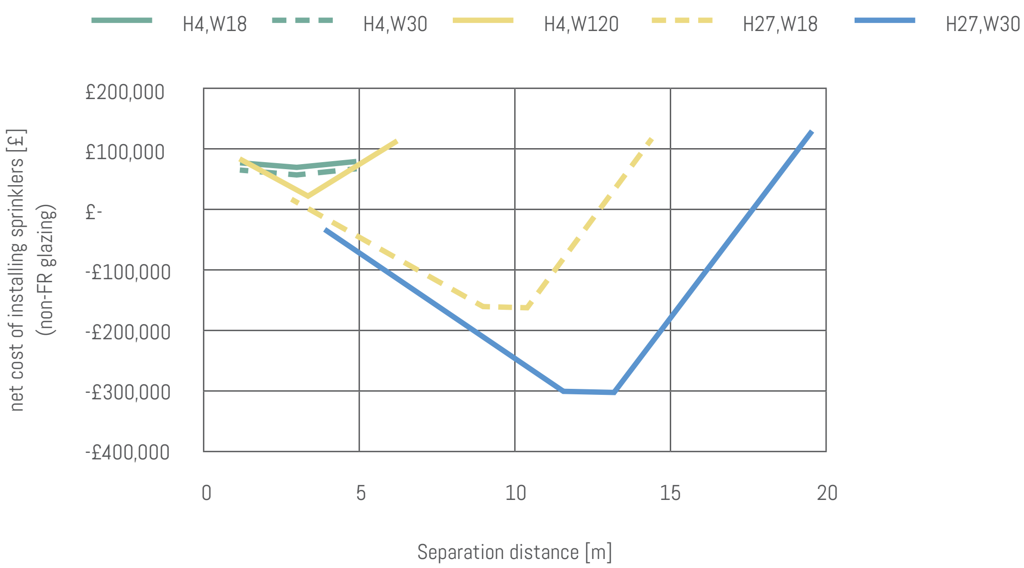


Figure 6-5 shows the overall net cost impact of installing automatic sprinklers after the savings on passive fire protection are included for a range of uncompartmented office building sizes and boundary distances. It highlights that for smaller buildings the cost impact is minimal whilst for larger buildings or those located at a specific distance, the entire cost of the automatic sprinkler system can be offset by the savings made in reducing the amount of fire rated glazing required.

Figure 6-5 Net cost of sprinklers accounting for savings in structural fire protection
(H = Building height in [m], W = building width in [m])



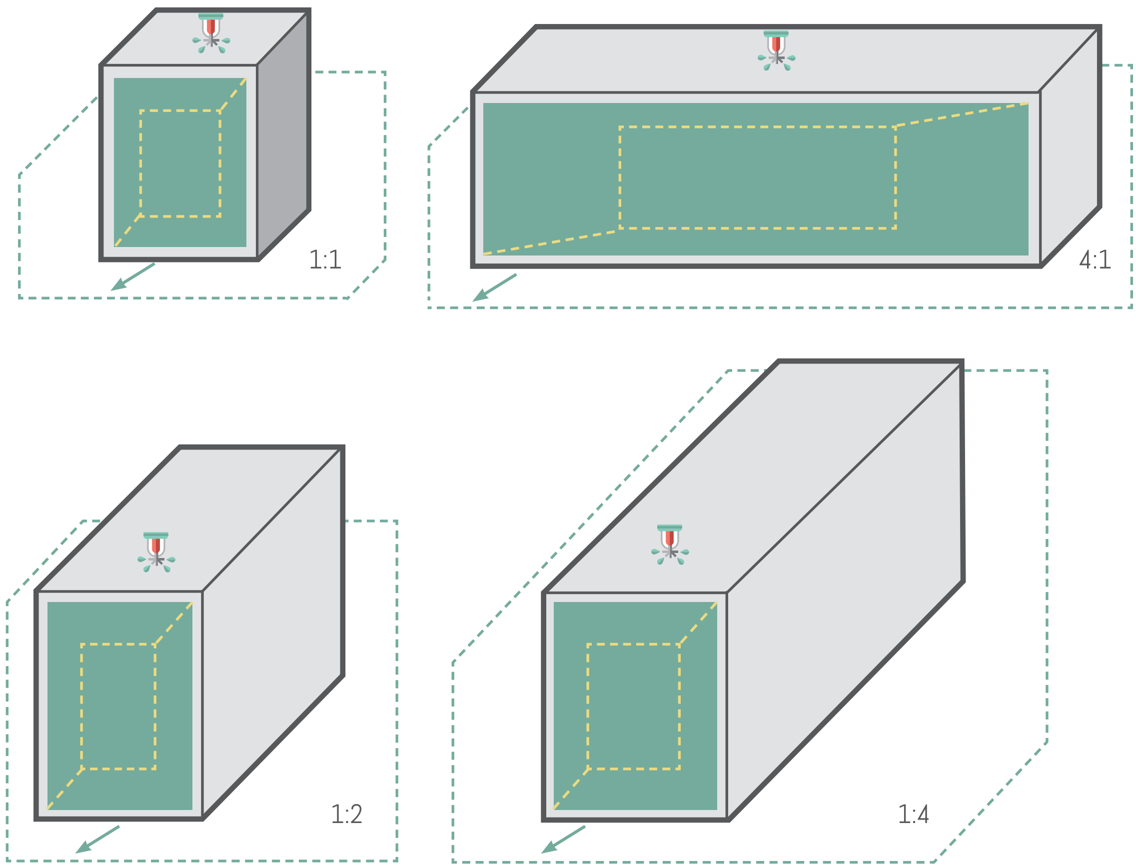
USING FIRE ENGINEERING TO DERIVE FURTHER VALUE

The savings presented in relation to the façade above are based on the use of standard guidance. Fire engineering can yield further value with each case being assessed individually to develop a building-specific solution. For the case study presented under the Aesthetics Section, the options under standard guidance would have been either to provide a fire rating to a section of the façade, change the façade to a solid material or introduce internal compartmentation to sub-divide the floorplate. Whilst the section of façade requiring treatment was only 10m long, the building is 280m high, giving a total façade area of 2,800m^2. Being a high-profile project, consideration of a fire-rated façade was made. However, the cost difference between installing 60-min FR glazing and non-FR glazing is c. £1,100/m^2 giving a total cost of c. £3.0m. The building incorporated compartmentation and automatic sprinklers to satisfy other fire safety objectives regardless of the façade so this serves as a good example of how fire engineering can maximise the benefits of automatic sprinkler installation.

RATIO OF FLOOR AREA VS. LENGTH OF RELEVANT FAÇADE

Another factor in deriving the comparison between the cost of automatic sprinklers against the cost of the façade is the shape of the building, expressed as the ratio of the façade width vs. the building depth. Figure 6-6 shows different ratios.

Figure 6-6 Different ratios of façade length to building depth



This ratio affects the cost efficiency of automatic sprinklers and requires evaluation along with any impact on the required fire rated façade. In the examples given in Figure 6-6, where a long façade is required to be fire-rated as shown in the 4:1 ratio example it would be more cost-effective to install automatic sprinklers whereas for the 1:4 example it would be less effective. This is because automatic sprinklers are required to be installed throughout the building rather than just on the elevation of concern.

FAÇADE COST SUMMARY

- A building's façade may need to be fire-rated depending on a number of factors: building shape and size, compartmentation, proximity to the boundary and the amount of glazing contained in the façade.
- The cost of a fire-rated glazed façade is significant and of a similar order to that associated with automatic sprinklers.
- Automatic sprinklers can be a cost-saving alternative to passive fire protection.
- The optimum size for a building to benefit from automatic sprinklers as an alternative to a fire-rated façade would be between 3 and 8 storeys with a boundary distance closer than 15m.

Each building will have a unique combination of factors and would need to be reviewed by a competent person to assess the cost impact on a scheme from the installation of automatic sprinklers.

6.5 FIRE-PROTECTION OF STRUCTURAL ELEMENTS

Standard fire safety guidance states that the level of structural fire protection required can be reduced when automatic sprinklers are provided. In particular, for buildings up to 18m high, providing automatic sprinklers can reduce the structural fire resistance from 60 minutes to 30 minutes, whilst for those buildings between 18m and 30m high it can be reduced from 90 minutes to 60 minutes.

The cost impact of this reduction can be measured against the cost of the automatic sprinklers. To conduct the comparison the costs associated with intumescent coatings have been used as follows (see Section 5.5):

- 30min-FR £12.38/m^2 GIA
- 60min-FR £21.57/m^2 GIA
- 90min-FR £44.38/m^2 GIA
- 120min-FR £67/m^2 GIA

Different approaches to achieve required fire protection for steel structures can be followed. Intumescent coating is one of the common methods. Rates for cement spray are marginally less than the rates given above whilst rates associated with fire rated boarding are greater. Therefore the rates above are a reasonable mid-point.

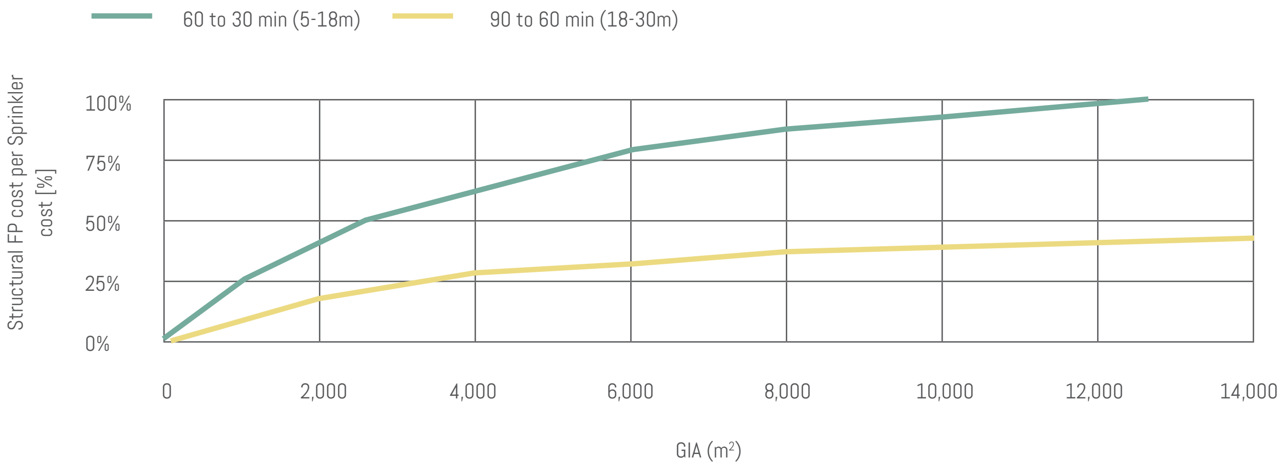
Applying the rates to the reduced structural fire protection gives;

- Reduction from 60 to 30 min-FR saves £9.19/m^2 GIA[10];
- Reduction from 90 to 60 min-FR saves £22.81/m^2 GIA;
- The automatic sprinkler system cost was estimated using the calculation method discussed earlier in section 5 (i.e. £70k + £17.25/m^2 GIA).

Figure 6-7 shows the expected returns by varying the gross internal floor area (GIA). It highlights that a significant portion of the automatic sprinkler installation cost can be offset by savings made via reduced passive fire protection.

[10] Midpoints of price ranges have been used

Figure 6-7 The reduced cost of structural fire protection expressed as a % of sprinkler cost



6.6 NET INTERNAL AREA

By incorporating automatic sprinkler systems into an office building, the net to gross internal area ratio can be increased by reducing the size and number of escape routes (i.e. stairs and corridors). This can then be expressed in terms of rental yield for offices since these values are readily available, as follows[12]:

- London £650/m²/yr,
- Manchester £320/m²/yr,
- Birmingham £270/m²/yr,
- Leeds £220/m²/yr, and
- Milton Keynes £190/m²/yr

The gains in terms of lettable area require evaluation against the cost of the automatic sprinkler system.
BS 9999 recognises the added value from incorporating automatic sprinkler systems in office buildings by extending permitted travel distances and reducing the width of escape routes including stairs. For example, a reduction of 8 - 11% on means of escape widths is readily achieved.

Table 6-1 Variation of means of escape width with and without sprinklers

Risk profile	A1/A2: Offices [mm/ppl]		Reduction [%]
	Non-Sprinklered	Sprinklered	
Min. stair width factor (2 floors)	3.80	3.40	11%
Min. exit width factor	3.60	3.30	8%

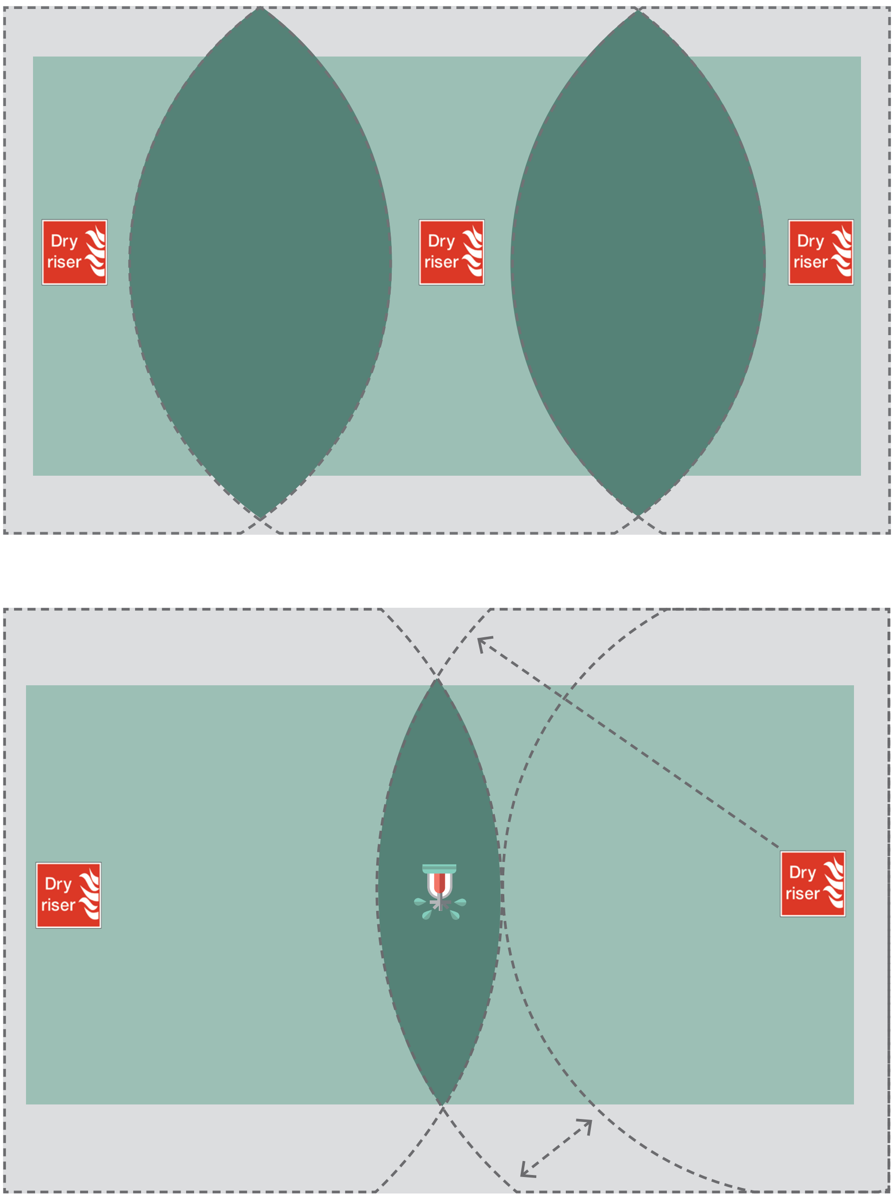
To equate this against the cost of automatic sprinklers is best demonstrated through an example. For a typical office with six storeys and two stairs, automatic sprinklers would enable the stairs to be reduced in width to create an additional c. 21m². Using rental values of £250 / m² / year the additional lettable area would yield £5,500 / year. An automatic sprinkler system would cost in the region of £240,000 which results in a long payback period (>30 years). However, this example is based on a real project where fire engineering was undertaken to justify the use of a single (slightly larger) stair rather than a two-stair design. The elimination of the stair created an additional c. 140m² across the building. Again using rental values of £250 / m² / year would yield £36,000 / year from the increase in lettable area comfortably reducing the payback period to less than 10 years. Clearly using higher rental values whilst also considering any reduction in escape corridor width would reduce the payback period further.

[12] Zoopla 09/2016

6.7 DRY RISERS

By incorporating automatic sprinkler systems in an office building, savings up to £10,000 per dry riser eliminated can be achieved. This is permissible in standard fire safety guidance which states that the hose reach from a dry riser can be increased from 45m to 60m when automatic sprinklers are provided. Depending on the layout of the building this extension may result in reducing the number of dry risers required in the building.

Figure 6-9 Impact of sprinkler on dry riser requirements



6.8 AESTHETIC IMPACTS

The inclusion of automatic sprinklers can have a positive impact on building aesthetics in much the same way as capital costs explained in the previous section. In particular, flexibility is introduced with regards to the façade material and internal layouts. Whilst sprinkler heads themselves are commonly considered visually unappealing, the use of concealed heads ensures that they can be discreet when desired. This section discusses the relevance of automatic sprinklers to aesthetics objectives.

FAÇADE MATERIAL

Standard fire safety guidance requires the façade to be fire-resistant where it is within a prescribed distance to the site boundary. The inclusion of automatic sprinklers allows these distances to be increased thereby reducing the controls required on the façade material. This is recognised in standard guidance and can be used as part of a fire-engineered design.

PROJECT EXAMPLE

PROJECT TEAM

Client: Brookfield Property Partners
Architect: Foster + Partners
Main contractor: Brookfield Multiplex
Structural Engineer: WSP Group
Building Services: WSP group
Cost Manager: T Clarke

Principal Place, London is a mixed-use scheme consisting of 600,000 sq ft of premium office, residential and retail space. It includes a brand new public piazza comprising half an acre of public realm and an events space along with more than 20,000 sq ft of retail space, including cafés and restaurants offering alfresco dining.

The 15 storey office block will include a full height internal atrium. It is located on a site with close boundaries and was required to have a section of the glazed façade to be fire-rated when applying the guidance of BR187.

An alternative, fire-engineered approach was applied which fully assessed the fire safety benefit of the inclusion of the automatic sprinkler system. This fire engineering assessment concluded that the automatic sprinkler system provided sufficient fire protection such that the façade could remain as the original design intended without any further measures such as the use of fire-rated glazing or the installation of fire resisting panels behind the glazing.

INTERNAL LAYOUT

Fire protection and safety requirements can restrict the flexibility of internal spaces via the need for adequate escape routes and fire separation between different areas. For office developments in particular, the number and size of stairs can be reduced through standard guidance or fire engineering on the basis of automatic sprinkler inclusion. Additionally, the maximum travel distances in an office building can be increased by c.15% when an automatic sprinkler system is incorporated. This provides flexibility in the location of staircases and reduces the necessity of introducing escape corridors.

ATRIUM DESIGN

Atria in offices are commonly incorporated for architectural, environmental and/or economic reasons. They are typically glazed to introduce natural lighting to create a more pleasant internal environment than using artificial lighting, whilst also reducing the energy consumption associated with electrical lighting. These factors aid in ensuring that new commercial developments meet the criteria for Grade A office space that is in high demand by top firms. Atria however pose a fire and smoke spread risk that can be addressed via a combination of compartmentation, automatic sprinklers and smoke ventilation. Automatic sprinklers are not commonly required for offices under 18m high so they can act as a trade-off for reducing compartmentation requirements and/or smoke ventilation system requirements. This is justifiable under BS 9999 as well as through fire engineering. Whilst the solutions will be project-specific, clearly reducing the separation requirements between the office floor plate and atrium will aid the overall project's objectives of including the atrium within the design.

6.9 CONSTRUCTION PROGRAMME IMPACTS

The majority of examples given can have an impact on the construction programme, typically through simplifying the design. This is countered by the need to install automatic sprinklers where potentially they would not have been required. Each case requires considering on its own merits where the benefits gained are considered against the impact.

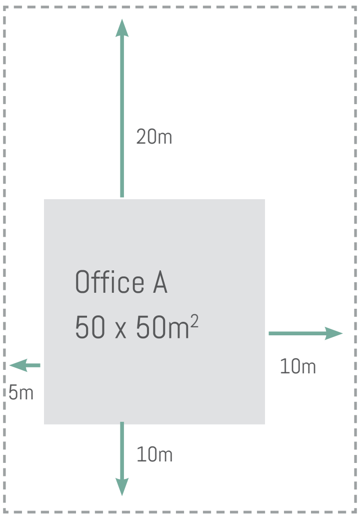
6.10 WORKED EXAMPLES

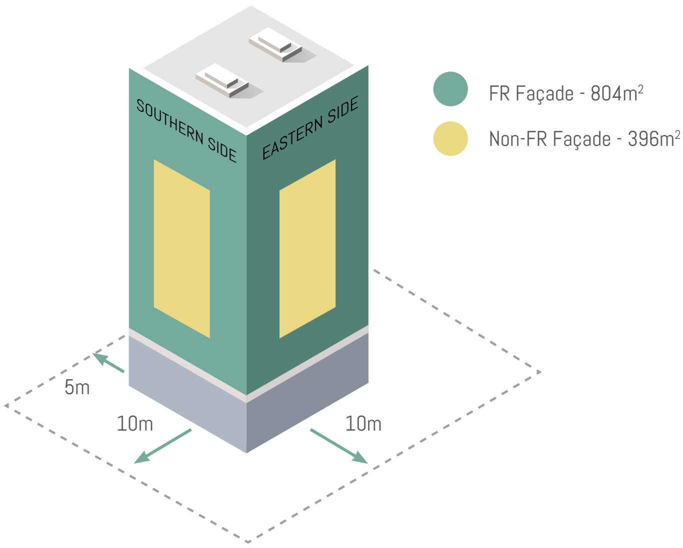
This section illustrates the details contained herein for offices to show where automatic sprinklers are likely to have the greatest impact.

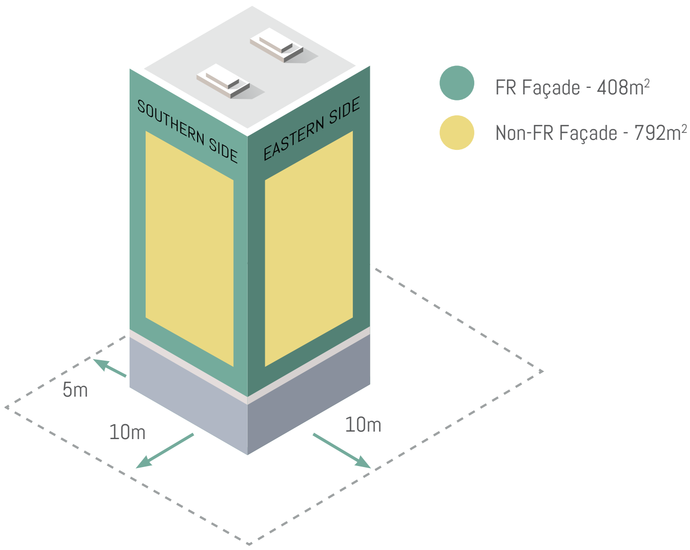
OFFICE BUILDING A:

This example features a six-storey office building located in central London with 15,000m^2 GIA and fully-glazed façades. The design guidance used is BS 9999 (no fire engineering) and the designs with and without automatic sprinklers are compared in terms of capital cost.

- Offices 50x50 m^2
- 6 storeys – c. 24m
- Separation distances are;
  - Northern side 20m
  - Eastern side 10m
  - Southern side 10m
  - Western side 5m
- Glazed façade
- 4 staircases







Firstly, the design impacts of incorporating an automatic sprinkler system on the fire protection measures are demonstrated in Table 6-2. Secondly, cost analysis of the impact is shown in Table 6-3.

Table 6-2 Impact of sprinklers on the required fire protection measures for Building A

BUILDING A	Without Sprinklers	With Sprinklers
Fire-rated façade area required	• Northern side (17%) = 204 m^2 • Southern side (67%) = 804 m^2 • Eastern side (67%) = 804 m^2 • Western side (80%) = 960 m^2	• Northern side (0%) = 0 m^2 • Southern side (34%) = 408 m^2 • Eastern side (34%) = 408 m^2 • Western side (60%) = 720 m^2
Stairs minimum width	1276 mm Stairs area 61.25m^2 per floor	1120 mm Stairs area 53.75m^2 per floor
Structural fire protection rating	90 minutes	60 minutes
Dry risers	3	2

Table 6-3 Cost analysis of incorporating sprinklers in Building A

BUILDING A	Without Sprinklers	With Sprinklers
Sprinklers installation cost	–	£328,750
Façade cost[13]	Non FR façade= 2,028m^2 x £600/m^2 = £1,216,800 90min-FR façade= 2,772m^2 x £2,200/m^2 = £6,098,400 Total = £7,315,200	Non FR façade= 3,264m^2 x £600/m^2 = £1,958,400 60min-FR façade = 1,536m^2 x £1,700/m^2 = £2,611,200 Total = £4,569,600
Structural fire protection cost	90min-FR = 15,000m^2 x £44.38/m^2 = £665,700	60min-FR = 15,000m^2 x £21.57/m^2 = £323,550
Rental yields derived from changes to net internal area	–	45m^2 x £650/m^2/yr = £29,250/yr
Dry risers costs	3 x £1,500/landing x 6 floors = £27,000	2 x £1,500/landing x 6 floors = £18,000
Total costs	£8,007,900	£5,239,900 - £29,250/yr
Total cost impact of sprinklers	Capital cost impact = £2,768,000 saved by including sprinklers Rental yield = £29,250/yr greater income by including sprinklers	

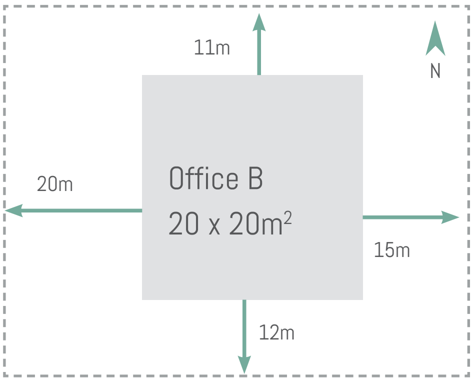
- **Verdict:** Installing automatic sprinklers in Building A can accumulate initial capital cost savings of c. £2.8M with an additional rentable area that can generate about £30k/yr. The additional rental income alone would pay for the automatic sprinkler system in 11 years. These values need to be used carefully however since there may be alternative measures that could be considered to reduce the cost of the façade such as an increase in compartmentation. This is particularly relevant here where the façade cost is high due to the need for fire-rated glazing. However, in this example automatic sprinklers have been shown that they can have a positive financial impact on a project.

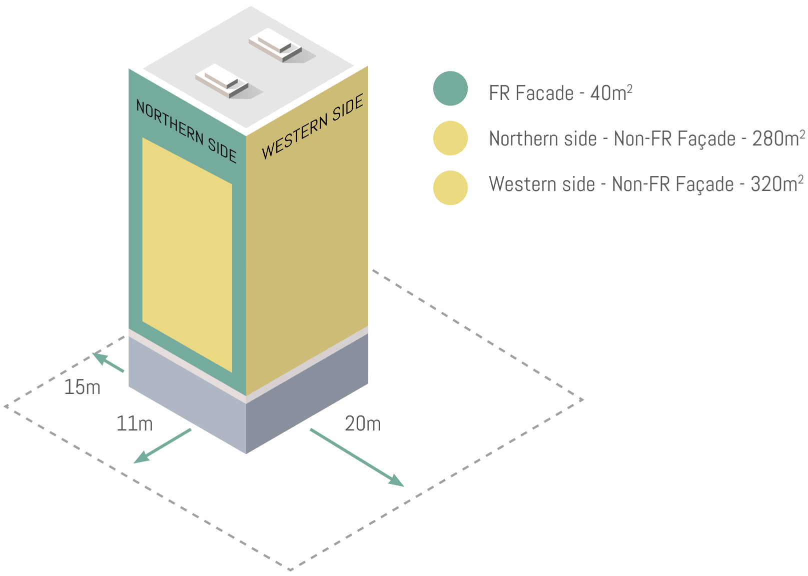
[13] Glazed fire-rated façade assumed required for aesthetic reasons by the client.

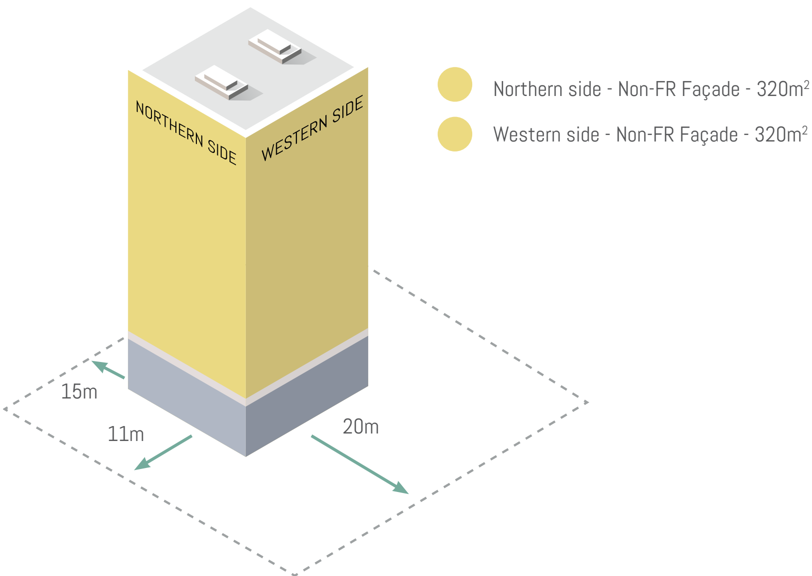
OFFICE BUILDING B:

The example features a four-storey office building located in Manchester with 1,600m^2 GIA and fully-glazed facades. The separation distances around the building are:

- Offices 20x20 m^2
- 4 storeys – c. 16m
- Separation distances are;
  - Northern side 11m
  - Eastern side 20m
  - Southern side 12m
  - Western side 15m
- Glazed façade
- Occupancy capacity of the building
- 2 staircases







Firstly, the impacts of incorporating an automatic sprinkler system on the fire protection measures are demonstrated in Table 6-4. Secondly, cost analysis of the impacts is conducted in Table 6-5.

Table 6-4 Impact of sprinklers on the required fire protection measures for Building B

BUILDING B	Without Sprinklers	With Sprinklers
Fire-rated façade area required	• Northern side (12.5%) = 40 m^2 • Southern side (0%) = 0 m^2 • Eastern side (0%) = 0 m^2 • Western side (0%) = 0 m^2	• Northern side (0%) = 0 m^2 • Southern side (0%) = 0 m^2 • Eastern side (0%) = 0 m^2 • Western side (0%) = 0 m^2
Stairs minimum width	1000 mm Stairs area 24m^2 per floor	1000 mm Stairs area 24m^2 per floor
Structural fire protection rating	60 minutes	30 minutes
Dry risers	1	1

Table 6-5 Cost analysis of incorporating sprinklers in Building B

BUILDING B	Without Sprinklers	With Sprinklers
Sprinklers installation cost	£0	£97,600
Façade cost[14]	Non FR façade= 1,240m^2 x £600/m^2 = £744,000 60min-FR façade= 40m^2 x £1,700/m^2 = £68,000 Total = £812,000	Non FR façade= 1,280m^2 x £600/m^2 = £768,000 Total = £768,000
Structural fire protection cost	60min-FR = 1,600m^2 x £21.57/m^2 = £34,512	30min-FR = 1,600m^2 x £12.38/m^2 = £19,808
Rental yields derived from changes to net internal area	0 m^2	0 m^2
Dry risers costs	1 x £1,500/landing x 4 floors = £6,000	1 x £1,500/landing x 4 floors = £6,000
Total costs	£852,512	£891,408
Total cost impact of sprinklers	Capital cost impact = £38,896 added to the project cost plan by including sprinklers	

- **Verdict:** Installing automatic sprinklers in Building B is shown to add cost to the project and would not be recommended when reviewed against the impacts (cost, aesthetics etc.) reviewed herein. Unless there is another requirement requiring their inclusion (business continuity, property protection)

[14] Glazed fire rated façade assumed required for aesthetic reasons by the client.

6.11 IN CONCLUSION

For office buildings it has been shown that the installation of automatic sprinklers can have a significant impact on three key areas as follows:

1. Façade material

Reduction of the fire resistance required for façades in office buildings which can impact on capital costs and building aesthetics. These gains depend mainly on three factors;

- Separation distance between the building and relevant boundary;
- Necessity of glazed façade; and
- Façade area.

2. Internal layout

Increased flexibility of internal layout design in office buildings (e.g. extended travel distances, increased internal area, etc.) can impact life-cycle costs and building aesthetics. The extent of these impacts depends on several factors such as:

- Building height;
- Complexity of layout;
- Building location.

3. Structural fire resistance

Reduction of the structural fire resistance required for office buildings can reduce capital costs. This depends primarily on the total section surface area that needs to be protected. Ultimately this can be quantified based on two factors;

- Building height;
- Building GIA.

In summary, it is concluded that the consideration of automatic sprinklers should be included as part of any robust design development of a new office project, particularly when the office is greater than three storeys and where the site boundary is close to the building façade.

Summary

The evidence contained within this report demonstrates the importance of considering automatic sprinkler systems. By identifying suitable applications where automatic sprinklers are appropriate and by incorporating them at the earliest stages of the design process, stakeholders can realise the added value and design options that can be created by their inclusion.

Whether you are building an office or hotel, a warehouse or industrial facility, the design solutions presented are always required to meet the life safety (fire) requirements of the building regulations. They highlight the potential advantages, many of which should either reduce the overall building cost, offer advantages in the overall building use or allow the approval of a particular design.

Automatic sprinklers can permit freedom of design which in turn can create savings in the initial capital and lifecycle costs and the construction programme. We trust this report will help stakeholders understand and appreciate the benefits of the investment in sprinkler systems and will encourage their consideration on more projects at the earliest stage possible.

Further Information

If you have any question regarding the impact of automatic sprinklers on building design, or would like to provide feedback on the content of this report, please do hesitate to contact us:
info@business-sprinkler-alliance.org

A FIRE ENGINEERING REVIEW

www.business-sprinkler-alliance.org

Business Sprinkler Alliance
53 Chandos Place
London WC2N 4HS

info@business-sprinkler-alliance.org