NHS Scotland Assure

Quality in the healthcare environment

NHS National Services Scotland

Automatic fire suppression system: Water-based sprinklers

Literature Review

27.03.2023

v1.0

NHSS Assure Tech HCS

Key Information

Document title:	Automatic fire suppression system: Water-based sprinklers: Literature Review
Date published/issued:	27.03.2023
Date effective from:	27.03.2023
Version/issue number:	v1.0
Document type:	Literature review
Document status:	Final
Author:	Joanne Kinloch (Lead author) and Laura Rodriguez-Labajos (Supporting author) Healthcare Scientists (Research) NHSS Assure
Owner:	NHSS Assure Tech Healthcare Scientist Team

Document information

Description:	This literature review examines the available professional literature on water-based sprinklers in the health and care setting.
Purpose:	To inform NHSScotland decisions on the feasibility of on water-based sprinklers.
Target Audience:	All NHSScotland staff involved in the procurement, design, maintenance, and operation of healthcare facilities in Scotland.
Update schedule:	Updated as required by SMEs, with changes made to recommendations as required.
Cross reference:	SOP Literature Review Process.
Update level:	Practice – Will be used to inform future SME/SHTM guidance and decisions related to sprinklers in healthcare settings. Research – Further experimental studies required. In addition to case studies of existing systems in Scottish healthcare premises.

Contact

NHSS Assure Tech Healthcare Scientist Team

Email: **NSS.assuretechhcs@nhs.scot**

Version history

This literature review will be updated, as required by SME, if any significant changes are found in the professional literature or from national guidance/policy.

Version	Date	Summary of changes
v1.0	27.03.2023	Final report

Approvals

Version	Date Approved	Name
v1.0	26.07.2022	SMEs/Fire Safety Advisory Group (FSAG)

Abbreviation list

Acronym	Definition
AFSS	Automatic fire suppression system
AHJ	Authority having jurisdiction
ASET	Available safe escape time
BAFSA	British Automatic Fire Sprinkler Association
BCR	Benefit-to-cost ratio
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
BS	British standard
BSA	Business sprinkler alliance
BSI	British Standards Institution
CIBSE	Chartered Institution of Building Services Engineers
CO	Carbon monoxide
CO2	Carbon dioxide
CPVC	Chlorinated polyvinyl chloride
DIP	Defend in place
FED	Fractional effective dose
FRS	Fire and Rescue Services
FSAG	Fire safety advisory group
HCl	Hydrogen chloride
HCN	Hydrogen cyanide
HFS	Health Facilities Scotland
ICU	Intensive care unit
LPC	Loss Prevention Council
LPS	Loss Prevention Standard
NFCC	National Fire Chiefs Council
NFIRS	National Fire Incident Reporting System
NFPA	National Fire Protection Association
NFSM	National Fire Sprinkler Association
NO	Nitric oxide
PD	Published documents

Acronym	Definition
PHE	Progressive horizontal evacuation
RSET	Required safe escape time
SD	Standard deviation
SFPN	Scottish Fire Practice Note
SHTM	Scottish Health Technical Memoranda
SME	Subject matter experts
SPFN	Scottish Fire Practice Note
TB	Technical Bulletin

Contents

1. **Introduction** 8

2. **Summary of Evidence** 10

3. **Methods** 17

4. **Results** 19

5. **Discussion** 20

6. **Implications for research** 47

7. **Conclusion** 48

8. **Summary of Key Findings** 49

9. **References** 55

Appendix 1: Search Strategy 57

Appendix 2: Flow of evidence screening 60

Appendix 3: Grades of recommendation 61

Appendix 4: SIGN 50 levels of evidence 62

1. Introduction

1.1. This review aimed to explore and understand the risk-benefit of water-based sprinklers applicable to health and care settings. Although this review was conducted through a systematic process, the gathered evidence primarily consists of statutory guidance, building regulations and expert opinion. The outcome of this review will inform the development of NHSScotland (NHSS) guidance, ensuring decisions are evidence-based and providing avenues for future research.

Review Questions

1.2. This literature review identified and assessed the extant professional and scientific literature regarding the risk-benefit of water-based sprinklers within fire experiments and health and care settings. To support this purpose, 13 research questions were developed in conjunction with the subject-matter experts (SME), which are:

- What are the national and international standards and recommendations for incorporating sprinklers within healthcare premises?
- What are the national and international standards and recommendations for incorporating sprinklers within residential care premises?
- What are the design trade-offs and compensatory features of implementing sprinklers?
- In the case of fire, what are the differences between full, partial or non-sprinklered environments?
- What are the statistics of fire suppression, fire deaths, and injuries internationally between premises with sprinklers installed compared to those without?
- What is the reliability and effectiveness of sprinklers?
- What are the operational consequences of sprinklers?
- What are the environmental impacts of sprinklers?
- What are the savings associated with implementing sprinklers in healthcare premises and residential care facilities?
- What is the disruption to business continuity in the event of a fire in full, partial or non-sprinklered healthcare premises and residential care facilities?
- What are the installation requirements and associated costs?
- What are the maintenance requirements and associated costs?
- What is the risk reduction to fire service personnel whilst carrying out firefighting operations within premises fitted with sprinklers compared to those without?

Report Structure

1.3. This review is structured as follows. Section 2 presents an overview of the evidence gathered. The review methodology is detailed in Section 3, providing details of the search strategy, inclusion and exclusion criteria and procedures. The outcome of the searches are described in Section 4, with Section 5 providing full details of the evidence summarised in Section 2, along with the associated references and areas for future research. The review concludes by summarising the extent and quality of the evidence (Section 6) and providing recommendations (Sections 7).

2. Summary of Evidence

2.1. This section summarises the evidence for each of the research question from Section *1: Introduction*. As already stated this evidence primarily consists of statutory guidance, building regulations and expert opinion. Full review of the evidence with findings can be found in Section *5: Discussion.*

What are the national and international standards and recommendations for incorporating sprinklers within healthcare premises?

2.2. Hospitals in Scotland only require sprinkler installation in specific areas, typically related to their vicinity to patient areas or high-dependency units. However, there are instances where additional or full sprinkler coverage may be required or recommended (Arup, 2006, 2019; BAFSA, 2016; HFS, 2007, 2013a; NFSM & NFCC, 2019) including:

- as part of fire safety engineering
- to protect vulnerable occupants
- in buildings over 25m
- where existing site constraints impact Fire and Rescue Services (FRS) activities
- in atriums with accommodation above and a high or unknown fire load
- to increase evacuation time and reduce numbers requiring evacuation
- in areas vulnerable to wilful fire-raising

2.3. Where installed in hospitals, sprinklers should comply with the standards in BS EN 12845 and the Loss Prevention Council (LPC) Rules.

What are the national and international standards and recommendations for incorporating sprinklers within residential care premises?

2.4. Scotland, Wales, USA, Hong Kong, Australia, Canada and New Zealand all recommend sprinklers in new or altered residential care premises and existing premises in Finland following a risk assessment. Although not required in England, their benefits are recognised within trade-offs specified in the regulations. Reoccurring reasonings for sprinklers cite serious fires and fatalities in residential care premises. The benefits of sprinklers in these premises are for protecting vulnerable occupants, affording additional evacuation time, reducing numbers requiring evacuation, and allowing a balance between fire safety and a comfortable living environment (i.e. furnishing and décor).

2.5. Where installed in UK residential care premises, sprinklers should comply with the standards in BS EN 9251. However, where the building height exceeds 20 m, any room exceeds 180 m2, or there are significant fire loadings, then BS EN 12845 should be applied.

What are the design trade-offs and compensatory features of implementing sprinklers?

2.6. Most trade-offs and compensatory features are achieved through fire safety engineering. However, caution should be taken due to the complexity of a project utilising this approach, and consultation with a fire engineer/consultant is recommended. However, sprinkler trade-offs can also be achieved through designing with the 'time equivalence' method (BS EN 1991-1-2) or a performance-based approach to means of escape design (PD 7974: Part 6).

2.7. There are various cost savings and design flexibility that can be achieved through sprinkler installation (Arup, 2006; Scottish Government, 2019; BAFSA, 2010; BAFSA, 2016; HFS, 2013a; HFS, 2013b), including:

- increased compartment volumes and sizes
- increased distance from the fire mains outlet
- increased areas of external and internal glazing
- increased flexibility concerning existing site constraints
- increased escape travel distances
- increased capacity to use 'unacceptable' hazards
- reduced number of firefighting shafts
- reduced external fire spread space separation between buildings or compartments
- reduced fire-resisting materials and/or passive fire protection measures
- reduced minimum compartments floor areas
- reduced replacement air changes within a mechanical smoke clearance system
- reduced exit width
- allowing the use of basement mechanical smoke extraction system
- allowing for improved quality of life in residential care premises by considering human factors, which might be regarded as "high risk" of fire
- In healthcare and residential care premises, specifically:
    - increased number of beds contained in bedrooms from one
    - increased the number of beds in protected areas to more than ten
    - reduced levels of protection to escape routes
    - reduced extent of automatic detection systems
    - allowing the use of thermally activated dampers instead of fire and smoke dampers
    - no requirement for self-closing bedroom doors

In the case of fire, what are the differences between full, partial or non-sprinklered environments?

2.8. Simulations and experiments conducted in residential care bedrooms and hospital rooms concluded those in non-sprinklered environments are more likely to suffer quicker from heat exposure and extensive third degree burns. In the room of fire origin, conditions can be considered lethal in 3 minutes. In sprinklered environments, this timeframe can be extended to 5 minutes. Sprinkler activation reduces heat transfer, toxic gases, smoke, and flashover; allowing tenable conditions for those out with the room of origin and, in most cases, those not directly involved in the fire within the room. It also increases escape time and keeps fires small for FRS arrival.

2.9. It is essential to highlight that there can be "worse case" conditions with sprinkler activation; the door to room of fire origin left open, small room volumes, leakage from poorly maintained fire doors, sprinklers not fully extinguishing the fire, and slow developing or shielded fires.

What are the statistics of fire suppression, fire deaths, and injuries internationally between premises with sprinklers installed compared to those without?

2.10. In case of fire, sprinklers can reduce injury by half, chances of death by 50%-75%, hospital treatment by 22%, and being overcome by smoke by 30%. People are 18% more likely to receive a precautionary check, the lowest recordable level of support, at the scene.

2.11. Vulnerable occupants in residential care premises are most at risk, with 32% and 48% of fire fatalities occurring during escape or within the bedroom, respectively. Findings from the US, which have mandated sprinklers in residential accommodation, have had one death in a sprinklered fire in over 30 years.

What is the reliability and effectiveness of sprinklers?

2.12. Sprinklers have reported figures of 88-99% for reliability, 85-97% for effectiveness, and, when activated, have effectively controlled fires in 96-99% of instances. Once activated, fires have been controlled in 62% and extinguished in 37% of cases. UK Sprinkler temperature activation is 57°C or 68°C and can activate in 2mins for fast growing fires and 8-10mins for slow growing fires, with experiments showing this is 72 seconds on average.

2.13. Sprinklers' state of "readiness" is a known quantity due to frequent and thorough maintenance and obvious defects. PD7974- 7 probability figures show successful sprinkler activation between 75% and 95%. The use of third-party certified sprinkler installers, maintenance companies and sprinkler components can increase the reliability of the system's anticipated effective performance and components in the event of a fire. However, there is not the same maintenance required for passive systems, which may also be installed incorrectly, be improperly used, or have no site-specific fire training for locum staff on fire policies and procedures. Therefore, passive fire measure probability shows a 30% chance of fire doors being blocked open, a 20% chance of failed closure of self-closing fire doors, and fire resisting structure of suspended ceilings partition walls only having a 25% and 65% chance of achieving 75% protection. Frequently mentioned in expert opinion are human factors concerning residential care premises, which include difficulties with self-closing doors, a requirement for assisted evacuation and monitoring, extending evacuation periods (particularly at night), and a tendency to take familiar (and not escape) circulation routes.

2.14. Reported figures state that sprinklers fail to operate in only 7% of building fires. However, this number may be overrepresented, as successful sprinkler operation may not always be recorded. Delay in sprinkler activation can occur by heat conduction to the sprinkler pipes, sprinkler orientation, airflow deflection, the latent heat of fusion for solder links, and compartmentation, which may prevent smoke getting to a detector (or conversely concentrate smoke and lead to earlier detection). Issues in sprinkler systems are predominantly due to water supplies, human error, management, and systems maintenance. Investigation into sprinkler non-operation shows most common reasons are the system being shut off, manual intervention defeating the system, the fire in an area not covered by the system or insufficient heat.

What are the operational consequences of sprinklers?

2.15. Some reported operational consequences of sprinklers include cooling of the hot smoke causing down drag and poor visibility, thermal shock leading to breaking glass and reduction in effectiveness of natural smoke exhaust systems. However, there is a consensus of expert opinion that the advantages of sprinklers in fires "far outweigh" these operational consequences, and people will often be moving away from fire vicinity before their occurrence.

2.16. There is limited risk of electrical conduction, boil over of hot oil, spuriously operating of the sprinkler head, or legionella infection. This can be further reduced through routine inspection and maintenance, installing sprinkler head guards (or concealed heads), and connection to an existing legionella monitoring system.

What are the environmental impacts of sprinklers?

2.17. The sustainability benefits of sprinklered fires can include lower carbon emissions, reduced water use, reduced consequences for the wider environment and local communities, and reduced contamination of firefighting water runoff to watercourses and drainage systems. In addition, due to trade-offs for installing sprinklers, they can reduce the requirement for non-sustainable fire-resisting materials and contribute towards sustainability standards within BREEAM or similar schemes.

2.18. Sprinklered fires are reported to use 6-10 times less water compared with FRS intervention in non-sprinklered fires. Another source has reported this as 0.02% to 17% of the water used in non-sprinklered fires. This figure does not account for recycled and reused water, estimated to be utilised in 70-80% of new systems. Sprinklered fires release between an estimated 7.8% and 21.6% fewer carbon emissions than non-sprinklered fires, including installation, operation and maintenance, and their use to control fires in 5,000-10,000m^2 buildings over a 30-year lifespan. In addition, water use and damage is limited, as sprinkler heads operate independently, and only those in the direct vicinity of the fire open; figures determine that 65% of fires are controlled by only one head, and 85% with fewer than four.

What are the savings associated with implementing sprinklers in healthcare premises and residential care facilities?

2.19. A 2004 cost-benefit analysis UK report concluded sprinklers would be cost-effective in residential care premises but not in other premises: accounting for installation costs, water supplies, maintenance and testing, fatality and injuries reduction, and property loss savings. Subsequently leading to Scotland's recommendation for sprinklers in residential care premises. Some of the cost benefits not considered in the report, which could result in further savings, are reduced environmental impacts, reduced insurance premium (65-75%), reduced property damage with associated business interruption and social impact, post fire trauma and ongoing treatment, design trade-off savings and FRS savings. Other countries' reports conclude sprinklers are not cost-effective without low costs or trade-offs.

2.20. A 2009 report commissioned by the Scottish Government, and supported by a 2011 report by NHSS FSAG, concluded that the costs of installing automatic fire suppression systems exceed the quantified benefits and provided statistics that between 2001-2007 very few NHSS healthcare premises were involved in a fire, 84% where limited to the room of origin and no associated deaths occurred.

What is the disruption to business continuity in the event of a fire in full, partial or non-sprinklered healthcare premises and residential care facilities?

2.21. In a non-sprinklered fire 70% of a compartment area and 50% or more of the building can be structurally damaged, compared with 10% and none in sprinklered fires. Damage can be reduced by approximately 50% when sprinklers operate and can reduce property loss anywhere between 34 and 68%. In residential premises a non-sprinklered fire can cause: a significant loss of funding and revenue (not always covered by insurance) while closed for repairs, distress for residents through relocation, families or resident's decision to permanently relocate to another residential care premises and for staff, additional travel or commuting difficulties and even temporary job loss. Sprinklers can allow businesses to continue the following day, whereas non-sprinklered premises can be out of action for considerable periods or even permanently; figures reporting that more than 50% of all businesses cease to trade within two years of experiencing a fire.

2.22. Between 2001-2007 in NHSS healthcare premises, 84% of fires were limited to the room of origin, with evacuation from the room required in 71% of instances. The average length of evacuation was 30 minutes, with 82% evacuated for less than one hour, 60% of premises unavailable for one day or less, and 23% unavailable for between two and seven days.

What are the installation requirements and associated costs?

2.23. Water supplies must provide sufficient flow and pressure and include a review of water source, building height, size and construction and hazard classification. Water storage and pipework requirements should be considered in the early design stage to ensure sympathetic design choices. Sprinkler installation should comply with BS EN 12845, BS EN 805, BS EN 806, BS 8558, and the LPC rules for automatic sprinkler installations; with specialist, trained and experienced personnel undertaking sprinkler system design, installation, and maintenance. In the UK, this is often third-party certificated installers. Prior to the system to becoming operational, leakage, hydraulic and alarm tests and a complete visual inspection must be conducted and passed. A compliance certificate that details the system's compliance with British Standards (BS) is issued. Under the LPS 1048-1 scheme, the sprinkler contractor issues a third-party Certificate of Conformity for each system installed.

2.24. The main cost associated with sprinklers is the capital cost of installation, which could equate to 2-3% of the construction cost or between 0.1% to 3% of the capital cost of the building in healthcare premises. However, it is case specific and can vary widely. 2006 estimated installation costs for a 26 bed residential care premises average

£7,800. 2009 figures for healthcare premises vary widely between £26 and £800 per m2, with an average of £32.

What are the maintenance requirements and associated costs?

2.25. Sprinklers should be maintained according to the installation standard used to design the system. BS EN 12845 and Technical Bulletin TB 203 detail service, maintenance and inspection programme covering the lifecycle of the sprinkler system, which, if well maintained, could be 50 years. Weekly and monthly inspections should be carried out by competent onsite personnel. In addition, they should schedule quarterly, half yearly and yearly routine tests, service and maintenance by a competent (typically third-party certified) sprinkler contractors. There may be addition inspection requirements carried out by insurance surveyors , FRS inspectors and/or certification scheme assessors. Records of maintenance and works done should be kept for a minimum of three years. The weekly tests should be carried out on all water and air pressure gauge readings, water levels, position of main stop valves, the alarm, and any automatic pumps and power supplies.

2.26. Suitable contingency plans should be adopted during periods of sprinkler downtime. These can be to restore the systems quickly, limit shutdown to periods of limited building use and high-risk processes, division through fire resisting materials, zone systems to prevent whole system ineffectiveness, training additional staff, more immediate evacuation strategies, informing FRS, and notifying users.

2.27. Estimated annual maintenance costs are difficult to quantify but can be in the region of 10% of the original capital cost. 2009 figures for healthcare premises vary widely between £3 to £22 per m^2 (average of £8).

What is the risk reduction to fire service personnel whilst carrying out firefighting operations within premises fitted with sprinklers compared to those without?

No evidence was identified by this review regarding this topic.

3. Methods

3.1. A systematic literature review was chosen for this topic as it entails a thorough, transparent, and replicable literature search and analysis process. This review was produced using an established two-person systematic methodology, which will be briefly discussed in this section. The research questions informed the search terms presented in Table 3-1. A search strategy was subsequently developed and adapted for three electronic databases (Embase, Medline, and Scopus); details of these are in Appendix 1. A search of grey literature was conducted in Google, Google Scholar, and Barbour and in relevant databases/organisation relevant to the topic as provided by SME (i.e. BAFSA).

Table 3-1: Search terms

Word Group 1 (Setting/population)	Word Group 2 (Intervention)	Word Group 3 (Outcome)	
• healthcare facility • hospital • care home	• sprinklers • fire suppression • passive fire protection • fire incident • fire risk	• insurance • maintenance • installation • training • fire protection • fire prevention • Legionella • escape • death • fatality • injury • life safety	• patient • fire fighter • inhalation • activation • smoke • compartment • fire safety • fire extinguish • containment • evacuation • regulations

Note: Terms within word groups combined using “or”; word groups combined using “and”

Study selection, eligibility criteria, data extraction and quality assessment

3.2. This review adopted a two-stage screening process which assessed the relevance of the studies to the topic. This was facilitated by adherence to the inclusion and exclusion criteria presented in Table 3-2. The authors conducted a first screening (reading the title and abstract) of all the studies and a second screening (assessing the full text of eligible studies). The outcomes from the screening process were recorded in the flow of evidence screening chart in Appendix 2.

Table 3-2 Inclusion and exclusion criteria

Inclusion	Exclusion
• Empirical research, peer-reviewed, in English, any country, any date and any study design.	• Systematic literature reviews, commentaries, audits, dissertations, presented as a poster or abstract at a conference, and reviews

Inclusion	Exclusion
• Grey literature from the UK and internationally. • Setting in healthcare premises and residential care facilities, controlled experiments, and when the text refers to buildings in general • Research that involve standardised water-based automatic sprinklers that are currently recommended for widespread use in healthcare settings.	• Non water-based sprinklers or water mist systems. • Studies focusing primarily on warehouses, schools and domestic premises. • Situations where a fire is initiated outside the building (i.e. in a garden).

3.3. Eligible studies were then critically appraised using the Scottish Intercollegiate Guidelines Network (SIGN) SIGN50 methodology checklists (Appendix 3), compliant with the criteria used by Appraisal of Guidelines for Research and Evaluation in Europe (AGREE) (Appendix 4).

3.4. Grey literature from non-peer reviewed sources constitutes the majority of gathered evidence.

4. Results

4.1. This review consists of four studies, included as per the flow diagram of paper screening in Appendix 2. There are 36 grey literature publications from key recognised organisations including UK Governments, British Standards Institution (BSI), Chartered Institution of Building Services Engineers (CIBSE), Loss Prevention Council (LPC), Building Research Establishment (BRE), Health Facilities Scotland (HFS), Arup, Business Sprinkler Alliance (BSA), British Automatic Fire Sprinkler Association (BAFSA), National Fire Chiefs Council (NFCC), and the National Fire Protection Association (NFPA). Evidence gathered from these sources constitutes statutory guidance, building regulations and expert opinion.

5. Discussion

5.1. Within this section, each research question is presented and evidence synthesis and cited narratively.

What are the national and international standards and recommendations for incorporating sprinklers within healthcare premises?

5.2. Within the UK, fire safety legislation and the resulting regulations for all building premises are contained within: Building Regulations, 2010 for England and Wales (devolved in 2011), Building Regulations (NI) 2012 for Northern Ireland, Building (Scotland) Regulations 2004 for Scotland, and Isle of Man Building Regulations 2003. In addition, technical standards are provided by: Approved Document B for England and Wales, Technical Booklet E for Northern Ireland, and Technical Handbooks (domestic and non-domestic) for Scotland. These documents focus on life safety and fire prevention (BAFSA, 2021, Arup, 2006). Furthermore, Scotland has specific guidance and recommendations for healthcare premises provided by Health Facilities Scotland (HFS) Firecode comprising of Scottish Health Technical Memoranda (SHTM) and Scottish Fire Practice Note (SFPN) (BAFSA, 2021, Williams, 2009, Arup, 2006).

5.3. Where sprinklers are provided in hospitals, these should be designed and installed per BS EN 12845 (BSI, 2020b, BSI, 2020a, 2019, HFS, 2013a, BRE, 2016). This system should additionally comply with the Loss Prevention Council (LPC) Rules for sprinkler installations (containing the text of BS EN 12845 and a series of Technical Bulletins) that provide additional guidance to meet insurers' requirements (Arup, 2006, HFS, 2013b, BRE, 2016, BSI, 2020b). In addition, expert opinion from the UK recommends "the Fire Protection Association's Design guide" to inform requirements for the protection of buildings (Williams, 2009).

5.4. In compliance with section 2.15.3 of the Scottish Governments Building Standards Technical Handbook 2019: Non-Domestic (2019), it is mandatory, in certain circumstances, to have an automatic life safety fire suppression system installed in specific high risk hospital departments. Areas that require coverage are shown in Table 4-1. The areas should be provided with sprinklers in List A where they are directly below, or directly adjoin, any other hospital department to which patients have access and areas in List B where they are directly below or directly adjoin, operating theatres, intensive therapy units, or special care baby units (Scottish Government, 2019).

Table 5-1 Table taken from Scottish Governments Building Standards Technical Handbook 2019: Non-Domestic (2019) Section 2, fire: Annex 2B

LIST A	LIST B
a. boiler house	a. central staff change
b. central stores	b. central sterile supplies
c. commercial enterprises	c. hospital sterilising and disinfecting unit
d. flammable stores	d. health records
e. laundry	e. pathology
f. main electrical switchgear	f. manufacturing pharmacy.
g. main kitchens	
h. refuse collection and incineration	
i. works department.	

5.5. Even if a fire engineering solution is used, SHTM 81: Part 2 (HFS, 2009b) and BS EN 12845 (BSI, 2020b) must be adhered to. These require separation of sprinkler and non-sprinkler protected areas by at least 60-minute fire resisting construction. Although, this does not apply in small areas such as en-suite facilities (BAFSA, 2016).

5.6. There are additional circumstances that may recommend sprinkler protection, as detailed by SPFN 6 V3 and SHTM 81 Part 2 and 3, Scottish technical standards and Arup, including:

- the installation of fast response systems in some patient care areas for life safety purposes rather than property protection (HFS, 2007)
- targets for deliberate fire raising/protests (i.e., premises accommodating vehicles such as ambulances, animals and medical research facilities or laboratories). Due to the impact multi seated fires can have on the effectiveness of evacuation strategies (HFS, 2007)
- if a defend in place (DIP) evacuation strategy is used, there is usually a need for sprinklers for the fire suppression component of the system (HFS, 2009b)
- In addition to the areas specified for a hospital, in any premises, full sprinkler coverage may be required:
  - in a building containing any storey over a height of 25m (every storey should have a sprinkler) (Scottish Government, 2019)
  - to facilitate fire service activities in buildings where external rescue is challenging to achieve (Arup, 2006)
  - if specified within a fire safety engineering approach (Arup, 2006)
  - in an atrium that provides access to adjacent accommodation above the

atrium base level. Unless a discrete fire load (islands of up to 10m2 with a fire load density of up to 115 MJ/m2) or separate fire loads are clearly defined (by at least 4m), then partial sprinkler coverage can be utilised. Noting that the system's design should consider the reduced effectiveness when high above the seat of a fire (Scottish Government, 2019, HFS, 2013a)

  - to reduce the fire hazard in buildings where the occupancy characteristics are such that the risk to life from fire is considered excessive (Arup, 2006)

5.7. SHTM 81 Part 1 reports that progressive horizontal evacuation (PHE) is usually part of hospital fire safety strategies due to the restricted mobility, impairments or influence of medication, particularly for those dependent on electrical/mechanical equipment for survival (HFS, 2009a). Although not required, the installation of sprinklers for these circumstances is recommended by BAFSA (2016) and NFSM & NFCC (2019) due to providing increased time available for evacuation and reducing the number of people requiring evacuation.

What are the national and international standards and recommendations for incorporating sprinklers within residential care premises?

5.8. Where sprinklers are provided in residential care premises, these should be designed and installed per BS 9251 (BSI, 2014, Scottish Government, 2019, BSI, 2020a). According to the standard, Category 2 sprinklers can be installed in residential care premises with ten residents or fewer and Category 3 systems with more than ten (BSI, 2014). However, BS EN 12845 should be applied where the building height exceeds 20 m, room exceeds 180 m^2, or there are significant fire loadings (BRE, 2016).

5.9. The number of sprinklers may be limited to two in communal areas or corridors classified as "managed areas" and considered sterile within a fire strategy report or with agreement by the authority having jurisdiction (AHJ) (BSI, 2014). However, BAFSA (2010) suggest these areas may have decorations and furnishing to create a comfortable living environment, which would increase fire loading – this should be considered if residents commonly access it.

5.10. Scotland, Wales, USA, Hong Kong, Australia, Canada, and New Zealand recommend sprinklers within residential care premises. Similarly, Finland recommend sprinklers in residential care premises, if required by a risk assessment (BAFSA, 2010).

- In 2005, Scotland was the first area in the UK to introduce the requirement for sprinklers in residential care in new or altered premises (BAFSA, 2010, Scottish

Government, 2019). Arup (2006) states several serious fires influenced this requirement in residential care premises and findings from the BRE report by Williams et al. (2004a). The Scottish Government (2014) states fire poses a serious risk to residents within residential care premises, particularly referencing the 14 resident fatalities from smoke inhalation and toxic gases occurring at Rosepark Care Home in 2004, from a rapidly developing fire that began in a bedroom corridor cupboard.

- Since 2009, the USA has required sprinklers in all new healthcare occupancies and to be retrofitted in existing ones. Similarly to Scotland, these were implemented following 2003 fires in several non-sprinklered nursing homes with a total of 31 resident fatalities and as per the recommendations of a 2004 United States Government Accountability Office report. Recommendations conclude that sprinklers are the single most effective fire protection feature and that there has never been multiple deaths in a fully sprinklered nursing home fire (BAFSA, 2010).
- In Hong Kong, the 2005 Code of Practice for Residential Care Premises recommends sprinklers be provided in premises greater than 230m² (BAFSA, 2010).
- In Australia, the 2009 Building Code of Australia states sprinklers should be installed in residential care premises. The recommendations resulted from a study undertaken following a serious fire at Kew Cottages which resulted in nine fatalities (BAFSA, 2010).

What are the design trade-offs and compensatory features of implementing sprinklers?

5.11. There is a consensus of expert opinion that sprinkler installation can offer design flexibility and cost-savings through trade-offs (note: the below are general examples unless highlighted in bold a specific premises), including:

- increased escape travel distances (Arup, 2006)
- increased unobstructed distance from the fire mains outlet from 45m to 60m, on any one storey (Scottish Government, 2019)
- increased compartment volumes and sizes, leading to extended travel distances (Arup, 2006)
- justified shortfall in the exit width, as the use of fast response sprinkler heads can increase escape distances (Arup, 2006)
- reduced Required Safe Escape Time (RSET) by early fire detection and extending Available Safe Escape Time (ASET) by limiting the amount of smoke production and reducing heat exposure (Arup, 2006)
- reduced number of firefighting shafts, from one shaft for every 1000m^2 to one in every 1500m^2 (BAFSA, 2016)
- reduced extent of automatic detection systems, as each sprinkler head serves

as a heat detector (Arup, 2006). In addition, when activated, sprinklers actuate a mechanical alarm outside the building: providing an alarm, which is often connected to the building's fire control panel without the need for electrical connections, alerting building users and providing a signal to call FRS (BAFSA, 2016)

- reduced external envelope protection requirements for re-entrant angle protection (i.e. 1m storey height fire-resistant banding and 3m for resistant protection to low-level roof abutments) (BAFSA, 2016)
- reduced smoke extract requirements
- to allow thermally activated dampers in some locations instead of fire and smoke dampers linked to the fire alarm and detection system (BAFSA, 2016)
- to half external fire spread space separation distances required between buildings or facing compartments (BAFSA, 2016)
- be used as a compensatory feature due to a potential fire size and growth reduction, such as when firefighting access recommendations (BS 5588: Part 5) cannot be achieved due to site constraints (Arup, 2006)
- reduced fire resistance standard with an increase in unprotected areas relative to adjacent boundaries, equating to a reduction in fire-resisting materials and increased areas of external glazing on elevations. This reduction in fire resistance of structural elements can incur savings (Arup, 2006), e.g.:
    - in **residential care and hospital premises,** this allows external walls more than 1m from the boundary to change from medium fire resistance to no fire resistance duration (Scottish Government, 2019)
    - no size limits on un-insulated glazing in sub-compartment walls (BAFSA, 2016). In addition, using non-fire resisting glazing to atria and lightwells can reduce the protection required to escape routes. Thin-film intumescents are more widely available at the lower periods of fire resistance, with panel sizes and pane thicknesses larger and thinner (Arup, 2006)

5.12. The Scottish Government (2011) states that not all reported sprinkler 'trade-offs' are viable within **healthcare premises**. However, listed below are recommendations from expert opinion and guidance that installation of sprinklers in **healthcare premises** can:

- reduce compartment walls' fire resistance from 60 minutes to 30 minutes on floors up to 12m above ground (integrity and insulation). In cases over this height, sprinkler protection should be risk assessed (BAFSA, 2016)
- reduce the minimum four compartment floor area from 500m^2 to 350m^2, which is required when buildings are over 12m high, no hospital street is provided, and escape uses progressive horizontal evacuation (PHE) (BAFSA, 2016)
- reduce replacement air changes within a mechanical smoke clearance system from six to four per hour, in atriums with fire loads (HFS, 2013a).
- mitigate the risk from ignition sources classed as 'unacceptable' hazards without

the need to limit the type and quantity of combustible materials (BAFSA, 2010, HFS, 2013b, HFS, 2013a)

- in the English building regulations, (HM Government (Eng), 2010) there are trade-offs specified for sprinkler installation, including :
  - the boundary distance can be halved to a minimum distance of 1m
  - the amount of unprotected area can be doubled
  - a mechanical smoke extraction system may be provided as an alternative to natural venting within basement storeys, sprinklers do not need to be installed on other storeys to comply.

5.13. Some suggestions of sprinkler trade-offs in the report by BAFSA (2010), commissioned by Arup Fire, on the potential benefits of sprinklers in **residential care premises** are:

- being able to consider human factors and occupancy profiles to create a balance between fire safety and a comfortable living and care environment. Allowing design to achieve appropriate levels of independence and interior design that improve resident's quality of life without increased risk of ignition (BAFSA, 2010)
- Bedroom fire doors do not need to be fitted with self-closing devices, reducing the challenge of opening them for frail residents (BAFSA, 2010). Although there is conflicting evidence on how these doors should be used, as HM Government (Eng) (2010) recommend staff closing resident's doors at night but findings by BAFSA (2010) reveal that some residents prefer the bedroom doors ajar to allow in diffused corridor lights and staff prefer this for checking in on residents without disruption of opening the door.
- bedrooms can contain more than one bed (BAFSA, 2010). In addition to this HM Government (Eng) (2010) stated that when PHE is in use, protected areas can contain more than ten beds

5.14. There is a consensus in expert opinion that sprinklers can be used in a fire safety engineering approach to provide design flexibility and cost savings, in particularly beneficial in the fire protection of existing buildings. This approach designs a fire loading specifically representative of the building and its contents, rather than utilising the standards: meaning alternative solutions outside the scope of prescriptive guidance can be achieved, but that demonstrate compliance with the functional standards (Arup, 2006, Scottish Government, 2019). However, due to the specialised nature of this approach and the approvals required BAFSA (2010) recommends consulting a fire engineer/consultant.

5.15. Alternatively, there are specific standards that provide other approaches to prescriptive guidance. The first is the "time equivalence" method, detailed in BS EN 1991-1-2, applied to several UK projects. Within sprinklered environments, the time equivalence value may be reduced by a factor of 0.61, potentially reducing passive fire protection measures (Arup, 2006). There is also BSI (2017) BS 9999, which can be used as a middle ground between a fire safety engineering approach and prescriptive guidance. This standard combines occupancy characteristics and fire growth rate to show that sprinklers can reduce building risk profiles by one class. In **residential care premises**, this reduces from C2 to C1, with the following relaxations being:

- increased travel distances from 12-18m to 18-27m with two-way travel and 6-9m to 9-13m for one-way travel
- reduced exit widths from 4.1 to 3.6mm per person (not less than 800mm or 850mm for unassisted wheelchair access)
- reduced door width from 3.3 to 2.4mm per person (not less than 800mm or 850mm for unassisted wheelchair access)
- reduced escape stair width (varies per number of building floor levels but must be a minimum of 1000mm)
- reduced periods of fire resistance from 90 to 60mins when, from the point of access, the depth of the basement exceeds 10m and height is between 18 and 30m, with more detailed reductions where ventilation conditions are met (ventilation 10% of floor area and opening height 30-90% of storey height)
- reduced Management Level 1 to Management Level 2 (this suggestion should be treated with caution as it does not appear in the most recent standard but has been mentioned by BAFSA (2010) as something that appeared in the 2008 edition of the standard)

In the case of fire, what are the differences between full, partial or non-sprinklered environments?

5.16. Expert opinion agrees that sprinkler installation provides life protection to the occupants outside the room of fire origin regarding temperature and smoke but less protection to those inside the room (Arup 2006; BRE, 2006; BAFSA, 2010). However, if the door is left open to the room of fire origin, conditions can become unsurvivable, even with sprinklers, as although fire growth is suppressed, there would be significant amounts of smoke, and therefore, visibility would be reduced to untenable conditions (BRE et al., 2006). Although sprinklers are not expected to save people in direct contact with flames (although they have in some instances) (Williams, 2009), they can at least protect others in the room of fire origin (Arup, 2006). Typically, extinguishing or, at least, preventing further fire growth once activated: reducing smoke production, heat transfer to the structure, flashover, leaving more time for escape and a smaller fire for FRS (Chitty and Fraser-Mitchell, 2003; Arup, 2006; Williams, 2009).

~~5.17.~~ More specifically, in residential care premises, simulations conducted by BRE et al. (2006) have shown that bedroom fires can lead to untenable conditions for all room occupants. However, sprinklers in the bedroom limit heat and toxic gases, providing adequate protection for those in the room of fire origin. However, they are unlikely to operate soon enough to prevent fatal or severe injuries to residents in direct contact with the flames and/or heat. In the case of non-sprinklers and worst-case scenario sprinkler operation (approx. 15mins to activate), simulations have shown that death for the person in the bed (location of the fire) is predicted at around five minutes due to heat and/or flame contact. For non-sprinklered tests, conditions become rapidly untenable due to convected heat, and for another seated occupant of the room, pain from heat exposure and extensive third-degree burns happened at around 12 minutes. Therefore, conditions can remain tenable for those not in direct contact with the fire for the worst-case scenario sprinkler operation. These simulations are supported by a recorded case study in New Zealand, where an occupant in direct contact with a fire in their bedroom died of burns, but sprinklers activated, and the other occupant survived.

5.18. Other simulations in residential care premises have shown that sprinklers lower the temperature (Nam, 2005; BAFSA, 2010). Fire and smoke modelling studies by BAFSA (2010) show temperatures within a sprinklered room of fire origin are in the region of 70-80°C throughout the model (ten minutes), with the temperature dropping below 60°C after approximately 8 minutes. In the corridors and adjacent rooms, temperatures do not exceed 35°C. By contrast, in non-sprinkler scenarios, the temperatures in the room of fire origin exceeded 120°C within two minutes and were between 60°C and 80°C beyond the room. It is important to note that in sprinklered and non-sprinklered scenarios, visibility within the room of fire origin drops to less than 2m (at 2m above ground). However, unlike the non-sprinklered scenario, visibility remains tenable for the sprinklered scenario in all adjacent rooms within the fire compartment and adjacent compartments. These findings highlight that sprinklered fires can improve conditions, particularly outside the room of fire origin. It is important to note that the authors attribute the poor performance of sprinklers in certain circumstances due to using, "worse-case" scenarios within the model: (1) the small room volume, (2) significant leakage from fire doors which, if well maintained passive fire protection then would prevent the smoke transfer, (3) sprinklers not extinguishing the fire, when in reality it is considered most sprinklers will extinguish the fire, and (4) evacuation from the room of origin only when conditions become untenable, with the door being left open for 60 seconds.

5.19. Hostikka et al. (2020;2021) conducted experimental studies in hospital rooms, recreating 16 fires (UL 1626 corner fires), seven large fires, and seven small textile fires. Most of these were sprinklered fires, with only two non-sprinklered (free-burn) UL 1626 fires and one free burn case for each textile fire. Findings show sprinklers fully extinguished the UL 1626 corner fires in three cases and suppressed the fire in all 14 cases, preventing spread to the plywood corners where the fire was situated. The smaller textile fires were fully extinguished in three cases. Sprinkler activation showed a rapid decrease in temperature, which peaked at 50°C. The peak carbon monoxide (CO) concentrations of the sprinklered UL 1626 and large textile fires are between 450ppm and 2500ppm, i.e., one order of magnitude smaller than the corresponding free-burns (x103). In the UL 1626 sprinklered fires, the highest asphyxiant concentration (excluding CO) was nitric oxide (NO) at about 50 ppm. In the free burn cases with the UL 1626 and large textile fires, the peak temperatures were above 200°C and 160°C, respectively. In addition, CO concentrations reached 37,600 and 17,800 ppm in two UL 1626 cases. In addition, multiple other gases exceeded 400 ppm. The studies also calculated for the airborne concentration of contaminants and level absorbed by an occupant or fractional effective dose (FED). In sprinklered fires, incapacitation will likely occur 5 minutes after the start of the fire, 3-4 minutes after sprinkler activation. In comparison, conditions can be considered lethal in the free burn cases in 3 min: with safe evacuation only possible before 2.1-3.2 min in UL 1626 and large textile fires. FED exceeding 1.0 will cause incapacitation in 50% of the population, and sprinklers decrease this in UL 1626 and large textile fires from 0.9-1.0 in free burn cases to about 0.4. The authors conclude that sprinklers improve life safety and provide additional time for escape: these were particularly effective for fire which had the potential to grow in size and power. The sprinklers maintained temperatures at tolerable levels and reduced toxicity, through fire development control. However, they do not entirely remove the risk of incapacitation caused by toxic gases. These results were less conclusive in fires that remained small.

5.20. Experimental studies by Williams et al. (2004a; 2004b;2004c) conducted within sprinklered and non-sprinklered houses and compartment fires concluded that sprinklers effectively reduced casualties in the room of fire origin and connected spaces. However, "worse-case" scenarios of shielded and slow-growing fires prevented effective sprinkler operation; before producing enough heat for sprinkler operation, toxic smoke could cause untenable conditions. Although once activated, sprinklers would control the fire, prevent it from spreading, and reduce the risk of flashover conditions within the room of fire origin. In addition, closing the door to the room of fire origin can effectively keep tenable conditions in connecting spaces. Therefore, there would still be safety benefits associated with providing sprinklers.

What are the statistics of fire suppression, fire deaths, and injuries internationally between premises with sprinklers installed compared to those without?

5.21. Non-sprinklered fires can lead to multiple casualties and fatalities, in most cases due to smoke inhalation rather than direct flame contact. 2018-19 figures from Scottish FRS (Scottish Fire & Rescue Service, 2019) show that during that time, there were:

- 45 fatalities: 36 of which occurred in accidental dwelling fires, with fatalities in those aged 80-89 over three times higher than the Scottish average and six times higher in the group over 90s
- 1,191 non-fatal casualties: 60.5% due to gas, smoke, or toxic fumes, 10.6% due to burns: although non-fatal casualties in the over 80s had significantly higher

rates of injury, those aged 17-29 had rates over 40% higher than the Scottish average

5.22. 2005 UK fire statistics show 93,100 fires in buildings attended by FRS resulted in 403 fire deaths and 13,000 non-fatal casualties (Williams, 2009); of these, 35,300 fires occurred in buildings other than dwellings, with 27 fatalities and 1400 non-fatal casualties. BAFSA (2010), reporting on UK annual fire statistics from CLG/ODPM found there are between 800 to 900 fires in residential care premises, with more than 45 fatalities each year. Authors state this is above the national average compared to other building premises, which they attribute, among other factors, to occupant's characteristics and ability to escape. Data collected from the FDR1 database of the London Fire Brigade between 2005 and 2008 by BAFSA (2010) shows that burn damage in areas larger than 20m² (regarded as developing beyond the room of origin) was less than 3% of incidents in residential care premises. However, areas larger than 20m² damaged by fire heat and smoke were approximately 22% (equating to an area covered by two sprinkler heads if provided). Authors conclude that although the fires are typically restricted to the room of origin, heat and smoke can spread to adjacent rooms or circulation spaces, putting those out with the room of origin at risk. This is supported by their review of fire case studies in residential care premises, where most residents were treated or died of smoke inhalation. In 2015, there were 3,648 fires, an average of approximately ten per day in UK healthcare premises, resulting in 412 casualties, including four fatalities. It is estimated that 196 or 4% of these fires were set deliberately (BAFSA, 2016).

5.23. Evidence is consistent that sprinklers reduce the number of casualties and fatalities within fires but are not effective in all circumstances, such as those in direct contact with fire. Arup (2006), providing data from a 2005 report by NFPA US Experience with sprinklers and other fire extinguishing equipment, concluded that when sprinklers are present, the chances of dying in a fire are reduced by between 50% and 75%. NFSM & NFCC (2019) found that between 2013 and 2018, 192,094 fires occurred in the UK in all building premises. In non-sprinklered buildings, there were 42,001 non-fatal casualties and 1,462 fatalities. Conversely, 3,046 fires occurred in sprinklered buildings. Out of these, sprinklers activated in 1,300 cases, in which there were 156 recorded casualties and five fatalities. In buildings (not categorised as dwellings), there is a non-fatal fire casualty in every 17.32 and 33.1 fires in non-sprinklered and sprinklered buildings, respectively – indicating you are half as likely to be injured when sprinklers are installed. Williams (2009), reporting on The National Fire Protection Association (NFPA) US Fire Statistics data from 2002 to 2004, concluded that in most property classes, the fire death rate per 1,000 reported that structure fires are lowered by 57% or more where sprinklers are installed. When sprinklers control fire, people are 22% less likely to require hospital treatment with no incidence of shock and other physical injuries (such as fractures, head injuries, and chest and abdominal injuries). Sprinklered fires had higher recordings of “other injuries”, indicating more minor impacts are likely, an example being 18% are more likely to receive a precautionary check, the lowest recordable level of support, than another form of treatment at the scene (NFSM & NFCC, 2019).

5.24. Due to the heat required to activate a sprinkler (approx. 68 degrees), there is a chance of receiving direct burns or burns from radiant heat. In cases where an individual is directly involved in a fire, by the time the temperature is high enough to activate the system, the victim will already have experienced significant direct burns and damage to their airway (NFSM & NFCC, 2019). However, in sprinklered fires, people are 30% less likely to be overcome by smoke and, therefore, less likely to experience breathing difficulties (NFSM & NFCC, 2019).

5.25. Where sprinklers have been mandated, there is evidence of their life safety benefits. In case study examples, Vancouver, US has required sprinkler installation in new residential care premises since 1990, with no recorded fire deaths. Similarly, Scottsdale, Arizona (US) has required sprinklers since 1985 and reported only one death of an individual who died from direct burns because of smoking while using oxygen (NFSM & NFCC, 2019). According to BAFSA (2010) 32% of fire related deaths in older adults in US residential care facilities occur during escape, and 48% of fatalities occur within the bedroom.

5.26. Data provided by NFSM & NFCC (2019) from the UK FRS showed that, in the last five years prior to 2019, 317 fire incidents occurred in buildings with sprinklers. In 180 incidents, the system did not operate, resulting in 111 casualties, and in 137, the system operated with 29 casualties. 17% of the UK FRS reported they had not experienced a single fatality or injury in sprinklered fires.15% reported 166 sprinkler activations with no recorded casualties. If these fires had occurred in non-sprinklered buildings, this would have resulted in nine casualties in 166 fires in non-dwelling buildings (NFSM & NFCC, 2019).

What is the reliability and effectiveness of sprinklers?

5.27. Arup (2006) reported that reliability figures are typically in the upper 90% (over 99% in Australasia). This is supported by a 2007 paper cited in Williams (2009), which showed sprinklers had operational reliability of 93% and effectiveness reliability of 97% where the fire was large enough to activate the systems and where the system was present in the fire area. This was in addition to evidence in a report by Ahrens (2017) with figures derived from the US Fire Administration's National Fire Incident Reporting System (NFIRS) between 2010-2014 concluding that sprinklers (wet pipe only) operated in 89% of instances (88% in healthcare). In addition, they operated effectively in 86% of instances (85% in healthcare) and effectively controlled fire in 96% of instances (97% in healthcare). An NFSM & NFCC (2017) report stated that they worked as intended in 94% of cases and controlled or extinguished fires in 99%.

5.28. SHTM 81 Part 3 reports that effective, correctly installed, and maintained sprinklers will reduce the risk of a fire developing and spreading and limit the heat and smoke produced (HFS, 2013a). In addition, various aspects contribute to system reliability:

- in recent years, life safety sprinklers have met Building Regulations requirements or satisfied the Fire Safety Order. The unique requirements of life safety sprinklers are intended to increase the reliability of the system and its ongoing availability, including duplication of water supplies, wet pipe systems (permanently water charged), 'quick' response sprinklers, and limiting the size of division zones that can be closed off for maintenance (Williams, 2009; BRE, 2016)
- using third-party certified sprinkler installers and maintenance companies and third-party approved and listed sprinkler components can increase the reliability of the system's anticipated effective performance and components in a fire. Certification of systems and components reduce the likelihood of problems occurring but cannot completely prevent them. However, they can be investigated and dealt with if problems arise and are reported (Williams, 2009, Arup, 2006, BSI, 2019b, HM Government (Eng), 2010; BSI, 2020b; BSI, 2020a). The benefits of complying with BS and using third-party certified sprinkler installers and maintenance companies are corroborated by Williams (2009), who noted in real case studies of sprinkler failure, the issues relate to problems with water supplies and are a failure of the management and maintenance of the systems
- results from an experimental study by Nam (2005) show the use of exposed Chlorinated polyvinyl chloride (CPVC) pipes and fittings can withstand flame and high heat (up to 791 degrees)

5.29. A report by NFSM & NFCC (2017) involved FRS data of fires within UK premises with sprinklers fitted between 2011 to 2016 (75% in non-residential and 18% in dwellings). There were 2,294 identified cases: 945 had sprinkler activation, of which 677 have evidence of the impact of sprinklers. Of these 677 cases, the sprinklers contained or controlled the fires in 62% and extinguished the fire in 37%. Thus, giving the performance effectiveness of sprinklers 99% across all building types.

5.30. Arup (2006) provided case study examples showing the dramatic effects sprinklers can have in a series of fire tests conducted by Wiltshire FRS at Studley Green, recorded on video. In addition to an experimental study in an office building in Australia, sprinklers had to be turned off to allow the fire to develop and then extinguished the fire as soon as turned back on. Another example is a case of fire that developed on the twelfth floor of the First Interstate Bank, Philadelphia, USA that was prevented from spreading above the sixteenth floor due to it being sprinklered.

5.31. For normal conditions in the UK, the sprinkler temperature rating will be 57°C or 68°C. However, this does not necessarily preclude using a fusible link sprinkler with a temperature rating of 74°C (BRE, 2016). An experimental study by Nam (2005) shows that sprinklers can typically actuate between 8 and 10 min in slow growing fire cases and around 2 min in fast growing fire cases. An experimental study by Hostikka et al. (2020) showed sprinklers activated on average 72 seconds with SD of 13 seconds. Delay in sprinkler activation time can occur due to numerous factors such as heat conduction to the sprinkler pipes, sprinkler orientation, airflow deflection and the latent heat of fusion for solder links (Chitty and Fraser-Mitchell, 2003; HFS, 2009b).

5.32. An experimental study (as part of expert opinion evidence) by Williams et al. (2004a) found minor damage or injury occurs when sprinklers are operated in response to a smoke detector. This is because smoke alarms activate earlier than sprinkler operational temperatures (12-33s compared to minutes for sprinkler activation). Sprinklers can be linked to smoke alarms. However, they are far more complex (and expensive) than a standard system and present a risk of unnecessary water discharge resulting from a false alarm or minor incident, which could cause distress and harm to elderly residents (e.g., from shock or pneumonia).

5.33. A recent study by Ahrens (2017) found 240 instances of the ineffectiveness of sprinklers in fire in all premises that were not confined to the room of origin but large enough for sprinkler activation. In two of every five (43%) cases of sprinkler (wet pipe only) ineffectiveness, the main reason was that the water did not reach the fire. Other causes were insufficient water released (32%), manual intervention that defeated the system (10%), damage to system components (6%), lack of maintenance (5%), and inappropriate system for the type of fire (5%).

5.34. Arup (2006) reported on data from the NFPA for USA fires, concluding that sprinklers failed to operate in only 7% of building fires. However, nearly all these failures were due to human influences (two thirds of the cases were because the system had been shut off). Analysis of the UK Fire Statistics data from 1994 to 2005 by Williams (2009) found that in 1,012 cases of sprinklers failure, there were 731 cases where sprinklers did not operate and 281 where they operated but did not control the fire. The reasons given for sprinkler failure were: stated unknown and other (606), system shut off for other reasons before fire (157), not enough water discharged to control fire (62), system defective (59), water discharged but could not reach fire (54), heat/smoke deflected away from heads (29), faulty sprinkler heads (17), system shut off to prevent excessive water damage by system (10), fire flashed into an inaccessible area (8), low mains pressure or water supply failed (7), and rapid build-up of heat due to nature of fire load (7). A report by NFSM & NFCC (2017) analysed the reasons for non-operation recorded in 879 cases: findings show that in 42% of the cases the fire was in an area not covered by the system, 53% the reason was 'other', with 31% of these being due to insufficient heat. In addition, there were a small number of "system" reasons for non-operation, which amounted to 4.7% of cases and included, the system turned off (2%), system fault (1.4%), system fire damage (0.8%), and system improperly set up (0.5%). However, only 57 cases out of 879 were identified where the system could have been expected to work but did not. A recent study by Ahrens (2017) reported 530 instances of failure of sprinklers to operate in fire in all premises that were not confined to the room of origin but large enough for sprinkler activation. In three of every five (59%) sprinklers (wet pipe only) cases, the main reason was failure to operate as the system had been shut off. Other causes were manual intervention that defeated the systems (20%), damage to system components (7%), lack of maintenance (7%), and inappropriate system for the type of fire (7%). There are several reasons for the failure of sprinklers: however, Williams (2009) adds that consideration should be given within figures that sprinkler failures were overrepresented and that some sprinkler successes may not be reported in the statistics. For example, a successful operation does not always require the attendance of FRS: therefore, the statistics will not record the fire.

5.35. Any fire safety system will likely fail if the real hazard exceeds the design hazard: no system can be designed and installed to cope with all eventualities. For example, compartmentation can impact sprinkler activation, it may concentrate smoke and lead to earlier detection or prevent smoke from getting to a detector (Chitty and Fraser-Mitchell, 2003). Sometimes passive systems are perceived as more reliable than active systems. The impression is that passive systems are easy to maintain or require no maintenance and are long lasting. In practice, however, many passive provisions are not visible, may be incomplete from the time of their installation, be poorly maintained, or the 'human factor' can render them ineffective, leading to false security and inferior performance in fire. Well documented examples include wedged open or poorly fitting fire doors, punctured or incomplete cavity barriers, and non-existent or inadequate fire stopping (BAFSA, 2010, Arup, 2006). A criticism of sprinklers is that they may fail or be ineffective in controlling a fire. However, they are easy to monitor through frequent and inexpensive maintenance and monitoring, and therefore their state of 'readiness' is a known quantity. The performance of sprinklers, in terms of reliability, is high in comparison to other forms of protection, even for systems installed to older regulations. British Standard 5306: Part 2 LPC and the Rules ensure stricter design and maintenance criteria to further raise performance and reliability parameters (Arup, 2006). PD7974- 7 (based on US figures) gives the probability for successful sprinkler activation between 95% (new systems) and 75% (old systems). With typical probabilities between 80% (new property protection systems) and 90% (new life safety systems. Updated data from the US suggests a probability of 93% (BSI, 2019b). Therefore, sprinkler figures can be viewed as favourably compared to passive fire system figures with probability figures, including fire doors being blocked open at 30% and self-closing doors failing to close correctly on demand at 20%. In addition, the probability of fire resisting structures achieving at least 75% of the designated fire resistance standard is only 25% for suspended ceilings and 65% for partition walls (BAFSA, 2010). This is exemplified in a case study of 35 London ICUs by Murphy and Foot (2011), which found significant weaknesses in fire safety related to unit design, staff training, equipment, and planning. The most significant weakness was the lack of site-specific fire training for temporary (locum) staff in 66% of units, although well provided for permanent staff. In addition to inadequate fire doors (20%), ventilation cut-outs (17%), escape routes (up to 60%) and the ability to transfer patients safely compromised in 74% of units by the lack of enough portable monitoring equipment. Evacuation plans were often limited in scope (96% expected to remain on their floor: 14% had plans to obtain medications after evacuation), and 60% had not rehearsed. Although not recommended by the authors, from this evidence, it could be concluded that many of these areas of weakness could be supported by sprinklers. Williams (2009) and BAFSA (2010) state that the human element and the maintenance/ installation of any fire protection measures are crucial to their reliability to perform as intended in a fire and evidenced in the case of both active and passive fire protection methods.

5.36. Assisted evacuation is common within residential care premises, with residents often requiring individual attention and monitoring when in a place of safety. Reducing night-time staff (as low as two persons in small residential care premises) can result in significant delays and extended evacuation periods. BAFSA (2010), referencing US Federal Emergency Management Agency statistical data from 1999, states that at least 75% of residents require some assistance to escape, and 63% use wheelchairs to travel. Their review of UK residential care premises fire incidents supports this in many instances where fatalities occurred during the evening and night-time hours. In addition, PD7974-6 gives a pre-movement time in the region of 30-40 minutes for residential care premises. In addition to requiring assisted evacuation, the report on past research has shown that residents typically take regular routes of circulation for evacuation rather than less familiar escape routes. Highlighting improvements to fire emergency training for staff and residents and fire protection measures which allow these routes to remain tenable throughout the evacuation period. In reviewing the risks associated with the occupants who reside in residential care premises, extended evacuation periods may be required to get all residents to a place of relative safety. Therefore, the escape routes must be maintained for evacuation during this extended period. The provision of automatic fire suppression to supplement passive fire protection can help reduce the risks in residential care premises (BAFSA, 2010). A good example of the effectiveness of sprinklers can be evidenced in a report by BAFSA (2010). The report highlights that care home residents are often more vulnerable in the event of a fire than most of the general population due to a combination of factors. In particular, they are more likely to suffer from reduced sensory abilities such as smell, touch, vision and hearing, and mental and physical impairment (e.g., memory loss and arthritis). Such impairments can have the following effects: delayed escape, inability to escape unaided, reduction in movement speed, and even more likelihood of accidental ignition caused by occupants. In particular, for residential care premises, self-closing doors present a challenge for day-to-day movement in and out of a room, for frail residents, people using walking frames and people in wheelchairs. Thus some doors may be more likely to be wedged open, increasing the likelihood of the doors failing to close (BAFSA, 2010).

What are the operational consequences of sprinklers?

5.37. Both BSI and expert opinion agree that negative interactions can occur between sprinklers and other systems or building elements, which include:

- thermal shock, due to sudden cooling by sprinkler sprays, causing windows to break (Chitty and Fraser-Mitchell, 2003)
- a water spray cooling the hot gas layer, making a natural smoke exhaust system less efficient. Additionally, smoke ventilation systems can hamper the effectiveness of sprinkler performance. However, coherent design mitigates this risk (Chitty and Fraser-Mitchell, 2003; BSI, 2019)
- cooling of the hot smoke by a water spray, which may lead to a loss of buoyancy and mixing of the smoky layer with clear air beneath (down drag), thus causing poor visibility in escape routes and for fire-fighters (Chitty and Fraser-Mitchell, 2003, Arup, 2006; Williams, 2009). This is a behaviour observed in experimental fires, unless the sprinkler spray is applied from the side, beneath the rising smoke. However, the advantages of the sprinklered fire over non-sprinklered “far outweighs” this effect (Arup, 2006, CIBSE, 2019) and tests by NFPA (2003) conclude the problem is minimal for means of escape. Furthermore, Arup (2006) reports that typically by the time sprinklers are operating, people are moving away from the immediate fire area
- many water systems, including from water mains, can contain some form of legionella. However, an issue only occurs when conditions within systems support legionella growth. Therefore, sprinklers fed directly from the public mains water present no significant risk of infection. Although there is more risk when water is fed in from a poorly maintained tank, where organic material and heat can enter, providing conditions for growth (Arup, 2006). LPC (1999), as cited in Arup (2006), provides recommendations for controlling legionella in firefighting systems, including utilising existing legionella monitoring systems onsite, adequate testing, inspections and routine maintenance

5.38. Water damage can be a concern either through unwanted activation or a disproportionate level of water damage compared to other firefighting operations (Arup, 2006; BAFSA, 2010). However, statistics by the LPC within the Arup (2006) report show the likelihood of a sprinkler head operating spuriously is 1 in 500,000. Accidental activation may be caused by the accidental or malicious breaking of a sprinkler head or the leaking of the water supply system. The accidental operation due to mechanical damage is statistically low and can be mitigated by providing sprinkler head guards (or concealed heads) in exposed areas. SHTM 86 states that accidental sprinkler activation may adversely affect electrical systems (HFS, 2009b). However, BAFSA (2016) states there is little danger of electrical conduction as water is discharged from sprinkler heads in small droplets in a finely divided stream. They also state that it is equally safe to use sprinklers in kitchens or where hot oil is used as boil over will not follow sprinkler activation.

What are the environmental impacts of sprinklers?

5.39. Expert opinion of real fire case studies in single storey commercial and industrial buildings by BSA (2011) detail several environmental impacts of fires. Although this excluded information on sprinklered environments, it provides an overview of how fires in non-sprinklered buildings can impact sustainability. In case studies:

- the fire's impact on air quality and contamination of watercourses, due to firefighting runoff, were deemed minor and insignificant or not recorded in assessments by Environment Agency (EA)
- EA assessments reflect that potential pollutants are effectively contained by:
  - the building being a sufficient distance from local residents
  - the relatively non-hazardous nature of the building's contents and actions to manage and minimise the air quality impact: including temporary evacuation or advice for residents to stay indoors with windows closed

5.40. The above case study findings by BSA (2011) were supplemented by a model providing water use and carbon emissions in fire scenarios in sprinklered and non-sprinklered environments. The findings show that automatic sprinklers significantly reduced water consumption compared to non-sprinklered fires. Water used when fighting fires in the case studies varied widely from an estimated 71,280 litres to 51,828,000 litres. In comparison, water use by sprinklers activated by developed fires is estimated to be 12,000 litres; approximately 0.02% to 17% of the quantity used in non-sprinklered building fires. For example, if 364 fires occurred over a year (as National Fire Statistics indicate for commercial and industrial buildings), non-sprinklered buildings would result in 25,945,920 to 18,865,392,000 litres of water use, 43,243 and 31,422,320 domestic water use of households in a day, respectively. If all these fires had occurred in sprinklered buildings, the quantity would fall to 4,368,000 litres per year, equivalent to the water use of 7,280 households daily. These figures exclude water consumption for routine testing, not considered to make a significant contribution. Water use for testing is estimated to be a maximum of 145,600 litres per year. However, this is considered an overestimate as it does not account for recycled and reused water, estimated to be used in 70-80% (and rising) of all newly installed systems and significantly reduces water consumption for routine inspection and testing. In addition by Arup (2006) provides statistics on water consumption during a fire; a sprinkler head uses 30-100 litres/minute, compared to 600 and 1100 litres/minute from a handheld fire brigade hose and platform monitor. Concluding sprinklers can use 6-10 times less water than expected from FRS intervention. In addition, sprinkler heads open independently when their operating temperature is reached, only the sprinklers in the direct vicinity of the fire open, the others remain closed. This limits the water damage to areas with fire and reduces the water used (BAFSA, 2016). Additionally, National Fire Protection Association statistics in the report by Arup (2006) show that the vast majority of sprinklered fires (85%) are controlled with fewer than four heads operating, 62.3% are controlled by a single sprinkler head and 96.3% by ten or fewer, supported by their case studies. Sprinklers can suppress and control fires with four or fewer sprinklers (Williams, 2009).

5.41. Any fire reductions will minimise the volume of toxic gases released into the atmosphere (commonly carbon monoxide (CO): carbon dioxide (CO2), hydrogen chloride (HCl), and hydrogen cyanide (HCN). Additionally, it reduces the chance of contamination in firefighting water, which can be challenging to contain and often finds its way into watercourses and drainage systems. Finally, the reductions lead to less impact on nearby wildlife habitats (BAFSA, 2010; BAFSA, 2016; Arup, 2006). Additionally, installing sprinkler can reduce the extent of fire resisting partitions, walls, and glazing (BAFSA, 2010), which is beneficial to the environment as they often utilise materials from non-sustainable sources and excessive amounts of CO2 in their manufacture (Arup, 2006). The carbon calculator tool BSA (2011) used concluded an estimated reduction in carbon emissions from sprinklered fires compared with non-sprinklered fires. This is shown to be a 7.8% to 11.2% reduction in the lower scenario (the building is 30% full, and 30% of the content burns or four sprinklers discharge) and a more significant 18% to 21.6% in the upper scenario (the building is 75% full and either 75% of contents burn or four sprinklers discharge). The benefit of installing sprinklers in commercial and industrial buildings in England and Wales that suffer a fire is estimated to reduce total carbon emissions from 145,000 (lower scenario) to 348,000 (upper scenario) tCO2 per annum. The report's calculations of the net benefit of installing sprinklers in all industrial and commercial buildings in England and Wales illustrate that there is estimated to be a benefit of sprinklers over the 30-year lifespan of buildings greater than 5,000-10,000m^2 but not for buildings in the smaller size ranges. This is because the carbon emissions associated with installing, operating, and maintaining sprinklers, including their use to control fires in buildings where a fire occurs, are less than those associated with non-sprinklered fires in these buildings. The authors conclude that benefits to water and carbon reductions highlight sprinklers could play an essential role in achieving sustainability standards and meeting the increasingly stringent sustainability targets set by the BRE Environmental Assessment Method (BREEAM) scheme.

5.42. In all case study fires by BSA (2011), greater than 30% of the building was destroyed, resulting in entire building demolition. By preventing fires, sprinklers can remove the need for people or business relocation and reduce the extent of refurbishment or repair. In addition to protecting important documents that may have historical importance to future generations (BAFSA, 2010; Arup, 2006). Most of these case study fires, although in industrial areas, impacted employees, local businesses, residents or schools, which had to be evacuated following the fire – impacting surrounding buildings - often requiring local evacuation of surrounding buildings, impacting on businesses. For the building in the fire, this amounted to direct economic losses, for example, losses of equipment, redundancies, re-building costs, and the loss of clients to competitors. Associated incalculable business consequences include, for example, the long term loss of client confidence and damage to reputation. In terms of direct economic impacts, works of art worth £50 million were lost in one fire (BSA, 2011).

5.43. Expert opinion suggests that the indirect consequences of a fire can be frequently overlooked, particularly those associated with social, human, environmental and sustainability aspects. Sprinklers can limit this by controlling or extinguishing the fire (BAFSA, 2010, BAFSA, 2016, Arup, 2006). An additional point to note is that within current UK legislation, there are no specific requirements for protecting property, business continuity and the social impact of fire (BAFSA, 2010). However, the Technical Handbook (2019) suggests sustainability objectives within building standards systems could be achieved by protecting against fires in buildings that serve as social assets and components of the local economic network.

What are the savings associated with implementing sprinklers in healthcare premises and residential care facilities?

5.44. According to the ODPM report "The economic cost of fire estimates for 2003", The total cost of fires in England and Wales was estimated at £7.7 billion, equivalent to approximately 0.9% of the gross value added of the economy. In a commercial building, the average cost of fire is estimated at £58,000, £45,000 of which is related to the cost of fire damage to property (BRE, 2016). A report by Williams (2009) of an analysis of serious fires in the UK (involving fatalities and/or a loss greater than £100,000) concluded the total estimated fire losses reported by insurers for 384 building fires in 2005 was £413 million.

5.45. Sprinklers are sometimes dismissed for building designs because of costs, complexities, and aesthetics. However, the cost benefits of sprinklers are only realised in the long term, and decisions need to consider the whole picture, including reduced potential fire losses for the life of the building (BRE, 2016). The following are examples of cost savings associated with sprinklers:

- savings can be achieved via trade-offs that can result in a more cost-effective design (Arup, 2006)
- they can reduce insurance premiums substantially and, in some instances, are a requirement. The advantage in terms of reduced insurance is case specific (BRE, 2016), reporting that installation of sprinklers in schools can result in a 75% reduction in fire insurance cost, and the Arup (2006) report cites examples with 65% reductions in premiums (BRE, 2016)
- although FRS cost savings are difficult to quantify, key benefits are (1) smaller fires to contend with and subsequent reduction in attendance period or fire may be extinguished by arrival, (2) reduction in the number of fire service pumps required (BAFSA, 2010)

5.46. BAFSA (2010) suggests that a cost-benefit analysis can help fund sprinkler installation. This is evidenced within the BRE Research report by Williams et al. (2004a; 2004b; 2004c) on the cost-benefit analysis of sprinkler installation. The analysis considers installation costs, water supplies, maintenance and testing, and the benefits of lives saved (£1,243,000 each), injuries prevented (£58,300), and property loss savings. The report concluded that sprinklers would be cost-effective in residential care premises (for older adults, children and disabled people). BAFSA (2010) highlights this report formed part of the Regulatory Impact Assessment in England, Wales, and Scotland. However, the results in the published fire safety guidance were different between England/Wales and Scotland. While Scotland considered residential sprinklers to be cost-beneficial in residential care premises and includes the recommendation for sprinklers, this was not the case in England and Wales (note: guidance by Welsh Government (2020) has since been amended to include sprinklers in new residential premises). Many in the fire safety community have questioned the decision not to recommend sprinklers within residential care premises, especially when recommended by the BRE report by BAFSA (2010). BRE (2016) review of the aforementioned report states that, in general, the cost-benefit conclusions from other countries' experiences were the same as in this study, i.e., sprinklers were not cost-effective unless systems were low-cost or can trade-offs. However, benefits not considered in the report were environmental impact reductions, insurance premium reductions, fire brigade savings and design trade-off savings. BAFSA (2010) stated that although not explicitly providing monetary value, they could result in further savings. An additional BRE report by Williams (2009) states significant benefits to include in a sprinklers cost-benefit analysis include:

- a reduced insurance premium
- if proposed as a compensatory feature, indirect cost reductions due to building design changes
- in the event of a fire:
    - reduced risk of deaths and injuries
    - reduced property damage
    - reduced business interruption
    - reduced environmental and social impact
    - reduced FRS costs

5.47. The Scottish Government commissioned a cost-benefit analysis of installing sprinklers in new hospital buildings. The analysis considers the costs of installation, maintenance, and the benefits of cost of injury/fatality, damage to property, FRS, service delivery, catastrophic events, and environmental impacts. It concluded that the costs of installing the automatic fire suppression systems exceed the quantified benefits with a benefit-to-cost ratio (BCR) of 0.06 and 0.04. The report includes Scottish Government statistics on Scottish hospitals. Figures show that Between 2001 and 2006, the number of fires in hospitals fell from 278 to 184 (almost 34%). In addition, hospital fires account for only 1.8% of ‘other building’ fires (non-dwelling premises). This report is referenced, and conclusions upheld by the expert opinion of HFS Fire Safety Advisory Group (Scottish Government, 2011). The report collected 2001/2 to 2007/8 statistics from Scottish Health authorities (15), which show that:

- the majority (76%) of health authority fires are in residential hospitals
- the majority (63%) of fires are accidental
- there were no deaths associated with hospital fires
- the likelihood of an injury is greater if the fire is deliberately started rather than if accidentally started
- the majority (84%) of fires are restricted to the room of origin with little or no damage outside the room of origin and with negligible effect on the availability of facilities

5.48. Expert opinion by BAFSA (2010) highlights that post-fire trauma in residential care premises can significantly impact residents' wellbeing. This can be linked to exposure to injury, death and damage resulting from fire. Therefore, they consider that the primary objective in reducing trauma should be to minimise the impact of fire (by reducing the size of the fire and resultant damage). However, this is not always a significant consideration, particularly within cost/benefit analysis since the effects are not always apparent immediately after the incident or go unreported. In an article cited in BAFSA (2010) “Management of post-incident trauma: a fire service perspective”, suggests management through de-briefing and peer group support for those affected, referral to healthcare services for those experiencing rising or persisting anxiety, and if symptoms persist or recur, then referral to more specialist healthcare services. In addition to the emotional impact, there can be a monetary impact on the resident's family due to the potential relocation of the residents and the associated travel costs their friends and family may incur visiting them (BAFSA, 2010).

What is the disruption to business continuity in the event of a fire in full, partial or non-sprinklered healthcare premises and residential care facilities?

5.49. Expert opinion suggests that fire damage in premises can be extensive, with sprinklers showing to reduce this significantly. Arup (2006) includes findings from a 2005 report by NFPA US, Experience with Sprinklers and Other Fire Extinguishing Equipment, that the average property loss per fire is reduced by between 50% and 66% compared to fires where sprinklers are not present. Further presenting the findings from a survey published in Fire Prevention Science and Technology No.17 that 70% of a compartment area could be involved in a non-sprinklered fire, with 50% or more of the building structurally damaged. Compared to less than 10% of the compartment area involved in a sprinklered fire, with no structural damage. Williams (2009), reporting on The National Fire Protection Association (NFPA) US Fire

Statistics data from 2002 to 2004, concluded that in most property classes, the average property loss per fire is lowered by 34% to 68% compared with fires where sprinklers are not present.

5.50. NFSM & NFCC (2017) report that in England between 2011/12 and 2015/16 the average area of fire damage in a non-residential sprinklered building (excluding those with over 10,000m^2 of damage) was 30m^2: half the average area of fire damage reported for all "other building" fires (59 to 62 m^2). The authors conclude that damage can be reduced by approximately 50% when sprinklers operate.

5.51. A report by BAFSA (2010) states that fires resulting from arson can be particularly hazardous as there can be multiple seats of fire, use of accelerants, and location usually targeted in circulation or escape routes. These fires are not often considered part of the standard fire safety requirements. However, sprinklers have been shown to automatically raise the alarm and call FRS while simultaneously controlling the fire's development: meaning the fire will be smaller upon FRS arrival. A case study detailed by Arup (2006) occurred in a sprinklered primary school in Manchester in 2002 and had been the target of an arson attack. A single head activated and extinguished the fire with FRS automatically called and damage amounting to only a few hundred pounds. The school day was unaffected, and the sprinklers were reinstated and fully operational by the end of the day. The report concluded that sprinklers could play a significant role in business continuity and that if a sprinkler successfully controls a fire, the downtime of the school could be less than a day (Arup, 2006).

5.52. In general, fire damage has often been markedly reduced in sprinklered premises to the extent that business can be continued the following day. In contrast, the unprotected premises have been out of action for considerable periods or even permanently (Arup, 2006). A report by Arup (2006) shows evidence that more than 50% of all businesses cease to trade within two years of experiencing a fire. Furthermore, they state that reduced trade and business can often have a far more significant monetary impact than the material damage resulting from a fire. BAFSA (2010) highlights that financial implications due to the closure of residential care premises can be significant due to funding based on the number of residents. Therefore, residents' relocation can lead to revenue loss and business interruption, which may not always be met by insurance. In addition, the family or resident might decide to relocate to another residential care premises.

5.53. Data collected from the Scottish healthcare premises by Optimal Economics (2009) show that in case of fire:

- 84% of cases, the fire and damage were restricted to the room of origin, with evacuation of the room of origin required in 71% of instances
- 82% of cases, the premises were evacuated for less than one hour, the mean being 6 hours (excluding two fires resulting in one being closed for one year and

the other for three months)
- the median and mode length of evacuation was 30 minutes
- 60% of cases, the facilities were rendered unavailable for one day or less, with a further 23% of fires rendering the facilities unavailable for between two and seven days
- Most of the fires resulted in very low costs. One fire, however, resulted in damage costs of £9 million (unoccupied) and significant consequential costs. One other fire produced over £1 million in damage, but the next highest cost was just £35,000
- There are also the human impacts of such business closures to consider. For example, BAFSA (2010) highlights that in case of serious fire within residential care premises, both residents and staff can be impacted, in particular regarding relocation:
    - This can cause distress for residents moving from familiar to unfamiliar settings, particularly those with dementia
    - Relocating for work can cause commuting concerns or additional travel costs for staff. In addition, some staff may be required to find interim employment elsewhere

What are the installation requirements and associated costs?

5.54. The sprinklers' water supplies must be adequate and reliable for the long term, i.e., provide sufficient flow and pressure to satisfy the system design requirements and be available in case of fire. Therefore, the town mains should be performance tested before installation to determine the minimum available pressure and flow characteristics. The performance test results will inform the design of the water supply for the sprinklers (BRE, 2016; Arup, 2006). In addition design of the system is dependent on the building height and hazard classification (Arup, 2006). Sprinkler heads are generally located near the ceiling and spaced so that there is always a sufficient flow of water to combat fire in the area of operation. The flow is calculated so that each head delivers enough water to control a fire, considering the size and construction of the building, its use and the nature of the contents stored in it (BAFSA, 2016).

5.55. BRE (2016) states that the large water tanks, pumps, and rigid heavy pipework can be seen as a disadvantage of sprinklers but argue that sympathetic design choices can be made when considered early in the project.

5.56. The main cost associated with sprinklers is the capital cost of the installation (Arup, 2006). BRE et al. (2006), Arup (2006), Optimal Economics (2009) and BRE (2016) provide estimated costs of sprinkler installation but all state that capital cost for sprinklers is case specific. Therefore, the confidence level of the cost effectiveness of sprinklers is very dependent on the installation costs, which have high levels of uncertainty. Arup (2006) provides a method to assess sprinklers' capital costs as a percentage of the build cost. Findings from school premises show that installation cost (when included in the initial design brief) is estimated to be 2-3% of the construction cost (Arup, 2006, BSI, 2019b). Figures are provided for all building types by Arup (2006), from a 2004 article in The Architects Journal (ex VAT) of £23-28 f/m^2 for light hazard, £27-37 f/m^2 for ordinary hazard and £33-39 f/m^2 for extra high hazard. BRE (2016) provides 2006/7 figures from various sources. These are £25/m2 to £40/m^2 for industrial/storage, £27/m^2 to £37/m^2 for Ordinary hazard systems (including retail) and £23/m2 to £68/m^2 for Schools. More specifically, BRE et al. (2006) provide average installation costs for a 26 bed residential care premises of £5,600 to £16,700; but for 95% confidence, the average cost would be £7,800. Data related to Scottish healthcare premises sprinkler installation figures were collected by Optimal Economics (2009), finding installation costs range from £26 per m^2 to £800 per m^2: The average being £32 per m^2 or 0.1-3% of the capital cost of the building.

5.57. Internationally, BS EN 12845 and the LPC rules for automatic sprinkler installations are consistently applied (BRE, 2016). Where appropriate, sprinkler pipework should be installed per BS EN 805, BS EN 806, and BS 8558. Sprinkler heads should be stored, handled, and installed per the manufacturer's instructions. Care should be taken to ensure that: (1) vent holes are not obstructed: (2) the sprinkler heads are not damaged before fitting: and (3) sprinklers are installed using the appropriate wrench supplied by the manufacturer (BSI, 2014). Once correctly installed, leakage, hydraulic and alarm tests must be conducted, in addition to a complete visual inspection, and passed for the system to become operational. On satisfactory completion of the commissioning tests, the competent person should issue a compliance certificate, which attests that the sprinkler system has been designed, installed, and commissioned per this British Standard (BSI, 2014).

5.58. Only specialist, trained and experienced personnel should undertake sprinkler systems' design, installation, and maintenance. Most sprinklers are installed and maintained by certificated installers in the UK. The Loss Prevention Certification Board (LPCB) operates a third-party certification scheme for sprinkler contractors, LPS 1048-1, which applies to commercial and industrial buildings. Certified sprinkler installers are listed in the LPCB's List of approved fire and security products and services, known as the Red Book. Under this scheme, the sprinkler contractor issues a third-party Certificate of Conformity for each system installed (BRE, 2016; Williams, 2009). Using third-party certified installers ensures that installations have been designed, installed, and commissioned by suitably qualified and experienced contractors to appropriate standards. This can increase the system's reliability and anticipated effective performance in the event of a fire and satisfies insurers and/or approving bodies (Williams, 2009).

5.59. In addition to certificated installers, the LPCB operates certification schemes for sprinkler products. As appropriate, certified sprinkler products are marked with CE and LPCB marks and listed in the Red Book. These sprinkler component approved products are similar to products approved by Underwriters Laboratories and Factory Mutual Global (BRE, 2016).

What are the maintenance requirements and associated costs?

5.60. As sprinkler technology, including components and design, is well established and detailed in the standards, then a well maintained system should be operational for 50 years (BRE, 2016). The sprinkler system should be maintained according to the installation standard used to design it (Williams, 2009). In addition, it should be regularly serviced, maintained and periodically inspected (BRE, 2016). BS EN 12845 and Technical Bulletin TB 203 detail an extensive service, maintenance and inspection programme covering the entire sprinkler lifecycle, including weekly, monthly, quarterly, yearly, three yearly and ten yearly checks and tests (BRE, 2016).

5.61. The responsible person (usually the building owner) should ensure that competent onsite personnel conduct a programme of weekly and monthly inspections and checks. In addition, a competent sprinkler maintenance contractor should schedule quarterly, half yearly and yearly routine tests, service, and maintenance (BRE, 2016; Williams, 2009; BSI, 2020b; HFS, 2013b). The responsible person should notify interested parties of the intent to conduct tests and/or of the results (BRE, 2016). Occasionally, inspection requirements are conducted by insurance surveyors, FRS inspectors, and certification scheme assessors (Williams, 2009). SHTM 86 states that comprehensive records of maintenance and work undertaken should be held on the premises and kept for a minimum of three years (HFS, 2013b).

5.62. Using third-party certified contractors assures suitably qualified, and experienced contractors have conducted maintenance to appropriate standards. Therefore increasing the reliability of the anticipated effective performance of the system, satisfying insurers and approving bodies (Williams, 2009).

5.63. During routine maintenance, the competent onsite person will identify and rectify problems, e.g. changes of fire hazards and faulty or damaged components (Williams, 2009). In addition, during weekly tests by the building user, checks are conducted on all water and air pressure gauge readings, water levels, the correct position of all main stop valves and the sounding of the water motor alarm. Where installed, checks should also be conducted on any automatic pumps and associated primary or backup power supplies (Williams, 2009; BSI, 2020b).

5.64. Water supplies, which met the demand characteristics at installation, may become insufficient due to pressure reduction. If this is the case, onsite water storage may become necessary (Arup, 2006).

5.65. Where sprinklers are part of a fire safety engineering approach, the fire procedures should detail the contingency arrangements to be adopted during periods of downtime to ensure maintenance of equivalent fire safety, e.g. for repairs, tests and routine maintenance or failures of any kind (HFS, 2013b; BRE, 2016; Williams, 2009). Williams (2009) provides a list of management procedures to mitigate risk, including:

- restoring the system to full working order as soon as possible
- limiting any planned shutdown to low risk periods when people using the building are at a minimum or when the building is not in use. This is particularly important when the system is a life safety system or forms part of the fire safety engineering requirements
- consideration of the need to isolate the area without the benefit of working sprinklers from the rest of the premises by fire resisting material
- avoiding higher risk processes such as hot work
- training additional staff dedicated to forming fire patrols
- suspension of phased or staged evacuation strategy, in these circumstances, evacuation should be immediate and complete
- conducting maintenance on a zoned basis to prevent leaving the whole system ineffective
- informing the local FRS
- notifying the users of the building, i.e., the responsible person and other occupants

5.66. According to Arup (2006), sprinkler heads are effectively maintenance free with any costs associated with other maintenance, including weekly tests. They advise that these costs are compared with annual maintenance costs of electronic fire and security systems, which may be in the region of 10% of the original capital cost of the system. However, maintenance costs are difficult to quantify as they depend on the equipment used (Arup, 2006). Therefore, there are no firm costs, but estimates have been given by:

- BRE (2016), taking figures from a report by Arup and EC Harris LLP, estimate the annual cost associated with regular servicing, maintenance, and inspection to be:
  - Storage or retail premises = £750 to £1500 (2006)
  - Schools = £250 to £750 (2006) and £1100 (2007)
- Arup (2006), who estimated annual maintenance costs at:
  - small domestic property = £50-75
  - small school = £250-350
  - large school = £500-750

  - large warehouse or retail premises = £750-1500
- Data collected from Scottish healthcare premises by Optimal Economics (2009) found maintenance costs within healthcare premises ranged widely: from £3 to £22 per m^2, with a mean of £8 per m^2

What is the risk reduction to fire service personnel whilst carrying out fire-fighting operations within premises fitted with sprinklers compared to those without?

No evidence was identified by this review regarding this topic.

6. Implications for research

6.1. Generally, there was a lack of high-quality primary research examining sprinklers in health and residential care settings. Therefore, much of the evidence for recommendations are based on mandatory guidance and standards or expert opinion from recognised fire safety organisations. This may unintentionally introduce an element of bias and it is recommended that caution be taken when directly interpreting the evidence. However, for the most part, there is consensus of expert opinion that sprinklers can enhance life safety in healthcare premises.

6.2. Although excluded from this literature review, some evidence commented on the use of water mist systems. Table 1 in BSI (2020a) 5306 Part 0 states water mist systems are “unsuitable” to be installed in healthcare environments due to being out of the scope of system design, installation and maintenance standards. However, evidence from SHTM 81 Part 2 suggests water mist systems could be beneficial in areas where sprinklers are less effective (HFS, 2009b). In addition, the introduction of the EN 14972 series of water mist design, installation, maintenance and fire test protocol standards could show compliance with clause 2.15.1 in the Scottish Government (2019), Technical Handbook - Non-domestic: which states water mist systems may be an acceptable alternative to sprinklers if they adhere to best practice standards for components, are verified by third parties and can be proven to be as reliable.

7. Conclusion

7.1. This literature review aimed to gather evidence on sprinklers in health and residential care settings. Most evidence was based on expert opinion, with many studies not reported in detail. Grey literature determined that, in many cases, consideration of the installation of sprinklers only occurs after real fire incidents. Overall, there is a lack of experimental studies for healthcare settings. It would be beneficial to conduct fire simulation involving different healthcare settings, layouts, designs, and control different variables (e.g., temperature) to see how sprinklers respond under a fire (e.g., smoke, the time required for evacuation, the impact on users of the facilities). Conducting the same scenarios with and without sprinklers would allow for detailed comparisons and informed decisions on the evidence of these fire safety systems.

7.2. For Scottish healthcare premises, the only mention of sprinklers installation is in the now withdrawn Firecode SHTM 82: Supplement A. This literature review provides evidence that would be beneficial to include in Firecode SHTM.

8. Summary of Key Findings

8.1. The following recommendations for water sprinklers were provided based on evidence gathered by this literature review. Due to the limitations of available evidence and the majority being based on expert opinion, all the recommendations, apart from those in mandatory guidance, have been graded as a Category C recommendation, in line with the AGREE tool (See Appendix 4). This grading means recommendations are based expert opinion, with no robust professional or scientific literature available to inform guidance. Therefore when interrupting these recommendation, they must be considered with caution and on a case-by-case basis.

What are the national and international standards and recommendations for incorporating sprinklers within healthcare premises?

In the UK, healthcare premises should be incorporating sprinklers to BS EN 12845 and the Loss Prevention Council (LPC) Rules for sprinkler installations.

In Scotland, sprinkler should be installation in specific high risk hospital departments listed in Section 2, fire: Annex 2B of the Scottish Government (2019) Building standards technical handbook 2019: non-domestic.

Sprinkler installation in Scotland should adhere to guidance in SHTM for healthcare premises.

Sprinkler and non-sprinkler protected areas should be separated by at least 60-minute fire resisting construction.

Sprinklers should be installed in a building containing over a height of 25m.

Sprinklers should be installed in an atrium with an unknown or high fire load.

(Mandatory)

Sprinklers can be considered as part of a fire safety engineering approach.

Sprinklers can be installed in areas vulnerable to wilful fire raising.

Sprinklers can be installed to protect vulnerable occupancy characteristics.

Sprinklers can be installed to offset the risks when a defend in place (DIP) evacuation strategy is used.

(Category C)

What are the national and international standards and recommendations for incorporating sprinklers within residential care premises?

In the UK, residential care premises should be incorporating sprinklers to BS EN

9251.

In the UK, residential care premises should be incorporating sprinklers to BS EN 12845 when the building height exceeds 20 m, any room exceeds 180 m^2, or there are significant fire loadings.

In Scotland, sprinklers should be installed new or altered residential care premises.

(Mandatory)

In agreement with the AHJ, sprinklers can be limited to two in communal areas or corridors, when they are "managed areas" and considered sterile.

(Category C)

What are the design trade-offs and compensatory features of implementing sprinklers?

Sprinklers in residential care and hospital premises can allow external walls more than 1m from the boundary to change from medium to no fire resistance duration.

Sprinklers can allow an increased unobstructed distance from the fire main outlet, from 45m to 60m.

Although trade-offs in BS 9999 cannot be applied directly to healthcare premises, they can be adopted as part of a fire safety engineering approach.

Not all trade-offs for installing sprinklers are viable within healthcare premises and should be considered on a case-by-case basis. Use of sprinklers as part of a fire safety engineering approach can achieve project specific trade-offs.

When considering sprinkler installation, a performance-based approach to means of escape design can allow for increased escape travel distances.

The 'time equivalence' method in BS EN 1991-1-2 can be applied with sprinklers to reduce passive fire protection measures.

When sprinklers are installed in atriums with fire loads, the replacement air changes within a mechanical smoke clearance system can be reduced from six to four per hour.

Within healthcare premises, sprinklers can be used to mitigate the risk from ignition sources classed as 'unacceptable' hazards without limiting the type and quantity of combustible materials.

Sprinklers can allow for a balance between a comfortable living/care environment and fire protection measures.

(Category C)

In the case of fire, what are the differences between full, partial or non-sprinklered environments?

Sprinklers can be installed to protect those not directly involved with fire in the room of origin and those outside.

Compared to non-sprinklered environments, sprinklers can offer benefits to FRS when tackling fires.

Compared to non-sprinklered environments, sprinklers can increase escape time.

Compared to non-sprinklered environments, sprinklers can significantly reduce amounts of toxic gases and smoke.

(Category C)

What are the statistics of fire suppression, fire deaths, and injuries internationally between premises with sprinklers installed compared to those without?

Compared to non-sprinklered environments, sprinklers can significantly reduce fire fatalities and injuries.

Sprinklers can be considered in spaces for older or vulnerable populations, as evidence states above average fatalities in residential care premises, with most occurring in bedrooms or during escape.

Evidence from other countries shows sprinklers in residential care premises has significantly reduced the number of fire fatalities to almost zero.

(Category C)

What is the reliability and effectiveness of sprinklers?

Sprinkler reliability and effectiveness can be increased by using third-party certified sprinkler installers, maintenance companies and sprinkler components.

The evidence concludes sprinklers have reliability figures of 88-99%, effectiveness figures of between 85-97% and effectively control fire when activated in 96-99% of instances.

Sprinklers can be installed to reduce the failure or ineffectiveness of passive fire protection measures.

Most sprinkler failure and ineffectiveness is related to water supplies, human error, management and maintenance of the systems, system not covering location of fire, and insufficient heat. These should be carefully managed when intending to install a system.

(Category C)

What are the operational consequences of sprinklers?

Risk mitigation of legionella infection, although unlikely, can be managed by using existing legionella monitoring systems onsite, along with adequate testing, inspections and routine maintenance.

Sprinklers can be designed in relation to other building elements to reduce negative interactions.

Evidence from expert opinion shows accidental operation of sprinklers is highly unlikely.

Sprinkler head guards (or concealed heads) can be used in areas exposed to potential damage.

(Category C)

What are the environmental impacts of sprinklers?

Compared to non-sprinklered fires, sprinklers can reduce water consumption by 0.02% to 17% or 6-10 times less.

Compared to non-sprinklered fires, sprinklers can reduce carbon emissions by 7.8% and 21.6%.

Compared to non-sprinklered fires, sprinklers can reduce toxic gases released to the atmosphere, contamination to watercourse drainage systems from firefighting water runoff and reduce the impact on wildlife habitats.

Sprinklers can reduce requirements for fire resisting materials, which lowers amounts of CO2 from its production.

Installation of sprinklers can contribute to achieving sustainability targets.

(Category C)

What are the savings associated with implementing sprinklers in healthcare premises and residential care facilities?

Cost-benefit analysis can determine cost effectiveness of sprinkler installation.

Aspects which can be considered in a cost-benefit analysis are environmental and social impacts, insurance premiums, business interruption, design trade-off and FRS resources.

In general, the evidence concludes that sprinkler installation would be cost-effective in residential care premises.

In general, the evidence concludes that sprinkler installation would not be cost-effective in other premises, including healthcare.

Sprinklers installation in healthcare premises may not be sufficiently warranted as evidence concludes that most fire fatalities and injuries occur in residential premises, primarily dwellings. Figures show that in Scottish hospital there were limited numbers of fires, most of which were confined to the room of fire origin.

Associated savings should be considered over the entire life cycle of the sprinkler system, in addition to impacts of fire.

(Category C)

What is the disruption to business continuity in the event of a fire in full, partial or non-sprinklered healthcare premises and residential care facilities?

Compared to non-sprinklered fires, sprinklers can reduce property loss by 34% to 68%, and damage by 50%.

In case of fire, sprinklers can provide protection in premises of long term or reoccurring occupancy, such as specialised healthcare premises, where there could be reputation, social, and economic impacts.

Disruption to business continuity within NHSS healthcare premises from fire is limited and not considered significant.

(Category C)

What are the installation requirements and associated costs?

Leakage, hydraulic and alarm tests and a complete visual inspection must be conducted and passed for the sprinkler system to become operational.

(Mandatory)

Third-party certificated installers should design and install the system.

The use of certificated sprinkler products is recommended to ensure compliance with

BS.

Although there is limited evidence and it is case specific, sprinkler installation could be estimated at 2-3% of the construction cost and 0.1-3% in NHSScotland healthcare premises with median figures of £32 per m^2.

Installation of sprinklers should be considered at the earliest possible project stage to ensure sympathetic and coherent design.

(Category C)

What are the maintenance requirements and associated costs?

A competent sprinkler maintenance contractor should conduct quarterly, half yearly and yearly routine tests, service and maintenance.

There should be a programme of weekly and monthly inspections and checks carried out by competent onsite personnel.

Contingency arrangements should be in place during periods of sprinkler downtime to ensure equivalent fire safety.

Check the system is achieving the correct water pressure, and if at any time becomes insufficient, onsite water storage must be installed.

Third-party certificated contractors should undertake maintenance on the system.

Zoning of sprinkler systems can be recommended to prevent whole system ineffectiveness during periods of downtime.

Although there is limited evidence and is typically case specific, sprinkler maintenance costs could be 10% of the original capital cost or £8 per m2 for healthcare premises.

(Category C)

9. References

AHRENS, M. 2017. U.S. Experience with Sprinklers. National Fire Protection Association.

ARUP 2006. Sprinklers for Safety: Uses und Benefits of Incorporating Sprinklers in Buildings und Structures. Cambridgeshire: British Automatic Fire Sprinkler Association.

BAFSA 2010. Sprinklers for Safer Living: The Benefits of Automatic Fire Suppression Systems in Residential Care Premise. Sheffield: British Automatic Fire Sprinkler Association.

BAFSA 2016. Information File: Sprinklers and Healthcare Premises: BIF No 17. Aberfeldy: British Automatic Fire Sprinkler Association.

BAFSA 2021. British Automatic Fire Sprinkler Association Yearbook 2021/2022. Stirling: British Automatic Fire Sprinkler Association.

BRE 2016. BRE Expert Collection 10: Fire safety in buildings: A collection of BRE expert guidance on fire risk, protection and detection. Building Research Establishment.

BRE, SHIPP, M. & CLARK, P. 2006. ODPM Final Research Report: BD2546 Sprinkler Effectiveness in Care Homes, BRE Output no. 228-138pv. London: Building Research Establishment Ltd.

BSA 2011. Assessing the role for fire sprinklers: 4162845. Business Sprinkler Alliance.

BSI 2014. BS 9251:2014: Fire sprinkler systems for domestic and residential occupancies – Code of practice. London: British Standards Institution.

BSI 2017. BS 9999:2017: Fire safety in the design, management and use of buildings – Code of practice. London: British Standards Institution.

BSI 2019a. PD7974-6: Application of fire safety engineering principles to the design of buildings: Part 6: Human factors: Life safety strategies - Occupant evacuation, behaviour and condition (Sub-system 6). London: British Standards Institution.

BSI 2019b. PD 7974-7:2019 Application of fire safety engineering principles to the design of buildings. Probabilistic risk assessment (+A1:2021). London: British Standards Institution.

BSI 2020a. BS 5306-0:2020: Fire protection installations and equipment on premises. Part 0: Guide for selection, use and application of fixed firefighting systems and other types of fire equipment. London: British Standards Institution.

BSI 2020b. BS EN 12845:2015 Fixed firefighting systems - automatic sprinkler systems - design, installation and maintenance (+A1:2019) (Incorporating corrigenda December 2015 and January 2016). London: British Standards Institution.

CHITTY, R. & FRASER-MITCHELL, J. 2003. BR 459: Fire safety engineering – a reference guide. London: BRE.

CIBSE 2019. Guide E, Fire engineering. 4th ed ed.: CIBSE.

HFS 2007. NHS Scotland Firecode: SPFN 6 V3: The prevention and control of deliberate fire-raising in NHSScotland healthcare premises. National Services Scotland.

HFS 2009a. NHS Scotland Firecode: SHTM 81 Part 1: Fire precautions in new healthcare premises. National Services Scotland.

HFS 2009b. NHS Scotland Firecode: SHTM 81 Part 2: Guidance on the fire engineering of healthcare premises. National Services Scotland.

HFS 2013a. NHS Scotland Firecode: SHTM 81 Part 3: Atria in healthcare premises. National Services Scotland.

HFS 2013b. NHS Scotland Firecode: SHTM 86: Fire Risk Assessment. National Services Scotland.

HM GOVERNMENT (ENG) 2010. Building Regulations 2010: Approved Documents B: Fire safety - Volume 2: Buildings other than dwellings. 2019 edition incorporating 2020 amendments (For use in England).

HOSTIKKA, S., VEIKKANEN, E., HAKKARAINEN, T. & KAJOLINNA, T. 2020. Experimental investigation of human tenability and sprinkler protection in hospital room fires. *Fire and Materials*.

HOSTIKKA, S., VEIKKANEN, E., HAKKARAINEN, T., KAJOLINNA, T. & KLING, T. 2021. Effect of sprinklers on the patient's survival probability in hospital room fires. *Fire Safety Journal,* 120.

LPC 1999. Technical Briefing Note No.14, Legionella and fireghting systems.

MURPHY, G. R. & FOOT, C. 2011. ICU fire evacuation preparedness in London: a cross-sectional study. *British Journal of Anaesthesia,* 106**,** 695-8.

NAM, S. Fire tests to evaluate CPVC pipe sprinkler systems without fire resistance barriers. Conference Papers - Fire and Materials 2005, 2005.

NFPA 2003. NFPA 750, Standard for water mist fire protection systems. 4th ed ed.: National Fire Protection Association.

NFSM & NFCC 2017. Efficiency and Effectiveness of Sprinkler Systems in the United Kingdom: An Analysis from Fire Service Data.

NFSM & NFCC 2019. Efficiency and Effectiveness of Sprinkler Systems in the United Kingdom: An Analysis from Fire Service Data. Incidence of Deaths and Injuries in Sprinklered Buildings: A Supplementary Report.

OPTIMAL ECONOMICS 2009. Cost Benefit Assessment of Installing Sprinklers in New Hospital Buildings. *In:* DIVISION, S. G. B. S. (ed.). Scottish Government.

SCOTTISH FIRE & RESCUE SERVICE 2019. FIRE AND RESCUE INCIDENT STATISTICS (SCOTLAND) 2018-19. Scottish Fire & Rescue Service.

SCOTTISH GOVERNMENT 2011. Fire Safety Policy for NHSScotland 2011. *In:* INFORMATION, S. G. H. F. A. (ed.). Scottish Government.

SCOTTISH GOVERNMENT 2014. PRACTICAL FIRE SAFETY: GUIDANCE FOR CARE HOMES: Issued by Scottish Ministers in terms of section 61(2) of the Fire (Scotland) Act 2005.

SCOTTISH GOVERNMENT 2019. Technical Handbook - Non-domestic:. *In:* DIRECTORATE, L. G. A. C. (ed.).

WELSH GOVERNMENT 2020. Building Regulations 2010: Approved Documents B2 Fire safety - Volume 2 - Buildings other than dwellinghouses (2006 edition incorporating 2010, 2013, 2016, 2017 and 2020 amendments) (For use in Wales).

WILLIAMS, C. 2009. automatic fire sprinkler systems: A good practice guide. Watford: BRE Trust.

WILLIAMS, C., FRASER-MITCHELL, J., CAMPEBELL, S. & HARRISON, R. 2004a. Effectiveness of sprinkler in residential premises: Section 1: Summary Report. BRE.

WILLIAMS, C., FRASER-MITCHELL, J., CAMPEBELL, S. & HARRISON, R. 2004b. Effectiveness of sprinkler in residential premises: Section 2: Desciption of the Project. BRE.

WILLIAMS, C., FRASER-MITCHELL, J., CAMPEBELL, S. & HARRISON, R. 2004c. Effectiveness of sprinkler in residential premises: Section 3: Pilot Study. BRE.

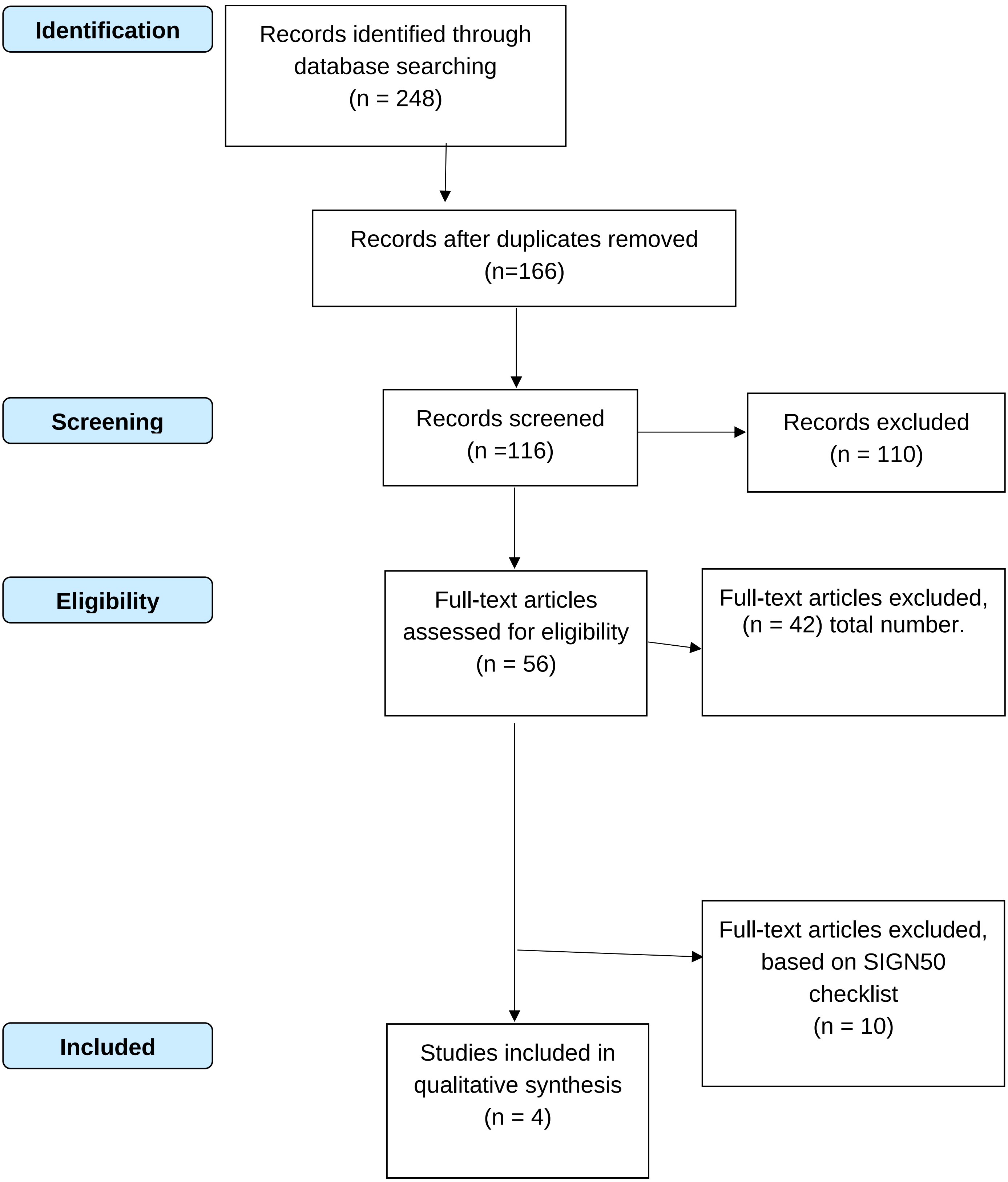
Appendix 1: Search Strategy

Database	Number of results	Search string
Embase	Initial search: 62	1 sprinkler*.ti,ab,kw. 516 2 "auto* sprinkler system*".ti,ab,kw. 6 3 "fire suppress*".ti,ab,kw.443 4 "water mist".ti,ab,kw. 103 5 "passive fire protection".ti,ab,kw.7 6 "fire incident".ti,ab,kw. 63 7 "fire door*".ti,ab,kw. 12 8 "fire risk*".ti,ab,kw. 453 9 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 1571 10 exp operating room/ 41651 11 ((building* or facilit*) adj5 (health*care or health or care or medical)).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, candidate term word] 170818 12 (hospital* or "care home*").mp. 2806274 13 exp nursing home/ 55234 14 exp prison/ 15456 15 10 or 11 or 12 or 13 or 14 2981922 16 exp insurance/ 355853 17 (maintenance or maintain*).mp. 1262709 18 instal*.mp. 47239 19 train*.mp. 883277 20 (fire adj5 protection).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, candidate term word] 2231 21 (fire adj5 prevention).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, candidate term word] 555 22 exp Legionella/ 12097 23 escap*.mp. 80261 24 death*.mp. 1491865 25 fatal.ti,ab,kw. 174561 26 injur*.ti,ab,kw. 1137724 27 "life safety".ti,ab,kw. 605 28 patient*.mp. 11220346 29 exp fire fighter/ 3433 30 inhal*.ti,ab,kw. 161773 31 activation.mp. 1559376 32 smoke.mp. 79924 33 compartment.ti,ab,kw. 129325 34 "fire safety".ti,ab,kw. 752 35 "fire extinguish*".mp. 388 36 containment.mp. 18078 37 evacuation.mp. 23202

Database	Number of results	Search string
		38 regulations.mp. 65129 39 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 15247394 40 9 and 15 and 39 92 41 limit 40 to yr="2001 - 2021" 66 42 limit 41 to english language 62
Ovid MEDLINE(R)	Initial search: 48	1 sprinkler*.ti,ab,kw. 430 2 "auto* sprinkler system*".ti,ab,kw. 6 3 "fire suppress*".ti,ab,kw.383 4 "water mist".ti,ab,kw. 86 5 "passive fire protection".ti,ab,kw.13 6 "fire incident".ti,ab,kw. 49 7 "fire door*".ti,ab,kw. 8 8 "fire risk*".ti,ab,kw. 409 9 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 1353 10 exp operating room/ 14754 11 ((building* or facilit*) adj5 (health*care or health or care or medical)).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms] 149054 12 (hospital* or "care home*").mp. 1732652 13 exp nursing home/ 9482 14 exp prison/ 10821 15 10 or 11 or 12 or 13 or 14 1855559 16 exp insurance/ 189415 17 (maintenance or maintain*).mp. 970239 18 instal*.mp. 34495 19 train*.mp. 635021 20 (fire adj5 protection).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms] 346 21 (fire adj5 prevention).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms] 407 22 exp Legionella/ 6611 23 escap*.mp. 66657 24 death*.mp. 988014 25 fatal.ti,ab,kw. 130908 26 injur*.ti,ab,kw. 862282 27 "life safety".ti,ab,kw. 373 28 patient*.mp. 7593637

Database	Number of results	Search string
		29 exp fire fighter/ 1320 30 inhal*.ti,ab,kw. 115905 31 activation.mp. 1243222 32 smoke.mp. 59565 33 compartment.ti,ab,kw. 97492 34 "fire safety".ti,ab,kw. 675 35 "fire extinguish*".mp. 486 36 containment.mp. 16104 37 evacuation.mp. 17314 38 regulations.mp. 49536 39 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 10965215 40 9 and 15 and 39 70 41 limit 40 to yr="2001 - 2021" 51 42 limit 41 to english language 48
Scopus (conducted by PHS Librarian)	Initial search: 138	(TITLE-ABS-KEY (sprinkler* OR "auto* sprinkler system*" OR "fire suppress*" OR "water mist" OR "passive fire protection" OR "fire incident" OR "fire door*" OR "fire risk*")) AND (TITLE-ABS-KEY ("operating room") OR TITLE-ABS-KEY ((building* OR facilit*) W/5 (health*care OR health OR care OR medical)) OR TITLE-ABS-KEY (hospital* OR "care home*" OR carehome OR "nursing home" OR prison*)) AND (TITLE-ABS-KEY (insurance OR maintenance OR maintain* OR intal* OR train* OR (fire W/5 protection) OR (fire W/5 prevention) OR legionella OR escap* OR death* OR fatal OR injur* OR "life safety" OR patient* OR "fire fighter" OR inhal* OR activation OR smoke* OR compartment OR "fire safety" OR "fire extinguish*" OR containment OR evacuation OR regulations)) limited 2001-2021 and English Language = 138 results (search run 250821).

Appendix 2: Flow of evidence screening



Appendix 3: Grades of recommendation

Grade	Descriptor	Levels of evidence
Mandatory	‘Recommendations’ that are directives from government policy, regulations or legislation	N/A
Category A	Based on high to moderate quality evidence	SIGN level 1++, 1+, 2++, 2+, AGREE strongly recommend
Category B	Based on low to moderate quality of evidence which suggest net clinical benefits over harm	SIGN level 2+, 3, 4, AGREE recommend
Category C	Expert opinion, these may be formed by the NIPC groups when there is no robust professional or scientific literature available to inform guidance.	SIGN level 4, or opinion of NIPC group
No recommendation	Insufficient evidence to recommend one way or another	N/A

Appendix 4: SIGN 50 levels of evidence

1++	High quality meta-analyses, systematic reviews of RCTs, or RCTs with a very low risk of bias
1+	Well conducted meta-analyses, systematic reviews of RCTs, or RCTs with a low risk of bias
1-	Meta analyses, systematic reviews of RCTs, or RCTs with a high risk of bias
2++	High quality systematic reviews of case-control or cohort studies High quality case-control or cohort studies with a very low risk of confounding, bias, or chance and a high probability that the relationship is causal
2+	Well conducted case control or cohort studies with a low risk of confounding, bias, or chance and a moderate probability that the relationship is causal
2-	Case control or cohort studies with a high risk of confounding, bias, or chance and a significant risk that the relationship is not causal
3	Non-analytic studies, e.g. case reports, case series
4	Expert opinion