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Department for Communities and Local Government
Final Work Stream Report:

BD 2887

Compartment sizes, resistance to fire and fire safety project

Work stream 5 – Sprinkler provisions

286859 (D27V1)

CPD/04/102

Prepared for:

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FIRE

BD 2887

Compartment sizes, resistance to fire and fire safety project

Final Work Stream Report for Work Stream 5 – Sprinkler provisions

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Executive Summary

Building Regulations Division, Department for Communities and Local Government (DCLG) commissioned BRE to carry out a project titled "Compartment sizes, resistance to fire and fire safety". The main aim of this project was to produce robust evidence and data based on research, experimental fire testing, computer modelling and laboratory testing, where necessary, on a number of linked work streams in relation to fire safety and associated provisions in Schedule 1 of Part B of the Building Regulations 2010.

This Final work stream report describes the findings of the research for Work stream 5 – Sprinkler provisions. The guidance in Approved Document B (AD B) currently provides that most buildings over 30 m tall should have sprinkler protection with the exception of purpose groups: 2(a) – residential (institutional), 2(b) – residential (other) and 7(b) – (car parks). The principal aim of this work stream was to produce robust evidence and data to explore the options for fire sprinklers in tall buildings above 30 m not currently requiring sprinklers.

The work conducted under this work stream was desk-based and has involved the collection and preparation of suitable input data and cost benefit analysis modelling. This work stream has also involved the participation of an industry Steering Group. The statistical analysis presented in this report has been performed by BRE using raw statistical data supplied by DCLG.

It was not feasible to examine the risks of fire as a function of building height for buildings falling under AD B purpose groups 2(a) – residential (institutional), 2(b) – residential (other) and 7(b) – (car parks), since, unlike blocks of flats, data on the number of buildings of different heights was not available. However, it was possible to determine the number of beds, rooms or parking spaces, as appropriate, for these different building types and therefore, it was decided to use the "accommodation unit" as the basis for the cost benefit analysis.

Assumptions

This cost benefit analysis assumed the following:

- The risk for a building was assumed to be proportional to the number of accommodation units it contained.

  Risk was not explicitly a function of building height.

- Sprinkler system costs were calculated on the basis that the buildings are fully sprinkler protected in accordance with AD B and BS EN 12845 or BS 9251, as appropriate (with permitted exceptions).
- Water supply costs assumed a pump and tank was provided, with costs shared over the accommodation units within the building. Costs for a boosted mains option were also provided.
- Additional charges that could be imposed by water companies (e.g. design checking) were not included.
- Sprinkler effectiveness was estimated on the basis of the reduction in fire area (Note. The relationship between fire area and risk is non-linear).
- The reliability of the sprinkler system was assumed to be 98% ± 0.5%.

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- Life safety benefits were valued according to the principles laid out in the Treasury Green Book.
- Property damage was valued according to the data presented in the DCLG report "The Economic Cost of Fire 2004", uprated to current prices in line with the Retail Price Index.
- Environmental impacts and sustainability were not included. The omission of these factors was not expected to make a significant difference to the conclusions.
- Any cost savings resulting from less onerous requirements for building management were not included. However, an illustrative example was provided for care homes.
- Future trends in fire risks were not considered.

Conclusions

The conclusions of this study are:

- The following building types would be expected to experience a net cost benefit from the installation of sprinklers for buildings much less than 10 storeys (30 m) in height:
    - Care homes
    - Places of lawful detention
    - Hostels
    - Blocks of flats (comparison control group).

- The following building types could experience a net cost benefit from the installation of sprinklers for buildings above 10 storeys (30 m) in height, although this conclusion is not particularly robust (confidence level below 95%):
    - Residential accommodation for boarding schools
    - Halls of residence

- The following building types would be unlikely to experience a net cost benefit from the installation of sprinklers, even in buildings above 10 storeys (30 m) in height:
    - Hospitals
    - Hotels and boarding houses
    - Multi-storey car parks.

These conclusions were further supported by the sensitivity analysis which assumed the highest possible effectiveness for sprinkler mitigation of fire consequences. The uncertainties in sprinkler effectiveness for the reduction in deaths and injuries were generally very large. However, the sensitivity analysis showed that the cost benefit results were not greatly influenced by the effectiveness in reducing deaths and injuries. Most of the benefit from sprinkler protection arose from property protection.

It is possible that, dependent on the specific circumstances of a building design, sprinklers could be cost beneficial for some cases where they would not be for a generic building. The converse is also true.

Note. This cost benefit analysis concentrates solely on sprinklers and does not consider other fire protection measures which may or may not be more cost effective, according to circumstances.

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Confidence levels

The following table shows the confidence level for the hypothesis that sprinklers are cost effective, in the various building types. The higher the confidence level, the more likely sprinklers are to be cost-effective. A confidence level of 95% means there is only a 1-in-20 chance of incorrectly predicting sprinklers to be cost-effective when they actually would not be. A confidence level of 50% arises when the calculated costs and benefits are exactly equal, but the uncertainty in the calculation means that it is equally likely that sprinklers actually are or are not cost-effective.

Building type	Accommodation unit	Confidence level for hypothesis that sprinklers are cost-effective				
		n* = 1	n* = 10	n* = 100	n* = 1000	n* = ∞
Hospital	Bed	0%	0%	4%	9%	9%
Care home	Bed	23%	96%	100%	100%	100%
School (residential)	Bed	0%	0%	47%	69%	71%
Place of lawful detention	Bed	20%	100%	100%	100%	100%
Hotel and Boarding house	Room	0%	0%	0%	0%	0%
Hall of residence	Room	0%	0%	78%	85%	85%
Hostel	Room	100%	100%	100%	100%	100%
Multi-storey car park	Parking space	0%	0%	0%	0%	0%
Block of flats	Flat	0%	32%	98%	98%	98%

* n = number of accommodation units per building

Key to shading: red = confidence level below 5%, amber = confidence level between 5% and 95%, green = confidence level above 95%

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1 Introduction and Objectives

This Final work stream report is delivered as part of the Department for Communities and Local Government (DCLG) project BD 2887, titled "Compartment sizes, resistance to fire and fire safety", DCLG Contract reference CPD/04/102/010. The main aim of this project was to produce robust evidence and data based on research, experimental fire testing, computer modelling and laboratory testing (where necessary) on a number of linked work streams in relation to fire safety and associated provisions in Schedule 1 of Part B of the Building Regulations 2010. The project was broken down into specific work streams.

This report describes the findings of the research for Work stream 5 – Sprinkler provisions.

The guidance in Approved Document B (AD B) [1] currently provides that most buildings over 30 m tall should have sprinkler protection. This is with the exception of purpose group 2(a) – residential (institutional), 2(b) – residential (other) and 7(b) – (car parks).

In 2010, DCLG invited external partners to submit their ideas and evidence on ways to improve the Building Regulations. Sprinklers were raised by a number of respondents, but, it was concluded that there was not any significant new evidence on the health and safety benefits of greater sprinkler provision. However, the previous cost benefit analysis work [2, 3] did not look specifically at the inclusion of sprinklers in buildings that fall into the purpose groups as detailed above, nor did it look at sustainability alongside life safety as a cumulative benefit.

For those buildings not currently requiring sprinklers above 30 m, there is an assumption that a higher degree of management and control would be in place to counteract the increasing risk with building height. However, this higher degree of management would result in additional running costs which would be incurred throughout the life of the building. Recently, it has been suggested that the inclusion of sprinklers for these types of buildings could be a more cost-effective approach.

The principal aim of this work stream was to produce robust evidence and data to explore the options for fire sprinklers in tall buildings above 30 m not currently requiring sprinklers. The specific objectives of this work stream were to a) examine the alternative options other than those detailed in AD B (based principally on life risk), taking into account other factors such as environmental impact and b) to identify the costs and benefits and any risks that are associated with them

The Work stream 5 tasks were:

- Task 5.1 – Establishment and meetings of the Satellite Steering Group
- Task 5.2 – Collection and preparation of input data
- Task 5.3 – Cost benefit analysis modelling, analyse results and draw conclusions
- Task 5.4 – Reporting.

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2 Programme of work

2.1 Building types considered

This work stream considered the following building types:

- AD B purpose group 2(a) – Residential (institutional)
    - Hospital
    - Care homes
    - School (residential accommodation)
    - Places of lawful detention
- AD B purpose group 2(b) – Residential (other)
    - Hotel
    - Boarding house
    - Residential college
    - Hall of residence
    - Hostel
- AD B purpose group 7(b) – Car parks.

At the start of this work, it was thought unlikely that any work with regards to car parks would demonstrate a positive benefit in relation to health and safety due to the fact that fires in car parks are rare and there are few deaths or injuries recorded to date in the UK in car parks, although this was included to ensure the research is robust in addressing all issues.

This cost benefit analysis assumes that buildings are fully sprinkler protected in accordance with AD B and BS EN 12845: 2004 [4] or BS 9251: 2005 [5], as appropriate (with permitted exceptions).

2.2 Stakeholder engagement

This work stream has involved the participation of an industry Steering Group, Satellite Steering Group B. This group provided input during the course of the work, giving feedback on the research methodology as well as key deliverables and milestones. This group met three times.

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The organisations represented at the Steering Group are as follows.

Organisations represented at the Steering Group
• Building Regulations and Standards Division, Department for Communities and Local Government (DCLG) • BRE Project team • Association of Specialist Fire Protection (ASFP) • Association of Building Engineers (ABE) • British Automatic Fire Sprinkler Association (BAFSA) • British Parking Association • British Standards Committee FSH/25/3 Smoke ventilation in car parks • Business Sprinkler Alliance (BSA) • Chief Fire Officers Association (CFOA) • The Chartered Institute of Building (CIOB) • Fire Brigades Union (FBU) • Fire Industry Association (FIA) • Institution of Fire Engineers (IFE) • LABC • National Fire Sprinkler Association (NFSN) • National Register of Access Consultants (NRAC) • Passive Fire Protection Federation (PFPF) • RICS Building Control Professional Group (RICS) • RISC Authority • Scottish Building Standards (SBS) • Shore Engineering • Smoke Control Association • Water UK • Welsh Government (WG)

At the third Satellite Steering Group B meeting held on 19th January 2015, the Work stream 5 cost benefit analysis was presented and discussed in detail. From this meeting, the following should be noted:

- The difference was between a 'boarding house' and a 'hostel' was discussed as this was unclear. It was felt that a boarding house is short stay accommodation for recreational purposes, like a small hotel and a hostel is run by charitable organisations for welfare purposes.

- Building types 'Hotels' and 'Boarding houses' would be combined as a result of the definition of boarding houses being unclear and that data on the numbers of boarding houses in England could not be found.

- There is a recent growth trend in the UK in the last five years of building very tall blocks of student accommodation involving 'cluster flats'. Steering Group members expressed concerns about these. It was felt that these types of premises could be treated as being similar to blocks of flats.

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2.3 Collection and preparation of input data

The data collection and review has concentrated on England-specific and UK Treasury data, where appropriate and where possible. Data gathering covered the following areas:

- Fire statistics. The most up-to-date raw fire statistics data available from DCLG for England were requested for 2009 to 2013 (four years) [6]. The method of recording fire statistics changed in 2008/9. There are some issues with data consistency before and after this date. Therefore, data collected in 2009 and later from the DCLG Incident Reporting System (IRS) were concentrated on.

  The statistical analysis presented in this report has been performed by BRE using raw statistical data supplied by DCLG.

- Number of "accommodation units" of each type. It was easier to find information on the numbers of beds or rooms than the numbers of buildings. There was one exception to this; numbers of boarding houses could not be found. As the fire statistics (IRS) classified boarding houses as recreational buildings, it was decided to amalgamate boarding houses with hotels. The number of accommodation units was used with the DCLG fire statistics in order to derive the risks on a "per unit" basis.

- Costs of sprinkler system installation and maintenance. Published cost data has been used, adjusted for inflation.

- Costs of water supplies. Published cost data for water supplies have been used, adjusted for inflation. This did not include water company charges.

- A literature review and web search was conducted to obtain supplementary information.

Details of the input data used in the calculations are given in Appendix B.

2.3.1 Previous work

Previous relevant work was reviewed [e.g. 2, 3, 7, 8, 9, 10, 11] and the most relevant to this work stream are summarised as follows.

BRE carried out a cost benefit analysis of residential sprinklers for the Chief Fire Officers Association (CFOA report) [7]. This study looked at houses, flats, houses of multiple occupation and care homes. It used FDR1 fire statistics data from 2003 to 2008 and did not explicitly address the height of buildings.

BRE carried out a cost benefit analysis of residential sprinklers for Welsh Government in connection with the Domestic Fire Safety (Wales) Measure 2011 [8]. Building types that were considered were: houses, purpose built and converted flats, houses in multiple occupation, residential care homes, residential colleges, boarding schools and student halls of residence. The input data was Welsh specific data wherever possible.

The Callow Mount sprinkler pilot project in Sheffield [9] was a 13-storey block containing 47 flats operated as social housing that was retrofitted with a residential sprinkler system in September 2011, funded by the British Automatic Fire Sprinkler Association. As part of this pilot scheme, the full costs of the project were recorded.

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Blocks of flats are included in this cost benefit analysis as a control group for comparison with previous work [2] and to check the methodology with the IRS fire statistics data. There are good data for the risks of fire as a function of building height for blocks of flats and the number of buildings of each height.

2.4 Initial investigation of fire statistics

The DCLG IRS fire statistics data for England for 2009 to 2013 [6] was initially analysed and this concluded:

- Sample sizes for the numbers of deaths and injuries in the building types to be studied were small. Therefore, correlations between fire area and risk were likely to be uncertain.
- A theoretical analysis [12] suggests that fire risk is a quadratic function of the number of floors in the building. There is some support for this theory from the fire statistics, mainly based on flats and offices. This was further investigated for the property types of interest in this study and was found not to be robust.
- Previous work for DCLG [2] showed sprinklers were cost effective in tall blocks of flats due to the increasing number of fires that such buildings experienced. More recent work [7, 8] showed that economies of scale in tall buildings also helped the cost effectiveness of sprinklers.
- Data on the numbers of buildings of different heights in each of the property types of interest were needed, before the effect of fire frequency on risk could be seen. (The statistics analysis gives the consequences per fire only).
- For flats, there is information on the numbers of flats in buildings of different heights, which allows the risk as a function of height to be investigated (see Appendix C). This showed that the risk in a flat did not depend strongly on the building height. For other buildings, it was argued that this dependence would be even weaker.
- The property types of interest do not have information on the numbers of buildings in different height ranges. Therefore, it was decided to utilise an "accommodation unit" type and size approach instead, where an accommodation unit type could be, for example, a bed, a room, a parking space and the size of the unit = the footprint of unit multiplied by the height of the unit.
- The risk per unit was assumed to be constant, i.e. independent of building height.

2.5 Cost benefit modelling

The cost benefit analysis was performed using a spreadsheet-based methodology/tool that has undergone considerable development and refinement over a number of years.

The current version combines the England fire statistics data from the DCLG IRS, numbers of accommodation units, and other information, to calculate various risk metrics (e.g. risk of death/injury, extent of fire damage) for unsprinklered buildings.

Direct statistical evidence for sprinkler effectiveness in buildings in England (and UK) is extremely limited (because most buildings do not have sprinklers), and statistical evidence from other countries (such as the USA) may not be applicable, due to different standards, etc. Therefore, the efficiency of sprinklers was estimated on the basis of a reduced fire area, and corresponding reductions in other risks (e.g. risks of death) which are correlated with fire area.

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The cost benefit analysis handles uncertainties in the input data and produces robust confidence intervals for the results.

The results of the cost benefit analysis are presented on a "per accommodation unit" basis. Costs were itemised (e.g. cost of sprinkler installation, cost of water supply). Benefits, in terms of reductions in fire impacts over the whole lifetime of the sprinkler system, were converted to monetary terms. Uncertainties and confidence intervals are also presented.

The specific risk metrics that were included are:

- Risk of death per building per year (with each death prevented valued using UK Treasury guidance [13] on Willingness to pay, currently about £1.8 m)
- Risk of injury per building per year (with each injury prevented valued based on UK Treasury advice [14]; a weighted average for serious and slight injuries was calculated)
- Fire damage, related to area burnt (m^2) and converted to £ using Economic Cost of Fire data [14].

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The input data is detailed in Appendix B. Costs that were considered include:

- Sprinkler system installation costs
- Sprinkler system water supply costs
- Maintenance costs for sprinkler systems
- Building running costs, including management (e.g. staffing levels).

Figure 1 shows schematically how the costs and benefits are assumed to vary with the number of "accommodation units".

Some costs, such as provision of water supplies, or system maintenance, will be incurred regardless of the number of units that the system protects. Hence, as the number of units increases, the fixed costs are shared, and the cost per unit decreases.

Benefits are assumed to be directly proportional to the number of units. There will be a number of units at which the benefits exceed the costs.

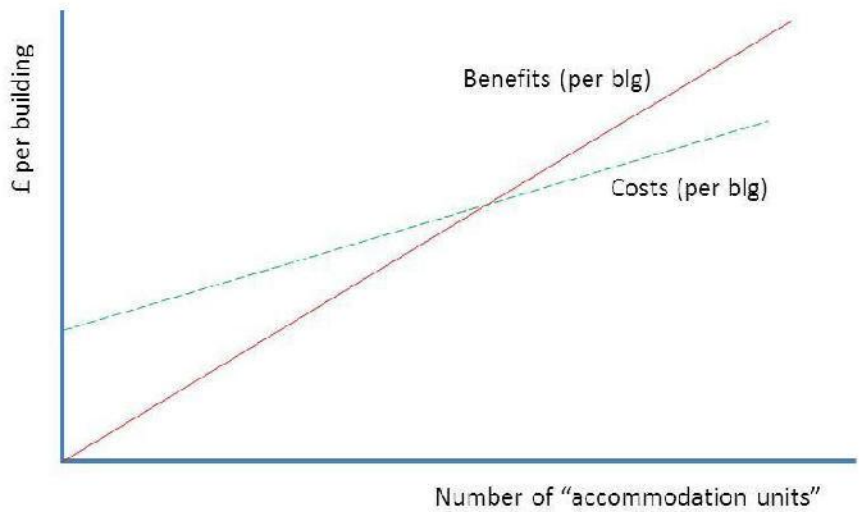

Figure 1 - Schematic illustration of the assumed variation in costs and benefits with the number of "accommodation units"

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2.6 Analysis of results

For details of the cost benefit calculations for the main analysis, see Appendix D.

The results of the main analysis are summarised in Tables 1 and 2.

In Table 1, n is the number of accommodation units within the building. As it is assumed that costs such as water supply, maintenance etc. are shared over the n accommodation units, the cost benefit ratio improves (gets larger) as n increases.

Table 1 - Cost-benefit ratios for n = 1, 10, 100, 1000, infinity for the selected building types

Building type	Accommodation unit	Cost benefit ratio (R)				
		n = 1	n = 10	n = 100	n = 1000	n = ∞
Hospital	Bed	0.18 ± 0.02	0.63 ± 0.05	0.85 ± 0.08	0.88 ± 0.09	0.88 ± 0.09
Care home	Bed	0.23 ± 0.03	1.30 ± 0.18	2.44 ± 0.51	2.67 ± 0.61	2.70 ± 0.62
School (residential)	Bed	0.05 ± 0.01	0.38 ± 0.08	0.98 ± 0.25	1.16 ± 0.33	1.19 ± 0.34
Place of lawful detention	Bed	0.20 ± 0.03	1.76 ± 0.24	7.87 ± 0.95	12.08 ± 1 58	12.83 ± 1.73
Hotel and Boarding house	Room	0.03 ± 0.00	0.20 ± 0.02	0.50 ± 0.04	0.60 ± 0.05	0.61 ± 0.06
Hall of residence	Room	0.11 ± 0.01	0.63 ± 0.08	1.18 ± 0.24	1.30 ± 0.29	1.31 ± 0.29
Hostel	Room	1.17 ± 0.06	4.94 ± 0.24	7.29 ± 0.37	7.66 ± 0.39	7.70 ± 0 39
Multi-storey car park	Parking space	0.01 ± 0.01	0.10 ± 0.07	0.27 ± 0.18	0.32 ± 0.22	0.33 ± 0.22
Block of flats	Flat	0.18 ± 0.03	0.94 ± 0.13	1.63 ± 0.31	1.76 ± 0.36	1.78 ± 0.37

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In Table 2, the values given are:

- The number of accommodation units required to achieve a cost benefit ratio of 1.00 (i.e. exactly break-even; when n is higher the benefits exceed the costs). Note. The uncertainties in the calculations mean that the confidence level that the ratio will be 1.00 (or higher) in practice is 50%.
- The number of accommodation units required to give a confidence level of 95% that the benefits will exceed the costs. For some building types, this level of confidence cannot be achieved even with an infinite number of accommodation units to share fixed costs, because the uncertainties are too large.

Table 2 – Number of accommodation units giving a cost benefit ratio = 1.00, and number giving confidence = 95%, for the selected building types

Building type	Accommodation unit	Number of accommodation units	
		No. for R = 1	No. for confidence = 95%
Hospital	Bed	–	--
Care home	Bed	7	10
School (residential)	Bed	111	--
Place of lawful detention	Bed	6	8
Hotel and Boarding house	Room	--	--
Hall of residence	Room	34	--
Hostel	Room	1	1
Multi-storey car park	Parking space	--	--
Block of flats	Flat	12	30

Note: "--"means that the specified cost benefit ratio or confidence level could not be achieved, even with an infinite number of accommodation units.

2.7 Sensitivity analysis

Because the sprinkler effectiveness values were very uncertain in many cases, a sensitivity analysis was performed where these effectiveness values were taken as 100%. These are the highest possible values, so the only way to improve the cost benefit further would be to reduce the costs.

For details of the cost benefit calculations for the sensitivity analysis, see Appendix E.

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The results of the sensitivity analysis are summarised in Tables 3 and 4.

Table 3 – Cost benefit ratios for n = 1, 10, 100, 1000, infinity for selected building types for the sensitivity analysis

Building type	Accommodation unit	Cost benefit ratio (R)				
		n = 1	n = 10	n = 100	n = 1000	n = ∞
Hospital	Bed	0.20 ± 0.02	0.70 ± 0.05	0.94 ± 0.09	0.97 ± 0.09	0.97 ± 0.09
Care home	Bed	0.28 ± 0.03	1.56 ± 0.19	2.93 ± 0.59	3.21 ± 0.70	3.25 ± 0.72
School (residential)	Bed	0.06 ± 0.01	0.46 ± 0.08	1.19 ± 0.27	1.42 ± 0.36	1.45 ± 0.38
Place of lawful detention	Bed	0.24 ± 0.03	2.12 ± 0.22	9.52 ± 0.73	14.60 ± 1.35	15.52 ± 1.52
Hotel and Boarding house	Room	0.03 ± 0.00	0.21 ± 0.02	0.53 ± 0.04	0.63 ± 0.06	0.64 ± 0.06
Hall of residence	Room	0.13 ± 0.01	0.71 ± 0.09	1.33 ± 0.27	1.46 ± 0.32	1.47 ± 0.33
Hostel	Room	1.34 ± 0.05	5.66 ± 0.22	8.36 ± 0.35	8.78 ± 0.37	8.83 ± 0.37
Multi-storey car park	Parking space	0.03 ± 0.00	0.21 ± 0.02	0.54 ± 0.04	0.65 ± 0.06	0.66 ± 0.06
Block of flats	Flat	0.22 ± 0.03	1.16 ± 0.15	2.02 ± 0.38	2.18 ± 0.44	2.20 ± 0.45

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Table 4 – Number of accommodation units giving cost-benefit ratio = 1.00, and number giving confidence = 95%, for selected building types for the sensitivity analysis

Building type	Accommodation unit	Number of accommodation units	
		No. for R = 1	No. for confidence = 95%
Hospital	Bed	–	--
Care home	Bed	5	7
School (residential)	Bed	48	--
Place of lawful detention	Bed	5	6
Hotel and Boarding house	Room	–	--
Hall of residence	Room	23	--
Hostel	Room	1	1
Multi-storey car park	Parking space	--	--
Block of flats	Flat	7	13

Note: "--"means that the specified cost-benefit ratio or confidence level could not be achieved, even with an infinite number of accommodation units.

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3 Conclusions

It was not feasible to examine the risks of fire as a function of building height for buildings falling under Approved Document B purpose groups 2(a) – residential (institutional), 2(b) – residential (other) and 7(b) – (car parks), since, unlike blocks of flats, data on the number of buildings of different heights was not available.

However, it was possible to determine the number of beds or rooms or parking spaces, as appropriate, for these different building types and therefore, it was decided to use the "accommodation unit" as the basis for the cost benefit analysis.

This cost benefit analysis assumed the following:

- The risk for a building was assumed to be proportional to the number of accommodation units it contained.
- Risk was not explicitly a function of building height (based on findings, see Appendix C).
- Sprinkler system costs were calculated on the basis that the buildings are fully sprinkler protected in accordance with AD B and BS EN 12845 or BS 9251, as appropriate (with permitted exceptions).
- Water supply costs assumed a pump and tank was provided, with costs shared over the accommodation units within the building. Costs for a boosted mains option were also provided.
- Additional charges that could be imposed by water companies (e.g. design checking) were not included.
- Sprinkler effectiveness was estimated on the basis of the reduction in fire area (Note. The relationship between fire area and risk is non-linear).
- The reliability of the sprinkler system was assumed to be 98% ± 0.5%.
- Life safety benefits were valued according to the principles laid out in the Treasury Green Book.
- Property damage was valued according to the data presented in the DCLG report "The Economic Cost of Fire 2004", uprated to current prices in line with the Retail Price Index.
- Environmental impacts and sustainability were not included. The omission of these factors was not expected to make a significant difference to the conclusions.
- Any cost savings resulting from less onerous requirements for building management were not included. However, an illustrative example was provided for care homes.
- Future trends in fire risks were not considered.

The conclusions of this study are:

- The following building types would be expected to experience a net cost benefit from the installation of sprinklers for buildings much less than 10 storeys (30 m) in height:
    - Care homes
    - Places of lawful detention
    - Hostels

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  - Blocks of flats (comparison control group).

- The following building types could experience a net cost benefit from the installation of sprinklers for buildings above 10 storeys (30 m) in height, although this conclusion is not particularly robust (confidence level below 95%):
  - Residential accommodation for boarding schools
  - Halls of residence

- The following building types would be unlikely to experience a net cost benefit from the installation of sprinklers, even in buildings above 10 storeys (30 m) in height:
  - Hospitals
  - Hotels and boarding houses
  - Multi-storey car parks.

These conclusions were further supported by the sensitivity analysis which assumed the highest possible effectiveness for sprinkler mitigation of fire consequences. The uncertainties in sprinkler effectiveness for the reduction in deaths and injuries were generally very large. However, the sensitivity analysis showed that the cost benefit results were not greatly influenced by the effectiveness in reducing deaths and injuries. Most of the benefit from sprinkler protection arose from property protection.

It is possible that, dependent on the specific circumstances of a building design, sprinklers could be cost beneficial for some cases where they would not be for a generic building. The converse is also true.

This cost benefit analysis concentrates solely on sprinklers and does not consider other fire protection measures which may or may not be more cost effective, according to circumstances.

4 Acknowledgements

The authors, Jeremy Fraser-Mitchell and Corinne Williams, would particularly like to acknowledge the valuable contribution provided by members of Satellite Steering Group B and the overall Project Steering Group.

5 References

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Appendix A – Summary of the Research

Building Regulations Division, Department for Communities and Local Government (DCLG) commissioned BRE to carry out a project titled "Compartment sizes, resistance to fire and fire safety". The main aim of this project was to produce robust evidence and data based on research, experimental fire testing, computer modelling and laboratory testing, where necessary, on a number of linked work streams in relation to fire safety and associated provisions in Schedule 1 of Part B of the Building Regulations 2010.

This Final work stream report describes the findings of the research for Work stream 5 – Sprinkler provisions. The principal aim of this work stream was to produce robust evidence and data to explore the options for fire sprinklers in tall buildings above 30 m not currently requiring sprinklers,

The work conducted under this work stream was predominantly desk-based and has involved input data gathering and cost benefit analysis modelling. This work stream has also involved the participation of an industry Steering Group.

Based on the assumptions detailed in the report, the conclusions of this study are:

- The following building types would be expected to experience a net cost benefit from the installation of sprinklers for buildings much less than 10 storeys (30 m) in height: Care homes, Places of lawful detention, Hostels and Blocks of flats (comparison control group).
- The following building types could experience a net cost benefit from the installation of sprinklers for buildings above 10 storeys (30 m) in height, although this conclusion is not particularly robust (confidence level below 95%): Residential accommodation for boarding schools and Halls of residence.
- The following building types would be unlikely to experience a net cost benefit from the installation of sprinklers, even in buildings above 10 storeys (30 m) in height: Hospitals, Hotels and boarding houses and Multi-storey car parks.

These conclusions were further supported by the sensitivity analysis which assumed the highest possible effectiveness for sprinkler mitigation of fire consequences. The uncertainties in sprinkler effectiveness for the reduction in deaths and injuries were generally very large. However, the sensitivity analysis showed that the cost benefit results were not greatly influenced by the effectiveness in reducing deaths and injuries. Most of the benefit from sprinkler protection arose from property protection.

It is possible that, dependent on the specific circumstances of a building design, sprinklers could be cost beneficial for some cases where they would not be for a generic building. The converse is also true.

This cost benefit analysis concentrates solely on sprinklers and does not consider other fire protection measures which may or may not be more cost effective, according to circumstances.

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Appendix B – Input data to the cost benefit analysis

B1 Cost of sprinkler installation

For this study, the costs of sprinkler installations were provided by earlier data, as follows:

- CFOA report [B1], for sprinkler systems for residential and domestic buildings
- BAFSA 2006 report [B2] for sprinkler systems for commercial buildings, coupled with advice from BSA [B3], that prices had effectively been frozen (falling in real terms) since 2010.

Table B1 summarises the sprinkler installation costs that were used.

European standard BS EN 12845 [B4] is the principal standard used in the UK for the design, installation and maintenance of automatic sprinkler systems for commercial and industrial buildings. British Standard BS 9251 is the principal standard used in the UK for the design, installation and maintenance of automatic sprinkler systems for domestic and residential occupancies. The most recent version of BS 9251 was published in 2014 but the cost data is for BS 9251: 2005 [B5].

This cost benefit analysis assumes that buildings are fully sprinkler protected in accordance with AD B and BS EN 12845: 2004 or BS 9251: 2005, as appropriate (with permitted exceptions).

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Table B1 - Sprinkler system installation costs

Building type	Accommodation "unit"	Sprinkler type	Cost per accommodation "unit"	Notes
Hospital	Bed	BS EN 12845, OH1	£5,184 ± £468	1, 2, 3, 9
Care home	Bed	BS 9251	£715 ± £156	4, 10
School (residential)	Bed	BS 9251	£356 ± £78	5, 10
Place of lawful detention	Bed	BS EN 12845, OH1	£320 ± £29	10, 12, 13
Hotel and Boarding house	Room	BS EN 12845, OH1	£960 ± £88	1, 2, 6, 9
Hall of residence	Room	BS 9251	£715 ± £156	7, 10
Hostel	Room	BS 9251	£715 ± £156	7, 10
Multi-storey car park	Parking space	BS EN 12845, OH2	£961 ± £127	1, 2, 8, 11
Block of flats	Flat	BS 9251	£620 ± £124	4, 10

Notes

1. Data from BAFSA report [B2], Ordinary Hazard sprinkler system cost per m^2 in 2004 is £27 - £37
2. Uprate by x1.2 for 2010 prices
3. Assume 135 m^2 per bed based on for example, Hospital A [B6] has 410 beds in 65,000m^2, 159 m^2 per bed, Hospital B [B6] has 179 beds in 15,000 m^2, 84 m^2 per bed and Hospital C [B6] has 600 beds in 72,000 m^2, 120 m^2 per bed, Worcestershire Royal Hospital [B7] has 550 beds in 38,000 m^2, 69m^2 per bed , Great Western Hospital [B8] has 412 beds in 55,000m^2 of space, 133 m^2 per bed, Royal London Hospital [B9] has 727 beds in 145,300 m^2 of floor space, 200 m^2 per bed.
4. Data from CFOA report [B1].
5. Assume similar costs to care homes, but two beds per room
6. Assume 25 m^2 per room based on [B10]. This does not include circulation space, catering, assembly rooms, etc.
7. Assumed the same as care homes (though could also have assumed same as flats)
8. Average size of a parking space has been taken as 24.0 ± 2.3 m^2 [B11]
9. Data for sprinkler system in accordance with BS EN 12845: 2004 [B4] Ordinary Hazard Group 1 (OH1)
10. Data for sprinkler system in accordance with BS 9251: 2005 [B5]

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11. Data for sprinkler system in accordance with BS EN 12845: 2004 [B4] Ordinary Hazard Group 2 (OH2)

12. Place of detention: data from Hansard, 19 March 1996, part 15: "ideal minimum size" for single person cell is 5.5 m^2.

13. Assumed sprinkler costs higher (x 1.5) because density of heads (1 per cell) is greater than that required by standard for less compartmented buildings

B2 Cost of sprinkler system maintenance

The CFOA report [B1] provides sprinkler system maintenance cost data for domestic and residential buildings. The BAFSA 2006 report [B2] provides sprinkler system maintenance cost data for commercial buildings.

Table B2 summarises the sprinkler system maintenance costs that were used.

Table B2 - Sprinkler system maintenance costs

Building type	Sprinkler type	Cost per sprinkler system	Notes
Hospital	BS EN 12845, OH1	£863 ± £99	1, 2, 3
Care home	BS 9251	£178 ± £13	4, 5
School (residential)	BS 9251	£178 ± £13	6
Place of lawful detention	BS EN 12845, OH1	£863 ± £99	1, 2, 3
Hotel and Boarding house	BS EN 12845, OH1	£863 ± £99	1, 2, 3
Hall of residence	BS 9251	£178 ± £13	6
Hostel	BS 9251	£111 ± £1	4, 5
Multi-storey car park	BS EN 12845, OH2	£863 ± £99	1, 2, 3
Block of flats	BS 9251	£181 ± £36	4, 5

Notes

1. Data from BAFSA report [B2], annual maintenance of system for "large school" in 2004 is £500 - £750

2. Uprate by x1.38 to convert to 2014 prices from 2004

3. As a consistency check, the BAFSA report [B2] quotes £750 - £1,500 annually (2004 prices) for a large warehouse or retail premises; uprating to 2013 prices gives £1,013 - £2,025. For the BSA

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report [B2], BAFSA quoted £1,250 for warehouses below 10,000m^2, and £2,000 per annum for larger buildings.

4. Data from CFOA report [B1] (2010 prices)
5. Uprate by x 1.15 to convert to 2014 prices from 2010
6. Assumed the same as care homes. The data for care homes presented in the CFOA report [B1] was for moderately sized buildings of about 20 beds.

B3 Cost of sprinkler water supplies

The CFOA report [B1] provides cost data for water supplies for sprinkler systems for domestic and residential buildings. The BAFSA 2006 report [B2] provides sprinkler installation cost data which includes the cost of water supplies for sprinkler systems for commercial buildings.

Table B3 summarises the sprinkler system water supply costs that were used. It should be noted that none of the costs in Table B3 include water company charges (e.g. for design checking, providing additional mains connections, etc.)

Table B3 - Sprinkler system water supply costs

Building type	Sprinkler type	Boosted mains	Pump and tank	Notes
Hospital	BS EN 12845, OH1	--	--	1
Care home	BS 9251	£701 ± £91	£3,526 ± £683	2, 5
School (residential)	BS 9251	£701 ± £91	£3,526 ± £683	3
Place of lawful detention	BS EN 12845, OH1	--	--	1
Hotel and Boarding house	BS EN 12845, OH1	--	--	1
Hall of residence	BS 9251	£701 ± £91	£3,526 ± £683	3
Hostel	BS 9251	£579 ± £55	£1,399 ± £98	4, 5
Multi-storey car park	BS EN 12845, OH2	--	--	1
Block of flats	BS 9251	£577 ± £69	£1,291 ± £116	2, 5

Notes

1. Included in the cost of installation
2. CFOA report [B1] data (2010 prices)
3. Assumed same as care homes

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4. CFOA data for HMO (2010 prices) [B1] – it was assumed that a traditional HMO had on average six bedsits per building.
5. Uprate by x1.15 to convert to 2014 prices from 2010

B4 Sprinkler system lifetime

Based on estimates by BAFSA [B12] and others [B13], the lifetime of the sprinkler system has been assumed to be uniformly distributed between 40 and 50 years, i.e. U(40, 50).

B5 Capital recovery factor

If the amount of capital to be repaid is C, the annual payment A is given by

$$A = C.K \qquad \text{[Equation B.1]}$$

Here, K is the Capital Recovery Factor.

The Present Value (PV) of the annual payment in year y is

$$A_y = \frac{A_1}{\prod_{i=1}^{y-1}(1+r_i)} \qquad \text{[Equation B.2]}$$

The interest rate r_i recommended in the Treasury Green Book [B14] is 3.5%. For repayment periods of more than 30 years, a rate of 3% is used after year 30.

The sum of the PV's over the repayment term t must equal the capital sum (this is a restatement of Equation B1), i.e.

$$C = \sum_{y=1}^{t} \frac{A_1}{\prod_{i=1}^{y-1}(1+r_i)} \qquad \text{[Equation B.3]}$$

And hence $K = A_1 / C$.

For a repayment term equal to the lifetime of the sprinkler system, K = 0.043 ± 0.001.

B6 Numbers of accommodation "units"

Previous cost benefit studies of sprinkler systems in dwellings have treated each dwelling (house or flat) as an individual accommodation "unit". For other residential occupancies, e.g. HMOs and care homes, the building has been treated as the "unit". However, it would be equally valid for the "unit" to be the number of occupants, if this value is known, and the costs and fire risks can be expressed per person per year.

Table B4 shows the numbers of accommodation "units", with sources, used as input data for this study.

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Table B4 – Number of accommodation units

Building type	Accommodation "units"		Notes
	Number	Unit	
Hospital	148,440 ± 868	Beds	1
Care home	453,472	Beds	2
School (residential)	90,535	Beds	3
Place of lawful detention	87,719	Beds	4
Hotel and Boarding house	599,200	Rooms	5, 6
Hall of residence	409,758 ± 1,306	Rooms	7
Hostel	38,534	Rooms	8
Multi-storey car park	280,000 ± 23,094	Spaces	9
Block of flats	4,142,000 ± 69,462	Flats	10

Notes

1. Hospitals: the value quoted is the daily number of beds open (overnight and day only), averaged over Q1 2014/15 and Q4 2013/14 [B15]
2. Care homes: there were 453,472 residential places in 18,378 residential care homes in England at the end of March 2009 [B16]. As a consistency check, the CFOA report [B1] referred to 18,200 homes in 2001, for whole UK (so the latest data implies an increase in provision of about 25%).
3. Boarding schools: 68,453 pupils board at schools represented by the Independent Schools Council (ISC) [B17]. The ISC schools account for around 80 per cent of independently educated pupils. In addition, there are 4,969 boarders in 37 state schools [B18].
4. Places of lawful detention: usable operational capacity at 12.09.2014 [B19]
5. Hotels: 135,000 rooms in London, and 464,200 in other regions [B20]
6. Boarding houses: data has not been found. It has been assumed the number of hotel rooms includes boarding houses (or if not, does not significantly affect the total)
7. Halls of residence: number of students in institution-maintained property or private-sector halls, average for 2001/12 and 2012/13 [B21]. The number of rooms assumes one student per room.
8. Hostel: spaces available for single homeless people (September to December 2013) [B22]
9. Car parks: 3 to 4 million parking spaces in 17 to 20,000 non-residential car parks, 8% of which are multi-storey [B23]
10. Flats: numbers of purpose-built and converted flats in England, presented in CFOA report [B1]

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B7 Fire statistics

Data on the number of fires, deaths, and injuries, have been extracted from the Incident Recording System (IRS) for the years 2009/10 to 2012/13 inclusive (four years) [B24]. This information is summarised in Table B5. The uncertainties (error on the mean) are ± one standard deviation.

Table B5 – Fires and casualties in different building types for a four-year period (2009/10 to 2012/13) (IRS data)

Building type	Fires	Casualty fires	Deaths	Injuries (severe/slight)
Hospital	3,220	100	0	72
Care home	3,843	315	15	152
School (residential)	147	4	0	2
Place of lawful detention	1,810	198	0	84
Hotel and Boarding house	1,544	89	1	57
Hall of residence	1,834	85	0	42
Hostel	983	90	1	52
Multi-storey car park	125	9	0	4
Block of flats	43,984	6,496	202	3,936

As a consistency check, the fire statistics for 2003 to 2008 (FDR1 forms) presented in the CFOA report [B1] were:

- Care homes: 4,812 fires, 28 deaths and 452 injuries in four years (This gives reasonably good agreement, given the uncertainties, and also the death of 14 residents in the Rosepark fire of 2004 [B25] affects the results)
- Flats: 82,932 fires, 400 deaths and 17,464 injuries in four years (UK rather than England, but even so, the values are roughly double the values from the IRS data)
- Note the total numbers of all injuries, including first aid and precautionary checks, are 431 and 8,695 for care homes and flats, respectively, in the IRS data

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B8 Fire risks

By combining the numbers of accommodation "units" and the fire statistics, estimates of the risk can be made. These are summarised in Table B6.

Table B6 - Fire risks in different accommodation "units"

Building type	Fires per million unit.years	Deaths per million unit.years	Injuries per million unit.years
Hospital	5425 ± 96	2 ± 0.2	122 ± 12
Care home	2119 ± 34	8 ± 0.5	84 ± 5
School (residential)	409 ± 34	3 ± 2	7 ± 3
Place of lawful detention	5161 ± 121	3 ± 0.2	240 ± 17
Hotel and Boarding house	645 ± 16	0.4 ± 0.04	24 ± 3
Hall of residence	1120 ± 26	0.6 ± 0.07	26 ± 3
Hostel	6384 ± 204	7 ± 1	341 ± 36
Multi-storey car park	113 ± 10	1 ± 0.3	4 ± 1
Block of flats	2655 ± 13	12 ± 0.2	238 ± 3

Note. The "accommodation units" may be different (e.g. beds, rooms, parking spaces, or flats) and therefore care should be taken in comparing risks across different building types.

As a consistency check, the CFOA report [B1] presented the following results:

- Care homes for the elderly: 2,443 fires, 18 deaths and 265 injuries per million occupants per year (Note. The time period considered in the CFOA report included the Rosepark care home fire [B24] with 14 fatalities).
- Purpose-built flats: 4,306 fires, 20 deaths and 895 injuries per million flats per year.
- Note. The total risks for all injuries per million unit.years, including first aid and precautionary checks, are 238 and 525 for care homes and flats, respectively, in the IRS data.

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B9 Environmental impact

The subject of fire and the environment and building sustainability is wide ranging and covers a large number of issues. A scoping study for DCLG [B26] has shown that it is far from clear that any form of fire protection that is applied to the building stock through the application of the Building Regulations can have anything other than a negative environmental impact, although for a few fire protection systems this will not be the case i.e. some systems may have a net benefit to the environment. The scoping study concluded that it was not possible, with the state of knowledge at the time, to recommend any particular course of action other than further directed research. Potential areas of further work were identified.

A cost benefit analysis for Welsh Government for residential sprinklers in Wales [B27] included an estimate for the carbon dioxide (CO_2) released in dwelling fires. This was converted to monetary terms using the non-traded cost of carbon, which was about £50 - £100 per tonne. The amount of CO_2 release avoided as a consequence of providing sprinklers in all new dwellings in Wales was shown to be equivalent to that released by the normal activities of just two people. The monetary saving was 0.05% of the Net Present Value of the sprinkler systems (calculated for a 10-year policy evaluation period). Note that this study for the Welsh Government only considered CO_2 release; none of the other environmental factors were considered.

A study into the costs and benefits of sprinklers in warehouses for the Business Sprinkler Alliance [B28] included an investigation into some environmental aspects. A detailed life-cycle analysis (LCA) was undertaken for the construction of an exemplar 15,000 m^2 warehouse; this included the environmental impacts of providing the sprinkler system. Attempts were also made to estimate the environmental impacts of the fire and looked at the CO_2 released from burning of the warehouse contents, CO_2 embodied in the replacement of the contents (and the warehouse too, if it was sufficiently damaged to require demolition and rebuilding), and the use of water for fire-fighting. Converted to monetary terms, the environmental impact accounted for 1% - 4% of the overall cost of fires (which were dominated by the losses due to property damage).

The state of the art in relation to environmental impacts of fires is still developing and due to a lack of the relevant data, we are still unable to provide a robust or comprehensive estimate of the overall environmental impact of fires and fire protection. Based on the experience gained from the studies mentioned above and the data that is available, the environmental impacts are small, relative to other fire impacts. As such, for the purposes of the cost benefit analysis presented in this report, the environmental impacts have not been included.

B10 Sprinkler effectiveness

Most domestic and residential buildings in England are not fitted with sprinklers, so there is a dearth of statistics that can be used directly to estimate the effectiveness of sprinklers in reducing deaths, injuries and property damage. For this reason, a correlation between fire area and fire risk is looked for, and the assumption is made that reducing the fire area (due to sprinkler activation) leads to a consequent reduction in risk.

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Table B7 - Estimated sprinkler effectiveness in different building types for a four-year period (2009/10 to 2012/13) (IRS data)

Building type	Reduction in deaths (%)	Reduction in injuries (%)	Reduction in fire area (%)
Hospital	15 ± 36	1 ± 2	94 ± 3
Care home	41 ± 33	12 ± 19	94 ± 3
School (residential)	46 ± 44	53 ± 37	97 ± 1
Place of lawful detention	64 ± 48	27 ± 27	86 ± 8
Hotel and Boarding house	52 ± 50	54 ± 15	98 ± 1
Hall of residence	30 ± 41	32 ± 20	92 ± 3
Hostel	43 ± 28	7 ± 14	94 ± 2
Multi-storey car park	41 ± 39	73 ± 28	89 ± 5
Block of flats	76 ± 8	58 ± 14	93 ± 2

Notes.

1. The methodology used to determine the effectiveness is similar to that used in the CFOA report [B1], though based on different data (IRS 2009 – 2013 rather than FDR1 2003 – 2008).

2. The smallest area of fire damage recorded in the IRS is "under 5 m^2". The sprinkler effectiveness can be estimated on the basis that fires which would otherwise grow larger are constrained to this area, and the fire risks are similarly constrained. The sprinkler effectiveness is defined as 1 – N(spr)/N(unspr) where N(spr) is the number of deaths, injuries, or m^2 damage expected for sprinklered fires, and N(unspr) is the observed number for unsprinklered fires.

3. As the smallest area of fire damage has a large range, it is necessary to make a better estimate of the average area of fires in this category. This is done by fitting a power law to the Cumulative Probability Distribution for the number of fires whose area is less than A, for the size categories "under 5 m^2", 5 – 10 m^2", "10 – 20 m^2". This power law has the form $N(A) = a.A^b$. With some algebra it can be shown that the average area of fires in the "under 5 m^2" category is 5.b/(b+1).

4. Previous research [B1] estimated the fire area at which the first sprinkler would operate; this was approximately Normally-distributed with a mean of 0.3 m^2 and standard deviation of 0.1 m^2.

5. The sprinkler effectiveness calculated as per note 2 applies for an average area calculated as per note 3. Therefore, the sprinkler effectiveness at the actual area of sprinkler activation could be calculated by interpolation (since the effectiveness would by definition be 100% if the fire area could be reduced to zero).

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6. The sprinkler reliability, assumed to be Normally-distributed with a mean of 98% and standard deviation of 0.5% as per the CFOA report [B1], was factored into the effectiveness values presented in the table.

7. Monte Carlo and Bootstrap Sampling techniques were used to estimate the uncertainty levels.

As a consistency check, the CFOA report [B1] presented the following results:

- For care homes for elderly people, sprinklers reduced deaths by 62%, injuries by 73% and property damage by 86%.
- For purpose-built flats, sprinklers reduced deaths[1] by 90%, injuries by 61% and property damage by 88%.
- For converted flats, sprinklers reduced deaths by 95%, injuries by 66% and property damage by 92%.

The effectiveness of sprinklers in reducing property damage is directly proportional to the fire area.

B11 Value of each death prevented

The Department of Transport figure, used in the Treasury Green Book [B14] and Economic Cost of Fire 2004 [B26] was £1,350,000. This needs to be converted to a value in 2014, by multiplying by the increase in GDP from 2004 to 2010, a factor of 1.23, and then by a further factor 1.05 to increase from 2010 to 2014. Therefore, the value in 2014 is calculated to be £1,778,000.

B12 Value of each injury prevented

The Department of Transport figure, used in the Treasury Green Book [B14] and Economic Cost of Fire 2004 [B26], for a serious injury was £155,000, and for a minor injury was £12,000. Uprated to 2014, the values are £200.4k and £15.5k, respectively. The IRS defines whether injuries are serious, slight, requiring first aid only, or precautionary check advised. The monetary consequences of the latter two categories have been assumed to be negligible.

The weighted average value of each serious or slight fire injury prevented was £41,680.

B13 Value of property damage in a fire

In the Economic Cost of Fire 2004 [B29], the average value of property damage in dwellings was £7,300, and in commercial buildings the average value was £27,700. In order to convert to 2014 prices, these values should be multiplied by a factor of 1.38 to account for the rise in RPI (not GDP). Therefore, property damage in dwellings is estimated to be on average £10,075 (current prices), and £38,226 in commercial buildings.

Note. According to the Association of British Insurers [B30], property damage in commercial buildings in 2004 was significantly lower than in other years in the period 2000 to 2008. However, dwelling fire losses did not show a matching dip.

[1] The apparently large difference between the value of sprinkler effectiveness in preventing death in Table B7 and the value in the CFOA report may be explained in part by the use of different data sets (IRS and FDR1 respectively), the fact that the FDR1 data categorised the area of fire damage more precisely, and random variations due to finite sample sizes.

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It has been assumed that, with the exception of flats, all other building types would have losses in accordance with the average commercial rate. There would probably be a large uncertainty due to applying this "one size fits all" value (which also includes e.g. retail buildings, industrial buildings, warehouses) to the disparate range of building types considered in this study; however it has not been possible to quantify this uncertainty.

B14 Sprinkler system reliability

The reliability is defined as the probability that a sprinkler system will activate, given that the fire generates sufficient heat to activate a sprinkler head. It has been assumed that the reliability was normally distributed, N(0.98, 0.005).

This reliability figure assumes that the sprinkler system is maintained according to the appropriate standard. If maintenance is neglected, it would be likely for the reliability to decrease, but the extent of the effect is unknown.

B15 Sprinkler system activation

Following the method of the CFOA report [B1], the fire area (m^2) at the time of sprinkler activation was taken to be Normally distributed, N(0.3, 0.1).

B16 Management cost savings with sprinklers

In some cases (e.g. care homes), having sprinklers may enable a skeleton staff to be provided during the night time. The report for Work stream 7 of this project quoted an average annual salary of £27,000, based on 220 working days of 7.5 hours each. An overhead of 30% was added. On this basis, the costs of providing one extra member of staff for 12 hours a day for 365 days per year would be £93,000. This figure is provided for illustrative purposes only, and has not been included in the cost benefit calculations.

Note. The Work stream 7 report also quoted an alternative (higher) value for staff time to reflect charge-out rates, i.e. lost earning potential when spending time on non-fee earning activities such as training. That rate would not be applicable for this situation.

Rehousing costs and other community disruption costs for buildings without sprinkler systems installed are outside the scope of this work and in some circumstances these could be a significant factor, for example, rehousing costs borne by housing associations.

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Appendix C – Risk as a function of building height

When a fire starts in a building, there is the potential for fire or smoke to spread to higher floors (spread to lower floors is also possible but much rarer in practice). The risk of death or injury per fire might therefore be expected to increase as the number of floors potentially affected rises. However, the IRS fire statistics for 2009 to 2013 [C1] do not show any compelling evidence for such an increase. Figure C1 shows the risks, for fires in all of the building types under consideration. Whilst there is some evidence that the risk from a fire on the top (or only) floor of the building (which by definition cannot affect a floor above) is somewhat lower than other circumstances, there is no clear trend of increasing risk with increasing height difference.

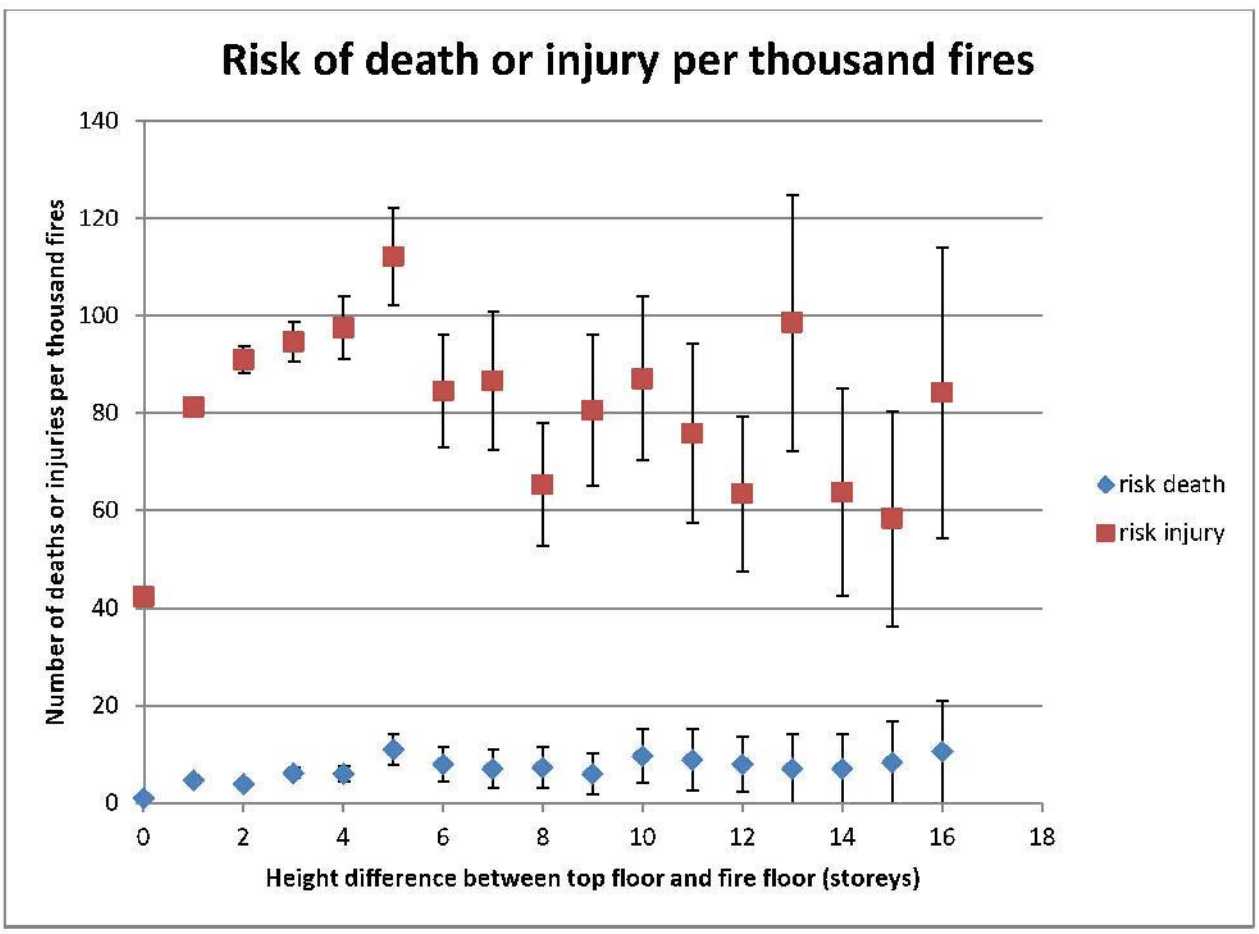

Figure C1 - Risk of death or injury per thousand fires, as a function of the height difference between the floor of fire origin and the top floor of the building

Data are available, from the English House Condition Survey [C2] for the numbers of flats in buildings of different heights. The risks per flat can therefore be estimated. See Tables C1 to C3.

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Table C1 - Fires and casualties in flats, annual average 2009/10 to 2012/13 (IRS data)

Building type	Number of flats	Fires	Deaths	Injuries (severe/slight)
Flats (1-3 storeys)	2,328,828	5940	26	550
Flats (4-10 storeys)	756,193	2019	9	176
Flats (11+ storeys)	161,598	1020	8	80

Table C2 - Likelihood and risk from fire per flat, annual average 2009/10 to 2012/13 (IRS data)

Building type	Fires per million unit.years	Deaths per million unit.years	Injuries per million unit.years
Flats (1-3 storeys)	2551 ± 310	11 ± 4	236 ± 32
Flats (4-10 storeys)	2669 ± 247	11 ± 3	232 ± 46
Flats (11+ storeys)	6309 ± 1298	48 ± 33	492 ± 117

Table C3 - Risk of death and injury per fire, annual average 2009/10 to 2012/13 (IRS data)

Building type	Deaths per thousand fires	Injuries per thousand fires
Flats (1-3 storeys)	4.3 ± 1.8	93 ± 17
Flats (4-10 storeys)	4.2 ± 1.0	87 ± 19
Flats (11+ storeys)	7.6 ± 5.4	78 ± 24

These results show that there is an increase in risk per flat as the building height increases, but that this is due to an increased likelihood of fire in taller buildings, and not an increased consequence per fire.

It has been suggested by members of the steering group that fires on higher floors would be more risky due to the increased time required for Fire and Rescue Services to get sufficient resources to the fire area (i.e. the fire floor, or the floor below) in order to commence operations in accordance with their fire fighting procedures. Figure C2 shows the risk of death (per thousand fires) in flats, against the height of the floor where the fire started. There is some evidence for increased risk for fires above the 8th storey, but the uncertainties are very large. A constant risk level of about 5 deaths per thousand fires would also be compatible with the data and the error bars. Figure C3 shows the risk of injury against the height of the fire origin. Here, there is no evidence for any increase in the risk of injury as the fire height increases.

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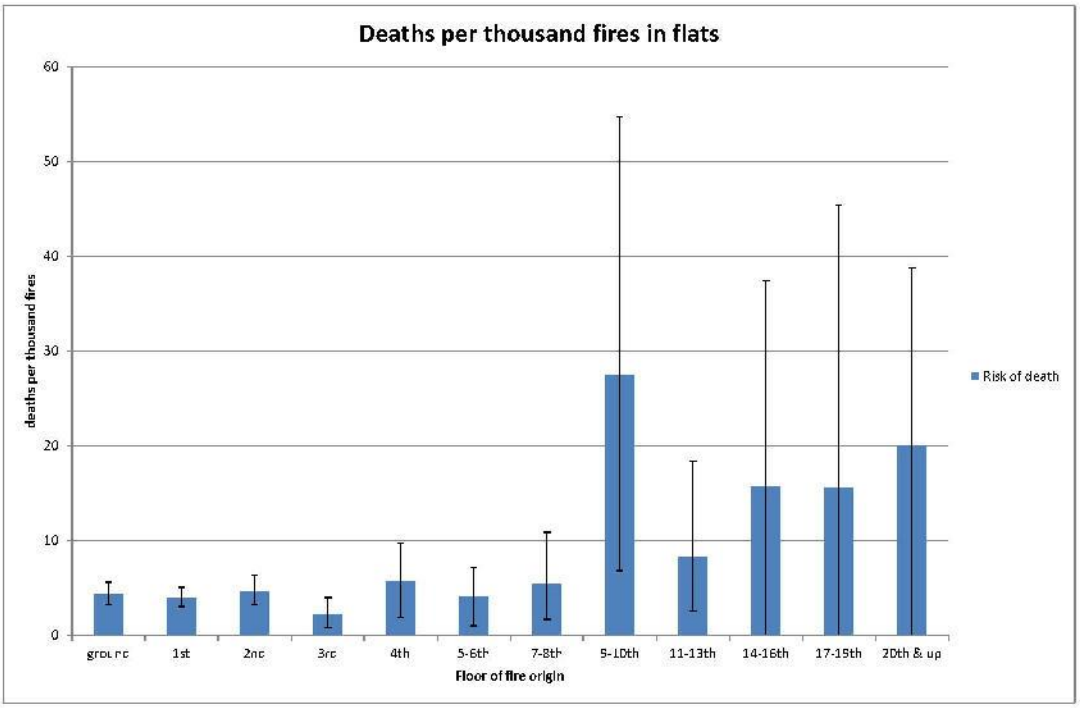

Figure C2 - Risk of death per thousand fires, as a function of the height of the floor of fire origin.

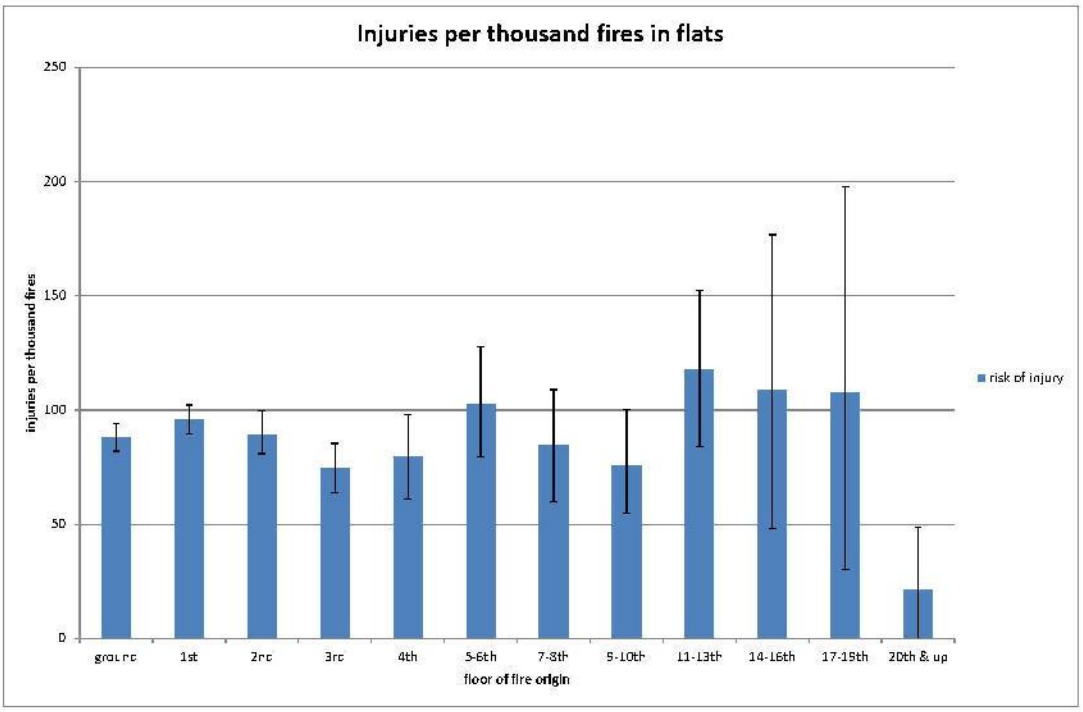

Figure C3 - Risk of injury per thousand fires, as a function of the height of the floor of fire origin.

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Historically, high-rise flats have tended to be located in more socially-deprived areas (e.g. inner cities), and the increased likelihood of fire may be linked with the social deprivation rather than the nature of the building itself. Modern high-rise flats are often marketed as "luxury living", so the link between the fire likelihood and the building height may weaken in future years as the building stock changes.

For buildings other than flats, there would not appear to be any reason why the likelihood of fire (per accommodation "unit") should vary with building height. If both the likelihood and consequences of fire are constant per accommodation "unit", the risk per building would then be proportional to the number of accommodation "units".

C1 References for Appendix C

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Appendix D – Details of cost-benefit calculations for main analysis

This Appendix contains tabulated calculations of the cost-benefit ratio and uncertainty for each building type, for n = 1 and n = infinity, where n is the number of "accommodation units". The Appendix also contains the bottom line results for n = 10, 100 and 1,000.

Flats: n = 1 flat

PROPERTY TYPE: Flats				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£620		£124	0.00
Water supply/storage (per unit)	£1,291		£116	0.00
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£81.71			
Annual Inspection Cost	£181		£36	0.02
Total Annual Cost	**£262.71**			
Deaths per Million Units	12		0	0.00
Sprinkler Effectiveness Factor	0.76		0.08	0.01
Deaths saved per Million Units	9			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£16.48			
Injuries per Million Units	238		3	0.00
Sprinkler Effectiveness Factor	0.58		0.14	0.01
Injuries saved per Million Units	138			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£5.74			
Fires per Million Units	2,655		13	0.00
Sprinkler Effectiveness Factor	0.93		0.02	0.00
Unsprinklered property damage	£10,075		£0	0.00
Reduced property damage per fire	£9,370			
Monetary Benefit per Single Unit	£24.87			
Total Monetary Benefit per unit	**£47.10**			
Benefit : Cost ratio	**0.18**		**+/-**	**0.03**
Confidence Level (ratio > 1)	**0%**			

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Flats: n = 10 flats

Benefit : Cost ratio	**0.94**		**+/-**	**0.13**
Confidence Level (ratio > 1)	**32%**			

Flats: n = 100 flats

Benefit : Cost ratio	**1.63**		**+/-**	**0.31**
Confidence Level (ratio > 1)	**98%**			

Flats: n = 1000 flats

Benefit : Cost ratio	**1.76**		**+/-**	**0.36**
Confidence Level (ratio > 1)	**98%**			

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Flats: n = ∞ flats

PROPERTY TYPE: Flats				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£620		£124	0.36
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.05
Annual Cost of Loan	£26.51			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£26.51**			
Deaths per Million Units	12		0	0.01
Sprinkler Effectiveness Factor	0.76		0.08	0.07
Deaths saved per Million Units	9			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£16.48			
Injuries per Million Units	238		3	0.00
Sprinkler Effectiveness Factor	0.58		0.14	0.05
Injuries saved per Million Units	138			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£5.74			
Fires per Million Units	2,655		13	0.00
Sprinkler Effectiveness Factor	0.93		0.02	0.02
Unsprinklered property damage	£10,075		£0	0.00
Reduced property damage per fire	£9,370			
Monetary Benefit per Single Unit	£24.87			
Total Monetary Benefit per unit	**£47.10**			
Benefit : Cost ratio	**1.78**		**+/-**	**0.37**
Confidence Level (ratio > 1)	**98%**			

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Hospital: n = 1 beds

PROPERTY TYPE: Hospital				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£5,184		£468	0.00
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£221.65			
Annual Inspection Cost	£863		£99	0.02
Total Annual Cost	**£1,084.65**			
Deaths per Million Units	2		0	0.00
Sprinkler Effectiveness Factor	0.15		0.36	0.00
Deaths saved per Million Units	0			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£0.45			
Injuries per Million Units	122		12	0.00
Sprinkler Effectiveness Factor	0.01		0.02	0.00
Injuries saved per Million Units	1			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.05			
Fires per Million Units	5,425		96	0.00
Sprinkler Effectiveness Factor	0.94		0.03	0.01
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£35,932			
Monetary Benefit per Single Unit	£194.92			
Total Monetary Benefit per unit	**£195.43**			
Benefit : Cost ratio	**0.18**		**+/-**	**0.02**
Confidence Level (ratio > 1)	**0%**			

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Hospital: n = 10 beds

Benefit : Cost ratio	**0.63**		**+/-**	**0.05**
Confidence Level (ratio > 1)	**0%**			

Hospital: n = 100 beds

Benefit : Cost ratio	**0.85**		**+/-**	**0.08**
Confidence Level (ratio > 1)	**4%**			

Hospital: n = 1000 beds

Benefit : Cost ratio	**0.88**		**+/-**	**0.09**
Confidence Level (ratio > 1)	**9%**			

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Hospital: n = ∞ beds

PROPERTY TYPE: Hospital				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£5,184		£468	0.08
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.03
Annual Cost of Loan	£221.65			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£221.66**			
Deaths per Million Units	2		0	0.00
Sprinkler Effectiveness Factor	0.15		0.36	0.00
Deaths saved per Million Units	0			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£0.45			
Injuries per Million Units	122		12	0.00
Sprinkler Effectiveness Factor	0.01		0.02	0.00
Injuries saved per Million Units	1			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.05			
Fires per Million Units	5,425		96	0.02
Sprinkler Effectiveness Factor	0.94		0.03	0.03
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£35,932			
Monetary Benefit per Single Unit	£194.92			
Total Monetary Benefit per unit	**£195.43**			
Benefit : Cost ratio	**0.88**		**+/-**	**0.09**
Confidence Level (ratio > 1)	**9%**			

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Care home: n = 1 bed

PROPERTY TYPE: Care Home				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£156	0.00
Water supply/storage (per unit)	£3,526		£683	0.02
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£181.33			
Annual Inspection Cost	£178		£13	0.01
Total Annual Cost	**£359.33**			
Deaths per Million Units	8		0	0.00
Sprinkler Effectiveness Factor	0.41		0.32	0.01
Deaths saved per Million Units	3			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£6.05			
Injuries per Million Units	84		5	0.00
Sprinkler Effectiveness Factor	0.12		0.19	0.00
Injuries saved per Million Units	10			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.42			
Fires per Million Units	2,119		34	0.00
Sprinkler Effectiveness Factor	0.94		0.03	0.01
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£35,932			
Monetary Benefit per Single Unit	£76.15			
Total Monetary Benefit per unit	**£82.61**			
Benefit : Cost ratio	**0.23**		**+/-**	**0.03**
Confidence Level (ratio > 1)	**0%**			

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Care home: n = 10 beds

Benefit : Cost ratio	**1.30**		**+/-**	**0.18**
Confidence Level (ratio > 1)	**96%**			

Care home: n = 1000 beds

Benefit : Cost ratio	**2.44**		**+/-**	**0.51**
Confidence Level (ratio > 1)	**100%**			

Care home: n = 1000 beds

Benefit : Cost ratio	**2.67**		**+/-**	**0.61**
Confidence Level (ratio > 1)	**100%**			

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Care home: n = ∞ beds

PROPERTY TYPE: Care Home				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£156	0.59
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.08
Annual Cost of Loan	£30.57			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£30.57**			
Deaths per Million Units	8		0	0.01
Sprinkler Effectiveness Factor	0.41		0.32	0.15
Deaths saved per Million Units	3			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£6.05			
Injuries per Million Units	84		5	0.00
Sprinkler Effectiveness Factor	0.12		0.19	0.02
Injuries saved per Million Units	10			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.42			
Fires per Million Units	2,119		34	0.04
Sprinkler Effectiveness Factor	0.94		0.03	0.08
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£35,932			
Monetary Benefit per Single Unit	£76.15			
Total Monetary Benefit per unit	**£82.61**			
Benefit : Cost ratio	**2.70**		+/-	**0.62**
Confidence Level (ratio > 1)	**100%**			

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Boarding school accommodation: n = 1 beds

PROPERTY TYPE: Boarding School accommodation				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£356		£78	0.00
Water supply/storage (per unit)	£3,526		£683	0.00
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£165.98			
Annual Inspection Cost	£178		£13	0.00
Total Annual Cost	**£343.98**			
Deaths per Million Units	3		2	0.00
Sprinkler Effectiveness Factor	0.46		0.44	0.01
Deaths saved per Million Units	2			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£2.80			
Injuries per Million Units	7		3	0.00
Sprinkler Effectiveness Factor	0.53		0.37	0.00
Injuries saved per Million Units	4			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.15			
Fires per Million Units	409		34	0.00
Sprinkler Effectiveness Factor	0.97		0.01	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£37,079			
Monetary Benefit per Single Unit	£15.15			
Total Monetary Benefit per unit	**£18.11**			
Benefit : Cost ratio	**0.05**		**+/-**	**0.01**
Confidence Level (ratio > 1)	**0%**			

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Boarding school accommodation: n = 10 beds

Benefit : Cost ratio	**0.38**		**+/-**	**0.08**
Confidence Level (ratio > 1)	**0%**			

Boarding school accommodation: n = 100 beds

Benefit : Cost ratio	**0.98**		**+/-**	**0.25**
Confidence Level (ratio > 1)	**47%**			

Boarding school accommodation: n = 1000 beds

Benefit : Cost ratio	**1.16**		**+/-**	**0.33**
Confidence Level (ratio > 1)	**69%**			

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Boarding school accommodation: n = ∞ beds

PROPERTY TYPE: Boarding School accommodation				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£356		£78	0.26
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.04
Annual Cost of Loan	£15.22			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£15.22**			
Deaths per Million Units	3		2	0.08
Sprinkler Effectiveness Factor	0.46		0.44	0.18
Deaths saved per Million Units	2			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£2.80			
Injuries per Million Units	7		3	0.00
Sprinkler Effectiveness Factor	0.53		0.37	0.01
Injuries saved per Million Units	4			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.15			
Fires per Million Units	409		34	0.08
Sprinkler Effectiveness Factor	0.97		0.01	0.01
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£37,079			
Monetary Benefit per Single Unit	£15.15			
Total Monetary Benefit per unit	**£18.11**			
Benefit : Cost ratio	**1.19**		**+/-**	**0.34**
Confidence Level (ratio > 1)	**71%**			

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Place of lawful detention: n = 1 beds

PROPERTY TYPE: Place of lawful detention				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£320		£29	0.00
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£13.68			
Annual Inspection Cost	£863		£99	0.02
Total Annual Cost	**£876.68**			
Deaths per Million Units	3		0	0.00
Sprinkler Effectiveness Factor	0.64		0.48	0.00
Deaths saved per Million Units	2			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£3.26			
Injuries per Million Units	240		17	0.00
Sprinkler Effectiveness Factor	0.27		0.27	0.00
Injuries saved per Million Units	65			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£2.71			
Fires per Million Units	5,161		121	0.00
Sprinkler Effectiveness Factor	0.86		0.08	0.02
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£32,874			
Monetary Benefit per Single Unit	£169.68			
Total Monetary Benefit per unit	**£175.64**			
Benefit : Cost ratio	**0.20**		**+/-**	**0.03**
Confidence Level (ratio > 1)	**0%**			

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Place of lawful detention: n = 10 beds

Benefit : Cost ratio	**1.76**		**+/-**	**0.24**
Confidence Level (ratio > 1)	**100%**			

Place of lawful detention: n = 100 beds

Benefit : Cost ratio	**7.87**		**+/-**	**0.95**
Confidence Level (ratio > 1)	**100%**			

Place of lawful detention: n = 1000 beds

Benefit : Cost ratio	**12.08**		**+/-**	**1.58**
Confidence Level (ratio > 1)	**100%**			

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Place of lawful detention: n = ∞ beds

PROPERTY TYPE: Place of lawful detention				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£320		£29	1.16
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.38
Annual Cost of Loan	£13.68			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£13.69**			
Deaths per Million Units	3		0	0.02
Sprinkler Effectiveness Factor	0.64		0.48	0.18
Deaths saved per Million Units	2			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£3.26			
Injuries per Million Units	240		17	0.01
Sprinkler Effectiveness Factor	0.27		0.27	0.20
Injuries saved per Million Units	65			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£2.71			
Fires per Million Units	5,161		121	0.29
Sprinkler Effectiveness Factor	0.86		0.08	1.15
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£32,874			
Monetary Benefit per Single Unit	£169.68			
Total Monetary Benefit per unit	**£175.64**			
Benefit : Cost ratio	**12.83**		**+/-**	**1.73**
Confidence Level (ratio > 1)	**100%**			

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Hotel and Boarding House: n = 1 rooms

PROPERTY TYPE: Hotel & Boarding House				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£960		£87	0.00
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£41.05			
Annual Inspection Cost	£863		£99	0.00
Total Annual Cost	**£904.05**			
Deaths per Million Units	0		0	0.00
Sprinkler Effectiveness Factor	0.52		0.50	0.00
Deaths saved per Million Units	0.2			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£0.39			
Injuries per Million Units	24		3	0.00
Sprinkler Effectiveness Factor	0.54		0.15	0.00
Injuries saved per Million Units	13			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.54			
Fires per Million Units	645		16	0.00
Sprinkler Effectiveness Factor	0.98		0.01	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£37,461			
Monetary Benefit per Single Unit	£24.15			
Total Monetary Benefit per unit	**£25.08**			
Benefit : Cost ratio	**0.03**		+/-	**0.00**
Confidence Level (ratio > 1)	**0%**			

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Hotel and Boarding House: n = 10 rooms

Benefit : Cost ratio	**0.20**		**+/-**	**0.02**
Confidence Level (ratio > 1)	**0%**			

Hotel and Boarding House: n = 100 rooms

Benefit : Cost ratio	**0.50**		**+/-**	**0.04**
Confidence Level (ratio > 1)	**0%**			

Hotel and Boarding House: n = 1000 rooms

Benefit : Cost ratio	**0.60**		**+/-**	**0.06**
Confidence Level (ratio > 1)	**0%**			

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Hotel and Boarding House: n = ∞ rooms

PROPERTY TYPE: Hotel & Boarding House				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£960		£87	0.06
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.02
Annual Cost of Loan	£41.05			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£41.05**			
Deaths per Million Units	0		0	0.00
Sprinkler Effectiveness Factor	0.52		0.50	0.01
Deaths saved per Million Units	0.2			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£0.39			
Injuries per Million Units	24		3	0.00
Sprinkler Effectiveness Factor	0.54		0.15	0.00
Injuries saved per Million Units	13			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.54			
Fires per Million Units	645		16	0.01
Sprinkler Effectiveness Factor	0.98		0.01	0.01
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£37,461			
Monetary Benefit per Single Unit	£24.15			
Total Monetary Benefit per unit	**£25.08**			
Benefit : Cost ratio	**0.61**		**+/-**	**0.06**
Confidence Level (ratio > 1)	**0%**			

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Hall of residence: n = 1 rooms

PROPERTY TYPE: Hall of residence				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£156	0.00
Water supply/storage (per unit)	£3,526		£683	0.01
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£181.33			
Annual Inspection Cost	£178		£13	0.00
Total Annual Cost	**£359.33**			
Deaths per Million Units	1		0	0.00
Sprinkler Effectiveness Factor	0.30		0.41	0.00
Deaths saved per Million Units	0.2			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£0.33			
Injuries per Million Units	26		3	0.00
Sprinkler Effectiveness Factor	0.32		0.20	0.00
Injuries saved per Million Units	8			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.35			
Fires per Million Units	1,120		26	0.00
Sprinkler Effectiveness Factor	0.92		0.03	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£35,168			
Monetary Benefit per Single Unit	£39.37			
Total Monetary Benefit per unit	**£40.05**			
Benefit : Cost ratio	**0.11**		**+/-**	**0.01**
Confidence Level (ratio > 1)	**0%**			

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Hall of residence: n = 10 rooms

Benefit : Cost ratio	**0.63**		**+/-**	**0.08**
Confidence Level (ratio > 1)	**0%**			

Hall of residence: n = 100 rooms

Benefit : Cost ratio	**1.18**		**+/-**	**0.24**
Confidence Level (ratio > 1)	**78%**			

Hall of residence: n = 1000 rooms

Benefit : Cost ratio	**1.30**		**+/-**	**0.29**
Confidence Level (ratio > 1)	**85%**			

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Hall of residence: n = ∞ rooms

PROPERTY TYPE: Hall of residence				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£156	0.29
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.04
Annual Cost of Loan	£30.57			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£30.57**			
Deaths per Million Units	1		0	0.00
Sprinkler Effectiveness Factor	0.30		0.41	0.01
Deaths saved per Million Units	0.2			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£0.33			
Injuries per Million Units	26		3	0.00
Sprinkler Effectiveness Factor	0.32		0.20	0.01
Injuries saved per Million Units	8			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.35			
Fires per Million Units	1,120		26	0.03
Sprinkler Effectiveness Factor	0.92		0.03	0.04
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£35,168			
Monetary Benefit per Single Unit	£39.37			
Total Monetary Benefit per unit	**£40.05**			
Benefit : Cost ratio	**1.31**		**+/-**	**0.29**
Confidence Level (ratio > 1)	**85%**			

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Hostel: n = 1 room

PROPERTY TYPE: Hostel				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£0	0.00
Water supply/storage (per unit)	£1,399		£98	0.02
Capital Recovery Factor	0.043		0.001	0.02
Annual Cost of Loan	£90.39			
Annual Inspection Cost	£111		£1	0.01
Total Annual Cost	**£201.39**			
Deaths per Million Units	7		1	0.00
Sprinkler Effectiveness Factor	0.43		0.28	0.02
Deaths saved per Million Units	3			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£5.01			
Injuries per Million Units	341		36	0.00
Sprinkler Effectiveness Factor	0.07		0.14	0.01
Injuries saved per Million Units	24			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.99			
Fires per Million Units	6,384		204	0.04
Sprinkler Effectiveness Factor	0.94		0.02	0.02
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£35,932			
Monetary Benefit per Single Unit	£229.39			
Total Monetary Benefit per unit	**£235.40**			
Benefit : Cost ratio	1.17		**+/-**	**0.06**
Confidence Level (ratio > 1)	**100%**			

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Hostel: n = 10 rooms

Benefit : Cost ratio	**4.94**		**+/-**	**0.24**
Confidence Level (ratio > 1)	**100%**			

Hostel: n = 100 rooms

Benefit : Cost ratio	**7.29**		**+/-**	**0.37**
Confidence Level (ratio > 1)	**100%**			

Hostel: n = 1000 rooms

Benefit : Cost ratio	**7.66**		**+/-**	**0.39**
Confidence Level (ratio > 1)	**100%**			

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Hostel: n = ∞ rooms

PROPERTY TYPE: Hostel				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£0	0.00
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.23
Annual Cost of Loan	£30.57			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£30.57**			
Deaths per Million Units	7		1	0.02
Sprinkler Effectiveness Factor	0.43		0.28	0.11
Deaths saved per Million Units	3			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£5.01			
Injuries per Million Units	341		36	0.00
Sprinkler Effectiveness Factor	0.07		0.14	0.07
Injuries saved per Million Units	24			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.99			
Fires per Million Units	6,384		204	0.24
Sprinkler Effectiveness Factor	0.94		0.02	0.16
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£35,932			
Monetary Benefit per Single Unit	£229.39			
Total Monetary Benefit per unit	**£235.40**			
Benefit : Cost ratio	**7.70**		**+/-**	**0.39**
Confidence Level (ratio > 1)	**100%**			

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Multi-storey car park: n = 1 spaces

PROPERTY TYPE: Multi-Storey Car Park				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£922		£83	0.00
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£39.40			
Annual Inspection Cost	£863		£99	0.00
Total Annual Cost	**£902.40**			
Deaths per Million Units	12		0	0.00
Sprinkler Effectiveness Factor	0.41		0.40	0.01
Deaths saved per Million Units	5			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£8.89			
Injuries per Million Units	4		1	0.00
Sprinkler Effectiveness Factor	0.73		0.28	0.00
Injuries saved per Million Units	3			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.12			
Fires per Million Units	113		10	0.00
Sprinkler Effectiveness Factor	0.89		0.05	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£34,021			
Monetary Benefit per Single Unit	£3.83			
Total Monetary Benefit per unit	**£12.84**			
Benefit : Cost ratio	**0.01**		**+/-**	**0.01**
Confidence Level (ratio > 1)	**0%**			

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Multi-storey car park: n = 10 spaces

Benefit : Cost ratio	**0.10**		**+/-**	**0.07**
Confidence Level (ratio > 1)	**0%**			

Multi-storey car park: n = 100 spaces

Benefit : Cost ratio	**0.27**		**+/-**	**0.18**
Confidence Level (ratio > 1)	**0%**			

Multi-storey car park: n = 1000 spaces

Benefit : Cost ratio	**0.32**		**+/-**	**0.22**
Confidence Level (ratio > 1)	**0%**			

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Multi-storey car park: n = ∞ spaces

PROPERTY TYPE: Multi-Storey Car Park				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£922		£83	0.03
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.01
Annual Cost of Loan	£39.40			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£39.41**			
Deaths per Million Units	12		0	0.00
Sprinkler Effectiveness Factor	0.41		0.40	0.22
Deaths saved per Million Units	5			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£8.89			
Injuries per Million Units	4		1	0.00
Sprinkler Effectiveness Factor	0.73		0.28	0.00
Injuries saved per Million Units	3			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.12			
Fires per Million Units	113		10	0.01
Sprinkler Effectiveness Factor	0.89		0.05	0.01
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£34,021			
Monetary Benefit per Single Unit	£3.83			
Total Monetary Benefit per unit	**£12.84**			
Benefit : Cost ratio	**0.33**		**+/-**	**0.22**
Confidence Level (ratio > 1)	**0%**			

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Appendix E - Details of cost-benefit calculations for sensitivity analysis

This Appendix contains tabulated calculations of the cost-benefit ratio and the associated uncertainty for each building type, for n=1 and n=infinity for the sensitivity analysis (where sprinkler effectiveness = 100%). The Appendix also contains the bottom line results for n=10, 100 and 1,000, where n is the number of "accommodation units"

Flats: n = 1 flat

PROPERTY TYPE: Flats				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£620		£124	0.00
Water supply/storage (per unit)	£1,291		£116	0.00
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£81.71			
Annual Inspection Cost	£181		£36	0.03
Total Annual Cost	**£262.71**			
Deaths per Million Units	12		0	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	12			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£21.68			
Injuries per Million Units	238		3	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	238			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£9.90			
Fires per Million Units	2,655		13	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£10,075		£0	0.00
Reduced property damage per fire	£10,075			
Monetary Benefit per Single Unit	£26.75			
Total Monetary Benefit per unit	**£58.33**			
Benefit : Cost ratio	**0.22**		**+/-**	**0.03**
Confidence Level (ratio > 1)	**0%**			

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Flats: n = 10 flat

Benefit : Cost ratio	**1.16**		**+/-**	**0.15**
Confidence Level (ratio > 1)	**86%**			

Flats: n = 100 flat

Benefit : Cost ratio	**2.02**		**+/-**	**0.38**
Confidence Level (ratio > 1)	**100%**			

Flats: n = 1000 flat

Benefit : Cost ratio	**2.18**		**+/-**	**0.44**
Confidence Level (ratio > 1)	**100%**			

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Flats: n = ∞ flat

PROPERTY TYPE: Flats				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£620		£124	0.44
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.07
Annual Cost of Loan	£26.51			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£26.51**			
Deaths per Million Units	12		0	0.01
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	12			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£21.68			
Injuries per Million Units	238		3	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	238			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£9.90			
Fires per Million Units	2,655		13	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£10,075		£0	0.00
Reduced property damage per fire	£10,075			
Monetary Benefit per Single Unit	£26.75			
Total Monetary Benefit per unit	**£58.33**			
Benefit : Cost ratio	**2.20**		**+/-**	**0.45**
Confidence Level (ratio > 1)	**100%**			

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Hospital: n = 1 beds

PROPERTY TYPE: Hospital				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£5,184		£468	0.00
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£221.65			
Annual Inspection Cost	£863		£99	0.02
Total Annual Cost	**£1,084.65**			
Deaths per Million Units	2		0	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	2			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£3.02			
Injuries per Million Units	122		12	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	122			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£5.10			
Fires per Million Units	5,425		96	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£207.37			
Total Monetary Benefit per unit	**£215.49**			
Benefit : Cost ratio	**0.20**		**+/-**	**0.02**
Confidence Level (ratio > 1)	**0%**			

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Hospital: n = 10 beds

Benefit : Cost ratio	**0.70**		**+/-**	**0.05**
Confidence Level (ratio > 1)	**0%**			

Hospital: n = 100 beds

Benefit : Cost ratio	**0.94**		**+/-**	**0.09**
Confidence Level (ratio > 1)	**23%**			

Hospital: n = 1000 beds

Benefit : Cost ratio	**0.97**		**+/-**	**0.09**
Confidence Level (ratio > 1)	**37%**			

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Hospital: n = ∞ beds

PROPERTY TYPE: Hospital				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£5,184		£468	0.09
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.03
Annual Cost of Loan	£221.65			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£221.66**			
Deaths per Million Units	2		0	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	2			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£3.02			
Injuries per Million Units	122		12	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	122			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£5.10			
Fires per Million Units	5,425		96	0.02
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£207.37			
Total Monetary Benefit per unit	**£215.49**			
Benefit : Cost ratio	**0.97**		**+/-**	**0.09**
Confidence Level (ratio > 1)	**38%**			

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Care home: n = 1 beds

PROPERTY TYPE: Care Home				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£156	0.01
Water supply/storage (per unit)	£3,526		£683	0.02
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£181.33			
Annual Inspection Cost	£178		£13	0.01
Total Annual Cost	**£359.33**			
Deaths per Million Units	8		0	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	8			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£14.75			
Injuries per Million Units	84		5	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	84			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£3.50			
Fires per Million Units	2,119		34	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£81.01			
Total Monetary Benefit per unit	**£99.26**			
Benefit : Cost ratio	**0.28**		**+/-**	**0.03**
Confidence Level (ratio > 1)	**0%**			

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Care home: n = 10 beds

Benefit : Cost ratio	**1.56**		**+/-**	**0.19**
Confidence Level (ratio > 1)	**100%**			

Care home: n = 100 beds

Benefit : Cost ratio	**2.93**		**+/-**	**0.59**
Confidence Level (ratio > 1)	**100%**			

Care home: n = 1000 beds

Benefit : Cost ratio	**3.21**		**+/-**	**0.70**
Confidence Level (ratio > 1)	**100%**			

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Care home: n = ∞ bed

PROPERTY TYPE: Care Home				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£156	0.71
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.10
Annual Cost of Loan	£30.57			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£30.57**			
Deaths per Million Units	8		0	0.03
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	8			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£14.75			
Injuries per Million Units	84		5	0.01
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	84			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£3.50			
Fires per Million Units	2,119		34	0.04
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£81.01			
Total Monetary Benefit per unit	**£99.26**			
Benefit : Cost ratio	**3.25**		**+/-**	**0.72**
Confidence Level (ratio > 1)	**100%**			

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School (residential): n = 1 beds

PROPERTY TYPE: Boarding School accommodation				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£356		£78	0.00
Water supply/storage (per unit)	£3,526		£683	0.01
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£165.98			
Annual Inspection Cost	£178		£13	0.00
Total Annual Cost	**£343.98**			
Deaths per Million Units	3		2	0.01
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	3			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£6.10			
Injuries per Million Units	7		3	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	7			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.29			
Fires per Million Units	409		34	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£15.62			
Total Monetary Benefit per unit	**£22.00**			
Benefit : Cost ratio	**0.06**		**+/-**	**0.01**
Confidence Level (ratio > 1)	**0%**			

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School (residential): n = 10 beds

Benefit : Cost ratio	**0.46**		**+/-**	**0.08**
Confidence Level (ratio > 1)	**0%**			

School (residential): n = 100 beds

Benefit : Cost ratio	**1.19**		**+/-**	**0.27**
Confidence Level (ratio > 1)	**76%**			

School (residential): n = 1000 beds

Benefit : Cost ratio	**1.42**		**+/-**	**0.36**
Confidence Level (ratio > 1)	**87%**			

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School (residential): n = ∞ beds

PROPERTY TYPE: Boarding School accommodation			
	average	uncertainty	net effect
Capital Cost of System (per unit)	£356	£78	0.32
Water supply/storage (per unit)	£0	£0	0.00
Capital Recovery Factor	0.043	0.001	0.04
Annual Cost of Loan	£15.22		
Annual Inspection Cost	£0	£0	0.00
Total Annual Cost	**£15.22**		
Deaths per Million Units	3	2	0.18
Sprinkler Effectiveness Factor	1.00	0.00	0.00
Deaths saved per Million Units	3		
Monetary Value per Death Saved	£1,778,000	£0	0.00
Monetary Benefit per Single Unit	£6.10		
Injuries per Million Units	7	3	0.01
Sprinkler Effectiveness Factor	1.00	0.00	0.00
Injuries saved per Million Units	7		
Monetary Value per Injury Saved	£41,680	£0	0.00
Monetary Benefit per Single Unit	£0.29		
Fires per Million Units	409	34	0.08
Sprinkler Effectiveness Factor	1.00	0.00	0.00
Unsprinklered property damage	£38,226	£0	0.00
Reduced property damage per fire	£38,226		
Monetary Benefit per Single Unit	£15.62		
Total Monetary Benefit per unit	**£22.00**		
Benefit : Cost ratio	**1.45**	**+/-**	**0.38**
Confidence Level (ratio > 1)	**88%**		

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Place of lawful detention: n = 1 beds

PROPERTY TYPE: Place of lawful detention				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£320		£29	0.00
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£13.68			
Annual Inspection Cost	£863		£99	0.03
Total Annual Cost	**£876.68**			
Deaths per Million Units	3		0	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	3			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£5.09			
Injuries per Million Units	240		17	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	240			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£10.02			
Fires per Million Units	5,161		121	0.01
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£197.30			
Total Monetary Benefit per unit	**£212.41**			
Benefit : Cost ratio	**0.24**		**+/-**	**0.03**
Confidence Level (ratio > 1)	**0%**			

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Place of lawful detention: n = 10 beds

Benefit : Cost ratio	**2.12**		**+/-**	**0.22**
Confidence Level (ratio > 1)	**100%**			

Place of lawful detention: n = 100 beds

Benefit : Cost ratio	**9.52**		**+/-**	**0.73**
Confidence Level (ratio > 1)	**100%**			

Place of lawful detention: n = 1000 beds

Benefit : Cost ratio	**14.60**		**+/-**	**1.35**
Confidence Level (ratio > 1)	**100%**			

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Place of lawful detention: n = ∞ beds

PROPERTY TYPE: Place of lawful detention				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£320		£29	1.41
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.47
Annual Cost of Loan	£13.68			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£13.69**			
Deaths per Million Units	3		0	0.03
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	3			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£5.09			
Injuries per Million Units	240		17	0.05
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	240			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£10.02			
Fires per Million Units	5,161		121	0.34
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£197.30			
Total Monetary Benefit per unit	**£212.41**			
Benefit : Cost ratio	**15.52**		**+/-**	**1.52**
Confidence Level (ratio > 1)	**100%**			

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Hotel and Boarding House: n = 1 rooms

PROPERTY TYPE: Hotel & Boarding House				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£960		£87	0.00
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£41.05			
Annual Inspection Cost	£863		£99	0.00
Total Annual Cost	**£904.05**			
Deaths per Million Units	0		0	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	0.4			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£0.75			
Injuries per Million Units	24		3	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	24			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£1.00			
Fires per Million Units	645		16	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£24.64			
Total Monetary Benefit per unit	**£26.39**			
Benefit : Cost ratio	**0.03**		**+/-**	**0.00**
Confidence Level (ratio > 1)	**0%**			

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Hotel and Boarding House: n = 10 rooms

Benefit : Cost ratio	**0.21**		**+/-**	**0.02**
Confidence Level (ratio > 1)	**0%**			

Hotel and Boarding House: n = 100 rooms

Benefit : Cost ratio	**0.53**		**+/-**	**0.04**
Confidence Level (ratio > 1)	**0%**			

Hotel and Boarding House: n = 1000 rooms

Benefit : Cost ratio	**0.63**		**+/-**	**0.06**
Confidence Level (ratio > 1)	**0%**			

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Hotel and Boarding House: n = ∞ rooms

PROPERTY TYPE: Hotel & Boarding House				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£960		£87	0.06
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.02
Annual Cost of Loan	£41.05			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£41.05**			
Deaths per Million Units	0		0	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	0.4			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£0.75			
Injuries per Million Units	24		3	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	24			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£1.00			
Fires per Million Units	645		16	0.02
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£24.64			
Total Monetary Benefit per unit	**£26.39**			
Benefit : Cost ratio	**0.64**		**+/-**	**0.06**
Confidence Level (ratio > 1)	**0%**			

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Hall of residence: n = 1 rooms

PROPERTY TYPE: Hall of residence				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£156	0.00
Water supply/storage (per unit)	£3,526		£683	0.01
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£181.33			
Annual Inspection Cost	£178		£13	0.00
Total Annual Cost	**£359.33**			
Deaths per Million Units	1		0	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	0.6			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£1.10			
Injuries per Million Units	26		3	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	26			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£1.08			
Fires per Million Units	1,120		26	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£42.80			
Total Monetary Benefit per unit	**£44.97**			
Benefit : Cost ratio	**0.13**		**+/-**	**0.01**
Confidence Level (ratio > 1)	**0%**			

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Hall of residence: n = 10 rooms

Benefit : Cost ratio	**0.71**		**+/-**	**0.09**
Confidence Level (ratio > 1)	**0%**			

Hall of residence: n = 100 rooms

Benefit : Cost ratio	**1.33**		**+/-**	**0.27**
Confidence Level (ratio > 1)	**89%**			

Hall of residence: n = 1000 rooms

Benefit : Cost ratio	**1.46**		**+/-**	**0.32**
Confidence Level (ratio > 1)	**92%**			

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Hall of residence: n = ∞ rooms

PROPERTY TYPE: Hall of residence				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£156	0.32
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.04
Annual Cost of Loan	£30.57			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£30.57**			
Deaths per Million Units	1		0	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	0.6			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£1.10			
Injuries per Million Units	26		3	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	26			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£1.08			
Fires per Million Units	1,120		26	0.03
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£42.80			
Total Monetary Benefit per unit	**£44.97**			
Benefit : Cost ratio	**1.47**		**+/-**	**0.33**
Confidence Level (ratio > 1)	**93%**			

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Hostel: n = 1 rooms

PROPERTY TYPE: Hostel				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£0	0.00
Water supply/storage (per unit)	£1,399		£98	0.03
Capital Recovery Factor	0.043		0.001	0.02
Annual Cost of Loan	£90.39			
Annual Inspection Cost	£111		£1	0.01
Total Annual Cost	**£201.39**			
Deaths per Million Units	7		1	0.01
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	7			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£11.65			
Injuries per Million Units	341		36	0.01
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	341			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£14.20			
Fires per Million Units	6,384		204	0.04
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£244.03			
Total Monetary Benefit per unit	**£269.89**			
Benefit : Cost ratio	**1.34**		**+/-**	**0.05**
Confidence Level (ratio > 1)	**100%**			

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Hostel: n = 10 rooms

Benefit : Cost ratio	**5.66**		**+/-**	**0.22**
Confidence Level (ratio > 1)	**100%**			

Hostel: n = 100 rooms

Benefit : Cost ratio	**8.36**		**+/-**	**0.35**
Confidence Level (ratio > 1)	**100%**			

Hostel: n = 1000 rooms

Benefit : Cost ratio	**8.78**		**+/-**	**0.37**
Confidence Level (ratio > 1)	**100%**			

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Hostel: n = ∞ rooms

PROPERTY TYPE: Hostel				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£715		£0	0.00
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.26
Annual Cost of Loan	£30.57			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£30.57**			
Deaths per Million Units	7		1	0.04
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	7			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£11.65			
Injuries per Million Units	341		36	0.05
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	341			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£14.20			
Fires per Million Units	6,384		204	0.25
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£244.03			
Total Monetary Benefit per unit	**£269.89**			
Benefit : Cost ratio	**8.83**		**+/-**	**0.37**
Confidence Level (ratio > 1)	**100%**			

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Multi-storey car park: n = 1 spaces

PROPERTY TYPE: Multi-Storey Car Park				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£922		£83	0.00
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.00
Annual Cost of Loan	£39.40			
Annual Inspection Cost	£863		£99	0.00
Total Annual Cost	**£902.40**			
Deaths per Million Units	12		0	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	12			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£21.68			
Injuries per Million Units	4		1	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	4			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.16			
Fires per Million Units	113		10	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£4.30			
Total Monetary Benefit per unit	**£26.15**			
Benefit : Cost ratio	**0.03**		**+/-**	**0.00**
Confidence Level (ratio > 1)	**0%**			

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Multi-storey car park: n = 10 spaces

Benefit : Cost ratio	**0.21**		**+/-**	**0.02**
Confidence Level (ratio > 1)	**0%**			

Multi-storey car park: n = 100 spaces

Benefit : Cost ratio	**0.54**		**+/-**	**0.04**
Confidence Level (ratio > 1)	**0%**			

Multi-storey car park: n = 1000 spaces

Benefit : Cost ratio	**0.65**		**+/-**	**0.06**
Confidence Level (ratio > 1)	**0%**			

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Multi- storey car park: n = ∞ spaces

PROPERTY TYPE: Multi-Storey Car Park				
	average		uncertainty	net effect
Capital Cost of System (per unit)	£922		£83	0.06
Water supply/storage (per unit)	£0		£0	0.00
Capital Recovery Factor	0.043		0.001	0.02
Annual Cost of Loan	£39.40			
Annual Inspection Cost	£0		£0	0.00
Total Annual Cost	**£39.41**			
Deaths per Million Units	12		0	0.01
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Deaths saved per Million Units	12			
Monetary Value per Death Saved	£1,778,000		£0	0.00
Monetary Benefit per Single Unit	£21.68			
Injuries per Million Units	4		1	0.00
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Injuries saved per Million Units	4			
Monetary Value per Injury Saved	£41,680		£0	0.00
Monetary Benefit per Single Unit	£0.16			
Fires per Million Units	113		10	0.01
Sprinkler Effectiveness Factor	1.00		0.00	0.00
Unsprinklered property damage	£38,226		£0	0.00
Reduced property damage per fire	£38,226			
Monetary Benefit per Single Unit	£4.30			
Total Monetary Benefit per unit	**£26.15**			
Benefit : Cost ratio	**0.66**		**+/-**	**0.06**
Confidence Level (ratio > 1)	**0%**			

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