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Cost benefit analysis of residential sprinklers for Wales –

Report of cost benefit analysis

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Protecting People, Property and the Planet

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Executive Summary

Welsh Government has commissioned BRE to carry out a project 'Domestic sprinkler regulatory impact assessment', Welsh Government contract number C/133/2011/2012 and BRE proposal number 130367, dated 4 November 2011. The overall aim of this project is to prepare contributions to the draft RIA to support the Welsh Government's intention to regulate for the installation of sprinklers in new and converted residential accommodation, and in particular to carry out a cost benefit analysis of the provisions in the Domestic Fire Safety (Wales) Measure 2011. Accommodation types that are covered by this Measure are: houses, purpose built and converted flats, houses of multiple occupation, residential care homes (for children, disabled people, elderly people), residential colleges, boarding schools, and student halls of residence.

According to the UK fire statistics (2001 to 2010), there are, on average, 2,168 fires and 17 deaths and 503 injuries in fires in residential premises in Wales per year. It is considered that the voluntary installation of smoke alarms has probably reached its peak level. However due to the regulatory requirements introduced in 1992, smoke alarm penetration into the new build and refurbishment domestic housing sector has increased. This affects the baseline risk against which the impact of residential sprinklers will be assessed by lowering it. The introduction of sprinklers is one way of further reducing the number of deaths and injuries in these premises. There may also be other fire protection measures that could be cost effective.

This report contains details of the cost benefit analysis which involved a brief literature review, data gathering, cost benefit analysis, uncertainty and sensitivity analysis. This study considered residential sprinkler systems designed, installed and maintained to British Standard BS 9251 *Sprinklers for residential and domestic occupancies – Code of Practice*, 2005. The input data and assumptions for this study have been confirmed with or advised by Welsh Government and are specific to Wales wherever possible.

The value of a statistical life used in this analysis is based on the Department for Transport "willingness to pay" figure, which was originally used in the context of road safety but is now typically used in other contexts due to absence of any other appropriate figure.

The monetised costs used in this cost benefit analysis are the costs of the residential sprinkler installation and the water supply (water company charges and for pump and tank systems, the cost of the pump and tank) which are one-off costs and the costs of the residential sprinkler system maintenance which is an annual ongoing cost. The monetised benefits used in this cost benefit analysis are the reduced risk of deaths and injuries and reduced property damage which are all annual benefits. At the request of the Welsh Government, BRE was also asked to estimate the reduction in greenhouse gases, specifically carbon dioxide, from fires where a residential sprinkler system was installed to inform the cost benefit analysis and a future impact assessment. The reduction of greenhouse gases from fire is also an annual benefit but the monetised value is estimated to be very small compared with the other benefits.

All monetary data are expressed in 2010 prices. 2010 is the last year for which the Gross Value Added (GVA)/Retail Price Index figures are available. Present Values and Net Present Values (see glossary of terms) were discounted on the basis that 2010 is year zero. Costs and benefits were calculated for the whole life of the sprinkler systems (40 to 50 years), for all new residential premises constructed during a ten year window (2013 to 2022).

The first table presents the predicted costs and benefits arising from sprinkler installation in Wales for each type of residential premises over the whole life of the sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales. The table shows the overall Net Present Value of the policy, Present Values of costs and benefits and the net cost per life saved. For the purposes of this report, sprinklers are cost effective if the Net Present Value is positive (and is greater than the uncertainty (see Results section for further information)).

Table of predicted overall costs and benefits over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Accommodation Type	Present Value total costs (£m)	Present Value total benefits (£m)	Total lives saved	Total injuries prevented	Present Value cost per statistical life saved (£m)	Overall Net Present Value (£m)
House	-£216.7m	£27.9m	24.6	427	£8.8m	-£188.7m
Flat	-£10.8m	£12.4m	7.3	297	£1.5m	£1.6m
Traditional HMO	-£0.1m	£0.1m	0.1	2	£1.1m	£0m
Shared house	-£4.4m	£1.9m	1.7	28	£2.6m	-£2.4m
Hostel	-£2m	£0.3m	0.2	2	£8.2m	-£1.7m
Care home	-£1.9m	£2.3m	0.6	10	£3m	£0.5m
Sheltered house	-£2m	£0.6m	0.3	12	£7.2m	-£1.4m
Sheltered flat	-£0.5m	£0.8m	0.4	16	£1.3m	£0.3m
Hall/Dormitory	-£0.9m	£2.3m	0.2	4	£5.5m	£1.5m
Total for subset where cost effective or marginally cost effective	**-£14.2m**	**£18.1m**	**8.6**	**330**	**£1.6m**	**£3.8m**
Total for all accommodation types	**-£239.3m**	**£48.8m**	**35.5**	**799**	**£6.7m**	**-£190.5m**

Note. Values are based on 'central' estimates of costs.

All values in the Table are subject to uncertainty, due to uncertainties in the values for the input data. As an example the Net Present Value for the total for all accommodation types (-£190.5m) can be expressed as -£190.5m ± £8.8m. The value of £190.5 is the 'central estimate' and the value of £8.8m is the uncertainty (1 standard deviation). Therefore, in this case, the uncertainty is about 5% of the value.

Based on the input data, assumptions and main analysis described in this report, the conclusions of this cost benefit analysis are:

- Fitting sprinklers in all new residential premises in Wales is not cost effective.
- Sprinklers are cost effective in new care homes and halls/dormitories. This is mainly due to the reduction in financial losses from damage to the building, its contents and business interruption.
- Sprinklers may also be marginally cost effective, (i.e. not statistically significant) in new blocks of flats, blocks of sheltered flats (not including sheltered houses) and "traditional" HMOs (on average six accommodation units per building; not including shared houses or hostels).

  The key reason for this is that costs can be shared over a number of accommodation units.

- Sprinklers are not cost effective in new single occupancy houses, shared houses, hostels and sheltered houses.

This cost benefit analysis has focussed on new build premises rather than conversions. The cost of sprinkler installation may be higher in building conversions than in new build. The benefits of sprinkler protection are expected to be similar in both new build and converted accommodation units. It should be noted that benefits resulting from compensatory features and trade-offs were not included in the cost benefit analysis, but they might be expected to result in some cost savings if included at the design stage on a case by case basis.

A sensitivity analysis was carried out for a) all new residential properties and b) the subset of residential properties where sprinklers are predicted to be cost-effective or marginally cost-effective. This subset comprised new blocks of flats, new blocks of sheltered flats, new “traditional” HMOs, new care homes, new halls of residences and new dormitories.

The sensitivity analysis involved examining the following to see their influence on the cost benefit analysis results:

- Examining the effect of varying the value of lives saved/injuries prevented by ± 25% of the value (Cases 1a and 1b)
- Examining the effect of varying the percentage of severe injuries (Cases 2a and 2b)
- Reducing sprinkler installation costs by 30% to reflect economies of scale in large developments, for houses (Case 3)
- Considering the direct mains water supply cost option, for houses and sheltered housing (Case 4)
- Examining the effect of varying the proportions of new build accommodation units that are houses and flats to 90:10 (from 79:21) (Case 5)
- Examining the options of no maintenance with no decline in reliability and no maintenance with consequential decline in reliability (Cases 6a and 6b)
- Examining the effect of an overall decrease in installation costs by 25% as installers gain experience and become more competitive, for all property types (Case 7).

The second and third tables summarise the sensitivity analysis results for each sensitivity case.

Table of sensitivity analysis results showing overall costs and benefits for all new residential premises over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Case	Present Value total costs (£m)	Present Value total benefits (£m)	Total lives saved	Total injuries prevented	Present Value cost per statistical life saved (£m)	Overall Net Present Value (£m)
Baseline	-£239.3m	£48.8m	35.5	799	£6.7m	-£190.5m
1a	-£239.3m	£41.6m	35.5	799	£6.7m	-£197.7m
1b	-£239.3m	£56.1m	35.5	799	£6.7m	-£183.2m
2a	-£239.3m	£58.7m	35.5	799	£6.7m	-£180.6m
2b	-£239.3m	£75.7m	35.5	799	£6.7m	-£163.6m
3	-£215.3m	£48.8m	35.5	799	£6.1m	-£166.4m
4	-£247.5m	£48.8m	35.5	799	£7m	-£198.7m
5	-£263.8m	£46.2m	35.1	703	£7.5m	-£217.6m
6a	-£144.3m	£48.8m	35.5	799	£4.1m	-£95.5m
6b	-£144.3m	£33.9m	24.6	554	£5.9m	-£110.4m
7	-£216.4m	£48.8m	35.5	799	£6.1m	-£167.6m

Note. Values are based on 'central' estimates of costs.

Table of sensitivity analysis results showing overall costs and benefits for subset of residential premises showing cost effectiveness or marginal cost effectiveness over the whole life of the residential; sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Case	Present Value total costs (£m)	Present Value total benefits (£m)	Total lives saved	Total injuries prevented	Present Value cost per statistical life saved (£m)	Overall Net Present Value (£m)
Baseline	-£14.2m	£18.1m	8.6	330	£1.6m	£3.8m
1a	-£14.2m	£16m	8.6	330	£1.6m	£1.8m
1b	-£14.2m	£20.1m	8.6	330	£1.6m	£5.9m
2a	-£14.2m	£22.1m	8.6	330	£1.6m	£7.9m
2b	-£14.2m	£29.1m	8.6	330	£1.6m	£14.9m
3	-£14.2m	£18.1m	8.6	330	£1.6m	£3.8m
4	-£14.2m	£18.1m	8.6	330	£1.6m	£3.8m
5	-£8.5m	£11.5m	4.8	174	£1.8m	£3m
6a	-£12.6m	£18.1m	8.6	330	£1.5m	£5.5m
6b	-£12.6m	£12.5m	6.0	229	£2.1m	-£0.1m
7	-£12m	£18.1m	8.6	330	£1.4m	£6m

Note. Values are based on 'central' estimates of costs.

The sensitivity analysis results confirmed the conclusions of the main analysis except for one case, case 6b for the subset of residential premises where sprinklers are predicted to be cost-effective or marginally cost-effective. This is the case where the sprinkler systems are not maintained with a consequential 30% reduction in reliability which gives a small overall Net Present Value and a large uncertainty. (See Results section for further information).

Other factors which may influence the risks in the future include: the introduction of reduced ignition propensity cigarettes, an increasingly ageing, infirm and mobility impaired population living in their own homes, increasing tendency for singleton living, changes in water connection charges, simpler sprinkler system design, changes in sprinkler system maintenance regime, trend for multi-storey and open plan flats, increasing use of combustible materials including plastics and insulation in the construction of residential premises. Some of these trends may, for example, increase the risks of death and injury and/or reduce the costs associated with the sprinkler systems and/or lead to increased levels of property damage making sprinklers more cost effective and some may reduce the cost effectiveness.

Glossary of terms

Term	Meaning
Present Value (PV)	Represents a future series of cash flows expressed in prices for 2010
Present Value annual costs	Sum of the discounted annual costs over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales
Present Value one-off costs	Sum of the discounted one-off costs over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales
Present Value total costs	Sum of the PV one-off costs and the PV annual costs
Present Value total benefits	Sum of the discounted annual benefits for the lives saved, injuries prevented and the property loss, etc over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales
Total lives saved	Number of lives saved over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales
Total injuries prevented	Number of injuries prevented over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales
Present Value cost per statistical life saved	Present Value total costs divided by the number of lives saved
Overall Net Present value (NPV)	The difference between the Present Value of all the benefits and the Present Value of all the costs over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales

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Appendix G – Sensitivity analysis

1 Introduction and Background

A member proposed Measure of the National Assembly for Wales, the Domestic Fire Safety (Wales) Measure 2011, to require the provision of automatic fire suppression systems in new and converted residential premises in Wales (a Welsh law) received Royal Approval on 7 April 2011 and has now become Welsh law.

The scope of the Measure covers the construction of new and converted residences. The definition of residences currently includes dwelling-houses, flats, residential care homes, boarding schools, residential colleges and student halls of residence. It also applies to the creation of new houses in multiple occupation and common areas such as stairways in buildings containing one or more new residences. It does not require retro-fitting of automatic fire suppression systems in existing properties.

Technical regulations now need to be made to enact this measure. A Regulatory Impact Assessment relevant to Wales will also need to be prepared to support these regulations. This Assessment will include a detailed and robust cost benefit analysis of residential sprinklers for each of the relevant building types.

Welsh Government has commissioned BRE to carry out a project 'Domestic sprinkler regulatory impact assessment', Welsh Government contract number C/133/2011/2012 and BRE proposal number 130367, dated 4 November 2011. This report details the work to carry out a cost benefit analysis of the provisions in the Domestic Fire Safety (Wales) Measure 2011. It explains the scope, method, data, assumptions, and conclusions presented as a main report with technical Appendices A to F. This study is limited to residential sprinkler systems designed, installed and maintained to British Standard BS 9251 Sprinklers for residential and domestic occupancies – Code of Practice[1].

[1] British Standards Institution, BS 9251, Sprinklers for residential and domestic occupancies – Code of Practice, 2005.

2 Description of the project

The main stages of this cost benefit analysis (CBA) involved a brief literature review, data gathering, cost benefit analysis, uncertainty and sensitivity analysis.

The literature review concentrated on Welsh-specific literature and information, in particular, The Explanatory Memorandum 2010 and other relevant submissions, notes and information from the Welsh Government meetings with the three water companies relevant to Wales. BRE was already conversant with the UK and overseas available literature relevant to the cost benefit analysis of sprinklers.

Input data were collected and prepared. Welsh-specific data and Treasury data were used where appropriate and available. However, if Welsh data were unavailable or sparse then the information was supplemented with UK data, as appropriate. Data from overseas may or may not be applicable to Wales, due to differences in building standards, culture, etc, and therefore were not used in this analysis.

The input data and assumptions for this study were confirmed with or provided by the Welsh Government prior to carrying out the modelling work.

Data gathering covered the following areas:

- Fire statistics. The Welsh Government provided the most up to date raw data.
- Number of existing buildings of each type. The Welsh Government provided (links to) the relevant data for Wales or agreed a method for deriving this information from the available statistics. BRE had access to results from the English House Condition survey and Survey of English Housing, which was used to supplement the Welsh data, where necessary. This information on the number of buildings /accommodation units is used with the fire statistics in order to derive the risks on a "per-building" basis. Projected numbers of new buildings in Wales. The Welsh Government provided projected numbers of new buildings in Wales. As the cost benefit analysis calculates its results on a per-building basis, multiplying by the projected numbers of new buildings enables an estimate of the impact for Wales as a whole.
- Costs of sprinkler system installation and maintenance. BRE used 2010 data provided by residential sprinkler installer members of the British Automatic Fire Sprinkler Association (BAFSA) and Fire Sprinkler Association (FSA) (see Appendix D for further information). This is the most recent year for which economic, housing and fire statistics are all available.
- A meeting of BRE and Welsh Government with the three relevant water companies to Wales was held on 1 February 2012 at the Welsh Government Offices in Cardiff, to confirm their position and to discuss technical aspects and costs of water supplies for residential sprinkler systems. Following discussions, the two main water companies, Dwr Cymru Welsh Water and Dee Valley Water, calculated and provided new water company charges for domestic and residential sprinkler systems anticipating the future rather than their current charges based on bespoke projects,(see Appendix E). At the meeting, Severn Trent Water agreed the project should use the costs from the two main companies. The influence of water company charges on the results of the CBA were determined as part of the sensitivity analysis.

The CBA was performed using a spreadsheet tool specially developed for this project. The tool comprises a series of interlinked Excel spreadsheet pages and was adapted from a tool that has undergone considerable development and refinement over a number of years. The new features that were introduced calculate the Present Value and Net Present Value (see Appendix A for a fuller explanation) taking account of different numbers of buildings constructed in different years, with variations in the discount rate.

This cost benefit analysis considered sprinkler systems specified in accordance with British Standard BS 9251: 2005[2]. It is recognised that there are potential alternative fixed suppression systems such as lower cost domestic sprinkler systems[3],[4] or fixed water mist systems[5]. However, it has not been possible to include these in this work as currently there are no full published British or European standards covering these types of systems and also, the reliability figures for these systems are unknown.

Building types that were considered are:

- houses,
- purpose built flats,
- converted flats,
- houses in multiple occupation,
- residential care homes (for children, disabled people, elderly people),
- residential colleges,
- boarding schools, and
- student halls of residence.

Because there was not always a one to one correspondence between definitions of different building types in the housing statistics and in the fire statistics, and because the numbers of buildings (and number of fires) in some categories were low, categories were merged in some cases. The merged list of categories is as follows:

- houses,

[2] British Standards Institution, BS 9251, Sprinklers for residential and domestic occupancies – Code of Practice, 2005.

[3] Standards New Zealand, NZS 4517, Fire sprinkler systems for houses.

[4] The Fire Protection Association, Development of a lower-cost sprinkler system for domestic premises in the UK, Fire Research Technical Report 2/2007, published by Communities and Local Government Publications, April 2007.

[5] British Standards Institution, BS DD 8458-1, Fixed fire protection systems. Residential and domestic watermist systems. Code of practice for design and installation, 2010.

- flats,
- houses in multiple occupation,
- hostels,
- residential care homes (for children, disabled people, elderly people),
- sheltered housing,
- residential colleges, boarding schools, and student halls of residence.

A sensitivity analysis was carried out for a) all residential properties and b) the subset of residential properties where sprinklers are predicted to be cost-effective or marginally cost-effective. This subset was for: new blocks of flats, new blocks of sheltered flats, new “traditional” HMOs, new care homes, new halls of residences and new dormitories. See Appendix G for further details of the sensitivity analysis.

2.1 Glossary of terms

Term	**Meaning**
Present Value (PV)	Represents a future series of cash flows expressed in prices for 2010
Present Value annual costs	Sum of the discounted annual costs over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales
Present Value one-off costs	Sum of the discounted one-off costs over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales
Present Value total costs	Sum of the PV one-off costs and the PV annual costs
Present Value total benefits	Sum of the discounted annual benefits for the lives saved, injuries prevented and the property loss, etc over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales
Total lives saved	Number of lives saved over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales
Total injuries prevented	Number of injuries prevented over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales
Present Value cost per statistical life saved	Present Value total costs divided by the number of lives saved
Overall Net Present value (NPV)	The difference between the Present Value of all the benefits and the Present Value of all the costs over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales

3 Assumptions

3.1 Forecast period and the use of discounting

The assumptions relating to the forecast period and the use of discounting are as follows.

All monetary data are expressed in 2010 prices. 2010 is the last year for which the Gross Value Added (GVA)/Retail Price Index figures are available.

Present Values and Net Present Values were discounted on the basis that 2010 is year zero. Costs and benefits were calculated for the whole life of the sprinkler system i.e. 40 to 50 years, for all new residential premises constructed during a ten year period (2013 to 2022).

For their work on the RIA for the Building Regulations Part L, Welsh Government has assumed a policy life of 10 years, with a 60 year asset life – i.e. Welsh Government looked at new dwellings built between 2014 (one year phase-in period from 2013) and 2023, with capital costs arising in the build year and additional costs/benefits occurring over a 60 year period. A ten year period was assumed to be reasonable since technologies and other assumptions were likely to change beyond that timeframe. Therefore, Welsh Government suggested using a ten year policy period for comparability purposes (but with the asset life equal to the lifetime of the sprinkler system assumed to be 40 to 50 years).

The Net Present Value represents the present value of the stream of costs and benefits over the policy period, and is used to determine whether or not government intervention can be justified. In general, the higher the Net Present Value is, the better the outcome of the expected policy. For the purposes of this work, it has been agreed with the Welsh Government that sprinklers are cost effective if the Net Present Value is positive (and is greater than the uncertainty).

In line with the Treasury Green Book[6] recommendation, the discount rate for discounting future values used in the cost benefit analysis was 3.5% for terms less than 30 years duration and a rate of 3% for terms longer than 30 years.

Projected increases in population[7] are used to predict numbers of new buildings constructed over the next ten years. For houses and flats, Welsh Government has made annual predictions for the numbers of new buildings. For other building types, the numbers of existing buildings pro-rata have been increased with the increase in population.

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[6] HM Treasury, The green book: appraisal and evaluation in central government, ISBN 0115601074, January 2003.

[7] Statistics for Wales 2011, StatsWales data table 034803.

The current (2010) population of Wales is 3.01m[8] and is predicted to rise to 3.17m in 2020, i.e. a fractional increase of 5.4%. Note. The same percentage increase applies for any 10 year period starting between 2010 and 2015, so the precise start year is not significant.

The growth in new-build houses and flats has been based on projected increases in the number of households, with estimates ranging between 65,830 and 67,860 over 10 years (starting from 2011-12 to 2014-15). The 2011 to 12 base figure is a three year average of actual completions between 2008-09 and 2010-11. The average value is 66,848. Welsh Government advises that:

“These are not official Welsh Government housing policy projections, but an illustrative example of what *could* be built in Wales up to 2023, forming the basis for the Welsh Government Part L cost benefit analysis (subject to Policy confirmation).

The projections are based on growth in the number of households in Wales and do not account for changes in average household size.

Welsh Government has used a central case dwelling mix of 30% detached, 38.5% semi-detached, 10.5% mid-terrace and 21% apartments (32 units to a block). Changes in household size could be captured by altering the dwelling mix over the policy period, although this would be difficult to apply due to uncertainties (e.g. when to apply changes)”.

3.2 Baseline assumptions used in the calculation of costs and benefits

The baseline assumptions used in the cost benefit calculations are as follows.

3.2.1 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 is assumed that the reliability was normally distributed, N(0.98, 0.005). This reliability figure also assumes that the sprinkler system is annually maintained according to the BS 9251: 2005 standard. If maintenance is neglected, it would be likely for the reliability to decrease, but the extent of the effect is unknown.

3.2.2 Sprinkler system lifetime

Based on estimates by the sprinkler industry[9] and others[10], the lifetime of the sprinkler system has been assumed to be uniformly distributed between 40 and 50 years, i.e. U(40, 50).

3.2.3 Sprinkler system effectiveness

As there is little or no relevant UK or Welsh statistical information upon which to base an estimate of sprinkler system effectiveness, it is necessary to make an indirect estimate. The principle behind the

[8] Statistics for Wales 2011, StatsWales data table 034803.

[9] Young R, Advised lifetime of residential sprinkler systems, Private Communication, 2010.

[10] Ramachandran, G, The economics of fire protection, E&FN Spon, 1998.

approach is the same as that in the previous work on residential sprinkler effectiveness[11], namely, that the risks of death, injury, etc are correlated with the area of fire damage. It is assumed that if a sprinkler constrains the area of damage to the area of the fire at the point of activation, then the risks of death and injury will also be reduced to correspond with this area, (see Appendix C for further details).

For the purposes of this study, the fire area (m^2) at the time of sprinkler activation was taken to be Normally distributed, N(0.3, 0.1) m^2. Monte Carlo calculations were performed to take account of the reduction in fire area (from the unsprinklered area, i.e. area of damage as recorded in the fire statistics, to the area at activation N(0.3, 0.1)), the statistical correlation between risk and fire area, and the uncertainties in these quantities.

The correlation between fire size and risk has been derived from UK (England and Scotland) fire statistics data rather than Welsh fire statistics data because the Welsh data do not include details of the area of fire damage.

3.2.4 Sprinkler system installation costs

Sprinkler system costs were for one-off cases and therefore do not include any economies of scale for large developments. It is not known what the proportion of new buildings will be in large developments. Therefore a sensitivity analysis was performed for this factor. According to a study of sprinklers in the Thames Gateway[12], costs could be reduced by up to 30% in large developments.

3.2.5 Water supply costs

It was assumed for all accommodation types, with the exception of flats, that the water supply costs were based on a single pump and tank per building.

For flats with a pump and tank supply, it was assumed that two pumps and tanks would be provided for the entire building. Note that this is different to the assumption made previously[13] where the pump and tank option was costed on the basis of one per floor, where each floor contained four flats.

3.2.6 Sprinkler system maintenance costs

For flats, it was assumed that all parts of the system requiring maintenance would be accessible from the common parts and therefore repeated visits would not be required to gain access to all flats. The maintenance charge would therefore be relatively low, and shared by all flats in a block. This could also

[11] Williams, C, Fraser-Mitchell, J, Harrison, R and Campbell, S, The effectiveness of residential sprinklers, BRE report 204505 for the Office of the Deputy Prime Minister, February 2004.

[12] Gros S, Spackman, M and Carter, S, A cost benefit analysis of options to reduce the risk of fire and rescue in areas of new build homes, Department for Communities and Local Government, Fire Research Series 1/2010, February 2010.

[13] Williams, C, Fraser-Mitchell, J, Harrison, R and Campbell, S, The effectiveness of residential sprinklers, BRE report 204505 for the Office of the Deputy Prime Minister, February 2004.

apply to other types of property where water supplies could be a shared pump and tank, such as sheltered flats and "traditional" HMOs.

Based on advice from the sprinkler industry[14], it has been assumed that 100% of systems will be maintained annually in accordance with BS 9251: 2005.

Costs associated with any regular treatment of water in tanks have not been included in this analysis.

3.2.7 Fires, deaths and injuries

The UK Fire Statistics database was interrogated to provide estimates of the annual numbers of fires, deaths, and injuries in various domestic and residential building types in Wales[15]. The data were collected from the years 2001 to 2010. A summary of the data is given in Table 1.

Table 1 - Annual average numbers of fires, deaths, injuries, for different building types

Accommodation type	Fires	Fatal fires	Deaths	Injury fires	Injuries
House (single occupancy)	1,421	13	14	240	345
Flat (all types)	415	2	2	84	113
House (multiple occupancy)[1]	81	1	1	12	18
Hostel	16	0	0	1	1
Care home (all types)	62	<1	<1	4	6
Sheltered housing[2]	100	<1	<1	15	18
Halls/Dormitories[3]	73	0	0	2	2

Notes

1. The fire statistics do not distinguish between "traditional" HMOs and shared houses, so these data are the sum of the two accommodation types.
2. Due to small sample sizes (and recent statistics not distinguishing between sheltered houses and sheltered flats), these data are the sum of the two accommodation types.
3. Due to the small sample size, the data for halls of residence and dormitories have been merged.

[14] British Automatic Fire Sprinkler Association, Private Communication, 2010.

[15] Welsh Government, Welsh Fire Statistics data, 2012.

3.2.8 Numbers of accommodation units

Data on the numbers of different accommodation units in the current housing stock has mainly come from the StatsWales website, supplemented by other sources[16, 17]. Data from the English House Condition Survey (EHCS) for 2007 and 2008 has also been analysed to provide estimates of the numbers of the different types of buildings[18] on the assumption that the proportions in England and Wales are similar.

For the different building types, accommodation units have been defined as follows:

- House, single occupancy – each accommodation unit = one house
- House, multiple occupancy – each accommodation unit = one shared house, one bedsit, or one hostel
- Flat – each accommodation unit = one flat (therefore, a block of 32 flats = 32 accommodation units)
- Care home – each accommodation unit = one care home
- Sheltered housing – each accommodation unit = one house or flat
- Hall of residence or dormitory – each accommodation unit = one hall or dormitory.

There is no universal definition of houses in multiple occupation (HMO) within the UK. In the survey of English housing, HMOs include “shared houses” and “bed-sit type dwellings” (“traditional” HMOs). Hence the number of each category is known and these are added together to give the total number of HMOs. The nature of HMOs in England has been changing rapidly in recent years, with many bedsits being converted to flats (to increase revenue and avoid the need for licensing)[19]. About half of the bedsits extant ten years ago have been converted. Other changes include a greater proportion of HMOs occupied by families with children, and more overcrowding generally, both factors which may increase the risk of death or injury per fire.

The fire statistics do not provide the same breakdown for HMOs. Prior to 2008, there was just one category which included both shared houses and traditional HMOs. Post 2008, it has been possible to record whether an HMO is licensed or unlicensed but not define if it is a shared house or traditional HMO. As such, the statistics available to support this work relating to HMOs mean that the risks can only be evaluated over all HMOs and are therefore dominated by the risks in shared houses. In the future, for the subset of HMOs that are licensed, the number of licensed buildings should be known, and in the event of a fire, the fact that a building was licensed should be recorded in the fire statistics collected using the new Incident Reporting

[16] IPSOS MORI, Living in Wales survey for the data unit, 2008.

[17] Statistics for Wales 2011.

[18] White, K, Numbers of different dwelling types and accommodation units, extracted from English Housing Survey results database 2007 and 2008, Private Communication 2011.

[19] Davidson, M, HMOs in England, Private Communication, Private Communication, 2011.

System[20]. The fire statistics for 2010-11 suggest that there are more fires in licensed HMOs than in unlicensed HMOs, although these figures must be treated with some caution as the largest category of fires in HMOs (over 40%) are recorded as “unknown if licensed”

For HMOs in Wales, the numbers from the StatsWales website include shared houses, as well as traditional HMOs (e.g. bedsit-type accommodation).

It is known from the Survey of English Housing[21] that there are 339,000 shared houses (93.8%) and 22,400 traditional HMOs (6.2%). It is also known from this survey that the ratio of single occupancy to multiple occupancy is 49:1. If it is assumed that a similar ratio applies to Wales, then 2% of the 1.234m houses and HMOs would be in multiple occupancy, suggesting the number of buildings in multiple occupancy in Wales is 2% x 1.234m = 24,643. This is close to the figure on the StatsWales website. If it is further assumed that the same proportion of shared houses and traditional HMOs for England also applies to Wales, there would be 19,928 x 0.938 = 18,692 shared houses and 19,928 x 0.062 = 1,236 traditional HMO accommodation units.

The results of the analysis are shown in Table 2 with the underlying assumptions in the notes below.

Table 2 - Estimated numbers of different accommodation unit types, from various data

Accommodation type	Estimated number of accommodation units	Uncertainty
House (single occupancy)[1]	1,214,151	12,500
Flat (all types)[2]	146,000	4,500
Traditional HMO[3]	1,236	Not known
Shared house[4]	18,692	Not known
Hostel[5]	4,089	Not known
Care home (all types)[6]	1,806	Not known
Sheltered house[7]	8,690	Not known
Sheltered flat[8]	12,220	Not known
Halls/Dormitories[9]	254	Not known

[20] Department for Communities and Local Government, Incident Recording System – Questions and lists, Version 1.4 – (XML Schemas v1-0n), September 2009, ISBN: 978-1-4098-1864-9.

[21] White, K, Numbers of different dwelling types and accommodation units, extracted from English Housing Survey results database 2007 and 2008, Private Communication 2011.

Notes.

1. The total number of dwellings in Wales is 1.38m[22], when multiplied by 13,766/(13,766 + 1,625) gives 1.234m houses and HMOs (13,766 and 1,625 are the sample sizes for houses including HMOs, and flats, respectively, when extrapolated to a 100% response to the Mori poll[23]). Deducting the number of HMOs (see 3) gives the number of houses.
2. The number of dwellings (1.38m) minus the number of houses and HMOs (1.234m); see 1.
3. Assuming the same proportions of shared houses and traditional HMOs are found in Wales as are found in England, the number of traditional HMOs is estimated from 19,928 HMOs of all types[24] x 0.062 (proportion of traditional HMOs) = 1,236.
4. The number of shared houses is assumed to be the total number of HMOs minus the number of traditional HMOs; see 3.
5. The number of hostels was taken directly from the StatsWales website[25]. These figures relate to social housing only.
6. The total number of settings (i.e. buildings) is comprised of 1,616 settings for "adult services" and 190 settings for "children's services"[26]. The number of child day care settings (4,445) should not be included in the total. Note that the average number of places per setting is 16.75.
7. Taken directly from the StatsWales website[27]. These figures relate to social housing only.
8. Taken directly from the StatsWales website[28]. These figures relate to social housing only.
9. The number of student halls estimated from 149,590 students[29] x 16%[30] in halls/100 students per hall = 239. In addition, there are 15 boarding schools (on average 84 boarders each)[31].

[22] Statistics for Wales 2011, Council tax in dwellings in Wales: 2011-12, Table 3, January 2011.

[23] IPSOS MORI, Living in Wales survey for the data unit, 2008.

[24] Statistics for Wales 2011, StatsWales data table 032320, average for Wales for 2006 to 2011.

[25] Statistics for Wales 2011, StatsWales data table 031415, average for Wales for 2002 to 2011.

[26] Statistics for Wales 2011, StatsWales data table 31736, values for Q1 2011 to 2012.

[27] Statistics for Wales 2011, StatsWales data table 031368, averages for Wales for 2002 to 2011.

[28] Statistics for Wales 2011, StatsWales data table 031368, averages for Wales for 2002 to 2011

[29] Wikipedia, Universities in Wales.

[30] Various university websites.

[31] Statistics for Wales 2011, StatsWales data table 007547, value in 2010/11.

3.2.9 Number of residents per building

For some buildings, the number of residents needs to be known in order to estimate the building size and hence the cost to provide sprinkler protection.

For care homes, the average number of occupants is 16.75[32]. (This figure is consistent with estimated sizes that have been used for care homes in the UK as a whole in other studies).

For flats, Welsh Government has advised to assume 32 flats per block, for consistency with the RIA performed for proposed changes to Building Regulations Part L.

For traditional HMOs, an average of 5~6 accommodation units per building is estimated from the Survey of English Housing[33]. (Costs of the system are calculated per building, but the cost benefit analysis is calculated per accommodation unit, so each accommodation unit only "pays" its share of the building cost).

For sheltered housing, it is known that there is a mixture of houses and flats. It has been assumed that the average number of flats per block is the same as ordinary flats, i.e. 32.

3.2.10 Risks of fire, death, injury and average damage

By combining the fire statistics data with the numbers of accommodation units, it is possible to estimate the annual risks in different accommodation unit types. The estimation procedure is described in Appendix A. The results are shown in Table 3.

[32] Statistics for Wales 2011, StatsWales data table 31736, values for Q1 2011 to12.

[33] White, K, Numbers of different dwelling types and accommodation units, extracted from English Housing Survey results database 2007 and 2008, Private Communication 2011.

Table 3 - Estimate of the annual risks from fire in different accommodation types

Accommodation type	Number of accommodation units	Fires per 10^6 units	Deaths per 10^6 units	Injuries per 10^6 units
House (single occupancy)[1]	1,214,151	1,170 ± 10	12 ± 1	284 ± 8
Flat (all types)[2]	146,000	2,846 ± 44	13 ± 3	772 ± 36
Traditional HMO[3]	1,236	4,069 ± 143	36 ± 18	893 ± 122
Shared house[4]	18,692	4,069 ± 143	36 ± 18	893 ± 122
Hostel[5]	4,089	3,908 ± 309	24 ± 24	345 ± 117
Care home (all types) [6]	1,806	34,113 ± 1,351	221 ± 312	3,461 ± 888
Sheltered house[7]	8,690	4,777 ± 151	14 ± 8	856 ± 83
Sheltered flat[8]	12,220	4,777 ± 151	14 ± 8	856 ± 83
Halls/Dormitories[9]	254	286,681 ± 8,961	392 ± 392	9,939 ± 3,027

Notes

1. For details of the risk calculation, based on fire and housing statistics, see Appendix A.
2. Risks are per flat, not per block
3. Risks per accommodation unit have been averaged over all types of HMO (shared house and "traditional" HMO). Note that the fire statistics do not distinguish between shared houses and "traditional" HMOs. It has been assumed that the risk per accommodation unit is the same, whether for a traditional HMO or a shared house.
4. See 3.
5. Since hostels can be distinguished in both the housing and fire statistics, it is possible to calculate their risks independently. The uncertainties are relatively large due to the small sample size.
6. Risks have been averaged over all types of care home (the fire statistics distinguish between care homes for the elderly, for disabled persons, and for children; also, since 2009, residential nursing homes). The housing data on StatsWales distinguishes only between care homes for adults and for children (also children's day care centres, not included in the total number of buildings).
7. Before 2009 it was possible to distinguish between sheltered houses and sheltered flats; however due to small sample sizes the risks have been calculated for all sheltered housing combined.
8. See 7.
9. The uncertainties quoted for the risks are only those arising from the fire statistics sample sizes; there has been no inclusion of the uncertainty in the average hall size (and hence number of buildings). The component of uncertainty for the average hall size may be dominant.

3.3 Main risks/uncertainties/limitations associated with the analysis

All of the input data are uncertain to a greater or lesser degree: there are statistical uncertainties due to small sample sizes and in other cases there are uncertainties connected with trends in the future. For some of the factors which may influence the risks in the future, a sensitivity analysis has been carried out to look at their importance and influence on the conclusions.

3.4 Smoke alarms and the effect on the baseline risks

It is considered that the voluntary installation of smoke alarms has probably reached its peak level. However due to the regulatory requirements introduced in 1992, smoke alarm penetration into the new build and refurbishment domestic housing sector has increased. This affects the baseline risk against which the impact of residential sprinklers will be assessed by lowering it.

3.5 Other factors which may influence the risks in the future

Other factors which may influence the risks in the future include: the introduction of reduced ignition propensity cigarettes, an increasingly ageing, infirm and mobility impaired population living in their own homes, increasing tendency for singleton living, changes in water connection charges, simpler sprinkler system design, changes in sprinkler system maintenance regime, trend for multi-storey and open plan flats, increasing use of combustible materials including plastics and insulation in the construction of residential premises.

Some of these trends may, for example, increase the risks of death and injury and/or reduce the costs associated with the sprinkler systems and/or lead to increased levels of property damage making sprinklers more cost effective and some may reduce the cost effectiveness.

The introduction of "reduced ignition propensity" (RIP) cigarettes. The European Union has enacted legislation to replace current cigarettes with new "reduced ignition propensity" (RIP) cigarettes with an intention to improve fire safety. Whilst it is preferable for people not to smoke at all, it is recognised that this is not achievable in the short to medium term. As such, RIP cigarettes have been developed by cigarette manufacturers and in November 2011 replaced "conventional" cigarettes, as a way of improving fire safety by reducing the number of accidental fires related to careless use of smokers' materials. A reduction in the number of accidental fires might result in a reduction in the number of fire deaths, injuries and property damage. As yet there is no definitive data to indicate whether RIP cigarettes will have an effect on the number of accidental fatal fires due to the "careless use of smokers' materials".

The effect of an increasingly ageing, infirm and mobility impaired population living in their own homes. People are on average living longer and consequently the population is ageing. Various initiatives will mean that elderly, infirm and mobility impaired people will be living in their own homes rather than in residential care homes or hospitals, as in the past. The numbers of elderly, infirm and mobility impaired people living in their own homes is likely to increase. This might be expected to increase the risk of fires, fire deaths and injuries.

An increasing tendency for singleton living. There is an increasing tendency for people to live on their own rather than in larger family groups as in the past. Singleton living tends to increase the risk of fires, fire deaths and injuries.

Changes in water connection charges. The cost of water supplies for sprinklers is an important cost. There is the potential for water connection charges to change significantly and reduce due to various initiatives including improved dialogue with water companies and more widespread adoption of sprinkler systems.

Simpler sprinkler system design. Cheaper residential sprinkler systems could be achieved by re-specifying systems with a simpler different design to current BS 9251 systems. However, these systems may or may not have negative consequences by having decreased reliability and less effective performance in the event of fire. Caution is needed and any negative consequences need to be carefully considered and quantified.

Changes in sprinkler system maintenance regime. It is important to regularly maintain a residential sprinkler system so that it will work properly in the event of a fire, in accordance with the relevant British Standard. However, it is recognised that, in practice, not all systems will be maintained.

BS 9251: 2005 recommends annual maintenance by a suitably qualified and experienced sprinkler contractor. Maintenance involves a visual inspection of the sprinkler heads and system components, a water flow test, an internal and external alarm test, and if a leak is suspected, a pressure test. Additional to BS 9251, the industry has recognised that fire pumps should be churned over automatically at least once every 60 days.

Maintenance provisions will be reviewed in the forthcoming revision of BS 9251 to incorporate current industry practice. Increasing the use of remote monitoring and decrease in the frequency of tests or inspection visits are expected to result in higher figures for reliability and lower maintenance costs.

Trend for multi-storey and open plan flats. Due to a number of factors including energy efficiency, land prices, housing costs and living preferences, there is a current increasing trend for open plan layouts in flats and houses and a trend for multi-storey flats and houses of more than three storeys. Open plan living provides less compartmentation and therefore uninterrupted fire and smoke spread is more likely to occur in a fire, depending upon the fire protection measures installed such as sprinklers. The qualitative trend of an increase in the use of multi-storey and open plan designs could affect the cost benefit factors if there were an increasing number of deaths, injuries and property damage.

Increasing use of combustible materials including plastics and insulation in the construction of residential premises. There is a trend for a greater use of combustible materials including plastics and insulation in the construction of new residential buildings and in the refurbishment of existing residential buildings, driven by sustainability and energy use targets. This is resulting in more highly insulated buildings, which depending upon a number of factors including the ventilation, might lead to more rapid fire growth rates and therefore shorter available time for escape. To date there are no definitive data to quantify any new additional risks but it is possible that this trend could lead to an increase in the risk of death, injury and property damage.

4 Monetised costs and benefits

The monetised costs are the costs of the residential sprinkler installation and the water supply (water company charges and for the pump and tank systems, the cost of the pump and tank) which are one off costs and the costs of the residential sprinkler system maintenance which is an annual cost.

The monetised benefits are the reduced risk of deaths and injuries and reduced property damage which are annual benefits. At the request of the Welsh Government, BRE was also asked to estimate the reduction in greenhouse gases, specifically carbon dioxide, from fires where a residential sprinkler system was installed to inform the CBA and a future impact assessment. The reduction of greenhouse gases from fire is also an annual benefit but the monetised value is estimated to be very small compared with the others, see Appendix F.

4.1 Value of each death prevented

The value of a statistical life used in this analysis is £1,620,000 (in 2010). This is based on the Department for Transport “willingness to pay” figure[34] converted to a value in 2010, which was originally used in the context of road safety but is now also typically used in other contexts[35].

4.2 Value of each injury prevented

The value for a fire injury used in this analysis is £19,960 (in 2010). This value is based on Department of Transport figures for serious and minor injuries[36] converted to a value in 2010 and is weighted using Welsh fire statistics records of apparent injuries sustained during fire incidents.

4.3 Value of property damage in a fire

The value for the average value of property damage in domestic accommodation units used in this analysis is £8,800 (in 2010). This ignores costs associated with displacement of accommodation unit occupants unless covered by insurance.

The value for the average value of property damage in care homes used in this analysis is £33,700 (in 2010).

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[34] Department for Transport, Transport Analysis Guidance (TAG), the Accidents Sub-Objective, TAG Unit 3.4.1, April 2011. Available from http://www.dft.gov.uk/webtag/documents/expert/unit3.4.1.php#02.

[35] HM Treasury, The green book: appraisal and evaluation in central government, ISBN 0115601074, January 2003.

[36] Department for Transport, Transport Analysis Guidance (TAG), the Accidents Sub-Objective, TAG Unit 3.4.1, April 2011. Available from http://www.dft.gov.uk/webtag/documents/expert/unit3.4.1.php#02.

Care homes are larger than domestic accommodation units and would also incur losses due to business interruption. Therefore, the average value of property damage used in this analysis for care homes was assumed to be that of commercial buildings.

These values are based on figures in the Economic cost of fire 2004[37], converted to 2010 prices. Although updates to the Economic Cost of Fire were published for 2006 and 2008, neither contained the necessary level of information to determine the costs of fire damage.

4.4 Sprinkler system effectiveness

Calculated sprinkler effectiveness values used in this analysis are given in Table 4. Note that the uncertainties in the effectiveness for reducing risks in care homes are large as a consequence of the small statistical sample size.

Table 4 - Results of calculations of sprinkler effectiveness at reducing risks

Accommodation type	Deaths (%)	Injuries (%)	Damage (%)
House (single occupancy)	90 ± 4	64 ± 11	93 ± 2
Flat (all types)	90 ± 4	62 ± 12	88 ± 4
Traditional HMO[1]	100 ± 0	67 ± 11	93 ± 2
Shared house[2]	100 ± 0	67 ± 11	93 ± 2
Hostel[3]	100 ± 0	67 ± 11	93 ± 2
Care home (all types)	63 ± 20	66 ± 14	88 ± 4
Sheltered house[4]	63 ± 20	66 ± 14	88 ± 4
Sheltered flat[5]	63 ± 20	66 ± 14	88 ± 4
Halls/Dormitories[6]	90 ± 4	62 ± 12	88 ± 4

Notes:

1. Effectiveness in all types of HMO (traditional, shared house, or hostel) has been assumed to be similar, since the statistics upon which the effectiveness estimates were based did not distinguish HMO types.
2. See 1.
3. See 1.

[37] Office of the Deputy Prime Minister, Economic cost of fire: estimates for 2004, 2006.

4. Effectiveness in sheltered housing has been assumed to be the same as for care homes.
5. See 4.
6. Effectiveness in Halls/Dormitories has been assumed to be the same as for flats.

4.5 Sprinkler system installation costs

Sprinkler system installation costs for new build premises used in this analysis are given in Table 5 and Appendix D.

These costs were based on sprinkler installation costs for various types and sizes of buildings from residential sprinkler installer members of the British Automatic Fire Sprinkler Association (BAFSA) and the Fire Sprinkler Association (FSA)[38]. No corrections or weighting have been applied (e.g. to account for the market share of the various members of BAFSA and FSA) and the samples sizes are small.

Table 5 - Sprinkler system installation costs, new build, no economies of scale

Accommodation type	**Sprinkler system installation cost**
House (single occupancy)	£1,950 ± £170
Flat (all types)[1]	£620 ± £124
Traditional HMO[2]	£576 ± £53
Shared house[3]	£1,950 ± £170
Hostel[4]	£1,950 ± £170
Care home (all types)[5]	£10,714 ± £1,624
Sheltered house[6]	£1,950 ± £170
Sheltered flat[7]	£620 ± £124
Halls/Dormitories[8]	£63,964 ± £9,695
Notes: 1. This is a cost per flat. 2. Cost per accommodation unit (e.g. per bedsit).	

[38] British Automatic Sprinkler Association and Fire Sprinkler Association, sprinkler system installation costs, Private Communication, 2010.

3. Assumed the same as a single occupancy house.
4. See 3.
5. This value has been derived from the cost per bed, with an average size of 16.75 beds per care home in Wales (see section 3.2.9).
6. Assumed the same as a single occupancy house.
7. Assumed the same as a flat.
8. This value assumes the same cost per bed as a care home, but an average building size of 100 occupants.

4.6 Water supply costs

Water supply costs for new build premises for the pump and tank option used in this analysis are given in Table 6 and Appendix D. For this option, the water supply costs comprise the cost of the pump and tank and the additional water company charges.

These costs were based on sprinkler pump and tank installation costs for various types and sizes of buildings provided by residential sprinkler installer members of the British Automatic Fire Sprinkler Association (BAFSA) and the Fire Sprinkler Association (FSA)[39]. No corrections or weighting have been applied (e.g. to account for the market share of the various members of BAFSA and FSA) and the sample sizes are small.

The additional water company charges for fire sprinkler systems for domestic and residential premises were calculated and provided by the water companies relevant to Wales. These estimated charges were for the cases of a pump and tank water supply or a direct mains connection. These charges also anticipated the future i.e. following implementation of the Domestic Fire Safety (Wales) Measure 2011 rather than the current position. Appendix E provides details of these charges.

[39] British Automatic Sprinkler Association and Fire Sprinkler Association, sprinkler system pump and tank costs, Private Communication, 2010.

Table 6 - Sprinkler water supply costs for pump and tank including water company charges

Accommodation type	Water supply cost
House (single occupancy)[1]	£1,125 ± £106
Flat (all types)[2]	£259 ± £6
Traditional HMO[3]	£1,211 ± £14
Shared house[4]	£1,125 ± £106
Hostel[5]	£7,168 ± £106
Care home (all types)[6]	£9,153 ± £592
Sheltered housing [7]	£1,125 ± £106
Sheltered flat[8]	£259 ± £6
Halls/Dormitories[9]	£9,153 ± £592

Notes:

1. The cost of the pump and tank is £1,113 ± £106. The additional charge by the Welsh water companies for connections to a single occupancy house is £12 ± £5.
2. This is based on the costs for two pump and tank sets shared between 32 flats per block. The Welsh water companies' additional charge is £6,055 shared between 32 flats per block.
3. Based on the pump and tank cost of £1,213 ± £85 shared between 6 accommodation units per building The Welsh water companies' additional charges are £6,055 shared between 6 accommodation units per building in "traditional" HMOs.
4. Assumed to be the same as a single occupancy house.
5. The cost of the pump and tank is assumed to be the same as a single occupancy house. The Welsh water companies' additional charge is £6,055.
6. Estimates were based on buildings with about 20 beds. The cost estimate for the pump and tank was £3,098 ± £592, with a surcharge of £6,055 applied by the Welsh water companies.
7. Assumed to be the same as a single occupancy house.
8. Assumed to be the same as a flat.
9. Assumed the same as care homes (but note that the average number of occupants in a hall is about six times larger than a care home).

4.7 Sprinkler system maintenance costs

Sprinkler system maintenance costs for new build premises used in this analysis are given in Table 7 and Appendix D.

These costs were based on sprinkler system maintenance costs for various types and sizes of buildings provided by residential sprinkler installer members of the British Automatic Fire Sprinkler Association (BAFSA) and the Fire Sprinkler Association (FSA)[40].

[40] British Automatic Sprinkler Association and Fire Sprinkler Association, sprinkler system maintenance costs, Private Communication, 2010.

Table 7 - Sprinkler annual maintenance costs

Accommodation type	Annual maintenance cost
House (single occupancy)	£96 ± £1
Flat (all types)[1]	£5 ± £1
Traditional HMO[2]	£18 ± £1
Shared house[3]	£96 ± £1
Hostel[4]	£96 ± £1
Care home (all types)[5]	£154 ± £11
Sheltered house[6]	£96 ± £1
Sheltered flat[7]	£5 ± £1
Halls/Dormitories[8]	£154 ± £11

Notes:

1. An annual charge of £157 ± £31 shared between 32 flats per block.
2. An annual charge of £108 ± £6 shared between 6 accommodation units per building.
3. Assumed the same as a single-occupancy house.
4. See 3.
5. Based on a care home with approximately 20 beds.
6. Assumed the same as a single-occupancy house.
7. Assumed the same as a flat.
8. Assumed the same as care homes (but note that the average number of occupants in a hall is about six times larger than a care home, so this may be an underestimate – the larger the system the more time/ money needed to maintain it).

5 Results

Tables 8 to 10 summarise the results of cost benefit analysis calculations arising from sprinkler installation in residential premises in Wales.

These baseline calculations are where the water supply is a pump and tank. The direct mains connection water supply is investigated in the sensitivity analysis.

Table 8 – Predicted costs accrued over the whole life of residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Accommodation types	Present Value total costs (£m)			Present Value one-off costs (£m)			Present Value annual costs (£m)		
House	-£216.7m	±	£8.4m	-£126.3m	±	£8.2m	-£90.3m	±	£1.5m
Flat	-£10.8m	±	£1.4m	-£9.6m	±	£1.4m	-£1.2m	±	£0.2m
Traditional HMO	-£0.1m	±	£0m	-£0.1m	±	£0m	-£0m	±	£0m
Shared house	-£4.4m	±	£0.2m	-£2.5m	±	£0.2m	-£1.8m	±	£0m
Hostel	-£2m	±	£0m	-£1.7m	±	£0m	-£0.4m	±	£0m
Care home	-£1.9m	±	£0.1m	-£1.6m	±	£0.1m	-£0.3m	±	£0m
Sheltered house	-£2m	±	£0.1m	-£1.2m	±	£0.1m	-£0.8m	±	£0m
Sheltered flat	-£0.5m	±	£0.1m	-£0.5m	±	£0.1m	-£0.1m	±	£0m
Hall/Dormitory	-£0.9m	±	£0.1m	-£0.8m	±	£0.1m	-£0m	±	£0m
Total for subset where cost effective or marginally cost effective	**-£14.2m**	±	**£11m**	**-£12.6m**	±	**£9.8m**	**-£1.6m**	±	**£1.3m**
Total for all accommodation types	**-£239.3m**	±	**£8.5m**	**-£144.3m**	±	**£8.3m**	**-£95m**	±	**£1.5m**

Note. Future sums are/have been discounted to 2010 prices. The uncertainties in the table represent ± 1 standard deviation.

Table 9 – Predicted benefits accrued over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Accommodation Type	Present Value total benefits (£m)			Total lives saved			Total injuries prevented		
House	£27.9m	±	£1.8m	24.6	±	3.0	427	±	5
Flat	£12.4m	±	£1.3m	7.3	±	1.9	297	±	2
Traditional HMO	£0.1m	±	£0m	0.1	±	0.1	2	±	0
Shared house	£1.9m	±	£0.5m	1.7	±	0.8	28	±	0
Hostel	£0.3m	±	£0.2m	0.2	±	0.2	2	±	0
Care home	£2.3m	±	£0.6m	0.6	±	0.9	10	±	0
Sheltered house	£0.6m	±	£0.1m	0.3	±	0.2	12	±	0
Sheltered flat	£0.8m	±	£0.2m	0.4	±	0.2	16	±	0
Hall/Dormitory	£2.3m	±	£0.1m	0.2	±	0.2	4	±	0
Total for subset where cost effective or marginally cost effective	**£18.1m**	±	**£12.9m**	**8.6**	±	**7.4**	**330**	±	**298**
Total for all accommodation types	**£48.8m**	±	**£2.3m**	**35.5**	±	**3.8**	**799**	±	**5**

Note. Future sums are/have been discounted to 2010 prices. The uncertainties in the table represent ± 1 standard deviation.

Table 10 – Predicted Present Value cost per statistical life saved, and overall Net Present Value over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Accommodation Type	Overall Net Present Value (£m)			PV cost per statistical life saved (£m)		
House	-£188.7m	±	£8.5m	£8.8m	±	£1.1m
Flat	£1.6m	±	£1.9m	£1.5m	±	£0.4m
Traditional HMO	£0m	±	£0m	£1.1m	±	£0.5m
Shared house	-£2.4m	±	£0.6m	£2.6m	±	£1.3m
Hostel	-£1.7m	±	£0.2m	£8.2m	±	£8.2m
Care home	£0.5m	±	£0.6m	£3m	±	£4.3m
Sheltered house	-£1.4m	±	£0.1m	£7.2m	±	£4.2m
Sheltered flat	£0.3m	±	£0.2m	£1.3m	±	£0.8m
Hall/Dormitory	£1.5m	±	£0.2m	£5.5m	±	£5.8m
Total for subset where cost effective or marginally cost effective	**£3.8m**	±	**£2.2m**	**£1.6m**	±	**£1.9m**
Total for all accommodation types	**-£190.5m**	±	**£8.8m**	**£6.7m**	±	**£0.8m**

Note. Future sums are/have been discounted to 2010 prices. The uncertainties in the table represent ± 1 standard deviation.

Tables 11 to 13 show the effect on the baseline results for the different sensitivity cases for all residential properties

Case	Sensitivity parameter
1a and 1b	Examining the effect of varying the value of lives saved/injuries prevented by ± 25% of the value.
2a and 2b	Examining the effect of varying the % of severe injuries.
3	Reducing sprinkler installation costs by 30% to reflect economies of scale in large developments, for houses.
4	Considering the direct mains water supply cost option, for houses and sheltered housing
5	Varying the proportions of new build accommodation units that are houses and flats to 90:10 (from 79:21).
6a and 6b	Examining the options of no maintenance with no decline in reliability and no maintenance with consequential decline in reliability. Note. The sprinkler industry recent advice is that all BS 9251: 2005 systems should be maintained in accordance with the standard.
7	Examining the effect of an overall decrease in installation costs by 25% as installers gain experience and become more competitive, for all property types.

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Table 11 – Sensitivity analysis results showing overall predicted costs accrued over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Case	Present Value total costs (£m)			Present Value one-off costs (£m)			Present Value annual costs (£m)		
Baseline	-£239.3m	±	£8.5m	-£144.3m	±	£8.3m	-£95m	±	£1.5m
1a	-£239.3m	±	£8.5m	-£144.3m	±	£8.3m	-£95m	±	£1.5m
1b	-£239.3m	±	£8.5m	-£144.3m	±	£8.3m	-£95m	±	£1.5m
2a	-£239.3m	±	£8.5m	-£144.3m	±	£8.3m	-£95m	±	£1.5m
2b	-£239.3m	±	£8.5m	-£144.3m	±	£8.3m	-£95m	±	£1.5m
3	-£215.3m	±	£6.9m	-£120.3m	±	£6.7m	-£95m	±	£1.5m
4	-£247.5m	±	£13.7m	-£152.5m	±	£13.6m	-£95m	±	£1.5m
5	-£263.8m	±	£9.5m	-£156.9m	±	£9.4m	-£106.9m	±	£1.7m
6a	-£144.3m	±	£8.3m	-£144.3m	±	£8.3m	-£0m	±	£0m
6b	-£144.3m	±	£8.3m	-£144.3m	±	£8.3m	-£0m	±	£0m
7	-£216.4m	±	£7m	-£121.4m	±	£6.9m	-£95m	±	£1.5m

Note. Future sums are/have been discounted to 2010 prices. The uncertainties in the table represent ± 1 standard deviation.

Table 12 – Sensitivity analysis results showing overall benefits for all new residential premises over the whole life of the sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Case	Present Value total benefits (£m)			Total lives saved			Total injuries prevented		
Baseline	£48.8m	±	£2.3m	35.5	±	3.8	799	±	5
1a	£41.6m	±	£1.8m	35.5	±	3.8	799	±	5
1b	£56.1m	±	£2.9m	35.5	±	3.8	799	±	5
2a	£58.7m	±	£3m	35.5	±	3.8	799	±	5
2b	£75.7m	±	£4.6m	35.5	±	3.8	799	±	5
3	£48.8m	±	£2.3m	35.5	±	3.8	799	±	5
4	£48.8m	±	£2.3m	35.5	±	3.8	799	±	5
5	£46.2m	±	£2.3m	35.1	±	3.8	703	±	5
6a	£48.8m	±	£2.3m	35.5	±	3.8	799	±	5
6b	£33.9m	±	£1.6m	24.6	±	2.7	554	±	3
7	£48.8m	±	£2.3m	35.5	±	3.8	799	±	5

Note. Future sums are/have been discounted to 2010 prices. The uncertainties in the table represent ± 1 standard deviation.

Table 13 – Sensitivity analysis results showing predicted Present Value cost per statistical life saved, and overall Net Present Value for all new residential premises over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Case	Overall Net Present Value (£m)			PV cost per statistical life saved (£m)		
Baseline	-£190.5m	±	£8.8m	£6.7m	±	£0.8m
1a	-£197.7m	±	£8.7m	£6.7m	±	£0.8m
1b	-£183.2m	±	£9m	£6.7m	±	£0.8m
2a	-£180.6m	±	£9m	£6.7m	±	£0.8m
2b	-£163.6m	±	£9.6m	£6.7m	±	£0.8m
3	-£166.4m	±	£7.2m	£6.1m	±	£0.7m
4	-£198.7m	±	£13.9m	£7m	±	£0.8m
5	-£217.6m	±	£9.8m	£7.5m	±	£0.9m
6a	-£95.5m	±	£8.7m	£4.1m	±	£0.5m
6b	-£110.4m	±	£8.5m	£5.9m	±	£0.7m
7	-£167.6m	±	£7.4m	£6.1m	±	£0.7m

Note. Future sums are/have been discounted to 2010 prices. The uncertainties in the table represent ± 1 standard deviation.

Tables 14 to 16 show the effect on the baseline results for the different sensitivity cases for b) the subset of residential properties where sprinklers are predicted to be cost-effective or marginally cost-effective.

Table 14 – Sensitivity analysis results showing overall predicted costs for subset of residential premises showing cost effectiveness or marginal cost effectiveness over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Case	Present Value total costs (£m)			Present Value one-off costs (£m)			Present Value annual costs (£m)		
Baseline	**-£14.2m**	**±**	**£11m**	**-£12.6m**	**±**	**£9.8m**	**-£1.6m**	**±**	**£1.3m**
1a	-£14.2m	±	£11m	-£12.6m	±	£9.8m	-£1.6m	±	£1.3m
1b	-£14.2m	±	£11m	-£12.6m	±	£9.8m	-£1.6m	±	£1.3m
2a	-£14.2m	±	£11m	-£12.6m	±	£9.8m	-£1.6m	±	£1.3m
2b	-£14.2m	±	£11m	-£12.6m	±	£9.8m	-£1.6m	±	£1.3m
3	-£14.2m	±	£11m	-£12.6m	±	£9.8m	-£1.6m	±	£1.3m
4	-£14.2m	±	£11m	-£12.6m	±	£9.8m	-£1.6m	±	£1.3m
5	-£8.5m	±	£5.6m	-£7.6m	±	£4.9m	-£1m	±	£0.7m
6a	-£12.6m	±	£9.8m	-£12.6m	±	£9.8m	-£0m	±	£0m
6b	-£12.6m	±	£9.8m	-£12.6m	±	£9.8m	-£0m	±	£0m
7	-£12m	±	£9.3m	-£10.4m	±	£8.1m	-£1.6m	±	£1.3m

Note. Future sums are/have been discounted to 2010 prices. The uncertainties in the table represent ± 1 standard deviation.

Table 15 – Sensitivity analysis results showing overall benefits for subset of residential premises showing cost effectiveness or marginal cost effectiveness over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Case	Present Value total benefits (£m)			Total lives saved			Total injuries prevented		
Baseline	£18.1m	±	£12.9m	8.6	±	7.4	330	±	298
1a	£16m	±	£11.2m	8.6	±	7.4	330	±	298
1b	£20.1m	±	£14.6m	8.6	±	7.4	330	±	298
2a	£22.1m	±	£16.5m	8.6	±	7.4	330	±	298
2b	£29.1m	±	£22.7m	8.6	±	7.4	330	±	298
3	£18.1m	±	£12.9m	8.6	±	7.4	330	±	298
4	£18.1m	±	£12.9m	8.6	±	7.4	330	±	298
5	£11.5m	±	£6.8m	4.8	±	3.6	174	±	143
6a	£18.1m	±	£12.9m	8.6	±	7.4	330	±	298
6b	£12.5m	±	£8.9m	6.0	±	5.1	229	±	207
7	£18.1m	±	£12.9m	8.6	±	7.4	330	±	298

Note. Future sums are/have been discounted to 2010 prices. The uncertainties in the table represent ± 1 standard deviation.

Table 16 – Sensitivity analysis results showing predicted Present Value cost per statistical life saved, and overall Net Present Value for subset of residential premises showing cost effectiveness or marginal cost effectiveness over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Case	Overall Net Present Value (£m)			PV cost per statistical life saved (£m)		
Baseline	£3.8m	±	£2.2m	£1.6m	±	£1.9m
1a	£1.8m	±	£1.5m	£1.6m	±	£1.9m
1b	£5.9m	±	£3.7m	£1.6m	±	£1.9m
2a	£7.9m	±	£5.5m	£1.6m	±	£1.9m
2b	£14.9m	±	£11.8m	£1.6m	±	£1.9m
3	£3.8m	±	£2.2m	£1.6m	±	£1.9m
4	£3.8m	±	£2.2m	£1.6m	±	£1.9m
5	£3m	±	£1.7m	£1.8m	±	£1.8m
6a	£5.5m	±	£3.3m	£1.5m	±	£1.7m
6b	-£0.1m	±	£1.3m	£2.1m	±	£2.4m
7	£6m	±	£3.8m	£1.4m	±	£1.6m

Note. Future sums are/have been discounted to 2010 prices. The uncertainties in the table represent ± 1 standard deviation.

6 Conclusions

Table 17 presents the predicted costs and benefits arising from sprinkler installation in Wales for each type of residential premises over the whole life of the sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales. The table shows the overall Net Present Value of the policy, Present Values of costs and benefits and the net cost per life saved. For the purposes of this report, sprinklers are cost effective if the Net Present Value is positive (and is greater than the uncertainty (see Results section for further information)).

All monetary data are expressed in 2010 prices. 2010 is the last year for which the Gross Value Added (GVA)/Retail Price Index figures are available. Present Values and Net Present Values (see glossary of terms) were discounted on the basis that 2010 is year zero. Costs and benefits were calculated for the whole life of the sprinkler systems (40 to 50 years), for all new residential premises constructed during a ten year window (2013 to 2022).

Table 17 - Predicted overall costs and benefits over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Accommodation Type	Present Value total costs (£m)	Present Value total benefits (£m)	Total lives saved	Total injuries prevented	Present Value cost per statistical life saved (£m)	Overall Net Present Value (£m)
House	-£216.7m	£27.9m	24.6	427	£8.8m	-£188.7m
Flat	-£10.8m	£12.4m	7.3	297	£1.5m	£1.6m
Traditional HMO	-£0.1m	£0.1m	0.1	2	£1.1m	£0m
Shared house	-£4.4m	£1.9m	1.7	28	£2.6m	-£2.4m
Hostel	-£2m	£0.3m	0.2	2	£8.2m	-£1.7m
Care home	-£1.9m	£2.3m	0.6	10	£3m	£0.5m
Sheltered house	-£2m	£0.6m	0.3	12	£7.2m	-£1.4m
Sheltered flat	-£0.5m	£0.8m	0.4	16	£1.3m	£0.3m
Hall/Dormitory	-£0.9m	£2.3m	0.2	4	£5.5m	£1.5m
Total for subset where cost effective or marginally cost effective	**-£14.2m**	**£18.1m**	**8.6**	**330**	**£1.6m**	**£3.8m**
Total for all accommodation types	**-£239.3m**	**£48.8m**	**35.5**	**799**	**£6.7m**	**-£190.5m**

Note. Values are based on 'central' estimates of costs.

All values in the Table are subject to uncertainty, due to uncertainties in the values for the input data. As an example the Net Present Value for the total for all accommodation types (-£190.5m) can be expressed as -£190.5m ± £8.8m. The value of £190.5 is the 'central estimate' and the value of £8.8m is the uncertainty (1 standard deviation). Therefore, in this case, the uncertainty is about 5% of the value.

This cost benefit analysis has focussed on new build premises rather than conversions. The cost of sprinkler installation may be higher in building conversions than in new build. The benefits of sprinkler protection are expected to be similar in both new build and converted properties.

It should be noted that benefits resulting from compensatory features and trade-offs were not included in the cost benefit analysis, but they might be expected to result in some cost savings if included at the design stage on a case by case basis.

Based on the input data, assumptions and main analysis described in this report and summarised in Table 17 above, the conclusions of this cost benefit analysis are:

- Fitting sprinklers in all new residential premises in Wales is not cost effective.
- Sprinklers are cost effective in new care homes and halls/dormitories. This is mainly due to the reduction in financial losses from damage to the building, its contents and business interruption.
- Sprinklers may also be marginally cost effective, (i.e. not statistically significant) in new blocks of flats, blocks of sheltered flats (not including sheltered houses) and "traditional" HMOs (assuming six accommodation units per building; not including shared houses or hostels).

  The key reason for this is that costs can be shared over a number of accommodation units.
- Sprinklers are not cost effective in new single occupancy houses, shared houses, hostels and sheltered houses.

Tables 18 and 19 summarise the sensitivity analysis results for each sensitivity case for a) all new residential properties and b) the subset of residential properties where sprinklers are predicted to be cost-effective or marginally cost-effective, respectively. This subset comprised new blocks of flats, new blocks of sheltered flats, new "traditional" HMOs, new care homes, new halls of residences and new dormitories.

Table 18 - Sensitivity analysis results showing overall costs and benefits for all new residential premises over the whole life of the residential sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Case	Present Value total costs (£m)	Present Value total benefits (£m)	Total lives saved	Total injuries prevented	Present Value cost per statistical life saved (£m)	Overall Net Present Value (£m)
Baseline	-£239.3m	£48.8m	35.5	799	£6.7m	-£190.5m
1a	-£239.3m	£41.6m	35.5	799	£6.7m	-£197.7m
1b	-£239.3m	£56.1m	35.5	799	£6.7m	-£183.2m
2a	-£239.3m	£58.7m	35.5	799	£6.7m	-£180.6m
2b	-£239.3m	£75.7m	35.5	799	£6.7m	-£163.6m
3	-£215.3m	£48.8m	35.5	799	£6.1m	-£166.4m
4	-£247.5m	£48.8m	35.5	799	£7m	-£198.7m
5	-£263.8m	£46.2m	35.1	703	£7.5m	-£217.6m
6a	-£144.3m	£48.8m	35.5	799	£4.1m	-£95.5m
6b	-£144.3m	£33.9m	24.6	554	£5.9m	-£110.4m
7	-£216.4m	£48.8m	35.5	799	£6.1m	-£167.6m

Note. Values are based on 'central' estimates of costs.

Table 19 - Sensitivity analysis results showing overall costs and benefits for subset of residential premises showing cost effectiveness or marginal cost effectiveness over the whole life of the residential; sprinkler systems installed in buildings constructed from 2013 to 2022 in Wales (Present Values, 2010 base year)

Case	Present Value total costs (£m)	Present Value total benefits (£m)	Total lives saved	Total injuries prevented	Present Value cost per statistical life saved (£m)	Overall Net Present Value (£m)
Baseline	-£14.2m	£18.1m	8.6	330	£1.6m	£3.8m
1a	-£14.2m	£16m	8.6	330	£1.6m	£1.8m
1b	-£14.2m	£20.1m	8.6	330	£1.6m	£5.9m
2a	-£14.2m	£22.1m	8.6	330	£1.6m	£7.9m
2b	-£14.2m	£29.1m	8.6	330	£1.6m	£14.9m
3	-£14.2m	£18.1m	8.6	330	£1.6m	£3.8m
4	-£14.2m	£18.1m	8.6	330	£1.6m	£3.8m
5	-£8.5m	£11.5m	4.8	174	£1.8m	£3m
6a	-£12.6m	£18.1m	8.6	330	£1.5m	£5.5m
6b	-£12.6m	£12.5m	6.0	229	£2.1m	-£0.1m
7	-£12m	£18.1m	8.6	330	£1.4m	£6m

Note. Values are based on 'central' estimates of costs.

The sensitivity analysis results confirmed the conclusions of the main analysis except for one case, case 6b for the subset of residential premises where sprinklers are predicted to be cost-effective or marginally cost-effective. This is the case where the sprinkler systems are not maintained with a consequential 30% reduction in reliability which gives a small overall Net Present Value and a large uncertainty.

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Appendix A - Cost benefit analysis methodology

A.1 Outline cost benefit calculation

This appendix provides an outline of the cost benefit calculation, in order to introduce the input variables and the relationships used to calculate the cost effectiveness. All costs and benefits need to be expressed in common units, and for this analysis these are the Present Values in 2010 prices per accommodation unit.

The cost benefit calculation involves a comparison between the costs on the one hand, and the monetised benefits on the other. These costs and benefits may occur throughout the whole life of the asset (the sprinkler system).

The Net Present Value (NPV) is the difference between the Present Value of all the benefits, and the Present Value of all the costs. A positive Net Present Value indicates that the benefits outweigh the costs, and the system is therefore cost-beneficial. Conversely, a negative NPV indicates that the system is not cost-beneficial.

Most of the input values will have a greater or lesser degree of uncertainty associated with them. This uncertainty propagates through the calculation, leading to uncertainty in the output values. Whether or not two values are "different" depends on the magnitude of the difference, and the magnitude of the uncertainties involved. As a general rule, if the difference between two values is greater than the uncertainty, the difference is becoming statistically significant. This is particularly relevant when deciding if sprinklers are cost beneficial, i.e. is the NPV significantly greater than zero?

A.2 One-off costs

The one-off costs are the installation cost for the sprinkler system (including labour, materials, etc) and the cost of providing the water supply. In the baseline calculations for this report it has been assumed that the water supply involves the provision of a pump and tank (with costs for labour, materials etc as before). In addition there will be a connection charge applied by the Welsh water companies (which covers design approval, inspection, provision of additional pipework and metering in some cases).

Let

£S = System installation cost (one-off, per accommodation unit)

£W = Water supply cost (one-off, per accommodation unit)

$£C_0$ = Total one-off cost (per accommodation unit)

then

$$£C_0 = £S + £W \qquad \text{[Equation A1]}$$

These quantities are all expressed in 2010 prices. However, because the cost benefit analysis is being applied to residential accommodation units that are predicted to be constructed in a ten year window from 2013-2022 inclusive, it is necessary to apply a discount factor for these costs since they will be incurred in the future, relative to 2010.

Let

y_0 = the date of construction (and also the installation of the sprinkler system, water supply etc.)

r_1 = discount rate for the first 30 years (up to 2040) = 3.5%

£PV_0 = the Present Value in 2010 prices of the one off costs incurred in year y_0

then

$$\pounds PV_0 = \frac{-\pounds C_0}{(1+r_1)^{y_0-2010}} \qquad \text{[Equation A2]}$$

Note. A negative value for £PV_0 signifies a cost.

A.3 Annual costs

The annual costs cover inspection and maintenance of the sprinkler system. These will be accrued over ever year of the lifetime of the sprinkler system.

As these costs will all be incurred in the future, relative to 2010, they will all need to be discounted. The factor for each individual cost depends on the number of years into the future, and the discount rate appropriate to that number of years.

Let

£M = Maintenance (annual, per accommodation unit)

y_0 = the date of construction

y_s = the date when the sprinkler system reaches the end of its lifetime

r_1 = discount rate for the first 30 years (up to 2040), = 3.5%

r_2 = discount rate for sums after the first 30 years (i.e. after 2040), = 3.0%

£PV_a = the Present Value in 2010 prices of the annual costs incurred in year y_0 to y_s inclusive

then

$$\pounds PV_a = \frac{-\pounds M}{(1+r_1)^{y_0-2010}}\left[\sum_{n=1}^{2040-y_0}\left(\frac{1}{(1+r_1)^n}\right) + \frac{1}{(1+r_1)^{2040-y_0}}\sum_{n=1}^{y_s-2040}\left(\frac{1}{(1+r_2)^n}\right)\right] \qquad \text{[Equation A3]}$$

Note. A negative value for £PV_a signifies a cost.

A.4 Annual benefits

The annual benefits arise from the reduction in the consequences of fires, in terms of lives saved, injuries prevented, property damage and emission of greenhouse gases reduced. These will be accrued over ever year of the lifetime of the sprinkler system. Each benefit needs to be expressed in monetary terms

As these costs will all be incurred in the future, relative to 2010, they will all need to be discounted. The factor for each individual cost depends on the number of years into the future, and the discount rate appropriate to that number of years.

Let £B = Benefit (annual, per accommodation unit)

where the following subscripts refer to different components of the overall benefit:

d = deaths

i = injuries

p = property damage reduction

g = greenhouse gas reduction

tot = total

and

y_0 = the date of construction

y_s = the date when the sprinkler system reaches the end of its lifetime

r_1 = discount rate for the first 30 years (up to 2040) = 3.5%

r_2 = discount rate for sums after the first 30 years (i.e. after 2040) = 3.0%

$£PV_b$ = the Present Value in 2010 prices of the annual benefits incurred in year y_0 to y_s inclusive

then

$$£B_{tot} = £B_d + £B_i + £B_p + £B_g \quad \text{[Equation A4]}$$

and

$$£PV_b = \frac{+£B_{tot}}{(1+r_1)^{y_0-2010}}\left[\sum_{n=1}^{2040-y_0}\left(\frac{1}{(1+r_1)^n}\right) + \frac{1}{(1+r_1)^{2040-y_0}}\sum_{n=1}^{y_s-2040}\left(\frac{1}{(1+r_2)^n}\right)\right] \quad \text{[Equation A5]}$$

Note. A positive value for $£PV_b$ signifies a benefit.

A.5 Net Present Value

The Net Present Value is the sum of the Present Value for one-off initial costs (for the sprinkler system and the water supply and connection charges), Present Value for annual costs (such as maintenance) and Present Value for benefits (lives saved, injuries and property damage and greenhouse gas emissions prevented). The Present Value for costs will by definition be negative, and for benefits will be positive.

With

£NPV_{y0} = Net Present Value, in 2010 prices, of a system installed in year y_0

£PV_0 = the Present Value in 2010 prices of the one off costs incurred in year y_0

£PV_a = the Present Value in 2010 prices of the annual costs incurred in year y_0 to y_s inclusive

£PV_b = the Present Value in 2010 prices of the annual benefits incurred in year y_0 to y_s inclusive

then

$$\pounds NPV_{y_0} = \pounds PV_0 + \pounds PV_a + \pounds PV_b$$ [Equation A6]

Note that the first two terms on the right hand side are costs and hence will be negative.

Also note that because the sprinkler lifetime (y_s-y_0) is an uncertain quantity (assumed to have a uniform distribution U(40,50)), it is necessary to calculate an average NPV to take account of this. For each year y_0 of new building, we use Simpson's Rule for integration to calculate

$$\overline{\pounds NPV_{y_0}} = \frac{1}{20}\left[\pounds NPV_{y_s-y_0=40} + 2\pounds NPV_{y_s-y_0=41} + 2\pounds NPV_{y_s-y_0=42} + \cdots + 2\pounds NPV_{y_s-y_0=49} + \pounds NPV_{y_s-y_0=50}\right]$$

[Equation A7]

All of the PV components of the NPV are functions of y_0 and y_s, except for the PV of one-off costs which only depends on y_0.

Similarly, the uncertainty in $\overline{\pounds NPV_{y_0}}$ that arises as a result of the uncertain sprinkler lifetime is given by the standard deviation of the NPVs for different lifetimes, with NPVs for lifetimes 41 to 49 years given twice the weighting of NPVs for lifetimes of 40 or 50 years.

A.6 Costs and benefits for Wales as a whole

The Net Present Value for a sprinkler system in a residential accommodation unit depends on the year of construction. A separate calculation is required for each year y_0 of new building. The NPV for the whole of Wales is given by

$$\overline{\pounds NPV_{Wales}} = \sum_{y_0=2013}^{2022} N_b(y_0) \times \overline{\pounds NPV_{y_0}}$$ [Equation A8]

where $N_b(y_0)$ is the number of new buildings constructed in the year y_0. Strictly speaking, there should be a further level of summation, over all different residential building types. (The NPV is type-dependent, since the costs and benefits depend on the building type). The results of the calculations have been presented by building type, assuming certain rates of construction in the years 2013-2022, and also aggregated for all building types.

A.7 Evaluation of the benefits of residential sprinklers

The annual benefits have been introduced in section A.3. They all arise as a result of reducing the risk from fire should it occur (the likelihood of fires is not affected by sprinklers, only the consequences).

Let

R = Risk (annual, per accommodation unit)

ε = Effectiveness of sprinklers in reducing risk (assuming 100% reliability)

r = Sprinkler reliability (i.e. activate if fire large enough)

£V = Value of protection (e.g. each death prevented)

£B = Benefit (annual, per accommodation unit)

where the following subscripts refer to different components of the overall benefit:

d = deaths

i = injuries

p = property damage reduction

g = greenhouse gas reduction

The annual values of reducing the risks per accommodation unit are

$$\pounds B_d = \pounds V_d . R_d . r . e_d$$ [Equation A9]

$$\pounds B_i = \pounds V_i . R_i . r . e_i$$ [Equation A10]

$$\pounds B_p = \pounds V_p . R_p . r . e_p$$ [Equation A11]

$$\pounds B_g = \pounds V_g . R_g . r . e_g$$ [Equation A12]

The annual risks are determined by dividing, for example, the annual numbers of deaths in buildings of a particular type, by the number of buildings of that type. The effectiveness of sprinklers in reducing the risk is a function of the fire area at the time sprinklers are expected to operate (see Appendix C), and also include an explicit factor for the reliability of sprinklers to operate when expected.

A.8 Estimation of fire risks to life safety

The fire risks used in the cost benefit calculation are expressed in terms of:

- The number of fires per accommodation unit per year
- The number of fire-related deaths per accommodation unit per year
- The number of fire-related injuries per accommodation unit per year.

In principle, this is a simple calculation, taking the numbers of fires, etc from the fire statistics, and the number of accommodation units from housing statistics. However, due to small sample sizes in some instances, there may be cases where there may be no deaths, for example. In order to estimate the risks and their uncertainties in such cases, a method based on Bayesian Inference is employed.

The theory of the method is as follows. Suppose that n Bernoulli trials are performed, achieving r results of one type (do not confuse the parameter r in this section with the sprinkler reliability), and n-r results of the other. It is desired to estimate the probability, p, of achieving a result of the first type in any given trial. Before performing any trials, there is no information on p, so it can take any value between 0 and 1, with all values equally likely, i.e. the prior distribution is Uniform, $p_{prior} \sim U(0,1)$. Following the observation of r results in n trials, it can be shown that the posterior distribution of the probability p is a Beta distribution, $p_{posterior} \sim Be(m,s)$, where is m the mean and s the standard deviation:

$$\mu = \frac{r+1}{n+2}$$ [Equation A13]

$$\sigma = \left(\frac{(r+1).(n-r+1)}{(n+2).(n+2).(n+3)}\right)^{1/2}$$ [Equation A14]

Note that when of r and n are reasonably large (>>1), the values of m and s asymptotically tend to those expected from a Binomial distribution.

In order to apply the method to estimate:

- the number of fires per accommodation unit per year, set r to the number of fires observed over a period of y years, and n to the number of accommodation units multiplied by the number of years, and use Equations A13 and A14 to calculate the mean and standard deviation;
- the number of fire-related deaths per accommodation unit per year, set r to the number of fatal fires and n to the number of fires, both observed over a period of y years. Then multiply the number of fatal fires per fire by the average number of fatalities per fatal fire, and the number of fires per accommodation unit per year as calculated in the first bullet point above;
- the number of fire-related injuries per accommodation unit per year, set r to the number of non-fatal casualty fires and n to the number of fires, both observed over a period of y years. Then multiply the number of non-fatal casualty fires per fire by the average number of injuries per non-fatal casualty fire, and the number of fires per accommodation unit per year as calculated in the first bullet point above.

A.9 Summary of the input parameters used in the cost benefit calculation

The input parameters are summarised in Table A1.

Table A1 - Input factors for cost benefit analysis

Symbol	Parameter	Unit	Discussion
£S	Sprinkler system installation cost	£ per accommodation unit	See sections 3.2.4 and 4.5
£W	Water supply cost	£ per accommodation unit	See sections 3.2.5 and 4.6
£M	Sprinkler system annual maintenance cost	£ per accommodation unit per year	See sections 3.2.6 and 4.7
y_s-y_0	Sprinkler system average lifetime	Years	See section 3.2.2
r	Sprinkler reliability	%	See section 3.2.1
R_d	Risk of death	Deaths per accommodation unit per year	See section 3.2.10
ε_d	Sprinkler effectiveness at reducing deaths	%	See sections 3.2.3 and 4.4
£V_d	Value of life saved	£	See section 4.1
R_i	Risk of injury	Injuries per accommodation unit per year	See sections 3.2.10
ε_i	Sprinkler effectiveness at reducing injuries	%	See sections 3.2.3 and 4.4
£V_i	Value of injury prevented	£	See sections 4.2 and B.2
R_p	Risk of fire	Fires per accommodation unit per year	See section 3.2.10
ε_p	Sprinkler effectiveness at reducing property damage	%	See sections 3.2.3 and 4.4
£V_p	Value of property damage per fire	£	See sections 4.3 and B.3
R_g	Risk of greenhouse gas emission	kg CO_2 per accommodation unit per year	See Appendix F
ε_g	Sprinkler effectiveness at reducing greenhouse gases	%	Since greenhouse gas emissions and property damage are both assumed to be directly

			proportional to the area of fire damage, $\varepsilon_g = \varepsilon_p$
$£V_g$	Value of greenhouse gas emission prevented	£	Not quantified (taken as £0, since overall benefit will be tiny compared to other benefits)
r_1, r_2, r_3	Rates for discounting future values	%	See sections 3.1 and B.4

Appendix B – Further details and additional calculations for some of the input data for the cost benefit analysis

This Appendix contains further details and additional calculations for some of the input data for the cost benefit analysis.

B.1 Value of each death prevented

The latest Department for Transport figure, for the "Willingness to Pay" value of a statistical life, was £1,585,000 in 2009[41]. Note that, although originally used in the context of road safety, this value is now widely used by the UK Government in other contexts[42]. The value needs to be converted to a value in 2010, by multiplying by the increase in GVA from 2009 to 2010, a factor of 1.02. Welsh Government has advised the use of the GVA value for the UK, rather than Wales, since the value is a UK-wide figure. Hence the value in 2010 is £1,620,000.

B.2 Value of each injury prevented

Similarly, the Department for Transport figures for 2009 were £178,000 for a serious injury and £13,700 for a minor injury[43]. These figures also need to be uprated to 2010 values, as per deaths, to give £182,000 for a serious injury and £14,000 for a minor injury.

Since 2009, the UK fire statistics have recorded the apparent severity of injuries sustained during fire incidents. For all incidents in Wales, the proportions were: 8% serious, 37% minor (although the victim went to hospital), 34% treated by first aid at scene, and 21% where a precautionary check was advised. The latter two categories were assumed to be negligible in terms of cost and hence the weighted value for a fire injury is £19,960.

Note. This weighted value is lower than was previously assumed. Before 2009 when fire statistics were not available, it was assumed[44] that all injuries involving burns were serious, and all cases of physical injury or shock were minor. 25% of all smoke inhalation injuries were considered to be serious, with the remainder minor. Injuries recorded as a precautionary check were assumed to be negligible. An update[45] considered

[41] Department for Transport 2011 Analysis Guidance (TAG), the Accidents Sub-Objective, TAG Unit 3.4.1, April 2011. Available from http://www.dft.gov.uk/webtag/documents/expert/unit3.4.1.php#02

[42] HM Treasury, The green book: appraisal and evaluation in central government, ISBN 0115601074, January 2003.

[43] Department for Transport, Transport Analysis Guidance (TAG), the Accidents Sub-Objective, TAG Unit 3.4.1, April 2011. Available from http://www.dft.gov.uk/webtag/documents/expert/unit3.4.1.php#02.

[44] Office of the Deputy Prime Minister, Economic cost of fire: estimates for 2004, 2006.

[45] Entec, Economic cost of fire: estimates for 2006.

100% of all smoke inhalations to be serious (with the classification of other types injury unchanged). The reason behind this was not discussed in the update.

B.3 Value of property damage in a fire

In the Economic Cost of Fire 2004, the average value of property damage in domestic accommodation units was £7,300, and in commercial buildings the average value was £27,700. In order to convert to 2010 prices, these values should be multiplied by a factor to account for the rise in RPI (not GDP). The UK RPI time series data are recorded monthly. In June 2004, the RPI was 186.8; by October 2010, it was 225.8. Hence, the multiplication factor is 1.21, and the average value in 2010 of property damage in domestic accommodation units was £8,800. For care homes, which are larger than domestic accommodation units and would also incur losses due to business interruption, the average value was assumed to be that of commercial buildings, i.e. £33,700 in 2010.

Note that the figures from 2004 were used as the starting point, rather than more up-to-date values. Although updates to the Economic Cost of Fire were published for 2006 and 2008, neither contained the necessary level of information to determine the costs of fire damage.

B.4 Discount rate for discounting future values

The discount rate recommended in the Treasury Green Book[46] has been used. This is 3.5% for terms less than 30 years duration and a rate of 3% for terms longer than 30 years. As the Present Value for all prices has been discounted back to 2010, this means that the discount rate is 3.5% for any costs incurred or benefits received up to 2040, and 3% if after 2040 (see Net Present Value calculation, see Appendix A).

[46] HM Treasury, The green book: appraisal and evaluation in central government, ISBN 0115601074, January 2003.

Appendix C - Estimate of sprinkler effectiveness

C.1 Method of estimating sprinkler effectiveness

Previous research[47] established that it was not possible to determine the effectiveness of residential sprinklers directly from the UK fire statistics, due to paucity of data. An indirect method was proposed, based on a correlation between the risk of death, injury etc. per fire, and the size of the fire (the area damaged). This indirect method is used here, with a refined estimate of the fire size at the time of sprinkler activation.

The principle behind this indirect method of estimating the effectiveness is to assume that a correlation between ultimate fire size and risk of death etc would apply equally to sprinklered fires as well as unsprinklered. Following the technique of Ramachandran[48,49,50], if the fire area can be limited to a certain value, then the risks of death and injury can be reduced.

Figure C1 shows the risk of death is increasing with fire area. However, assuming that sprinklers control the fire, the area does not exceed some value A_{max} (shown by the vertical lines). The consequence of this is that fires which would have grown larger without sprinklers, now do not grow larger, and thus have the same risk R_{max} (shown by the horizontal lines, and different coloured shading for the top of each bar). In the right-hand diagram, A_{max} is smaller than for the left-hand diagram, and so R_{max} is smaller.

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[47] Williams, C, Fraser-Mitchell, J, Harrison, R and Campbell, S, The effectiveness of residential sprinklers, BRE report 204505 for the Office of the Deputy Prime Minister, February 2004.

[48] Ramachandran, G, Early detection of fire and life risk, Fire Engineers Journal, pp 33-37, December 1993.

[49] Melinek, S J, Effectiveness of sprinklers in reducing fire severity, Fire Safety Journal, 21, pp 299-311, 1993.

[50] Fraser-Mitchell, J, The costs and benefits of residential sprinkler systems, Interflam, Interscience Communications, pp 339-350, 2004.

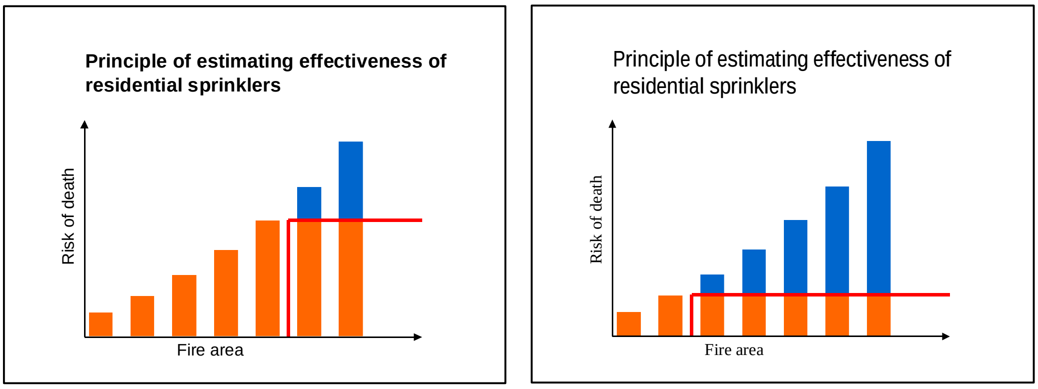

Figure C1 Principle behind the indirect estimate of sprinkler effectiveness

C.2 Risk as a function of ultimate fire size

The fire size is defined for this purpose as the horizontal area damaged (m^2) (FDR1 code = AREABURN). In this analysis it has been assumed that there is no difference in the distribution of fire sizes for houses and flats, enabling an improvement in the sample sizes, particularly for the larger fires, and thus make the underlying trends clearer.

Since most fire deaths are due to smoke inhalation, rather than burns, it might be thought that AREATOT (which includes smoke damage) would be a better measure to use than AREABURN which only measures fire damage. However, AREABURN is used because it possible to estimate the fire area when sprinklers operate, whereas this is not feasible in the case of AREATOT. Since larger fires tend to produce more smoke, there is a strong correlation between fire area and risk anyway.

Figure C2 shows the distribution of the numbers of fires for the different size categories. It can be seen that most of the fires only damage a small area.

Note. The figures in this Appendix use data from 1994 to 2002 (when the statistics on fire area were more comprehensive than they are now) in order to illustrate the principle behind the method. The Monte Carlo cost benefit calculation uses the most up-to-date information available, from the relevant building type.

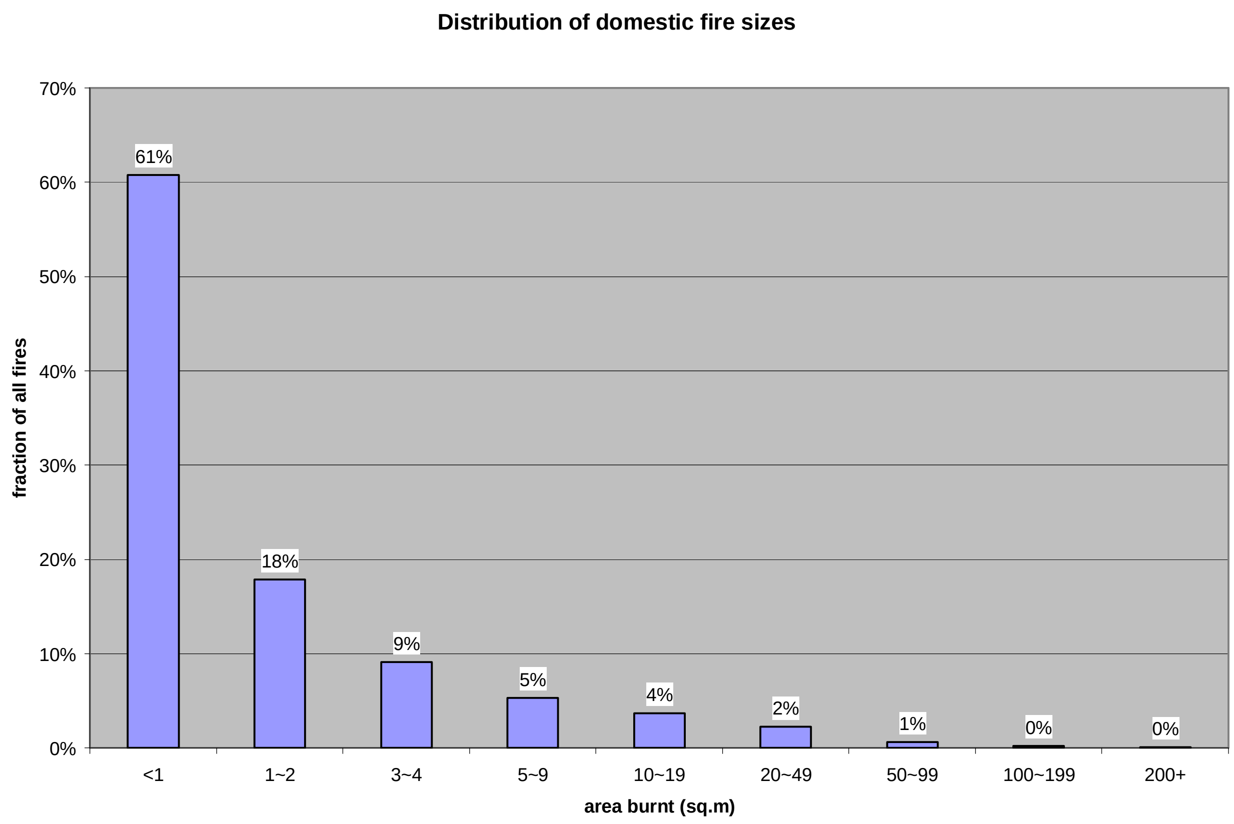

Figure C2 **Actual numbers of UK fires that damage different areas from FDR1 forms (1994 to 2002)**

Data for the risk of death per fire are shown in Figure C3, injuries per fire in Figure C4, and the average area of all damage (AREATOT) in Figure C5. There is a clear trend for the larger fires to have greater numbers of deaths, injuries etc.

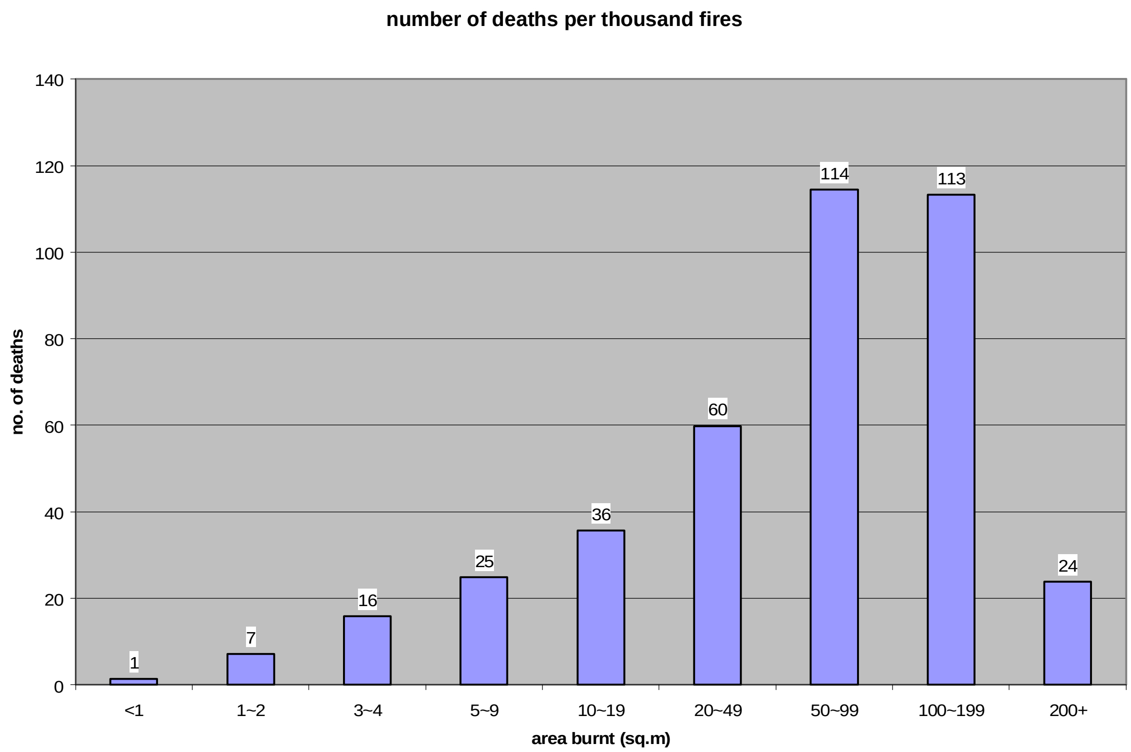

Figure C3 Actual variation in the risk of UK fire deaths, depending on ultimate fire size from FDR1 forms (1994 to 2002)

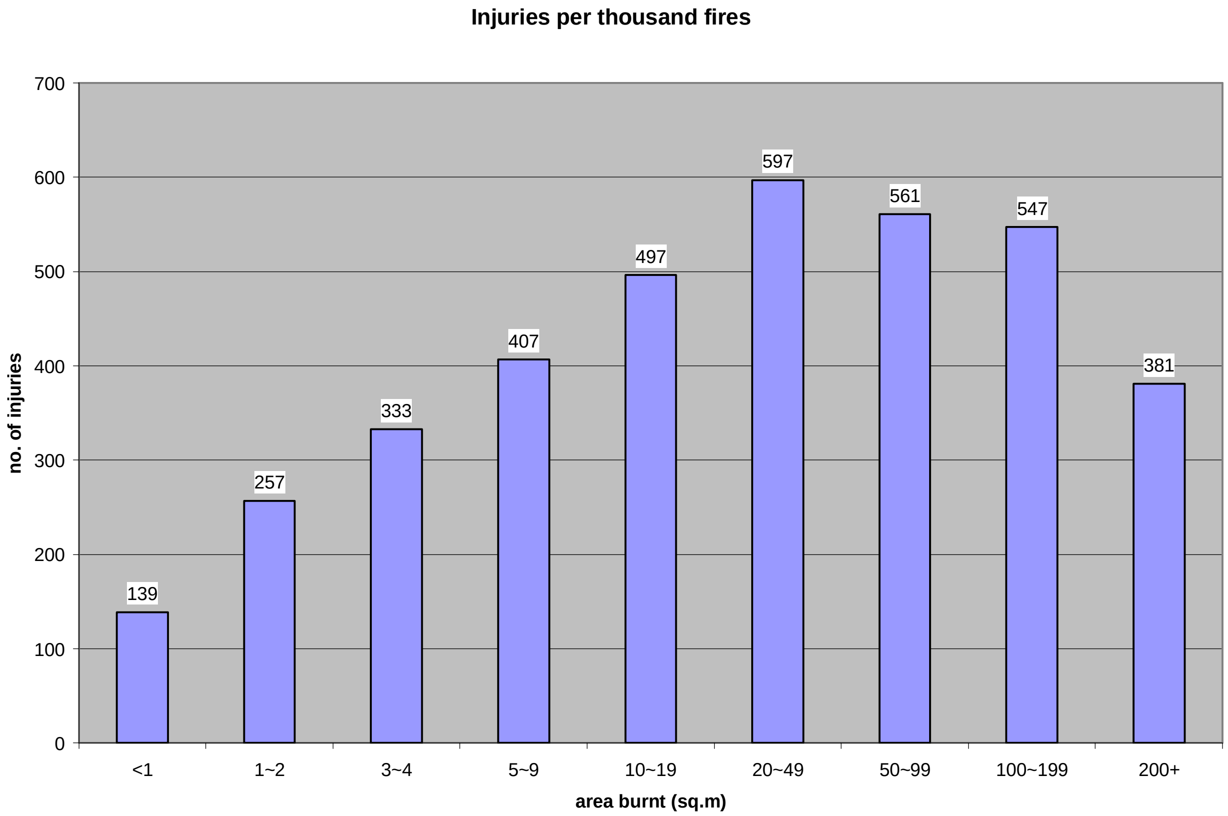

Figure C4 Actual variation in the risk of UK fire injury, depending on ultimate fire size from FDR1 forms (1994 to 2002)

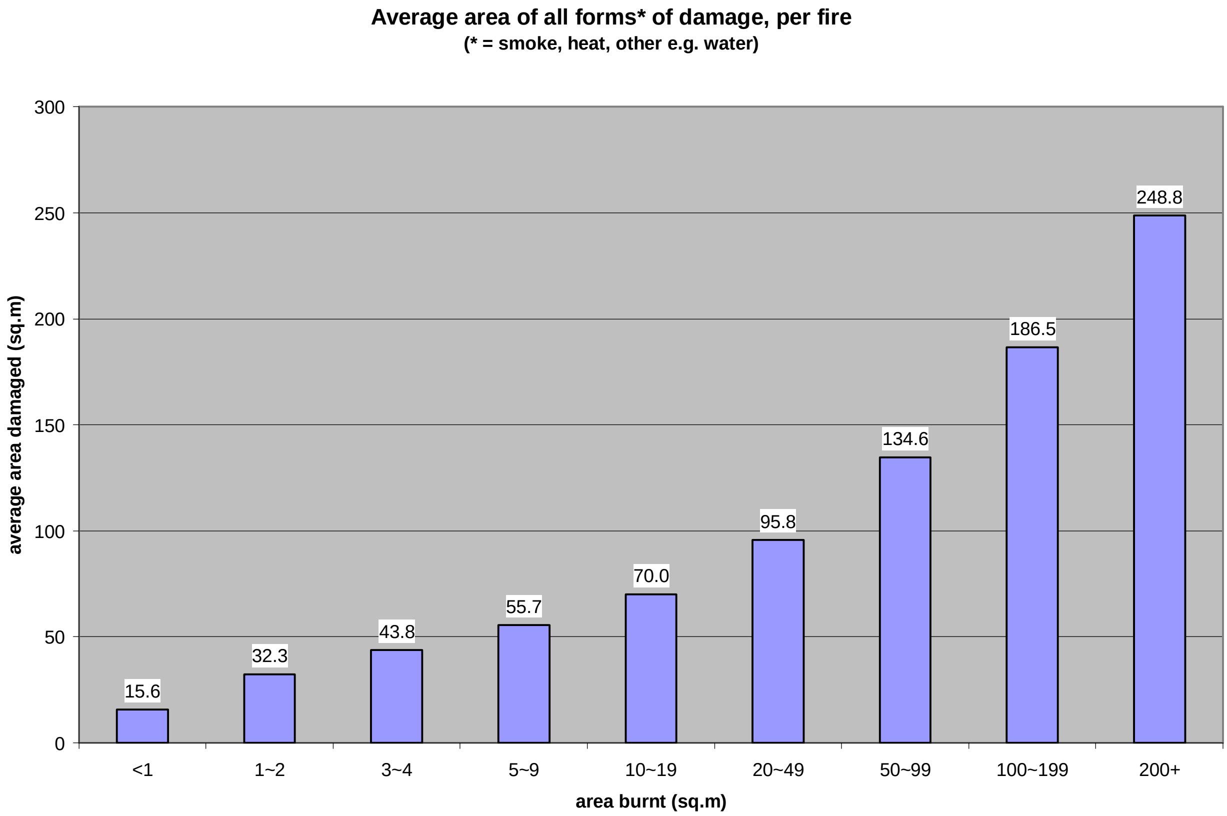

Figure C5 Actual variation in the average area of all damage per UK fire, depending on ultimate fire size from FDR1 forms (1994 to 2002)

C.3 Sprinkler effectiveness as a function of restricted fire size

Sprinkler effectiveness will be defined as the percentage reduction in fire consequences (deaths, injuries, etc). There will be a different effectiveness for each different consequence.

Assume that sprinklers constrain the fire to some size "X" m^2. Fires below this size are unaffected, so the number of deaths caused by fires of size "<X" m^2 is unchanged. However, for fires that would have grown larger, the "X" m^2 are now assumed to have the same risk as a fire of X m^2, and thus the number of deaths prevented will be the sum of {no. of fires that would have grown to "Y" (>"X") m^2, multiplied by the difference in risk between fires of "Y" m^2 and "X" m^2} for all fire sizes greater than "X" m^2. The number of injuries prevented, and the reduction in the average of the total area damaged, can be calculated in the same manner. The percentage reductions (i.e. sprinkler effectiveness) are shown in Figure C6.

Without any information to the contrary, it will be assumed that the property loss in unsprinklered fires is divided 50:50 into that due to the area burnt, and that due to the total damage. This then enables the effectiveness of sprinklers in reducing property damage to be estimated. (In the previous research[51] it was assumed, on the basis of USA statistics, that the overall property protection effectiveness might be 50%).

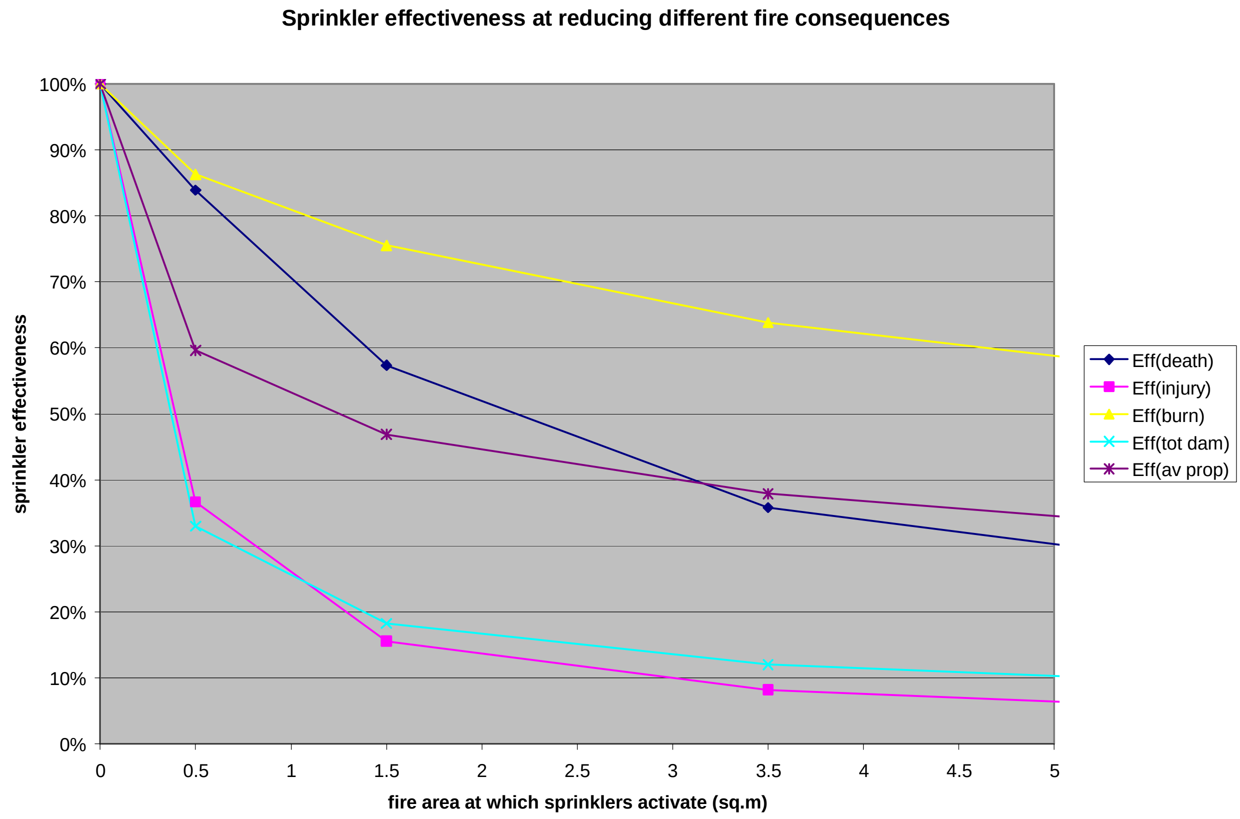

Figure C6 The effectiveness of sprinklers, depending on the fire size at activation

C.4 Fire size at sprinkler activation

If the fire size at sprinkler activation is known, Figure C6 can be interpolated to give the sprinkler effectiveness. Since there are a number of uncertain factors that will affect the fire size at the point when sprinklers would be expected to activate, it will not be possible to specify a precise area; instead, a probability distribution for the area can be derived.

Mowrer's spreadsheet implementation[52] of the DETACT model integrates the following equation for the temperature of the sprinkler head

[51] Williams, C, Fraser-Mitchell, J, Harrison, R and Campbell, S, The effectiveness of residential sprinklers, BRE report 204505 for the Office of the Deputy Prime Minister, February 2004.

$$T_d(t) = T_d(0) + \int_0^t \frac{\sqrt{u_g}}{RTI}\left(T_g - T_d\right).dt$$ [Equation C1]

in order to find the time when the sprinkler activates (i.e. the head temperature T_d equals the activation temperature of the sprinkler). RTI is the response time index of the sprinkler.

It has been assumed that the ceiling jet will be unconfined (i.e. the fire is in a room with a “normal” aspect ratio, rather than a corridor), and therefore:

- the gas temperature is given by

$$T_g(t) = T_g(0) + 16.9\frac{\dot{Q}(t)^{2/3}}{H^{5/3}} \quad \text{for} \quad \frac{R}{H} < 0.2$$ [Equation C2a]

and

$$T_g(t) = T_g(0) + \frac{5.4}{H}.\frac{\dot{Q}(t)^{2/3}}{R^{2/3}} \quad \text{for} \quad \frac{R}{H} > 0.2$$ [Equation C2b]

- the ceiling jet velocity is given by

$$u_g(t) = 0.95\frac{\dot{Q}(t)^{1/3}}{H^{1/3}} \quad \text{for} \quad \frac{R}{H} < 0.2$$ [Equation C3a]

and

$$u_g(t) = 0.2H^{1/2}.\frac{\dot{Q}(t)^{2/3}}{R^{5/6}} \quad \text{for} \quad \frac{R}{H} > 0.2$$ [Equation C3b]

In these equations R is the distance of the sprinkler head from the plume centreline, H is the plume rise height from the surface of the burning item to the ceiling, and the heat release rate is given by a “t-squared” growth:

$$\dot{Q}(t) = at^2$$ [Equation C4]

Assume that the heat release rate per unit area is a constant, i.e.

$$\dot{Q}(t) = kA_f(t)$$ [Equation C5]

where A_f is the area of the fire.

Knowing the time of sprinkler head activation, the heat release rate can be estimated, and hence the fire size at activation. If the input parameters have random values to reflect the degree of uncertainty, then the

[52] Mowrer, F, Spreadsheet templates for fire dynamics calculations, downloaded from Fire Risk Forum, www.fireriskforum.com, 2003.

output value (the fire area at activation) will also be a stochastic variable. The DETACT model has been run in Monte-Carlo mode in order to determine the probability distribution for the fire size at activation.

The random input parameters are listed in Table C1.

Table C1 Values of the stochastic input parameters

Symbol	Meaning	Value	Unit
H	Plume rise height (based on random item height, and a fixed ceiling at 2.4m above the floor)	$= 2.4 - U(0,1)$	m
R	Radial distance of nearest sprinkler head from plume centreline, based on 4m spacing between heads	$= \sqrt{U(0,2)^2 + U(0,2)^2}$	m
T(0)	Ambient temperature (for ceiling jet and sprinkler head at t = 0)	$= 18 + U(0,4)$	^{o}C
α	t-squared growth coefficient	77% slow, = 0.003 20% medium, = 0.012 3% fast, = 0.047	kW.s^{-2}
K	Heat release rate per unit area	$= U(500,1000)$	kW.m^{-2}

The other input parameters were an activation temperature of 68^{o}C, and an RTI of 50 (m.s)$^{0.5}$.

The distribution of the fire area at sprinkler activation is shown in Figure C7.

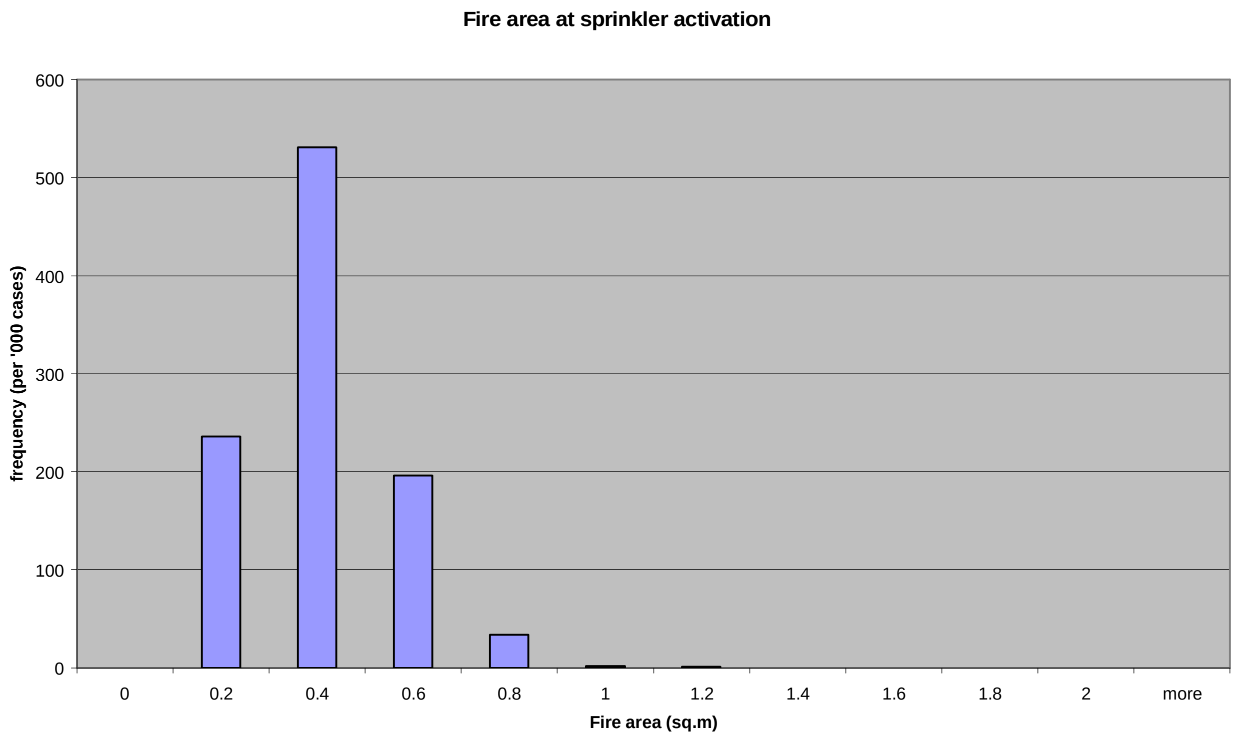

Figure C7 Distribution of the area burnt at the time of pendent type sprinkler activation

Note that the fire area estimated by this method is less than that used in BRE's previous research (an estimate by the Steering Group of that study ~1m^2 [53]]) and the calculations reported in the Interflam paper (values between 0.5 ~ 1m^2)[54]. As a result, the estimate of sprinkler effectiveness will be higher than in the previous research.

The robustness of the DETACT calculation used to estimate the time of sprinkler activation has been investigated by several authors[55,56]. Compared with experiments, the model is found to usually give conservative results (i.e. later predicted activations than reality).

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[53] Williams, C, Fraser-Mitchell, J, Harrison, R and Campbell, S, The effectiveness of residential sprinklers, BRE report 204505 for the Office of the Deputy Prime Minister, February 2004.

[54] Fraser-Mitchell, J, The costs and benefits of residential sprinkler systems, Interflam, Interscience Communications, pp 339-350, 2004.

[55] Madrzykowski, D, Evaluation of sprinkler activation prediction methods, ASIAFLAM'95. International Conference on Fire Science and Engineering, First Proceedings, Interscience Communications Ltd, March 15-16, 1995, Kowloon, Hong Kong, pp 211-218, 1995.

[56] Wade, C, Spearpoint, M J, Bittern, A, Tsai, K, Assessing the sprinkler activation predictive capability of the BRANZFIRE fire model. Fire Technology, 43 (3), pp 175-193, September 2007.

The main source of uncertainty in the area at sprinkler activation is due to the value for the heat release rate per unit area. It was assumed the value for a typical domestic fire would be between 500 and 1000 $kW.m^{-2}$. Note the cost benefit analysis for the Thames Gateway performed by Gros et al used a value of 250 $kW.m^{-2}$ for this parameter. This would triple the fire area at activation relative to the BRE calculation.

The RTI rating of the sprinkler head can also have a significant effect on the speed of response and hence the fire area at activation[57]. For this work it was assumed that the residential sprinkler system would be fully compliant with BS 9251: 2005, and hence the residential sprinkler heads would be 'quick' response and have an effective RTI of 50 $(m.s)^{0.5}$.

C.5 Estimates of sprinkler effectiveness

The mean fire size at sprinkler activation, from the distribution shown in Figure C7, is 0.309 m^2, and the median is 0.290 m^2. The standard deviation is 0.1 m^2.

A further Monte Carlo calculation took a random fire area, sampled from the above probability function of fire size at sprinkler activation. The graphs of sprinkler effectiveness versus fire area were then interpolated to give the values at this particular fire size. The resulting distributions for sprinkler effectiveness have parameter values as given in Table C2.

Table C2 – Results of Monte Carlo calculations of sprinkler effectiveness at reducing risks

Accommodation type	Deaths (%)[1]	Injuries (%)[2]	Damage (%)[3]
House (single occupancy)	90 ± 4	64 ± 11	93 ± 2
House (multiple occupancy)	100 ± 0	67 ± 11	93 ± 2
Flat (all types)	90 ± 4	62 ± 12	88 ± 4
Care home (all types)	63 ± 20	66 ± 14	88 ± 4

Notes:

1. An earlier estimate[58] of 55% ~ 85% for all building types was based on a Steering Committee estimate of 1 m^2 for the fire area at sprinkler activation.
2. An earlier estimate[59] was 15% ~ 45% for all building types, derived on a similar basis to 1.
3. An earlier estimate[60] was 35% ~ 65% for all building types, based on USA statistics.

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[57] Annable, K, Effectiveness of sprinklers in residential premises – an evaluation of concealed and recessed pattern sprinkler products, Section 5: Thermal sensitivity, BRE report 218113 for ODPM, 2006.

[58] Williams, C, Fraser-Mitchell, J, Harrison, R and Campbell, S, The effectiveness of residential sprinklers, BRE report 204505 for the Office of the Deputy Prime Minister, February 2004.

[59] Williams, C, Fraser-Mitchell, J, Harrison, R and Campbell, S, The effectiveness of residential sprinklers, BRE report 204505 for the Office of the Deputy Prime Minister, February 2004.

Appendix D – Cost data from residential sprinkler installers

This study used cost data provided by residential sprinkler installer members of the British Automatic Fire Sprinkler Association (BAFSA) and the Fire Sprinkler Association (FSA).

Tables D1 to D13 show individual installation costs, pump and tank costs, and annual maintenance costs for different building types. These were for one-off cases and therefore do not include any economies of scale for large developments.

Note that the small sample sizes, and the fact that no corrections or weighting have been applied (e.g. to account for the market share of the sprinkler installer members), mean that the distributions may not be representative of the actual costs across the UK. However, these values are the best available information at the time of writing.

D.1 Sprinkler system installation costs

Table D1 – Sprinkler system installation cost for two-storey house, one-off new build (2010)

Range of values:	£1,200	£2,100	£1,400	£900	£1,900	£2,500	£1,800	£1,700
Range of values:	£2,715	£2,000	£2,550	£2,635				

Also used for shared houses and hostels in calculations.

Table D2 – Sprinkler system installation cost for three-storey HMO, per accommodation unit, one-off retrofit (2010)

Range of values:	£650	£1,000	£1,200	£1,365	£280	£450	£400	£165
Accommodation units per building	1	1	1	1	1	1	1	1
Values per accommodation unit	£650	£1,000	£1,200	£1,365	£280	£450	£400	£165

Range of values:	£4,000	£5,230	£3,570	£3,200	£2,200	£3,000	£3,500	£2,750
Accommodation units per building	8	12	6	6	6	6	6	6

[60] Williams, C, Fraser-Mitchell, J, Harrison, R and Campbell, S, The effectiveness of residential sprinklers, BRE report 204505 for the Office of the Deputy Prime Minister, February 2004.

Values per accommodation unit	£500	£436	£595	£533	£367	£500	£583	£458

Used for “traditional” HMOs in calculations.

Table D3 – Sprinkler system installation cost for flats, one-off new build (2010)

Range of values:	£400	£900	£600	£300	£107,000
Accommodation units per building	1	1	1	1	119
Values per accommodation unit	£400	£900	£600	£300	£899

Table D4 – Sprinkler system installation cost for flats, one-off retrofit (2010)

Range of values:	£560	£1,000	£800	£300	£1,000	£80,000
Accommodation units per building	1	1	1	1	1	56
Values per accommodation units	£560	£1,000	£800	£300	£1,000	£1,429

Used for converted flats in calculations.

Table D5 – Sprinkler system installation cost for care home per bed (<20), one-off new build (2010)

Range of values:	£1,400	£7,200	£3,000	£1,050	£2,000	£9,600	£5,500	£1,350
Accommodation units per building	6	6	6	6	12	12	12	12
Values per bed	£233	£1,200	£500	£175	£167	£800	£458	£113

Range of values:	£550	£400	£1,250	£1,300
Accommodation units per building	1	1	1	1
Values per bed	£550	£400	£1,250	£1,300

D.2 Sprinkler system pump and tank costs

Table D6 - Pump and tank cost for house (2010)

Range of values:	£1,100	£1,200	£900	£1,050	£900	£1,400	£500	£1,195
Range of values:	£900	£1,900	£1,195					

Also used for shared houses and hostels in calculations.

Table D7 - Pump and tank cost for HMO (2010)

Range of values:	£1,300	£1,500	£900	£1,250	£1,300	£1,500	£900	£1,050

Used for "traditional HMOs" in calculations.

Table D8 - Pump and tank cost for flats (2010)

Range of values:	£1,100	£1,000	£900	£1,050	£1,100	£1,000	£900	£1,050
Range of values:	£1,100	£2,000						

Table D9 - Pump and tank cost for care homes (2010)

Range of values:	£1,300	£4,500	£1,100	£1,250	£1,300	£4,500	£1,200	£1,250
Range of values:	£2,000	£4,000	£8,975	£4,000	£4,000	£4,000		

D.3 Annual maintenance costs for sprinkler system

Table D10 - Maintenance cost for house (2010)

Range of values:	£100	£95	£95	£95

Also used for shared house and hostel in calculations.

Table D11 - Maintenance cost for HMO (2010)

Range of values:	£100	£105	£100	£125

Also used for "traditional HMOs" in calculations.

Table D12 - Maintenance cost for flats (2010)

Range of values:	£100	£125	£100	£125	£100	£250	£300

Table D13 - Maintenance cost for care homes (2010)

Range of values:	£150	£125	£150	£150	£195

Appendix E – Water company charges for fire sprinkler systems

E.1 Dee Valley Water Company charges for fire sprinklers received by BRE 14 to 20 February 2012

Fire sprinkler additional charges to a standard domestic connection

New or converted single family house	Direct mains	Tank supply	Normal standard non sprinkler domestic connection for comparative purposes
Long side (2m to 8m communication pipe), including excavation	£1,127.49	£15.56	£919.74
Short side (up to 2m communication pipe), including excavation	£918.51	£15.56	£516.63

Assumptions

1. Fire sprinkler connection is carried out at the same time as new connection
   There will be an additional admin cost of £58.34 if the sprinkler connection is installed on a separate occasion
2. For supply up to and including 32mm for both scenarios
3. Excludes building water and infrastructure charges
4. Excludes VAT
5. Prices as at 2011/2012, increase due April 2012
6. Includes inspection charges
7. For a tank fed supply, includes byelaws, regulations checks and investigation of mains network e.g. pressure checks.

E.2 Dwr Cymru Welsh Water Company charges for fire sprinklers received from Mike Bishop by BRE 17 to 21 February 2012

Additional charges for fire sprinklers for domestic and residential premises

These costs exclude VAT and are at 2011/2012 prices.

Assuming there are three types of installation a), b), c):

a) One off domestic new or converted single occupancy house with pump and tank storage

As the pipework is a tee off an existing or new installation within the property our increased cost will be the byelaw inspections. Assuming a non recession workload of 12k connections per year and the need for a minimum of 5% inspection rate and considering the geography we would need three byelaw inspectors at a total cost of £120k per annum. The cost of each connection would be £10.

b) One off domestic new or converted single occupancy house for direct mains feed

Long side direct mains feed on same basis as Dee Valley = £676

Short side direct mains feed on same basis as Dee Valley = £594

All on same basis i.e. 32mm, no building or infrastructure included and same price base

Assuming split of lay only and made/unmade is 80:20

c) Typical non domestic multi occupancy connection with pump and tank storage

Non domestic would apply to: multiple occupancy house, purpose-built and converted block of flats, old persons', children's or disabled persons' care homes, residential colleges, boarding schools, student halls of residence.

Assuming a 90mm pipe installation and equal number of lay only, unmade, footway and highway installations and also equal number of long and short side (giving an average of 3m additional pipework):

Material cost	= £900
Installation lay only	= £500 plus £22 per metre
Installation unmade	= £1,300 plus £30 per metre
Installation footway	= £1,550 plus £65 per metre
Installation highway	= £1,900 plus £75 per metre
Average of four excavation types	= £1,455
Design and administration costs	= £3,700 (which include inspection fees)

Total average cost = material + design and administration + pipe installation costs = £6,055

Appendix F - Greenhouse gas emissions

At the request of the Welsh Government, BRE was also asked to estimate the reduction in greenhouse gases, specifically carbon dioxide, from fires where a residential sprinkler system was installed to inform the CBA and a future impact assessment. The reduction of greenhouse gases from fire is also an annual benefit but the monetised value is estimated to be very small compared with the others,

Following the procedure outlined in a recent paper[61], emission of carbon dioxide (CO_2) as a result of a fire is assumed to be proportional to the area of fire damage.

In estimating sprinkler effectiveness, the area is assumed to be restricted to the fire area at the time of first sprinkler activation.

The effectiveness of sprinklers in reducing property damage is directly proportional to the fire area. Similarly, with the assumption above, reduction in greenhouse gas emissions from a fire would also be directly proportional to the reduction in fire area. The effectiveness factor would therefore be the same as that for the reduction of property damage.

According to Table A8 in British Standard Published Document BS PD 7974-1:2003[62], the average fire load density for a "dwelling" is 780 $MJ.m^{-2}$. The standard deviation is about 160 $MJ.m^{-2}$. For many fuels, the heat of combustion, in MJ, is to a good approximation given by the relation

$$\Delta H_c = 13.2\, m_{O_2} \qquad \text{[Equation F1]}$$

where m_{O2} is the mass of oxygen consumed, in kg.

Hence, if the area burnt is A, the average heat release will be $780.\ A$ (MJ) and the mass of oxygen consumed will be

$$m_{O_2} = \frac{780\, A_{fire}}{13.2} \qquad \text{[Equation F2]}$$

[61] Charters, D and Fraser-Mitchell, J, The potential role and contribution of fire safety to sustainable buildings, Proceedings, Interflam, 2007.

[62] British Standards Institution, BS PD 7974-1:2003 Application of fire safety engineering principles to the design of buildings, initiation and development of fire within the enclosure of origin (Sub-system 1), 2003.

The complete combustion of a number of common polymers may be represented by the following chemical reactions.

Material	**Combustion reaction**	**Yield of CO_2 (kg per kg O_2)**
Cellulose (e.g. wood/paper)	$(C_6H_{10}O_5)_n + 6n\ O_2 \rightarrow 6n\ CO_2 + 5n\ H_20$	1.375
Polystyrene	$(C_8H_8)_n + 10n\ O_2 \rightarrow 8n\ CO_2 + 4n\ H_2O$	1.10
PMMA	$(C_5O_2H_8)_n + 6n\ O_2 \rightarrow 5n\ CO_2 + 4n\ H_2O$	1.15
Polythene	$(C_2H_4)_n + 3n\ O_2 \rightarrow 2n\ CO_2 + 2n\ H_2O$	0.92
Polypropylene	$2(C_3H_6)_n + 9n\ O_2 \rightarrow 6n\ CO_2 + 6n\ H_2O$	0.92

Not knowing the likelihood of different materials to be involved in the fire, it has been assumed that the yield of CO_2 has a mean of 1.09 and a standard deviation of 0.19 kg per kg of O_2 consumed. Combining this with Equation F2, the result arrived at is

$$m_{CO_2} = (64 \pm 17).A_{fire} \qquad \text{[Equation F3]}$$

where the mass of CO_2 is measured in kg, and the area of the fire is in m^2.

Table F1 - Effect of sprinklers on reduction of CO_2 emissions from fires

Accommodation type	**Unsprinklered fire area**[1]	**CO_2 production per fire**[2]
House (single occupancy)	4.3	0.3 ± 0.1
Flat (all types)	2.5	0.2 ± 0.0
Traditional HMO[3]	4.5	0.3 ± 0.1
Shared house[3]	4.5	0.3 ± 0.1
Hostel[3]	4.5	0.3 ± 0.1
Care home (all types)	3.2	0.2 ± 0.1
Sheltered house[4]	4.3	0.3 ± 0.1
Sheltered flat[5]	2.5	0.2 ± 0.0
Halls/Dormitories[6]	3.2	0.2 ± 0.1

Notes

1. Unsprinklered fire area is the average per fire (without sprinklers), in m^2
2. CO_2 production is given by multiplying the average unsprinklered fire area and the yield of CO_2 per m^2 of fire area. The units are tonnes CO_2 per fire.
3. The fire statistics do not differentiate between different types of HMOs, so the same unsprinklered

fire area has been assumed to apply in each case.

4. The unsprinklered fire area in sheltered houses has been assumed to be the same as in single occupancy houses
5. The unsprinklered fire area in sheltered flats has been assumed to be the same as in other flats
6. The fire area in halls and dormitories has been assumed to be similar to care homes

The uncertainties in the table represent ± 1 standard deviation.

Estimate of overall carbon dioxide emissions from fires reduced by sprinklers

The estimated benefits in terms of reduced CO_2 emissions are given in Table F2. The values are calculated from the CO_2 emissions per fire, multiplied by the sprinkler effectiveness at reducing CO_2 emissions (assumed the same as the effectiveness in reducing property damage), the sprinkler reliability, the number of fires per accommodation unit per year, and the number of accommodation units constructed during the period 2013 to 2022.

Table F2 – Overall CO_2 emissions from fires reduced over the whole life of sprinkler systems in new accommodation units constructed during the period 2013-2022

Accommodation type	Reduced CO_2 (tonnes)
House (single occupancy)	701 ± 193
Flat (all types)	250 ± 69
Traditional HMO	3 ± 1
Shared house	51 ± 14
Hostel	11 ± 3
Care home (all types)	29 ± 8
Sheltered house	27 ± 7
Sheltered flat	21 ± 6
Halls/Dormitories	34 ± 9
Total for subset where cost effective or marginally cost effective	337 ± 71
Total for all accommodation types	1,127 ± 206

The uncertainties in the table represent ± 1 standard deviation.

To put these CO_2 savings in context, each adult person in the UK produces 12 tonnes of CO_2 per year as a result of their normal day-to-day activities[63]. In other words, the lifetime savings from the installation of sprinklers in all new build is approximately matched by the emissions due to two people over the same lifetime period.

The monetary value of the reduced carbon dioxide is in the region of £50-£100 per tonne[64]. As the total reduction for Wales over the whole life of residential sprinkler systems installed between 2013 and 2022 is just over 1000 tonnes, the total monetary value is in the region of £50k to £100k. When compared against an NPV of -£190 million, the benefit of reduced carbon dioxide alone is very small.

[63] Dickie, I, and Howard, N, , Assessing environmental impacts of construction, Industry consensus, BREEAM and UK Ecopoints, BRE Digest 446, 2000.

[64] DECC, central values of non traded carbon for different years, available at http://www.decc.gov.uk/en/content/cms/emissions/valuation/valuation.aspx

Appendix G – Sensitivity analysis

A sensitivity analysis was carried out for a) all residential properties and b) the subset of residential properties where sprinklers are predicted to be cost-effective or marginally cost-effective. This subset was for: new blocks of flats, new blocks of sheltered flats, new "traditional" HMOs, new care homes, new halls of residences and new dormitories.

The sensitivity analysis involved examining the following to see their influence on the cost benefit analysis results:

- Examining the effect of varying the value of lives saved/injuries prevented by ± 25% of the value (Cases 1a and 1b)
- Examining the effect of varying the % of severe injuries (Cases 2a and 2b)
- Reducing sprinkler installation costs by 30% to reflect economies of scale in large developments, for houses (Case 3)
- Considering the direct mains water supply cost option, for houses and sheltered housing (Case 4)
- Varying the proportions of new build accommodation units that are houses and flats to 90:10 (from 79:21) (Case 5)
- Examining the options of zero maintenance with no decline in reliability and no maintenance with consequential decline in reliability (Cases 6a and 6b).
- Examining the effect of an overall decrease in installation costs by 25% as installers gain experience and become more competitive, for all property types (Case 7).

G.1 Valuation of fatalities and injuries prevented (Cases 1a and 1b)

When Willingness to Pay was established as the basis for valuation of deaths and injuries, the proposed value of death prevented was assumed to be £1,000,000 ± £250,000. Over the years the value has been increased in line with GVA (such that the value in 2010 prices is £1.63m). This process has resulted in an apparently "precise" value. Welsh Government has recommended a sensitivity analysis for the value of each death prevented, to reflect the initial 25% uncertainty.

The value for injuries was originally set as a fraction of the value for deaths, so this would have a similar level of uncertainty.

At the low end of the range, the values for death and weighted average fire injury are £1.22m and £15k, respectively. At the high end, they are £2.04m and £25k, respectively.

G.2 Proportions of injuries with different severities (Cases 2a and 2b)

In section B.2 it was shown that the proportions of injuries in the fire statistics were 8% serious, 37% minor, remainder negligible. It was noted that the Economic cost of fire 2004 and 2006 used a different approach, since the fire statistics were recorded in less detail.

In the Economic cost of fire 2004 the proportions worked out to 24% serious and 55% minor. In the Economic cost of fire 2006 the definition of “serious” was changed (to include all fires involving smoke inhalation. In 2004, a quarter of such fires were deemed “serious”, with three quarters “minor, resulting in 56% serious injuries and 23% minor.

A sensitivity analysis was performed to compare these alternative definitions with the definition that was used in section B.2. The effect is that the baseline definition in section B.2 has a weighted average value of £20k per injury, whereas the Economic cost of fire 2004 has a weighted average value of £51k, and the Economic cost of fire 2006 a value of £105k.

G.3 Reduced sprinkler installation costs, reflecting economies of scale in large developments for houses (Case 3)

According to the study by NERA[65], a 30% reduction in costs of sprinkler installation might be expected in large developments, reflecting economies of scale.

This reduction has been interpreted to apply only to estates of single-occupancy houses, and only the installation component of the initial cost, not the cost of water supply.

Since the proportion of new developments that are expected to be large scale are not known, the 30% reduction in installation costs has been applied to all new houses.

G.4 Direct mains water supply cost option for houses and sheltered flats (Case 4)

Welsh water companies have supplied charges that they would apply in various circumstances, see Appendix E. For a direct mains connection to a single occupancy house, these charges are £829 ± 274. Prices for other types of property are not quoted, and it is assumed that the water companies would not provide a direct mains supply in these cases. However, it has been assumed that a direct mains supply would be acceptable for sheltered houses but not for sheltered flats.

G.5 Proportions of new build accommodation units that are houses and flats (Case 5)

The example new build projections for houses and flats assumed that the proportions of new accommodation units would be 79% houses and 21% flats. Welsh Government advised that any use of these projections should be subject to a sensitivity analysis. Therefore, an alternative has been considered, where the proportions are 90% houses and 10% flats.

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[65] Gros S, Spackman, M and Carter, S, A cost benefit analysis of options to reduce the risk of fire and rescue in areas of new build homes, Department for Communities and Local Government, Fire Research Series 1/2010, February 2010.

G.6 Option of no maintenance, with possible consequential decline in reliability (Cases 6a and 6b)

It has been assumed that all residential systems would be maintained in accordance with the relevant Standard, BS 9251: 2005.

However, this may not actually occur in practice, particularly for systems in single-occupancy houses. For example it is known that about 25% (or less) of domestic gas boilers are maintained, even though the relevant standard requires 100%.

Failure to maintain the system as specified may lead to a reduction in reliability, although by how much is unknown.

For the sensitivity analysis, two cases have been considered, one with 0% maintenance and 98% reliability, and one with 0% maintenance and a 30% reduction in reliability (from 98% to 68%). This is broadly consistent with estimated reliability for “low cost” residential sprinkler systems in New Zealand which are designed to be zero maintenance.

These effects have been applied to all property types.

G.7 Effect of an overall decrease in sprinkler installation costs as installers gain experience and become more competitive (Case 7)

The experience following the adoption of the Sprinkler Ordinance in Scottsdale, Arizona was that installation costs fell by 50% over a ten year period. For sensitivity analysis, a similar effect has been assumed to apply. The net effect is a 25% reduction which is the average of 0% at the start to 50% at the end of the ten year period.

This reduction has been applied to all property types.