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Cost Benefit Analysis of residential sprinklers - Final Report

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Protecting People, Property and the Planet

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Executive Summary

Automatic sprinklers are a well established technology and have demonstrated their effectiveness in protecting life and property in industrial and commercial applications over many years. In the UK, sprinkler systems have been installed into domestic and residential buildings as part of the package of fire protection measures, primarily to reduce the risk to life but also to reduce the risk of property damage caused by fire.

This is the Final Report of the project 'Cost Benefit Analysis of residential sprinklers' commissioned by The Chief Fire Officers Association (CFOA) and carried out by BRE Global (BRE proposal number 127279, dated 14 June 2010). This project has involved the participation of a Stakeholder Group involving representation from CFOA, BAFSA, NFSN, EFSN, Department for Communities and Local Government, ABI. Residential sprinkler systems designed, installed and maintained to British Standard BS 9251: 2005 Sprinklers for residential and domestic occupancies – Code of Practice have been considered in this study.

The specific objectives of this project were to update a previous BRE Cost Benefit Analysis published in 2004[1] and to consider sprinkler protection in new build residential premises related to the impact of future trends on fires and their potential consequences. It should be noted that benefits resulting from compensatory features and trade-offs were not included in the cost benefit analysis.

It has become apparent during this work that there is no universal definition of houses in multiple occupation (HMOs) in the UK. The survey of English housing records the number of HMOs which include "shared houses" and "bedsit type dwellings" ("traditional HMOs"). The fire statistics do not provide the same breakdown. Prior to 2008, there was just one category of HMO. Since 2008, it has been possible to record whether an HMO is licensed or unlicensed, but not define if it is a "shared house" or a "traditional HMO". It would be a significant development if a universal definition and breakdown of HMOs could be adopted for use in the UK to reduce the uncertainties associated with the correlation between the number of building types and fires.

Based on the cost data supplied by Industry as part of this work and the analysis described in this report, residential sprinklers as an additional safety measure are cost-effective for:

- all residential care homes for elderly people, children and disabled people (including those with single bedrooms).
- most blocks of purpose built flats and larger blocks of converted flats (see Figure 1) where costs are shared.

[1] C Williams, J Fraser-Mitchell, S Campbell and R Harrison, Effectiveness of sprinklers in residential sprinklers, BRE project report 204505 for the Office of the Deputy Prime Minister, 2004.

- Traditional bedsit type HMOs where there are at least six bedsit units per building and the costs are shared.

The analysis carried out for residential sprinklers in two storey houses and the shared houses category of HMOs did not demonstrate that they would currently be cost effective. There are a number of factors that have impacted on this outcome which are described in detail in this report. For example, the responses to the consultation with the Industry regarding the costs of systems, installation and maintenance indicate that currently, the number of residential installations in the UK is low in number. As a consequence, the current costs reflect the fact that each application tends to be treated independently and a bespoke solution provided. If residential sprinklers were in more widespread use, it might be expected that some of the costs, such as installation and maintenance, would reduce.

To change the outcome for two storey houses and/or the shared houses category of HMOs, it can be concluded that there would need to be a reduction in the costs of the systems and annual maintenance and/or an increase in the benefits which would require a change in the risks of death, injury, property damage or the value attributed to these. In addition, there are opportunities to consider trade off during the design of buildings would tend to result in cost savings. Clearly, as residential sprinklers become more widely used, direct statistical data will become available, from sources such as Wales, to inform and provide a more robust technical evidence base.

Future trends will potentially impact on the cost effectiveness of residential sprinklers in houses and the shared houses category of HMOs. These impacts would be reflected in the fire statistics in time. They would need to be reviewed in any future research and include an ageing population alongside changes to social care and health policies meaning that people will tend to live alone for longer, care in the community for people with physical and/or mental impairment and decreasing funding for public sector services. These trends have been reviewed qualitatively as part of this work. At this time, there is either not enough or no data to properly quantify the potential impact of the identified trends.

Contents

1 Introduction

Automatic sprinklers are a well established technology and have demonstrated their effectiveness in protecting life and property in industrial and commercial applications over many years. In the UK, sprinkler systems have been installed in domestic and residential buildings as part of the package of fire protection measures, primarily to reduce the risk to life but also to reduce the risk of property damage caused by fire

In 2002, BRE carried out a research study commissioned by Communities and Local Government (formerly the Buildings Division of the Office of the Deputy Prime Minister, ODPM) on the effectiveness of residential sprinklers [Williams et al 2004]. This study was published in 2004 and included a cost benefit analysis. The conclusions of that cost benefit analysis were:

- *"Residential sprinklers are probably cost-effective for residential care homes (care homes for elderly people, children and disabled people) and for tall blocks of flats (eleven storeys and above). However, residential sprinklers are not cost-effective for other dwellings.*
- *In order for sprinklers to become cost-effective, high risk buildings may be targeted and justified in a case by case basis using the developed cost benefit approach. Also, in order to be cost-effective in a broader range of dwellings, installation and maintenance costs must be minimal, and/or trade-offs may be provided to reduce costs by indirect means.*
- *In general, the cost benefit conclusions from other countries' experiences were the same as this project, i.e. that sprinklers were not cost-effective, unless systems were low cost or trade-offs could reduce costs."*

The Chief Fire Officers Association (CFOA) has commissioned BRE Global to carry out some cost benefit analyses of residential sprinklers (BRE proposal number 127279, dated 14 June 2010). The specific objectives of this project were to update the BRE 2004 cost benefit analysis using current cost data for sprinkler systems installation and maintenance and to consider sprinkler protection in new build residential premises related to the impact of future trends on fires and their potential consequences. This study considers residential sprinkler systems designed, installed and maintained to British Standard BS 9251 Sprinklers for residential and domestic occupancies – Code of Practice [British Standards Institution 2005a].

This Project has involved the participation of a Stakeholder Group. The contributions from the Stakeholders are gratefully acknowledged.

This report is the Final report which presents the analysis, findings and conclusions of this project.

2 Description of Project

During the project, a Stakeholder Group was formed and met three times. Members of the Stakeholder Group included representatives of: The Chief Fire Officers Association (CFOA), NFSN (The National Fire Sprinkler Network), BAFSA (British Automatic Fire Sprinkler Association), ESFN (European Fire Sprinkler Network), Sustainable Buildings Division, Department of Communities and Local Government (DCLG) and the Association of British Insurers (ABI). This Group provided information, comment and data in support of the BRE Global work.

The programme of work was conducted in two stages, Work Package 1 and Work Package 2.

Work Package 1 – Life loss and injury (and property protection)

The BRE/CLG cost benefit analysis research on the effectiveness of sprinklers in residential premises, 2004 was updated, with more recent information and refined analysis methods, as follows.

The literature review from the previous study was updated. This included information from other countries. Input data for the cost benefit analysis was confirmed and/or obtained. This included the costs of installing and maintaining sprinkler systems from industry. Building types that were considered are: houses, purpose built flats, converted flats, Houses in Multiple Occupation (HMOs), residential care homes (for children, disabled people, elderly people), as for the 2004 study. Specific cases such as social housing schemes, where some of the cost benefit analysis factors may vary were not included within this project. UK Fire Statistics data from 2003 to 2008 and housing data from the English House Condition Survey (EHCS) from 2007 and 2008 were utilised.

The current BRE Cost Benefit Analysis (CBA) tool was utilised to perform the cost benefit analysis and uncertainty analysis. The analyses covered property protection benefits (analysis with and without sprinklers) but not environmental impact. These have been used for the baseline cases.

Work Package 2 – Economic factors

The qualitative impact of future trends on system costs, the number of fires, and the consequences of a fire was considered. This extended to other consequences, such as environmental impact, not covered in Work Package 1.

There are a number of future trends that could affect the outcome of the current cost benefit analysis in relation to fire safety and sprinkler protection in residential premises. Some future trends and their potential impact on fire safety in domestic and residential premises were qualitatively identified from BRE Global knowledge and from discussions with the Stakeholder Group.

Linked to this, a sensitivity analysis was performed using the BRE CBA tool, where the change in the outcome for a given change in the variable was determined. The identified qualitative trends provide valuable insight into how changes in a specific variable resulting from anticipated future trends on fires might impact on the outcomes of the cost benefit analysis.

There may be special cases where some of the factors in the cost benefit analysis would have different input values to those used in the main analysis. If the effects on the input values can be quantified, the sensitivity analysis permits the cost benefit ratio to be estimated for these special cases.

3 Previous work on sprinkler effectiveness and cost benefit

The previous BRE/CLG research on the effectiveness of sprinklers in residential premises [Williams et al 2004] included a literature review of other countries' experiences, both in terms of effectiveness and also costs and benefits. That literature review has been updated to include more recent literature and is included in Appendix A.

The results are summarised in Tables 1 to 10. It is important that these summary results are not quoted out of context.

It is important to realise that all the values will have a greater or lesser degree of uncertainty associated with them (although only a few sources explicitly state what the estimated uncertainty is). In Tables 1 to 10, if the uncertainty in a value is not mentioned, it should be assumed that the reference source did not provide this information, rather than the uncertainty being negligible.

Some values may have been deduced from other information within the reference source. Any assumptions connected with the deduction are another potential source of uncertainty.

3.1 Sprinkler reliability

The definition of sprinkler system reliability that has been used for the cost benefit analysis described later (see section 5.6) is that the sprinklers operate when the fire generates sufficient heat to activate a sprinkler head.

Alternative definitions (see e.g. literature review in [Williams et al 2004]) are that the sprinkler(s) activate provided that the fire is large enough and the system is operational (e.g. not turned off for maintenance); alternatively, that sprinklers activate and control or extinguish the fire (e.g. as deduced from [Vancouver Fire Brigade 2001]).

The results of the literature review relating to sprinkler reliability are summarised in Table 1.

Table 1 - Reliability of sprinklers

Reference	Reliability, *r*	Comments
Vancouver Fire Brigade 2001	94.5%	Value for sprinklers in HMOs, deduced from data quoted in reference
Vancouver Fire Brigade 2001	81% ~ 95%	Value for sprinklers in HMOs, deduced from data quoted in reference, including "unknown" sprinkler activation status
Williams et al 2004	84% ~ 99.5%	Consensus values from literature review in the reference; note that different sources have different definitions of "reliability"

Williams et al 2004	100%	Value used in cost-benefit analysis in the reference

3.2 Sprinkler effectiveness

It is important to clearly define what is meant by the term "sprinkler effectiveness". In the context of this cost benefit analysis (see section 5.9), it is the proportion of deaths (or injuries or property damage) per building per year that is prevented when a sprinkler system is provided, assuming 100% reliability (the actual reliability is an additional factor). However, it is more common for other estimates to include the reliability as part of the overall effectiveness.

Different sources may estimate the effectiveness of sprinklers in different ways. The ideal method would involve the use of statistical estimates of the numbers of deaths, injuries and damage, in buildings with and without sprinklers, giving the risk per building per year. A similar method involves the statistics of the number of deaths etc per reported fire, assuming the risks of death per fire are proportional to the risks of death per building per year (i.e. the same number of reported fires per building per year with or without sprinklers). However, both these methods require suitable data to exist for both sprinklered and non-sprinklered buildings.

In an attempt to address the problems of small or non-existent sample size, some sources have relied on judgement to estimate the consequences assuming sprinklers were (or were not) present[2]. For example, the circumstances of fatalities in care home fires were examined in detail, with factors such as the size of fire, nature of injury, etc affecting the subjective probability of survival had sprinklers been present [Shipp and Clark 2006]. In another example, applying a similar approach in reverse, each residential sprinkler activation in Scottsdale was examined and the subjective probability of each person exposed becoming a fatality was estimated [Ford 1997]. Care needs to be taken when using this last approach not to equate lives saved with the number of people exposed, even though a (substantial) fraction would statistically be expected to survive if sprinklers were not present.

The results of the literature review relating to sprinkler effectiveness in preventing deaths, injuries and property damage are summarised in Tables 2, 3 and 4.

Table 2 - Effectiveness of sprinklers, prevention of deaths

Reference	Effectiveness, e_d	Comments
Dwellings		
Ford 1997	98.5%	Dwellings in Scottsdale, Arizona, USA. Based on estimated consequences, had sprinklers not been present, in fires where sprinklers activated.

[2] The method adopted in this cost benefit analysis is a variant of this approach; a correlation between fire size and risk of death, etc, is used to estimate the consequences when sprinklers are present. See Appendix B for details.

Ford 2003	> 50%	Dwellings in Scottsdale, Arizona, USA. This particular reference is only available as an Executive summary and therefore the detail behind this reported figure is unclear.
Hall 2010	83%	All dwellings in USA.
Robbins et al 2008	83%	Dwellings in New Zealand, for a “low cost” sprinkler system incorporated into the normal plumbing system. Baseline case has no alarms.
Siarnicki 2001, Weatherby 2009	100%	Dwellings in Prince George County, Maryland, USA.
Sziklai 2007	97.5%	Dwellings in Vancouver, BC, Canada. Stated value with no further details.
Williams et al 2004	82% ~ 84%	Sprinklers plus smoke alarms compared with baseline case of neither sprinklers nor alarms. Consensus values from literature review in the reference. UK based data.
Williams et al 2004	62% ~ 66%	Value, for sprinklers and alarms, in comparison with baseline case of smoke alarms only. Deduced, derived from the values above. UK based data.
Williams et al 2004	70%	Value used for all property types, based on correlation between risk and fire area (although subsequent work showed a lower value would be appropriate for care homes for elderly persons). UK based data.
Houses		
Butry et al 2007	100%	Houses in the USA, based on statistics from NFPA.
Gros et al 2010	70%	NERA study of houses in Thames Gateway area in the UK, used value from [Williams et al 2004], with a value of 90% for sensitivity analysis.
Parsons 2009	100%	Houses in Studley Green in the UK based on a sample size of two fires.
Care homes		
Ahrens 2006	82%	Care homes in USA.
Hall 2010	68%	Care homes in USA.
Hall 2010	76%	Hospitals, nursing homes, etc in USA.

Shipp and Clark 2006	33%	Care homes for elderly people in the UK. Based on estimated consequences, had sprinklers been present, in all fires causing fatalities 1994 to 2002. Note. This is considerably lower than other values in this Table for reasons as discussed in Appendix A section A1.8.

Note: the effectiveness of sprinklers is the reduction in risk, compared with a "baseline" case. Except where specified, the baseline case is assumed to have smoke alarms present, but no sprinklers.

Table 3 - Effectiveness of sprinklers, prevention of injuries

Reference	Effectiveness, e_i	Comments
Butry et al 2007	57%	Houses in the USA, based on statistics from NFPA.
Gros et al 2010	30%	NERA study of houses in Thames Gateway area in the UK, used value from [Williams et al 2004]. In addition, a value of 60% was used for sensitivity analysis.
Robbins et al 2008	75%	Dwellings in New Zealand, for a "low cost" sprinkler system incorporated into the normal plumbing system. Baseline case has no alarms.
Weatherby 2009	0%	Dwellings in Prince George County, Maryland, USA. Deduced value, based on number of fires and injuries, in buildings with and without sprinklers. In both sprinklered and unsprinklered cases, the risk (expressed as number of injuries per thousand fires) was the same.
Williams et al 2004	75% ~ 84%	Sprinklers plus smoke alarms, in comparison with baseline case of neither sprinklers nor alarms. Consensus values from literature review in the reference. UK based data.
Williams et al 2004	17% ~ 47%	Deduced value, for sprinklers and alarms, in comparison with baseline case of smoke alarms only. Derived from the values above. UK based data.
Williams et al 2004	30%	Value used for all property types, based on correlation between risk and fire area.

Note:

The effectiveness of sprinklers is the reduction in risk, compared with a "baseline" case. Except where specified, the baseline case is assumed to have smoke alarms present, but no sprinklers.

Table 4 - Effectiveness of sprinklers, reduction of property damage

Reference	Effectiveness, e_p	Comments
Butry et al 2007	32%	Houses in the USA, based on statistics from NFPA.
Ford	90%	Buildings (not just dwellings) in Scottsdale, Arizona, USA based on fire statistics.
Gros et al 2010	50%	NERA study of houses in Thames Gateway area in the UK, used value from [Williams et al 2004], with a value of 80% for sensitivity analysis.
Robbins et al 2008	88%	Dwellings in New Zealand, for a “low cost” sprinkler system incorporated into the normal plumbing system. Baseline case has no alarms. Deduced value based on statistics for fraction of building damaged in unsprinklered fires, and assumed limit on fire damage with sprinklers present.
Robbins et al 2008	52%	Dwellings in New Zealand, for a “low cost” sprinkler system incorporated into the normal plumbing system. Baseline case has no alarms. Stated value.
Siarnicki 2001	64%	Dwellings in Prince George County, Maryland, USA. Deduced value based on estimated number of fires and property losses, in buildings with and without sprinklers.
Sziklai 2007	90%	Dwellings in Vancouver, BC, Canada. Stated value with no further details.
Vancouver Fire Brigade 2001	3.5%	Dwellings in Vancouver, BC, Canada. Deduced value based on number of fires and property losses, in buildings with and without sprinklers.
Weatherby 2009	49%	Dwellings in Prince George County, Maryland, USA. Deduced value based on number of fires and property losses in buildings, with and without sprinklers.
Williams et al 2004	13% ~ 87%	Range of values (little or no consensus) from literature review in the reference. UK based data.
Williams et al 2004	50%	Value used for all property types, based on USA statistics.

Note. The effectiveness of sprinklers is the reduction in risk, compared with a “baseline” case. Except where specified, the baseline case is assumed to have smoke alarms present, but no sprinklers.

3.3 Sprinkler costs

The results of the literature review relating to sprinkler installation, water supply and annual maintenance costs are summarised in Tables 5, 6 and 7.

Costs have not been uplifted from the time the reference was written. Where costs have been converted from foreign currencies, the present day exchange rates have been used, rather than historical rates. Costs, particularly for overseas systems which comply with standards which may differ from UK standards, should be regarded as indicative.

Table 5 - Sprinkler installation costs

Reference	Installation cost, £I	Comments
Dwellings in general		
Fire Protection Research Foundation 2008	£1,450 ~ £9,900	Range of values from 30 actual installations in the USA.
Fire Protection Research Foundation 2008	£10 / m^2	Average cost from 30 actual installations in the USA.
Ford 2003	£3.40 ~ £4.60 / m^2	Actual costs of installation in Scottsdale, Arizona, USA.
Jones 2010	£978 ~ £1,719	Average value for installation costs in dwellings in Wales (based on 37% of new-build being flats).
Houses		
Brown et al 2005, Butry et al 2007	£2.80 ~ £10 / m^2	Based on cost estimates from installers, for different-sized houses in the USA.
Gros et al 2010	£1,200 ~ £2,800	Based on cost estimates from installers, for houses in the Thames Gateway in the UK.
Gros et al 2010	£1,500	Average value used in analysis, for houses in the Thames Gateway in the UK.
Robbins et al 2008	£750 ~ £1,650	Values for small (70 m^2) and large (135 m^2) houses, respectively, in New Zealand.
Williams et al 2004	£1,650	Average cost per house, based on information from Industry.
Houses of Multiple Occupation		
Gros et al 2010	£3,500 ~ £4,000	Based on cost estimates from installers, for HMOs in the Thames Gateway in the UK.

Williams et al 2004	£550	Average cost per HMO accommodation unit (e.g. bedsit), based on information from Industry.
Flats		
Gros et al 2010	£625 ~ £1,200	Based on cost estimates from installers, for flats in the Thames Gateway in the UK.
Gros et al 2010	£750	Average value used in analysis, for flats in the Thames Gateway in the UK.
Williams et al 2004	£900	Average cost per purpose-built flat, based on information from Industry.
Williams et al 2004	£1,100	Average cost per converted flat, based on information from Industry.
Seaber 2012	£1,150	Cost per flat in Callow Mount project, Sheffield, UK
Care homes		
Gros et al 2010	£12,000 ~ £20,000	Based on cost estimates from installers, for care homes for elderly people in the Thames Gateway in the UK.
Gros et al 2010	£6,000 ~ £8,000	Based on cost estimates from installers, for care homes for children in the Thames Gateway in the UK.
Williams et al 2004	£4,450	Average cost per care home for elderly people (average size 19 beds), based on information from Industry.
Williams et al 2004	£2,800	Average cost per care home for children (average size nine beds), based on information from Industry.
Williams et al 2004	£2,650	Average cost per care home for disabled people (average size eight beds), based on information from Industry.

Table 6 - Sprinkler water supply costs

Reference	**Water supply cost, $£W$**	**Comments**
Dwellings in general		
Dwr Cymru 2008	£700	Stated additional cost for mains connection to sprinkler system in dwellings in Wales.
Jones 2010	£nil	Assumed that most sprinkler systems in dwellings in Wales could be supplied direct from the mains; additional costs were stated to be negligible.
King 2011a	£nil	Scottish Water advised cost of upgrading pipe size is negligible.
Young 2011b	£120	Cost of increasing from 25 mm to 32 mm water supply.
Houses		
Brown et al 2005, Butry et al 2007	£nil	Most sprinkler systems in houses in the USA could be supplied direct from mains; additional costs were stated to be negligible.
Gros et al 2010	£1,200 ~ £1,350	Range of quoted costs for a pump and tank in houses in the Thames Gateway in the UK.
Gros et al 2010	£1,300	Value for pump and tank cost used in the cost benefit analysis for houses in the Thames Gateway in the UK.
Gros et al 2010	£700	Value for boosted mains cost used in the cost benefit analysis for houses in the Thames Gateway in the UK.
Robbins et al 2008	£nil	Low-cost sprinkler system in houses in New Zealand which is part of the normal plumbing system; additional costs were stated to be negligible.
Williams et al 2004	£465	Average cost per house, based on information from Industry. Value has high degree of uncertainty.

Houses of Multiple Occupation		
Gros et al 2010	£6,000 ~ £7,500	Range of quoted costs for a pump and tank in HMOs, blocks of flats, and care homes in the Thames Gateway in the UK.
Williams et al 2004	£140	Average cost per HMO accommodation unit (e.g. bedsit), based on information from Industry. Value has high degree of uncertainty.
Flats		
Gros et al 2010	£400	Value for pump and tank cost per flat used in the cost benefit analysis for the Thames Gateway in the UK.
Gros et al 2010	£200	Value for boosted mains cost per flat used in the cost benefit analysis for the Thames Gateway in the UK.
Williams et al 2004	£78	Average cost per purpose-built flat, based on information from Industry. Value has high degree of uncertainty.
Williams et al 2004	£112	Average cost per converted flat, based on information from Industry. Value has high degree of uncertainty.
Care homes		
Williams et al 2004	£835	Average cost per care home for elderly people (average size 19 beds), based on information from Industry. Value has high degree of uncertainty.
Williams et al 2004	£835	Average cost per care home for children (average size nine beds), based on information from Industry. Value has high degree of uncertainty.
Williams et al 2004	£835	Average cost per care home for disabled people (average size eight beds), based on information from Industry. Value has high degree of uncertainty.

Table 7 - Sprinkler annual maintenance costs

Reference	Maintenance cost, $£M$	Comments
Brown et al 2005, Butry et al 2007	£nil	Most sprinkler systems in houses in the USA could be supplied direct from mains, hence no pump and tank; also no backflow prevention or integrated alarm. Annual inspection is therefore not required.
Gros et al 2010	£75	Value used in cost benefit analysis for each house or flat where pump and tank, or boosted mains, was present, for dwellings in Thames Gateway in the UK. Sensitivity analysis looked at the effect of different proportions of dwellings with pump and tank, boosted mains, or direct mains connection (£nil maintenance for the latter).
Jones 2010	£25	Value for houses in Wales based on the stated assumption that only one-third of home owners would pay for maintenance at £75/year.
Jones 2010	£20	Estimated value per flat in Wales.
Robbins et al 2008	£nil	Low-cost sprinkler system in houses in New Zealand which is part of the normal plumbing system; additional costs were stated to be negligible.
Williams et al 2004	£50	Cost per house, flat, HMO accommodation unit or care home, based on information from Industry.
Seaber 2012	£250	Cost per block of 47 flats on Callow Mount project, Sheffield, UK (based on assumption that due to the design of the sprinkler system, access to individual flats would rarely be required).

3.4 Sprinkler benefits

The results of the literature review relating to sprinkler benefits of the monetary value of each death and injury prevented are summarised in Table 8.

Table 8 – Monetary value of each death prevented

Reference	Value of death, $£V_d$	Comments
Brinson 2011	€2.5 to €3.0m	Value recommended for the French Government for 2011.
Butry et al 2007	£4.89m	USA value, $7.94m in 2005 based on median of results reported by [Viscusi and Aldy 2003].

Duvall 2008	£3.54m	Value recommended by US Department of Transportation ($5.4m; also requires sensitivity analysis using values of $3.2m and $8.4m).
Gros et al 2010	£1.55m	Value for the UK in 2007.
Kniesner et al 2007	£3.36m ~ £4.59m	Refinement of approach followed by [Viscusi and Aldy 2003] for values in the USA.
Martin 2011	£1.63m	UK Treasury value for 2010.
Robbins et al 2008	N/A	The BRANZ study for houses in New Zealand, expressed the cost benefit analysis in terms of the cost to save a life.
Viscusi and Aldy 2003	£0.3m ~ £12.8m	International survey (mainly USA) of values using the “revealed preference” approach (see note below table)
Williams et al 2004	£1.28m	Value for the UK in 2002, as advised by ODPM

Note.

The US approach is based on wage differentials for jobs entailing different life risks (“revealed preference” approach), whereas the UK approach is based on canvassing opinion on how much is worth spending on road safety improvements to reduce risks of death in traffic accidents (“stated preference” approach), with the same value of a life derived by this method subsequently applied to a wider range of risks (such as fire in this case).

Table 9 – Monetary value of each injury prevented

Reference	Value of injury, $£V_i$	Comments
Butry et al 2007	£106k	Average value for all injuries in USA.
CLG 2008	£80.5k	Treatment costs for child aged 0-14, very serious scald burn.
CLG 2008	£26.8k	Treatment costs for adult aged 15-59, very serious scald burn.
CLG 2008	£27.6k	Treatment costs for elderly person aged 60+, very serious scald burn.
CLG 2008	£41.1k	Treatment costs for child aged 0-14, serious scald burn.
CLG 2008	£13.9k	Treatment costs for adult aged 15-59, serious scald burn.
CLG 2008	£14.6k	Treatment costs for elderly person aged 60+, serious scald burn.
CLG 2008	£0.2k	Treatment costs for all ages, minor scald burn.

Clinical Services Journal 2008	£1.5k	Daily cost of intensive care, UK.
Clinical Services Journal 2008	£0.4k	Daily cost of non-intensive care, UK.
Duvall 2008	£7.1k	Value recommended by US Department of Transportation, for minor injuries. Deduced from the stated defined fraction of the value of a life for this severity, and the value of life (see [Duvall 2008] in Table 8).
Duvall 2008	£54.9k	Value recommended by US Department of Transportation, for moderate injuries. Deduced from the stated defined fraction of the value of a life for this severity, and the value of life (see [Duvall 2008] in Table 8).
Duvall 2008	£203.7k	Value recommended by US Department of Transportation, for serious injuries. Deduced from the stated defined fraction of the value of a life for this severity, and the value of life (see [Duvall 2008] in Table 8).
Duvall 2008	£664.3k	Value recommended by US Department of Transportation, for severe injuries. Deduced from the stated defined fraction of the value of a life for this severity, and the value of life (see [Duvall 2008] in Table 8).
Duvall 2008	£2,698k	Value recommended by US Department of Transportation, for critical injuries. Deduced from the stated defined fraction of the value of a life for this severity, and the value of life (see [Duvall 2008] in Table 8).
Gros et al 2010	£174k	Value for serious injury involving burns, 2007.
Gros et al 2010	£44k	Value for injury involving smoke inhalation (weighted average of serious and minor injuries), 2007.
Gros et al 2010	£0.6k	Value for other minor injuries (physical injury, precautionary check), 2007.
Gros et al 2010	£39.2k	Average value for all injuries and precautionary checks, deduced from above values and proportions of different injuries.
Patil et al 2010	£1.4k	Daily cost of intensive care, Australia (no difference between burns and non-burns patients with similar acuity).
Robbins et al 2008	£111k	Average value for all injuries in New Zealand.
Williams et al 2004	£140k	Value for serious injury in the UK, 2002, as advised by ODPM.(see section 5.2, and Appendix A section A4)

Williams et al 2004	£11k	Value for minor injury in the UK, 2002, as advised by ODPM.
Williams et al 2004	£58k	Weighted average value for serious and minor injuries (but did not account for precautionary checks).

Note.

Treatment costs for a given severity of injury tend to be less that the “willingness to pay” value for the prevention of an injury. The average costs of all fire injuries in the UK include people referred to hospital for precautionary checks and fire fighters among the total number of casualties. In this work it has been assumed that the statistics for other countries also include fire fighter injuries.

It is standard practice for a single value to be assigned to an injury of a given severity, regardless of how the injury was sustained, rather than define separate values for fire-specific injuries.

3.5 Property damage costs without sprinklers

The results of the literature review relating to property damage costs without sprinklers are summarised in Table 10.

Table 10 - Average value of property damage (without sprinklers)

Reference	Value of damage, $£V_p$	Comments
Butry et al 2007	£11k	4-year average value for all house and apartment fires in USA (2002 to 2005).
Ford 1997	£5.8k	Average value for house fires in Scottsdale, Arizona, USA.
Ford 1997	£10.4k	10-year average value for all building fires in Scottsdale, Arizona, USA.
Ford 2003	£27.4k	15-year average value for all building fires in Scottsdale, Arizona, USA. It is not clear from the reference why this should be so much higher than the 10-year average (above).
Gros et al 2010	£7.3k	Average value of domestic fire damage in the UK, 2004.
Hall 2010	£10.4k	5-year average value for all house and apartment fires in USA (2003 to 2007).
Robbins et al 2008	£14.5k	Average value for all house fires in New Zealand.
Siarnicki 2001	£5.8k	Value for dwelling fires in Prince George County, Maryland, USA, deduced, based on stated numbers of fires and total loss.

Vancouver Fire Brigade 2001	£13.7k	Average value for all fires (not just dwellings) involving structural loss in Vancouver, BC, Canada.
Vancouver Fire Brigade 2001	£14.7k	Value for all fires (not just dwellings) involving structural loss in Vancouver, BC, Canada, deduced, based on stated numbers of fires and total loss.
Weatherby 2009	£6.1k	Value for dwelling fires in Prince George County, Maryland, USA.
Williams et al 2004	£7.5k	Average value for domestic properties in UK, 2002, as advised by ODPM. Same value was used in the cost benefit analysis in this reference for damage in care homes.

Note 1. Some costs are for houses, others are averages for all dwellings, and others are for all building types as indicated in the comments. Therefore, a direct comparison is not always appropriate.

Note 2. When a property is damaged by fire there will be costs associated with displacement to alternative accommodation which may include rental during repair and additional travel to and from work and/or place of education etc.

4 Cost benefit analysis methodology

This section 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, namely for this analysis as cost per dwelling per year. Let

£S = System installation cost (one-off, per accommodation unit) (capital cost of system per unit in Appendix E)
£W = Water supply cost (one-off, per accommodation unit) (water connection charge per unit in Appendix E)
K = Capital Recovery Factor
£M = Maintenance (annual, per accommodation unit) (annual inspection cost in Appendix E)
£C = Cost (annual, total, per accommodation unit)

and

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
tot = total

The overall annual cost per accommodation unit is

$$\pounds C = K(\pounds S + \pounds W) + \pounds M$$ [Equation 1]

The annual values of reducing deaths, injuries and property damage per accommodation unit are

$$\pounds B_d = \pounds V_d . R_d . r . e_d$$ [Equation2]

$$\pounds B_i = \pounds V_i . R_i . r . e_i$$ [Equation 3]

$$\pounds B_p = \pounds V_p . R_p . r . e_p$$ [Equation 4]

The annual risks are determined by dividing e.g. 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 B), and also include an explicit factor for the reliability of sprinklers to operate when expected.

The total annual benefit is

$$\pounds B_{tot} = \pounds B_d + \pounds B_i + \pounds B_p$$ [Equation 5]

In order for residential sprinklers to be cost-effective, the following inequality needs to be satisfied:

$$\left(\frac{\pounds B_{tot}}{\pounds C}\right) \geq 1$$ [Equation 6]

Example calculations are shown in Appendix B.

Most, if not all, values will have some uncertainty associated with them. In previous work [Williams et al 2004] an analytical approach was used to estimate the uncertainties in the final answer, based on the uncertainties of the input values. However, whilst this is convenient when producing spreadsheets to perform the calculations, it does have a limitation. In the current work, the uncertainty has been estimated using an improved, Monte Carlo, approach. For the details of the uncertainty analysis, see Appendix F.

5 Input data for the cost benefit analysis

The input data for the cost benefit analysis uses values which are specific to the UK (as a whole). Where explicit UK specific input data do not exist, sprinkler effectiveness input data have been calculated based upon correlation with area of fire damage (see section 5.8) and compared with overseas data to achieve greater confidence in the result rather than using the overseas data directly.

5.1 Value of each death prevented

The Department of Transport figure, used in the Treasury Green Book [HM Treasury 2003] and Economic Cost of Fire 2004 [ODPM 2006] was £1,350,000. This needs to be converted to a value in 2010, by multiplying by the increase in GDP from 2004 to 2010, a factor of 1.23. Hence the value in 2010 is calculated to be £1,692,000.

A nominal fractional uncertainty of 5% has been assumed for this figure, i.e. the value used in the Monte Carlo calculation has been sampled as a Normal distribution, N(1692000, 84240).

5.2 Value of each injury prevented

The Department of Transport figure, used in the Treasury Green Book [HM Treasury 2003] and Economic Cost of Fire 2004 [ODPM 2006], for a serious injury was £155,000, and for a minor injury was £12,000. In order to calculate the average fire injury cost, it was assumed that all injuries involving burns were serious, and all cases of physical injury or shock were minor. Between 20% - 30% (sampled as U(0.2, 0.3) of all smoke inhalation injuries were considered to be serious, with the remainder minor (hence the average cost would be U(40600, 54900)). Injuries recorded as a precautionary check were assumed to be negligible.

In 2007, figures from the UK fire statistics suggest the number of different injuries were distributed as follows:

- Smoke inhalation: number = N(3788, 62)
- Burns: number = N(1718, 41)
- Physical injuries: number = N(358, 19)
- Burns and smoke inhalation: number = N(357, 19)
- Shock: number = N(664, 26)
- Precautionary checks: number = N(5658, 75)

The Monte Carlo calculation procedure was as follows: sample the number of injuries of each type, multiply by the appropriate 2004 value (with a nominal 5% fractional uncertainty), calculate the total number of all types of injury and the total cost, and hence the average cost per injury. Finally, the average cost in 2004 was increased to 2010 prices by multiplying by a factor of 1.23 to account for the rise in GDP.

The results of the Monte Carlo calculations were that the average value of each fire injury prevented was £50,450, with a standard deviation of £2,870.

5.3 Value of property damage in a fire

In the Economic Cost of Fire 2004, the average value of property damage in dwellings was £7,300, and in commercial buildings the average value was £27,700. Nominal fractional uncertainties of 5% were assumed for both of these values. 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 January 2004, the RPI was 183.1; by December 2004, it was 189.9. For the Monte Carlo calculation, a random month in 2004 was chosen (sampled as U(1,12)) to obtain the RPI applicable to the 2004 values. The RPI in October 2010 (225.8) was then used to calculate the multiplication factor.

The results of the Monte Carlo calculations were that the average value in 2010 of property damage in dwellings was £8,800, with a standard deviation of £460. For care homes, which are larger that dwellings, the average value was assumed to be that of commercial buildings, i.e. £33,600 with a standard deviation of £1,700.

5.4 Interest rate for discounting future values

The interest rate recommended in the Treasury Green Book [HM Treasury 2003] is 3.5%. A nominal fractional uncertainty of 5% of this value has been assumed, i.e. the rate used in the Monte Carlo calculation is sampled from a Normal distribution N(0.035, 0.002).

5.5 Capital recovery factor

The Capital Recovery Factor [Ramachandran 1998] is defined as

$$K = r\frac{(1+r)^y}{(1+r)^y - 1}$$ [Equation 12]

where r is the rate of interest expressed as a decimal fraction, e.g. 0.035 for 3.5%, and y is the length of the payback period in years. If the amount of capital to be repaid is C, the annual payment A is given by

$$A = C.K$$ [Equation 13]

With the interest rate r sampled as N(0.035, 0.002), and the payback period y taken as the sprinkler system lifetime, sampled as U(40, 50), the result of the Monte Carlo calculations was that the capital recovery factor K had an average value of 4.5% with a standard deviation of 0.2%.

5.6 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 assumes that the sprinkler system is maintained according to the BS 9251 standard. If maintenance is neglected, it would be likely for the reliability to decrease, but the extent of the effect is unknown.

5.7 Sprinkler system lifetime

Based on estimates by BAFSA [Young 2010] and others [Ramachandran 1998], the lifetime of the sprinkler system has been assumed to be uniformly distributed between 40 and 50 years, i.e. U(40, 50).

5.8 Sprinkler system activation

As there is little or no relevant UK statistical information upon which to base an estimate of sprinkler system effectiveness, it is necessary to make an indirect estimate using the same principles used in the previous work on residential sprinkler effectiveness [Williams et al 2004], 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.

The first time this approach was used to estimate the effectiveness of sprinklers [Williams et al 2004], the fire area at the time of activation was taken to be $1m^2$ based on the advice received from sprinkler industry representatives on the project Steering Group. In subsequent studies, attempts have been made to estimate the fire area by means of calculations [Fraser-Mitchell 2004]. The most recent refinement was to adopt a Monte Carlo calculation to estimate the distribution of fire sizes. As the details of this most recent calculation have not previously been published, they are included in Appendix B.

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).

5.9 Sprinkler system effectiveness

For each of the Monte Carlo calculations, fire area (m^2) at the time of sprinkler activation was used to derive the effectiveness of sprinklers in reducing risks (on the basis of the statistical correlation between risk and fire area). The results of these calculations are shown in Table 11. Details of the calculations can be found in Appendix B.

Note that the uncertainties in the effectiveness for reducing risks in care homes are large as a consequence of the small statistical sample size. As an example, due to the large uncertainties, the 95% confidence interval for the effectiveness of preventing deaths in care homes for disabled people covers almost the entire range of possibilities between 0~100%.

Table 11 - Results of calculations of sprinkler effectiveness at reducing risks

Building type	Deaths (%)	Injuries (%)	Damage (%)
House (single occupancy)	90 ± 4	64 ± 11	93 ± 2
House (multiple occupancy)	100 ± 0	66 ± 10	93 ± 2
Flat (purpose-built)	90 ± 3	61 ± 12	88 ± 4

Flat (converted)	95 ± 4	66 ± 11	92 ± 2
Care home (elderly people)	62 ± 19	73 ± 9	86 ± 4
Care home (children)	97 ± 9	56 ± 18	99 ± 2
Care home (disabled people)	30 ± 32	51 ± 25	99 ± 3

5.10 Installation costs

A questionnaire was circulated to residential sprinkler installer members of BAFSA (and Fire Sprinkler Association (FSA)), requesting details of installation, water supply and annual maintenance costs for various types and sizes of buildings. Responses were received from 10 organisations. Some responders were not able to provide information for all values of interest. However, among the 10 replies there were at least 4 responses to each question.

The responses to the questionnaire indicate that currently, the number of applications for residential sprinkler installations is relatively small. As such, each application is treated independently and a bespoke solution provided. It is recognised that the costs that have been supplied by the industry for this project reflect the current situation. It might therefore be expected that some of the installation costs would reduce if sprinklers were in more widespread use.

The information received was used to construct Cumulative Density Functions (CDF's) of the probability distributions for each value. For each Monte Carlo cost-benefit calculation, a uniform random number U(0,1) defined the fractile of the CDF that would be used as the value in that calculation. Linear interpolation was used as necessary. (This calculation was implemented using the Excel PERCENTILE function)

An example may make this clearer. Five different values were received for the installation costs per flat (new build). These were as given below, together with the CDF value:

- Installation cost value: £300 £400 £600 £899 £900
- Corresponding fractile: 0.00 0.25 0.50 0.75 1.00

Hence, if U(0,1) = 0.367 for the example case, the corresponding value given by linear interpolation is

$$\pounds C = \frac{(0.5 - 0.367) \times \pounds 400 + (0.367 - 0.25) \times \pounds 600}{(0.5 - 0.25)} = \pounds 494$$

Tables showing the installation costs supplied for different building types are given in Appendix C.

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 responding organisations), 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.

5.11 Water supply costs

The questionnaire to BAFSA and FSA members also asked for details of water supply costs. The water supply costs (water connection charge in Appendix E) include the costs for different components within the specific options presented. Two options were considered: boosted mains, and pump and tank. A third option was mains supply with no extra provision required for which the water supply cost was negligible. These options were requested for each of the different building types and sizes.

As with installation costs, the information received was used to construct Cumulative Density Functions (CDF's) of the probability distributions for each value. For each Monte Carlo cost-benefit calculation, a uniform random number U(0,1) defined the fractile of the CDF that would be used as the value in that calculation.

Tables showing the water supply costs for different options and building types are given in Appendix C.

In the case of flats with a pump and tank supply, it was assumed that two pumps and tanks (for redundancy) would be provided for the entire building. (BRE Global was subsequently advised this should be two pumps but only one tank. However, BRE Global did not have cost breakdowns for this). Note that this is different to the assumption made previously [Williams et al 2004] where the pump and tank option was costed on the basis of one per floor, where each floor contained four flats.

For the case of flats supplied by boosted mains, a single booster pump was assumed for the entire building.

For the cost benefit calculations, in every case, the cost for water connection to the mains has been assumed to be zero.

5.12 Maintenance costs

Annual maintenance costs were also estimated by BAFSA and FSA members and included on the questionnaire responses.

As with installation costs, the information received was used to construct Cumulative Density Functions (CDFs) of the probability distributions for each value. For each Monte Carlo cost-benefit calculation, a uniform random number U(0,1) defined the fractile of the CDF that would be used as the value in that calculation.

Tables showing the annual maintenance costs for different building types are given in Appendix C.

With flats, it was assumed that all parts of the system requiring maintenance would be accessible from the common parts (hence repeated visits would not be required to gain access to all flats). The maintenance charge would thus be relatively low, and would be shared by all flats in a block and might be true in developments where adjacent houses are sprinklered. This also applies to other types of property where water supplies could be a shared pump and tank such as bed-sit-type (traditional HMOs).

In all cases, based on advice from the sprinkler industry, this work has assumed that 100% of systems will be maintained in accordance with BS 9251: 2005. Options for reducing the cost of maintenance are discussed in section 7.1.4 – Maintenance regime.

5.13 Fires, deaths, injuries, and property damage

The UK Fire Statistics database was interrogated to provide estimates of the annual numbers of fires, deaths, injuries and extent of fire damage, in various domestic and residential building types [Gamble 2010]. The data were collected from the years 2003 to 2008 (provisional data in this last year).

A summary of the data is given in Table 12. Full details can be found in Appendix D.

Table 12 - Annual average numbers of fires, deaths, injuries, for different building types

Building type	Fires	Deaths	Injuries
House (single occupancy)	25,312	214	5,312
House (multiple occupancy)	1,543	11	339
Flat (purpose-built)	17,852	82	3,705
Flat (converted)	2,881	18	663
Care home (elderly people)	746	6	81
Care home (children)	206	<1	17
Care home (disabled people)	251	1	15

5.14 Numbers of buildings

Data from the English House Condition Survey (EHCS) for 2007 and 2008 were analysed to provide estimates of the numbers of the different types of buildings [White 2011]. Less detailed data were also obtained for Wales [Ipsos MORI 2008, Statistics for Wales 2011], Scotland [Scottish Government 2009] and Northern Ireland [NIHCS 2009]. Some further analysis was then performed to estimate the numbers for the whole of the UK. The results of this analysis are shown in Table 13, with the underlying assumptions given in the notes below it. In the case of care homes, BRE Global does not have new estimates, so used the same values as the previous study [Williams et al 2004].

Table 13 - Estimated numbers of different building/dwelling types, from various data

Building type	Estimate	Uncertainty
House (single occupancy) – England	17,736,000	160,000[a]
House (multiple occupancy - shared / lodgers) – England	339,000	21,000[a]
House (multiple occupancy - bedsits) – England	22,400	5,000[a]
Houses and HMOs – Wales	1,234,000[b]	12,000[a]
Houses and HMOs – Scotland	1,478,000	32,000[a]
Houses and HMOs – Northern Ireland	680,000	--
House (single occupancy) – UK	21,060,000[c]	163,000[d]
House (multiple occupancy) – UK	429,000[e]	22,000[d]
Flat (purpose-built) – England	3,317,000	60,000[a]
Flat (converted) – England	825,000	35,000[a]
Flats – Wales	146,000[f]	4,000[a]
Flats – Scotland	836,000	27,000[a]
Flats – Northern Ireland	59,800	--
Flat (purpose-built) – UK	4,151,000[g]	64,000
Flat (converted) – UK	1,033,000[h]	35,000
Care home (elderly people) – UK	16,000	--
Care home (children) – UK	1,400	--
Care home (disabled people) – UK	11,000	--

Notes.

a) Uncertainty defined as estimate value, divided by SQRT(sample). Note that the uncertainty is based on sample size only, and does not reflect discrepancies with other estimates based on other data samples.

b) The total number of dwellings in Wales is 1.38m, 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).

c) The proportion of all houses in England which are in single occupancy is 17.736m / (17,736m + 0.339m + 0.022m) = 98%. It has been assumed that the same proportion applies to Wales, Scotland and Northern Ireland.

d) Uncertainty based on component uncertainties added in quadrature.

e) The proportion of all houses in England which are in multiple occupancy is 2% (see note c). It has been assumed that the same proportion applies to Wales, Scotland and Northern Ireland. It should be noted that there is uncertainty in the actual number of HMOs in the UK because of the absence of a precise definition.

f) The difference between the total number of dwellings and the total number of houses in Wales (see note b).

g) The proportion of all flats in England which are purpose-built is 3.317m / (3.317m + 0.825m) = 80%. It has been assumed that the same proportion applies to Wales, Scotland and Northern Ireland.

h) The proportion of all flats in England which are in converted buildings is 20% (see note g). It has been assumed the same proportion applies to Wales, Scotland and Northern Ireland.

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) [Davidson 2011]. 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 System [CLG 2009]. 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”

5.15 Number of residents per building

A statistical bulletin [Kilbey et al 2001] provides information on the residential, nursing and private hospitals and clinics provision (predominantly for adults), and on residential and nursing care placements funded by Local Authorities, at 31 March 2001.

Over the period 1995 to 2000, there were on average 12,826 care homes for elderly people in England, with 243,178 places available. The average number of places per home was 18.97, standard deviation 0.49. There were also 11,209 homes for people with various physical and/or mental disabilities, with 93,063 places, an average of 8.29 per building, standard deviation 0.27.

The average size of children’s homes was estimated at 9.95 places, from data presented in a report for the Department for Children, Schools and Families (DCSF) [Deloitte 2006]. With a total of 6,600 children in care, this would imply that the number of children’s homes in England was 660.

Between 6,500 and 7,000 children in secure units, children's homes and hostels, over the years 2004 to 2008, with a further 200 to 250 in other residential care homes.

Although the average size of care homes is relatively small, there is a tendency for new (or newly converted) homes to be considerably larger. Based on an analysis of ABI data [Hartless Private Communication 2010] on planning proposals 2005 to 2006, the average size of all types of proposed care homes was 49 beds (median 46 beds).

The average number of beds in care homes was used to estimate the sprinkler installation costs (since the questionnaire returns were converted to a cost per bed).

An analysis of planning proposals for new (or newly converted) blocks of flats in 2005 to 2006 estimated that there were 266,213 flats proposed in 14,160 blocks, an average of 18.8 per block.

The average number of flats in a block was used to estimate the costs of water supply and annual maintenance on a per flat basis (from a per building basis). It was assumed that there was no difference between purpose-built and converted flats, although other sources [Wright et al 1997, White 2011] suggest that purpose built flats may be in larger blocks than converted, although the sources do not agree on the actual numbers. The more recent data [White 2011] suggest an average of 10 purpose-built flats per block, compared with 7.25 converted flats per block. Note that these numbers also disagree with the estimate derived from the analysis of the planning proposals.

Given that existing blocks of converted flats are smaller than purpose-built blocks, and that existing blocks of both purpose-built and converted flats are smaller than the average size estimated from planning data (above), a sensitivity analysis was conducted to determine the cost-effectiveness of sprinklers as a function of the number of flats in the block.

5.16 Risks of fire, death, injury and average damage

By combining the fire statistics data with the numbers of buildings, it is possible to estimate the annual risks in different building types. These are shown in Table 14.

Table 14 - Estimate of the annual risks from fire in different building types

Building type	Fires per 10^6 buildings [a]	Deaths per 10^6 buildings [a]	Injuries per 10^6 buildings [a]
House (single occupancy)	1,202	10	254
House (multiple occupancy)	3,606	26	795
Flat (purpose-built)	4,306	20	895
Flat (converted)	2,791	18	641
Care home (elderly people)	46,412	351 [b]	5,034
Care home (children)	164,994 [c]	291 [c]	12,955 [c]
Care home (disabled people)	23,295	80	1,416

Notes

a) Risks in flats are per flat, not per building (block).

b) Includes the effect of the Rosepark fire 2004, in which 14 people died.

c) The uncertainties on these values are very large, due to very small sample sizes in the fire statistics.

It can be seen in Table 14 that the risks in HMOs are similar to those for flats. The fire statistics used in this study include both traditional bedsit-type HMOs and shared houses as well as licensed and unlicensed in the HMO category. The statistics collected using the Incident Recording System [CLG 2009] should distinguish between licensed and unlicensed HMOs in the future. It is possible that this information will highlight a difference in risk between licensed and unlicensed HMOs. If reliable data for the number of licensed and unlicensed HMOs becomes available, then a cost benefit analysis could be carried out on each of the categories separately in the future.

6 Results of the cost benefit analysis

The Monte Carlo cost benefit analysis calculations, for sprinklers as an additional safety measure, were performed 1,000 times for each building type in order to build up the probability distributions for the outcomes. The summarised results are shown in Tables 15 and 16. More details are to be found in Appendix E.

Table 15 - Summary results of CBA calculations for sprinklers as an additional safety measure

Building type	Annual Net Benefit	Benefit-to-cost ratio	Net Present Value
House (single occupancy)	-£198 ± 26	0.14 ± 0.02	-£5,885 ± 633
House (multiple occupancy – shared)	-£132 ± 29	0.43 ± 0.07	-£2,937 ± 802
House (multiple occupancy – bedsit type)	£48 ± 18	1.96 ± 0.49	£2,858 ± £666
Flat (purpose-built)	£48 ± 14	2.36 ± 0.69	£2,915 ± 562
Flat (converted)	£20 ± 15	1.51 ± 0.48	£1,872 ± 516
Care home (elderly people)	£1,038 ± 476	2.82 ± 1.35	£60,766 ± 17,124
Care home (children)	£5,693 ± 28,926	13.33 ± 91.40	£268,107 ± 1.29m
Care home (disabled people)	£332 ± 287	1.86 ± 0.86	£22,848 ± 11,285

The uncertainties in the table represent ± 1 standard deviation.

Note. These calculations are where the water supply is a pump and tank.

It is important to realise that the uncertainty reflects only the component that can be quantified (e.g. estimated from statistics). It does not include other components, which may in some cases be more significant, for example, uncertainties in the average cost of fire in care homes.

The figures shown in Table 15 have assumed that the water supply costs are due to the provision of a pump and tank (the most expensive of the three water supply options we have considered). The rationale behind this is that, if sprinklers are cost-effective for the most expensive water supply option, they will also be effective for cheaper options. Appendix G contains the results of a sensitivity analysis, which (among other things) allow the effect of cheaper water supplies to be evaluated. With reference to Table 15, it can be seen that the outcome of the cost benefit analysis for HMOs is presented as two different cases. The first one is for shared houses and the second one is for traditional bedsit-type HMOs. In carrying out the cost benefit analysis for these two different cases, it should be noted that the numbers of fires, deaths, and injuries taken from the fire statistics are averaged over both types of HMOs and that it is not possible to assign any numbers specifically to traditional HMOs or to shared houses. In addition, it has been assumed that on average there are six traditional bedsit-type HMOs per building [White 2011] and that the costs of the system, installation and maintenance will be shared between individual traditional bedsit-type HMOs within the building. Clearly, if there are less than six traditional bedsit-type HMOs per building or the costs cannot be shared for any reason, then the assumptions upon which the cost benefit outcome reported in table 15 will no longer be valid.

As a reminder, for residential sprinklers to be cost-effective, the following inequality needs to be satisfied:

$$\left(\frac{\pounds B_{tot}}{\pounds C}\right) \geq 1 \qquad \text{[Equation 6]}$$

In the single-occupancy house, the annual net benefit is negative. In this case, the cheapest water supply option (negligible cost) would save about £45 per year, relative to the pump and tank option. Based on the cost data supplied by the Industry, the analysis as described and using the cheapest (£nil) water supply option, the conclusion is that sprinklers will not be cost-effective for single occupancy houses in the UK.

In the current work, the net benefit of sprinklers in flats is generally positive, particularly in new-build. In the previous work [Williams et al 2004], sprinklers were only shown to be significantly cost-effective in blocks of flats above 10 storeys in height. The main differences in the data and assumptions that have caused the assessment to change are that the installation cost is lower, the maintenance costs are lower because (according to industry advice via the project Stakeholder Group) access is not required to each flat, the higher revised estimates of sprinkler effectiveness in preventing deaths and injuries and reduced fire damage.

In the shared houses category of HMOs, the annual net benefit is negative. This is consistent with the outcome reported above for single occupancy housing and indicates that with the current costs associated with the system, installation and maintenance of a sprinkler system (as provided by the Industry) and the current recorded risks of death, injury and property damage, sprinklers will not be cost-effective for shared houses.

In traditional bed-sit type HMOs where there are at least six bed-sit units per building and costs of the system, installation and maintenance are shared, then the annual net benefit is positive and cost effective. If, in the future, the collection of data for the fire statistics and English Housing survey can be aligned, then it might be expected that higher risks will be associated with traditional bed-sit type (or licensed) HMOs which, assuming all other parameters remain constant, would improve the cost effectiveness of sprinklers. In care homes, the current estimates of installation and water supply costs are significantly higher than they were in the previous work. However, this is counterbalanced by higher estimates of sprinkler effectiveness. Previously, it was assumed that the cost of damage in care homes (in the absence of sprinklers) was the same as in domestic dwellings (about £7.5k in 2010 prices). In the current calculations, it was assumed that the cost of fire in care homes (which are larger than domestic dwellings, significantly so in the case of care homes for elderly people) should be £33.6k per fire, using the value recommended for “non-domestic” occupancies.

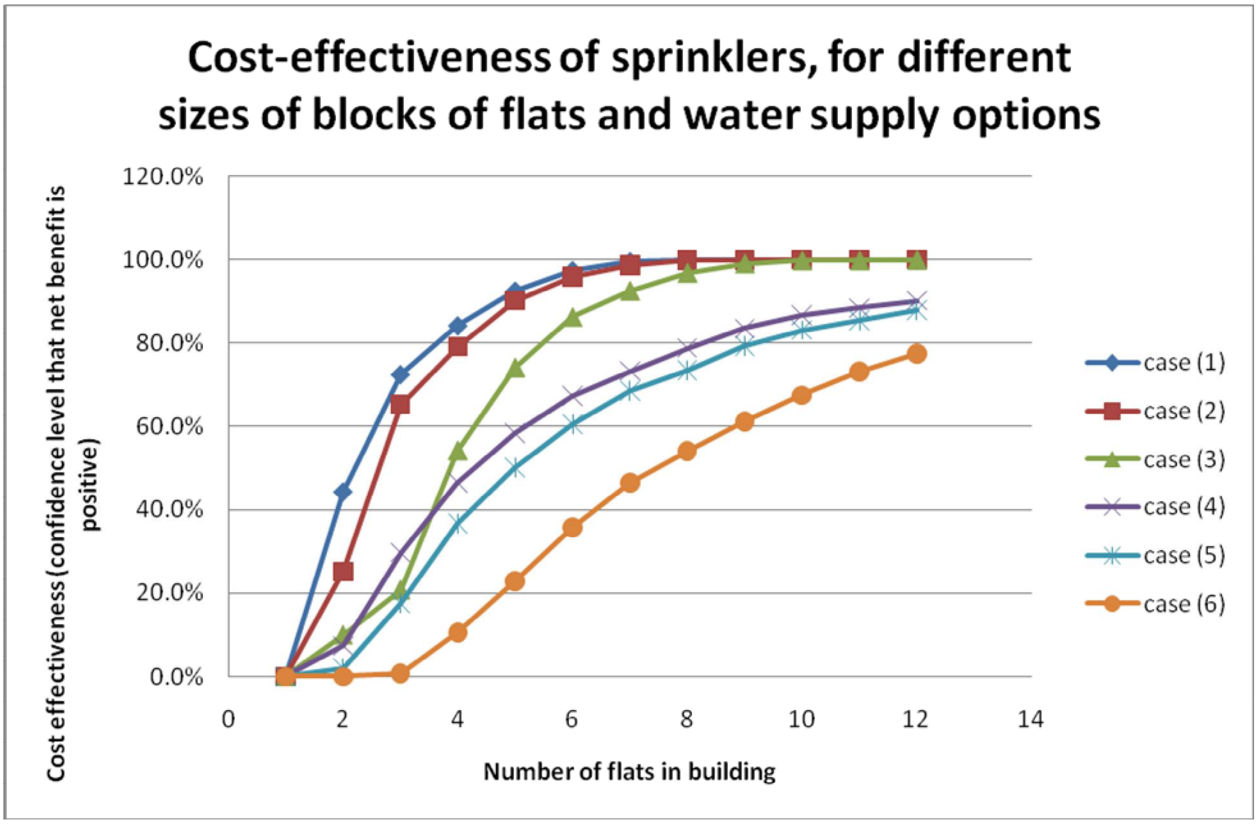
As shown in Table 15, the results of the cost benefit analysis are subject to uncertainties which may be large in some cases. One way to appreciate the influence of uncertainty on the conclusions is to calculate the likelihood that the net cost benefit will be positive. The results of these calculations are shown in Table 16.

Table 16 - Confidence level that benefits exceed costs, for sprinklers as an additional safety measure

Building type	**Confidence level** **(cheapest option, zero water supply cost)**	**Confidence level** **(most expensive option, water supply is pump and tank)**
House (single occupancy)	0%	0%
House (multiple occupancy – shared)	0%	0%
House (multiple occupancy – bedsit type)	100%	99%
Flat (purpose-built)	100%	100%
Flat (converted)	96%	91%
Care home (elderly people)	100%	99%
Care home (children)	99%	99%
Care home (disabled people)	97%	90%

These confidence levels have been estimated directly from the Monte Carlo calculation results, from the proportion of calculations where the net benefits are positive. It is possible that the currently un-quantified components of the uncertainty would reduce the confidence levels, if they could be included.

A sensitivity analysis was conducted to determine the cost-effectiveness of sprinklers as a function of the number of flats in a block, with different water supply options (no extra cost, boosted mains, or pumps and tanks). The results are shown in Figure 1.



Case 1 = purpose-built flats, no additional water supply cost; case 2 = purpose-built flats, boosted mains; case 3 = purpose-built flats, pump and tank, case 4 = converted flats, no additional water supply cost; case 5 = converted flats, boosted mains; case 6 = converted flats, pump and tank.

Figure 1 - The confidence level that sprinklers will be cost-effective as an additional safety measure, as a function of the number of flats in a building (block), for different water supply options

In order to be "certain" that sprinklers will be cost-effective, a confidence level in excess of 95% should be achieved (this is a common convention in statistical analysis). Figure 1 shows that there is a clear relationship between the 95% confidence level for larger blocks of flats where more flats share the system, installation and maintenance costs. For example, a purpose-built block reaches this level with 8 or more flats for the most expensive of the three water supply options. Converted flats have greater costs (due to retro-fitting) and smaller benefits (see Appendix E), so a greater number of flats is required to share the system, installation and maintenance costs.

To summarise, based on the cost data supplied by the Industry, the assumptions presented in this report (including all sprinkler systems assumed to be based on a tank and pump and with zero cost for connection to the water mains) and the analysis as described:

- residential sprinklers as an additional safety measure would be cost-effective in most blocks of purpose built flats where the costs of the system, installation and maintenance are shared.
- residential sprinklers as an additional safety measure would be cost-effective in larger blocks of converted flats where the costs of the system, installation and maintenance are shared.

- residential sprinklers as an additional safety measure would be cost-effective in traditional bedsit type HMOs where there are at least six bed-sit units per building and costs of the system, installation and maintenance are shared.
- residential sprinklers as an additional safety measure would be cost-effective in care homes for elderly people, children and disabled people (including those with single bedrooms)
- residential sprinklers as an additional safety measure would not be cost-effective in shared houses as included in the English housing survey definition of HMOs.
- residential sprinklers as an additional safety measure would not be cost-effective in two storey houses

A sensitivity analysis has been performed, that gives the change in the outcome (net benefit) for a given change in any input parameter. This is more flexible than a “what-if” analysis that reruns the calculations for specific alternative values of one or more input parameters. The results of this analysis are given in Appendix G.

One of the uses of this information is to quantify the possible effect of future trends, providing the trend can be expressed in terms of changes to one or more of the input parameter values. Future trends are discussed in section 7.

7 Variations: Future Trends, Special Cases, Trade-offs and "What-if" scenarios

As clearly evidenced by the preceding sections of this report, the cost-benefit analysis relies on many factors. The impacts of all of these factors are subject to lesser or greater degrees of uncertainty. The acquisition of further data in the future should help to reduce this uncertainty.

In some cases, uncertainty arises due to future trends, where the data is expected to change over time. A number of these trends have been identified, and the expected qualitative impacts discussed below. Few of the future trends can currently be quantified with any degree of robustness.

In mitigation of these difficulties, the sensitivity analysis (see section 6 and Appendix G) can be exploited to consider the effects of different "what-if" scenarios. Such an approach can yield valuable insights, and provide impetus to drive future developments in promising directions.

It should be noted that the cost-benefit calculations presented in the previous sections were performed for "average" examples of each building property type. In reality, the individual circumstances of particular developments could significantly affect whether or not sprinklers would be cost-effective in these cases.

This chapter considers current "trade-off's", future trends "special cases" and "what-if" scenarios.

7.1 Future trends

There are a large number of future trends that could affect the outcome of the current cost benefit analysis in relation to fire safety and sprinkler protection in residential premises. The trends that were identified in consultation with the project Stakeholder Group were:

- Social changes
- Economic impact
- Building changes
- Regulatory and technical standards changes
- Environmental impact.

Although important, environmental impact was outside the scope of this project. This is currently an active area of research, which, in time, will yield quantitative results and a means of bench-marking different fire protection strategies, based upon overall environmental impact assessment. The other trends are discussed further in the following sections.

All of the future trends will affect the cost-benefit analysis to a greater or lesser degree. In some cases the trends may make sprinklers more cost-effective in future, and in some cases some trends may reduce the cost-effectiveness. If a future trend is considered in isolation, this rightly comes under the category of a what-if scenario, and the results of any analysis are presented as such.

Facts from the most recent digest of the UK fire statistics [Williams et al 2010] for the period April 2008 – April 2009 included the following;

- The total number of dwelling fires was 49,600, of which 41,000 were started accidentally
- 'Misuse of equipment and appliances' accounted for 1/3 of accidental fires
- Cooking appliances were the cause of over half of all accidental fires (there is an overlap between this category and the one above)
- The leading cause of fatal accidental fires was 'careless handling of fire or hot substances (mainly the careless disposal of cigarettes)', accounting for 113 out of a total of 294 accidental fire deaths in 2008. However, the overall trend is for a decline in the number of fatal fires caused by smoker's materials.
- Although cooking appliances caused over 50% of accidental fires, they were only responsible for about 15% of accidental fire deaths.

  In addition, some long-term trends in the numbers of different types of fire and causes of death included:

- Chip pan fires fell by half from 1998, to 4,800 fires in 2008
- Over the same period, instances of playing with fire have fallen by 2/3
- Candle fires fell by 1/3 from 2,100 in 2000 to 1,400 in 2008
- Smoking-related fires fell by 1/3 from 2000 to 2008

7.1.1 Social changes

Social changes could include:

- Ageing, infirm and mobility impaired population
- Long term unemployment and reduced disposable income (social deprivation)
- Singleton living
- Home working
- Smoking
- Immigration.

<u>Ageing, infirm and incapacitated population</u>

People are on average living longer and consequently the population is ageing. Various initiatives, for example, 'Care in the Community' etc 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 would increase the risk of fires and fire deaths [Arson Control Forum 2006].

In addition, there is a trend of an increase in obesity in the population. Larger and heavier people will find it harder to escape or be rescued in the event of a fire.

Therefore, the qualitative trend of an increasingly ageing, infirm and mobility impaired population would affect the cost benefit factors by increasing the risk of fires and associated fire deaths and injuries It is also suggested that there would be a resulting increase in the number of fire injuries and property damage. In addition, the sprinkler effectiveness factors for death and injury would decrease.

Those aged between 70 and 80 are twice as likely to be killed in a house fire than would be expected given their prevalence within the general population (16% compared with 7%), with those aged over 80 nearly five times more likely to be killed in a house fire than would be expected (19% compared with 4%) given the current age-profile of the population [Arson Control Forum 2006]. The impact of this trend is illustrated in section 7.2

Long term unemployment and reduced disposable income

This recession, as in past recessions, has seen an increase in unemployment. A long term unemployed person with a reduced disposable income might spend more time at home and have less money to spend on replacing or maintaining old appliances (see Economic impact section 7.1.2). Similarly, cheaper options for heating and lighting might be used, for example candles, open fires or portable heating appliances. These might result in an increased risk of a fire occurring.

Therefore, the qualitative trend of increasing unemployment and reduced disposable income would probably affect the cost benefit factors by increasing the number of fires. It is also suggested that there would be a resulting increase in the number of fire deaths, injuries and property damage.

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 increases the risk of fires and fire deaths [Arson Control Forum 2006]. Therefore, the qualitative trend of increasing singleton living would affect the cost benefit factors by increasing the number of fires and fire deaths.

Home working

With changes in working patterns, locations, computer technology, the cost of housing and the need for flexibility, there is a current trend for people to work more from home. The impact of this is difficult to estimate. It could be argued that an increase in home working would affect the cost benefit analysis factors by increasing the number of fires and increasing the number of fire deaths, injuries and property damage or conversely, if a home is occupied for greater periods of time, the occurrence of a fire may be more easily detected.

Smoking

Changes in smoking trends would be expected to impact on fire safety as ‘careless use of smokers’ materials is responsible for about half the accidental fatal fires in the UK [Williams et al 2010].

In response to this baseline fact, which is mirrored in many other countries, 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. 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”.

If the qualitative trend of either declining smoking and/or a reduction in the number of accidental fires the impact on the cost benefit factors would be a decrease in the number of fires and reduction in the number of fire deaths, injuries and property damage. Conversely, if RIP cigarettes do not impact on the fire statistics, then the current status quo would be maintained.

<u>Immigration</u>

There has been a recent trend in increasing numbers of people coming to live and work in the UK from the European Union and other countries. People from different countries run their households differently, for example different sized family groups, operate different safety regimes, may have greater or lesser use of candles and open fires. There are no UK data to determine how the qualitative trend of an increase in immigration would affect the cost benefit factors.

7.1.2 Economic impact

Economic impact could include:

- Recession and ageing appliances
- Reliability of water supplies
- Water connection charges
- Reliability of electricity supplies.

<u>Recession and ageing appliances</u>

In a recession, people may keep their electrical appliances for a longer period of time before replacing them and are less likely to maintain their equipment due to a lack of disposable income. Ageing and faulty electrical appliances increase the risk of a fire occurring [Arson Control Forum 2006], although there is no statistical data to indicate by how much.

Therefore, the qualitative trend of an increase in ageing and poorly maintained appliances would affect the cost benefit factors by increasing the number of fires. There is also a suggested possibility that the number of fire deaths, injuries and property damage would also increase.

In a recession, another effect would be to reduce the capital recovery factor in the cost benefit analysis.

<u>Reliability of water supplies</u>

The reliability of water supplies is critical to the performance of the residential sprinkler system. It is important that sprinkler system water supplies are reliable and provide sufficient flow and pressure to satisfy the system design requirements. The reliability of water supplies can be reduced by interruptions to the water and pressure reduction initiatives. The qualitative trend of a reduction in the reliability of water supplies would affect the cost benefit factors by decreasing the sprinkler effectiveness factor for death, injury and property damage.

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, more widespread adoption of sprinkler systems and possible amendments to the water industry Act [King 2011b]. The qualitative trend of decreasing water connection charges will make the installation of residential sprinklers more cost beneficial.

Reliability of electricity supplies

The reliability of electrical supplies is critical to the performance of the residential sprinkler systems containing electrical components, e.g. electric sprinkler pumps.

Meeting the demand for electricity is an issue for the UK in the short to medium term. The infrastructure of aged power plants is unlikely to satisfy the demand and power cuts are probable. This qualitative trend of a reduction in the reliability of electrical supplies needs to be considered when installing a sprinkler system as it will impact on the cost benefit factors by decreasing the sprinkler effectiveness factor for death, injury and property damage. If the reliability of electrical supplies is reduced, there is also a suggested possibility that the number of fires would increase due to the use of candles for lighting, open fires for heating and cooking and this would result in an increase in the number of fire deaths, injuries and property damage.

7.1.3 Building changes

Building changes could include:

- Ageing existing stock and refurbishment
- Multi-storey and open plan designs
- Smaller size and more densely packed buildings
- Modern methods of construction
- Use of plastics and insulation
- Contents and ignition sources.

Ageing existing stock and refurbishment

To enable the UK to meet its carbon reduction targets, energy improvements are focussed on the refurbishment of the existing building stock. This is because this will result in a much greater impact in a shorter period of time due to existing buildings being the much greater proportion of the building stock than new build.

Some of the new techniques being used in refurbishment to improve the energy performance of buildings, such as increased foamed polymeric thermal insulation, could introduce new uncharacterised fire risks. However, there are no definitive data to quantify any new additional risks at this time although there is a suggested possibility that an ageing building stock and the increasing drive for refurbishment might increase the number of fire deaths, injuries and property damage.

The fitting of sprinklers to existing building stock could mitigate against potential additional fire risks. However, if considering the costs and benefits, information from the industry does suggest that the costs of installation of a sprinkler system into an existing building would be higher than for new build.

Multi-storey and open plan designs
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.

Smaller size and more densely packed buildings

Due to energy efficiency and housing costs, there is a current trend for building smaller size houses and flats and packing them more densely which could affect the cost benefit factors by decreasing the sprinkler installation and water supply costs.

Modern methods of construction

Modern Methods of Construction and innovative materials are being considered to meet the sustainability agenda. These materials tend to be more combustible and it needs to be ensured that these new technologies are properly assessed for their potential performance in fire so that any fire risks that they introduce can be managed using appropriate fire protection measures (active and passive) to deliver the performance required by the building regulations.

Based on the fire statistics to date, although there appears to be an emerging trend of fire incidents leading to disproportionate property damage both during (e.g. timber-frame) and post construction, there is no evidence of associated increased injuries or loss of life in lightweight modern methods of construction. Various fire safety protection measures (including sprinklers, fire detection and passive fire protection in isolation and in combination) are being proposed to provide protection to timber-frame buildings during the construction phase.

Use of plastics and insulation

There is a trend for a greater use of 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.

7.1.4 Regulatory and technical standards changes

Regulatory and technical standards changes could include

- Smoke alarms
- Re-specified/improved/simpler system design

- Maintenance regime.
- Fire safety legislation in Wales

Smoke alarms

Due to the current regulatory requirements, smoke alarm penetration into the domestic housing sector affects the baseline risk against which the impact of residential sprinklers will be assessed. That is, the greater the number of buildings protected by smoke alarms, the lower the baseline risk will be. However, it is considered that the voluntary installation of smoke alarms has probably reached its peak level and therefore further market penetration will only be achieved through new buildings and refurbishment projects.

Further, it should be noted that if every building were protected by smoke alarms, the risk of fire death or injury would not be reduced to zero i.e. some fire deaths and injuries do occur in buildings protected by smoke alarms. In 2010 about half the fire deaths (150+) occurred where there were working smoke detectors. Some of these deaths would have been prevented had sprinklers been present.

Re-specified/improved/simpler 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.

Features of low cost prototype systems (in relation to current BS 9251 systems) include: direct connection to towns mains water supply; combined sprinkler and plumbing system; less components; little maintenance; use of ‘standard’ residential sprinkler heads; less water/lower pressures/flows; restrictions to certain types of houses; fewer protected areas in house, compliance with water authority regulations.

There is relevant published information on work on the development of ‘lower cost’ sprinkler systems, including work by the Building Research Association New Zealand (BRANZ) carried out on behalf of the New Zealand Fire Service Commission [Duncan et al 2000] and The Fire Protection Association, UK, commissioned by the Department for Communities and Local Government [Fire Protection Association 2007]. The New Zealand low cost system is specified in an additional New Zealand standard, NZS 4517 [Standards New Zealand 2010]. The DCLG ‘lower cost’ domestic sprinkler system specification is unpublished.

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 decreasing the frequency of tests or inspection visits are expected to result in higher figures for reliability and lower maintenance costs. This would have a beneficial impact on the cost benefit calculations presented in this work.

Fire safety legislation in Wales.

Over time, with the introduction of sprinklers into all new residential buildings in Wales, a reduction in deaths, injuries and property damage would be expected. It will take time for the impact of the new legislation to become apparent. This is because the legislation only affects new-build and refurbished domestic and residential buildings and it would take a period of time before buildings constructed or refurbished in accordance with the legislation became a significant fraction of the building stock in Wales. Clearly, once the legislation is in force, then data relating to the costs of installing sprinkler systems and the impact of sprinklers on deaths, injuries and property damage will become more relevant and realistic and will become the basis to inform such future decisions in other parts of the UK.

7.2 Estimating the quantitative effect of future trends

If the effect that a future trend has on an input parameter's value can be quantified, the results of the sensitivity calculation can then predict how the net benefit of sprinklers would be affected. Two example calculations are given below to illustrate the procedure.

The proportion of elderly people in the population is increasing. The Office of National Statistics has estimated [Dunnell 2008, Office of National Statistics 2009] that the proportion of people aged between 65 and 85 will rise from 14% to 18% from 2009 to 2034, and the proportion of people aged above 85 would rise from 2% to 5%. Statistics have shown that elderly people are more likely to die in fires. For people aged between 70 and 80 the risk is 2 times higher, and for people above 80 the risk is 5 times higher [Arson Control Forum 2006]. Although there is not a precise correspondence between the age categories in the two sets of statistics, a rough estimate of the increase in deaths due to the aging population would be 2x 4% + 5x 3% = 23% over 25 years (from 2009 to 2034). If the growth rate is approximately linear, then the increase in deaths is roughly equivalent to an increase of 11.5% over all 25 years.

This estimate assumes that the proportions of elderly persons in houses and care homes remain similar to their current values. If, for example due to government policies, the proportion of elderly people remaining in their houses increases in future years, then the effect of the ageing population on the number of fire deaths may be greater.

In houses, the current risk of death (over the whole population) is 10 deaths per year per million houses. An increase of 11.5% is 1.15 deaths per year per million houses. From the sensitivity analysis of the costs and benefits of sprinklers in single-occupancy houses (see Appendix G), the annual net benefit changes by £1.49 for every additional death per year per million houses. Hence, the effect of the aging population would be to increase the annual net benefit by 1.15 x £1.49 = £1.73. As the net benefit is currently -£200 per year (i.e. a net cost), based on the figures presented here, the effect of the ageing population, assuming that all other factors remain unchanged, does not alter the overall outcome of the cost benefit analysis.

7.3 Residential sprinkler trade-offs

Trade-off benefits, also known as alternative solutions or compensatory features, are currently widely used, but their application varies from country to country. They are applied successfully across the whole range of domestic and residential buildings, from houses, through residential care homes to high rise blocks of flats.

The cost benefit analysis considered residential sprinklers as an additional safety measure. If sprinklers are considered as compensatory features, then the costs saved by trade-offs such as those discussed below would need to be valued and factored into the cost benefit analysis. Depending on the trade-offs, residential sprinklers could become cost-effective in a broader range of residential buildings.

7.3.1 Building Regulations and Approved Document B

In England and Wales, Approved Document B ("AD B") is one of a series of documents providing practical guidance with respect to the requirements of Schedule 1 to and Regulation 7 of the Buildings Regulations 2000 [SI 2000/2531]. AD B is intended to provide guidance for some of the more common building situations; however, it is recognised that there may be more than one way of achieving compliance with the requirements of the Building Regulations. For some situations, alternative solutions that involve the use of residential sprinkler systems are expressly mentioned by AD B.

Examples of residential sprinkler trade-offs mentioned in AD B include:

- Removal of second staircase in 4-storey house
- Flexibility in terms of open-plan design and loft conversions
- Decreased building separation
- Flexibility in layouts for "multi-level" flats
- Flexibility in certain aspects of design and fire safety management of residential care homes
- Any block of flats with a floor at a height of more than 30m above ground should have sprinklers
- Fewer fire-fighting shafts need to be provided
- Basements need not have provision for natural ventilation
- Increased travel distances and compartment sizes

<u>Removal of second staircase</u>

AD B volume 1 [2006], clause 2.7, states that dwelling houses with two or more floors more than 4.5m above the ground (i.e., most 4-storey houses) should have alternative escape routes (i.e. a second stairwell, in most cases) for each storey above 4.5m. Fire resisting construction may also be needed. Alternatively if the house is fitted throughout with a sprinkler system designed and installed in accordance with BS 9251:2005 then these measures may not be necessary. The benefit of using sprinklers would be to increase the proportion of the floor area of the house available for the habitable rooms, and hence increase the value of the house.

Dwelling houses with just one floor more than 4.5m above the ground (i.e. most 3-storey houses) should either have an alternative escape route as above, or a single protected stairway (AD B vol.1 [2006] clause 2.6). Whilst the walls would normally have the necessary fire resistance anyway, fire doors would also be required for doors leading to this stairway. Although AD B does not specifically mention sprinklers as an alternative in this case, it may be that there is a trade-off benefit to be had here as well (since clause 2.7 for 4-storey houses is more onerous than clause 2.6 for 3-storey houses).

Loft conversions and open-plan layouts

Clause 2.20 refers to loft conversions in existing dwellings. If this would result in a floor more than 4.5m above the ground then clause 2.6 would apply, with the specification of a protected stairway. However, some 2-storey houses are built with an “open-plan” layout for the ground floor. Rather than provide a partition between the stairway and the rest of the ground floor, if the open-plan area has sprinkler protection then it is sufficient for the upper floors to be protected to enable occupants to use escape windows on the first floor.

Multi-level flats

AD B volume 2 [2006] covers all building types other than dwelling houses. Thus it is relevant for blocks of flats (whether purpose-built or converted), residential care homes, etc.

Where (individual) flats are built on more than one level, clause 2.16 includes sprinkler protection and a protected stairway within the flat as one of the alternatives. As the protected stair features among all of the various alternatives in this clause, the potential benefit from using sprinklers just for this compensatory feature is not so clear. However, if sprinklers are also being used to compensate for other features as well, then this alternative may increase the benefits to be had.

Residential care homes

Residential care homes, particularly larger buildings, may see a number of benefits if they have sprinkler protection. According to clause 3.52 of AD B volume 2 [2006], if sprinklers are present then:

- Fire doors to the bedrooms do not require self-closers (although these are still required for fire doors within the corridors);
- The residential areas of care homes must be sub-divided into at least 3 protected areas by compartment walls – without sprinklers, each protected area may only have up to 10 beds, but with sprinklers there is no limit on the number; and
- Bedrooms may contain more than one bed if sprinkler protection is available

With regard to the last of these bullet points, it is worth commenting that the cost-benefit analysis (for sprinklers as an additional safety feature) did not explicitly consider whether bedrooms had more than one bed or not. However, as the analysis was based on fire statistics, and since few if any of the care homes where fires were reported had sprinklers, it would be reasonable to assume that most of these care homes only had one bed (which may be a double bed) in each bedroom. Even though AD B does not “require” sprinklers in care homes with only one bed per room, the cost-benefit analysis showed that sprinklers would be cost-effective as an additional measure in these cases.

Blocks of flats higher than 30m

Where blocks of flats have a top floor more than 30m above the ground level, sprinkler protection is the only option mentioned by AD B vol.2 (clause 8.14). This clause introduces some variation from the BS 9251: 2005 standard, in that sprinkler protection of the common parts is not required, only the individual flats. The fact that the Standard also strictly applies only to buildings with a top floor less than 20m high is ignored.

Reduced boundary distances

Where sprinkler protection is available, boundary distances may be reduced by half (subject to a minimum distance of 1m remaining) in comparison with an otherwise identical building without sprinklers (clause 9.15 of AD B vol.1, or 13.17 of AD B vol.2). This enables buildings to be constructed closer together, thus building more on smaller plot sizes, and ultimately increasing the value for the investor.

Fire-fighting shafts

Buildings with a floor more than 18m above the ground level (or access level for fire-fighters, if different) need to include fire-fighting shafts to enable the fire-fighters to gain access to the upper floors of the building (AD B vol.2, clauses 17.9-17.10). Without sprinklers, every point on the floor must be within 45m of a fire main outlet within a protected stairway, and within 60m of a fire main outlet in a fire-fighting shaft. With sprinkler protection, every point only needs to be within 60m of a fire main in a fire-fighting shaft. Sprinklers therefore reduce the number of fire mains that are required (though not the number of fire-fighting shafts, and probably not the number of protected stairways which would be determined primarily by vertical means of escape requirements).

Basements

Finally, if the building has a basement, sprinkler protection and mechanical smoke extraction for the basement eliminates the need to provide for natural ventilation (clause 18.13, AD B vol.2).

Inadequate Fire and Rescue Service Access

For the purposes of AD B, Vehicle access to the exterior of a building is needed to enable high reach appliances, such as turntable ladders and hydraulic platforms, to be used and to enable pumping appliances to supply water and equipment for fire fighting, search and rescue activities (AD B vol 2, Section 16). Access requirements increase with building size and height. In some cases, for example “infill developments” where new buildings are constructed away from main roads, provision of fire appliance access and water supplies as recommended may not be possible if the site is quite small and constricted. Sprinkler protection is increasingly being used to compensate for the additional time that firefighters would require as a consequence of the restricted access and lack of hydrants.

7.3.2 BS 9999 Code of practice for fire safety in design, management and use of buildings

Further opportunities for “trade-off” are described in BS 9999:2008 Code of practice for fire safety in the design, management and use of buildings. As the title of the document states, this is a code of practice, so contains recommendations rather than specifications. The scope of the document covers all buildings with the exception of dwelling houses.

One of the underlying principles supporting BS 9999:2008 is that all building types can be assigned a “risk profile”. This is primarily determined by the nature of the occupants (whether familiar with the building or not, and whether likely to be asleep or not), and the likely rapidity of fire growth. Domestic and residential buildings would tend to have a risk profile of “C2”, where “C” means occupants may be asleep within the building, and “2” means the likely fire growth would follow a “medium” t-squared fire. (A growth rate of “1” would be a “slow” fire, “3” would be “fast”, and “4” would be “ultra-fast”)

The risk profile is used to set guidelines for parameters such as travel distances, door widths, fire resistance, etc. A building with sprinkler protection is assumed to have a lower risk than an otherwise similar building without sprinklers. This is represented within BS 9999:2008 by reducing the growth rate by one step, thus a risk profile of C2 (without sprinklers) would be regarded as a risk profile of C1 with sprinklers present.

Consequences of changing the risk profile due to the inclusion of sprinklers include, for example:

- Increased travel distances
- Reduced fire resistance requirements

Increased travel distances

According to BS 9999:2008 Table 12, recommended travel distances for a risk level of "C2" are 18m where there are two possible directions of escape, and 9m where there is only one direction (i.e. a "dead end" configuration). If the risk is reduced to level "C1" then the recommended travel distances are 27m and 13m respectively.

By way of comparison, the recommended travel distances in AD B vol.2 (Table 2) for buildings in Purpose Group 2a ("Institutional") are also 18m (two directions) or 9m (one direction), as are the distances in bedrooms in Purpose Group 2b ("Other residential"). For common areas of flats, AD B vol.2 (Table 1) gives 30m (2 directions) or 7.5m (dead end). The Government guidance on the fire safety risk assessment for sleeping accommodation (Table 3) quotes values of 18m / 9m for bedrooms and higher risk areas, 30m / 18m for areas of normal fire risk, and 45m / 25m for areas of lower risk. The higher values are for situations where two directions are available, and the lower values are for dead end situations. Thus, there is a consistent principle that travel distance can be increased if risk is reduced, although there is less consistency when it comes to recommended values.

Reduced fire resistance

Clause 6.4 of BS 9999:2008 states that only sprinkler systems meeting the specification of BS EN 12845 (new systems) or BS 5306-2 (existing systems) would be acceptable to allow a reduction in the fire resistance of structural elements. However Table 25 (which defines the fire resistance requirements for different risk profiles) says in a footnote that systems compliant with BS 9251 are acceptable in domestic and residential occupancies (this is consistent with AD B). In Table 25, the relaxations are:

- Buildings in the "other residential" category may have 30 minutes less fire resistance if sprinklers are present, compared with when they are not.
- Buildings in the "other residential" category with a storey floor more than 30m above the access (i.e. ground) level should have sprinklers; for a block of flats the height limit is 18m (in contrast to the AD B limit of 30m).

Further trade-off options in BS 9999:2008

A number of further trade-offs that could be obtained with sprinklers present are similar in both BS 9999:2008 and AD B (2006). These include:

- The boundary distance separation for a sprinklered building may be half that of an otherwise similar unsprinklered building (clause 36.3.2, c.f. AD B clause 9.15 of AD B vol.1, or 13.17 of AD B vol.2). Alternatively the unprotected area (usually glazing) may be twice as large.
- The requirements for the number and placement of fire-fighting shafts (clause 21.2.3) are very similar to those in AD B (AD B vol.2, clauses 17.9-17.10). There are two differences; one is that only sprinkler systems meeting the specification of BS EN 12845 (new systems) or BS 5306-2 (existing systems) would be acceptable to allow a relaxation. However, like the fire resistance relaxation, the intention might have been to include BS 9251 systems in domestic or residential buildings. The other difference is that fire-fighting shafts are recommended once any storey floor height exceeds 11m (in AD B, the limit is 18m).
- Mechanical ventilation, rather than natural ventilation, can be used for basements, provided there is sprinkler protection (clause 28.3.3), as per AD B.

One option suggested by BS 9999:2008 (clause 46.9), not in AD B (2006), is that ordinary (non-evacuation) lifts could be used in the early stages of a fire, if a risk assessment concludes that this is reasonable (this approach is also suggested in Government guidance to the fire safety risk assessment for sleeping accommodation). For example, if the building is protected by sprinklers and either smoke control or significant compartmentation, then the risk assessment might determine that lifts could be used.

Further guidance on the trade-off benefits associated with the installation of sprinkler systems can be found in “Using sprinkler systems in buildings and structures” [BAFSA 2012].

7.3.3 BS 9991 Code of practice for fire safety in design, management and use of residential buildings

Opportunities for “trade-off” in residential buildings are described in BS 9991:2011 Fire safety in the design, management and use of residential buildings – Code of practice. As the title of the document states, this is a code of practice and therefore contains recommendations rather than specifications. The scope of the document covers single-family dwelling houses, self-contained flats or maisonettes, residential accommodation blocks with individual bedrooms and shared kitchen/sanitary facilities, sheltered housing and extra care housing.

Open plan flats.

In 2009 the NHBC Foundation published a report, “Open plan flat layouts. Assessing life safety in the event of fire”[Fraser Mitchell and Williams 2009]. Based on this research, BS 9991 states that open plan flat layouts with the front door opening into a living room, off which there are one or more bedrooms, are acceptable provided the flat is fitted with a sprinkler system and an enhanced fire detection and alarm system. Specifically, the sprinkler system should be installed throughout the flat in accordance with BS 9251 or BS EN 12845 in conjunction with a fire alarm system designed and installed in accordance with BS 5839-6, Grade D, LD1. There are limits on the dimensions of the flat in line with what was analysed in the

NHBC report. This measure allows a developer to make a larger living room out of the building footprint, which might potentially add more to the building value than the cost of the sprinkler and fire detection systems. Furthermore, potential purchasers of new flats often prefer open plan layouts, rather than having a corridor from the front door with the living room and bedrooms leading off it.

Fire Brigade access

Where the attendance time of the fire brigade is expected to be no more than 10 minutes, the distance between the fire appliance and any point within a house of up to three storeys (no floor more than 4.5m above ground level) may be up to 90m instead of 45m, provided the house is fully sprinklered. Similarly for four storey houses or flats (one floor more than 4.5m above ground level) the distance may be extended to 75m instead of 45m. This measure makes it possible to build in spaces that are not readily accessible to fire engines, where the access road is only wide enough for a car, such as behind other houses or buildings..

Increased travel distance

If a block of flats (excluding sheltered housing and extra care housing) is fitted with a sprinkler system, the maximum travel distance for escape in common corridors in one direction may be increased from 7.5m to 15m and for escape in more than one direction, from 30m to 60m. In some cases, this increase in maximum travel distance will result in one less staircase required in a building. As such, there is a trade-off between the savings on the staircase against the cost of the sprinkler system.

7.3.4 Fire engineering

Following the guidance in documents such as AD B (2006) or BS 9999:2008 is just one approach to designing buildings for fire safety. Nevertheless, it is still the responsibility of the building designer to ensure that this approach is adequate for the building in question. BS 9999:2008 (clause 19.1) states that “Any (trade-off benefit) should however be carefully reviewed and assessed by the designer”.

AD B notes (clause 0.30) that “Fire safety engineering can provide an alternative approach to fire safety. It may be the only practical way to achieve a satisfactory standard of fire safety “. BS 7974 is the Code of Practice for Fire Safety Engineering.

In general, the practice of Fire Safety Engineering need not be limited to these cases, and could be employed to exploit almost any conceivable trade-off – as long as it can be demonstrated to the satisfaction of the enforcer (BCO) that the requirements of the Building Regulations have been met by the fire-engineered approach.

Some examples of trade-off benefits that might be realised as a consequence of a fire-engineered design include:

- Compensating for reduced Fire and Rescue Service cover and increased attendance times
- Compensating for inadequate Fire and Rescue Service access
- Open plan design for flats
- Stay put policies for residential care

- Reduced staffing levels in care homes at night
- Avoid need for enhanced fire detection.

Reduced FRS cover and increased attendance time

"By their nature, high rise buildings present considerable logistical problems for Fire and Rescue Services in mounting both fire fighting and rescue operations. Moreover, the complexities of fighting fires in compartments within such buildings, establishing the required safe systems of work and the need to ensure firefighter safety all take time and resources. Therefore, it is unlikely that firefighters will be able to affect a safe entry and full fire attack into a flat above the seventh floor in under 15 to 20 minutes. This period of time (15 to 20 minutes) includes the average time taken from the caller ringing 999 to the Fire and Rescue Service tackling the fire. This is not an exact calculation; it is based upon exercises that have been performed and reviews of real incidents attended in high rise blocks of flats" [CFOA 2011].

Based on this statement, it is clear that sprinkler systems could be used as a compensatory measure in high rise buildings below 30m where fire service attendance and access could be an issue.

A correlation between the risk of death in fire, and the attendance time of the Fire Brigade, was used as the basis for establishing the need for Fire Service cover on a geographical basis. [Wright and Izoldi 2007] also makes some estimates of the potential effects of various measures aimed at reducing fire risks.

Inadequate Fire and Rescue Service access

For the purposes of AD B, vehicle access to the exterior of a building is needed to enable high reach appliances, such as turntable ladders and hydraulic platforms, to be used and to enable pumping appliances to supply water and equipment for firefighting, search and rescue activities. Access requirements increase with building size and height.

In some cases, for example "infill developments" where new buildings are constructed between existing buildings, providing access may be limited if the site is quite small and constricted. Sprinkler protection could compensate for the additional time that firefighters would require as a consequence of the restricted access.

Open-plan flat design

There is a growing trend for open-plan flats to be designed. Open-plan layouts are popular because they enable more of the footprint of the flat to be devoted to habitable space (thereby increasing the value of the development).

As guidance for designers, for open plan flat designs similar to those included in a study performed for the NHBC [Fraser-Mitchell and Williams, 2009], active fire protection comprising a sprinkler system in accordance with BS 9251 [British Standards Institution 2005a] or BS EN 12845 [British Standards Institution 2004b] as appropriate, together with an enhanced detection and alarm system (LD1) in accordance with BS 5839-6 [British Standards Institution 2004a], can provide a level of safety that is at least as good as that of a similar AD B compliant design.

These recommendations should not be applied to open plan designs that differ significantly from the cases that have been examined in this study, for example: flats larger than 12 m by 16 m; multi level flats; flats with smoke control systems, water mist and other suppression systems; flats with open plan kitchens close to the front door, and flats in blocks of more than 30m in height. Other differences include the characteristics of the occupants; for example “retirement” flats would have a much greater proportion of families solely comprising elderly occupants than the “typical” populations that have been considered in this study.

In such cases, further work would be required to determine the level of safety relative to a comparable AD B design. A fire engineered solution should consider all aspects of the whole fire system, including fire growth, smoke movement, detection, suppression, human behaviour, and interactions between them.

Residential care homes

The presence of a suitable sprinkler system can enable different options for the fire strategy to be considered. Two closely related possibilities could include the adoption of a “defend in place” strategy, where residents (initially at least) would remain in their rooms rather than be evacuated. Depending on the capabilities of the residents, an evacuation might require considerable assistance (from staff, or members of the fire and rescue services) in order to be effective. Conversely, with a defend in place strategy, the number of staff present at night might be reduced (since large numbers would not be required at night on the off-chance that they might need needed).

7.4 Estimating the quantitative effect of trade-off

As with future trends (section 7.2), it may be possible to quantify some or all of the impacts of alternative solutions on the cost-benefit analysis. Taking the costs of the sprinkler systems as invariant for a particular property type, the annual benefits would be:

- the net difference between the construction costs of the sprinklered building and the unsprinklered alternative(s), discounted (see section 5.5) over the lifetime of the sprinkler system (see section 5.7)
- the net difference between the value of the sprinklered building and the unsprinklered alternative(s), discounted over the lifetime of the sprinkler system
- the net difference between the annual costs of the sprinklered building (e.g. maintenance of the system) and the unsprinklered alternative(s)
- the reduction in annual expected deaths, injuries and property damage for the sprinklered building, compared to the UK averages for unsprinklered buildings of the same property type, converted to monetary terms.

Robust quantitative data are hard to find; however some illustrative calculations may demonstrate the scope for savings that sprinklers may provide. Data gathered for the CBA show that the cost of installation in a house, with the water supplied by a pump and tank, is currently estimated at just over £3,000 ± £600 (see Table E1; uncertainties for installation and water costs have been added in quadrature). According to research by *Build It* magazine [www.servicemagic.co.uk] the average cost to build a three-bedroom masonry house is £152,000. Therefore, if provision of sprinklers enables a saving of 2% of this cost, the installation would break even (although there would still be maintenance costs to consider).

Referring to Table E1, if the installation and water supply costs are effectively £nil (paid for by savings elsewhere), and assuming that the life safety benefits are the same as if the sprinklers were included as an additional safety measure, the annual costs would be £96 (maintenance) and the annual benefits would be worth up to £33.51 (deaths, injuries and property damage prevented, as before). In order to achieve a cost-benefit ratio of 1 when the maintenance costs are also taken into account, the reduction in the building costs would have to be about £4,500, i.e. 3% of the total building cost. If the annual benefit were £nil (i.e. increased risk from a relaxation to AD B guidance being precisely balanced by the reduced risk due to sprinklers) then the reduction in building cost would have to be £5,200, or 3.4%.

The above example shows that sprinklers could be cost-effective if relatively modest cost savings can be achieved as a result of trade-offs. It also illustrates that the ongoing maintenance costs can have a relatively significant impact on the cost-benefit equation.

Rather than reducing costs, another way that sprinklers may contribute to a net cost-benefit is by increasing the value of the property. A survey by the Halifax shows that in 2008, house prices varied between £780 and £2,280 (outside London). In the NHBC Foundation research on fire risks in open-plan flats [Fraser-Mitchell & Williams 2009], the floor area of the 2-bed flat "design" was 80m^2, of which 12m^2 was occupied by the hallway in the "conventional" layout. (Note – this was not an actual built example). Therefore, the open-plan design (no hallway) would have the same amount of living space as a 92m^2 flat with a 12m^2 hallway. The value of the extra 12m^2 of floor space would be between £9,400 and £27,100 using the house price data above. In another source [http://www.independent.co.uk/life-style/house-and-home/property/how-not-to-add-value-to-your-home-1715490.html] it has been suggested that increasing the floor area by 10% would increase value by 5% (i.e. half the benefit range above, £4,700 - £13,550). The NHBC Foundation research showed that an open-plan flat with sprinklers and an enhanced detection system would have fire risks that were no higher, and in many cases lower, than a conventional layout with a hallway. With sprinkler installation and water supply costs (Table E3) estimated at £730 ± £220, minimal maintenance costs, even allowing for the extra costs of enhanced detection, it is clear than open-plan flats should be a financially-attractive proposition.

In residential care homes, it has been suggested that sprinklers could enable the number of night-time staff to be reduced, coupled with a "defend in place" strategy. The national minimum wage, according to www.direct.gov.uk, is £4.98 for people aged 18-20, and £6.02 for people aged 21 or over. The salary for one person providing 8 hours cover at £6 per hour, 365 days a year, would be £17,500. This does not include other related costs, such as National Insurance contributions, etc. From Table E5, the annual cost of the sprinkler system in a care home for elderly persons was estimated at £780. Thus even though any other variations in building cost, or variations in benefits have not been considered, the potential saving for a care home operator would appear to be considerable.

A major issue with any alternative solution is the need to demonstrate that the requirements of the Building Regulations have been met. This is usually interpreted to mean that the risks of death / injury are no worse in the alternative approach than in an "AD B compliant" counterpart design (assuming such a design exists). This implicitly assumes that the "AD B compliant" design satisfies the Building Regulations, which will normally be the case.

Whilst the risks in the "compliant" design could be estimated from the fire statistics and data of the numbers of buildings of different types, this approach almost certainly will not work for the alternative design since (a) the statistics do not have sufficient detail, and (b) even if the detail were available, the sample size is too small to draw any meaningful conclusion. This leaves two options for estimating the risk of the alternative design:

- computer modelling may be used to estimate the risk, as was the case where BRE's risk assessment model "CRISP" was used to compare open-plan flats with traditional layouts [Fraser-Mitchell & Williams 2009]

- the reduced risk due to sprinklers is assumed to precisely balance the increased risk due to whatever relaxation(s) the sprinklers are being introduced to compensate for. Thus the net benefit of sprinklers would be £nil and any cost-effectiveness would come from reduced capital and ongoing costs compared to the "compliant" design.

In the case of the second bullet point, both AD B (2006) and BS 9999:2008 explicitly mention a number of possible trade-offs if sprinklers are present. However, it is not clear whether the sprinklers are intended to compensate for just one trade-off relaxation, or some or all where more than one trade-off may be possible. All one can do is re-iterate BS 9999:2008 (clause 19.1) which states that "Any (trade-off benefit) should however be carefully reviewed and assessed by the designer".

To summarise the discussion on trade-offs, these offer benefits which may be substantial. However quantification in terms of cost-benefit presents a number of difficulties, and further research to produce a robust data set in support of generic guidance is needed.

7.5 Special cases and "what-if" scenarios

For the cost-benefit analysis presented in this report, "UK average" property types have been considered. However another approach could be to identify high risk categories either by building type or occupant characteristics and then consider these, using an appropriate methodology, for the provision of sprinkler systems. This approach would be similar in some respects to the procedures adopted for protection of commercial buildings by the UK insurance industry and the approach adopted in Vancouver, Canada [Holdgate 2001, Sziklai 2007].

As an example of this "targeted" approach, suppose it is known that the occupants of a given house will be aged over 80, and hence the risk of death is expected to be 5 times higher than the national average for houses. The additional deaths expected (without sprinklers) would therefore be 40 per year per million houses, which from the sensitivity analysis would increase the annual net benefit by 40 x £1.49 = £59.60. Overall, if nothing else changed, the net benefit would still be negative, i.e. -£200 + £60 = £-140 (a net annual cost).

As another example, suppose it is known that the occupants of a given house are 7 times more likely to have a fire than the average household. If the numbers of deaths and injuries and amount of property damage per fire do not vary from the national average, then the effect is to increase all the benefits (not just those associated with an increased death rate) by a factor of 7. As the benefit-to-cost ratio for an average house with sprinklers is estimated to be 0.14 (see Appendix E), in this example where the risks (and hence benefits) are 7 times higher, the installation of sprinklers would break even, with a confidence level of 50% for a positive cost benefit value.

In some special cases, there may be benefits other than deaths, injuries and property damage prevented. For example, dwelling occupants may need to be re-housed following a fire whilst the damage is repaired. These re-housing costs could be significant, although figures have not been obtained (nor the extent to which re-housing costs, both in the social housing arena and private ownership, have already been included within the insurance data which forms the basis for the "property damage" value).

As future trends are hard to predict, a related approach is to use "what-if" analysis. In this case, certain specific assumptions are made, and the consequences evaluated. When presenting the results of a "what-if" analysis, the assumptions need to be explicit, and it must also be made clear that the presentation is not a prediction for the future.

8 Conclusions

It has become apparent during this work that there is no universal definition of houses in multiple occupation (HMOs) in the UK. The survey of English housing records the number of HMOs which include “shared houses” and “bedsit type dwellings” (“traditional HMOs”). The fire statistics do not provide the same breakdown. Prior to 2008, there was just one category of HMO. Since 2008, it has been possible to record whether an HMO is licensed or unlicensed, but not define if it is a “shared house” or a “traditional HMO”. It would be a significant development if a universal definition and breakdown of HMOs could be adopted for use in the UK to reduce the uncertainties associated with the correlation between the number of building types and fires.

Based on the cost data supplied by Industry as part of this work and the analysis described in this report, residential sprinklers as additional safety measures are cost-effective for:

- all residential care homes for elderly people, children and disabled people (including those with single bedrooms).
- most blocks of purpose built flats and larger blocks of converted flats (see Figure 1) where costs are shared.
- traditional bedsit type HMOs where there are at least six bedsit units per building and the costs are shared.

The analysis carried out for residential sprinklers in two storey houses and the shared houses category of HMOs did not demonstrate that they would currently be cost effective. There are a number of factors that have impacted on this outcome which are described in detail in this report. For example, the responses to the consultation with the Industry regarding the costs of systems, installation and maintenance indicate that currently, the number of residential installations in the UK is low in number. As a consequence, the current costs reflect the fact that each application tends to be treated independently and a bespoke solution provided. If residential sprinklers were in more widespread use, it might be expected that some of the costs, such as installation and maintenance, would reduce.

To change the outcome for two storey houses and/or the shared houses category of HMOs, it can be concluded that there would need to be a reduction in the costs of the systems and annual maintenance and/or an increase in the benefits which would require a change in the risks of death, injury, property damage or the value attributed to these. In addition, there are opportunities to consider trade off during the design of buildings would tend to result in cost savings. Clearly, as residential sprinklers become more widely used, direct statistical data will become available, from sources such as Wales, to inform and provide a more robust technical evidence base.

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Appendix A – Literature review

The previous work by BRE [Williams et al 2004] included a survey of other countries' experiences with residential sprinklers, both in terms of effectiveness and also costs and benefits. That survey has been supplemented by a review of more recent literature.

A1 Sprinkler effectiveness

A1.1 Previous BRE work

The literature study in the previous BRE work examined the effectiveness of residential sprinklers in other countries. These were either estimated from statistics, experimental studies, or were values quoted by one author and used by another. In order to provide a comparison against more recent figures, the consensus values reported by BRE [Williams et al 2004] for this survey of other countries were as follows:

- Alarms only, reduce deaths by 53% and injuries by 70%.
- Sprinklers only, reduce deaths by 70-80%, injuries by 45-65%, property loss by either 40-50% or 85%.
- Sprinklers plus alarms, reduce deaths by 83%, injuries by 45-85%, property loss presumably as for sprinklers only.
- All of the above reductions are in comparison with a baseline of no smoke alarms or sprinklers present, and are aggregated over all dwelling types.

These figures were used for comparison purposes, since they are for overseas countries and differences between construction methods, culture, etc may mean that the effectiveness estimates cannot be directly applied to the UK situation.

Additionally, it has been suggested [Pigot and Young 2004] that the above figures may underestimate the true effectiveness of a modern residential sprinkler system because some of the information may be out of date and technological developments may have occurred in the intervening period. Further, it is also worth noting that it is now recommended in Approved Document B that mains powered smoke alarms are installed in new dwellings.

The previous BRE work used "indirect" estimates of sprinkler effectiveness, based on a correlation between the area of fire damage and the risk per fire of death or injury. The area of fire damage with sprinklers was assumed to be limited to 1m^2, based on guidance from Steering Group members of that study. The effectiveness of sprinklers in preventing deaths was therefore assumed to be 70%, the effectiveness of sprinklers in preventing injuries was 30%, and a figure of 50% was used for a reduction in property damage (based on USA statistics). The work assumed that these effectiveness values applied to all dwellings and residential buildings.

A1.2 USA sprinkler experience

A direct assessment of sprinkler effectiveness requires widespread use of sprinklers in practice supported by collated fire statistics. This situation exists currently within the USA. The NFPA has published a series of statistical analyses of the USA experience with sprinklers [Rohr 2000, Hall 2007, Hall 2010]. In the most recent survey, the following estimates were made for wet-pipe sprinkler systems:

- The presence of sprinklers reduced the number of deaths in dwellings by 83%, compared with dwellings with no automatic extinguishing equipment.
- Property loss in dwelling fires was reduced by 76%.
- Sprinklers reduced deaths in boarding and care homes by 68% compared with homes with no automatic extinguishing equipment, and property loss by 50%.
- Sprinklers reduced deaths in health care premises (including hospitals and nursing homes) by 72% and property loss by 54%.
- That report also cited a figure for water damage from accidental discharge when there is no fire, which is 25% of the fire damage [Marryatt 1988]. As the average fire loss with sprinklers was US$4,000, the loss from accidental water damage would be US$1,000. It was also reported that 1 in 21 sprinkler activations are accidental, so the losses including water damage are equivalent to an average fire loss of US$4,050.

A1.3 Sprinklers in specific localities

A number of regions have passed local laws requiring sprinklers to be fitted in all or most types of new buildings, including dwellings. The most well-known examples are:

- Prince George County, Maryland, USA, since 1986 [Siarnicki 2001]
- Scottsdale, Arizona, USA, since 1988 [Ford 1997, Ford 2003]
- Vancouver, British Columbia, Canada, since 1990 [Robertson 2001].

It is not straightforward to extract estimates of sprinkler effectiveness from the various reports describing the experiences of these regions due to the currently limited statistical data. In general, for these examples, it is reported that there have been no deaths in sprinkler protected buildings. Based on this information, the sprinkler effectiveness is reported to be 100%. It has not been possible to verify this figure as part of this project.

In addition, for some localities where actual statistics are not available, sprinkler effectiveness has been estimated from numbers of fire victims who might have died had sprinklers not operated. This is a further example of an indirect estimate of sprinkler effectiveness (see section A1.1) with uncertainty about the number of lives that would actually be saved.

To improve on these approaches, data is required on the risk of death, per fire per year, with or without sprinklers. For this, it is necessary to know the numbers of buildings with and without sprinklers, and the fire statistics for buildings with and without sprinklers. These need to include those fires where the sprinkler system does not activate. It is expected that these data might become available in the future as the statistical database of information increases.

A1.4 Studley Green, UK

Studley Green, Wiltshire, England [Parsons 2009] is an estate of 212 units of “sustainable” housing that were constructed and fitted with sprinklers. In a ten-year period, there were two sprinkler activations. The report did not mention the number of fires which were too small to activate the sprinklers which is probably because many of these were not reported. In the UK, there were just over 1,600 fires per million single-occupancy houses [Williams et al 2004]. Based on the two sprinkler activations in isolation at Studley Green, there were at least 943 fires per million dwellings.

In the first case, sprinkler activation prevented a fire in a shed spreading beyond the kitchen when it entered the house. The second case of sprinkler activation involved a sofa fire at 2 am and the two occupants escaped after being alerted by their neighbour. The smoke alarm had been disabled but the neighbour had heard the operation of the sprinklers.

A third case of sprinkler activation occurred at 6.30 pm on 6th January 2010 [Wiltshire FRS 2011]. The two occupants of the house were downstairs when a fire started in an upstairs bedroom. The sprinkler extinguished the fire and damage was confined to a small area of bedding less than 1m^2 and some small electrical items. The occupants were alerted by the sprinkler activation when they heard “a loud popping noise”. The article did not mention the presence and operational status of smoke alarms.

The 2009 report suggests that sprinklers had saved the lives of both of the occupants in the second incident. However, this is a point of debate and opinion between different experts. For example, based on statistical evidence, it can be seen that all sofa fires do not result in fatalities, even if the occupants are asleep and there is no working smoke alarm. The UK fire statistics data show that, in 2001, there were 278 upholstery fires occurring between 1 am and 6 am where there were no smoke alarms or sprinklers. These 278 fires resulted in 16 deaths. Based purely on statistics, the sprinkler activation had saved 16/278 = 0.06 lives.

It can therefore be argued if the sprinkler activation is credited with saving every person who was present, the tendency will be to over-estimate the numbers of lives saved, beyond the numbers of lives that would be expected to be lost if there were no sprinklers present [Parsons 2009].

On the other hand, whether the sprinkler saved two lives or (statistically) only 0.06, the best estimate of the sprinkler effectiveness at preventing death would still be 100%.

It is clear that the problem with this type of analysis in the UK at this current time is because of the lack of data for sprinklered dwellings due to the very small sample size.

A1.5 Prince George County, USA

In Prince George County, Maryland, USA [Siarnicki 2001], there were 121 residential sprinkler activations (117 fires and four accidents) in the eight-year period from 1992 to 1999. The total fire loss was US$400,000, out of a potential loss of US$38 million (if each fire completely destroyed the property it occurred in). There were seven minor injuries, and no deaths. The author stated “154 reported lives saved”. These 154 people were present in the buildings at the time that the fires started, and as in Studley Green, some would have been expected to survive without sprinklers.

The overall USA figures had an annual average (dominated by homes without sprinklers) of 3,096 deaths in 323,800 residential fires (9.6 deaths per 1,000 fires). Based on statistical analysis, in the 117 fires in Prince

George County that led to sprinkler activation, assuming that the USA average fatality rate is also typical for Prince George County, the estimated number of deaths without sprinklers would be 9.6 x 0.117 = 1.1.

There were on average 14 deaths per year in unsprinklered homes in Prince George County. Making the same assumption that the death rate per fire is the same as the USA average, the number of fires can be estimated to be 1000 x 14/9.6 = 1,458. The property loss of US$13.8m equates to US$9,465 per fire. The property loss without sprinklers would be 117 x US$9,465 = US$1.1 million. As the actual property loss was $0.4 million, the sprinkler effectiveness at reducing property damage would be 64%.

The Prince George County statistics have been re-analysed and presented more recently [Weatherby 2009]. From 1992 to 2007, the population of Prince George County increased by 11%, roughly a linear growth over time. Therefore, averaged over the time period, it would be expected that 5.5% of dwellings would be “new build” and fitted with sprinklers. The fire department recorded 13,494 dwelling fires, of which 245 resulted in sprinkler activation (1.8%), so either the newer homes were less likely to have fires, or sprinklers did not activate in all cases (e.g. if the fire was too small).

101 deaths were recorded over the 15-year period in fires in Prince George County. There were no deaths in dwellings where sprinklers activated (245 fires in 15 years). However, it is not clear whether any of the 101 deaths occurred in buildings in which sprinklers were present but did not activate e.g. because the fire was too small. Had sprinklers not activated in the 245 fires, approximately two deaths (1.8% of 101) would have been expected. The small sample size means the confidence interval for the effectiveness is very large, i.e. an effectiveness of much less than 100% could still be consistent with the observed data.

Over the same 15 year period, there were 328 injuries in the 13,249 fires without sprinklers, and 6 injuries in the 245 fires with sprinklers. Based on statistics, the expected number of injuries in 245 fires without sprinklers would also be 6 (1.8% x 328). Therefore, there is no statistical evidence that sprinklers reduce the number of injuries, based on this small data set.

Values of the average property damage, with and without sprinklers, were US $4,883 and US $9,983, so the sprinkler effectiveness was 49%.

A1.6 Scottsdale, Arizona, USA

A report was produced [Ford 1997] detailing the Scottsdale, Arizona, USA experience with sprinklers 10 years after their provision had become mandatory under local bye-laws. Five years later, an executive summary update was produced. The 15-year period was 1986 to 2001. The civilian fatality rate was reduced by at least 50%. It was stated that 13 lives were saved which seems to be a case-by-case estimate rather than a statistical calculation. These 13 lives saved included non-residential fires. After 10 years, the estimate was eight lives “definitely” saved, a 50:50 split between residential and other fires.

The average property loss was reduced by 90% for all property types (including non-residential). Other statistics for the USA as a whole [Rohr 2000] suggested the reduction in residential property damage was much less.

There were 199 fires recorded in sprinklered buildings. It was unclear whether this figure was all fires or the subset of fires where sprinklers activated. These fires were broken down as 102 in commercial buildings, 48 in HMOs (i.e. blocks of apartments) and 49 in single family dwellings.

The total "structural fire loss" (assumed to be direct losses from building fires) was US$703,000 (less than 0.1% of the total property value of US$767m, although this larger figure was probably dominated by the commercial and HMO complexes). The average loss in these sprinklered fires (or fires in sprinklered buildings) was US$703k/199 = US$3,500, compared to US$45,000 in unsprinklered buildings.

39,000 single-occupancy homes and 19,000 HMOs had sprinklers installed by 2001. This is 53% of all residential units. Projecting the city growth forward to 2006 it was estimated that 49,000 single-occupancy homes would have sprinklers installed.

If 58,000 dwellings = 53% of the city total, 100% must be 109,000. If a linear growth is assumed from zero coverage in 1986 to 58,000 dwellings in 2001, the number of reported fires is 48/(19,000 x 15/2) = 377 per million HMO dwelling units, and 49/(39,000 x 15/2) = 168 fires per million single-family homes. These figures appear low when compared to previous work. The previous BRE work [Williams et al 2004] found 1616 fires per million houses in the UK, and 1147 per million accommodation units for HMOs, which might suggest they refer to sprinkler activations only, rather than including fires which did not get large enough to activate the sprinkler system).

Lives saved = 9/(59,000 x 15/2) = 20.7 per million dwellings (assuming no more commercial lives saved after 1996. It is known that there were estimated to be four of these up to 1996. This figure appears high compared with the figure for the USA as a whole which is about 15 deaths per million dwellings and for the UK is about 6 ~ 9 deaths per million dwellings. This suggests that either the predicted lives "definitely saved" may be an over-estimate and/or there were further deaths in commercial buildings that have not been taken out of the equation.

A1.7 Vancouver, Canada

From 1930 to 1967, there were on average eight deaths per year from fires in Vancouver, Canada. For a number of reasons, these deaths increased rapidly in the late 1960s and early 1970s, peaking at 40 deaths in 1973. Statistics highlighted the fact that fire deaths related to particular types of buildings (hotels, rooming houses, boarding and lodging facilities) were disproportionately high. In order to counteract this rise, sprinklers were installed in the most high-risk occupancies.

Three years into the upgrade programme, almost 90% of the identified buildings had been upgraded, a total of around 9,000 rooms. The next five years, from 1975 to 1979, saw the fire death rate drop to an average of 15.2 per year (previously 25.8), with 6.4 deaths (previously 14.4) per year from hotels and rooming houses. By 1980, upgrades had been completed in 800 high risk buildings. The number of deaths had declined to 7 per year in 1980.

In the late seventies, the upgrade policy was expanded to include all public hospitals and rest homes. During the early 1980s, over 700 such buildings had been upgraded. In 1990, the Building Bye-laws were amended to require sprinklers in all new one- and two-family homes, as well as new HMOs, hospitals and care facilities. Fire deaths and fire-related property damage continued to fall as a result. Other factors may also have contributed to this outcome. For example, in 1998, there were no fire deaths but not all buildings had sprinklers.

Since 1990, sprinklers have been installed in approximately 10,000 one and two-family dwellings, and over 42,000 multi- dwelling units; along with 18,000 dwellings sprinklered prior to 1990, giving a total of approximately 70,000 sprinklered dwellings [Holdgate 2001].

It is complex to try to estimate the effectiveness of sprinklers in Vancouver, particularly since the highest risk buildings were targeted first and the full statistical data relating to the outcomes do not appear to be publically available. The Vancouver Fire and Rescue Services [Sziklai 2007] have stated that sprinklers reduced damage by up to 90%, and in combination with smoke alarms, reduced deaths by 97%. .

The 2001 Annual Report of the Vancouver Fire and Rescue Services [Vancouver Fire and Rescue Service 2001] contains some details on sprinklers, which enable reliability estimates to be made.

In 2001, there were 7 fires in sprinklered single family homes, compared to 105 fires in unsprinklered homes. Of the 7, in 3 cases activation was effective, in one case the effectiveness was unknown, in two cases there was insufficient heat for activation, and in one case there was no sprinkler head present in the space of fire origin.

In multi-family dwellings, the split was 84 sprinklered and 101 unsprinklered fires. The sprinkler was effective in 35 cases and ineffective in two, a reliability of 35/37 = 94.5%. In 6 cases, the activation was unknown (so reliability ranges between 35/43 and 41/43, i.e. 81%~95%), in 30 cases there was insufficient heat, and in 11 cases there was no sprinkler head present where the fire started.

The total losses in sprinklered and unsprinklered buildings were $6.8m and $12.9m, respectively. The number of fires were (3+7+84+50) = 144 and (4+105+101+330) = 540, respectively. This resulted in an average loss per fire of $47,200 and $23,900, respectively, which means, based on this information, that the average loss per fire is greater with sprinklers. Clearly, this is not what would be expected and is probably due to the fact that the results are distorted by a $3.5m loss in a sprinklered hotel which had numerous voids that the sprinklers could not protect. If this incident is discounted, the losses per fire were $3.3m/143 = $23,076 and $12.9m/540 = $23,889.

A1.8 Care homes

An NFPA report [Ahrens 2006] included data on USA fires in care homes for elderly people. The annual averages for 1994 to 1998 were 3,000 fires, 12 deaths and 241 injuries (not including firefighters). The death rate (four deaths per 1,000 fires) was 60% of the average for all “structural” (i.e. building) fires, and the average property loss was 20% of the average for all fires. However, the rate of injuries per care home fire was 2.2 times higher than the average for all fires.

The effectiveness of sprinklers in preventing deaths in care home fires could be deduced from the data. There were 11,445 reported fires in which sprinklers were present (76% of all reported fires), and 22 deaths (1.9 per 1,000 fires), compared to 3,555 reported fires with no sprinklers, which caused 38 deaths (10.8 per 1,000 fires). Therefore, sprinklers are estimated to reduce the number of fire deaths by 82%.

It is interesting to compare the USA statistics with UK data for a similar time period (1994 to 1999) [Williams et al 2004]. UK care homes had 1,077 fires, 3.8 deaths (3.5 per 1,0000 fires) and 98.5 injuries, which include precautionary checks, per year. Noting that most UK care homes do not have sprinklers, the risks in the UK are significantly smaller than for “equivalent” care homes in the USA. The reasons for this difference in risk between the UK and USA are not clear and would require further investigation.

The estimate of sprinkler effectiveness in UK care homes is also very different to the USA figure. The previous BRE report [Williams et al 2004] assumed that the reduction in deaths if sprinklers were present was independent of property type (see section A1.1). However, if this assumption had not been made, the effectiveness would have been estimated, using the methodology of the BRE report [Williams et al 2004], to be 20%. A more detailed examination of the circumstances of every fire death in a care home for elderly people during 1994 to 2002 [Shipp and Clark 2006] estimated the effectiveness would have been slightly higher, at 33%.

The reason for the difference between the effectiveness of sprinklers in USA and UK care homes may be due to the nature of the fatal fires. Many, 26 out of 33, of the UK deaths during 1994 to 2002 were smoking-related, with either the victim's clothing or bedding set alight. Experimental tests (using pig carcasses) showed that the sprinklers did not operate quickly enough to prevent serious/life-threatening burn injuries [Shipp and Clark 2006]. In the USA, the nature of the fire scenarios was different, with a much smaller proportion involving smoking-related causes in which the victim was intimately involved with the fire.

Although the sprinkler effectiveness estimates were very different for the UK and the USA, the residual death rates in sprinklered care homes were quite similar, 1.9 per 1,000 fires in the USA, and an estimated value of 2.4 ± 0.5 per 1,000 fires in the UK.

One conclusion that is drawn from this analysis is that the experience of one country will not necessarily reflect what might be expected in another.

A2 Cost benefit analyses

A number of cost benefit calculations have been performed since the previous BRE work. Although these have been done for different countries, so it would not be expected for them to agree exactly, it is notable how different the results and conclusions are.

A2.1 UK - previous BRE work

The cost benefit analysis performed by BRE included a number of novel approaches, including the use of a correlation between fire area and fire risk in order to estimate the potential benefits of sprinklers in terms of risk reduction, and the use of uncertainty analysis to estimate the confidence level that sprinklers would be cost-beneficial. Full details can be found in the published report [Williams et al 2004].

The calculations are shown in Table A1, as a way of summarising the input values used.

Table A1 - Input values and CBA calculations from previous BRE work [Williams et al 2004]

	house	HMO	flat (1)	flat (2)	care home (3)	care home (4)	care home (5)
Capital Cost of System (per unit)	£1,650	£550	£900	£1,100	£4,455	£2,805	£2,640
Water connection charge (per unit)	£465	£140	£78	£112	£835	£835	£835
Capital Recovery Factor	0.043	0.043	0.043	0.043	0.043	0.043	0.043
Annual Cost of Loan	£90.17	£29.42	£41.70	£51.67	£225.53	£155.19	£148.15
Annual Inspection Cost	£50	£50	£50	£50	£50	£50	£50
Total Annual Cost	**£140.17**	**£79.42**	**£91.70**	**£101.67**	**£275.53**	**£205.19**	**£198.15**
Deaths per Million Units	15	13	27	23	245	143	72
Sprinkler Effectiveness Factor	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Deaths saved per Million Units	10.5	9.1	18.9	16.1	171.5	100.1	50.4
Monetary Value per Death Saved	£1,243,000	£1,243,000	£1,243,000	£1,243,000	£1,243,000	£1,243,000	£1,243,000
Monetary Benefit per Single Unit	£13.05	£11.31	£23.49	£20.01	£213.17	£124.42	£62.65
Injuries per Million Units	367	281	941	664	6073	12857	2523
Sprinkler Effectiveness Factor	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Injuries saved per Million Units	110.1	84.3	282.3	199.2	1821.9	3857.1	756.9
Monetary Value per Injury Saved	£58,300	£58,300	£58,300	£58,300	£58,300	£58,300	£58,300
Monetary Benefit per Single Unit	£6.42	£4.91	£16.46	£11.61	£106.22	£224.87	£44.13
Fires per Million Units	1616	1147	4841	2561	66074	149286	30990
Sprinkler Effectiveness Factor	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Unsprinklered property damage	£7,540	£7,540	£7,540	£7,540	£7,540	£7,540	£7,540
Reduced property damage per fire	£3,770	£3,770	£3,770	£3,770	£3,770	£3,770	£3,770
Monetary Benefit per Single Unit	£6.09	£4.32	£18.25	£9.65	£249.10	£562.81	£116.83
Total Monetary Benefit per unit	**£25.56**	**£20.55**	**£58.20**	**£41.28**	**£568.49**	**£912.10**	**£223.61**
Benefit : Cost ratio	**0.18**	**0.26**	**0.63**	**0.41**	**2.06**	**4.45**	**1.13**
Confidence Level (ratio > 1)	**0%**	**0%**	**0%**	**0%**	**97%**	**100%**	**66%**
Notes							
1 = purpose-built flat							
2 = converted flat							
3 = care home, elderly people							
4 = care home, children							
5 = care home, disabled people							

A2.2 New Zealand

A BRANZ report [Robbins et al 2008] updates a previous cost benefit analysis for "low cost" sprinklers in New Zealand dwellings, to include uncertainty using Monte Carlo techniques and sustainability issues.

Statistics [Wade and Duncan 2000, Duncan et al 2000] show that New Zealand experiences four (reported) fires per 1000 households per year, which is "higher than the equivalent Australian data; still expected to provide a conservative estimate of the actual fire incident rate due to the number of fires that are discovered and extinguished without a call to the fire service" [Duncan et al 2000].

Simple correlation of the statistics with sprinklers present or absent may understate the potential value of sprinklers "because it lumps together all sprinklers, regardless of type, coverage or operational status, and is limited to fires reported to fire departments" [Rohr and Hall 2005].

Over the years 1995~2005 when the number of fires was roughly constant, New Zealand statistics were as follows:

- Number of fires: 2770 ~ 3450, mean 3140, standard deviation 224
- Number of deaths: 15 ~ 28, mean 21, standard deviation 4.2
- Number of injuries: 180 ~ 300, mean 240, standard deviation 38
- Deaths per 1000 fires: 4.7 ~ 9.5, mean 6.8, standard deviation 1.3 (compare to 8~9 in UK)
- Injuries per 1000 fires: 57 ~ 88, mean 77, standard deviation 9.9 (compare to about 250 in UK, including precautionary checks).

Residential properties were divided into owned, or various classes of rented, for analysis purposes.

Table A2 gives the distribution of structural damage for houses.

Table A2 – Distribution of structural damage for houses [Robbins et al 2008]

0%	1-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91% +
1224	184	26	20	34	68	35	55	82	140	725

These costs were based on "low cost" sprinkler systems and so cannot be compared directly with the BRE cost benefit analysis for UK properties, see Table A3.

Table A3 – Cost of sprinklers in New Zealand [Robbins et al 2008]

Property type	Mean cost NZ$ /m^2	Sample SD cost NZ$ /m^2	95% fractile NZ$ /m^2	99% fractile NZ$ /m^2
Large house (135 m^2)	24	8	36	39
Small house (70 m^2)	22	12	39	44

The authors performed a literature review of factors included in various CBA reports, covering the USA [Rohr and Hall 2005, Hall 2007], UK [Williams et al 2004], Vancouver [Robertson 2001, Williams 2004], Scottsdale [Ford 1997], and New Zealand [Wade and Duncan 2000, Duncan et al 2000].

The values chosen for the updated New Zealand cost benefit analysis were as follows:

- Sprinkler "effectiveness" (i.e. to control fire, given it is large enough that activation would be expected) = 95% (+4%, -5%). (According to the definition used later, this is the "reliability").
- Smoke alarm "effectiveness" (assuming fire large enough to activate sprinkler system) = 62% (+28%, -12%).
- Sprinkler activation limits structure damage to 5% (+/- 3%), "a conservative estimate". Total loss of the structure is assumed if the damage is 70% (+/- 10%). The weighted average damage (assuming total loss over 70%) is 41%, so the effectiveness of the sprinklers would be (1 - 5/41) = 88%.
- The effectiveness of sprinklers and/or smoke alarms is shown in Table A4.

Table A4 - Values assumed for the effectiveness of sprinklers and/or smoke alarms [Robbins et al 2008]

Effectiveness	Alarms only	Sprinklers only	Alarms + sprinklers
Prevention of death	53%	80%	83%
Prevention of injury	70%	62%	75%

These figures are identical to [Wade and Duncan 2000] as reviewed in [Williams et al 2004]. It appears that injury does not include "precautionary check", which is a difference with the UK.

Sprinkler life time was assumed to be 50 years.

The direct costs of a fire injury were taken as NZ$30,000 (+34,800, -13,000), and the indirect costs were NZ$200,000 (+140,000, -64,000).

Unsprinklered property loss was NZ$30,000 (+70,000, -15,000). With sprinklers, the effectiveness of property protection was 52% (+43%, -32%). The reason for the discrepancy between this stated value, and the 88% figure deduced above, is not clear.

The cost benefit analysis included estimates for population growth and changes in housing stock, based on the last three census surveys. The results of the cost benefit analysis were expressed in terms of the cost per life saved.

A2.3 USA

Various studies have looked at the cost of sprinkler systems in the USA.

A study by the Fire Protection Research Foundation [Fire Protection Research Foundation 2008] found that, in terms of absolute costs, the total sprinkler system costs to the homebuilder ranged from US$2,386 to US$16,061 for 30 different houses across the country. The cost of sprinkler systems to the homebuilder, in US$ /sprinklered ft ^{2}, ranged from US$0.38 to US$3.66. This range represents the 30 different house plans, with the average cost being US$1.61/sprinklered ft^2. These costs include all costs to the builder associated with the sprinkler system including design, installation, and other costs such as permits, additional equipment, and increased tap and water meter fees, to the extent that they apply.

In Scottsdale, Arizona, installation costs were between US$0.55 ~ US$0.75 per ft^2, less than 1% of the total build cost [Ford 1997]. This is less than half the national average value above, and has been attributed to the effect of competition between vendors to keep the price down.

An analysis by NIST [Brown 2005] estimated costs for six different sprinkler system designs, in three different house sizes ranging from 109 m^2 to 310 m^2 in floor area. The sprinkler systems included a "low cost" system that was an extension to the normal plumbing for water, and standalone systems, with and without backflow prevention. The costs ranged from $4.61 to $15.96 per m^2 (roughly $0.40 to $1.60/ft^2).

The ASTM E917–02 standard [ASTM E 917 2002] for residential sprinklers allows "low cost" systems. Backflow prevention is not required by NFPA13 D [National Fire Protection Association NFPA 13D], but local regulations may demand it. If it is required, it will need inspection and maintenance, which will be costly [Brown 2005]. As a rough approximation, the cost of a USA "low cost" system is about half that of a traditional sprinkler system.

NIST then used the sprinkler cost data to perform a cost benefit analysis [Butry et al 2007]. This updated an earlier [Ruegg and Fuller 1984] report, with new values for costs and benefits. The benefits included insurance and uninsured indirect costs. A "low cost" system with negligible maintenance was considered.

Between 2002 and 2005, there were 296,500 residential fires for year, 10,188 injuries, 2566 deaths, and a property loss of US$5.3 billion per year. This gives 34.4 injuries and 8.65 deaths per thousand fires, and a property loss of US$17,875 per fire. The baseline risk is for a house already provided with smoke alarms.

Based on the statistics, sprinklers were present in 490 fires per year over a four-year period. With smoke alarms only, the death rate was 8.2 per thousand fires. Therefore, in the sprinklered fires, 4.1 people per year were saved (since there were no deaths in the sprinklered fires). Based on this information, it was assumed that sprinklers prevented death with an effectiveness of 100%. Other effectiveness estimates were for injury = 57%, and effectiveness for property protection = 32%, although these may be affected by building type. The unreliability of sprinklers was assumed to be 3% [Hall 2007].

The value of life, on the willingness to pay basis, was taken at US$7.94 million. This was the median value, in 2005. The range is from US$4 million to US$9 million [Viscusi and Aldy 2003], so the value is very uncertain. The willingness to pay value for injury prevention was US$171,620. Converting these to UK currency at 2010 rates, and with no inflation from the 2005 values, deaths would be valued at £5.13 million, and injuries at £111,000. These are substantially higher than the values normally used in the UK [HM Treasury 2003].

The benefits from deaths prevented account for approximately two-thirds of the total, US$236/US$318. This is attributable to the £5 million price tag for life, and sprinkler effectiveness at preventing death taken at 100% [Butry et al 2007].

Uninsured property losses were US$4,400 per fire, i.e. not the US$18,000 total loss from the statistics. Insurance was assumed to cover 80% of property loss [Ruegg and Fuller 1984].

A2.4 UK, Thames Gateway area

NERA [Gros et al 2010] was commissioned by CLG to perform a cost benefit analysis to consider whether an increase in the number of homes in the Thames Gateway area required additional fire stations, or whether the risk could be controlled by the use of residential sprinkler systems.

They developed an original spreadsheet-based model to estimate the benefits and costs, and based many of the relationships, data (such as the response times to FRS incidents) and parameter values on the CLG Fire Service Emergency Cover (FSEC) toolkit and an abridged version (the 'National Model').

This modelling approach required estimates to be made of future growth in the number of dwellings and other buildings, and the effect of increased traffic levels on Fire and Rescue Service attendance times. Note that road traffic collisions also require Fire and Rescue Service cover. In Kent, road traffic accidents (RTA's) account for 64% of Fire and Rescue Service incident fatalities. The study showed that in order to compensate for no increase in Fire and Rescue Service cover, sprinklers would not only have to save all the fatalities arising as a result of longer attendance times for fires, but also the fatalities arising from longer attendance times at RTA's.

The input data included:

- A time horizon (sprinkler system lifetime) of 50 years (sensitivity options of 30 and 40 years)
- A discount rate of 3.5% per year over the first 30 years, followed by 3.0% thereafter, in accordance with Treasury Green Book guidance
- In social housing, the rate of fires per person per year was assumed to be 50% higher than in other housing (sensitivity option of 100% higher). Different proportions of social housing were assumed for different areas within the Thames Gateway
- The rates of fire per person per year were as follows: London, social housing 0.0015, other housing 0.0007; Essex, social housing 0.0010, other housing 0.0006; Kent, social housing 0.0009, other housing 0.0006.
- The effect of vehicle response time on the fatality rate per casualty was taken from the CLG National Model. To account for all new houses having smoke alarms, the fatality rate per casualty was reduced by 10% in these dwellings, but the number of casualties was left unchanged

- The arrival time of the first four FRS vehicles influences the fatality rate per casualty, with the arrival time of the first vehicle having greatest weight (72%), the second having the next greatest (25%), and the third and fourth having least influence (weight of 1.5% each).
- Fire statistics were used to define 12% of injuries as serious burns, 32% of injuries due to smoke and fumes, and 46% of injuries as minor (including physical injuries and precautionary checks). Note that the percentages do not sum to 100% which may be a typographical error.
- The rates of fire per dwelling per year were as follows: London, social housing 0.0036, other housing 0.0017; Essex, social housing 0.0023, other housing 0.0014; Kent, social housing 0.0023, other housing 0.0014.
- Property loss was estimated for both a "linear growth" (i.e. a constant rate of increase in fire area over time) and a "t-squared" growth rate. In both cases, the property damage per m^2 was equated with the property value per m^2. For the "t-squared" growth rate, the rate parameter 'a' was assumed to be 0.006 $kW.s^{-2}$ based on estimates from London Fire Brigade [Holborn et al 2004], and the heat release rate per unit area was assumed to be 250 $kW.m^{-2}$. This latter calculation gave property losses that were a factor of two times larger than the linear approach.
- NERA contacted eight vendors for quotes to install sprinkler systems, and received four replies. The installation costs, in 2008 prices and excluding water supply costs and VAT were:
    - House, £1,750 - £2,800 (although costs can be between 18-31% lower for large developments, e.g. £1,200 for a semi-detached house at the lower end of the market in a large estate)
    - HMO, £3,500 - £4,000 (The size of the HMO is not clear)
    - Flats, £900 - £1,200 (but could be significantly lower in large developments, e.g. £750 per flat in a block of 10-50, of £625 per flat in a block of 50+)
    - Care home for children (9 beds), £6,000 - £8,000
    - Care home for elderly (19 beds) £12,000 - £20,000
    - Annual maintenance, £50 - £100 (although can vary widely depending on system complexity)
    - Pump and tank, domestic, £1,200 - £1,350
    - Pump and tank, multiple occupancy, i.e. block of flats, HMO, care home, £6,000 - £7,500.

On the basis of published literature and the quotes above, the values chosen by NERA for the cost benefit analysis were:

- Installation, house, £1,500 (sensitivity options £1,200 and £2,200)
- Installation, flat, £750 (sensitivity options £600 and £900)
- Water supply, pump only, house, £700, flat, £200
- Water supply, pump and tank, house, £1,300, flat, £400

- Annual inspection and maintenance £75 (sensitivity options £50 and £100)
- Pump sets would require replacement after 20 years, cost as above for pump only
- Prices did not include VAT.

NERA performed a literature survey for the effectiveness of sprinklers at reducing deaths, injuries and property damage in fires. The values they chose to use for the cost benefit analysis were the same as those in the BRE 2004 analysis [Williams et al 2004], with higher options as a sensitivity study:

- Reduction in fatalities 70% (sensitivity option 90%)
- Reduction in injuries 30% (sensitivity option 60%)
- Reduction in property damage 50% (sensitivity option 80%).

The monetary value of prevented casualties was based on recommendations by CLG:

- Fatality, £1.547 million
- Burns injury (based on Department for Transport “serious injury”), £174,354
- Injury from smoke or fumes (weighted average of serious and minor), £44,019
- Physical injury and precautionary check (“minor injury”), £574
- All values were in 2007 prices, and were assumed to increase in real terms by 2% per year (in line with assumed changes in GDP per capita, relative to inflation).
- Using the proportions of different injury types quoted earlier (and re-normalising to 100%), the average value for injury prevention was £39,200.

Other factors included in the CBA were the costs of FRS resources, and estimates of environmental impact (carbon dioxide emissions).

The findings from the modelling were consistent with previous studies in suggesting that the benefits of installing sprinklers in all new housing, in terms of reduced fatalities, injuries and property loss, would not exceed the costs.

A3 Value of each life saved

In the UK, the recommended value for each life saved is given in the UK Treasury “Green Book” [HM Treasury 2003]. This is derived from a figure for the value of a life originally used by the Department for Transport. The amount that society was deemed to be willing to pay to achieve a (small) reduction in risk in traffic accidents was extrapolated to give the value of a reduction from 100% risk of death to 0%, i.e. the value of a life. For example, if it is considered worthwhile to spend £1,500 to reduce the risk of death from 0.2% to 0.1%, then the value of a life would be £1,500/0.001 = £1.5 million.

The 2010 value of a life is about £1.7m, and is considered to apply to all risks of death (not only traffic accidents).

The approach in other countries may differ from that in the UK. For example, a cost benefit analysis may be expressed in terms of the cost to save each life, rather than assign a monetary value to each life saved and count these among the benefits.

The USA uses the “willingness to pay” approach, but the value of a life has been estimated on a different basis to that in the UK. The USA approach examines the risk of death in different jobs, and examines the correlation between risks in similar jobs and the salaries they attract. The assumption behind this approach is that the additional salary compensates for the increased risk of death. This is then scaled up, as in the UK approach, to determine how much salary would compensate for an increase in risk of 100%. This is then the value of a life as determined by this method. A key article [Viscusi and Aldy 2003] reviews more than 60 studies of mortality risk premiums from ten countries and approximately 40 studies that present estimates of injury risk premiums. Estimates of the value of statistical life (VSL) have a wide range from about $0.5 million to about $21 million. However, applying various correction factors yields both a reasonable average level and narrow range for the estimated value of a statistical life of about $5.5–$7.5 million [Kniesner et al 2007].

As a consequence of this and similar research, the USA Government has revised the value derived by this process when assessing the cost benefit of safety cases. A memo from the USA Department of Transportation [Duvall 2008] stated “*Based on our improved understanding of the academic research literature, we have determined that the best present estimate of the economic value of preventing a human fatality is $5.8 million. This value should be used, effective immediately, for analyses performed by DOT analysts. In addition, we will, for the first time, require supplementary analyses at values of $3.2 and $8.4 million.*”

The new USA Government policy results in a very significant increase on values used previously (which were roughly equivalent to the UK value).

The value of a prevented fatality remains controversial. “*While ’revealed preference studies‘ are often viewed as more credible because they are based on actual behaviour, they address scenarios that differ from those of concern in many regulatory analyses. ’Stated preference studies‘ are hypothetical but have the advantage of allowing researchers to tailor the scenario to the risks of concern*” [Robinson and Hammitt 2010]. The point is that neither approach is perfect. An example of the former approach would be the compensating wage differentials favoured by Viscusi. An example of the latter approach would be the UK Department for Transport approach with regard to accident fatality risks.

“*It is sometimes held that death – or injury – by fire is particularly ‘dreaded’ so that estimates of willingness-to-pay to avoid death – or injury – in a road accident may not be applicable to fire risks. However, we have found no evidence to support the idea that people are materially more averse to the risk of death from fire than from road accidents.*” – NERA [Gros et al 2010]

It has been proposed [Jones-Lee et al 2007] that the value of a prevented fatality (VPF) applied in safety regulation should not be a constant (as recommended by the UK Treasury Green Book), but instead should be a variable which depends on life expectancy. Therefore, the VPF for an elderly person with a lower continuing life expectancy (e.g. a further eight years if aged eighty) would be lower than that of a young or middle-aged adult. Such an approach might allow consistency between the VPF and the value of a life-year (VOLY) applied in health policy.

A4 Value of each injury prevented

In the same way that a "willingness to pay" value for each death prevented was derived, figures for serious and minor injury prevention have also been estimated, initially for traffic accidents, and subsequently applied to all risks.

There are a number of grounds on which this approach could be challenged for fire injuries:

- That the "willingness to pay" figure (for prevention) underestimates the cost of treatment
- That the willingness to pay figure does not adequately reflect people's fear of fire, and the trauma suffered by victims (particularly burns victims who may permanently disfigured)

However, it needs to be borne in mind that not all victims will have catastrophic injuries. If there are just a few extreme cases, and many more injuries of lesser severity, the effect of the extreme cases on the average severity may not be that large.

An Australian study [Patil et al 2010] found no significant difference in the mean daily intensive care unit cost (A$700, plus A$1411 nursing costs) of burns patients compared with non-burn controls matched for length of stay and acuity. In the UK, the cost per day for a stay on a NHS general or surgical ward is around £400, rising to £1,500 per day if surgical complications require the expertise of the intensive care unit [Clinical Services Journal 2008].

The Department for Communities and Local Government undertook a Regulatory Impact Assessment (RIA) for the proposed new edition of Approved Document G (Sanitation, Hot Water Safety and Water Efficiency) [Department for Communities and Local Government 2008]. Hospital Episode Statistics[Sambrook 1999] show that there were 767 serious scalding injuries caused by contact with hot tap water that led to hospital admissions in England and Wales in 2006 to 2007. In addition, 19 fatalities per year (average over three year period, 1993 to 1995), and many more minor injuries, are attributed to hot water from taps [Sambrook, 1999]. All fatalities and 93% of severe injuries are associated with hot water from bath taps. The total annual cost of scald injuries (including fatalities) currently amounts to £61.3 million.

This RIA is interesting for two reasons:

- It shows a departure from the "willingness to pay" method of valuing injury prevention to a method based on treatment costs.
- Treatment costs are estimated for a range of victims and severity of burn (scald):
    - Child 0-14, very serious burn, £80,500
    - Adult 15-59, very serious burn, £26,800
    - Elderly 60+, very serious burn, £27,600
    - Child 0-14, serious burn, £41,100
    - Adult 15-59, serious burn, £13,900
    - Elderly 60+, serious burn, £14,600
    - All ages, minor burn, £180.

The treatment costs above are all less than the “willingness to pay” values for injury prevention (see section 5.2).

In the USA, guidance on the costs of injuries, as a multiple of the VSL (see Table A5), have not changed since 1993 [Duvall 2008]. However, as the value of a statistical life has recently been revised upwards (see section A3.3), the injury costs are substantial.

Table A5 - USA Government guidance on the value of injury prevention [Duvall 2008]

MAIS level[1]	Severity	Fraction of VSL	Value, with VSL = US$5.8m US$
1	Minor	0.0020	11,600
2	Moderate	0.0155	89,900
3	Serious	0.0575	333,500
4	Severe	0.1875	1,088,000
5	Critical	0.7625	4,420,000
6	Fatal	1.0000	5,800,000

[1]MAIS = Maximum Abbreviated Injury Scale

Appendix B – Estimate of sprinkler effectiveness

B1.1 Method of estimating sprinkler effectiveness

Previous research [Williams et al 2004] 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 [Ramachandran 1993, Melinek 1993, Fraser-Mitchell 2004], if the fire area can be limited to a certain value, then the risks of death and injury can be reduced.

Figure B1 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.

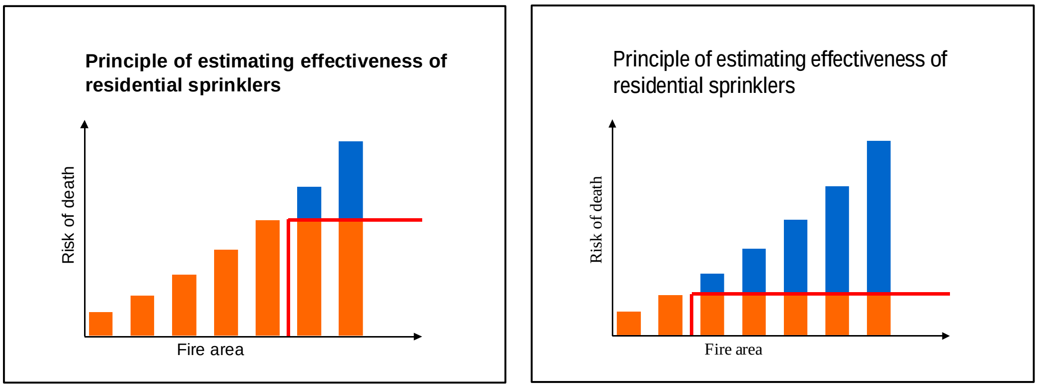


Figure B1 Principle behind the indirect estimate of sprinkler effectiveness

B1.2 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 we have assumed there is no difference in the distribution of fire sizes for houses and flats, enabling us to improve 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, we use AREABURN 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 B2 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 1994-2002 (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 however uses the most up-to-date information available, from the relevant building type.

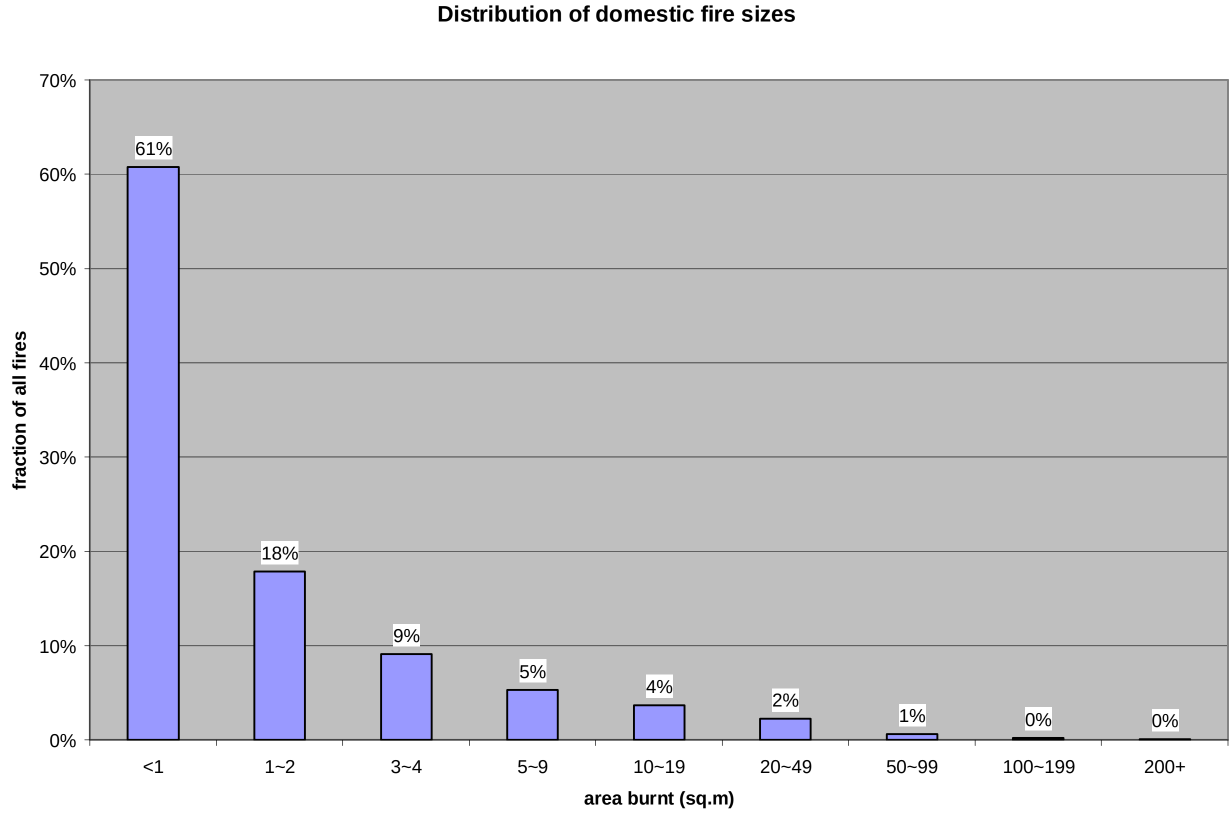


Figure B2 Actual numbers of UK fires that damage different areas from FDR1 forms (1994-2002)

Data for the risk of death per fire are shown in Figure B3, injuries per fire in Figure B4, and the average area of all damage (AREATOT) in Figure B5. There is a clear trend for the larger fires to have greater numbers of deaths, injuries etc.

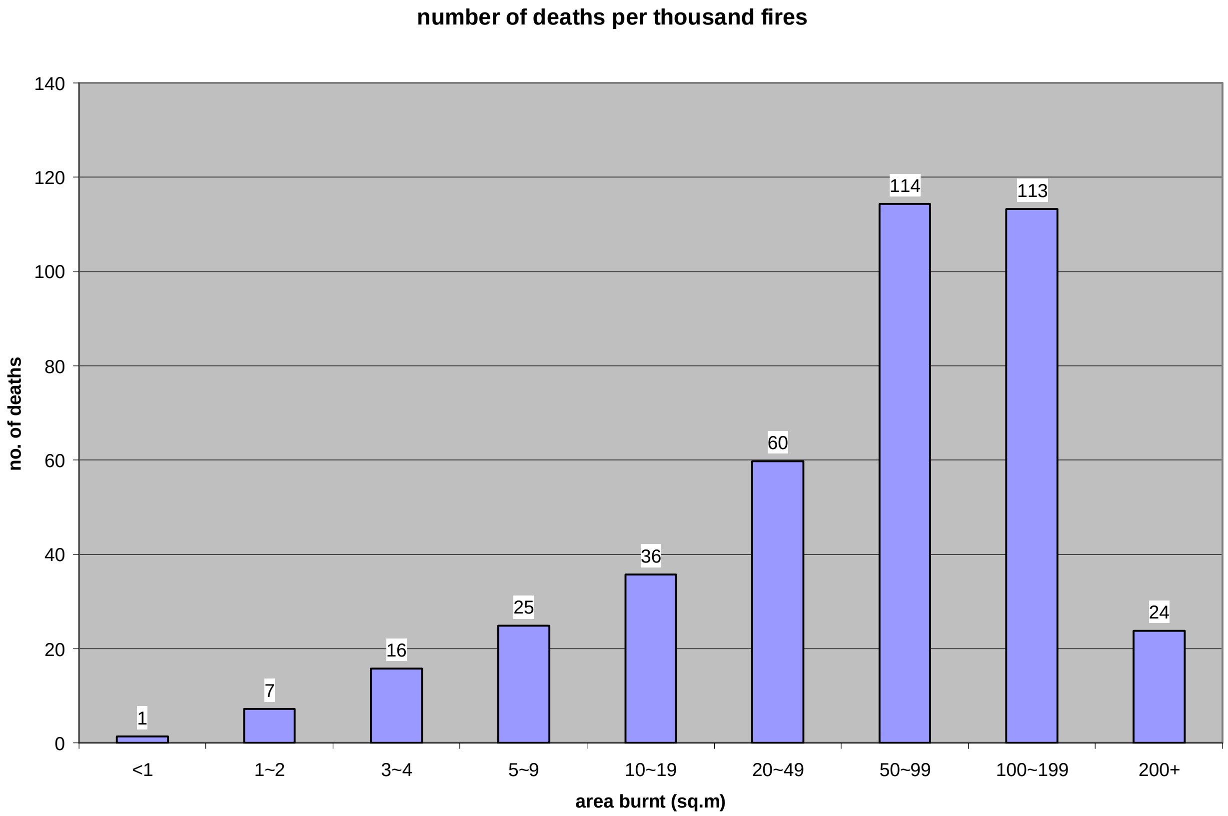


Figure B3 Actual variation in the risk of UK fire deaths, depending on ultimate fire size from FDR1 forms (1994-2002)

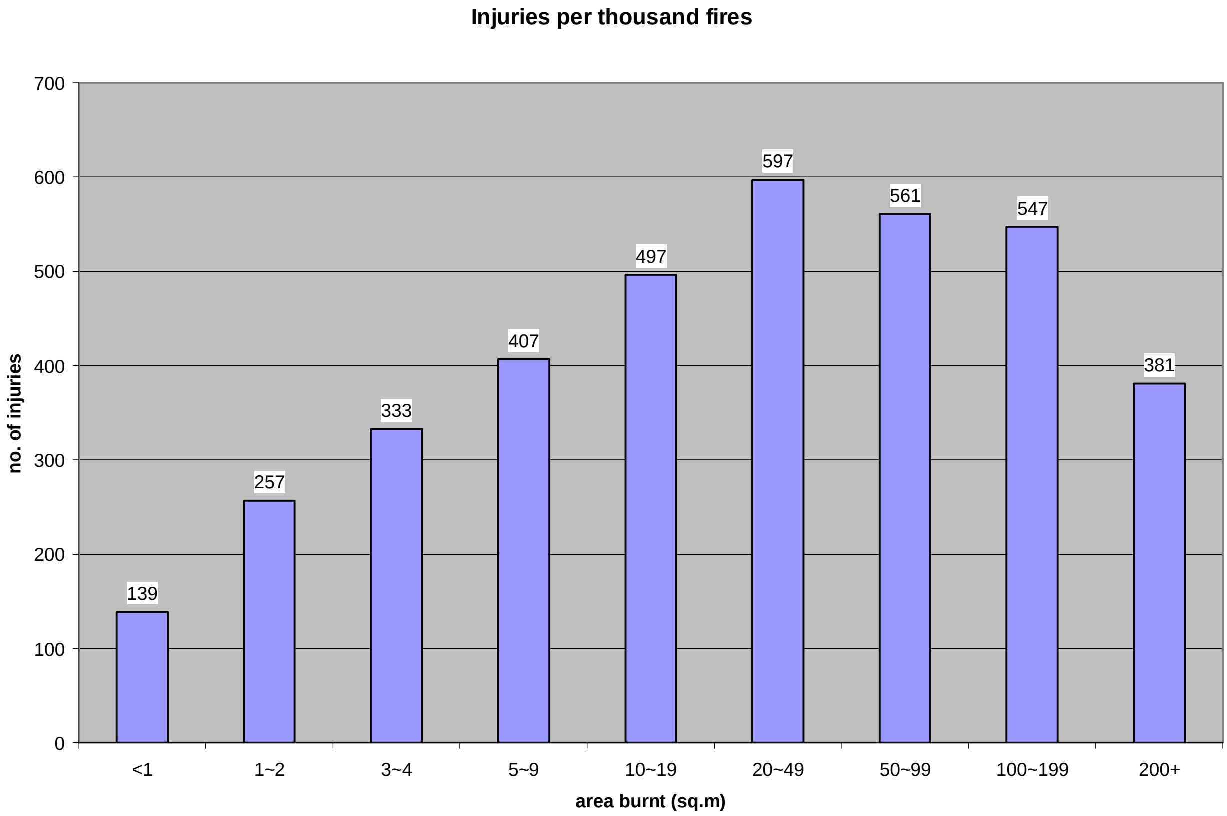


Figure B4 Actual variation in the risk of UK fire injury, depending on ultimate fire size from FDR1 forms (1994-2002)

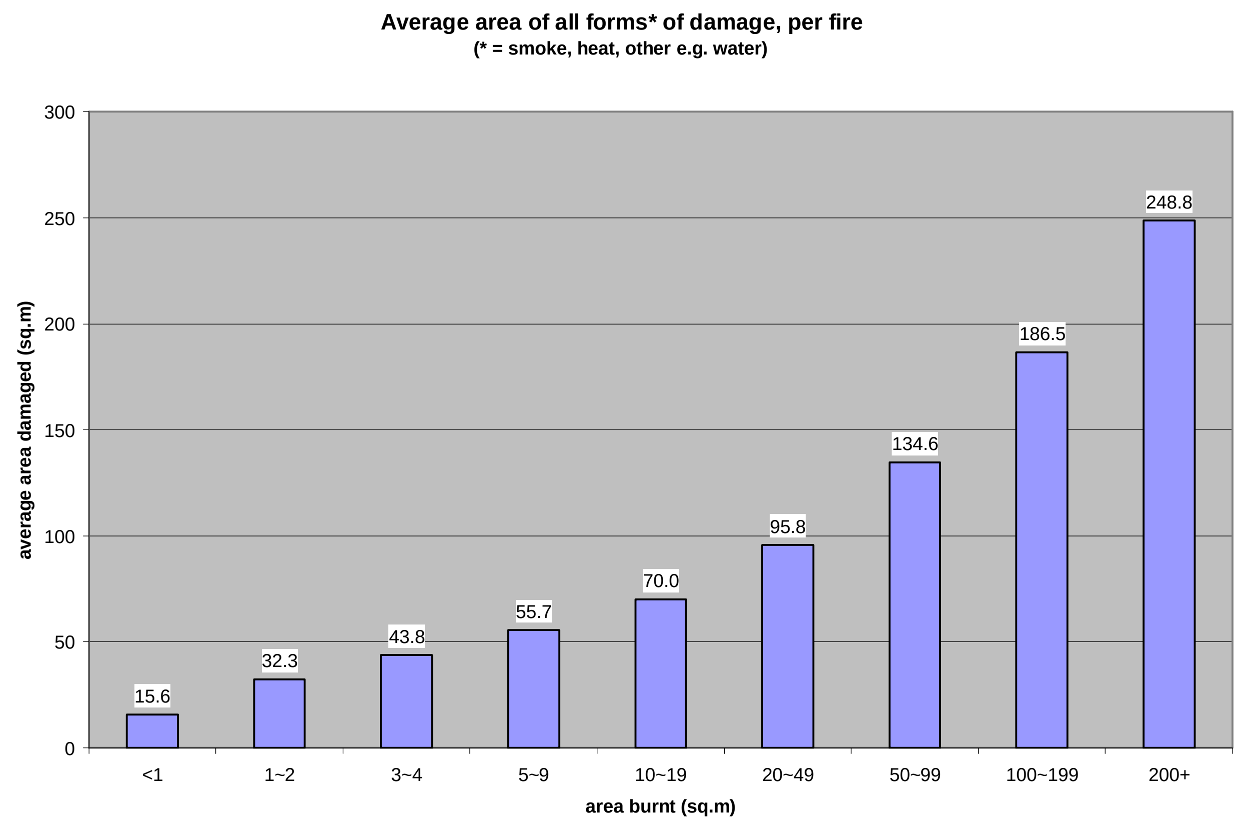


Figure B5 Actual variation in the average area of all damage per UK fire, depending on ultimate fire size from FDR1 forms (1994-2002)

B1.3 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.

Let us assume that sprinklers constrain the fire to some size “X” sq.m. Fires below this size are unaffected, so the number of deaths caused by fires of size “<X” sq.m is unchanged. However, for fires that would have grown larger, the “X” sq.m are now assumed to have the same risk as a fire of X sq.m, and thus the number of deaths prevented will be the sum of {no. of fires that would have grown to “Y” (>”X”) sq.m, multiplied by the difference in risk between fires of “Y” sq.m and “X” sq.m} for all fire sizes greater than “X” sq.m. 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 B6.

Lacking 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 [Williams et al 2004] it was assumed, on the basis of US statistics, that the overall property protection effectiveness might be 50%).

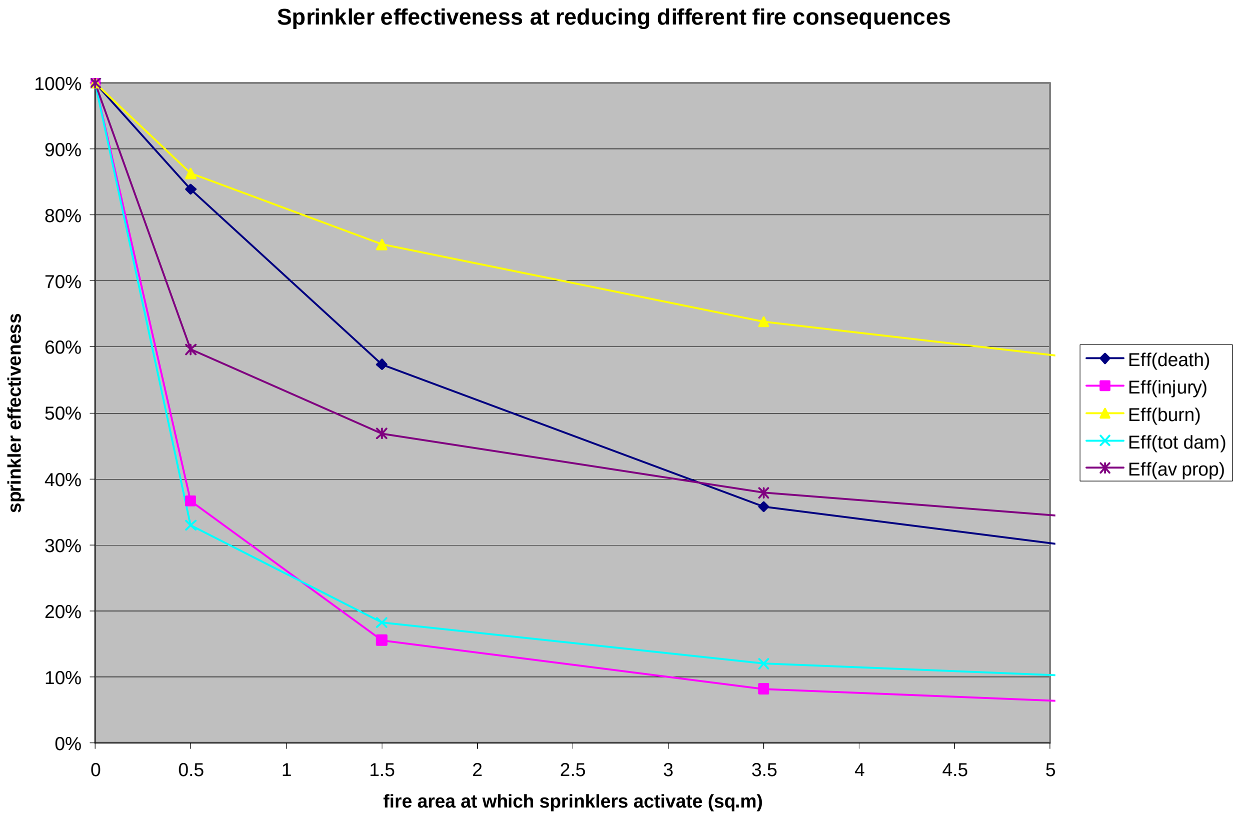


Figure B6 The effectiveness of sprinklers, depending on the fire size at activation

B1.4 Fire size at sprinkler activation

If the fire size at sprinkler activation is known, Figure B6 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 [Mowrer 2003] of the DETACT model integrates the following equation for the temperature of the sprinkler head

$$T_d(t) = T_d(0) + \int_0^t \frac{\sqrt{u_g}}{RTI}\left(T_g - T_d\right)dt \qquad \text{[Equation B1]}$$

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 B2a]

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 B2b]

- 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 B3a]

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 B3b]

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 B4]

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

$$\dot{Q}(t) = kA_f(t)$$ [Equation B5]

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 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 B1.

Table B1 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 B7.

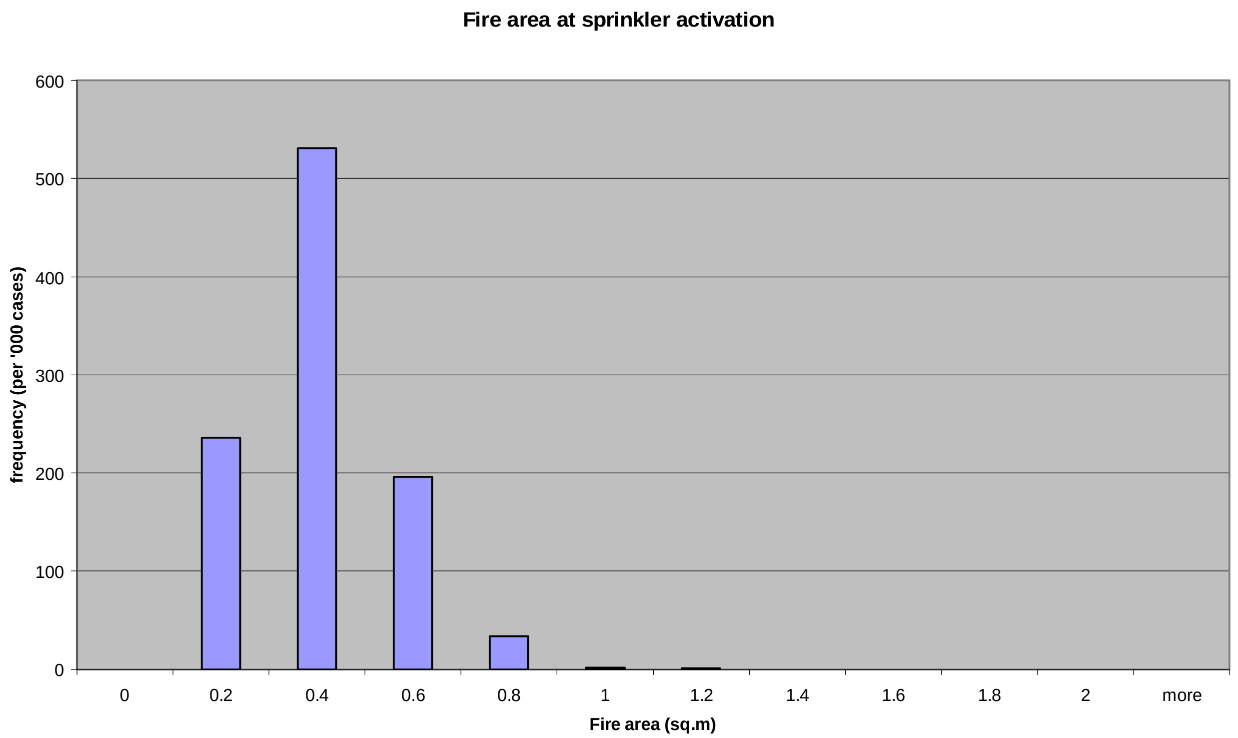


Figure B7 Distribution of the area burnt at the time of pendent type sprinkler activation

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 ~1m^2 [Williams et al 2004]) and the calculations reported in the Interflam paper (values between 0.5 ~ 1m^2) [Fraser-Mitchell 2004]. 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 [Madrzykowski 1995, Wade et al 2007]. Compared with experiments, the model is found to usually give conservative results (i.e. later predicted activations than reality).

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}. (However, note the CBA for the Thames Gateway performed by NERA 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 [Annable et al 2006]. 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)$^{0.5}$.

B1.5 Illustrative estimates of sprinkler effectiveness

The mean fire size at sprinkler activation, from the distribution shown in Figure B7, is 0.309 m^2, and the median is 0.290 m^2. Purely for the purposes of illustration, the sprinkler effectiveness ε, at these different areas, is:

- Deaths – at mean area ε_d = 90%, at median area ε_d = 91% cf. previous estimate 55% ~ 85%
- Injuries – at mean area ε_i = 61%, at median area ε_i = 63% cf. previous estimate 15% ~ 45%
- Property damage - at mean area ε_p = 75%, at median area ε_p = 77% cf. previous estimate 35% ~ 65%

The previous estimates [Williams et al 2004] were based on an activation fire area of approximately 1 m^2.

B1.6 Estimates of sprinkler effectiveness used in Monte-Carlo calculations

Each Monte-Carlo cost-benefit calculation takes a random fire area, sampled from the above probability function of fire size at sprinkler activation. The graphs of sprinkler effectiveness versus fire area are then interpolated to give the values at this particular fire size. The effectiveness values are then used for the overall calculation of sprinkler benefits. The Monte-Carlo calculations are repeated many times, to build up a probability distribution for the benefits, converted into monetary terms.

Appendix C – Cost data

Residential sprinkler installer members of BAFSA and FSA were requested to provide details of installation, water supply and annual maintenance costs for various types and sizes of buildings. Responses were received from ten organisations. Some responders were not able to provide information for all values of interest. However, amongst the ten replies there were at least four responses to each question.

Tables C1 to C22 show the installation costs, water supply costs, and annual maintenance costs for different building types. The questionnaire responses 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 responding organisations), 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.

Sprinkler installation costs

Table C1 - 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 house” in calculations.

Table C2 - Installation cost for three-storey house, one-off new build (2010)

Range of values:	£2,200	£2,000	£4,260	£2,750	£2,980	£9,000

Not used in calculations, included for completeness.

Table C3 - Installation cost for four-storey house, one-off new build (2010)

Range of values:	£2,500	£2,500	£3,500	£3,400

Not used in calculations, included for completeness.

Table C4 - Installation cost for two-storey HMO, per dwelling unit, one-off retrofit (2010)

Range of values:	£2,600	£2,000	£2,250	£3,000
Dwellings per building	4	4	4	4
Values per dwelling	£650	£500	£563	£750

Not used in calculations, included for completeness.

Table C5 - Installation cost for three-storey HMO, per dwelling unit, one-off retrofit (2010)

Range of values:	£650	£1,000	£1,200	£1,365	£280	£450	£400	£165
Dwellings per building	1	1	1	1	1	1	1	1
Values per dwelling	£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
Dwellings per building	8	12	6	6	6	6	6	6
Values per dwelling	£500	£436	£595	£533	£367	£500	£583	£458

Used for “traditional HMO” in calculations.

Table C6 - Installation cost for four-storey HMO, per dwelling unit, one-off retrofit (2010)

Range of values:	£3,900	£2,800	£4,000	£4,000	£4,900
Dwellings per building	8	8	8	8	8
Values per dwelling	£488	£350	£500	£500	£613

Not used in calculations, included for completeness.

Table C7 - Installation cost for flats, one-off new build (2010)

Range of values:	£400	£900	£600	£300	£107,000
Dwellings per building	1	1	1	1	119
Values per dwelling	£400	£900	£600	£300	£899

Table C8 - Installation cost for flats, one-off retrofit (2010)

Range of values:	£560	£1,000	£800	£300	£1,000	£80,000
Dwellings per building	1	1	1	1	1	56
Values per dwelling	£560	£1,000	£800	£300	£1,000	£1,429

Used for “converted flat” in calculations.

Table C9 - 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
Dwellings 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
Dwellings per building	1	1	1	1
Values per bed	£550	£400	£1,250	£1,300

Table C10 - Installation cost for care home per bed (20+), one-off new build (2010)

Range of values:	£150	£27,000	£400	£1,000	£1,100	£74,000	£44,300
Dwellings per building	1	70	1	1	1	60	60
Values per bed	£150	£386	£400	£1,000	£1,100	£1,233	£738

Not used in calculations, included for completeness.

Water supply costs

Table C11 - Pump and tank cost - 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 house” in calculations.

Table C12 - 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 HMO” in calculations.

Table C13 - 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 C14 - 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		

Table C15 - Boosted mains cost for house (2010)

Range of values:	£400	£600	£700	£300	£450

Also used for “shared house” in calculation.

Table C16 - Boosted mains cost for HMO (2010)

Range of values:	£500	£600	£700	£400	£500	£600	£700	£300
Range of values:	£600	£620	£250	£250				

Used for “traditional HMOs” in calculation.

Table C17 - Boosted mains cost for flats (2010)

Range of values:	£400	£600	£700	£300	£400	£600	£700	£300

Table C18 - Boosted mains cost for care homes (2010)

Range of values:	£500	£600	£900	£400	£500	£600	£1,000	£400

Annual maintenance costs for sprinkler system

Table C19 - Maintenance for house (2010)

Range of values:	£100	£95	£95	£95

Also used for “shared house” in calculations.

Table C20 - Maintenance cost for HMO (2010)

Range of values:	£100	£105	£100	£125

Used for “traditional HMOs” in calculations.

Table C21 - Maintenance cost for flats (2010)

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

Table C22 - Maintenance cost for care homes (2010)

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

Appendix D – UK Fire Statistics for dwellings and care homes

The UK Fire Statistics database was interrogated to provide estimates of the annual numbers of fires, deaths, injuries and extent of fire damage, in various domestic and residential building types [Gamble 2010]. The data were collected from the years 2003 to 2008 (provisional data in this last year).

House

Fire statistics data 2003 to 2008

Fire area (m^2)		1	2	4	9	19	49	99	199	299	Unspecified	Totals
Fires per year												
Average		7,561	1,992	1,400	764	532	274	88	35	13	12,653	25,312
Standard deviation		2,188	678	905	286	175	148	58	23	10	5,750	6,266
Deaths per year												
Average		12	15	16	18	22	18	5	4	0	103	214
Standard deviation		6	9	10	7	8	7	4	3	1	54	58
Injuries per year												
Average		1,102	570	421	290	232	134	34	16	4	2,509	5,312
Standard deviation		284	167	205	104	60	59	16	14	5	1,197	1,266

HMO

Fire statistics data 2003 to 2008

Fire area (m^2)		1	2	4	9	19	49	99	199	299	Unspecified	Totals
Fires per year												
Average		460	131	103	45	32	18	3	4	1	747	1,543
Standard deviation		122	52	91	24	13	10	1	7	1	277	322
Deaths per year												
Average		0	1	1	0	2	2	0	0	0	6	11
Standard deviation		0	1	1	0	1	2	0	0	0	4	5
Injuries per year												
Average		59	35	32	15	12	12	1	1	0	172	339
Standard deviation		13	8	18	5	2	9	1	2	0	73	78

Purpose built flat

Fire statistics data 2003 to 2008

Fire area (m^2)		1	2	4	9	19	49	99	199	299	Unspecified	Totals
Fires per year												
Average		7,123	1,245	715	381	214	93	21	5	7	8,050	17,852
Standard deviation		1,479	349	312	150	69	26	7	2	8	3,683	4,000
Deaths per year												
Average		7	10	10	8	8	4	0	1	0	36	82
Standard deviation		3	5	3	5	5	2	1	1	0	18	20
Injuries per year												
Average		1,062	322	241	186	105	56	9	4	1	1,719	3,705
Standard deviation		303	105	96	62	37	24	6	4	2	795	866

Converted flat

Fire statistics data 2003 to 2008

	Fire area (m^2)	1	2	4	9	19	49	99	199	299	Unspecified	Totals
Fires per year												
Average		909	184	152	73	52	24	7	4	2	1,476	2,881
Standard deviation		274	80	130	36	20	9	5	2	1	670	741
Average		1	2	2	2	1	1	0	0	0	10	18
Standard deviation		1	1	3	2	2	1	1	0	0	6	7
Injuries per year												
Average		138	54	54	38	27	14	3	2	2	331	663
Standard deviation		52	24	33	24	18	9	5	3	4	156	172

Care home for elderly people

Fire statistics data 2003 to 2008

	Fire area (m^2)	1	2	4	9	19	49	99	199	299	Unspecified	Totals
Fires per year												
Average		310	21	10	4	5	2	1	1	0	391	746
Standard deviation		85	9	7	1	2	1	1	1	1	180	200
Deaths per year												
Average		3	0	0	0	0	0	0	0	0	1	6
Standard deviation		6	1	1	1	0	0	0	0	0	1	6
Injuries per year												
Average		18	4	8	4	2	0	3	0	0	41	81
Standard deviation		6	2	13	5	3	1	6	0	0	23	29

Children's home

Fire statistics data 2003 - 2008

	Fire area (m^2)	1	2	4	9	19	49	99	199	299	Unspecified	Totals
Fires per year												
Average		54	5	4	1	1	1	1	0	22	117	206
Standard deviation		7	1	4	1	1	1	2	0	36	87	94
Deaths per year												
Average		0	0	0	0	0	0	0	0	0	0	0
Standard deviation		0	0	0	0	0	0	0	0	0	0	1
Injuries per year												
Average		3	1	1	0	1	0	0	0	2	10	17
Standard deviation		2	1	1	0	1	0	0	0	3	10	11

Disabled person's home, Fire statistics data 2003 - 2008

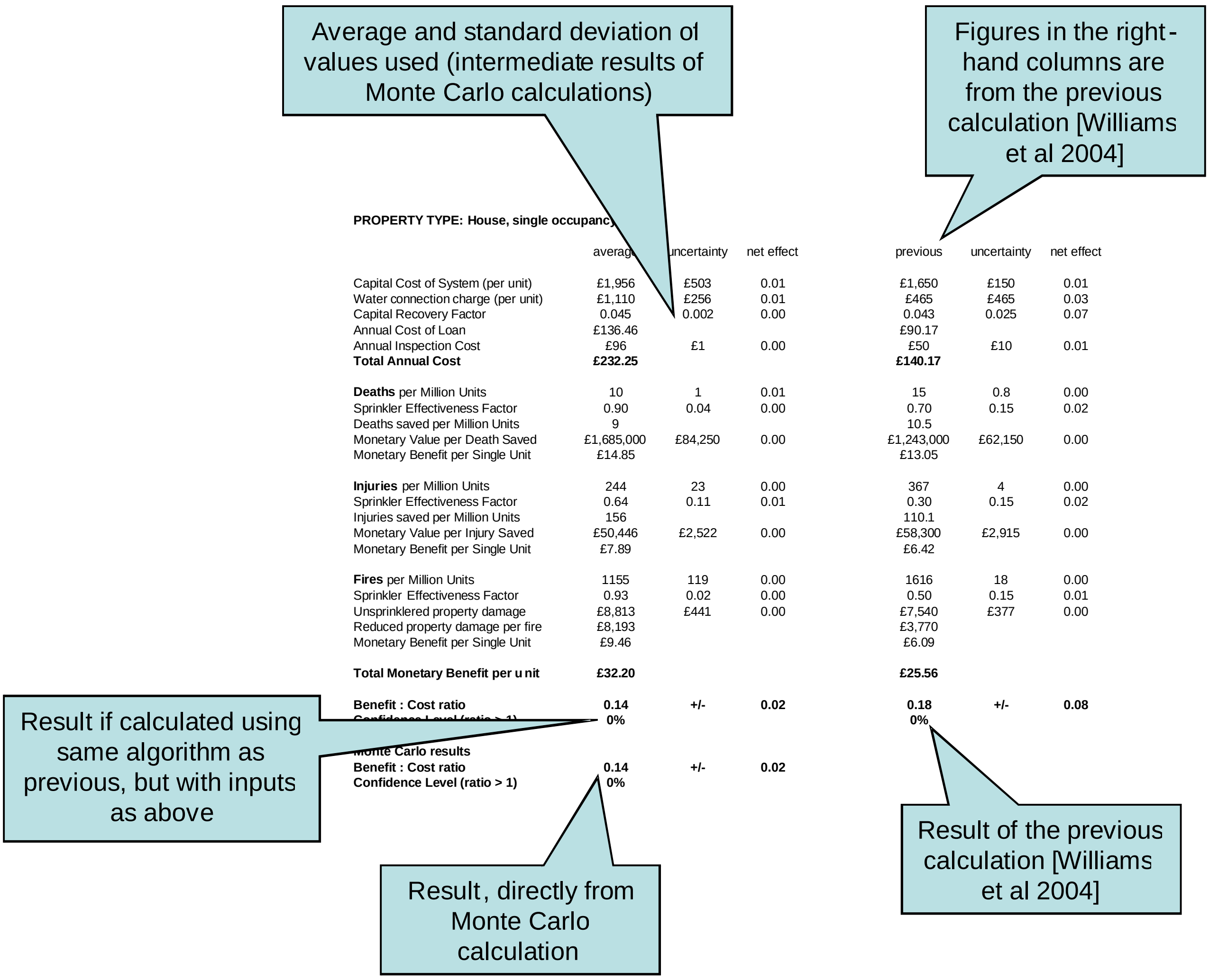
	Fire area (m^2)	1	2	4	9	19	49	99	199	299	Unspecified	Totals
Fires per year												
Average		59	6	3	1	0	0	0	0	76	106	251
Standard deviation		41	5	1	1	1	1	0	0	86	91	132
Deaths per year												
Average		0	0	0	0	0	0	0	0	0	0	1
Standard deviation		1	0	0	0	0	0	0	0	0	1	1
Injuries per year												
Average		4	1	0	0	0	0	0	0	6	4	15
Standard deviation		2	1	0	0	0	0	0	0	8	5	10

Appendix E – Results of cost benefit analysis

Monte Carlo CBA calculations have been performed, 1,000 cases for each building type, in order to build up the probability distributions for the outcomes.

For presentation purposes only, the calculations are shown in the same format as the previous work [Williams et al 2004]. This is to facilitate comparisons between this work and the previous work, and enable the differences to be seen clearly.

Figure E1 explains how each table should be interpreted.



PROPERTY TYPE: House, single occupancy

	average	uncertainty	net effect	previous	uncertainty	net effect
Capital Cost of System (per unit)	£1,956	£503	0.01	£1,650	£150	0.01
Water connection charge (per unit)	£1,110	£256	0.01	£465	£465	0.03
Capital Recovery Factor	0.045	0.002	0.00	0.043	0.025	0.07
Annual Cost of Loan	£136.46			£90.17		
Annual Inspection Cost	£96	£1	0.00	£50	£10	0.01
Total Annual Cost	**£232.25**			**£140.17**		
Deaths per Million Units	10	1	0.01	15	0.8	0.00
Sprinkler Effectiveness Factor	0.90	0.04	0.00	0.70	0.15	0.02
Deaths saved per Million Units	9			10.5		
Monetary Value per Death Saved	£1,685,000	£84,250	0.00	£1,243,000	£62,150	0.00
Monetary Benefit per Single Unit	£14.85			£13.05		
Injuries per Million Units	244	23	0.00	367	4	0.00
Sprinkler Effectiveness Factor	0.64	0.11	0.01	0.30	0.15	0.02
Injuries saved per Million Units	156			110.1		
Monetary Value per Injury Saved	£50,446	£2,522	0.00	£58,300	£2,915	0.00
Monetary Benefit per Single Unit	£7.89			£6.42		
Fires per Million Units	1155	119	0.00	1616	18	0.00
Sprinkler Effectiveness Factor	0.93	0.02	0.00	0.50	0.15	0.01
Unsprinklered property damage	£8,813	£441	0.00	£7,540	£377	0.00
Reduced property damage per fire	£8,193			£3,770		
Monetary Benefit per Single Unit	£9.46			£6.09		
Total Monetary Benefit per unit	**£32.20**			**£25.56**		
Benefit : Cost ratio	**0.14**	**+/-**	**0.02**	**0.18**	**+/-**	**0.08**
Confidence Level (ratio > 1)	**0%**			**0%**		
Monte Carlo results						
Benefit : Cost ratio	**0.14**	**+/-**	**0.02**			
Confidence Level (ratio > 1)	**0%**					

Figure E1 - Interpretation of the results tables

Table E1 - House, single occupancy, two storey

PROPERTY TYPE: House, single occupancy						
	average	uncertainty	net effect	previous	uncertainty	net effect
Capital Cost of System (per unit)	£1,956	£517	0.01	£1,650	£150	0.01
Water connection charge (per unit)	£1,086	£251	0.01	£465	£465	0.03
Capital Recovery Factor	0.045	0.002	0.00	0.043	0.025	0.07
Annual Cost of Loan	£135.38			£90.17		
Annual Inspection Cost	£96	£1	0.00	£50	£10	0.01
Total Annual Cost	**£231.19**			**£140.17**		
Deaths per Million Units	10	1	0.01	15	0.8	0.00
Sprinkler Effectiveness Factor	0.90	0.04	0.00	0.70	0.15	0.02
Deaths saved per Million Units	9			10.5		
Monetary Value per Death Saved	£1,685,000	£84,250	0.00	£1,243,000	£62,150	0.00
Monetary Benefit per Single Unit	£15.42			£13.05		
Injuries per Million Units	254	25	0.00	367	4	0.00
Sprinkler Effectiveness Factor	0.64	0.11	0.01	0.30	0.15	0.02
Injuries saved per Million Units	163			110.1		
Monetary Value per Injury Saved	£50,446	£2,522	0.00	£58,300	£2,915	0.00
Monetary Benefit per Single Unit	£8.23			£6.42		
Fires per Million Units	1202	125	0.00	1616	18	0.00
Sprinkler Effectiveness Factor	0.93	0.02	0.00	0.50	0.15	0.01
Unsprinklered property damage	£8,813	£441	0.00	£7,540	£377	0.00
Reduced property damage per fire	£8,198			£3,770		
Monetary Benefit per Single Unit	£9.86			£6.09		
Total Monetary Benefit per unit	**£33.51**			**£25.56**		
Benefit : Cost ratio	**0.14**	**+/-**	**0.02**	**0.18**	**+/-**	**0.08**
Confidence Level (ratio > 1)	**0%**			**0%**		
Monte Carlo results						
Benefit : Cost ratio	**0.14**	**+/-**	**0.02**			
Confidence Level (ratio > 1)	**0%**					

Definition of terminology in table:

"Capital cost of system (per unit)" is the installation cost of the system
"Water connection charge (per unit)" is the cost of the pump and tank
"Annual inspection cost" is the annual maintenance cost

The annual cost of the system has nearly doubled, compared with the previous calculation. There are two reasons for this, firstly the water connection charges shown here assume a pump and tank (the most expensive option), whereas in the previous calculation the water connection charges were a mixture of pump and tank and mains connection charges. Note that if the water connection charges were zero, this would save approximately £45 per year. Secondly, in this current project, the increased cost is due to a rise in the inspection and maintenance charges, from £50 to £96. This figure assumes that 100% of systems are maintained and inspected every year.

The risks per million units have decreased, relative to the values in 1994 to 1999 (the years used for the previous analysis). This may reflect the benefit of increased smoke alarm ownership, currently estimated to be in 80% of all dwellings (following guidance in Approved Document B for all new dwellings). The values of deaths prevented and property damage per fire have risen in line with inflation, but the average monetary value per injury saved is less than before, due to a revision in the weighting between serious, minor and negligible injuries to now include the latter.

The assumed effectiveness of sprinklers is higher than in the previous work, due to a revised (lower) estimate of the fire area at sprinkler activation which is based on a Monte Carlo calculation (see Appendix B).

However, taking all of these factors into account, based upon the cost data provided and the assumptions regarding maintenance, residential sprinklers are not cost-effective in two-storey houses. If sprinkler systems became more widely adopted, then it is probable that the costs for maintenance and installation would reduce. There is also the potential for trade-offs to be applied during house design and such trade-offs might save money during the construction particularly in three and four storey houses, but at this time, this has not been included within the cost benefit analysis. Finally, it is possible that sprinklers might be cost effective in specific cases, where, for example, mobility impairment may mean that independent escape from a house is difficult or not possible and the attendance times for the Fire and Rescue Service are long,

Referring to table E1, if it is assumed that the installation and water supply costs are £nil (paid for by savings elsewhere), the annual maintenance costs are 50% (based on the fact that everyone will not have their systems maintained), that the life safety benefits are the same as if the sprinklers were included as an additional safety measure, and the annual benefits would be worth up to £33.51 (deaths, injuries and property damage prevented, as before), a cost benefit ratio would be 0.7. In order to achieve a cost-benefit ratio of 1 when the maintenance costs (100%) are taken into account, the reduction in the building costs would have to be about £4,500, i.e. 3% of the total building cost. If the annual benefit were £nil (i.e. increased risk from a relaxation to AD B guidance being precisely balanced by the reduced risk due to sprinklers) then the reduction in building cost would have to be £5,200, or 3.4%.

The above example shows that sprinklers could be cost-effective if relatively modest cost savings can be achieved as a result of trade-offs. It also illustrates that the ongoing maintenance costs can have a relatively significant impact on the cost-benefit equation.

Table E2 – Houses in multiple occupation

The cost benefit analysis for HMOs is presented as two different cases. The first one is for shared houses (Table E2a) and the second one is for traditional bedsit-type HMOs (Table E2b). In carrying out the cost benefit analysis for these two different cases, it should be noted that the numbers of fires, deaths, and injuries taken from the fire statistics are averaged over both types of HMOs and that it is not possible to assign any numbers specifically to traditional HMOs or to shared houses.

Table E2a – Houses in multiple occupation – shared houses

PROPERTY TYPE: House, multiple occupancy - shared house			
	average	uncertainty	net effect
Capital Cost of System (per unit)	£1,953	£515	0.04
Water connection charge (per unit)	£1,107	£261	0.02
Capital Recovery Factor	0.045	0.002	0.01
Annual Cost of Loan	£136.15		
Annual Inspection Cost	£96	£1	0.00
Total Annual Cost	**£231.91**		
Deaths per Million Units	26	5	0.04
Sprinkler Effectiveness Factor	1.00	0.00	0.00
Deaths saved per Million Units	26		
Monetary Value per Death Saved	£1,685,000	£84,250	0.01
Monetary Benefit per Single Unit	£44.14		
Injuries per Million Units	795	90	0.01
Sprinkler Effectiveness Factor	0.67	0.11	0.02
Injuries saved per Million Units	529		
Monetary Value per Injury Saved	£50,446	£2,522	0.01
Monetary Benefit per Single Unit	£26.71		
Fires per Million Units	3606	383	0.01
Sprinkler Effectiveness Factor	0.93	0.02	0.00
Unsprinklered property damage	£8,813	£441	0.01
Reduced property damage per fire	£8,227		
Monetary Benefit per Single Unit	£29.67		
Total Monetary Benefit per unit	**£100.51**		
Benefit : Cost ratio	**0.43**	**+/-**	**0.07**
Confidence Level (ratio > 1)	**0%**		
Monte Carlo results			
Benefit : Cost ratio	**0.43**	**+/-**	**0.07**
Confidence Level (ratio > 1)	**0%**		

Definition of terminology in table:

“Capital cost of system (per unit)” is the installation cost of the system
“Water connection charge (per unit)” is the cost of the pump and tank
“Annual inspection cost” is the annual maintenance cost

Table E2b – Houses in multiple occupation – traditional bedsit type

In this case, it has been assumed that on average there are six traditional bedsit-type HMOs per building [White 2011] and that the costs of the system, installation and maintenance will be shared between individual traditional bedsit-type HMOs within the building. Clearly, if there are less than six traditional bedsit-type HMOs per building or the costs cannot be shared for any reason, then the assumptions upon which the cost benefit outcome reported in table 15 will no longer be valid.

PROPERTY TYPE: House, multiple occupancy - traditional HMO			
	average	uncertainty	net effect
Capital Cost of System (per unit)	£585	£287	0.46
Water connection charge (per unit)	£203	£34	0.05
Capital Recovery Factor	0.045	0.002	0.05
Annual Cost of Loan	£35.07		
Annual Inspection Cost	£18	£1	0.04
Total Annual Cost	**£52.67**		
Deaths per Million Units	26	5	0.17
Sprinkler Effectiveness Factor	1.00	0.00	0.00
Deaths saved per Million Units	26		
Monetary Value per Death Saved	£1,685,000	£84,250	0.04
Monetary Benefit per Single Unit	£44.14		
Injuries per Million Units	795	90	0.06
Sprinkler Effectiveness Factor	0.67	0.11	0.08
Injuries saved per Million Units	529		
Monetary Value per Injury Saved	£50,446	£2,522	0.03
Monetary Benefit per Single Unit	£26.71		
Fires per Million Units	3606	383	0.06
Sprinkler Effectiveness Factor	0.93	0.02	0.01
Unsprinklered property damage	£8,813	£441	0.03
Reduced property damage per fire	£8,227		
Monetary Benefit per Single Unit	£29.67		
Total Monetary Benefit per unit	**£100.51**		
Benefit : Cost ratio	**1.91**	**+/-**	**0.52**
Confidence Level (ratio > 1)	**96%**		
Monte Carlo results			
Benefit : Cost ratio	**1.96**	**+/-**	**0.49**
Confidence Level (ratio > 1)	**99%**		

Definition of terminology in table:

“Capital cost of system (per unit)” is the installation cost of the system
“Water connection charge (per unit)” is the cost of the pump and tank
“Annual inspection cost” is the annual maintenance cost

Table E3 - Flat, purpose-built

PROPERTY TYPE: Flat, purpose-buit							
	average	uncertainty	net effect		previous	uncertainty	net effect
Capital Cost of System (per unit)	£612	£217	0.54		£900	£0	0.00
Water connection charge (per unit)	£115	£21	0.05		£78	£78	0.02
Capital Recovery Factor	0.045	0.002	0.07		0.043	0.025	0.17
Annual Cost of Loan	£32.38				£41.70		
Annual Inspection Cost	£8	£3	0.19		£50	£10	0.07
Total Annual Cost	**£40.27**				**£91.70**		
Deaths per Million Units	20	2	0.07		27	2	0.02
Sprinkler Effectiveness Factor	0.90	0.04	0.03		0.70	0.15	0.05
Deaths saved per Million Units	18				18.9		
Monetary Value per Death Saved	£1,685,000	£84,250	0.04		£1,243,000	£62,150	0.01
Monetary Benefit per Single Unit	£29.71				£23.49		
Injuries per Million Units	895	83	0.06		941	14	0.00
Sprinkler Effectiveness Factor	0.61	0.12	0.13		0.30	0.15	0.09
Injuries saved per Million Units	547				282.3		
Monetary Value per Injury Saved	£50,446	£2,522	0.03		£58,300	£2,915	0.01
Monetary Benefit per Single Unit	£27.61				£16.46		
Fires per Million Units	4306	384	0.07		4841	74	0.00
Sprinkler Effectiveness Factor	0.87	0.04	0.04		0.50	0.15	0.06
Unsprinklered property damage	£8,813	£441	0.04		£7,540	£377	0.01
Reduced property damage per fire	£7,711				£3,770		
Monetary Benefit per Single Unit	£33.20				£18.25		
Total Monetary Benefit per unit	**£90.53**				**£58.20**		
Benefit : Cost ratio	**2.25**	**+/-**	**0.61**		**0.63**	**+/-**	**0.22**
Confidence Level (ratio > 1)	**98%**				**0%**		
Monte Carlo results							
Benefit : Cost ratio	**2.36**	**+/-**	**0.69**				
Confidence Level (ratio > 1)	**100%**						

Definition of terminology in table:

"Capital cost of system (per unit)" is the installation cost of the system
"Water connection charge (per unit)" is the cost of the pump and tank
"Annual inspection cost" is the annual maintenance cost

The estimated total annual cost has more than halved, compared to the previous work. This is because the estimate of the installation cost has dropped by 1/3, and the annual inspection cost has dropped significantly. Previously, it was assumed that each flat would require separate maintenance. However, the current industry guidance is that most of the pumps, valve set etc would be accessible from the common parts and access to individual flats would not be essential. Therefore, maintenance costs are shared over all flats in the block. Note that this is not strictly in accordance with BS 9251: 2005. which is due for revision and will take account of current industry practice.

The cost of the water supply (water connection charge in table E5) has been estimated on the basis of two pumps and tanks per block (average number of flats per block is estimated to be 19). Previously, on the basis of industry guidance, the water supply costs were a mixture of mains connection charges, and one pump and tank per floor of the block (assumed to have four flats per floor).

The risk levels are unchanged (with the range of the uncertainty), monetary conversion factors have risen with inflation except for injuries (see the house CBA for discussion). The estimates of sprinkler effectiveness have risen, due to a revised (lower) estimate for the fire area at sprinkler activation, which is based on a Monte Carlo calculation (see Appendix B).

Based on the cost data supplied by the Industry and the analysis as described, residential sprinklers will be cost-effective in purpose built flats.

Table E4 - Flat, converted

PROPERTY TYPE: Flat, converted									
	average		uncertainty	net effect		previous		uncertainty	net effect
Capital Cost of System (per unit)	£841		£279	0.35		£1,100		£0	0.00
Water connection charge (per unit)	£115		£21	0.03		£112		£54	0.01
Capital Recovery Factor	0.045		0.002	0.05		0.043		0.025	0.12
Annual Cost of Loan	£42.55					£51.67			
Annual Inspection Cost	£8		£3	0.10		£50		£10	0.04
Total Annual Cost	**£50.44**					**£101.67**			
Deaths per Million Units	18		3	0.10		23		4	0.03
Sprinkler Effectiveness Factor	0.95		0.04	0.02		0.70		0.15	0.04
Deaths saved per Million Units	17					16.1			
Monetary Value per Death Saved	£1,685,000		£84,250	0.03		£1,243,000		£62,150	0.01
Monetary Benefit per Single Unit	£28.31					£20.01			
Injuries per Million Units	641		73	0.05		664		20	0.00
Sprinkler Effectiveness Factor	0.65		0.12	0.08		0.30		0.15	0.06
Injuries saved per Million Units	419					199.2			
Monetary Value per Injury Saved	£50,446		£2,522	0.02		£58,300		£2,915	0.01
Monetary Benefit per Single Unit	£21.12					£11.61			
Fires per Million Units	2791		316	0.05		2561		96	0.00
Sprinkler Effectiveness Factor	0.92		0.02	0.01		0.50		0.15	0.03
Unsprinklered property damage	£8,813		£441	0.02		£7,540		£377	0.00
Reduced property damage per fire	£8,124					£3,770			
Monetary Benefit per Single Unit	£22.67					£9.65			
Total Monetary Benefit per unit	**£72.10**					**£41.28**			
Benefit : Cost ratio	**1.43**		**+/-**	**0.40**		**0.41**		**+/-**	**0.15**
Confidence Level (ratio > 1)	**86%**					**0%**			
Monte Carlo results									
Benefit : Cost ratio	**1.51**		**+/-**	**0.48**					
Confidence Level (ratio > 1)	**91%**								

Definition of terminology in table:

"Capital cost of system (per unit)" is the installation cost of the system
"Water connection charge (per unit)" is the cost of the pump and tank
"Annual inspection cost" is the annual maintenance cost

As with purpose-built flats, the estimated annual cost has roughly halved in comparison with the previous estimates, mainly due to the sharing of the inspection and maintenance charges over the whole block. The water supply costs were estimated in an identical manner to those of purpose-built flats. The number of flats in a converted block was assumed to be the same as in a purpose-built block, i.e. 19 on average. If converted blocks were smaller than purpose-built blocks, the annual costs would rise because the costs would be shared over fewer flats.

Therefore, based on the cost data supplied by the Industry and the analysis as described, residential sprinklers will probably be cost-effective in converted flats (confidence level = 91%).

Table E5 - Care home for elderly people

PROPERTY TYPE: Care Home, old person's

	average	uncertainty	net effect	previous	uncertainty	net effect
Capital Cost of System (per unit)	£11,125	£7,536	1.03	£4,455	£405	0.13
Water connection charge (per unit)	£3,014	£1,776	0.24	£835	£260	0.08
Capital Recovery Factor	0.045	0.002	0.08	0.043	0.025	0.99
Annual Cost of Loan	£629.19			£225.53		
Annual Inspection Cost	£153	£15	0.05	£50	£10	0.07
Total Annual Cost	**£781.85**			**£275.53**		
Deaths per Million Units	351	148	0.20	245	100	0.32
Sprinkler Effectiveness Factor	0.62	0.19	0.15	0.70	0.15	0.17
Deaths saved per Million Units	216			171.5		
Monetary Value per Death Saved	£1,685,000	£84,250	0.02	£1,243,000	£62,150	0.04
Monetary Benefit per Single Unit	£363.30			£213.17		
Injuries per Million Units	5034	924	0.04	6073	498	0.03
Sprinkler Effectiveness Factor	0.73	0.09	0.03	0.30	0.15	0.19
Injuries saved per Million Units	3664			1821.9		
Monetary Value per Injury Saved	£50,446	£2,522	0.01	£58,300	£2,915	0.02
Monetary Benefit per Single Unit	£184.85			£106.22		
Fires per Million Units	46412	7670	0.28	66074	4026	0.06
Sprinkler Effectiveness Factor	0.86	0.04	0.09	0.50	0.15	0.27
Unsprinklered property damage	£33,591	£1,680	0.09	£7,540	£377	0.05
Reduced property damage per fire	£28,794			£3,770		
Monetary Benefit per Single Unit	£1,336.40			£249.10		
Total Monetary Benefit per unit	**£1,884.54**			**£568.49**		
Benefit : Cost ratio	**2.41**	**+/-**	**1.14**	**2.06**	**+/-**	**1.12**
Confidence Level (ratio > 1)	**89%**			**97%**		
Monte Carlo results						
Benefit : Cost ratio	**2.82**	**+/-**	**1.35**			
Confidence Level (ratio > 1)	**99%**					

Definition of terminology in table:

“Capital cost of system (per unit)” is the installation cost of the system
“Water connection charge (per unit)” is the cost of the pump and tank
“Annual inspection cost” is the annual maintenance cost

A comparison of the annual costs shows that the current estimate is nearly three times higher than the previous value. However, the installation costs (per resident) show a huge variation (see Appendix C). If the average cost were to be among the range of the lower current estimates, then the cost might be no higher than the previous estimate. Current estimates for the cost of a pump and tank for the water supply similarly show a huge variation, whereas the previous estimate was a mixture of pump and tank and mains connection charges.

The previous benefits we now believe to have been overestimated. In particular, we assumed that the effectiveness of sprinklers at preventing deaths (70%) would be similar in all domestic and residential premises. Subsequent work on fires in care homes [Shipp and Clark 2006] looked in more detail at fatalities in care homes for the elderly and showed many had set fire to themselves or their bedclothes, and would be expected to suffer very severe (probably fatal) burns before sprinklers could operate. Based on this detailed examination we would have estimated the sprinkler effectiveness at only 30%. The current estimate of sprinkler effectiveness is 62%, however the fire statistics may have been skewed by the Rosepark fire in which 14 people died. Ignoring the Rosepark fire, the average number of deaths per year in care homes for the elderly is 4.5 [Arup Fire 2010].

Note that the uncertainties in the effectiveness for reducing risks in care homes are large as a consequence of the small statistical sample size. As an example, due to the large uncertainties, the 95% confidence interval for the effectiveness of preventing deaths in care homes for disabled people covers almost the entire range of possibilities between 0~100%

Most of the increased benefit comes from the prevention of fire damage. We assumed that the unsprinklered fire loss would be nearer the “non domestic” value of £33.6k than the “domestic” £7.5k.

Therefore, based on the cost data supplied by the Industry and the analysis as described, residential sprinklers will be cost effective in care homes for the elderly.

Table E6 - Care home for children

PROPERTY TYPE: Care Home, children

	average	uncertainty	net effect	previous	uncertainty	net effect
Capital Cost of System (per unit)	£5,862	£3,979	3.74	£2,805	£255	0.24
Water connection charge (per unit)	£3,014	£1,776	1.67	£835	£260	0.24
Capital Recovery Factor	0.045	0.002	0.34	0.043	0.025	1.97
Annual Cost of Loan	£395.00			£155.19		
Annual Inspection Cost	£153	£15	0.31	£50	£10	0.22
Total Annual Cost	**£547.66**			**£205.19**		
Deaths per Million Units	291	1062	3.17	143	260	1.10
Sprinkler Effectiveness Factor	0.97	0.09	0.08	0.70	0.15	0.13
Deaths saved per Million Units	282			100.1		
Monetary Value per Death Saved	£1,685,000	£84,250	0.04	£1,243,000	£62,150	0.03
Monetary Benefit per Single Unit	£475.28			£124.42		
Injuries per Million Units	12955	67790	3.52	12857	2274	0.19
Sprinkler Effectiveness Factor	0.56	0.18	0.21	0.30	0.15	0.55
Injuries saved per Million Units	7299			3857.1		
Monetary Value per Injury Saved	£50,446	£2,522	0.03	£58,300	£2,915	0.05
Monetary Benefit per Single Unit	£368.21			£224.87		
Fires per Million Units	164994	781488	47.45	149286	20652	0.38
Sprinkler Effectiveness Factor	0.99	0.02	0.22	0.50	0.15	0.82
Unsprinklered property damage	£33,591	£1,680	0.50	£7,540	£377	0.14
Reduced property damage per fire	£33,252			£3,770		
Monetary Benefit per Single Unit	£5,486.40			£562.81		
Total Monetary Benefit per unit	**£6,329.89**			**£912.10**		
Benefit : Cost ratio	**11.56**	**+/-**	**47.87**	**4.45**	**+/-**	**2.54**
Confidence Level (ratio > 1)	**59%**			**100%**		
Monte Carlo results						
Benefit : Cost ratio	**13.33**	**+/-**	**91.40**			
Confidence Level (ratio > 1)	**99%**					

Definition of terminology in table:

“Capital cost of system (per unit)” is the installation cost of the system
“Water connection charge (per unit)” is the cost of the pump and tank
“Annual inspection cost” is the annual maintenance cost

Due to the small number of children’s homes, and the even smaller number of fires, deaths and injuries, the benefits of sprinkler systems are very uncertain. However, most of the benefit is due to the prevention of property damage. The calculation above is based on the “non domestic” rate of £33.6k per fire. If the calculation had used the lower value “domestic” rate of £7.5k, the benefits would still outweigh the costs.

Table E7 - Care home for disabled people

PROPERTY TYPE: Care Home, disabled people

	average	uncertainty	net effect	average	uncertainty	net effect
Capital Cost of System (per unit)	£4,872	£3,314	0.50	£2,640	£240	0.06
Water connection charge (per unit)	£3,014	£1,776	0.27	£835	£260	0.06
Capital Recovery Factor	0.045	0.002	0.05	0.043	0.025	0.49
Annual Cost of Loan	£350.95			£148.15		
Annual Inspection Cost	£153	£15	0.05	£50	£10	0.06
Total Annual Cost	**£503.60**			**£198.15**		
Deaths per Million Units	80	34	0.03	72	66	0.29
Sprinkler Effectiveness Factor	0.30	0.32	0.09	0.70	0.15	0.07
Deaths saved per Million Units	24			50.4		
Monetary Value per Death Saved	£1,685,000	£84,250	0.00	£1,243,000	£62,150	0.02
Monetary Benefit per Single Unit	£40.47			£62.65		
Injuries per Million Units	1416	434	0.02	2523	390	0.03
Sprinkler Effectiveness Factor	0.51	0.25	0.04	0.30	0.15	0.11
Injuries saved per Million Units	716			756.9		
Monetary Value per Injury Saved	£50,446	£2,522	0.00	£58,300	£2,915	0.01
Monetary Benefit per Single Unit	£36.12			£44.13		
Fires per Million Units	23295	6629	0.44	30990	3342	0.06
Sprinkler Effectiveness Factor	0.99	0.03	0.05	0.50	0.15	0.18
Unsprinklered property damage	£33,591	£1,680	0.08	£7,540	£377	0.03
Reduced property damage per fire	£33,364			£3,770		
Monetary Benefit per Single Unit	£777.22			£116.83		
Total Monetary Benefit per unit	**£853.80**			**£223.61**		
Benefit : Cost ratio	**1.70**	**+/-**	**0.73**	**1.13**	**+/-**	**0.63**
Confidence Level (ratio > 1)	**83%**			**66%**		
Monte Carlo results						
Benefit : Cost ratio	**1.86**	**+/-**	**0.86**			
Confidence Level (ratio > 1)	**89%**					

Definition of terminology in table:

"Capital cost of system (per unit)" is the installation cost of the system
"Water connection charge (per unit)" is the cost of the pump and tank
"Annual inspection cost" is the annual maintenance cost

Due to the small number of homes for disabled people, and the even smaller number of fires, deaths and injuries, the benefits of sprinkler systems are very uncertain. As an example, due to the large uncertainties, the 95% confidence interval for the effectiveness of preventing deaths in care homes for disabled people covers almost the entire range of possibilities between 0~100%.

As with the other types of care homes, most of the benefit is due to the prevention of property damage. It is important to note that the uncertainty level associated with the value of the unsprinklered property damage does not reflect the uncertainty in whether the average "non domestic" value of £33.6k is appropriate for buildings of this type. The monetary benefit could therefore be less, and the increased uncertainty would also tend to reduce the confidence level of a positive cost-benefit result.

Appendix F – Uncertainty analysis

Most, if not all, values will have some uncertainty associated with them. In previous work [Williams et al 2004], an analytical approach was used to estimate the uncertainties in the final cost-benefit ratio, based on the uncertainties of the input values. However, whilst this is convenient when producing spreadsheets to perform the calculations, the method does have a limitation.

Consider for example the benefit due to the number of deaths prevented, given by

$$b_d = V_d . e_d . r . D \qquad \text{[Equation F1]}$$

where V_d is the value of each life saved, e_d is the effectiveness of the system(s) at preventing deaths, r the reliability, and D is the expected annual number of deaths in the absence of the system(s). The contributions from the individual component uncertainties are added in quadrature, thus

$$(\Delta b_d)^2 = \left(\frac{\partial b_d}{\partial V_d}\right)^2 \Delta V_d^2 + \left(\frac{\partial b_d}{\partial e_d}\right)^2 \Delta e_d^2 + \left(\frac{\partial b_d}{\partial r}\right)^2 \Delta r^2 + \left(\frac{\partial b_d}{\partial D}\right)^2 \Delta D^2 \qquad \text{[Equation F2]}$$

Evaluating the individual derivatives, substituting and simplifying gives

$$\left(\frac{\Delta b_d}{b_d}\right)^2 = \left(\frac{\Delta V_d}{V_d}\right)^2 + \left(\frac{\Delta e_d}{e_d}\right)^2 + \left(\frac{\Delta r}{r}\right)^2 + \left(\frac{\Delta D}{D}\right)^2 \qquad \text{[Equation F3]}$$

This is very elegant, but unfortunately the error propagation formula, Equation F2, for a function, in this case b_d, that is a set of non-linear combination of the input variables, requires the function to be linearised by approximation to a first-order Maclaurin series expansion:

$$f(x+\Delta x) = f(x) + \left(\frac{\partial f}{\partial x}\right)\Delta x + \left(\frac{\partial f}{\partial x}\right)^2 . \Delta x^2 + \mathbf{K} \qquad \text{[Equation F4]}$$

$$f(x+\Delta x) \approx f(x) + \left(\frac{\partial f}{\partial x}\right)\Delta x \qquad \text{[Equation F5]}$$

Therefore Equation F2 is only formally correct when the individual uncertainties (ΔV_d etc) tend to zero. Unfortunately, although this approximation can be used for some of the components involved in the cost-benefit calculation, in other area the uncertainties can be rather large.

This problem has been resolved by using Monte-Carlo methods. Monte Carlo methods are experiments based on random numbers, usually produced by a computer. In this application, the Monte Carlo approach is applied to the cost-benefit calculation, which is repeated many times using different values for the input variables. The input variables are random numbers, sampled from appropriate probability distributions. The result of each cost-benefit calculation (e.g. the ratio of benefit to cost) is therefore also a random number.

From the distribution of the output random number, the mean, standard deviation, 95% (or other fractile) confidence bounds for the true value, and the proportion of cases where a positive net benefit is achieved can be worked out. Figure F1 shows a typical example of a probability distribution for the output of a Monte-Carlo cost-benefit calculation.

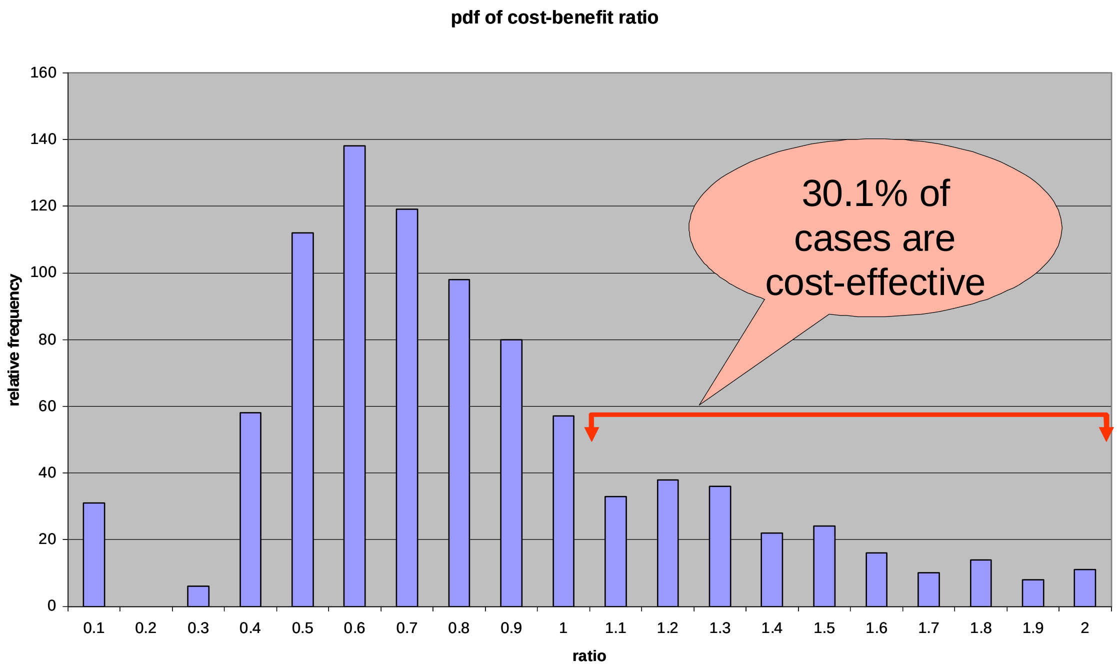


Figure F1 Example output from a Monte-Carlo cost-benefit calculation

Another advantage of the Monte-Carlo approach is realised when the probability of achieving a positive net benefit is calculated. In the previous work, the analytical approach to uncertainty propagation only gave the standard deviation of the uncertainty, not the distribution of the output quantity. It was therefore necessary to make an assumption about its distribution (Normal was assumed) in order to estimate the probability of achieving a positive net benefit. With the Monte-Carlo method, it is simply a question of counting the number of results passing a given threshold.

Appendix G – Results of sensitivity analysis

The purpose of the sensitivity analysis is to investigate how the result of the cost-benefit calculation varies, for small changes in the values of the input variables. For larger changes, the CBA calculation may not be a linear function of the input variable, and hence prediction of the result may be more inaccurate.

If the future look is able to provide quantitative estimates of changes to the input values for the CBA, the sensitivity analysis can then predict the change to the results of the CBA.

Because the CBA results have only been presented for the most expensive water supply option (pump and tank), the average costs of the three water supply options are also given in this Appendix, to enable the CBA results for the other options to be derived if desired.

G1 Method

The overall annual cost per accommodation unit is (see section 4)

$$£C = K(£S + £W) + £M$$ [Equation G1]

The annual values of reducing deaths, injuries and property damage per accommodation unit are

$$£B_d = £V_d.R_d.r.e_d$$ [Equation G2]

$$£B_i = £V_i.R_i.r.e_i$$ [Equation G3]

$$£B_p = £V_p.R_p.r.e_p$$ [Equation G4]

The annual risks are determined by dividing e.g. 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 B), and also include an explicit factor for the reliability of sprinklers to operate when expected.

The total annual benefit is

$$£B_{tot} = £B_d + £B_i + £B_p$$ [Equation G5]

and the net annual benefit is simply

$$£B_{net} = £B_{tot} - £C$$ [Equation G6]

The sensitivity of the net benefit to changes in the input parameters can be found by differentiation. For example, the sensitivity to the effectiveness in preventing deaths is

$$\frac{\partial(£B_{net})}{\partial e_d} = £V_d.R_d.r$$ [Equation G7]

For each replication of the Monte Carlo calculations, the sensitivity is calculated according to the values in use for that replication. The mean and standard deviation of the 1,000 sensitivity values for all the replications is then calculated. These means and standard deviations are presented in Tables G1 to G7 for the different building types.

G2 Results

The values in tables G1 – G3 below are presented in the form “mean ± 1 standard deviation”.

As an example of how these figures should be used, consider the sensitivity of the net benefit to the effectiveness in preventing death (see equation G7). For a house, this value is £17 ± £2. The effectiveness is currently estimated to be 90% (see Table 11 in section 5.9, or Table E1 in Appendix E). If this effectiveness estimate were to increase to 100% for some reason, a change of 10%, then the change in the net benefit would be

$$D\pounds B_{net} = \frac{\partial(\pounds B_{net})}{\partial e_d} \,.\, De_d \qquad \text{[Equation G8]}$$

i.e. 10% x (£17 ± £2) = £1.70 ± £0.20

As a further example, note that the sensitivity of the net benefit (per building per year) to the maintenance charge is -£1 ± £0 for all building types. This is very simple to understand: for every £1 that the annual maintenance charge increases by, the net benefit decreases by the same amount.

In the tables G1 – G3 below,

- Economic factors (£death, £injury, £property) are the monetary values for the prevention of death or injury, and the cost of property damage per fire
- Sprinkler factors: reliability is self-explanatory; lifetime1, lifetime2 and lifetime3 are the sensitivity of the net benefit to the sprinkler system lifetime for the three water supply cost options – 1 = no additional cost, 2 = boosted mains, 3 = pump and tank.
- Risk factors (fires, deaths, injuries) are the number of fires deaths and injuries per million buildings per year
- Effectiveness (deaths, injuries, property) are the fractional reductions in the numbers of deaths, injuries and the amount of property damage, when sprinklers are present, compared to when they are not.
- Cost factors (installation, water, maintenance) are the one-off installation and water supply costs, and the annual maintenance cost.

Table G1 Sensitivity factors, houses and HMOs

		House				HMO: shared house				HMO: traditional		
Economic factors	£death	0.00001	±	0.00000		0.00003	±	0.00001		0.00003	±	0.00001
	£injury	0.0002	±	0.0000		0.0005	±	0.0001		0.0005	±	0.0001
	£property	0.001	±	0.000		0.003	±	0.000		0.003	±	0.000
Sprinkler factors	Reliability	33	±	3		99	±	12		100	±	13
	Lifetime1	0.8	±	0.3		0.8	±	0.3		0.3	±	0.1
	Lifetime2	1.0	±	0.3		1.0	±	0.3		0.3	±	0.1
	Lifetime3	1.3	±	0.3		1.3	±	0.3		0.3	±	0.1
Risk factors	Fires	0.008	±	0.000		0.008	±	0.000		0.008	±	0.000
	Deaths	1.5	±	0.1		1.6	±	0.1		1.7	±	0.1
	Injuries	0.032	±	0.006		0.033	±	0.006		0.033	±	0.006
Effectiveness	Deaths	17	±	2		43	±	9		43	±	9
	Injuries	13	±	1		39	±	5		39	±	5
	Property	10	±	1		31	±	4		31	±	4
Cost factors	Installation	-0.045	±	0.002		-0.045	±	0.002		-0.045	±	0.002
	Maintenance	-1	±	0		-1	±	0		-1	±	0
	Water	-0.045	±	0.002		-0.045	±	0.002		-0.045	±	0.002

In order to indicate the relative consequences of changes to the cost-benefit input parameters note that the net benefit (per building per year) is -£198 ± £26 for houses, -£132 ± £29 for shared houses and +£48 ± £18 for traditional HMOs.

Table G2 Sensitivity factors, flats

		Purpose-built flats				Converted flats		
Economic factors	£death	0.00002	±	0.00000		0.00002	±	0.00000
	£injury	0.0005	±	0.0001		0.0004	±	0.0001
	£property	0.004	±	0.000		0.003	±	0.000
Sprinkler factors	Reliability	90	±	10		72	±	8
	Lifetime1	0.3	±	0.1		0.4	±	0.1
	Lifetime2	0.3	±	0.1		0.4	±	0.1
	Lifetime3	0.3	±	0.1		0.4	±	0.1
Risk factors	Fires	0.008	±	0.001		0.008	±	0.000
	Deaths	1.5	±	0.1		1.6	±	0.1
	Injuries	0.030	±	0.006		0.032	±	0.006
Effectiveness	Deaths	32	±	4		29	±	5
	Injuries	44	±	5		32	±	4
	Property	37	±	4		24	±	3
Cost factors	Installation	-0.045	±	0.002		-0.045	±	0.002
	Maintenance	-1	±	0		-1	±	0
	Water	-0.045	±	0.002		-0.045	±	0.002

In order to indicate the relative consequences of changes to the cost-benefit input parameters, note that the net benefit (per building per year) is £48 ± £14 for purpose-built flats, and £20 ± £15 for converted flats.

Table G3 Sensitivity factors, care homes

		Care home for elderly			Care home for children			Care home for disabled		
Economic factors	£death	0.00020	±	0.00008	0.00023	±	0.00248	0.00002	±	0.00003
	£injury	0.0036	±	0.0009	0.0069	±	0.0309	0.0008	±	0.0005
	£property	0.039	±	0.007	0.152	±	0.867	0.023	±	0.006
Sprinkler factors	Reliability	1856	±	357	5944	±	36391	850	±	220
	Lifetime1	4.6	±	3.3	2.4	±	1.7	2.0	±	1.4
	Lifetime2	4.8	±	3.3	2.7	±	1.7	2.3	±	1.4
	Lifetime3	5.8	±	3.4	3.7	±	1.9	3.3	±	1.7
Risk factors	Fires	0.028	±	0.002	0.032	±	0.002	0.033	±	0.002
	Deaths	1.0	±	0.3	1.6	±	0.2	0.5	±	0.5
	Injuries	0.036	±	0.005	0.028	±	0.009	0.025	±	0.013
Effectiveness	Deaths	584	±	245	394	±	4346	134	±	56
	Injuries	250	±	50	641	±	2641	71	±	22
	Property	1520	±	279	5143	±	30183	762	±	208
Cost factors	Installation	-0.045	±	0.002	-0.045	±	0.002	-0.045	±	0.002
	Maintenance	-1	±	0	-1	±	0	-1	±	0
	Water	-0.045	±	0.002	-0.045	±	0.002	-0.045	±	0.002

In order to indicate the relative consequences of changes to the cost-benefit input parameters, note that the net benefit (per building per year) is £1,038 ± £476 for care homes for the elderly, £5,693 ± £28,926 for care homes for children and £322 ± £287 for care homes for disabled people.

G3 Costs of water supplies

Three water supply options were considered: a negligible additional cost, the use of a boosted mains connection and the use of a pump and tank (or two pumps and tanks per block of flats). As the pump and tank option was the most expensive, results have just been shown for this case. The rationale behind this decision is that if sprinklers are cost-beneficial even with the most expensive water supply option, they will also be cost effective for less expensive water supplies.

The average costs, with their associated uncertainties, are shown in Table G4 for the different water supply options. These are the one-off costs; in order to assess the effect on the annual net benefit, the difference between the pump and tank option and a cheaper option should be multiplied by the Capital Recovery Factor, average value 0.0445, and added to the net benefit.

Table G4 - Average water supply costs, for different options and building types

Building type	No extra cost	Boosted mains	Pump and tank
House (single occupancy)	£0 ± £0	£489 ± £115	£1,110 ± £256
HMO (shared house)	£0 ± £0	£479 ± £116	£1,094 ± £246
HMO (traditional)	£0 ± £0	£84 ± £25 [a]	£203 ± £34 [b]
Flat (purpose-built)	£0 ± £0	£26 ± £8 [c]	£114 ± £20 [d]
Flat (converted)	£0 ± £0	£26 ± £8 [c]	£114 ± £20 [d]
Care home (elderly people)	£0 ± £0	£598 ± £178	£3,014 ± £1,776
Care home (children)	£0 ± £0	£598 ± £178	£3,014 ± £1,776
Care home (disabled people)	£0 ± £0	£598 ± £178	£3,014 ± £1,776

All uncertainties are ± 1 standard deviation.

Notes:

a) Cost of a single pump for boosted mains, divided by the average number of traditional HMOs per building

b) Cost of a single pump and tank, divided by the average number of traditional HMOs per building

c) Cost of a single pump for boosted mains, divided by the average number of flats per block

d) Cost of two pumps and tanks, divided by the average number of flats per block. This is a conservative estimate, since flats would need two pumps for redundancy, but only one tank [Young 2011a].