

**Effectiveness of sprinklers in
residential premises**

Section 3: Pilot Study

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3 Pilot Study

3.1 Introduction

The Pilot Study phase of the Project covered the following items:

1. A review and analysis of statistical and other information in order to determine the effectiveness of sprinklers in reducing life loss and property damage. The main source of data was expected to be the UK fire statistics database. This would be supplemented by information from other countries, especially the USA where residential and domestic sprinkler systems have been in use for a number of years. However, information from other countries may not be directly applicable to the UK situation, due to cultural and technical differences, and in particular is not appropriate for use in any future Regulatory Impact Assessment.
2. A simple assessment of the risks in residential premises, in order to determine the potential benefits of residential sprinklers for the UK housing sector.
3. A consideration of the suitability of DD 251 and DD 252 as a basis for future UK residential sprinkler standards, by carrying out a critical review of these documents to identify the technical knowledge gaps and other areas of uncertainty.

One of the first tasks was to decide which classification scheme for residential properties should be used. The various sources of statistical and other information tend to have differing categories, and it is not always clear how the categories of one scheme map on to those of another scheme.

Having chosen the classification scheme, the risks of fire in the different residential premises were determined from the UK fire statistics. These risks could be presented in a number of different perspectives, either the risks per person, risks per fire, or risks per building/ accommodation unit. All three versions were calculated, as all provided useful insights, although the latter was the most useful for the cost benefit analysis of the Project (see section 6).

As it proved impossible to make a direct estimate of sprinkler effectiveness from the UK fire statistics, an indirect method was devised. This exploited a correlation between the ultimate fire size (square m of area damaged) and the risk of death or injury per fire. If we assumed that sprinklers would restrict the fire growth, the risks of those fires that would have grown larger, in the absence of sprinklers, would be reduced. The risks from fires that were too small to trigger sprinkler activation would be unaffected.

The literature review encompassed the experience of residential sprinklers in the USA, New Zealand, Vancouver (BC, Canada) and Scottsdale (Arizona, USA). In particular, information on cost benefit analyses was sought, both in terms of the methods employed, and also the input data. As mentioned earlier, due to cultural differences etc, it was not anticipated that the data would necessarily be directly applicable to a UK-

based cost benefit analysis, but it would provide a useful check that figures used were plausible. Information on codes and standards referring to residential sprinklers was also sought, to compare with the review of the UK's DD 251 and DD 252.

3.2 Categories of domestic and residential accommodation

At the start of this Pilot Study, definitions of residential accommodation and HMO's were identified from various sources for use in this Project. One of the difficulties encountered at an early stage of the Project was that there were many different ways of categorising domestic and residential accommodation. Whichever categorisation scheme was eventually chosen for use in this project, it was not always clear how other schemes mapped on to it.

As the Project was being conducted to provide input to Approved Document B purposes, it would be ideal if the same definitions in AD B could also be used for this work. However, one of the constraints on the project was to consider sprinkler systems conforming to BS DD 251 and DD 252, which have different definitions. In particular, hospitals, detention centres, schools and hotels are not covered by DD 251.

Approved Document B (2000) defines five residential purpose groups: three groups of dwelling (flat or maisonette; house; house with habitable storey > 4.5m above ground level); institutional (including hospital, home, school or similar for care of elderly, children or disabled, or place of lawful detention); other institutional (including hotel, boarding house, residential college, hall of residence, hostel, or any other not covered elsewhere).

BS DD 251 and DD 252 cover two occupancy types: residential (for multiple occupation include apartments, residential homes, HMO's, blocks of flats, boarding houses, aged persons homes, nursing homes, residential rehabilitation accommodation, dormitories) and domestic (individual dwelling houses, individual flats, maisonettes and transportable homes).

The Housing Act contains a definition of a House of Multiple Occupation (HMO), but it is rather broad and so ODPM (previously DTLR) has developed a number of HMO categories for research and analytical purposes. These are (i) traditional HMO's; (ii) shared houses; (iii) households with lodgers; (iv) purpose-built HMO's; (v) hostels, guest houses, B&B hotels and boarding houses; (vi) self-contained converted flats.

One of the primary sources of information for this Project was the UK fire statistics [Gamble 1997]. Excluding hospitals, detention centres, schools and hotels (as they are not covered by DD 251), the basic categories of residential accommodation found in the UK fire statistics are:

- Houses
- Flats and maisonettes
- Homes (for elderly, children, handicapped)
- Welfare/charity
- Block accommodation (e.g. student hall)
- Others/unspecified.

As mentioned earlier, these categories do not exactly correspond to the AD B classification (minus hotels, hospitals, schools).

It was eventually decided, for the sake of consistency, to use the same classification of residential fire types as that used by Hartless in his work to support a future Regulatory Impact Assessment [Hartless 2002]. These classifications are as follows:

<ul style="list-style-type: none"> • House, single occupancy • House, multiple occupancy • Flat, purpose-built • Flat, converted 	<ul style="list-style-type: none"> • Care Home, old person's • Care Home, children • Care Home, disabled people
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3.3 The risks from fire in the absence of sprinklers

3.3.1 UK Fire statistics database and FDR1 codes

The bulk of the UK fire statistics are collected by the ODPM (formerly Home Office) Research, Development and Statistics Directorate. They are based on the FDR1(94) forms [Gamble 1998] filled in by the fire brigades after a fire has been attended. Since 1994, only a fraction of all reported fires have been transferred to the electronic database. However, all fires where there was injury or death are in the database. Each reported fire thus has a weighting figure (>1) which is the reciprocal of the fraction of reported fires recorded (varying from brigade to brigade).

Because the statistics are only based on fire brigade reports, the sample is biased when it comes to considering the population of all fires. There will be a large number of small fires that are unreported. Estimates from the British Crime Survey [Budd and Mayhew 1997] put this fraction at between 85-90%. This bias in the sample obviously requires that care be taken when interpreting the statistics. For example, looking at the statistics (alone) to estimate the effectiveness of sprinklers will give a lower value than the true case, since in many fires the sprinklers will be sufficiently effective that the fire brigade are never called out. We note, though, that the DD 251 standard recommends that the fire brigade are called out to switch the system off.

3.3.1.1 FDR1 Codes for residential (including domestic) properties

For the purposes of this study fires were classified as “residential” or otherwise, depending primarily on the value of the Type Of Property (TOP) field in each record of the database.

There is another field which is useful in defining the type of residential fire, and that is the Occupancy (OCCUP) – a value of 1 indicates single occupancy, values of 2 or 3 indicate multiple occupancy. This is only useful for houses (TOP = 411 ... 416) since the other property types are all classed as multiple occupancy by default.

The different classes of residential property types, and the TOP and OCCUP codes that correspond to them, are given in Table 3.1. (This information is provided in case further work is required in future)

Table 3.1 Classification of residential properties in this study

Residential classification	Fire statistics database codes
House, single occupancy	TOP = 411...416 and OCCUP = 1
House, multiple occupancy	TOP = 411...416 and OCCUP = 2...3
Flat, purpose-built	TOP = 421...422
Flat, converted	TOP = 471...472
Care Home, old person's	TOP = 311
Care Home, children	TOP = 322
Care Home, disabled people	TOP = 359, 369

3.3.2 Different measures of risk

Different measures of risk of death and injury can be used, for example risk per person exposed, risk per fire, or risk per building.

Annual risk is the probability of a given person dying or being injured in a fire per year. This approach has been preferred for RIA analysis [Hartless 2002], since it gives the risk as applicable to individual people. The annual risk of death can be calculated as follows:

$$\text{Annual risk} = \frac{\text{number of deaths}}{\text{total number of people living in a property class}} \quad \{3.1\}$$

$$= \frac{\text{number of deaths}}{(\text{average number of people in that type of property} \times \text{number of properties})} \quad \{3.2\}$$

In analysis of fire statistics worldwide (e.g. New Zealand, USA, Canada and UK) it is more common to calculate the risk per fire. One advantage of this approach is that all the data are contained in one source (the fire statistics), and it is not necessary to know the numbers of people or properties affected (which may cause problems if the data are not readily available, or the classification of property types does not match up with that of the fire statistics). Obviously, the number of fires and the number of deaths must both be counted over the same period of time. The risk per fire provides a comparison of average fire severity (in the life safety sense, not the fire resistance sense), and is calculated simply as follows:

$$\text{Risk per fire} = \frac{\text{number of deaths}}{\text{number of fires}} \quad \{3.3\}$$

Finally, there is the risk per building. This is the approach that has been chosen for the cost benefit analysis (see section 6) since it provides the easiest way to express the costs and benefits on a common basis (£ per accommodation unit per year). The time period needs to be specified. As the number of accommodation units (presumably) only changes slowly over time, the natural period to use is that over which the fire statistics are collected. The number of accommodation units or properties needs to be known, and this can cause problems as mentioned above. The risk per building is calculated as:

$$\text{Risk per building} = \frac{\text{number of deaths}}{\text{number of buildings}} \quad \{3.4\}$$

The risks of injury, or of experiencing a fire, can be calculated in an analogous manner.

3.3.3 Results

Between the years 1996 to 1999 inclusive, there were $72,800 \pm 600$ fires in domestic and residential buildings, causing 515 ± 40 deaths, and $14,700 \pm 300$ injuries (64% of all fires, 89% of all fire deaths, and 87% of all injuries). The population of the UK during this period was 58 million people, thus the number of deaths per million people was 8.9 ± 0.7 . All uncertainties represent \pm one standard deviation. These estimates do not include the fires that do not involve the brigade (about 85% of all fires [Budd & Mayhew 1997]) and which presumably have negligible consequences for life safety.

The numbers of injuries in the fire statistics are much higher than for other countries because the FDR1 injuries classification includes all precautionary check ups in hospital for minor smoke inhalation.

Table 3.2 shows the number of accommodation units, and the annual risks per million units. All uncertainties represent \pm one standard deviation. The numbers of units were taken mainly from the English House Condition Survey 1996, along with other sources [Hartless 2002]. As explained in the previous section, it has been chosen to express the risks in terms of the number of accommodation units, in order to tie in conveniently with the cost benefit analysis (section 6).

Table 3.2 Number of accommodation units, and annual risks per million units

Property type	Accommodation Units (000's)	People per unit	Risk of fires per year per 10^6 units	Risk of death per year per 10^6 units	Risk of injury per year per 10^6 units	Risk of rescues per year per 10^6 units
House, single	18,642	2.5	1616 ± 9	15 ± 0.4	367 ± 2	11 ± 0.3
House, multiple	1,337	1.9	1147 ± 29	13 ± 1	281 ± 6	21 ± 2
Flat, purpose-built	3,605	2.0	4841 ± 37	27 ± 1	941 ± 7	71 ± 2
Flat, converted	1,099	1.6	2561 ± 48	23 ± 2	664 ± 10	74 ± 3
Care Home, old persons	16.3	19.0	66074 ± 2013	245 ± 50	6073 ± 249	1472 ± 123
Care Home, children	1.4	8.9	149286 ± 10326	143 ± 130	12857 ± 1237	714 ± 292
Care Home, disabled people	11.1	7.7	30990 ± 1671	72 ± 33	2523 ± 195	243 ± 60

Appendix 3A also presents the risks in different formats (per person, and per fire). The results can be summarised as follows. The annual risks per member of the population, relative to a single-occupancy house, are fairly constant. In all residential categories the risk of death is within a factor of 3; the risk of injury is also within a factor of 3 except in children's care homes, where it is a factor of 10. The risk of requiring rescue is however, substantially higher for flats and care homes than for houses (both single and HMO). The risks per fire do not vary much over the different property classes; in fact the risks per fire are lower in the three types of care homes than they are for single-occupancy houses. The reason that the care homes have higher risks than other buildings is that they have many more fires.

- The number of fires per building/accommodation unit is the primary factor that determines the other risks (death, injury, etc).

3.4 Effect of building height

It is a widely held belief that taller buildings will have greater risks from fire – certainly it is true that escape from windows more than two storeys above ground is effectively impossible. The UK fire statistics contain a record of the number of storeys in the building. In order to investigate the effect of building height on risk of death, residential premises were re-categorised into four different classes of house, HMO, flat (purpose-built + converted) and care home (old person's + children + disabled people). This was particularly necessary for the care homes, in order to improve the sample size.

The number of fires, deaths per fire and injuries per fire for buildings with different number of storeys for 1998 and 1999 are given in Appendix 3B, and also the number of fires per accommodation unit.

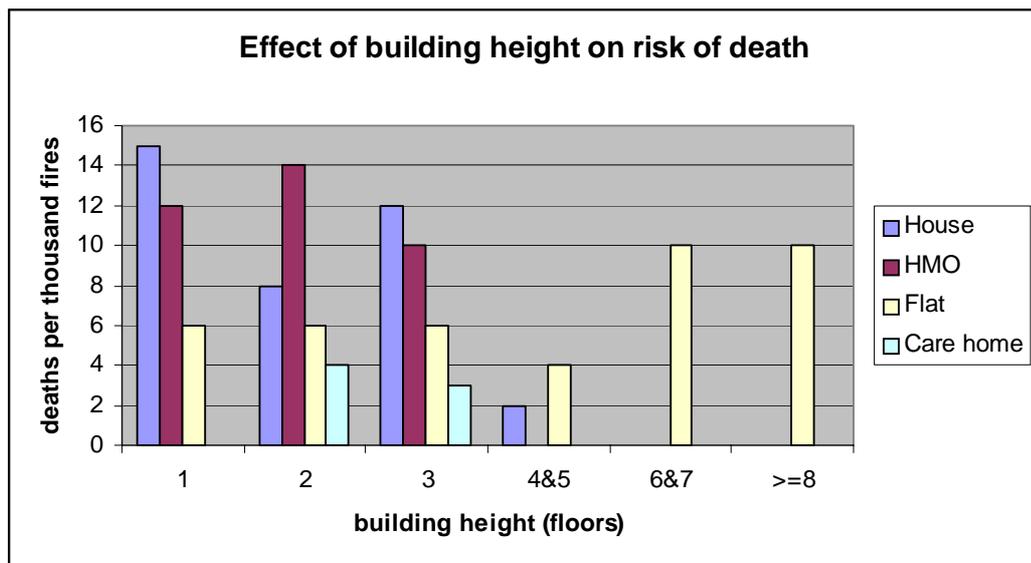


Figure 3.1 The risk of death per thousand fires, as a function of storey height

It might be supposed that building height would have two effects on the risk per fire. Escape (including rescues) via windows becomes increasingly difficult with building height, and in taller buildings there are more accommodation units, thus more people who could potentially become casualties. However, figure 3.1 shows that there is no clear trend that risk of death per 1000 fires is a function of building height. This suggests that most fires are confined to the accommodation unit of origin – i.e. compartmentation works – and that escape via windows is not that significant a factor, regardless of height. A bungalow has the highest risk of death per thousand fires - storey height is not the primary determining factor here, but more the fact that a higher than normal percentage of elderly people occupy bungalows.

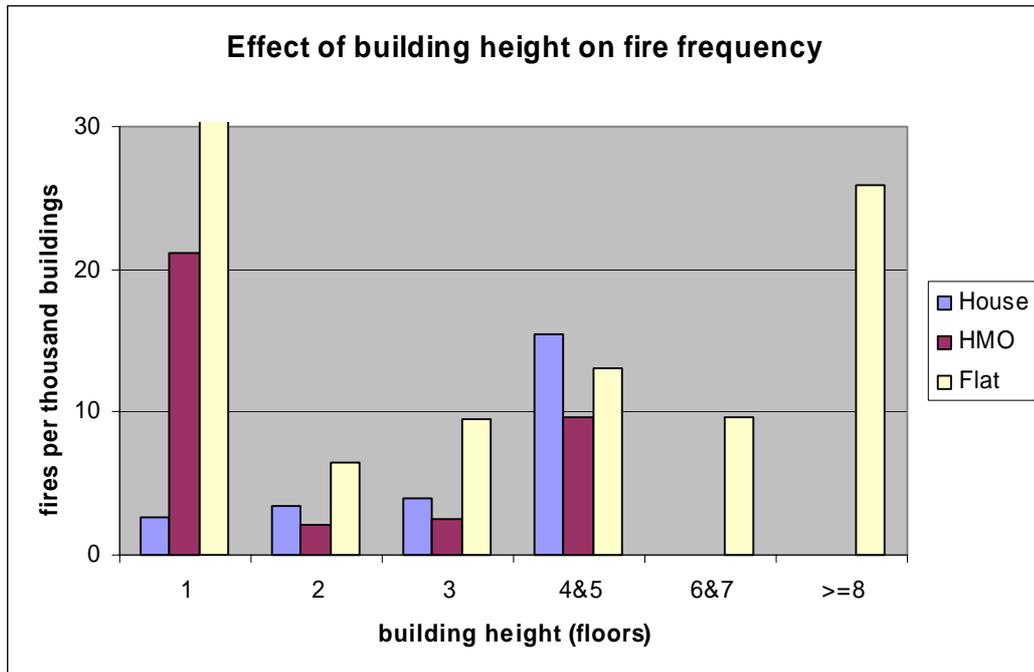


Figure 3.2 The effect of building height on fire frequency

Single-storey flats had very high risks of fire (86 per thousand accommodation units) but this value may be somewhat spurious since the sample sizes are small. The other results show evidence for increasing number of fires with building height.

It is concluded that:

- The frequency of fire per accommodation unit increases with building height
- The risk of death per fire is not significantly affected by building height.

The location of the floor of fire origin as a function of building height was also examined. Regardless of the number of floors, there were always more fires originating on the ground floor than any other (sometimes markedly so). In higher buildings, it was sometimes noticed that more fires originated on the top floor (or the one just below the top) than would be expected for a uniform distribution. These distributions were not investigated further at this stage of the project.

3.5 Direct estimate of sprinkler effectiveness in the UK

In principle, a direct estimate of sprinkler effectiveness can be made by comparing fires in sprinklered buildings with similar fires in unsprinklered buildings. However, there are insufficient sprinklered fires in the database for this to work. Not only are there very few residential buildings with sprinklers, the fires will not appear in the database if the sprinklers are effective.

For example, in 1996 there were only 13 records in the database, with weightings leading to an estimate of 63 fires – all of these were in purpose-built flats. This can be

compared with an estimate of 19,200 fires in all flats attended by brigades in 1996. Furthermore, it was noted that all the reports came from the same brigade. This suggests there is a discrepancy between their reporting system and that of the rest of the country. Therefore, it was not possible to derive meaningful estimates of sprinkler effectiveness from these figures.

3.6 Indirect estimate of sprinkler effectiveness

As have been seen above, a direct estimate of the benefits of sprinklers could not be made from the UK fire statistics. The Pilot Study therefore proposed an indirect method of estimating the effectiveness, by assuming 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], if the fire area can be limited to a certain value, then the risks of death and injury can be reduced. Therefore, it is possible to use the variation of risk with fire area to estimate the reduction in deaths, etc, making an assumption, that if sprinklers are present, they will either extinguish the fire or at least prevent it from spreading further.

3.6.1 Risk as a function of ultimate fire size

There were two possible measures of the extent of the fire in the fire statistics database. The first, which was initially expected to be more useful, was using:

- % destruction of item first ignited (FDR 1 code = FFIPERC)
- % destruction of room of origin (FDR1 code = FRMPERC)
- % destruction of floor of origin (excluding room of origin) (FDR1 code = FFLRPERC)
- and % destruction of rest of building (FDR1 code = FBLDPERC).

Attempts to find correlations were hindered by the fact that these fields were not completed for all the fire reports. The 1999 database was particularly poor in this regard. The logical progression of percentage damage would be FFIPERC > FRMPERC > FFLRPERC > FBLDPERC, but in many reported cases in the database, this was not so. It was not clear how to combine these four codes to produce a monotonic scale of increasing damage.

Therefore, attention was directed to the second measure, which involved using:

- the horizontal area damaged (m^2) (FDR1 code = AREABURN).

The horizontal area damaged (AREABURN) did not suffer from the drawbacks above (apart from the 1999 database where many fires did not have AREABURN recorded).

Three subsets of dwellings were considered: houses (TOP as above, and no distinction based on OCCUP); flats (TOP as above); and care, communal and other dwellings (TOP = 311, 322, 359, 369, 309, 409, 469 and 499). Appendix 3C presents the distribution of fire area damaged for fires, deaths, injuries and rescues for the seven residential categories

Figure 3.3 below shows the distribution of the numbers of fires for the different size categories. Note that the 'houses' category includes HMO's, the 'flats' category includes purpose-built and converted, and the 'care, communal' category includes the three types of care homes. This merging of categories was performed in order to improve the sample sizes, particularly for the care homes, and thus make the underlying trends clearer. It can be seen that most of the fires only damage a small area.

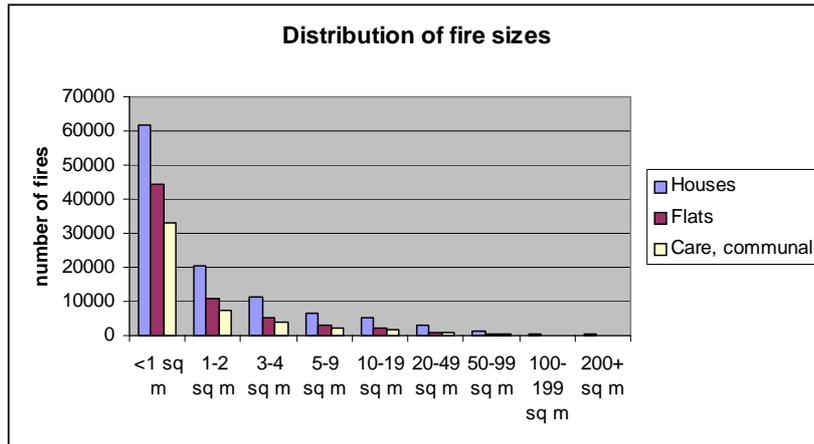


Figure 3.3 The numbers of fires that damage different areas

Data for risk of death per fire are shown in the Figure 3.4 below. The trends for injuries and rescues are similar. As with Figure 3.3, categories have been merged to clarify the trends. There is a clear trend for the larger fires to have greater numbers of deaths, injuries etc. For the largest fires of 100+ m², which occur infrequently, the values above have correspondingly large error bounds. So an apparent decrease in risk for very large fires should not be thought of as 'real'.

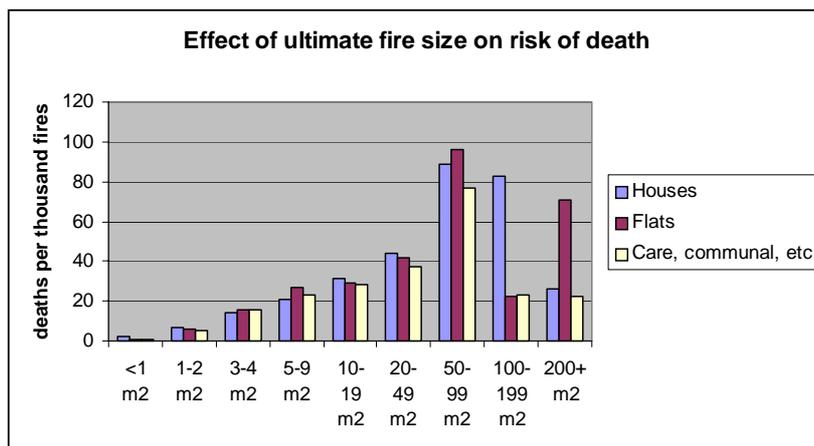


Figure 3.4 Variation in the risk of death, depending on ultimate fire size

If the ultimate fire size can be kept as small as possible, there will be two benefits:

- The risk of death per fire (Figure 3.4) will go down and
- The number of fires (Figure 3.3) affected by the sprinklers will increase.

Appendix 3C contains the detailed results of this analysis, showing how the risk of death, injury, and need for rescue varies with fire size. This analysis has been done for each of the seven residential categories.

3.6.2 Benefits of constraining the fire size

Figures 3.5 and 3.6 show the risk of death is increasing with fire area (i.e. a schematic representation of Figure 3.4). However, it can be assumed that sprinklers control the fire so that 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 Figure 3.6, A_{max} is smaller than for Figure 3.5, and so R_{max} is smaller. The additional benefit of keeping the fire size as small as possible is that lives are saved by increasing the number of fires affected, as well as reducing the risk per fire.

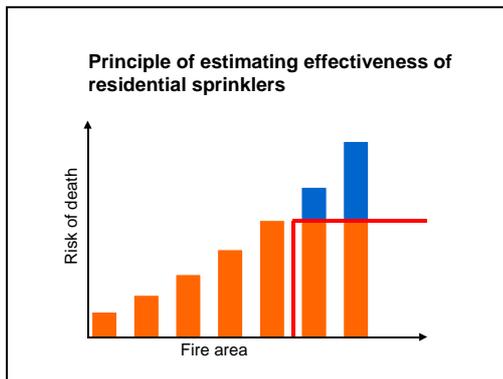


Figure 3.5

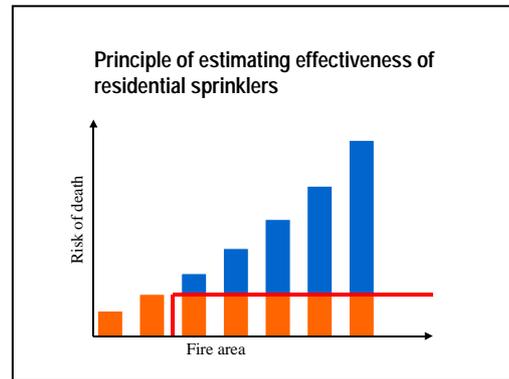


Figure 3.6

Let the risk of death per year, given that the area damaged by the fire was A_i , be denoted by R_i . The total number of deaths in all fires of area A_i will be denoted D_i , and the number of fires by N_i . The risk of death is therefore simply

$$R_i = D_i / N_i \quad \{3.5\}$$

and the total number of deaths in all fires is

$$D_{tot} = \sum_{i=1}^{all_areas} N_i \cdot R_i \quad \{3.6\}$$

The principle behind the estimate of sprinkler effectiveness is to assume that fires are controlled to some area A_{max} . Using N_i as the number of fires that would have grown to a size of A_i if sprinklers were not present, the number of deaths is now

$$D'_{tot} = \sum_{i=1}^{all_areas} N_i \cdot MIN(R_i, R_{max}) \quad \{3.7\}$$

where R_{max} is the risk when $A_i = A_{max}$. Hence the number of lives saved will be

$$D_{tot} - D'_{tot} = \sum_{i=1}^{all_areas} N_i \cdot MAX(0, R_i - R_{max}) \quad \{3.8\}$$

i.e. no lives will be saved if the fire would not grow enough to activate the sprinklers.

The error in the risk estimate is given by

$$\sigma^2(R_i) = \sigma^2(D_i) \cdot \frac{\partial^2(R_i)}{\partial D_i^2} + \sigma^2(N_i) \cdot \frac{\partial^2(R_i)}{\partial N_i^2} \quad \{3.9\}$$

Because the probability of a given building experiencing a fire in a given year is small (and the probability of a fire death even smaller), the distributions of N_i and D_i can both be described by the Poisson Distribution. One of the properties of the Poisson Distribution is that the variance is approximately equal to the mean. Because the statistics used are over a 6-year period, the estimate of the mean (and variance) of the deaths over that 6-year period will be

$$\sigma^2(6D_i) = 6D_i \quad \text{and hence} \quad \sigma^2(D_i) = \frac{D_i}{6} \quad \{3.10\}$$

However, although the number of fires is also being looked at over a six-year period, only about 1 in 5 of these fires are actually recorded if they do not result in casualties. The variance of this Binomial distribution will be

$$\sigma^2(6N_i) = 6N_i \times 0.2 \times (1 - 0.2) \quad \text{and hence} \quad \sigma^2(N_i) \cong N_i \quad \{3.11\}$$

Substituting these results into the variance of the risk estimate gives

$$\sigma^2(R_i) = R_i^2 \left(\frac{1}{N_i} + \frac{1}{6D_i} \right) \quad \{3.12\}$$

A similar approach can be used to estimate the variance of the number of lives saved.

$$\sigma^2(\Delta D_{tot}) = \sigma^2(N_i) \frac{\partial^2 \Delta D_{tot}}{\partial N_i^2} + \sigma^2(R_i) \frac{\partial^2 \Delta D_{tot}}{\partial R_i^2} + \sigma^2(R_{max}) \frac{\partial^2 \Delta D_{tot}}{\partial R_{max}^2} \quad \{3.13\}$$

where $\Delta D_{tot} = D_{tot} - D'_{tot}$ is the number of lives saved. Substitution yields

$$\sigma^2(\Delta D_{tot}) = \sum_{i=1}^{all_areas} N_i \cdot MAX(0, R_i - R_{max})^2 + N_i^2 (\sigma^2(R_i) + \sigma^2(R_{max})) \quad \{3.14\}$$

Finally, defining the sprinkler efficiency ε as

$$\varepsilon = \frac{\Delta D_{tot}}{D_{tot}} \quad \{3.15\}$$

results in the estimated variance of the efficiency being defined as

$$\sigma^2(\varepsilon) = \varepsilon^2 \cdot \left(\frac{1}{D_{tot}} + \frac{\sigma^2(\Delta D_{tot})}{\Delta D_{tot}^2} \right) \quad \{3.16\}$$

A similar procedure is used to estimate the effectiveness and uncertainty of the sprinklers in reducing the number of injuries, and rescues required.

It is important to note that these uncertainty estimates are only based on the uncertain numbers of fires and deaths in the UK fire statistics. There is a very significant aspect of the uncertainty that has not been included, and that is the uncertainty in the maximum fire size that will be reached (on average) when sprinklers are present.

3.6.3 Estimates of sprinkler benefits

The following Tables 3.3 to 3.5 provide a summary of the key results of the analysis. Note the error estimates in these tables are one standard deviation. The 95% confidence limits would be approximately twice this (\pm two standard deviations). In the last three property types (residential care homes) the estimates are particularly uncertain, due to the paucity of statistical data.

Table 3.3 Fractional reduction in number of deaths, if fire size restricted

Property type	Fire size < 1m ²	Fire size < 2m ²	Fire size < 4m ²	Fire size < 9m ²
House, single	0.835 +/- 0.038	0.590 +/- 0.033	0.375 +/- 0.028	0.281 +/- 0.025
House, multiple	0.918 +/- 0.165	0.532 +/- 0.138	0.473 +/- 0.128	0.245 +/- 0.111
Flat, purpose-built	0.822 +/- 0.061	0.549 +/- 0.051	0.295 +/- 0.042	0.110 +/- 0.035
Flat, converted	0.921 +/- 0.130	0.509 +/- 0.104	0.180 +/- 0.086	0.101 +/- 0.072
Care Home, old person's	0.330 +/- 0.179	0.063 +/- 0.116	0.075 +/- 0.098	0.006 +/- 0.113
Care Home, children	1.000 +/- 1.743	1.000 +/- 1.743	1.000 +/- 1.743	1.000 +/- 1.743
Care Home, disabled people	0.736 +/- 0.752	0.750 +/- 0.756	0.413 +/- 0.632	0.500 +/- 0.647

Table 3.4 Fractional reduction in number of injuries, if fire size restricted

Property type	Fire size < 1m ²	Fire size < 2m ²	Fire size < 4m ²	Fire size < 9m ²
House, single	0.391 +/- 0.009	0.138 +/- 0.007	0.069 +/- 0.006	0.036 +/- 0.005
House, multiple	0.409 +/- 0.043	0.236 +/- 0.038	0.116 +/- 0.033	0.068 +/- 0.029
Flat, purpose-built	0.299 +/- 0.012	0.163 +/- 0.010	0.091 +/- 0.009	0.044 +/- 0.007
Flat, converted	0.413 +/- 0.032	0.199 +/- 0.028	0.123 +/- 0.025	0.054 +/- 0.021
Care Home, old person's	0.309 +/- 0.068	0.088 +/- 0.051	0.067 +/- 0.046	0.012 +/- 0.049
Care Home, children	0.482 +/- 0.172	0.112 +/- 0.120	0.125 +/- 0.112	0.174 +/- 0.122
Care Home, disabled people	0.498 +/- 0.297	0.291 +/- 0.285	0.247 +/- 0.280	0.210 +/- 0.275

Table 3.5 Fractional reduction in number of rescues needed, if fire size restricted

Property type	Fire size < 1m ²	Fire size < 2m ²	Fire size < 4m ²	Fire size < 9m ²
House, single	0.437 +/- 0.030	0.205 +/- 0.025	0.105 +/- 0.021	0.052 +/- 0.017
House, multiple	0.560 +/- 0.102	0.267 +/- 0.083	0.370 +/- 0.081	0.129 +/- 0.068
Flat, purpose-built	0.644 +/- 0.036	0.456 +/- 0.032	0.133 +/- 0.025	0.165 +/- 0.022
Flat, converted	0.593 +/- 0.066	0.370 +/- 0.057	0.052 +/- 0.047	0.097 +/- 0.038
Care Home, old person's	0.840 +/- 0.467	0.707 +/- 0.462	0.506 +/- 0.450	0.605 +/- 0.459
Care Home, children	0.000 +/- 0.000	0.000 +/- 0.000	0.000 +/- 0.000	0.000 +/- 0.000
Care Home, disabled people	0.412 +/- 0.577	0.437 +/- 0.579	0.304 +/- 0.560	0.312 +/- 0.564

After the statistical analysis, an element of subjective judgement is required. The first major area of uncertainty is the area that the fire will be restricted to. When Ramachandran was investigating the benefits of sprinklers in commercial buildings [Ramachandran 1993, Melinek 1993], he found evidence to suggest that sprinklers had little or no influence on fires smaller than 3m². However, in domestic and residential buildings, sprinklers would be expected to restrict fires to smaller sizes on average, because the sprinklers are quick response, and because the room sizes, ceiling heights, etc. will be smaller (the smoke layer will be hotter). Obviously, the best performance that could possibly be obtained is to save every single fire death, injury etc. Were this to be achieved, the consequences would be as laid out in Table 3.2. Of course this is an unrealistic level of performance to expect in reality.

In addition to the uncertainty over the restricted fire size, there is also the uncertainty in assuming that all fires will be restricted to this size – if the sprinklers fail to operate, or control the fire for some reason, the fire will continue to grow. It must also be recognised that a fire that goes out having reached a given size is not the same as a fire controlled (but not extinguished) since the latter will continue to produce toxic smoke etc. In view of the very strong correlation between (unsprinklered) fire size and risk, these concerns should not invalidate the assumptions on which the method rests. However, it does mean the method is not particularly precise.

In the absence of better information, it might be estimated that the sprinklers' effectiveness could be represented as restricting the area of fire damage to about 1m²; in other words, the average of the first two columns of Tables 3.3 to 3.5. For deaths, this gives a value between about 85% and 55%. (The values for the three types of care home are so uncertain, the same value might be assumed for all types of property. Values for houses and flats are consistent with a uniform level of effectiveness regardless of property type). It is reassuring that this simple approach gives a result which is in close agreement with the estimate (73%) from American statistics [Rohr 2002] reported in section 3.7.3.1. It shall therefore be assumed that a similar approach will also give reasonable results for the effectiveness of sprinklers in reducing injuries and rescue requirements.

The effectiveness of sprinklers in reducing the average property damage per fire cannot be estimated from the UK statistics. Instead, a typical value of 50% shall be used, based on an examination of US statistics. The variability of this value is about ± 15% over different residential building types.

For the purposes of the cost benefit analysis, the effectiveness of sprinklers were assumed to be independent of property type, and to lie in the following ranges:

• Reduction in the number of deaths	55% ~ 85%
• Reduction in the number of injuries	15% ~ 45%
• Reduction in the number of rescues required	20% ~ 50% (flats 40% ~ 65%)
• Reduction in the average property damage	35% ~ 65%

(In fact the number of rescues required was not used in the cost benefit analysis, due to the difficulty in assigning a monetary value to them.)

3.7 Experience of residential sprinklers in other countries

The literature review performed as part of the Pilot Study encompassed the experience of residential sprinklers in the USA, New Zealand, Vancouver (BC, Canada) and Scottsdale (Arizona, USA). In particular, information on cost benefit analyses was sought, both in terms of the methods employed, and also the input data. Due to cultural differences etc, it was not anticipated that the data would necessarily be directly applicable to a UK-based cost benefit analysis, but it would provide a useful check that figures used were plausible. Information on codes and standards referring to residential sprinklers was also sought (see section 3.9).

The USA is the only country that has residential sprinklers in sufficient numbers for direct statistical estimates of their effectiveness to be made. The National Fire Incident Reporting System (NFIRS) is the most detailed of the representative, national fire incident databases in the USA. The National Fire Data Center of the United States Fire Administration of the Federal Emergency Management Agency administers NFIRS for the collection, analysis and dissemination of information on fire and other emergency incidents.

NFIRS statistics do not make any distinction between types of automatic suppression system, whether it is complete, up-to-date, or appropriate. For convenience all such systems were termed "sprinklers" since that is likely to be the case in residential premises.

Rohr of the Fire Analysis and Research Division of the NFPA, USA analysed data from NFIRS in the years 1988 to 1997 [Rohr 2000]. Part of this analysis on the US experience with sprinklers considered sprinklers in domestic and residential premises.

3.7.1 Factors considered in cost benefit analysis

The survey of sprinklers in the USA [Rohr, 2000] did not include a cost benefit analysis, nor the cost information to enable such an analysis to be attempted. However, it did cover risks of having a fire, risks of death in fire (with and without sprinklers), property losses (with and without sprinklers), sprinkler reliability, and the costs of water damage.

The cost benefit studies performed by BRANZ in New Zealand [Duncan and Wade 2000, Duncan et al 2000] considered the costs of installation (including water supplies, backflow prevention), annual maintenance, the discount rate and the number of years over which this is applied. On the benefits side, reduced deaths, injuries and property losses were considered. The sensitivity of the results to the sprinkler reliability was

studied, also the effects of providing partial coverage (bedrooms, kitchen and living room only) rather than the entire dwelling.

From July 5, 1985, all new multi-family and commercial structures in Scottsdale were required to have sprinkler protection. All new single-family dwellings followed suit on January 1, 1986. The report of the effects of sprinklers in Scottsdale [Ford 1997] did not explicitly include a cost benefit analysis, but provided enough information for a crude estimate to be made. Only the overall installation cost was quoted; maintenance costs were assumed to be negligible. Over a ten-year period there were 10 deaths; in the absence of sprinklers it was estimated there would have been 18. Reduced property losses were also observed. The city grew in size by about 50% during the period, but the fire brigade did not, resulting in a substantial saving. Reductions in insurance premiums could be offset against the installation costs. Finally, a number of specific relaxations in the design of residential developments were allowed in the building code as a result of sprinkler provision. These were:

- Density increase of 4% for single family communities was initiated.
- Reduction in residential street width from 32 ft (10 m) to 28 ft (8.5 m) was approved.
- Cul-de-sac lengths were increased from 600 ft (183 m) to 2,000 ft (610 m).
- For commercial development, the 360 degree access requirement for fire apparatus was eliminated for fully sprinklered structures.
- In the building code, the requirement for one hour construction was eliminated for single- and multi-family dwellings.
- The standards for rated doors separating single family homes from garages was also eliminated.

The most substantial impact for cost reduction of the sprinkler system was found to be in the Scottsdale water resources department:

- Fire hydrant spacing was increased from 330 ft (100 m) to 700 ft (213 m) for sprinklered commercial and multi-family developments.
- The required fire flow demand for structures was reduced by 50%, and resulted in a typical one step reduction in water main size.

These changes also resulted in the ability to provide smaller water storage tanks. An additional feature included with the water resource issue, was the ability to use reclaimed or “grey water” to provide supplies for the fire protection systems in commercial structures where community potable water systems were inadequate.

A number of cost benefit analyses were performed by the city of Vancouver [Robertson 2001] before the introduction of their sprinkler legislation. These various cost benefit analyses (in support or in opposition to the proposed mandatory sprinkler provision) showed how highly sensitive they were to the choice of major variables and future changes. These changes cannot be predicted with any level of confidence, and included:

- Changes in demographics – ageing population

- Changes in societal perceptions re. personal safety
- Changes in behaviour such as smoking, drug and alcohol abuse which can significantly affect fire safety
- Socio-economic factors affecting maintenance, repair and/or replacement of faulty systems
- Changes in construction technology and benefits of scale which may significantly reduce sprinkler costs
- Changes in building codes, which may either increase system reliabilities, or permit additional trade off which reduce overall construction costs
- Changes in sprinkler design which may affect the frequency and costs of accidental discharges
- Impact on the costs of providing public fire services
- Future changes in interest rates and inflation.

Despite the uncertainties, mandatory sprinkler legislation was passed. The City fire records for 1981 to 1990 and 1992 to 1998 were compared with those for Canada as a whole, permitting a retrospective cost benefit analysis. The factors that were mentioned include an estimate of the number of lives saved that could be attributed to sprinklers, the costs of sprinkler installation, savings associated with reduction in fire brigade requirements, direct savings in property damage, and reduction in construction costs associated with trade off.

There are about 60 identifiable 'trade-offs' or relaxations permitted in the Vancouver building code to allow for the benefits of sprinklers. However, it is important to limit these so that fire safety does not rely solely on the sprinkler system. Current concerns focus mainly on the availability of water supplies.

Table 3.6 Costs and benefits considered in different locations

Cost/Benefit	USA	New Zealand	Vancouver	Scottsdale
<input type="checkbox"/> Installation	X	✓	✓	✓
<input type="checkbox"/> Water Supplies	X	✓	(✓)	✓
<input type="checkbox"/> Annual inspection & maintenance	X	✓	(✓)	(✓)
<input type="checkbox"/> Sprinkler water damage	✓	X	X	X
<input type="checkbox"/> Lives saved	✓	✓	✓	✓
<input type="checkbox"/> Injuries prevented	X	✓	X	X
<input type="checkbox"/> Property loss savings	✓	✓	✓	✓
<input type="checkbox"/> Environment impact reduction	X	X	X	✓
<input type="checkbox"/> Insurance Premium reduction	X	X	X	✓
<input type="checkbox"/> Fire Brigade cost savings	X	X	✓	✓
<input type="checkbox"/> Other tradeoffs	X	X	✓	✓

The common factors are:

- Costs: installation, water supplies, and maintenance
- Benefits: lives saved, property protection. Injuries saved, fire brigade costs and other trade-offs also considered where data are available.

3.7.2 Fire risks

In New Zealand, there were (on average) 4668 fires per year [Irwin 1997], and 1,152,000 dwellings, during the period 1986-1994. Over the 5-year period 1993-1997, there were 5967 fires and 1,318,800 dwellings [Duncan et al 2000]. These figures give 4050 and 4525 fires per million dwellings, respectively. The number of deaths has remained fairly constant between 1986-1998, at 23 ± 4 deaths per year [Duncan et al 2000]; over 1.3m dwellings this gives 18 ± 3 deaths per million dwellings.

New Zealand has just under 10 fire deaths per million population per year compared with Canada with just over 15, USA with just under 20, and UK 15 per million population per year [Duncan et al 2000]; however, with a population of 3.79m people in 1998, 23 deaths is only 6 deaths per million population. 90% of the fire deaths in New Zealand were in domestic or residential buildings, so the discrepancy cannot be accounted for entirely by the higher figure being due to all fire deaths, not just domestic.

In the USA as a whole, between 1988 and 1997 there were 466,000 fires per year in all residential properties. There were 347,600 fires in 1- or 2-family dwellings, and 105,500 fires in apartments [Rohr 2000]. Another table in the same reference quotes 331,100 fires in all residential properties, with 9.5 deaths per 1000 fires implying a total of 3,150 deaths per year. There were 99m households (100m occupied housing units) with an average of 2.65 people each in 1995 [US Census Bureau website,

<http://www.census.gov>], implying a death rate of 12.0 per million population, and 31.5 deaths per million housing units. An NFPA study [Rohr 2000] quoted 3096 deaths in 323,800 residential fires (11.8 per million population, 31.0 per million housing units).

Scottsdale is a city in Arizona, its population was 107,000 in 1985 when the sprinkler ordinance was passed. Ten years later the population was 164,000. During this period there were 598 residential fires, and 10 fire fatalities (in all occupancies, not just residential) [Ford 1997]. It was estimated that without sprinklers there would have been 18 deaths (in all occupancies). As the average population during the 10-year period was 133,000, the average death rate was 0.75 per 100,000 people, or would have been 1.35 per 100,000 people without sprinklers.

In 1972 to 1974, Vancouver experienced just under 7 deaths per 100,000 population per year. This figure can be compared with about 3.5 deaths per 100,000 for Canada as a whole, just under 3 for the USA, and about 1.5 deaths per 100,000 for the UK, over the same period [Robertson 2001]. By the period 1992-1998, as the effect of the city's mandatory sprinkler regulations, the deaths were down to 0.61 per 100,000, compared to 1.3 per 100,000 for the rest of Canada. As in New Zealand, 90% of all Canadian fire deaths occur in residential properties.

It was stated that the 39,700 accommodation units fitted with sprinklers by 1998 comprised 27.5% of the total housing stock in Vancouver. Hence, with the population approaching 600,000 people (implying 4.15 people per housing unit, much higher than elsewhere), the implied risk of death is 24.9 people per million housing units.

Table 3.7 Risks of death, per million population and per million housing units

Location	Risk of death per million population	Risk of death per million housing units
New Zealand (1993-97)	6	18
United States (1995)	12	32
Scottsdale (1990)	8*	-
Vancouver (1998)	6*	25*

(* = a substantial fraction of the residential properties have sprinklers)

3.7.3 Estimates of sprinkler effectiveness

3.7.3.1 Risk of death

A cost benefit analysis of residential sprinklers, performed by BRANZ, included a literature review which came up with the figures listed in Table 3.8.

Table 3.8 Risks of death, according to BRANZ literature review

No sprinklers	7 deaths per 1000 fires [Beever and Britton 1999] 6 deaths per 1000 fires [Wade and Duncan 2000]
Sprinklers	1.46 ~ 3.89 per 1000 fires [Beever and Britton 1999] 50% reduction in deaths [Rahmanian 1995] 80 ~ 90% reduction in deaths [Ruegg and Fuller 1984]
Sprinklers + alarms	1.46 per 1000 fires [Ruegg and Fuller 1984]
Alarm, battery (1 year life)	2.8 deaths per 1000 fires [Wade and Duncan 2000]

Based on the literature review, the BRANZ study then assumed values for sprinkler effectiveness. A risk assessment (based on an event tree, that took into account system reliabilities, the probabilities of fire starts in different locations within the dwelling, etc) was also performed to estimate the effectiveness of a system complying with the existing standard (NZS 4515) and a low-cost system that only provided partial cover. Partial coverage means that the system is restricted to the bedroom, lounge and kitchen only.

Table 3.9 The assumed fatality rates per 1000 fires for different fire protection options (BRANZ study)

Option	Expected deaths per 1000 fires	% reduction	% reduction (event tree, NZS 4515 system)	% reduction (event tree, low cost system)
Nothing	6	-	-	-
Smoke alarms	2.8	53%	53%	53%
Sprinkler	1.2	80%	80%	72%
Both	1	83%	84%	82%

Sensitivity studies assumed the effectiveness of a measure was directly proportional to its reliability. For example, with sprinklers only (95% reliability) the death rate was 1.2 per 1000 fires; with no sprinklers (or present with 0% reliability) the death rate was 6.0 per 1000 fires. Interpolating, with 50% reliability the death rate would therefore be $1.2 + (6.0 - 1.2) / 2 = 3.6$ deaths per 1000 fires. According to this principle, even with only 70% reliability, sprinklers would still reduce the death rate by half.

The USA provides the only set of national statistics that can currently be used to directly estimate the effectiveness of residential sprinklers.

In the USA from 1988 to 1997, sprinklers extinguished 1,600 out of 466,000 residential fires (0.3%). Sprinklers extinguished 300 out of a total of 347,600 fires (0.1%) in one/two family dwellings, and 1,000 out of a total of 105,500 fires (0.9%) in apartments. This reflects the low proportion of residential properties being fitted with sprinklers, rather than ineffectiveness of sprinklers.

Residential sprinklers for one/two-family dwellings in the USA are reported in only 0.7% of the fires in these properties. However, the report then provides a table showing how the estimated percentage of fires in sprinklered residential buildings has risen steadily from 0.9% in 1980 to 3.0% in 1997 (greater coverage rather than worse performance).

Despite the low proportion of residential buildings with sprinklers, because the USA is such a large country, the sample size is sufficient to make meaningful estimates.

The US statistics tend to underestimate the potential value of a properly installed, well-maintained complete sprinkler system. This is because all automatic extinguishing systems are classed together, whether or not they involve partial coverage, are antiquated, inappropriate for the hazard, non-operational (e.g. water switched off), etc.

Table 3.10 Civilian deaths per 1000 fires with and without sprinklers for residential premises (US statistics 1988-97)

	Without sprinklers	With sprinklers	% reduction	No. fires without sprinklers	No. fires with sprinklers
All residential	9.5	2.2	77%	331,100	8,600
1/2-family dwellings	9.8	5.1	48%	252,800	1,800
Apartments	8.7	1.6	81%	71,000	4,900

Analysis by the National Institute of Standards and Technology, USA (NIST) [Ruegg and Fuller 1984] estimated the following reductions in death rate:

- 69% when upgrading from nothing to sprinklers only
- 53% when upgrading from nothing to smoke alarms only
- 82% when upgrading from nothing to sprinklers plus smoke alarms
- 63% when upgrading from smoke alarms to sprinklers plus smoke alarms.

The analysis was not based directly on statistics, but looked at the relative frequency of various types of fire scenarios, and the proximity of victims to these fires.

The latest estimate by the NFPA [Rohr 2000] is a 73% reduction in deaths per thousand fires, based on 17 deaths in 6,600 fires with sprinklers present (2.58 deaths per thousand fires), and 3,096 deaths in 323,800 non sprinklered fires (9.56 deaths per thousand fires). This latest estimate includes apartments, townhouses and condominiums, which were not included in the NIST study.

The study of the impact of sprinklers in the city of Scottsdale [Ford 1997] claimed a 98.5% reduction in the number of deaths, upgrading from nothing to sprinklers plus alarms, compared to a 50% reduction when upgrading to smoke alarms only. Over the ten years, the automatic sprinkler systems had a direct role in saving 8 lives (4 in residential properties, 4 in commercial) and there has not been a fire-related death in any sprinklered property. The size of the statistical sample from Scottsdale is so small, however, that saving the 4 lives in residential properties in 4 attempts would not be that unlikely even if the sprinkler effectiveness was as low as ~50%. ($0.5 \times 0.5 \times 0.5 \times 0.5 = 0.0625$). The uncertainty in the effectiveness of sprinklers, based purely on the Scottsdale results, is therefore very large.

For 1981 to 1990, the number of deaths per 100,000 population were 1.96 and 2.23 for Vancouver and Canada respectively [Robertson 2001]. In 1992 to 1998, they were 0.61 and 1.3 respectively. The Vancouver deaths had declined by 69% but the rest of Canada only by 42%; the extra 27% in Vancouver was equivalent to saving 3 lives per year. An alternative way of viewing these figures is to assume that, with no sprinklers, the death rate in Vancouver would decline at the same rate as the rest of Canada, resulting in 1.14

deaths per 100,000 population. Sprinklers therefore save 0.53 deaths per 100,000 population, an effectiveness of 47%. This figure is rather low compared to other estimates, but does not take account of the fact that not all buildings in Vancouver have yet been fitted with sprinklers.

3.7.3.2 Risk of injury

The cost benefit analysis of residential sprinklers, performed by BRANZ, also included estimates of the risk of injury based on the literature review. This came up with the figures listed in Table 3.11.

Table 3.11 Risks of injury, according to BRANZ literature review

No sprinklers	70 injuries per 1000 fires [Beever and Britton 1999] 40 injuries per 1000 fires [Wade and Duncan 2000]
Sprinklers	100 injuries per 1000 fires [Beever and Britton 1999] – inconsistent with no sprinklers case 15 ~ 30 per 1000 fires [Beever and Britton 1999] – estimate 15 injuries [Wade and Duncan 2000]
Sprinklers + alarms	14 injuries per 1000 fires [Ruegg and Fuller 1984]

Based on the literature review, the BRANZ study then assumed values for sprinkler effectiveness. A risk assessment (based on an event tree, that took into account system reliabilities, the probabilities of fire starts in different locations within the dwelling, etc) was also performed to estimate the effectiveness of a system complying with the existing standard (NZS 4515) and a low-cost system that only provided partial cover. Partial coverage means that the system is restricted to the bedroom, lounge and kitchen only.

Table 3.12 The assumed injury rates per 1000 fires for different fire protection options (BRANZ study)

Option	Expected injuries per 1000 fires	% reduction	% reduction (event tree, NZS 4515 system)	% reduction (event tree, low cost system)
Nothing	40	-	-	-
Smoke alarm	12	70%	70%	70%
Sprinkler	15	63%	63%	55%
Both	10	75%	87%	84%

When the effectiveness figures (third column of Table 3.12) were put into the event tree consequence analysis, the calculated percentage reduction (fourth column of Table 3.12) was the same as the input value when only one of the protection options was present. But when both were considered together, the reduction in injuries was 87% rather than 75%. There is clearly an inconsistency between the model and reality.

The USA statistics did not report the number of injuries directly. Analysis by the National Institute of Standards and Technology, USA (NIST) [Ruegg and Fuller 1984] estimated the following reductions in injury rate:

- 46% when upgrading from nothing to sprinklers only

- 46% when upgrading from nothing to sprinklers plus smoke alarms
- 44% when upgrading from smoke alarms to sprinklers plus smoke alarms.

The analysis was not based directly on statistics, but looked at the relative frequency of various types of fire scenarios, and the proximity of victims to these fires.

3.7.3.3 Risk of property loss

At the time the Pilot Study was performed, the following exchange rates were noted:

- Can \$1.00 = £0.44
- US \$1.00 = £0.68
- NZ \$1.00 = £0.28.

In the USA, reduction in property losses is notably lower in residential premises than for other types of premises [Rohr 2000]. However, the statistics almost certainly understate the effect of a properly designed and maintained system, as mentioned earlier. Ideally one would like to compare loss per fire, with and without sprinklers, in comparable fires. Table 3.13 shows the average property loss per fire.

Table 3.13 Average property loss per fire (US statistics 1988 ~ 1997)

	Without sprinklers	With sprinklers	% reduction
All residential	US \$9,400	US \$5,400	42%
1 / 2-family dwellings	US \$9,600	US \$7,800	19%
Apartments	US \$8,500	US \$4,400	49%
Apartments > 7 storey ht.	US \$3,200	US \$1,800	43%

Table 3.14 and Figure 3.7 shows distributions of areas of fire damage and average loss per fire, with and without sprinklers.

Table 3.14 Extent of fire damage and average loss per fire, with and without sprinklers (US statistics 1988 ~ 1997)

Extent of fire damage	Sprinklers			No sprinklers		
	Fires	% of total no.	Loss (US\$)	Fires	% of total no.	Loss (US\$)
First item	5,720	66.1	\$1.4k	132,520	40	\$1k
Area of origin	1,720	19.9	\$4.5k	74,900	22.6	\$3k
Room	570	6.6	\$8.8k	34,360	10.4	\$8.3k
Fire compartment	130	1.5	\$14.5k	3,550	1.1	\$14.6k
Floor	140	1.6	\$30.6k	13,740	4.1	\$20.9k
Building	310	3.6	\$50.1k	62,260	18.8	\$28.9k
Beyond structure	50	0.6	\$93k	9,780	3	\$34.7k
Total	8,650	100	\$5.4k	331,120	100	\$9.4k

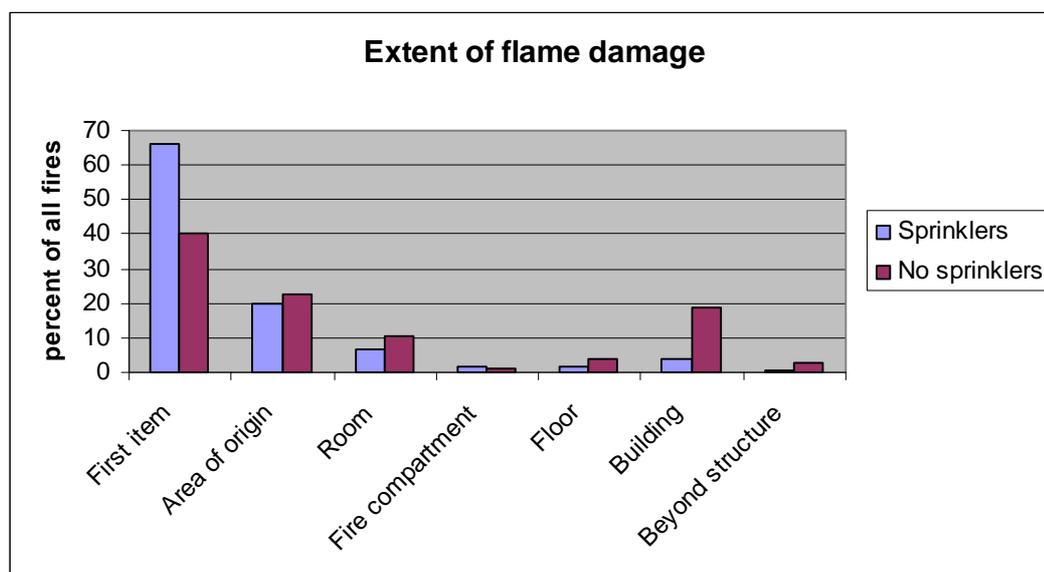


Figure 3.7 Distributions of the extend of fire damage, with and without sprinklers (US statistics 1988 ~ 1997)

These results indicate the effectiveness of residential sprinklers in reducing fire sizes. Where sprinklers are present, many more fires are confined to the item first ignited, and there is much less risk of damage to the entire building. However, the results also suggest the assumption made in the indirect estimate of sprinkler effectiveness (that all fires are restricted to a modest ultimate size) may be too idealised.

Note that if all sprinklered fires could be confined to the first item, the average loss per fire would only be \$1,400, giving an effectiveness of 85%. This would be consistent with the figures quoted by the BRANZ study [Duncan and Wade 2000] and Scottsdale [Ford 1997].

Property losses were assumed to be NZ \$17,200 for the BRANZ study [Duncan & Wade], based in part on figures of NZ\$13,300 [Insurance Council of NZ, 1999], and NZ\$16,000 [Rahmanian 1995, Irwin 1997]. When sprinklers were fitted, property losses were assumed to be NZ\$3,000 (c.f. US \$1,700). The effectiveness was therefore taken as 83%.

In Scottsdale, the potential structural fire loss was dramatically reduced for sprinklered incidents. The average fire loss per sprinklered incident in residential structures was only US\$1,544 compared to a non-sprinklered average loss of US\$11,624 (a reduction of 87%). Elsewhere the report quotes values of US\$17,067 (unsprinklered) reduced to US\$1,945 (sprinklered) average loss per fire. These figures refer to all types of property. In single-occupancy homes, fire tests prior to the introduction of the sprinkler ordinance estimated a reduction of loss from \$9,600 to \$1,700, an effectiveness of 87% [Ford 1997].

Fire losses (Can\$ per capita) were very similar at Can\$58.10 and Can\$57.86 for Vancouver and Canada respectively in 1981 to 1990 [Robertson 2001]. However, in 1992 to 1998 these had fallen to Can\$32 and Can\$43, a decline of 45% and 26% respectively. The average reduction in fire losses for Vancouver is estimated at

Can\$6.2m per year; subtracting these cost savings from the cost of installation (Can\$11.4m per year) gives a net cost to save a life of Can\$1.75m over the 7 year period, or Can\$0.25m over a 50 year period.

3.7.3.4 Sprinkler reliability

Obviously, the reliability of sprinkler systems will be a significant factor in determining the effectiveness of the system. The following reliability estimates are implicit in the effectiveness estimates of the preceding sections.

In the USA statistics for all types of properties (not just residential), sprinklers operated properly in 74 to 91% of cases (except where the fire was too small to cause activation). In residential properties the value was 84.5% [Rohr 2000].

Failure to maintain operational status was responsible for over 50% of sprinkler failures (70% of these were where the water was turned off).

14% of commercial sprinkler failures were due to an increase in hazard level, beyond that for which the sprinkler system has been designed. In domestic and residential situations, it might be expected that this mode of failure would not arise, and greater reliability would result. However, overall this would be a small effect (14% of ~10% unreliability = 1.4%).

Studies by NIST, USA estimated the reliability of sprinklers to be 92%, and that of smoke alarms to be 85% [Ruegg & Fuller 1984]. "Reliability" in this sense meant operating when required to. However, it was observed by NFPA that the reliability of smoke alarms was in fact only 70% [Rohr 2000]. If the same trend applied to sprinklers, the reliability would be 84%. Conversely, Marrayatt [Marrayatt 1988] quotes a "reliability" of 99.5%, but this is limited to the subset of cases where the system was operational, and the fire grew large enough that activation was to be expected.

The BRANZ study [Duncan et al] assumed that sprinklers had a reliability of 95%. It was also noted that the reliability of smoke alarms fell in the range 60%~90%; a value of 74% was used in the event tree risk assessment.

In Scottsdale, the population rose from 108,000 to 164,000 over ten years, an increase of 56,000. All new homes (presumably about 20~25,000) had sprinklers. There were 598 fires in all residential properties over 10 years, of which 44 (7.4%) resulted in sprinkler activation [Ford 1997]. Presumably in the bulk of the remaining cases, sprinklers were not present, or the fire was not large enough for activation to be expected.

3.7.3.5 Summary of estimates of sprinkler effectiveness and reliability

Table 3.15 Summary of estimates of fractional reductions in deaths, injuries and property losses, and reliability of systems

	Alarm only	Sprinkler only	Sprinkler + alarm
Reduction of deaths			
BRANZ review	0.53	0.80	0.83
NZS 4515	0.53	0.80	0.84
NZ low-cost system	0.53	0.72	0.82
US, all residential types		0.77	
US, 1~2 family dwelling		0.48	
US, apartments		0.81	
NIST estimate	0.53	0.69	0.82
NFPA latest estimate		0.73	
Scottsdale	0.50		0.985
Vancouver		0.47*	
Reduction of injuries			
BRANZ review	0.70	0.63	0.75
NZS 4515	0.70	0.63	0.87
NZ low-cost system	0.70	0.55	0.84
NIST estimate		0.46	0.46
Reduction of property loss			
USA, all residential types		0.42	
USA, 1~2 family dwelling		0.19	
US, apartments		0.49	
USA, apartments, 7+ storeys		0.13	
USA, confine fire to 1 st item		0.85	
BRANZ estimate		0.83	
Scottsdale		0.87	
Vancouver		0.26*	
Reliability			
USA, all residential types		0.845	
NIST estimate	0.85	0.92	
NIST observation	0.70	(0.84)	
Marryatt		0.995**	
BRANZ assumption	0.74	0.95	

* low figure, as not all residential figures fitted with sprinklers

** high figure, as restricted to operational systems where expected to activate

The consensus values from the above table are:

- Alarms only: reduce deaths by 53% and injuries by 70%
- Sprinklers only: reduce deaths by 70~80%, injuries by 45~65%, property loss either by 40~50% or 85%
- Sprinklers plus alarms: reduce deaths by 83%, injuries by 45~85%, property loss presumably as per sprinklers only.

3.7.4 Costs

The costs of installing sprinklers have reduced in recent years. In new construction, a complete system may add only 1 to 2% of the total cost [Rohr 2000].

In 1992 to 1998 the amount of residential construction in Vancouver was costed at Can\$5.3 billion (converted to value in year 2000), and over that period the costs of sprinkler installation remained relatively constant, between 1 to 2% of the total construction costs [Robertson 2001].

A further study estimated the savings of Vancouver fire department costs to be of the order of 20 to 30% of the sprinkler installation costs.

Examples of savings in construction costs due to trade-offs permitted by sprinklers in Vancouver are allowing 4-storey wood frame buildings (could not previously be wood frame if not sprinklered), and allowing increased window openings close to the property line. In high and medium density residential construction the net installation costs of sprinklers could be reduced by up to 100% by means of trade-offs. Cost savings of the order of 0.25% of construction costs, due to sprinkler trade offs, would be sufficient to bring the net cost per life saved to effectively zero.

In Scottsdale, fitting sprinklers led to reduced insurance premiums, typically by about 10%. In the section of the report entitled "sprinkler myths", it was claimed that the installation costs would be recouped in five years due to the reduction in premium.

The installation costs have been reduced dramatically, from US\$1.14 ft² (US\$12.27 per m²) in 1985 to US\$0.59 ft² (\$US 6.35 per m²) in 1995, a close to 50% reduction in cost. For custom-built houses, the costs were \$0.89 per ft² in 1989, falling to \$0.79 per ft² in 1996. The cost to the builder could be as low as \$1,200. The cost of all the fire protection measures (not just sprinklers, although these were the major component) was less than 1% of the sale value of the house.

Design freedoms gave savings per house of US\$158 for on-site construction tradeoffs, and an additional US\$1950 for off-site tradeoffs. Taking these into account, the total costs were estimated to be US\$157 per installation to the builder, and US\$212 to the house buyer. (NB. These sums, quoted from the BRANZ report [Wade and Duncan 2000], do not add up. These costs were at the start of the period, they dropped over the years).

The city population (and the number of houses) increased by ~ 50% over 10 years, yet the city area remained more or less constant. For the first 7 of the 10 years, the number of fire stations remained constant at 6, rising by one-third to 8 at the end of the 10 years. It was claimed that this saved an initial \$6m, plus \$1m in running costs per year. The proportion of the city budget spent on the fire brigade only increased by 1% over the 10 years. The Fire Department costs per capita rose from \$31.10 in 1985/6 to \$51.48 in 1994/5, an increase of 5.8% per year.

Water damage from sprinkler discharge only added 25% to the fire losses, so this was still much less than losses from fire alone when sprinklers were absent [Marryatt 1988]. The Scottsdale report ("sprinkler myths" section) [Ford 1997] claimed that only 1 in 16 million sprinkler heads trip accidentally. Any risks from accidental water damage were therefore negligible.

The BRANZ cost benefit analysis [Wade & Duncan 2000] assumed an 8% discount rate, a 2% inflation rate, an analysis period of 20 years, and assumed that the lifetime of the low-cost sprinkler system was 30 years [Duncan et al 2000]. The costs of installing sprinklers to the NZS 4515 standard was NZ \$6500, plus NZ \$200 water connection and annual maintenance of NZ \$635. The less onerous DZ 4517 standard (as specified in 2000) had installation costs of NZ \$4,700, water costs of NZ \$200 and annual maintenance costs of NZ \$280. If sprinklers were fitted retrospectively, the water costs would be \$2,300. The prevention of backflow in these systems was estimated to contribute \$300 to the installation costs [Wade and Duncan 2000]. In contrast, the low-cost system suggested by the BRANZ study only had costs of NZ \$970 ± 100, and no associated water or annual maintenance charges [Duncan et al 2000].

Table 3.16 Summary of cost estimates

	Sprinkler costs (relevant currency)	Cost (£)*
Installation and water costs		
USA [Rohr 2000]	1 ~ 2% of construction cost	
Vancouver	1 ~ 2% of construction cost	
Canadian Mort. Housing Corp.	\$2,500	£1,100
Scottsdale (1985/6)	\$2,280	£1,550
Scottsdale (1994/5)	\$1,180	£800
NZS 4515	\$6,700	£1,875
DZ 4517	\$4,900	£1,370
NZ low-cost system	\$970 ± \$100	£270 ± £30
NZ, water costs, retro-fit	\$2,000	£560
Maintenance		
NZS 4515	\$635	£180
DZ 4517	\$280	£80
NZ low-cost system	-	-
Capital Recovery Factor		
NZ, discount rate	8%	
NZ, inflation rate	2%	
Vancouver, inflation rate	2 ~ 3%	
NZ, system lifetime	30 years	
Vancouver, system lifetime	50 years	
Accidental Water Discharge		
Scottsdale	-	-
Insurance Savings		
Scottsdale	~10% reduction in premium; recoup installation in 5 years	£160
Fire Department Savings		
Scottsdale	\$16m for city (rather vague)	
Vancouver	20% ~ 30% of installation	
Trade-Off Savings		
Vancouver	0.25% of construction	£220
Scottsdale, on-site	\$158	£110
Scottsdale, off-site	\$1,950	£1,330

* converted using £1.00 = US \$1.47 = Can \$2.27 = NZ \$3.57

** high figure, as restricted to operational systems where expected to activate

The consensus values from the above table are:

- Installation costs typically 1~2% of total construction cost
- Installation costs typically £1,000 ~ £2,000
- Trade-off and other savings may recoup installation costs.

3.7.5 Monetary benefits

Very few of the sources examined in the Pilot Study literature review made reference to the monetary benefits of preventing deaths and injuries. However, there seemed to be an implicit assumption that the value of each life saved was about \$1m (in all currencies).

The net cost of sprinklering per life saved falls below Can\$1 million for Vancouver, and this is well below the limits at which most Canadian public agencies would consider safety programs to be worthwhile. For example in Canada, safety programs typically cost between Can\$0.17 million to \$3 million per life saved (£0.07m ~ £1.3m) [Robertson 2001].

The BRANZ study noted costs for injury from the literature, of A\$21,000 [Beever and Britton 1999] or US\$20,000 . Converting these for the exchange rate, they used a value of NZ\$30,000 (£8,400).

3.7.6 Results

In 1995, a study by Rahmanian [Rahmanian 1995] concluded that the New Zealand standard for domestic sprinklers is more conservative than any other around the world, resulting in higher costs (mainly due to the need for sprinkler heads in concealed spaces). If sprinklers were added to new properties only, over 100 lives and NZ\$450 million of property damage would be saved over a 30-year period. Additionally, fitting sprinklers to 10% of existing buildings per year could save 550 lives and NZ\$1.8 billion of property damage over the 30-year period. Despite this, the cost of installing sprinklers exceeds the expected benefits. The cost of installation and maintenance of a NZ 4515 system is NZ\$14,000, and the cost per life saved would be NZ\$35m (figures from table 3.18).

A cost benefit analysis in Australia [Beever and Britton 1999] for the Building Control Commission, Victoria, concluded that "...no recommendation can be made for extending building codes to require sprinklers to be installed in domestic dwellings in Australia at this given time". "The adoption of sprinklers should however, be reassessed in the future as their cost-effectiveness is expected to improve with predicted demographic changes (ageing population) and reducing costs." Although sprinklers would undoubtedly save lives and protect property, the cost of the systems was too expensive, the costs could be reduced by relaxing requirements on water flow rates, installation, sprinkler separation and sprinkler-to-wall distances and maintenance schedules. However, there were still numerous household safety features such as smoke alarms, fire extinguishers and the avoidance of trip and fall hazards that would improve safety at a considerably reduced cost.

Using the Scottsdale figures enables a rather crude estimate of the cost to save a life, as follows: the city population increased by 50,000 over the ten years. Assume that is about 20,000 new homes (within a factor of 2). The initial cost of sprinklers per home was US\$2300 but fell by half, so take the average cost as US\$1600. Four lives were saved in residential fires (the other 4 were in commercial occupancies), so the cost per life saved is $(20,000 \times \text{US}\$1600)/4 = \text{US}\$8\text{m}$. But when only the net costs are considered, i.e. taking the trade off savings due to design freedoms, these costs are about US\$270 per home. Now the arithmetic becomes $(20,000 \times \text{US}\$270)/4 = \text{US}\$1.35\text{m}$ per life saved. Also, given that the installation costs fell, but the design trade-off savings presumably did not, the cost per life saved may even be negative, i.e. not a cost at all.

There was considerable debate over the cost benefit analysis, performed both in support and in opposition to the proposed change in Vancouver. The Canadian Mortgage and Housing Corporation (opposed) produced figures of Can\$35 million to save a life, Can\$1.5 million to prevent injury, Can\$2,500 net life cycle cost of installation, and a net cost to society of Can\$10 spent for every Can\$1 saved in property damage [Robertson 2001]. Various studies by the National Research Council of Canada (commissioned in support) showed a wide variation in results for different but credible assumptions. The variation was between a net saving of Can\$1.2 million to a net cost of Can\$31.9 million to save a life, between -Can\$0.5 (saving) and Can\$2.8 million to prevent injury, - Can\$1250 to +Canadian\$6140 life cycle cost, and -Can\$3 to +Canadian\$19 spent per Can\$1 saved [Robertson 2001].

In 1992 to 1998 the amount of residential construction was costed at Can\$5.3 billion (converted to value in year 2000), and over that period the costs of sprinkler installation remained relatively constant, between 1 to 2% of the total construction costs. Over the 7 year period, that gave a cost of Can\$11.4 million per year, and hence a cost per life saved of Can\$3.8 million. There will be additional savings associated with reduction in fire brigade requirements, direct savings in property damage, and reduction in construction costs associated with trade off.

However, if the sprinklers, once fitted, were assumed to continue saving lives at the same rate (3 per year) for the estimated lifetime of the building (50 years) then the cost per life would come down to Can\$0.53 million, without considering additional savings.

The cost per life saved to date in Vancouver (including additional savings) is less than \$1m, and when extended over the anticipated life of the buildings may fall to \$0.15m or below. If reduced construction costs are included in the analysis the net cost per life saved may effectively fall to zero. However, over-reliance on sprinklers to the detriment of other fire safety systems is to be avoided, particularly in areas subject to interruptions in the domestic water supply.

The BRANZ study [Wade and Duncan 2000] included determining the cost effectiveness of the proposed DZ 4515/CD3 system compared with the NZS 4515 system. Projected costs can be inflated by commercial overheads from large commercial projects. Backflow prevention, water connection charges and building consent fees, all add fixed costs which in some cases may exceed those for the sprinkler system itself. The absence of a competitive market, due to a lack of installers, could increase the price by a factor of 2 [Ford 1997].

The results of the BRANZ study were a cost per life saved of NZ\$35 million using the existing NZS 4515: 1995 standard for sprinklers, or NZ\$18 million using the proposed document DZ 4515/CD3.

These two costs per life saved were compared with other fire protection strategies, as shown in Table 3.17.

Table 3.17 Estimated costs of different fire protection options (BRANZ study)

	Installation NZ\$	Maintenance NZ\$	Savings NZ\$	Net Cost NZ\$	Cost per life NZ\$
Smoke alarm	212	973	405	780	3,000,000
Smoke alarm, 10 year battery	340	741	414	667	2,400,000
Smoke alarm + low-cost sprinklers	1,180	973	1,065	1,088	2,800,000
Low cost sprinklers only	968	0	660	308	891,000
NZS 4515:1995	6,700	7,353	693	13,361	34,800,000
DZ 4515/CD3	4,270	3,242	693	6,820	17,800,000

The costs of the smoke alarm plus low-cost sprinkler system option are approximately one-tenth those of the current standard NZ 4515:1995 design.

A sensitivity study was performed to test some of the assumptions for the low-cost system. It found that the cost per life saved increased as follows:

- by \$2,900 for every \$1 design fee (assumed to be zero)
- by \$35,700 for every \$1 annual maintenance fee (assumed to be zero)
- by \$3000 for every \$1 installation fee in excess of \$1000 (assumed to be zero)

Table 3.18 Summary of estimates of cost per life saved, converted to £m*.

	Alarm only	Sprinkler only	Sprinkler + alarm
Scottsdale			£5.4m
Scottsdale, including trade-off			£0.92m
Canada Mort. Housing Corp.		£15.4m	
Canada NRC		-£0.52m ~ 14m	
Vancouver, 50-year projection		£0.23m	
Vancouver, 50-yr + trade-off		~£0m	
BRANZ study	£0.84m		
NZS 4515			£9.8m
DZ 4517			£5m
NZ low-cost system		£0.25m	£0.78m

* converted using £1.00 = US \$1.47 = Can \$2.27 = NZ \$3.57

In general, the conclusions from other countries' experiences are:

- Residential sprinklers are generally not cost-effective
- In order to be cost-effective, installation and maintenance costs must be minimal, or
- There must be additional benefits, beyond life safety, reduction of injury and property loss.

3.8 Codes and Standards

Currently, there is no requirement to fit residential sprinklers in the UK. Therefore, relatively few sprinkler systems have been installed in domestic and residential properties. Consequently, there is a paucity of statistical information concerning the performance and effectiveness of residential sprinklers in the UK.

However, there is some take up and sprinklers are being installed in various parts of the UK in a range of residential buildings for a variety of reasons [Hardy 2003]. The residential premises include both single buildings and whole developments and refurbished and new premises. The take up is both voluntarily, i.e. additional to recommendations in the Approved Document B and as a compensatory feature. The reasons for the compensatory feature include: instead of traditional alternative escape routes, to overcome fire brigade access problems, instead of fire extinguishers and to protect higher risk premises.

3.8.1 Review of DD 251 and DD 252

Residential and domestic sprinkler systems (DD 251) differ from commercial sprinkler systems (BS 55306 Part 2 or BS EN 12845) in a number of ways:

- a) Different sprinkler head products
- b) Different discharge design densities
- c) Typically designed for less heads
- d) Less maintenance required
- e) Water supplies
- f) Different patterns of water discharge.

Two British Standards Drafts for Development DD 251 (systems) and DD 252 (components) have been produced [British Standards Institution 2001 and 2002]. They are of a provisional nature and have been issued as Drafts for Developments (DDs) instead of full British Standards because it was recognised by the technical experts that UK experience needed to be gained.

The two DDs were prepared initially by Task Groups of FSH 18/2 the BSI sprinkler technical committee. The requirements and recommendations of these BS DDs were based on the best technical information available to the Task Group at the time of writing and were a consensus of opinion from the technical experts.

In this Pilot Study, DD 251 and DD 252 have been reviewed and the technical knowledge gaps and other areas of uncertainty have been identified. The main issues of discussion by the Task Group were:

- a) Areas of sprinkler protection
- b) Minimum flow rates and maximum coverage areas
- c) Minimum sprinkler head orifice size
- d) UK fire test for sprinklers
- e) Concealed and recessed sprinklers.

Currently, the available residential sprinkler head products have been predominantly developed and manufactured in the USA. Original research into the performance of residential sprinkler heads was carried out by Factory Mutual Research Corporation (FM) in 1970s [e.g. Kung et al, 1982 and 1980]. In 1983, FM issued an approval standard which was based on the FM research and included a fire test [Factory Mutual Research Corporation, 1983]. FM continued to carry out sprinkler research.

Separately, Underwriters Laboratory (UL) developed its own test specification UL1626 [Underwriters Laboratory Inc., 1986] which included a similar but different fire test which did not involve prefabricated furniture. The current sprinkler head products have predominantly been tested at and listed by UL to UL1626.

Manufacturers have continued to develop the sprinkler heads with lower and lower discharge densities down to 2 mm/min/m² and increased areas of coverage 15 m² up to 40 m² (and larger sprinkler spacings). These are known as 'low flow' residential sprinklers.

A problem arose in 1997, when the UL proposed to the American National Standards Institute, that UL1626 become the USA national fire test standard. In 1997 FM voted negatively. In 1998 to 1999, FM carried out some fire tests to the UL specification [Bill & Anderson 1999] but found that it could not reproduce the UL test results. "Flashover" instead of "control" was achieved for approved product where nominal discharge densities were less than 4.1 mm/min/m². FM submitted its results to support the negative vote.

The UL 1626 fire test involves burning a stylised, representative fuel package arranged inside a simulated residential "room" with wall and ceiling plywood panelling with two sprinkler heads installed. The fuel package essentially consists of a wood crib and two foam cushions attached to a wooden frame. There are two open doorways and outside one doorway is a third sprinkler head. The sprinkler system performance is determined by its performance in controlling the fire for a period of time measured after sprinkler operation, measured by the gas temperatures being limited to specified values and a dummy sprinkler head located outside the room not operating.

Issues that were of concern were partly to do with differences between the test protocols and also slight differences in specifying the fire load and its arrangement. The main test protocol issues were: the initial moisture content of the crib, the dryness of test room, the initial static pressure and non rapid decay of water to designed discharge pressure. The fire tests differences include variability in the dimensions, construction and composition of fuel packages and relative locations of simulated furniture packages to itself, walls, ceiling and sprinkler spray.

Both parties have been involved in trying to resolve this repeatability problem and develop a new fire test. They have had various discussions and have carried out various detailed experimental programmes [Bill et al 2001] but unfortunately, this has proved

complex and so far, have had no success. They had agreed that the original 1970s research should be the baseline against which the fire test should be compared but FM and UL have not yet agreed on a new single fire test.

The USA has been trying to resolve the fire test problems in the period when DD 252 was being prepared. DD 252 was needed to go with DD 251. The Task Group decided that because it was a DD it was best to include a fire test based on the FM fire test which was based on the original FM research, pending gaining some UK experience before the DDs are revised.

Therefore, the two main technical knowledge gaps in DD 251 and DD 252 concern

- 1) detailed UK experience in the performance of available residential sprinkler products in appropriate fire scenarios.
- 2) establishing the benchmark fire test for DD 252 for UK conditions.

One approach to address these knowledge gaps is as follows:

- i) Any UK experience of the use of the USA/FM fire test as it currently stands could be gained.
- ii) A test programme of fires could be drawn up which will include a sensitivity analysis of key parameters.
- iii) Suitable UK specified materials for the fire load arrangement (fuels, ceiling and wall linings) could be determined and characterised.
- iv) Various residential sprinkler heads could be examined and a few of these selected for use in the fire test programme. The selection process could be on the basis of water delivery to the walls and the floor.
- v) The performance of a selected range of selected domestic and residential sprinkler heads of selected temperature ratings and water flow rates could be evaluated using the test.

A review of DD 251 and DD 252 is due to be carried out within two years of publication and according to the comments received, FSH 18/2 will decide whether the DDs can be converted into full British Standards. In the meantime, it is important to gain UK experience in the benchmark fire test and performance of residential sprinkler product to submit to FSH 18/2 for the review.

Note: A review of DD 251 started after the Pilot Study in 2003 and is now in progress.

3.8.2 Developments in New Zealand codes, standards and legislation

The current standard for sprinkler systems for residential and domestic premises is NZS 4515: 1995 fire sprinkler systems for residential occupancies (including private dwellings) [New Zealand Standards 1995].

Following some multiple fatality fires in residential care homes for the elderly, legislation was passed which requires sprinkler systems in both new and existing residential care homes to NZS 4515. The outcome of this has been very successful.

However, there are very few sprinkler systems currently installed in domestic premises in New Zealand.

In order for sprinklers to be cost-effective, the design and installation costs would have to be reduced significantly and a large increase in value of life, injuries and insurance discount is required.

In 1999, Duncan, Wade and Saunders of BRANZ, New Zealand carried out a study on behalf of the New Zealand Fire Service Commission [Duncan et al 2000] and proposed an inexpensive sprinkler design for domestic premises (low cost system).

The cost of installation of this low cost system in a simple, single-level 3-bedroom house would be less than NZ\$1000. The cost per life saved was competitive with domestic smoke alarms, but absolute savings in lives and property would be expected to be more. The cost per life saved was less than NZ\$900,000.

The proposed low-cost multi-purpose sprinkler system varies from the current NZS 4515:1995 for the installation of domestic fire sprinkler systems, as follows:

- 1) Multi-purpose system (i.e. connected to domestic plumbing) rather than stand-alone.
- 2) No control valve set is required, since connected to plumbing with continual water flow through the pipes. This eliminates the need for backflow prevention, pressure sustaining valve and sprinkler system isolation.
- 3) Backflow prevention is not required, because only potable water is in the system.
- 4) An alarm to indicate sprinkler operation is not included (a flow switch would be inappropriate because there is continuous water flow). Smoke alarms should be fitted as well as the low-cost sprinkler system.
- 5) Sprinkler heads are not installed in the bathroom, toilet, wardrobe/cupboard space or ceiling cavity, where their impact would be expected to be minimal.
- 6) The domestic load for the hydraulic design is 12 litres/minute, compared with average household demand (peak 6 litres/minute) and NZS 4515:1995 requirements (57 litres/minute).
- 7) Installation will be by approved persons of demonstrated competency.
- 8) There are no ongoing maintenance requirements, since there is no control valveset. With the sprinkler system integrated with the domestic plumbing, the chance of unintentional water shut-off is minimised.
- 9) The system is not connected to alarms that call out the fire service.

The BRANZ study included a risk assessment (see 6.1.3), a cost benefit study (see 6.1.4) and some fire tests.

NZS 4515:1995 is in the process of being revised. In 1999, a draft document DZ 4515/CD3 was prepared [New Zealand Standards 2002]. However, the results of the BRANZ research will be included in the production of an additional standard covering

domestic, NZS 4517: fire sprinkler systems for domestic occupancies i.e. homes [16]. NZS 4515 and 4517 are due for publication at the end of 2001.

Note: NZS 4517 was actually published in 2002, and covers the low-cost system specified by the BRANZ study.

In addition, BRANZ has also recently completed a guide about combination domestic plumbing and fire sprinkler systems [BRANZ 2001] to aid designers, approved plumbers, builders, students, building owners and building approvers.

3.8.3 USA codes, standards and legislation

In the USA, the installation of sprinklers in residential and domestic premises is controlled at local authority level; by state, county or municipal legislation. Local ordinances call upon model enacted codes. These model codes specify the use of items, such as sprinkler heads and associated components which have been tested and approved by recognised organisations.

The main organisations which perform approvals and listing of sprinklers are the Underwriters Laboratory (UL) and Factory Mutual (FM). The sprinkler heads are rigorously tested to the appropriate standards. The installation of the approved heads would typically be to recognised standards. The National Fire Protection Association (NFPA) publishes such standards for the installation of residential sprinklers. The standard for domestic and residential fire sprinkler systems are NFPA 13R, the installation of sprinkler systems in residential up to 4-storeys, multiple family dwellings, 1999 [NFPA 1999a] and NFPA 13D, the installation of sprinkler systems in 1 and 2 family dwellings, 1999 [NFPA 1999b], respectively.

3.9 Conclusions of Pilot Study

It was eventually decided, for the sake of consistency, to use the same classification of residential fire types as that used by Hartless in his work to support a future Regulatory Impact Assessment. These classifications are as follows:

<ul style="list-style-type: none"> • House, single occupancy • House, multiple occupancy • Flat, purpose-built • Flat, converted 	<ul style="list-style-type: none"> • Care Home, old person's • Care Home, children • Care Home, disabled people
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There are a number of ways in which the risk from fire may be presented, either as the risk per member of the population, risk per fire, or risk per building/accommodation unit. The approach that has been chosen to use for this cost benefit analysis is the risk per building since it provides the easiest way to express the costs and benefits on a common basis (£ per accommodation unit per year).

The annual risks per member of the population, relative to a single-occupancy house, are fairly constant. The risks per fire also do not vary much over the different property classes; in fact the risks per fire are lower in the three types of care homes than they are

for single-occupancy houses. The reason that the care homes have higher risks per accommodation unit than other buildings is that they have many more fires.

- The number of fires per building / accommodation unit is the primary factor that determines the other risks (death, injury, etc) per building per year.

Examination of the risks as a function of building height concluded that:

- The frequency of fire per accommodation unit increases with building height
- The risk of death per fire is not significantly affected by building height.

and hence the risk of death per accommodation unit did increase with building height.

It was also observed that in multi-storey buildings, the number of fires per floor was not evenly distributed, but that there were more fires at the ground level.

It was not possible to provide a direct estimate of sprinkler effectiveness from the UK fire statistics. However, a strong correlation was observed between the risks of death and injury per fire, and the ultimate fire size (square m of area damaged). This formed the basis for an indirect estimate of sprinkler effectiveness. If the ultimate fire size can be kept as small as possible, there will be two benefits:

- The risk of death per fire will go down and
- The number of fires whose risk is affected by the sprinklers will increase.

Estimates of sprinkler effectiveness at reducing deaths and injuries were made for each of the seven residential categories. Due to the level of uncertainty in the results, it was reasonable to assume that the effectiveness of sprinklers was more or less independent of property type, and to lie in the following ranges:

- | | |
|---|-----------------------------|
| • Reduction in the number of deaths | 55% ~ 85% |
| • Reduction in the number of injuries | 15% ~ 45% |
| • Reduction in the number of rescues required | 20% ~ 50% (flats 40% ~ 65%) |
| • Reduction in the average property damage | 35% ~ 65% |

(In fact the number of rescues required was not used in the cost benefit analysis, due to the difficulty in assigning a monetary value to them.)

Experiences with residential sprinklers in other countries were also reviewed. Statistical and other data from other countries may not be directly applicable or appropriate for the UK situation, especially for any future Regulatory Impact Assessment due to cultural and technical differences. However, this material is useful for consideration as background information and comparison with UK estimates.

The common factors considered for cost benefit analyses were:

- Costs: installation, water supplies, and maintenance
- Benefits: lives saved, property protection. Injuries saved, fire brigade costs and other trade-offs also considered where data are available.

The consensus values for sprinkler effectiveness in other countries are:

- Alarms only: reduce deaths by 53% and injuries by 70%
- Sprinklers only: reduce deaths by 70~80%, injuries by 45~65%, property loss either by 40~50% or 85%
- Sprinklers + alarms: reduce deaths by 83%, injuries by 45~85%, property loss presumably as per sprinklers only.

The consensus values for sprinkler costs in other countries are:

- Installation costs typically 1~2% of total construction cost
- Installation costs typically equivalent to £1,000 ~ £2,000
- Trade-off and other savings may recoup installation costs

In general, the conclusions from other countries' experiences are:

- Residential sprinklers are generally not cost-effective
- In order to be cost-effective, installation and maintenance costs must be minimal, or
- There must be additional benefits, beyond life safety, reduction of injury and property loss.

UK standards for residential sprinklers (DD 251 and DD 252) were reviewed. The two main technical knowledge gaps concern:

- detailed UK experience in the performance of available residential sprinkler product in appropriate fire scenarios.
- establishing the benchmark fire test for DD 252 for UK conditions.

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Appendix 3A – UK statistics data

Annual risks, per million people

Property type	Accom. Units (000's)	People per unit	Fires	Death	Injury	Rescues
House, single	18,642	2.5	646	6	147	4
House, multiple	1,337	1.9	604	7	148	11
Flat, purpose-built	3,605	2	2421	14	471	36
Flat, converted	1,099	1.6	1601	14	415	46
Care Home, old person's	16.3	19	3478	13	320	77
Care Home, children's	1.4	8.9	16774	16	1445	80
Care Home, disabled person's	11.1	7.7	4025	9	328	32

Annual risks, per million people, relative to single-occupancy house

Property type	Fires	Death	Injury	Rescues
House, single	1.0	1.0	1.0	1.0
House, multiple	0.9	1.1	1.0	2.5
Flat, purpose-built	3.7	2.3	3.2	8.1
Flat, converted	2.5	2.4	2.8	10.5
Care Home, old person's	5.4	2.1	2.2	17.6
Care Home, children's	25.9	2.7	9.8	18.2
Care Home, disabled person's	6.2	1.6	2.2	7.2

Annual risks, per thousand fires

Property type	Accom. Units (000's)	People per unit	Fires	Death	Injury	Rescues
House, single	18,642	2.5	1000	9	227	7
House, multiple	1,337	1.9	1000	11	245	18
Flat, purpose-built	3,605	2	1000	6	194	15
Flat, converted	1,099	1.6	1000	9	259	29
Care Home, old person's	16.3	19	1000	4	92	22
Care Home, children's	1.4	8.9	1000	1	86	5
Care Home, disabled person's	11.1	7.7	1000	2	81	8

Annual risks, per thousand fires, relative to single occupancy house

Property type	Fires	Death	Injury	Rescues
House, single	1.0	1.0	1.0	1.0
House, multiple	1.0	1.2	1.1	2.7
Flat, purpose-built	1.0	0.6	0.9	2.2
Flat, converted	1.0	1.0	1.1	4.2
Care Home, old person's	1.0	0.4	0.4	3.3
Care Home, children's	1.0	0.1	0.4	0.7
Care Home, disabled person's	1.0	0.3	0.4	1.2

Annual risks, per million accommodation units

Property type	Accom. Units (000's)	People per unit	Fires	Death	Injury	Rescues
House, single	18,642	2.5	1616	15	367	11
House, multiple	1,337	1.9	1147	13	281	21
Flat, purpose-built	3,605	2	4841	27	941	71
Flat, converted	1,099	1.6	2561	23	664	74
Care Home, old person's	16.3	19	66074	245	6073	1472
Care Home, children's	1.4	8.9	149286	143	12857	714
Care Home, disabled person's	11.1	7.7	30990	72	2523	243

Annual risks, per million accommodation units, relative to single-occupancy house

Property type	Fires	Death	Injury	Rescues
House, single	1.0	1.0	1.0	1.0
House, multiple	0.7	0.9	0.8	1.9
Flat, purpose-built	3.0	1.8	2.6	6.5
Flat, converted	1.6	1.5	1.8	6.7
Care Home, old person's	40.9	16.3	16.5	133.8
Care Home, children's	92.4	9.5	35.0	64.9
Care Home, disabled person's	19.2	4.8	6.9	22.1

Appendix 3B – Effect of building height

Number of fires, for various residential types of buildings of different heights

Number of storeys:	1	2	3	4~5	6~7	8+	Total
House	6009	52264	4066	467	9	15	62831
HMO	161	2113	718	192	7	3	3194
Flat	714	13526	13690	10155	1195	7191	46470
Care home	450	1962	738	177	4	5	3336

Number of deaths per thousand fires, for various residential types of buildings of different heights

Number of storeys:	1	2	3	4~5	6~7	8+	Total
House	15	8	12	2	0	0	9
HMO	12	14	10	0	0	0	12
Flat	6	6	6	4	8	5	6
Care home	0	4	3	0	0	0	3

Number of injuries per thousand fires, for various residential types of buildings of different heights

Number of storeys:	1	2	3	4~5	6~7	8+	Total
House	224	235	229	261	0	0	234
HMO	168	213	199	209	0	0	207
Flat	158	229	226	210	140	161	210
Care home	24	34	205	28	0	0	38

Number of residential buildings of various heights

Number of storeys:	1	2	3	4~5	6~7	8+	Total
House	2,016,053	13,850,450	932,466	27,342			16,826,311
HMO	1,922	258,746	71,452	5,052			337,172
Flat	6,934	1,737,548	1,211,025	646,735	103,172	232,182	3,937,596

Figures in the table above were taken from the English House Condition Survey 2001 [White 2003]. However, the total numbers of buildings do not match those quoted by Hartless [14], particularly when it comes to the numbers of HMO's where there is a discrepancy by roughly a factor of four. As we have used Hartless' figures throughout the rest of this work, for consistency we have renormalized the numbers of buildings to give the same totals as Hartless, but the same proportions for different heights as the table above.

Renormalized number of residential buildings of various heights

Number of storeys:	1	2	3	4~5	6~7	8+	Total
House	2,233,601	15,345,021	1,033,086	30,292			18,642,000
HMO	7,621	1,026,015	283,331	20,033			1,337,000
Flat	8,284	2,075,740	1,446,736	772,614	123,253	277,373	4,704,000

Number of fires per thousand accommodation units (renormalized)

Number of storeys:	1	2	3	4~5	6~7	8+
House	3	3	4	15		
HMO	21	2	3	10		
Flat	86	7	9	13	10	26

Appendix 3C – Risks as a function of ultimate fire size, and indirect estimates of sprinkler efficiency

House, single occupancy, deaths

fire size (sq.m)	fires	deaths	deaths per '000 fires	
<1	14725.1	23.7	1.6 +/-	0.1
1-2	4617.3	34.0	7.4 +/-	0.5
3-4	2448.6	40.2	16.4 +/-	1.1
5-9	1452.8	33.7	23.2 +/-	1.7
10-19	1010.2	39.8	39.4 +/-	2.8
20-49	629.0	40.3	64.1 +/-	4.9
50-99	204.0	24.2	118.5 +/-	12.9
100-199	77.0	8.5	110.3 +/-	19.9
200+	28.4	1.3	47.0 +/-	18.8
undefined	4929.8	37.3	7.6 +/-	0.5
TOTAL	30122.1	283.0	9.4 +/-	0.2

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.84 +/-	0.04
1-2	0.59 +/-	0.03
3-4	0.38 +/-	0.03
5-9	0.28 +/-	0.03
10-19	0.15 +/-	0.02
20-49	0.06 +/-	0.01

House, single occupancy, injuries

fire size (sq.m)	fires	injuries	injuries per '000 fires	
<1	14725.1	2042.8	138.7 +/-	1.7
1-2	4617.3	1282.2	277.7 +/-	5.2
3-4	2448.6	845.5	345.3 +/-	8.5
5-9	1452.8	583.8	401.9 +/-	12.5
10-19	1010.2	495.8	490.9 +/-	17.9
20-49	629.0	345.5	549.3 +/-	25.0
50-99	204.0	101.0	495.1 +/-	40.1
100-199	77.0	35.0	454.3 +/-	60.5
200+	28.4	8.5	299.8 +/-	70.3
undefined	4929.8	1092.8	221.7 +/-	4.2
TOTAL	30122.1	6833.0	226.8 +/-	1.7

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.39 +/-	0.01
1-2	0.14 +/-	0.01
3-4	0.07 +/-	0.01
5-9	0.04 +/-	0.01
10-19	0.01 +/-	0.00
20-49	0.00 +/-	0.00

House, single occupancy, rescues

fire size (sq.m)	fires	rescues	rescues per '000 fires	
<1	244.5	1.5	6.1 +/-	2.1
1-2	20.8	0.0	0.0 +/-	0.0
3-4	10.3	0.3	32.5 +/-	25.2
5-9	5.0	0.0	0.0 +/-	0.0
10-19	2.9	0.0	0.0 +/-	0.0
20-49	1.2	0.0	0.0 +/-	0.0
50-99	0.7	0.8	1250.0 +/-	1630.0
100-199	0.2	0.0	0.0 +/-	0.0
200+	0.2	0.0	0.0 +/-	0.0
undefined	58.1	0.0	0.0 +/-	0.0
TOTAL	343.8	2.7	7.8 +/-	2.0

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.44 +/-	0.03
1-2	0.21 +/-	0.03
3-4	0.11 +/-	0.02
5-9	0.05 +/-	0.02
10-19	0.04 +/-	0.01
20-49	0.00 +/-	0.01

House, multiple occupancy, deaths

fire size (sq.m)	fires	deaths	deaths per '000 fires	
<1	727.9	0.7	0.9 +/-	0.5
1-2	257.8	2.7	10.3 +/-	2.7
3-4	142.6	1.8	12.9 +/-	4.0
5-9	85.6	2.5	29.2 +/-	8.2
10-19	61.4	1.8	29.9 +/-	9.8
20-49	41.2	2.5	60.7 +/-	18.3
50-99	13.5	1.8	135.6 +/-	55.1
100-199	4.8	1.0	206.7 +/-	126.3
200+	1.1	0.0	0.0 +/-	0.0
undefined	243.9	2.2	8.9 +/-	2.5
TOTAL	1579.9	17.0	10.8 +/-	1.1

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.92 +/-	0.17
1-2	0.53 +/-	0.14
3-4	0.47 +/-	0.13
5-9	0.25 +/-	0.11
10-19	0.24 +/-	0.10
20-49	0.12 +/-	0.07

House, multiple occupancy, injuries

fire size (sq.m)	fires	injuries	injuries per '000 fires	
<1	727.9	105.7	145.2 +/-	7.9
1-2	257.8	61.5	238.6 +/-	19.4
3-4	142.6	50.2	351.7 +/-	35.8
5-9	85.6	36.7	428.1 +/-	54.5
10-19	61.4	27.0	439.9 +/-	66.0
20-49	41.2	35.5	862.3 +/-	146.8
50-99	13.5	6.8	505.3 +/-	158.5
100-199	4.8	4.7	964.5 +/-	474.9
200+	1.1	0.3	290.0 +/-	339.5
undefined	243.9	47.8	196.1 +/-	17.1
TOTAL	1579.9	376.2	238.1 +/-	7.8

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.41 +/-	0.04
1-2	0.24 +/-	0.04
3-4	0.12 +/-	0.03
5-9	0.07 +/-	0.03
10-19	0.06 +/-	0.02
20-49	0.00 +/-	0.01

House, multiple occupancy, rescues

fire size (sq.m)	fires	rescues	rescues per '000 fires	
<1	727.9	5.8	8.0 +/-	1.4
1-2	257.8	5.8	22.6 +/-	4.1
3-4	142.6	1.5	10.5 +/-	3.6
5-9	85.6	3.3	38.9 +/-	9.7
10-19	61.4	2.5	40.7 +/-	11.7
20-49	41.2	4.5	109.3 +/-	27.1
50-99	13.5	0.7	49.3 +/-	28.1
100-199	4.8	0.2	34.5 +/-	37.9
200+	1.1	0.0	0.0 +/-	0.0
undefined	243.9	2.8	11.6 +/-	2.9
TOTAL	1579.9	27.2	17.2 +/-	1.4

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.56 +/-	0.10
1-2	0.27 +/-	0.08
3-4	0.37 +/-	0.08
5-9	0.13 +/-	0.07
10-19	0.12 +/-	0.06
20-49	0.00 +/-	0.00

Flat, purpose-built, deaths

fire size (sq.m)	fires	deaths	deaths per '000 fires	
<1	9366.0	9.7	1.0 +/-	0.1
1-2	2415.8	13.7	5.7 +/-	0.6
3-4	1126.9	16.0	14.2 +/-	1.5
5-9	617.5	15.8	25.6 +/-	2.8
10-19	420.1	11.8	28.2 +/-	3.6
20-49	223.6	10.5	47.0 +/-	6.7
50-99	39.3	4.0	101.9 +/-	26.4
100-199	19.1	0.7	35.0 +/-	19.3
200+	9.0	0.3	37.0 +/-	28.9
undefined	3215.3	15.0	4.7 +/-	0.5
TOTAL	17452.6	97.5	5.6 +/-	0.2

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.82 +/-	0.06
1-2	0.55 +/-	0.05
3-4	0.30 +/-	0.04
5-9	0.11 +/-	0.04
10-19	0.09 +/-	0.03
20-49	0.03 +/-	0.02

Flat, purpose-built, injuries

fire size (sq.m)	fires	injuries	injuries per '000 fires	
<1	9366.0	1267.2	135.3 +/-	2.1
1-2	2415.8	512.5	212.1 +/-	5.8
3-4	1126.9	330.0	292.8 +/-	10.9
5-9	617.5	241.3	390.8 +/-	18.8
10-19	420.1	212.7	506.3 +/-	28.5
20-49	223.6	138.0	617.3 +/-	46.5
50-99	39.3	30.2	768.2 +/-	135.3
100-199	19.1	12.2	638.1 +/-	164.2
200+	9.0	5.2	572.7 +/-	216.7
undefined	3215.3	643.3	200.1 +/-	4.8
TOTAL	17452.6	3392.5	194.4 +/-	2.0

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.30 +/-	0.01
1-2	0.16 +/-	0.01
3-4	0.09 +/-	0.01
5-9	0.04 +/-	0.01
10-19	0.01 +/-	0.01
20-49	0.00 +/-	0.00

Flat, purpose-built, rescues

fire size (sq.m)	fires	rescues	rescues per '000 fires	
<1	9366.0	51.5	5.5 +/-	0.3
1-2	2415.8	33.8	14.0 +/-	1.0
3-4	1126.9	51.3	45.6 +/-	2.9
5-9	617.5	21.8	35.4 +/-	3.4
10-19	420.1	27.7	65.9 +/-	6.0
20-49	223.6	25.8	115.6 +/-	12.1
50-99	39.3	2.0	50.9 +/-	16.8
100-199	19.1	5.7	297.2 +/-	85.1
200+	9.0	0.3	37.0 +/-	28.9
undefined	3215.3	34.7	10.8 +/-	0.8
TOTAL	17452.6	254.7	14.6 +/-	0.4

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.64 +/-	0.04
1-2	0.46 +/-	0.03
3-4	0.13 +/-	0.03
5-9	0.17 +/-	0.02
10-19	0.07 +/-	0.02
20-49	0.02 +/-	0.01

Flat, converted, deaths

fire size (sq.m)	fires	deaths	deaths per '000 fires	
<1	1348.7	1.0	0.7 +/-	0.3
1-2	389.0	4.0	10.3 +/-	2.2
3-4	205.7	4.8	23.5 +/-	4.7
5-9	139.3	4.0	28.7 +/-	6.4
10-19	105.2	3.3	31.7 +/-	7.7
20-49	58.4	2.5	42.8 +/-	12.4
50-99	14.1	0.7	47.3 +/-	26.8
100-199	4.8	0.7	139.3 +/-	94.4
200+	3.9	0.3	84.8 +/-	73.7
undefined	545.4	3.5	6.4 +/-	1.4
TOTAL	2814.6	24.8	8.8 +/-	0.7

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.92 +/-	0.13
1-2	0.51 +/-	0.10
3-4	0.18 +/-	0.09
5-9	0.10 +/-	0.07
10-19	0.08 +/-	0.05
20-49	0.03 +/-	0.03

Flat, converted, injuries

fire size (sq.m)	fires	injuries	injuries per '000 fires	
<1	1348.7	210.5	156.1 +/-	6.1
1-2	389.0	115.2	296.0 +/-	18.8
3-4	205.7	78.7	382.5 +/-	32.0
5-9	139.3	71.2	510.8 +/-	49.9
10-19	105.2	56.7	538.6 +/-	60.1
20-49	58.4	48.8	836.3 +/-	119.9
50-99	14.1	14.0	992.3 +/-	285.5
100-199	4.8	6.2	1288.0 +/-	625.7
200+	3.9	2.2	551.5 +/-	317.6
undefined	545.4	126.7	232.3 +/-	13.0
TOTAL	2814.6	730.0	259.4 +/-	6.3

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.41 +/-	0.03
1-2	0.20 +/-	0.03
3-4	0.12 +/-	0.03
5-9	0.05 +/-	0.02
10-19	0.05 +/-	0.02
20-49	0.01 +/-	0.01

Flat, converted, rescues

fire size (sq.m)	fires	rescues	rescues per '000 fires	
<1	1348.7	15.2	11.3 +/-	1.2
1-2	389.0	10.3	26.6 +/-	3.6
3-4	205.7	15.0	72.9 +/-	9.2
5-9	139.3	7.0	50.2 +/-	8.9
10-19	105.2	6.7	63.4 +/-	11.8
20-49	58.4	7.5	128.5 +/-	25.5
50-99	14.1	0.8	59.1 +/-	30.8
100-199	4.8	0.0	0.0 +/-	0.0
200+	3.9	0.0	0.0 +/-	0.0
undefined	545.4	18.7	34.2 +/-	3.6
TOTAL	2814.6	81.2	28.8 +/-	1.4

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.59 +/-	0.07
1-2	0.37 +/-	0.06
3-4	0.05 +/-	0.05
5-9	0.10 +/-	0.04
10-19	0.06 +/-	0.03
20-49	0.00 +/-	0.00

Care Home, old person's, deaths

fire size (sq.m)	fires	deaths	deaths per '000 fires	
<1	775.8	1.8	2.4 +/-	0.7
1-2	48.0	0.7	13.9 +/-	7.2
3-4	15.9	0.2	10.5 +/-	10.8
5-9	5.5	0.2	30.3 +/-	33.0
10-19	4.9	0.2	34.3 +/-	37.7
20-49	5.9	0.0	0.0 +/-	0.0
50-99	1.7	0.0	0.0 +/-	0.0
100-199	1.1	0.0	0.0 +/-	0.0
200+	3.4	0.0	0.0 +/-	0.0
undefined	214.7	0.8	3.9 +/-	1.8
TOTAL	1076.9	3.8	3.6 +/-	0.8

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.33 +/-	0.18
1-2	0.06 +/-	0.12
3-4	0.08 +/-	0.10
5-9	0.01 +/-	0.11
10-19	0.00 +/-	0.00
20-49	0.00 +/-	0.00

Care Home, old person's, injuries

fire size (sq.m)	fires	injuries	injuries per '000 fires	
<1	775.8	51.2	66.0 +/-	4.5
1-2	48.0	13.7	284.6 +/-	51.7
3-4	15.9	5.3	335.2 +/-	102.9
5-9	5.5	4.0	728.0 +/-	344.4
10-19	4.9	4.5	927.2 +/-	457.2
20-49	5.9	2.0	336.4 +/-	168.8
50-99	1.7	1.0	596.2 +/-	520.9
100-199	1.1	0.3	301.9 +/-	358.1
200+	3.4	0.0	0.0 +/-	0.0
undefined	214.7	16.5	76.9 +/-	9.3
TOTAL	1076.9	98.5	91.5 +/-	4.7

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.31 +/-	0.07
1-2	0.09 +/-	0.05
3-4	0.07 +/-	0.05
5-9	0.01 +/-	0.05
10-19	0.00 +/-	0.00
20-49	0.01 +/-	0.02

Care Home, old person's, rescues

fire size (sq.m)	fires	rescues	rescues per '000 fires	
<1	775.8	3.3	4.3 +/-	1.0
1-2	48.0	2.0	41.6 +/-	13.5
3-4	15.9	3.2	199.0 +/-	67.7
5-9	5.5	0.2	30.3 +/-	33.0
10-19	4.9	4.8	995.9 +/-	488.5
20-49	5.9	1.8	308.4 +/-	157.0
50-99	1.7	0.3	198.7 +/-	208.2
100-199	1.1	7.3	6641.5 +/-	6399.4
200+	3.4	0.0	0.0 +/-	0.0
undefined	214.7	1.3	6.2 +/-	2.2
TOTAL	1076.9	24.3	22.6 +/-	2.0

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.84 +/-	0.47
1-2	0.71 +/-	0.46
3-4	0.51 +/-	0.45
5-9	0.61 +/-	0.46
10-19	0.27 +/-	0.43
20-49	0.30 +/-	0.42

Care Home, children's, deaths

fire size (sq.m)	fires	deaths	deaths per '000 fires	
<1	133.2	0.0	0.0 +/-	0.0
1-2	29.8	0.0	0.0 +/-	0.0
3-4	10.5	0.0	0.0 +/-	0.0
5-9	2.0	0.0	0.0 +/-	0.0
10-19	1.9	0.2	86.3 +/-	106.4
20-49	2.5	0.0	0.0 +/-	0.0
50-99	0.5	0.0	0.0 +/-	0.0
100-199	1.3	0.0	0.0 +/-	0.0
200+	0.5	0.0	0.0 +/-	0.0
undefined	26.9	0.0	0.0 +/-	0.0
TOTAL	209.0	0.2	0.8 +/-	0.8

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	1.00 +/-	1.74
1-2	1.00 +/-	1.74
3-4	1.00 +/-	1.74
5-9	1.00 +/-	1.74
10-19	0.00 +/-	0.00
20-49	0.00 +/-	0.00

Care Home, children's, injuries

fire size (sq.m)	fires	injuries	injuries per '000 fires	
<1	133.2	5.5	41.3 +/-	8.0
1-2	29.8	5.0	168.0 +/-	43.5
3-4	10.5	1.3	126.5 +/-	59.4
5-9	2.0	0.0	0.0 +/-	0.0
10-19	1.9	0.2	86.3 +/-	106.4
20-49	2.5	1.3	524.7 +/-	377.9
50-99	0.5	0.3	666.7 +/-	1054.3
100-199	1.3	0.7	531.0 +/-	543.3
200+	0.5	0.0	0.0 +/-	0.0
undefined	26.9	3.2	117.9 +/-	35.4
TOTAL	209.0	17.5	83.7 +/-	10.0

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.48 +/-	0.17
1-2	0.11 +/-	0.12
3-4	0.13 +/-	0.11
5-9	0.17 +/-	0.12
10-19	0.14 +/-	0.12
20-49	0.01 +/-	0.07

Care Home, children's, rescues

fire size (sq.m)	fires	rescues	rescues per '000 fires	
<1	133.2	1.0	7.5 +/-	3.1
1-2	29.8	0.0	0.0 +/-	0.0
3-4	10.5	0.0	0.0 +/-	0.0
5-9	2.0	0.0	0.0 +/-	0.0
10-19	1.9	0.0	0.0 +/-	0.0
20-49	2.5	0.0	0.0 +/-	0.0
50-99	0.5	0.0	0.0 +/-	0.0
100-199	1.3	0.0	0.0 +/-	0.0
200+	0.5	0.0	0.0 +/-	0.0
undefined	26.9	0.0	0.0 +/-	0.0
TOTAL	209.0	1.0	4.8 +/-	2.0

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.00 +/-	0.00
1-2	0.00 +/-	0.00
3-4	0.00 +/-	0.00
5-9	0.00 +/-	0.00
10-19	0.00 +/-	0.00
20-49	0.00 +/-	0.00

Care Home, disabled person's, deaths

fire size (sq.m)	fires	deaths	deaths per '000 fires	
<1	244.5	0.2	0.7 +/-	0.7
1-2	20.8	0.0	0.0 +/-	0.0
3-4	10.3	0.2	16.3 +/-	17.0
5-9	5.0	0.0	0.0 +/-	0.0
10-19	2.9	0.2	57.6 +/-	66.8
20-49	1.2	0.0	0.0 +/-	0.0
50-99	0.7	0.2	250.0 +/-	395.4
100-199	0.2	0.0	0.0 +/-	0.0
200+	0.2	0.0	0.0 +/-	0.0
undefined	58.1	0.2	2.9 +/-	2.9
TOTAL	343.8	0.8	2.4 +/-	1.1

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.74 +/-	0.75
1-2	0.75 +/-	0.76
3-4	0.41 +/-	0.63
5-9	0.50 +/-	0.65
10-19	0.19 +/-	0.49
20-49	0.25 +/-	0.52

Care Home, disabled person's, injuries

fire size (sq.m)	fires	injuries	injuries per '000 fires	
<1	244.5	10.2	41.6 +/-	6.0
1-2	20.8	3.3	160.6 +/-	50.3
3-4	10.3	2.2	211.3 +/-	88.3
5-9	5.0	1.5	298.1 +/-	166.0
10-19	2.9	2.0	690.9 +/-	452.5
20-49	1.2	0.5	407.8 +/-	437.3
50-99	0.7	3.7	5500.0 +/-	6837.6
100-199	0.2	0.2	1000.0 +/-	2646.1
200+	0.2	0.2	1000.0 +/-	2646.1
undefined	58.1	4.2	71.7 +/-	17.2
TOTAL	343.8	27.8	81.0 +/-	7.6

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.50 +/-	0.30
1-2	0.29 +/-	0.29
3-4	0.25 +/-	0.28
5-9	0.21 +/-	0.28
10-19	0.14 +/-	0.26
20-49	0.15 +/-	0.26

Care Home, disabled person's, rescues

fire size (sq.m)	fires	rescues	rescues per '000 fires	
<1	244.5	1.5	6.1 +/-	2.1
1-2	20.8	0.0	0.0 +/-	0.0
3-4	10.3	0.3	32.5 +/-	25.2
5-9	5.0	0.0	0.0 +/-	0.0
10-19	2.9	0.0	0.0 +/-	0.0
20-49	1.2	0.0	0.0 +/-	0.0
50-99	0.7	0.8	1250.0 +/-	1630.0
100-199	0.2	0.0	0.0 +/-	0.0
200+	0.2	0.0	0.0 +/-	0.0
undefined	58.1	0.0	0.0 +/-	0.0
TOTAL	343.8	2.7	7.8 +/-	2.0

max size (sq.m)	est. sprinkler effect	
0	1.00	
<1	0.41 +/-	0.58
1-2	0.44 +/-	0.58
3-4	0.30 +/-	0.56
5-9	0.31 +/-	0.56
10-19	0.31 +/-	0.56
20-49	0.31 +/-	0.56