Effectiveness of sprinklers in residential premises

Section 1: Summary Report

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Summary Report

This Summary Report describes the Project "The effectiveness of sprinklers in residential premises" commissioned by the Buildings Division of the, Office of the Deputy Prime Minister (ODPM, formerly Department for Transport, Local Government and the Regions, DTLR) and carried out by FRS. Any views expressed in this report are not necessarily those of the ODPM.

Full details of this study and its findings are given in BRE report No 204505.

The background to this study is as follows. Residential sprinklers are the subject of much debate (in the UK) because they offer a potential means of saving lives in domestic/residential properties. The key question is: can a sprinkler system provide adequate fire control to allow escape/rescue at a reasonable cost? The publication of British Standard Drafts for Development DD251[1] and DD252[2] provides a basis on which an examination of both effectiveness and cost can be examined. There was a lack of information at the start of this project regarding the overall effectiveness of residential sprinklers. Also, firm and transparent guidance is needed regarding the design parameters for these systems.

FRS was commissioned by ODPM to carry out a two and a half-year study on the effectiveness of sprinklers in residential premises. The overall aim of the Project was to determine the benefits and effectiveness of sprinklers in residential accommodation. The specific objectives of this Project were:

a) To analyse statistical information to determine how effective they have been in reducing life loss and property damage

b) To make a risk-based assessment to determine potential benefits for the UK housing sector, including Houses in Multiple Occupation (HMOs), flats and maisonettes of varying heights

c) To collect data on the benefits and costs of residential sprinklers

d) To establish benchmark tests for UK conditions to support the further development of DD251 and DD252, and

e) To carry out an experimental programme to examine and quantify the effectiveness in fire suppression of residential sprinklers, in particular with regards to life safety in the room of origin.

To achieve these objectives, six main Tasks were carried out: Task 1 Steering Group, Task 2 Pilot study, Task 3 Cost benefit analysis, Task 4 Benchmark tests, Task 5 Experimental programme and Task 6 Dissemination of findings.

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[1] British Standards Institution, DD 251 Sprinkler systems for residential and domestic occupancies – Code of Practice, April 2000

[2] British Standards Institution, DD 252 Components for Residential Sprinkler Systems - Specification and Test Methods for Residential Sprinklers, July 2002

Initial dissemination of the emerging results of this study was via a seminar which was held in December 2003.

The results from this project will provide input into the development of full UK design standards and will also provide the Regulators with sound engineering-based results that they can use for Regulatory decisions. In the short term, this will undoubtedly assist those working within the fire arena, offering them the potential to consider informed alternative approaches to the current guidance contained in Approved Document B (Fire safety).

Steering group

The Steering group was established at the start of the project, and met six times during the course of the work programme. The members included representatives from government regulators, the sprinkler industry, the water industry, the housing industry and the fire service. They provided general advice and review on all aspects of the project methodology, and specific advice on sprinkler installation and water supply costs for the cost benefit analysis phase of the project. Also, there was a smaller experimental working group.

Pilot study

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.
2. A simple assessment of the fire 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 initial tasks was to decide which classification scheme to adopt for residential premises, as this would have an impact on what statistical information was collected and how it was analysed. It was eventually decided to use the following:

• House, single occupancy • House, multiple occupancy • Flat, purpose-built • Flat, converted	• Care Home, old persons • Care Home, children • Care Home, disabled people

Risk from fire may be presented, as the risk per member of the population; risk per fire; or risk per building/accommodation unit. Each provides a different perspective on the statistical information. The approach chosen to use for the cost benefit analysis is the risk per building since it provides the simplest way to express the costs and benefits on a common basis (£ per accommodation unit per year).

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

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, relatively speaking, they have many more fires.

Examination of the risks as a function of building height indicated 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.

As a result of these two points, the risks of fire 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 assumed that the effectiveness of sprinklers was independent of property type, and lay in the following ranges:

• Reduction in the number of deaths	70%	± 15%
• Reduction in the number of injuries	30%	± 15%
• Reduction in the number of rescues required	35% (flats 50%)	± 15%
• Reduction in the average property damage	50%	± 15%

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 provides background information and comparison with UK estimates.

The common factors considered for cost benefit analyses in other countries 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 and smoke alarm 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.

It is not known how these systems compare with current UK practice in all circumstances, so these values are intended as guidelines for our research. Also note, in the UK the statistics of "injuries" include people sent to hospital for precautionary checks.

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 the experiences of other countries are:

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

Finally, as part of the Pilot study, the UK British Standards Drafts for Development 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 products in appropriate fire scenarios.
- Establishment of the "benchmark" fire test[3] for DD 252 for UK conditions.

[3] The fire test specified by DD 252, to evaluate sprinkler performance

Cost benefit analysis

Cost benefit analyses have been performed for a range of domestic and residential building types, including houses, flats, various types of houses of multiple occupation (HMOs), and residential care homes. Further analyses were performed for different building heights, within certain of the broad categories listed above, in order to focus on properties that would be expected to have higher than average risks from fire.

The benefits of sprinklers include the prevention of deaths and injuries, and the reduction of property damage. The estimated effectiveness of sprinklers, in terms of the percentage reduction of deaths and injuries, was based on a correlation between fire size and risk of death and/or injury. Full details of this method are described in the section covering the Pilot study. The other benefit considered was the reduction in property damage. Rather than assume the cost of the fire was directly proportional to the area damaged by the fire (which would neglect the larger area damaged by smoke), the estimated effectiveness from the USA statistics was used.

Residential sprinkler systems costs include installation; provision of water supplies; annual maintenance. Estimates of these costs have been provided by members of the UK sprinkler and water industries. Government guidance was followed in assigning monetary values to the numbers of deaths and injuries prevented, the average cost of property damage per fire, and the interest rate to use when calculating the capital recovery factor to convert initial costs into annual terms.

The costs and benefits all have uncertain values. An uncertainty analysis has been performed to estimate the degree of confidence that the “true” ratio will have a value greater than 1. Note that a benefit: cost ratio greater than 1 may not be statistically significant, if the overall uncertainties are large. (Also note, an estimated benefit: cost ratio of exactly 1 will always have a confidence level of only 50% that the true ratio is greater or equal to 1).

The results of the calculations for the generic domestic and residential building types are:

Property Type	Benefit:cost ratio			confidence
House, single occupancy	0.18	+/-	0.08	0%
House, multiple occupancy	0.26	+/-	0.08	0%
Flat, purpose-built	0.63	+/-	0.22	0%
Flat, converted	0.41	+/-	0.15	0%
Care Home, old person's	2.06	+/-	1.12	97%
Care Home, children	4.45	+/-	2.54	100%
Care Home, disabled persons'	1.13	+/-	0.63	66%

The uncertainties are all ± two standard deviations. Normally a confidence level of 95% or higher would be required before dismissing the possibility that a high benefit: cost ratio arose by chance. However, as the estimates of the uncertainties used in the analysis are themselves rather uncertain, it is sensible to suggest that a confidence level of say 85% indicates promise, and merits further investigation with refined data.

From the table above, residential care homes indicate that sprinklers would be cost-effective, but the other property types do not.

The influence of building height was also studied. In these analyses, single occupancy houses were combined with HMOs in a single category "house", and all types of flats were considered as a single category:

Property Type	Benefit:cost ratio			confidence
House, 1 storey	0.21	+/-	0.10	0%
House, 2 storey	0.20	+/-	0.09	0%
House, 3 storey	0.29	+/-	0.13	0%
House, 4+ storey	1.25	+/-	0.64	78%
Flat, 1~2 storey	0.49	+/-	0.18	0%
Flat, 3~5 storey	0.77	+/-	0.27	4%
Flat, 6~10 storey	1.00	+/-	0.37	50%
Flat, 11+ storey	1.99	+/-	0.73	100%

On the basis of these calculations, flats in blocks 11 or more storeys high are worth considering for residential sprinklers.

The general conclusions of the cost benefit analysis are:

- Residential sprinklers are not cost-effective for most dwellings, but:
- Residential sprinklers are probably cost-effective for residential care homes.
- Residential sprinklers are probably cost-effective for tall blocks of flats (11+ storeys high)

In order for sprinklers to become cost-effective (in a wider range of buildings),

- Installation and maintenance costs must be minimal, and/or
- Trade-offs may provide reduced costs by indirect means, and/or

[Trade Offs again are we happy with this term? - DH]

- High risk buildings may be targeted, and justified on a case-by-case basis using the cost benefit approach of this project, but with actual cost quotations, risk estimates based on more detailed local risk data, etc.

Benchmark tests

Two British Standard Drafts for Development, DD 251 (systems) and 252 (components) have been published.

A series of experimental Benchmark tests were carried out to establish a benchmark fire test for UK conditions to support the further development of BS DD251 and 252 and to assess the performance of residential sprinklers in fire test conditions.

The DD 252 fire test essentially involves burning a stylised, representative fuel package of simulated furniture and wall and ceiling linings arranged inside a simulated residential 'room' with door openings and with two installed sprinkler heads. There are two open doorways and near the opening of one doorway is a third dummy sprinkler head. The sprinkler system performance is determined by its performance in controlling the fire for a period of time measured after sprinkler operation, the gas temperatures being limited to specified values and the dummy sprinkler head not operating.

A new experimental facility was built, instrumented and a suitable sprinkler system was installed. Two residential sprinkler heads of the same type were installed inside the experimental facility at a spacing of 4 m. There were 'dummy' sprinklers located within the experimental facility, which were not connected to the water supply. One dummy sprinkler was located outside the doorway according to the guidance given in DD 252. Another dummy sprinkler was located inside the doorway as specified in the USA Factory Mutual Research Corporation fire test.

Five pre-selected commercially-available residential sprinkler heads were obtained and these were characterised using vertical and horizontal water distribution measurements. Four were chosen for further study in the fire tests.

Suitable UK materials were obtained for the fuel package given in DD 252. The fuel package in DD 252 consists of: two polyether foam sheets (non-flame retardant) each attached to a wooden frame, a wall lining of four plywood sheets (non-flame retardant) and an ignition package. The ignition package in DD 252 consists of a wood crib consisting of eight layers of wood sticks placed on top of a steel tray containing commercial grade heptane.

Elements and the whole fuel package arrangement were characterised using seven calorimetry fires in free burns without sprinklers.

A series of eighteen fire tests was conducted, including repeat tests, based on the procedures given in DD 252 to examine the effect of varying parameters on the performance of residential sprinklers. The parameters investigated were: sprinkler model (four 15 mm pendent types), location of fuel package within sprinkler spray (wall, corner and directly beneath sprinkler configurations), the effect of the presence of 0.3 m lintels (with and without), sprinkler water flow rate (3 and 4 mm/min).

The general results from the Benchmark tests are:

- A number of issues relating to the procedures given in DD 252 have been identified
- 18 changes and additions to the fire test in DD 252 are recommended.

Experimental programme

The purpose of the Experimental programme was to examine and quantify the effectiveness of residential sprinklers, in particular to life safety in the room of fire origin. This programme was divided into three parts: house, compartment and calorimetry fires.

Sprinklers installed to in DD251 are not necessarily designed to extinguish the fires, but to control them to allow escape or rescue. The effectiveness of the residential sprinklers in the house and compartment fires was primarily assessed, particularly in the room of origin, by measuring their ability to control toxicity, temperature effects and visibility effects. In addition, the amount of fuel burnt by area, with and without sprinklers, was also measured.

Fractional Effective Dose calculations were performed using the results of each test in order to assess the tenability, both of the fire room and connected spaces. These calculations were based on carbon monoxide, carbon dioxide and oxygen concentrations at head height, head height gas temperatures, and optical density per metre.

House fires

Eight sprinklered and unsprinklered lounge fires using realistic fuel arrays were conducted inside the FRS house which was a two-storey detached house of traditional design, with a loft conversion The ground floor comprised a lounge (4 m by 3.5 m by 2.4 m), a kitchen, a dining room and a hallway. The ground floor could be converted into open plan by removing the lounge/hall wall. The first floor comprised two bedrooms and a bathroom area. There was a straight flight of conventional tread stairs up to the loft room which had a fire-resisting cut off door.

The lounge, main bedroom and loft windows were double glazed and were closed for the tests. Inside the lounge, there was a chimney, two low level air bricks. The door of the main bedroom was partially open, the door of the loft room and bathroom were closed, the dining room/kitchen, back bedroom/landing and kitchen/hallway doors were closed and sealed.

Five fire tests were performed in a standard lounge arrangement, and three in an open plan lounge arrangement.

The effect of lounge/hallway door (open/closed), water flow rate, sprinkler orientation and sprinkler model (two 15 mm pendent types) were studied. The sprinkler water flow rates were 60 l/min for a single sprinkler for standard lounge arrangement, and 60 l/min for a single sprinkler or 84 l/min for two sprinklers operating, for the open plan lounge arrangement.

In all the fires, smoke alarms situated in the lounge (the fire origin) activated 3~4 minutes after ignition. If the lounge door was open, detectors in the landing operated 1~2 minutes later; if the lounge door was closed, about 15 minutes later, or not at all due the absence of smoke.

Sprinklers typically operated after about 7 minutes from ignition. The sprinklers controlled all the fires. Most of the fires were extinguished. It was also noted that the sprinkler spray was not evenly distributed so fires in locations of low water delivery would not be controlled to the same extent.

For the sprinklered fires, the fire-damaged area was confined to between 30~50% of the television, slight damage to the table underneath and one curtain. The walls in the lounge were relatively clean.

For the unsprinklered fires, the fire damaged area was greater than when sprinklered. When the lounge door was closed, a layer of thick soot was produced on all surfaces in the lounge but the walls were clean elsewhere in the house. When the lounge door was open, or in the open plan lounge arrangement tests, there was less soot but it was observed throughout the house.

The main general conclusions for the 30 minute duration house fires are:

- With sprinklers, the fire gases were cooled sufficiently that the occupants of the room of origin would not have experienced extreme pain due to convected heat.
- Loss of consciousness would not have occurred in the standard lounge with the door open, but would have occurred with the door closed (fire gases confined to room of origin) or in the open-plan lounge (greater ventilation, leading to greater fire growth and production of fire gases). In all of the sprinklered fires, death would not have occurred.
- In all the fires (with and without sprinklers), visibility was lost after 5~7 minutes. Sprinkler activation therefore had no effect on the visibility.
- The life safety benefits of fitting smoke alarms was demonstrated. This includes the added benefits of fitting linked smoke alarms in both rooms and circulation spaces.
- Tenable conditions (apart from visibility) for the rest of the house could be maintained by sprinklers in the room of origin, or closing the door of the room of origin.
- The conditions in the loft room remained tenable for all tests with the loft door closed. However if the loft door had been open the conditions would have been similar to those in the bedroom and upper circulation spaces.
- Without sprinklers, it was estimated that occupants of the lounge would have lost consciousness, due to the dose of asphyxiant gases, after 13~16 minutes. The times for extreme pain due to convected heat, and loss of consciousness due to asphyxiants, would have occurred within 1~2 minutes of each other. Death would follow about 1 minute after loss of consciousness. These observations were independent of the lounge door being open or closed, or the lounge being standard or open plan.
- With the open-plan lounge, or the standard lounge with the doors open, fires without sprinklers would eventually cause untenable conditions throughout the house.

Summary of the compartment fires

Twenty-nine fires using realistic fuel arrays representative of residential premises were conducted inside a compartment experimental facility.

The compartment facility essentially comprised residential ‘rooms’ with a timber structure supporting plasterboard walls and a ceramic fibre board ceiling. The facility was configured to provide alternative fire rooms at either end, each measuring 4 m by 4 m by 2.5 m high, connected to a middle room measuring 3.8 m by 4 m by 2.5 m high. With the fire room door open the effective enclosure volume was approximately 118 m^3, reduced to 40 m^3 with the fire room door closed. Some of the fire tests involved a larger room size of 8 m by 4 m by 2.5 m high.

Smoke alarms were located inside the room of fire origin and its adjacent room and were replaced after every fire.

Initially, sixteen fires comprising four main fire scenarios were conducted, each with and without sprinklers and with the door of the room of fire origin open and closed. The scenarios were, as follows:

- Lounge, nightlight and television fire, shielded fire
- Lounge, fire under table directly beneath sprinkler, shielded fire
- Bedroom scenario, fire on duvet, unshielded fire.
- Lounge, fire on sofa (compliant with 1988 Furniture Regulations), unshielded fire.

The fuel was conditioned prior to each test and the house was allowed to dry out between tests.

Following these initial fires, the television and table fires were chosen for further study of the effect of compartment size (either 4m by 4 m or 8 m by 4m by 2.5 m high 2.5m), sprinkler model (one of two 15mm pendent models), sprinkler orientation (parallel or perpendicular to axis of facility) and water flow rate. The sprinkler water flow rates were 60 l/min or 42l/min for a single sprinkler for standard compartment, and 60 l/min for a single sprinkler or 84 l/min for two sprinklers operating, for the large compartment.

A kitchen scenario was examined, an unshielded oil pan fire, with or without sprinklers (two 15 mm pendent models).

The table fires and bed fires were found to have consistent ignition and burning characteristics. The televisions had slightly different burning characteristics, which complicated the analysis in studying the effect of different parameters but did not affect the broad conclusions. It was difficult to achieve consistency in burning characteristics with the nominally identical sofas used.

Smoke alarms fitted in the room of fire origin typically responded in the range 0.5 to 6 minutes from ignition, well before the lower toxicity tenability criterion had been exceeded. Smoke alarms fitted in adjacent spaces still provided useful warning – often before the lower toxicity tenability criterion was exceeded in the room of origin, even when the intervening door was closed.

Typical range of times of sprinkler operation was 2 to 20 minutes. The sprinkler extinguished the unshielded fires (including the oil pan), and controlled but did not completely extinguish all of the shielded fires (televisions and tables). The sprinkler spray was not evenly distributed so fires in locations of low water delivery would not be controlled to the same extent.

The main general conclusions for the room of origin in the compartment tests for a fire duration of 30 minutes:

- Sprinklers significantly reduced the effect of convected heat from the fire.
- However, sprinklers did not observably improve visibility.
- Television and bed fires. Sprinklers generally greatly improved conditions in the room of fire origin and maintained tenable conditions in terms of toxic effects; reduced the effects of convected heat but had no observed improvement in visibility.
- Table fires. For all the sprinklered and unsprinklered fires the conditions became unsurvivable. Sprinklers generally improved conditions in terms of toxic effects, except for one case.
- In one television fire and one sofa fire, where fire growth was slower than normal, a lot of smoke was produced prior to sprinkler operation and consequently conditions became unsurvivable. In another sofa fire, sustained ignition was not achieved, and a lot of smoke was produced but the sprinkler did not operate.
- The effects of the sprinkler type, water flow rate and orientation were inconclusive.
- For all the unsprinklered fires, the conditions became unsurvivable/lethal.
- For all the unsprinklered fires, the first tenability criteria to be reached was visibility, then convected heat then toxicity effects.
- The life safety benefits of fitting smoke alarms was demonstrated. This includes the added benefits of fitting linked smoke alarms in both rooms and circulation spaces.

Calorimetry fires

Fires were conducted underneath a 3 m furniture calorimeter to characterise each of the four principal fuel packages used for the compartment fires.

The fires under the calorimeter appeared to burn more rapidly than when in the house or in the compartment fire tests. Due to fully ventilated conditions, the peak values and the rates of burning observed are likely to be greater than would have occurred in the house and compartment tests.

The television fire was a slowly growing, shielded fire, rising to a heat release rate of 390 kW at 14 minutes, when the fire was manually extinguished.

The table fire was a rapidly growing, shielded fire giving a first peak of heat release rate of 402 kW at 3 minutes, when all the fuel beneath the table was burning and a second peak of heat release rate of 470 kW at 15 minutes when the wooden table top itself was burning. The fire was manually extinguished.

The bed fire was a rapidly growing, exposed fire which gave a heat release rate of 552 kW at 7.5 minutes, when the fire was manually extinguished.

The sofa fire burnt evenly along the back and side arm of the sofa. This was a slowly growing fire which gave a total heat release rate of 425 kW at 19 minutes, when the fire was manually extinguished

