BRANZ REPORT

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Cost-Effective Home Fire Sprinkler Systems

C. R. Duncan, C. A. Wade,
N. M. Saunders and J. C. Clampett

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Building Commission, Victoria, Australia.

PREFACE (Prepared by the Building Commission)

RESEARCH REPORT - COST EFFECTIVE HOME FIRE SPRINKLER SYSTEMS

This report was undertaken by the Building Research Association of New Zealand (BRANZ) on behalf of the Building Commission to put forward a concept for a home fire sprinkler system that would be more affordable than the current Australian Standard 2118.5-1995, "*Automatic fire sprinkler systems – Domestic".* Whilst the effectiveness of an AS2118.5 system is acknowledged, research indicates that the cost per life saved for a typical domestic home may exceed the generally accepted threshold for economic installation.

The Building Commission is committed to improving life safety within homes and has funded this research to assist in further ensuring cost effective and efficient fire safety systems are available for Victorian homes. The research provides an alternative by proposing a combined home plumbing and fire sprinkler system, thereby reducing installation and maintenance costs without significantly reducing the effectiveness of the system.

The research was also subject to input and review by the Plumbing Industry Commission who have highlighted useful areas of further research and additional matters that may require consideration by designers. These include that any combined system must not compromise the quality of potable water in the home or the community.

Users of the research report are therefore advised that the following additional matters are unresolved at the time of release and will require further research or consideration by any designer, and input from the relevant water authorities and Plumbing Regulations. The specific design considerations are in relation to separation of potable water supplies from sprinkler pipe work and whether dead legs, particularly where sprinkler heads occur, can lead to a reduction in water quality or that installation of roof or ceiling mounted pipes may have an adverse impact on water quality by raising water temperatures.

It is intended to change AS3500.1 to incorporate a pressure reduction device on a drinking water supply for a dwelling to a maximum of 500 kilopascals, therefore it would be advisable to have the residential fire service take off upstream of that device. To assist to resolve these issues designers are advised that -

(a) the minimum backflow provision required for the protection of the drinking water supply is a single resilient seated check valve; and

(b) a single sprinkler connection point should be provided where possible external to the building; and

(c) where a pressure reduction valve is installed in line or at the meter assembly, the connection point should be upstream of that pressure reduction device.

A copy of the research report is available on the Building Commission's website at www.buildingcommission.com.au. Additional home sprinkler design guidance can be found in the BRANZ publication 'Sprinklers for Houses Design Guide" available at www.branz.co.nz, or additional water quality guidance and installation requirements by contacting the Plumbing Industry Commission's technical advice line on 1800 015 129.

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AVJennings Limited supplied the working drawings for the four-bedroom home used in the sprinkler system design. Figure 17 and Figure 18 remain the copyright of AVJennings Limited.

Current fire incident statistics were provided by the Australasian Fire Authorities Council (AFAC) for the following fire brigades: New South Wales Fire Brigades, Queensland Fire Service, South Australia Metropolitan Fire Service, Tasmanian Fire Service, Melbourne Metropolitan Fire and Emergency Services Board, Country Fire Authority and the Western Australia Fire and Rescue Service.

Students from the Worcester Polytechnic Institute (WPI) of the United States who undertook a complementary study in conjunction with the Australasian Fire Authorities Council (AFAC), investigating community benefits from the installation of sprinkler systems in 'Greenfield' subdivisions. WPI collaborated by sharing some statistical information on Australian domestic fire incidents.

Peter Downey for consultation and advice on plumbing issues and hydraulic calculations for the sprinkler systems.

The Master Plumbers and Mechanical Services Association of Australia, provided assistance with obtaining quotes for the installation of plumbing and sprinkler systems in Victoria.

Plumbing Industry Commission, Housing Industry Association, and the Master Builders Association for advice and assistance.

Contents **Page**

Figures

Page

Tables **Page**

1. EXECUTIVE SUMMARY

1.1 Background and Scope

This project was carried out to investigate and put forward a concept for a home fire sprinkler system design that would be more affordable for Australian homeowners than the current AS 2118.5 standard complying sprinkler designs. The vast majority of building fire deaths in Australia (and throughout the world) occur in the home. Fire sprinklers are extremely effective in suppressing or controlling fires and in doing so, will often prevent life-threatening conditions from developing in a home. This means lower numbers of fatalities, injuries and reduced property damage due to fire.

The scope of the project was limited strictly to homes, as defined by the Class 1a occupancy descriptor in the Building Code of Australia (1996). Unless otherwise specified, all financial figures are Australian dollars.

It was also the intention of the project to analyse the cost-effectiveness of any proposed new fire protection measures, so that fire organisations, building regulators, and the wider community will have objective measures by which to evaluate different fire protection strategies aimed at reducing the incidence of fire deaths in Australian homes.

1.2 Methodology

The research involves extensive review of fire incident statistics, both from within Australia and from other countries. The collection of fire incident statistics suffers from many problems and is very dependent on the training and skill of those filling in the incident forms. This sometimes means that information can be missing, incomplete or miscoded. The populations of Australia and New Zealand are also relatively small with correspondingly small numbers of fire deaths and injuries, so that trends shown by the incident records may not always be statistically significant. For this reason it was useful to examine equivalent fire incident statistics from the USA to ensure that assumptions made for the rates of fire incidents, fatalities and injuries were of the right magnitude and appeared sensible.

Fire sprinkler design standards and previous research, case studies and related information were reviewed. This included particular reference to a 'multi-purpose' fire sprinkler design developed in the USA, where a domestic plumbing and fire sprinkler system are combined, removing the need for a number of components (e.g. valves, water flow alarms) that are normally needed on conventional, stand-alone fire sprinkler systems.

The methodology for the cost-benefit analysis followed that used by Beever and Britton (1999) in previous research for the former Victorian Building Control Commission. The cost-effectiveness of the proposed home fire sprinkler system is assessed through calculation of a cost per life saved, where the cost per life saved requires the calculation of installation costs, maintenance costs, savings in injury costs and savings in expected property losses. The net present value of these variables over the period of the analysis was determined. The expected number of lives saved is calculated and therefore a cost per life saved can be determined. The analysis requires additional assumptions regarding: a nominal discount rate (7.5%), inflation rate (2%), and analysis period (20 years). Where components have a different working life the replacement costs were included.

A similar analysis was previously carried out by the authors for the New Zealand Fire Service project (Duncan et al, 2000) and the results of this are also discussed in this report.

1.3 The Home Fire Sprinkler Proposal

The home sprinkler system design identified was a combined home plumbing and fire sprinkler system similar to that currently permitted by NFPA Standard 13D (NFPA, 1999). A combined system results in cost savings (compared to a separate plumbing and sprinkler system) due to reduced amount of piping, water connection charges, removal of sprinkler valvesets etc. It was anticipated that a combined system would require little or no maintenance, with a simple flow test able to be periodically done by the homeowner as a check on changes in future water supply characteristics. Sprinkler heads to be used in the fire sprinkler system must be of a listed and approved type, and installed according to the manufacturer's instructions for minimum pressure and flow and spacing criteria.

A simple event-tree-based risk assessment was carried out to assess the most appropriate rooms and spaces within a home in which to install fire sprinkler heads. It was concluded that sprinkler heads need not be installed in toilets, bathrooms, concealed spaces, closets or wardrobes, since the incidence of fires resulting in fatalities and injuries is low for fires originating in these spaces.

Integrating a fire sprinkler system with the domestic plumbing results in the addition of extra lengths of dead-end pipe. Although the combined sprinkler and plumbing system can be designed so as to minimise the number of dead-end lengths (using a loop design for example), the addition of the sprinklers to the plumbing system does result in an increase in their number. Concerns have been raised as to whether the stagnant water from these pipes is likely to decrease the quality of the potable water in the domestic plumbing system, and therefore whether backflow prevention devices should be required. Literature and research related to this issue were examined during this study.

1.4 Conclusions and Recommendations

This report has shown that it is feasible for a combined home plumbing and fire sprinkler system to be installed into a new three-bedroom Australian home (of simple design) for a cost of approximately $1,200 over and above the cost of the domestic plumbing system. For a more complex four-bedroom, two-storey home (with garage), the additional cost was determined to be approximately $4,600. These costs represent savings compared to the cost of installing a domestic fire sprinkler system to the current AS 2118.5 standard.

The cost-benefit analysis carried out and described in this report has resulted in an estimated cost per life saved of $3.3 million for the three-bedroom home based on average fire incident, fatality and injury rates. The estimated cost per life saved for the four-bedroom home was $19 million. Again, these represent a significant improvement on the cost per life saved of more than $30 million determined in earlier research for the former Victorian Building Control Commission by Beever and Britton (1999) for Australian Standard complying systems.

This report has also shown that the estimated cost per life saved for a combined home plumbing and fire sprinkler system is sensitive to a number of factors. One of the more important of these factors is the number of fire incidents per 1000 households per year. Therefore, it is recommended that selective targeting of at-risk communities, where the fire incident, fatality and injury rates are generally higher than the Australian average rates, would result in significantly better cost-benefit outcomes than indicated in this study.

This report described a concept for developing a combined home plumbing and fire sprinkler system; provided cost estimates for installing such a system in two specific home designs and calculated cost-effectiveness measures by which the cost-benefit could be evaluated. It should not be used as a substitute for a detailed design guide, code of practice or installation manual as further considerations regarding installation procedures, adequacy of water supplies and hydraulic design must be confirmed in each case. It is recommended that a code of practice be developed which will enable site-specific conditions to be accounted for and allow trained installers (including plumbers) to carry out a combined home plumbing and fire sprinkler system installation.

2. INTRODUCTION

2.1 Objective

The objective of this project was to investigate and propose an inexpensive home fire sprinkler system design with supporting information about its cost-effectiveness in reducing loss of life, injury and property damage due to fires in Class 1a (BCA, 1996) homes.

2.2 Scope

This report is an investigation into ways to reduce the cost of installing domestic fire sprinkler systems in Victorian homes. The research highlights where sprinklers can be targeted within a home to achieve effective protection and coverage. The report outlines a low-cost sprinkler system that will result in fewer fatalities and injuries and less property damage in a more cost-effective manner than is presently available.

2.3 Methodology

The research methodology is similar to that used in a research project for the New Zealand Fire Service Commission (Duncan et al, 2000) which investigated cost-effective domestic fire sprinkler systems for the New Zealand situation. This project provides a synopsis of the New Zealand research methodology and a summary of the outcomes.

A research report, published by the Victorian Building Control Commission of Victoria, Australia titled 'Research into cost-effective fire safety measures for residential buildings' (Beever and Britton, 1999), analyses the cost-effectiveness of several fire safety measures for the home. A summary of these research findings is provided, including the applicable details of the research methodology.

To establish if it is applicable to adapt the findings of the New Zealand study (Duncan et al, 2000) to the Australian situation, an understanding of Australian fire incident statistics is required. This report provides statistics of domestic fires in Australia and puts these into a global context by comparing them with international statistics; trends within the statistics are highlighted, with particular focus on fire incident statistics for the State of Victoria.

A summary of the Australian Standard for home fire sprinkler systems, AS 2118.5:1995 *Automatic fire sprinkler systems Part 5:Domestic* (Standards Australia, 1995), outlines the current specification for domestic sprinkler systems in Australia. These Australian specifications are compared with the domestic sprinkler code of the United States National Fire Protection Association's NFPA 13D:1999 *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes* (NFPA, 1999). A description of the multi-purpose sprinkler system, as defined by NFPA 13D:1999 (NFPA, 1999), is provided and a description of how the multi-purpose system varies from AS 2118.5:1995 (Standards Australia, 1995) given.

Analysis of fire incident statistics, the Australian domestic fire sprinkler codes and comparison to the findings of the New Zealand low-cost sprinkler system design results in a proposal for a domestic fire sprinkler system design alternative to the requirements of AS 2118.5:1995 (Standards Australia, 1995). The proposed sprinkler system design is outlined.

Two homes were used to assess the effectiveness of the proposed low-cost sprinkler system; a three-bedroom single-level home and a four-bedroom plus family room, two-storey home. Descriptions of both the three-bedroom home and the four-bedroom home are provided. Hydraulic calculations associated with the sprinkler system designs are summarised in the report with complete details included in the appendix.

A risk assessment is used to evaluate the effectiveness of the proposed alternative sprinkler system design. The risk assessment considers the impact that omitting sprinklers from some rooms and spaces is expected to have on the numbers of injuries and fatalities caused by domestic fires. An outline of the risk assessment methodology and the results from the assessment are provided.

A cost-benefit analysis of the proposed alternative domestic sprinkler system is compared with the results from a cost-benefit analysis previously undertaken (Beever and Britton, 1999) for a domestic sprinkler system installed to AS 2118.5:1995 (Standards Australia, 1995).

A literature search was undertaken to review the issue of stagnant water in lengths of pipe and the likelihood of this water contaminating potable water.

The report concludes with a proposal for a less expensive home fire sprinkler system than those installed to current Australian standards.

3. NEW ZEALAND RESEARCH

The New Zealand Fire Service Commission funded the Building Research Association of New Zealand (BRANZ) to investigate ways to reduce the cost of domestic fire sprinkler systems (Duncan et al, 2000). The impetus for investigation into domestic fire safety arose from historical records showing that fires occurring in the home contribute to the majority of fire deaths in New Zealand. Annually there are approximately 6000 domestic fires in New Zealand, with an average of 23 deaths each year (Grieve, 1999). The success of sprinklers in commercial applications for both life safety and property protection indicated that domestic sprinklers may be an option for increasing protection from fire in the home.

This section gives a description of the proposed multi-purpose sprinkler system. A risk assessment and cost-benefit analysis methodology are used to analyse the effectiveness of the proposed, low-cost sprinkler system. These analyses are outlined.

3.1 Outline of New Zealand Research

The objective of this project was to propose an inexpensive domestic fire sprinkler system design, with supporting information about its effectiveness in reducing loss of life, injury and property damage due to fires in houses. This objective is to be applied to the Australian situation.

The New Zealand research outlines a low-cost, multi-purpose sprinkler system that fulfils these objectives in a more cost-effective manner than the systems presently available. The proposed sprinkler system varies from the requirements of the current New Zealand Standard, NZS 4515 *Fire sprinkler systems for residential occupancies (including private dwellings)* (SNZ, 1995) in that it is not a stand-alone system; rather, it is integrated with the domestic plumbing.

The system omits sprinkler heads from the bathroom, toilet, wardrobe/cupboard spaces and ceiling cavity. Almost 90% of fatal fires in New Zealand originate in bedrooms, lounge/dining and kitchens. Installation of the system is by approved plumbers or sprinkler contractors and the system requires no control valveset or backflow prevention. The system does not have a sprinkler operating alarm, no specifications for annual maintenance, but does recommend the installation of smoke alarms to provide early warning of a fire.

The cost of installing this system into a simple, single-level three-bedroom new house in New Zealand was found to be approximately NZ$1000. Cost-benefit analysis showed the proposed system achieves a cost per life saved competitive with that of domestic smoke alarms; however it would be more effective in saving lives and property. The cost per life saved was found to be less than NZ$900,000.

3.2 Sprinkler System Proposal

The proposed design for the multi-purpose domestic sprinkler system is based strongly on the requirements of the National Fire Protection Association's residential sprinkler Standard, NFPA 13D:1999 (NFPA, 1999) and incorporates aspects of the Australian Standard, AS 2118.5:1995 (Standards Australia, 1995), for domestic sprinkler systems.

In summary, the specific details of the proposed multi-purpose sprinkler system are:

- A single mains connection feeds both the sprinkler system and the domestic water supply.

- Design pressure from the mains was taken to be 500 kPa (a typical mains pressure for residential areas) and hence a 25 mm diameter feed from the mains to the house was required to achieve the design pressures at the sprinkler heads. Where the mains pressure is less than 500 kPa, the system described here may not be suitable, and further design work will be required.

- The domestic load for the hydraulic design of the combined plumbing and sprinkler system was taken to be 12 litres per minute, in accordance with AS 2118.5 (Standards Australia, 1995).

- The main run of water supply pipe is 25 mm diameter; the pipe branches serving the sprinklers are 20 mm diameter; the pipe branches supplying the domestic services are 15 mm diameter.

- The sprinkler heads are of residential listing.

- The hydraulic calculations are based on two sprinkler heads operating simultaneously.

The proposed multi-purpose sprinkler system varies in the following ways from the current requirements of NZS 4515:1995 (SNZ, 1995) for the installation of domestic fire sprinkler systems:

1. NZS 4515:1995 (SNZ, 1995) requires the domestic sprinkler system to be a stand-alone system. The current New Zealand Residential Sprinkler Standard has no provisions for alternatives to the stand-alone system. The concept of the multi-purpose system, whereby the sprinkler system is integrated with the domestic plumbing, arises from the National Fire Protection Association Standard, NFPA 13D:1999 (NFPA, 1999).

2. A control valveset is not a requirement for the multi-purpose sprinkler system. The function of the control valveset as backflow prevention, pressure sustaining valve and sprinkler system isolation valve is not required where the sprinkler system is integrated with the plumbing and water is continuously flowing through.

3. Because only potable water is flowing through the system, no specific backflow prevention is required.

4. An alarm indicating sprinkler operation or requirement to evacuate is not included in the multi-purpose system. In the case of a stand-alone sprinkler system designed to NZS 4515:1995 (SNZ, 1995), a flow switch would trigger an alarm to indicate that the sprinkler system was operating. In the case of the multi-purpose system, where water is continuously flowing through it, a flow switch would not be an appropriate alarm mechanism. It is recommended that domestic smoke alarms be installed along with the multi-purpose system.

5. The design excludes sprinkler heads from the bathroom, toilet, wardrobe/cupboard space and the ceiling cavity. The statistical analysis indicates that the likelihood of a fire originating in these areas is minimal, as is death and injury.

6. All sprinkler heads are required to be listed and hence operate at the design pressures specified.

7. The domestic load for the hydraulic design is taken to be 12 litres per minute. This design flow is based on the requirements of AS 2118.5:1995 (Standards Australia, 1995). This figure has been used on the basis of evidence presented by Beever and Britton (1999) indicating that the average demand per household unit in Australia peaks at 6 litres per minute.

8. It is assumed that approved plumbers, sprinkler contractors, or others who have demonstrated competency to do the work will carry out the sprinkler system installation.

9. The integrated sprinkler and domestic plumbing system has no specific ongoing maintenance requirements. The maintenance requirements are specific to the control valveset. The proposed multi-purpose sprinkler system does not require a control valveset and subsequently no annual maintenance requirements are necessary. With the sprinkler system integrated with the domestic plumbing, the possibility of unintentional shut-off of the water supply is minimised.

10. The proposed multi-purpose sprinkler system does not need to be connected to the fire service.

3.3 Risk Assessment Approach

The literature review and analysis undertaken in the New Zealand research concluded that because of the strict requirements to have sprinkler heads listed, and the considerable research into performance and benefits of residential sprinklers, repetition of experiments into ways of modifying these parts of the sprinkler system is not necessary. It was concluded that a risk assessment approach, whereby the influence on expected numbers of injuries and fatalities caused by a reduction in sprinkler coverage is assessed, would be the focus for evaluating options to reduce the cost of the sprinkler system.

3.3.1 Risk assessment objectives

The risk assessment objectives were to:

- Investigate the number and location of injuries and fatalities as a result of domestic fires.
- Determine the impact on the number of injuries and fatalities as a result of installing combinations of domestic smoke alarms and sprinklers.
- Assess the impact on the number of injuries and fatalities as a result of reducing the reliability of the domestic fire sprinkler system.
- Assess the impact on the number of injuries and fatalities as a result of omitting sprinkler heads from the ceiling space, bathroom, toilet and wardrobe/cupboard spaces.

3.3.2 Outcomes from risk assessment

Outcomes from the New Zealand risk assessment analysis show:

- The majority of fatalities and injuries occur as a result of fires originating in the living room, bedroom or kitchen. The risk analysis shows that injuries are less likely to occur from fires originating in the bathroom and ceiling cavity.
- Results show that the combination of the multi-purpose sprinkler system with the smoke alarms is the most successful at reducing the number of injuries and fatalities in a domestic fire. The proposed multi-purpose sprinkler system alone is likely to reduce the number of injuries by approximately 55% and the number of fatalities by approximately 72%.
- The domestic smoke alarm system alone can potentially reduce the number of injuries by over two thirds and the number of fatalities by one half.
- For the option of the combined multi-purpose sprinkler system and smoke alarm, removal of sprinkler heads from the ceiling space, bathroom/toilet and wardrobe/cupboard space increases the expected number of fatalities per year from 4.8 to 5.7 (16%). Removal of sprinkler heads from these spaces increases the expected number of injuries per year from 27.3 to 31.5 (13%).

Table 1 indicates the influence removing sprinkler heads from bathroom/toilet, wardrobe/cupboard space and the ceiling cavity has on the expected numbers of fatalities and injuries.

Table 1: Comparison of Full Sprinkler Coverage with Reduced Sprinkler Coverage

	Fatalities/Year		Injuries/Year	
Option	**Full Coverage Sprinkler System**	**Reduced Coverage Sprinkler System**	**Full Coverage Sprinkler System**	**Reduced Coverage Sprinkler System**
Sprinkler/ Smoke Alarm	4.8	5.7	27.3	31.5
Sprinkler/ No Smoke Alarm	6.1	8.5	76.1	92

3.4 Cost-Benefit Analysis

3.4.1 Methodology

The methodology for the cost-effectiveness study followed that carried out by Beever and Britton (1999) in a study undertaken for the Victorian Building Control Commission. The study involved cost-benefit modelling to determine a dollar cost per life saved for the installation of specified fire safety measures.

A cost-effectiveness analysis was undertaken for the following fire sprinkler options:

- A fire sprinkler system installed in a new dwelling to the requirements of NZS 4515:1995 (SNZ, 1995) and the draft Standard DZ 4515/CD3 (SNZ, 1999).
- The proposed multi-purpose fire sprinkler system, with reduced coverage, installed in a new dwelling.

The results from the analysis of the cost-effectiveness of the sprinkler systems were compared with an analysis by Wade and Duncan (2000), which considered the cost-effectiveness of installing domestic smoke alarms.

A low-cost three-bedroom, single-storey home was used as the design home for the sprinkler installations. The same three-bedroom home will be used in the Australian analysis, with results from the cost-effectiveness analysis compared with the New Zealand findings.

3.4.2 Cost-benefit analysis results

Table 2 shows a summary of the results of the cost-benefit analysis (all prices quoted in Table 2 are New Zealand dollars).

Table 2: Results of Cost-Benefit Analysis

	Installation Costs (NPV $NZ)	**Maintenance Costs over 20 Years (NPV $NZ)**	**Savings on Injuries and Property Loss ($NZ)**	**Net Cost per Household ($NZ)**	**Deaths per Household**	**Expected Deaths per Year**	**Lives Saved per Year**	**$ Net Cost per Life Saved [88]**
Four stand-alone ionisation 1 year battery	212	973	405	780	0.000224	14.2	16.2	$3 m
Four stand-alone ionisation 10 year battery	340	741	414	667	0.0002	12.7	17.8	$2.4 m
Four battery powered smoke alarms (1 year battery) and multi-purpose sprinklers*	1180	973	1065	1,088	0.0000896	5.7	24.8	$2.8 m
Multi-purpose sprinklers only*	968	0	660	308	0.0001344	8.5	21.9	$891,000
NZS4515:1995 complying domestic sprinkler system	6700	7353	693	13,361	0.000096	6.1	24.4	$34.8 m
DZ 4515/CD3 complying domestic sprinkler system	4270	3242	693	6,820	0.000096	6.1	24.4	$17.8 m
No system	0	0	0	0	0.00048	30.5		

*assumes sprinklers omitted from bathrooms, ceiling spaces, wardrobes etc. [88]m=million

The cost per life saved for installation of the proposed multi-purpose sprinkler system was found to be NZ$891,000. This cost per life saved is 2.6% of the cost per life saved for a new sprinkler system installed to the current New Zealand Standard, NZS 4515:1996 (SNZ, 1995). A review of the current New Zealand Standard for the installation of domestic fire sprinkler systems is currently being undertaken to make the system more cost-effective. Analysis shows that the draft Standard has increased the cost-effectiveness of the sprinkler system, reducing the cost per life saved from NZ$34.8 million to NZ$17.8 million. The cost per life saved for installation of the proposed multi-purpose system of this project is 5% of the cost per life saved for new sprinkler system to the draft New Zealand Standard, DZ 4515/CD3 (SNZ, 1999). The comparison of these results show the proposed multi-purpose sprinkler system to be considerably more cost-effective than domestic sprinkler systems installed to current or draft standards.

For the New Zealand situation, reducing the cost of the domestic sprinkler system has achieved a cost-effectiveness in the range close to that of a domestic smoke alarm. The cost per life saved for the multi-purpose sprinkler system is considerably less than that of multiple smoke alarms.

Considering the net cost per life saved, the option of a multi-purpose sprinkler system offers the most cost-effective solution. Combination of the smoke alarm with the sprinkler system has the greatest effect in reducing the number of expected deaths per year. The smoke alarm plus sprinkler option potentially saves 25 lives per year. The cost per life saved for this option is NZ$2.8 million, similar to the Transit New Zealand criterion for value of human life (Miller & Guria, 1991).

4. RESEARCH INTO COST-EFFECTIVE FIRE SAFETY MEASURES FOR RESIDENTIAL BUILDINGS

A study by Beever and Britton (1999) for the Victorian Building Control Commission, researched the cost-effectiveness of a variety of fire safety measures for residential buildings in Australia. The research undertook, in part, a cost-benefit analysis for home fire sprinkler systems, with the methodology for this analysis subsequently used for a New Zealand study of cost-effective fire safety measures (Wade and Duncan, 2000) and a determination of a cost-effective home fire sprinkler system for New Zealand (Duncan et al, 2000).

The following outlines the research objective and methodology, provides a synopsis of the Beever and Britton (1999) statistical analysis, then summarises the outcomes from the research relevant to home sprinkler systems. Australian fire incident statistics used in the Beever and Britton (1999) report are predominantly for Melbourne (1993-94), Australia (1993-94) with some information on nationwide fire trends for Australia between 1989 and 1993. The Beever and Britton (1999) statistical analysis is later compared with New Zealand statistics, statistics from the United States and more current Australasian Fire Authorities Council (AFAC) fire incident data provided for this report.

4.1 Research Objective

The objective of the research by Beever and Britton (1999) was to examine the ability of fire safety measures to impact on reducing the risk of loss of life, injuries and damage to property. The study was directed towards comparing the cost of fire safety measures and their ability to impact on expected loss.

4.2 Research Methodology

An overview of statistics provides an indication of the observed risk of fire for the domestic situation in Australia. Statistics are used to evaluate the correlation between risk of fire and economic disadvantage.

Beever and Britton (1999) also undertook a series of experiments to examine sprinkler and smoke alarm effectiveness. The experiments looked at combinations of sprinkler system design and fuel loads to evaluate the effectiveness of sprinkler system design varying from the conventional sprinkler system.

The Australian study undertook a cost-benefit analysis for the installation of a variety of domestic fire safety systems. The cost-effectiveness of domestic sprinkler systems, smoke alarms, fire extinguishers and furniture flammability legislation was analysed.

4.3 The Observed Risk of Fire

The rate of recorded fire incidences is calculated as being 1.97 fires per 1000 households in the USA (Beever and Britton, 1999). A rate of 7 deaths per 1000 fires and 70 injuries per 1000 fires are recorded in Australia (Beever and

Britton, 1999). By examining fire rates by geographical area within Australia, statistically significant correlations between fires per 1000 population and weekly median income, percentage of population in rented accommodation and percentage of population between 65 and 85 were observed (Beever and Britton, 1999).

Other statistics presented by Beever and Britton (1999) helping to emphasise the problem of, and trends within, domestic fires in Australia, include:

- The fatality rate for the older age groups (75 and over) is an order of magnitude higher than that of younger age groups.

- A statistical comparison between fatality rates for private dwelling fires and homicides, accidental falls and motor vehicle traffic accidents. "*Whilst the accident rate for private dwelling fires may appear insignificant in comparison with other forms of accident, it should be noted that there may be significant benefit by reducing this rate further and that the cost of doing so may be an attractive investment when compared to the cost of reducing the risk of other forms of accident*" (Beever and Britton, 1999).

- A correlation between risk and economic disadvantage. The correlation is presented by calculating an index of relative socio-economic disadvantage. The relative disadvantage index summarises variables related to the economic resources of households, education and occupation statistics, and trends indicate that risk increases with a decrease in economic advantage.

- Other statistics include details of statistically significant correlations between fires per 1000 population and weekly median income, percentage of population in rented accommodation and percentage of population between 65 and 85 (Beever and Britton, 1999).

4.4 Experimental Series

Beever and Britton (1999) also undertook a series of experiments to examine sprinkler and smoke alarm effectiveness. The experiments investigated combinations of sprinkler system designs that vary from the conventional sprinkler system.

They identified, that to establish if a cheaper sprinkler system is possible, the following characteristics of fire and environment need to be considered:

- Fuel load

- Fuel load energy release rate – ability of a domestic sprinkler to control a fire will depend on the heat release rate of the burning fuel

- Likelihood of fire spread from item to item

- Ceiling geometry

- Sprinkler specification and activation time
- Sprinkler spacing and discharge density
- Structural impact
- Human ability to survive

A series of experiments were conducted, investigating which variations to the identified characteristics of fire and environment influence the effectiveness of the sprinkler system. The following is a summary of the experimental results (Beever and Britton, 1999):

- It is implied that property and content damage can still be considerably reduced with lower flow rates and increased sprinkler separations than prescribed in the current Australian Standard for domestic sprinklers (Standards Australia, 1995).
- The experiments showed that tenable conditions could be maintained with a 20% reduction in current domestic sprinkler discharge density requirements and with an increased spacing of sprinkler to wall distance.
- Lower flow rates have the effect of not being able to reduce air temperatures as quickly.
- Lower discharge densities result in reduced pre-wetting of material, which in turn reduces the ability of sprinklers to control fire.
- For the fire loads used, ionisation alarms detected smoke earlier than the photoelectric alarms in all locations, plus the tests indicated that around two minute’s extra warning time is available if smoke alarms are installed in every room rather than only a corridor or hallway (Beever and Britton, 1999).

The series of experiments indicate that changes in sprinkler spacing offer an option for reducing the cost of the sprinkler system.

4.5 Cost-Benefit Analysis

The cost-benefit modelling undertaken by Beever and Britton (1999) is the basis for the cost-benefit modelling undertaken in the New Zealand study (Duncan et al, 2000) and subsequently for this Australian study.

For analysis of specifically the sprinkler system cost-effectiveness, Beever and Britton (1999) investigated a domestic fire sprinkler system meeting AS 2118.5:1995 (SNZ, 1995) installed in a:

- Production house – built to a standard specification (150 m^2).
- Custom made house – built to client’s requirements (210 m^2)

- Existing house – (150 m^2)

- A domestic sprinkler system supplied from domestic supply, having a greater spacing of heads than specified in AS 2118.5:1995 (Standards Australia, 1995) and having a sprinkler head pressure lower than that specified in AS 2118.5:1995 for the above types of dwelling.

- A system as above, installed into a medium density housing estate where additional benefits may be accrued from a relaxing of building code regulations and Fire Brigade infrastructure costs.

Assumptions made in the analysis which are additional or alternative to the assumptions outlined in the cost-benefit analysis undertaken for the New Zealand situation include:

- A discount rate of 5% and an inflation rate of 3% is considered (Beever and Britton, 1999).

- A twenty-year life is considered for all fire safety measures, and where analysis has suggested that components of the system have a shorter working life than 20 years then either replacement costs are considered or an allowance is made for reduced reliability of the system with increasing age (Beever and Britton, 1999).

- Australian costs based on designs meeting AS 2118.5:1995 (Standards Australia, 1995) are compared with American designs meeting NFPA 13D:1999 (NFPA, 1999) and the decreases in costs seen in the United States with increased competition. The cost-benefit model is also run under the assumption that such reduction in costs would also be observed in future years in Australia (Beever and Britton, 1999).

- For AS 2118.5:1995 (Standards Australia, 1995), it is assumed that installation, testing and maintenance is undertaken by qualified tradesmen and that maintenance is in accordance with the requirements of AS 1851.3:1997 *Maintenance of Fire Protection Equipment – Automatic Fire Sprinkler Systems* (Standards Australia, 1997).

- Where the sprinkler installation is assumed to vary from the requirements of AS 2118.5:1995 (Standards Australia, 1995), standard plumbing costs along with installation, testing and maintenance procedures for domestic piping are considered (Beever and Britton, 1999).

The cost-benefit analysis was also run for:

- Domestic smoke alarms: (1) single mains powered ionisation smoke alarm installed in the hallway; (2) single battery-powered ionisation smoke alarm in the hallway; (3) five interconnected battery-powered ionisation smoke alarms (4) five interconnected mains-powered ionisation alarms

- Upholstered furniture flammability legislation
- Mattress flammability legislation
- Fire extinguisher

Table 3 below is a summary of the cost-effectiveness results from the Beever and Britton (1999) cost-benefit analysis of fire safety measures in domestic buildings.

Table 3: Summary of Cost-Effectiveness

Protection Scenario	**$A Cost per Life Saved**
Sprinkler Systems	
Australian Standard Sprinkler System	
Production house	$53 million to $30 million
Custom-built house	$60 million to $34 million
Existing house	$60 million to $34 million
Sprinkler System from Domestic Supply	
Production House	$46 million to $26 million
Production house, maintenance-free system	$5 million to $3 million
Custom-built house	$48 million to $27 million
Custom-built house, maintenance-free system	$7 million to $4 million
Existing house	$50 million to $28 million
Existing house, maintenance-free system	$10 million to $6 million
Throughout a new medium density housing estate	$16 million
New medium density housing estate - $100 maint/year	$2 million
Smoke Alarms	
Single battery-operated smoke alarm in hallway	
New house	<0

Existing house	<0
Single mains-powered smoke alarm in hallway	
New house	$350,000 (becomes <0 if maintenance costs can be reduced from $15 to $2 a year
Existing house	$670,000
Rented accommodation, existing or new house	<0
Five Interconnected Battery-Operated Smoke Alarms	
New house	$3.1 to $2.3 million
Existing house	$3.3 to $2.5 million
Five Interconnected Mains-Operated Smoke Alarms	
New house	$5.0 to $4.2 million
Existing house	$5.5 to $4.6 million
Other	
Upholstered furniture flammability legislation costing $50 per household to introduce	$10 million
Mattress flammability legislation costing $50 per household to introduce	$30 million
Fire extinguisher – 2kg powder	Benefit to cost ration of 2.5:1

(Reproduced from Beever and Britton, 1999)

Findings from the Australian research into the cost-effectiveness of domestic sprinkler systems concluded (Beever and Britton, 1999):

- Domestic fire sprinkler systems would reduce the number of fatalities and injuries in household fires and also significantly reduce property losses in Australian dwellings.

- On examination of the costs involved in sprinkler installation and maintenance, it is suggested that relaxation of the requirements surrounding flow rates, installation requirements, sprinkler separation, sprinkler to wall distances and maintenance schedules be considered in order to make sprinkler systems more cost-effective.

- Within a constrained household budget there are numerous household safety features such as smoke alarms, fire extinguishers and avoidance of trip and fall hazards that would reduce injuries, fatalities and amount of property loss, far more cost-effectively than sprinklers.

- Though not directly considered within this study, review of other work suggests that safety education programs offer the greatest level of reduction in fire accidents by very cost-effective means (Beever and Britton, 1999).

"*Based on the findings of this study, no recommendations 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*" (Beever and Britton, 1999).

The sprinkler tests also indicated:

"… that relaxing of the Australian Standard for domestic sprinklers would not have a substantial effect on property loss (where the window does not break), but may not be sufficient to protect persons adequately in the room of fire origin under very low flow rates. However, the tests indicate that a relaxed domestic sprinkler standard may offer adequate protection to those not in the room of fire origin." (Beever and Britton, 1999)

5. CASE STUDIES

Recommendation of compulsory installation of domestic sprinkler systems to combat the problem of fires in the home is not a new concept. The following is a brief consideration of:

1. initiatives where sprinkler systems have been installed in communities,
2. the success of these sprinkler installation programs,
3. the cost-effectiveness of compulsory sprinkler installation.

The United States has been successful in adopting legislation making domestic sprinkler systems compulsory. San Clemente and Corte Madera, California were some of the first communities in the United States to enact a home sprinkler ordinance (USFA, 1998-A). Communities that have initiated or plan to initiate residential sprinkler ordinances include: Livermore, California; Sarasota, Florida; Long Grove, Illinois; Chapel Hill, North Carolina; Germantown, Tennessee; Cobb County, Georgia; Altamonte Springs, Florida; Scottsdale, Arizona (USFA, 1998-A).

The United Kingdom also has trials investigating the effectiveness of domestic sprinkler systems. A project, organised by the West Wiltshire Residential Sprinkler Partnership, involved installing a sprinkler system in each of 212 new houses on the Studley Green estate in Trowbridge, Wiltshire, England. The project aims to demonstrate the effectiveness of residential sprinkler system and hopes to provide evidence to endorse claims that sprinkler systems be made compulsory in houses in multiple occupations (Fire Prevention, 1999).

The following section outlines a case study of the findings from Scottsdale, Arizona, USA, where the community chose to make domestic sprinklers compulsory.

5.1 Scottsdale Case Study

Some background information on the city of Scottsdale (Home Fire Sprinkler Coalition, 1997):

- The City of Scottsdale is located in Central Arizona in the United States and is part of the greater Phoenix metropolitan area.

- The population of the city in 1985, when the sprinkler ordinance was adopted, was 107,000 and ten years later in 1995, the population of the city was 164,090 equating to a 54% population increase in ten years.

- The city area encompasses 473 square kilometres.

- The fire services are contracted with Rural/Metro Fire Department operating 9 fire stations, with 120 full-time staff of which 65 are paramedics and 19 are fire prevention staff. The fire prevention activities include all aspects of public education, fire prevention engineering and plan review. The prevention responsibilities also ensure code compliance inspections for all new construction and existing occupancies.

5.1.1 Sequence of events

The process of developing a law for compulsory domestic sprinkler systems and implementation of that law took the City of Scottsdale ten years.

In September 1974 the City of Scottsdale enacted its first major sprinkler code to require automatic sprinkler protection for any structure that was larger than 7500 square feet or three storeys in height. At the time the ordinance was passed it was one of the most advanced in the United States.

The ordinance development was based on:

1. The understanding within the fire protection community that automatic sprinkler systems have been extremely effective in controlling or extinguishing fires.

2. The realisation that in spite of the best efforts of a community, large fire incidents often exceed the capability and available resources of the local fire service. These major incidents negatively impact the emergency service levels of a larger geographic area for an extended period of time.

It was recognized that in the late 1970s and early 1980s all the testing of domestic sprinkler systems had been conducted in the controlled environments of testing laboratories or in buildings of little value that were scheduled for demolition. In 1982 a plan was developed to test the various types of residential systems in new single-family homes. The objective of the tests were:

- to combine the results of many years of study and experimentation into one conclusive test and summary of the residential sprinkler concept;

- to complete actual, real life testing on the current fast-response sprinkler technology;

- to study the actual costs associated with the application of this technology for installation and effectiveness;

- to provide a conclusive test that indicated the potential benefits for life safety by placing participants in the rooms of origin for two of the initial tests.

The tests were used to establish life safety and property protection benefits that could be obtained from compulsory installation of domestic sprinkler systems, and to prove that the new sprinkler technology was effective.

In conjunction with the sprinkler tests, research into identifying 'design freedoms' was being undertaken to investigate ways of making the domestic sprinkler system more cost-effective. As a result of the research, the following 'design freedoms' were identified:

- Density increase of 4% for single family communities was initiated.
- Reduction in residential street width from 10 metres to 8.5 metres was approved.
- Cul-de-sac lengths were increased from 183 metres to 610 metres.
- 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 fire-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 100 metres to 213 metres 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.

Effective July 5, 1985, all new multi-family and commercial structures for which building permits are issued were required to be sprinklered. The ordinance also required that, effective January 1, 1986, all new single-family residences were to be sprinklered.

5.1.2 Ten years of domestic sprinklers

After ten years of compulsory domestic sprinkler installation, the cost-effectiveness of the proposal was considered.

Using the guidelines from 11 different local home designs, an average house was developed. The average home was used to assess the costs for installing a domestic sprinkler system. The average house was taken to be a 186 square metre, single-family home. The findings of the ten year study undertaken by Reese-Carr (Home Fire Sprinkler Coalition, 1997), indicated the total costs would be US$12.27 per square metre to install a domestic sprinkler system in a new, 186 square metre Scottsdale home. The design freedoms that were included in the ordinance equalled a per house savings of US$158.52 for on-site construction trade-offs and an additional US$1951.55 for off-site adjustments. When these ordinance design freedoms were included, the total costs of the residential system were estimated to be US$157.24 per installation to the builder and approximately US$212.27 per home to the buyers.

Points of interest from the ten-year study include:

- The population of the city increased by approximately 50% over the ten-year period, with the number of houses increasing by the same proportion. Interestingly, the area of the city did not expand, remaining at 474 square kilometres.

- Despite the significant population increase, the proportion of the city budget spent on the fire service remained almost constant over the ten-year period, increasing by less than one percent in ten years.

- The number of fire stations remained at six for the first seven years from the adoption of the ordinance even though the population was increasing. The number of fire stations increased from six to eight in the ten years.

- Sprinklers did not influence the amount of fire incidents, but they did have a significant impact on the amount of fire losses. The value of fire losses has an overall downward trend from 1985 to 1996.

In 1995, ten years since making domestic sprinkler systems compulsory for all new homes built in the city of Scottsdale, Arizona, the following are significant impacts the increased fire protection has made to the community:

- Over the ten years, the automatic sprinkler systems had a direct role in saving eight lives and there has not been a fire-related death in any sprinklered property.

- 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%).

- The cost economics associated with built-in protection can be addressed through design freedoms without negatively impacting fire suppression effectiveness.

- The impact and installation costs have been reduced dramatically, from US$12.27 per square metre to US$6.35 per square metre, close to a 50% reduction in cost.

- One or two heads controlled or extinguished the fire 92% of the time, with the majority of the exceptions a result of flammable liquid incidents.

- Estimated water flows were substantially reduced for the community.

- When Scottsdale reaches its full growth potential, it is estimated that it will be a community with over 300,000 residents and more than 65% of the residential homes and 85% of commercial property will be protected with automatic sprinkler systems. Scottsdale has been able to achieve such success in gaining coverage of domestic sprinklers in the community due to the rapid growth of the city.

The compulsory requirement for domestic sprinkler systems to be installed in Scottsdale homes has made the system more cost-effective. The cost-savings due to en-masse installation can potentially be applied to the Australian situation if domestic sprinklers were installed in communities. Potential cost savings to Australian communities are being investigated in a research project being undertaken by the Australasian Fire Authorities Council (AFAC, 2001).

6. STATISTICS

6.1 Domestic Fire Problem

Historical records of fire incident data indicate that fires originating in Class 1a buildings contribute to a great proportion of reported fires, fire injuries and fire fatalities in Australia. This trend, highlighting the incidence of fires occurring in the home, is reflected also in international fire incident statistics.

This section provides a statistical analysis of house fires in Australia. The statistical analysis undertaken by Beever and Britton (1991) provides some indication of fire incident trends, but the analysis is limited as the statistics refer predominantly to 1993 and 1994 data. More current fire incident statistics are added in this report to the Beever and Britton (1999) statistics in order to more accurately determine trends within the data. The more recent fire incident statistics were provided by the Australasian Fire Authorities Council (AFAC) for the following fire brigades: New South Wales Fire Brigades, Queensland Fire Service, South Australia Metropolitan Fire Service, Tasmanian Fire Service, Melbourne Metropolitan Fire and Emergency Services Board, the Western Australia Fire and Rescue Service and the Country Fire Authority in Victoria. Some statistics on domestic fire incidents were also supplied by Worcester Polytechnic (WPI) students undertaking a complementary study in conjunction with the Australasian Fire Authorities Council, investigating community benefits from the installation of sprinkler systems in 'Greenfield' subdivisions (AFAC, 2001).

Further on in this section, the statistics from Australia are compared to those reported from overseas and trends are discussed.

6.1.1 Limitations to statistical analysis

On analysis of the AFAC statistics, limitations arose as the data set supplied varied between the Brigades. The majority of the statistics supplied were for the financial years 1994-1997 (inclusive) with the exception of the Country Fire Authority, who reported 1998-2000 statistics, and Western Australia statistics, which excluded 1996. The variation in the years of fire incident reports caused difficulties in analysing the data as equivalent data sets for each year were not available.

Fire incident statistics for a maximum of four years are reported from some of the contributing fire brigades. Four years is a limited data set and trends are difficult to discern from the limited number of fire incidents reported and the short analysis period. Limitations also arise from the statistics provided by AFAC as nationwide trends for Australia need to be extrapolated from the data of the seven brigades.

In some regions of Australia it is compulsory to install smoke alarms in the home. Difficulties occur in trying to determine the influence smoke alarms have on the number of reported fire incidents.

Closer analysis of the data highlights inconsistencies in the accuracy of the information collected. For example the choice of ambiguous areas of fire origin such as the category 'other' are favoured amongst the statistics.

Fire fighters took industrial action during the years the data were collected, which led to inconsistencies in the analysis that occur as a result of incident reports not being filed.

It should be noted that the AFAC statistics quoted are predominantly for family homes classified in the Building Code of Australia as Class 1a buildings (ABCB, 1996):

"One or more buildings which in association constitute-

(a) Class 1a – a single dwelling being

(i) 7a detached house; or

(ii) one or more attached dwellings, each being a building, separated by a *fire-resisting* wall, including a row house, terrace house, town house or villa unit."

It is noted in the Fire Code Reform Centre (FCRC) Project Two Report (FCRC, 1996) that the Australian Fire Incident Reporting System (AFIRS) does not use BCA classes for building categories. Therefore the correlation of fire data with the BCA-based Categorisation of buildings is only approximate (FCRC, 1996).

The FCRC report also notes that data contained in AFIRS is not a complete coverage of Australia. The estimated AFIRS coverage for the years 1989 to 1993 are shown in Table 4. Where appropriate, compensation for the incomplete coverage is made and referenced in the statistical analysis.

Table 4: Estimated AFIRS Coverage of Australian Fire Data

Year	Estimated AFIRS Coverage
1989 – 1990	81%
1990 – 1991	85%
1991 – 1992	85%
1992 – 1993	85%

(Source: FCRC, 1996)

Fire incident rates determined from the fire incident statistics are based on the number of households accounted for in Australian Bureau of Statistics Census data (ABS, 1999). Australian census data shows that the separate house is the most popular type of dwelling, making up 79% of all dwellings (ABS, 1999), this is also reflected in the fire incident numbers. Table 5 shows a distribution of dwellings by state/territory for the year 1997-1998. The number of homes is adjusted accordingly to consider the coverage of each fire brigade and these adjustments are referenced where appropriate in the statistical analysis.

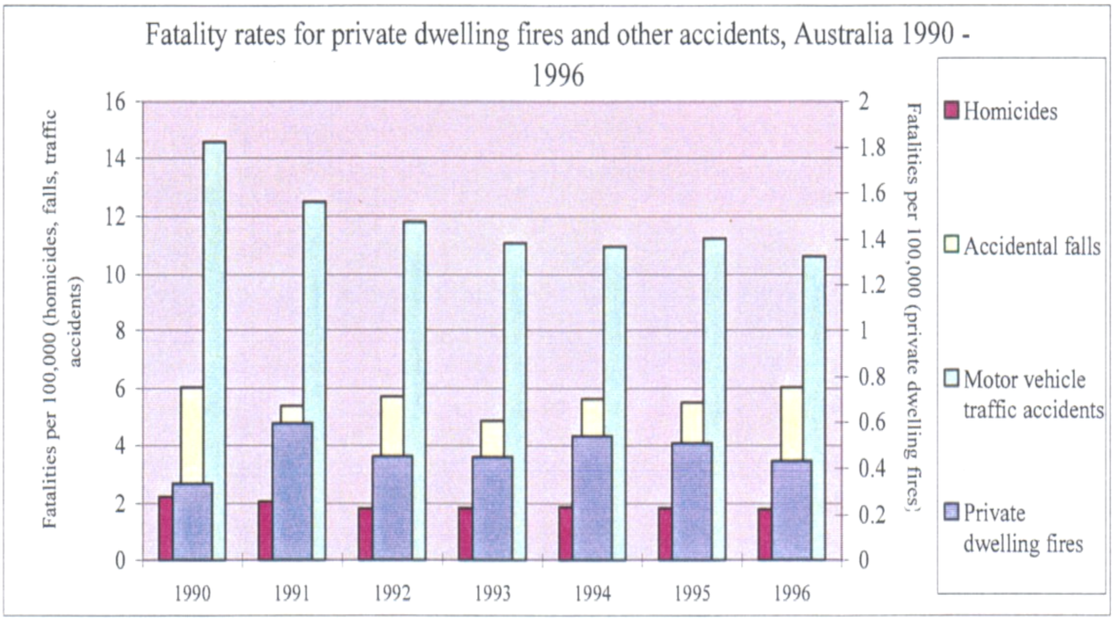
Table 5: Dwellings by Dwelling Structure and State/Territory – 1997-1998

State/Territory	Separate Houses (%)	Semi-detached/Row or Terrace House/Townhouses (%)	Flat/Unit/ Apartment (%)	Total Number of Houses
New South Wales	74.0	9.1	16.3	2,336,500
Victoria	81.2	7.2	11.2	1,724,700
Queensland	82.2	5.8	10.8	1,301,600
South Australia	78.5	13.2	7.5	603,100
Western Australia	81.9	12.9	5.0	689,300
Tasmania	84.4	9.1	5.8	185,800
Northern Territory	74.6	11.8	11.6	52,400
Australian Capital Territory	79.3	12.4	8.0	118,900
Australia	**78.8**	**8.8**	**11.7**	**7,012,300**

(Source: ABS, 1999)

6.1.2 Frequency

Figure 1 compares fatality rates due to dwelling fires with other accidents in Australia (Beever and Britton, 1999).



Sources: ABS, Cause of Deaths, publications 1990 to 1996. ABS unpublished statistics.

Figure 1: Fatality Rates by Cause
(Source: Beever and Britton, 1999)

Beever and Britton (1999) state that whilst the accident rate for private dwelling fires may appear insignificant in comparison with other forms of accident, it should be noted that there may be significant benefit by reducing this rate further and that the cost of doing so may be an attractive investment when compared to the cost of reducing the risk of other forms of accident.

Australian National Fire Incident Statistics for 1991-1992 (CSIRO, 1993) show that structure fires (21.6%) rate second to tree and grass fires (34%) when describing the major categories of fire in Australia (refer Figure 2).

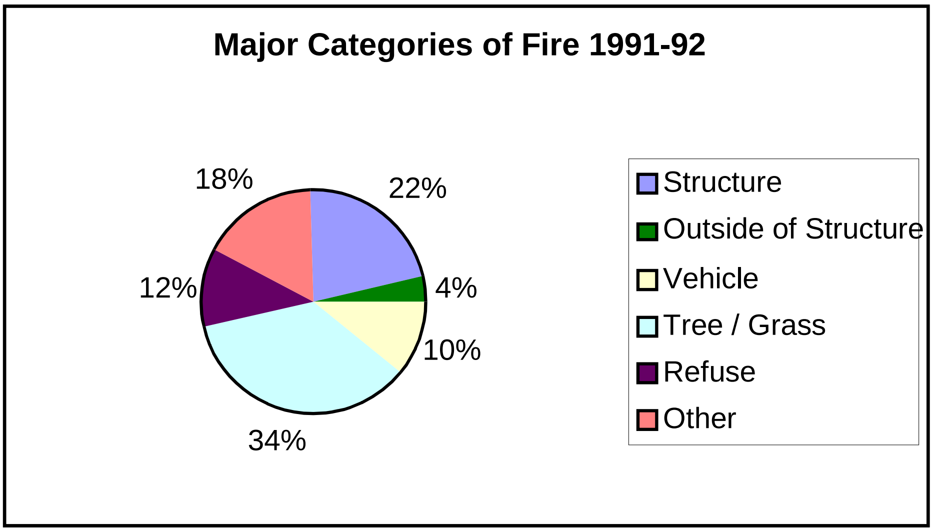


Figure 2: Major Categories of Fire 1991-92
(Source: CSIRO, 1993)

Fires in residential properties in Australia accounted for 59% of all structure fires in the period 1991-1992 (refer Figure 3).

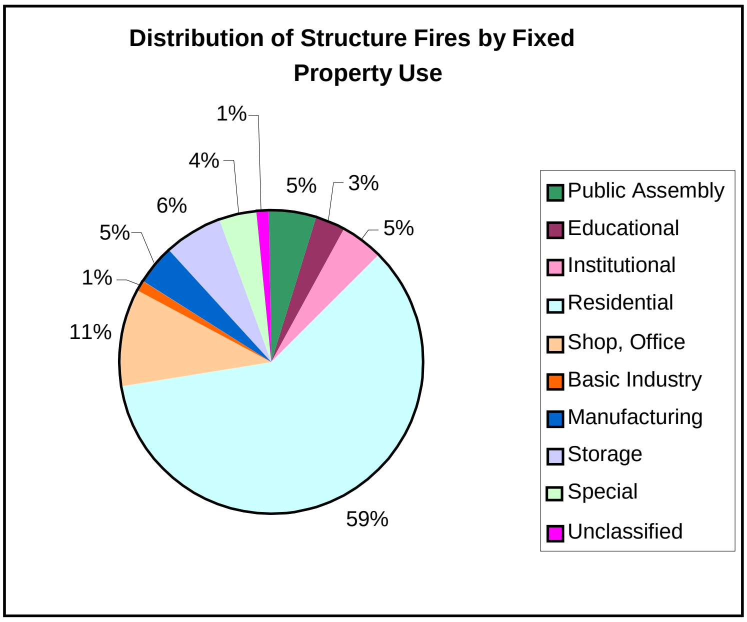


Figure 3: Distribution of Fires by Fixed Property Use 1991-92
(Source: CSIRO, 1993)

Statistics from AFAC indicate that, during the period 1994 to 1997 inclusive, Fire Service personnel from the three brigades of New South Wales Fire Brigades, Queensland Fire Service and Tasmania attended close to 20,000 domestic fire incidents, averaging around 5,000 incidents per year (refer Figure 4).

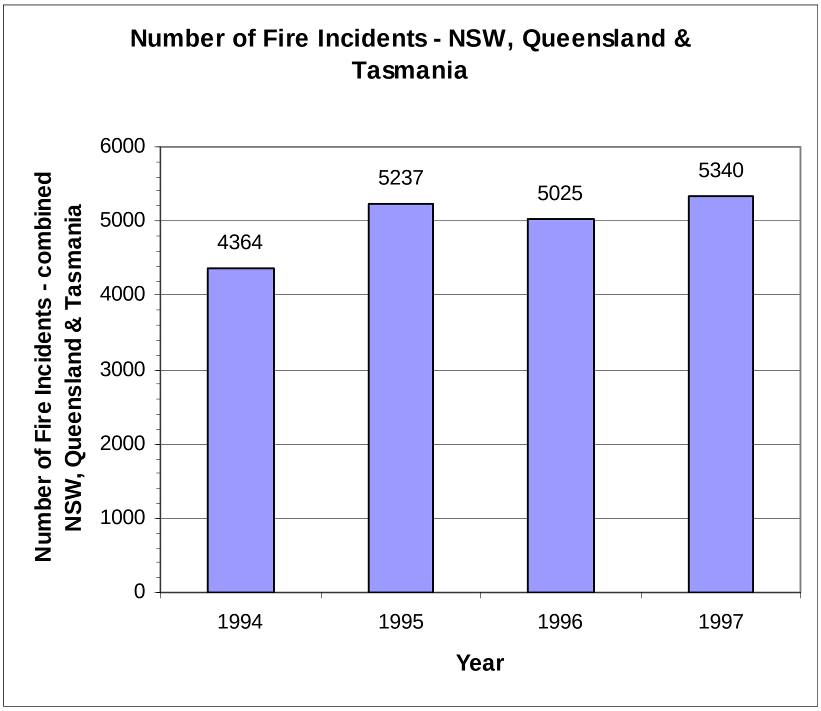


Figure 4: Fire Incidents per Year – Combined for New South Wales, Queensland and Tasmania (Source – AFAC, 2000)

Table 6: Fire Incident Rate – AFAC Statistics

Brigade	**Year (incl)**	**Total Number of Fires**	**Number of Households per Area**	**Fire Incident Rate - Fires/1000 Households/Year**
New South Wales Fire Brigades	1994-1997	13,377	1,557,667	2.1
Queensland Fire Service	1994-1997	4,248	1,106,360	1.0
Tasmanian Fire Service	1994-1997	2,341	157,930	3.7
South Australia Metropolitan Fire Service	1994, 1996, 1997	1,644	512,635	1.1
Victoria*	1998-2000	9,379	1,712,549*	1.8
Total		**30,989**	**5,047,141**	**1.7**

*Statistics supplied by WPI (AFAC, 2001)

Table 6 shows a summary of the fire incident rates calculated from the complete data supplied from AFAC.

[Where it is assumed that:

- New South Wales Fire Brigades cover two thirds of the homes located in New South Wales.]

From the statistics, the average fire incident rate is calculated to be 1.7 fires per 1000 households per year.

Data from the Australian Fire Incident Reporting System (AFIRS) was analysed by Beever and Britton (1999) who calculated the fire incident rate to be 1.87 fires per 1000 households per year. From statistics in the United States for the years 1985-1994 (FEMA, 1997), the fire incident rate in the United States is found to be 2.7 fires per 1000 households per year.

A study of fire incident statistics from New Zealand finds the fire incident rate to be 4 fires per 1000 households per year (Duncan et al, 2000).

For this study a fire incident rate of 2 fires per 1000 households per year is assumed. This is based on consideration of the Australian fire incident data (refer Table 6) and is aligned with that used in the Beever and Britton (1999) study.

A sensitivity analysis is included in the cost-benefit analysis to illustrate the impact increasing and decreasing the fire incident rate has on the cost-effectiveness of the system.

6.1.3 Location

Australian national fire incident statistics for the year 1991-1992 (CSIRO, 1993) show that the kitchen (34.4%) is the leading area of fire origin for all dwelling fires. Sleeping areas (14.6%) rate second and the lounge area (13.5%) is a close third. These statistics indicate that fires originating in either the kitchen, bedroom or living area contribute to approximately two thirds of all domestic structure fires in Australia.

6.1.4 Severity

Australian national fire incident statistics published for the years 1991-1992 (CSIRO, 1993) show that 69% of causalities in residential structures occur in homes.

Table 7 shows the average fatality rate in each brigade jurisdiction as calculated from the AFAC statistics.

Table 7: Fatality Rates – AFAC Statistics

Brigade	Year (incl)	Total Number of Fire Incidents	Total Number of Fatalities	Fatality Rate Fatalities/1000 house fires
New South Wales Fire Brigades	1994-1997	13,377	102	7.6
Queensland Fire Service	1994-1997	4,248	52	12.2
Tasmanian Fire Service	1994-1997	2,341	10	4.3
South Australia Metropolitan Fire Service	1994, 1996, 1997	1,644	13	7.9
Victoria*	1998-2000	9,379	65	6.9
Total		**30,989**	**242**	**7.8**

*Statistics supplied by WPI (AFAC, 2001)

From the statistics, the average fatality rate from house fires is calculated to be 7.8 deaths per 1000 house fires (refer Table 7).

Beever and Britton (1999) assumed the fire incident fatality rate to be 7 deaths per 1000 house fires.

A study of New Zealand's fire fatality statistics finds the fire fatality rate to be 6 deaths per 1000 house fires (Duncan et al, 2000).

For this study a fire fatality rate of 7 deaths per 1000 house fires, as used in the Beever and Britton (1999) analysis, is assumed. This fire fatality rate is equal to that calculated for the state of Victoria (refer Table 7).

Figure 5 shows the distribution area of fire origin for a domestic fire resulting in a fatality as reported by the New South Wales Fire Brigades sourced from the AFAC data.

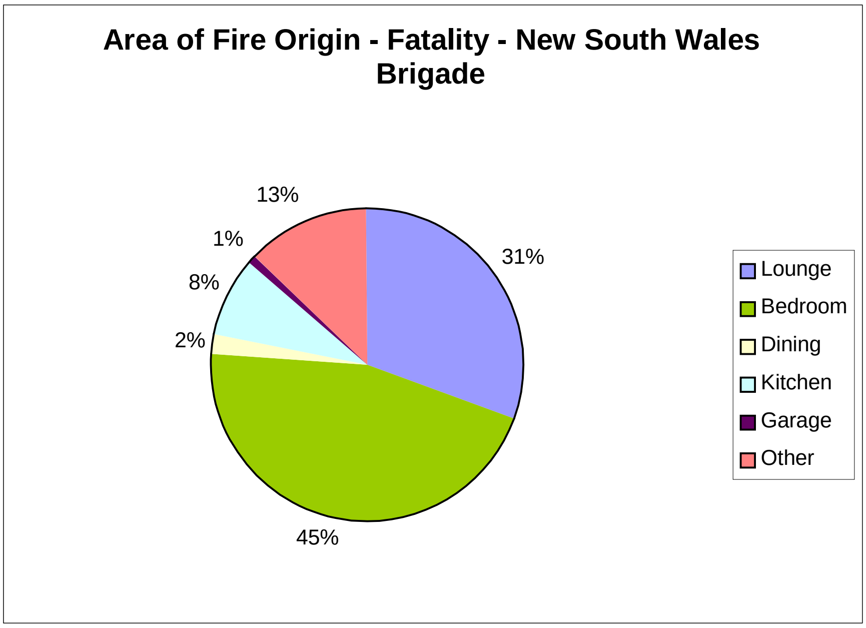


Figure 5: Area of Fire Origin – Fatality – New South Wales Fire Brigades

Trends from the New South Wales data show the three main areas of fire origin resulting in a fatality are the bedroom (45%), lounge (31%) and kitchen (8%). Trends in the data are difficult to discern due to the small data set of fatalities and the influence the category "other" area of fire origin has over the distribution.

Data provided by AFAC also show for the Queensland Fire Service that the bedroom, lounge and kitchen are the more frequent area of fire origin where the fire results in a fatality (refer Figure 6). Due to the large proportion of fires where the area of origin is classified as "other", it is difficult to decipher trends amongst areas of fire origin beyond the kitchen, bedroom and lounge.

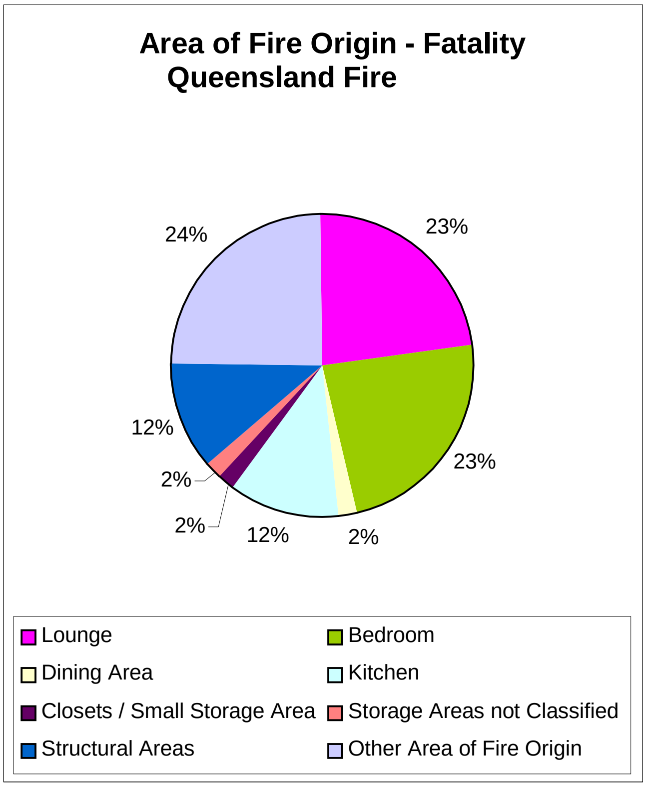


Figure 6: Area of Fire Origin – Fatality – Queensland Fire Service

Similar trends to Queensland and similar limitations to the data, are shown in the fire fatality statistics provided by AFAC for Tasmania (refer Figure 7).

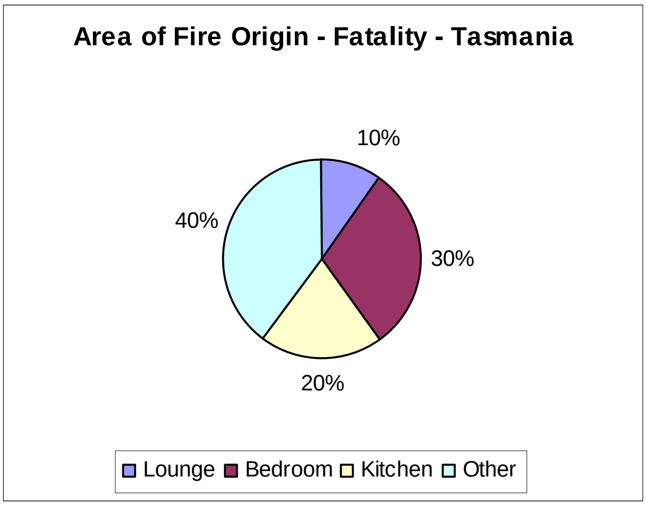


Figure 7: Area of Fire Origin – Fatality – Tasmania

The bedroom (30%), kitchen (20%) and lounge (10%) feature as the most common area of fire origin which results in a fatality (refer Figure 7). The category "other" makes up 40% of the fatality origin records and more information is required to determine trends from this data.

As determined from the AFAC statistics, Table 8 compares the distribution of area of fire origin where the fire results in a fatality.

Table 8: Area of Fire Origin – Fatality

Brigade	Number of Fatalities per Area of Fire Origin				
	Bedroom	**Lounge**	**Kitchen**	**Other**	**Total**
New South Wales Fire Brigades	46	31	11	14	**102**
Queensland Fire Service	12	12	7	21	**52**
Tasmania Fire Service	3	1	2	4	**10**
CFA	5	6	15	22	**48**
Total	**66**	**50**	**35**	**61**	**212**
Proportion	**31.1%**	**23.6%**	**16.5%**	**28.8%**	**100%**

Table 8 shows that the bedroom, lounge and kitchen are the most common area of fire origin where the fire results in a fatality, making up over 70% of all fires which result in a fatality. The bedroom (31.1%) is, on average, the leading area with the lounge (23.6%) second and the kitchen (16.5%) third.

Table 9: Injury Rates – AFAC Statistics

Brigade	**Total Number of Fire Incidents**	**Total Number of Injuries**	**Injury Rate** **Injuries/1000 house fires**
New South Wales Fire Brigades	13,377	956	71.5
Queensland Fire Service	4,248	250	58.9
Tasmanian Fire Service	2,341	121	51.7
South Australia Metropolitan Fire Service	1,644	66	40.1
Victoria*	9,379	529	56.4
Australia (Beever and Britton, 1999)	27,000	1,804	66.8
Total	**57,989**	**3,726**	**64.3**

*Statistics supplied by WPI (AFAC, 2001)

Table 9 shows the average injury rate in each brigade jurisdiction as calculated from the AFAC statistics.

From the statistics, the average injury rate from house fires calculates to be 64 injuries per 1000 house fires.

Beever and Britton (1999) assumed the fire incident injury rate to be 70 injuries per 1000 house fires.

New Zealand fire injury statistics show the fire injury rate to be 40 injuries per 1000 house fires (Duncan et al, 2000).

For this study a fire injury rate of 60 injuries per 1000 house fires is assumed.

Figure 8 shows the distribution area of fire origin for a domestic fire resulting in an injury as reported by the New South Wales Fire Brigades (1994-1997) sourced from the AFAC data.

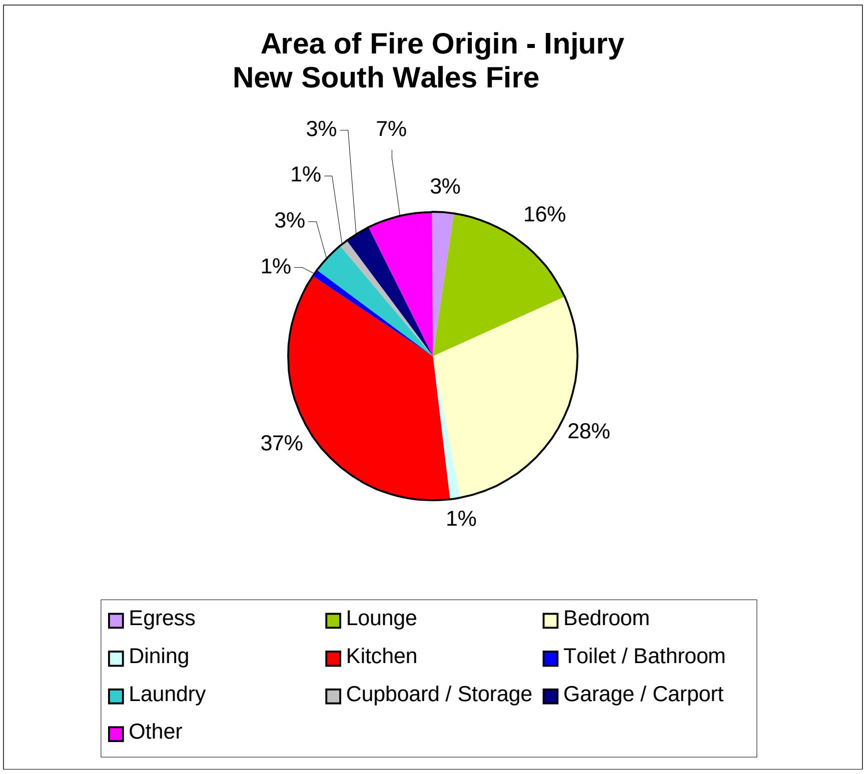


Figure 8: Area of Fire Origin – Injury – New South Wales Fire Brigades

Trends from the New South Wales data show that the lounge (16%), bedroom (29%) and the kitchen (36%) are the most common areas of fire origin which result in an injury.

Similar trends of area of fire origin resulting in an injury are shown by the Queensland Fire Service (refer Figure 9) and the Tasmanian Fire Brigade (refer Figure 10) data.

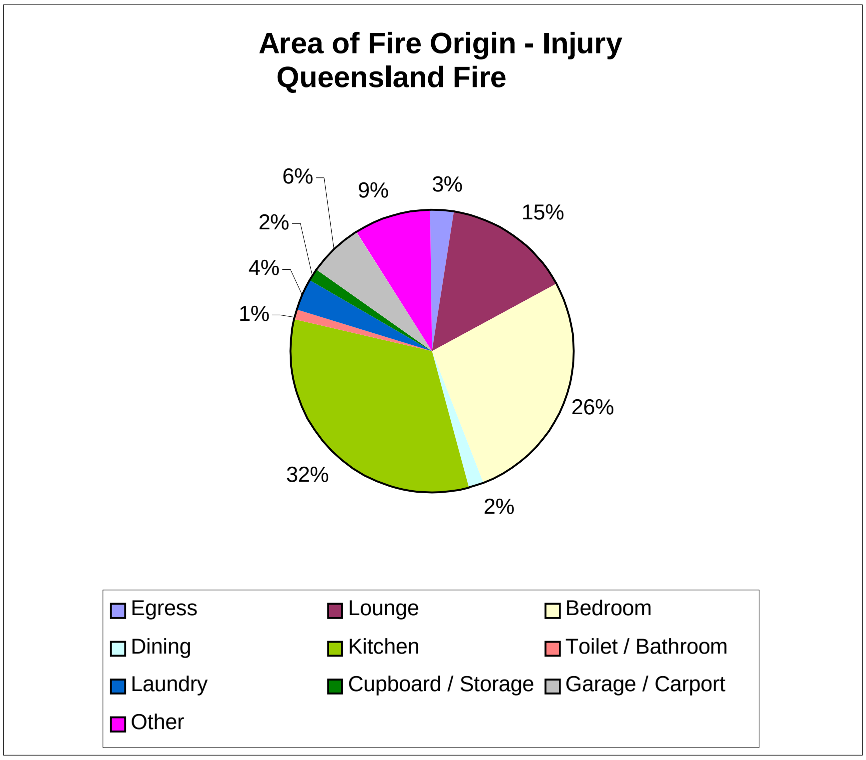


Figure 9: Area of Fire Origin – Injury – Queensland Fire Service

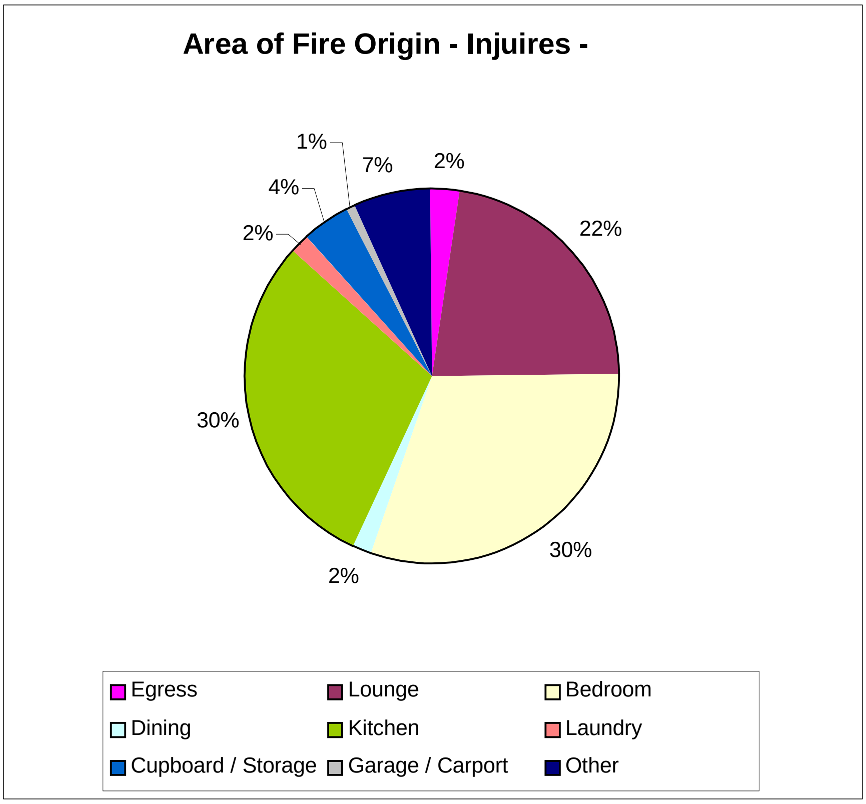


Figure 10: Area of Fire Origin – Injury – Tasmania Fire Brigade

Considering the three main areas of fire origin which result in an injury, data provided by AFAC shows the following (refer Table 10).

Table 10: Area of Fire Origin – Injury

Brigade	**Number of Injuries per Area of Fire Origin**				
	Bedroom	**Lounge**	**Kitchen**	**Other**	**Total**
New South Wales Fire Brigades	272	151	358	175	**956**
Queensland Fire Service	66	37	86	61	**250**
Tasmania Fire Service	36	27	38	20	**121**
Total	**374**	**215**	**482**	**256**	**1,327**
Proportion	**28.1%**	**16.2%**	**36.3%**	**19.3%**	**100%**

Trends from the data provided by AFAC show for the three fire brigades considered, the bedroom, lounge and kitchen are the three main areas of fire origin where the fire results in an injury, making up over three quarters of the reported incidents. The kitchen (36.3%) is, on average, the leading area of origin where the fire results in an injury. This compares with the bedroom (31.1%) being the most common area of fire origin where the fire results in a fatality. The bedroom (28.1%) rates second and the lounge (19.3%) the third most common area of fire origin where the fire results in an injury.

6.1.5 Case Study – Victoria, Australia

This section considers fire incident and population statistics for the state of Victoria for the years 1998-2000 (supplied by the Worcester Polytechnic Students [AFAC,2001]).

Two fire brigades service the State of Victoria, the Country Fire Authority (CFA), covering the area of Victoria beyond Melbourne, and the Melbourne Metropolitan Fire and Emergency Services Board (MFEB), covering Melbourne city. A distribution of the dwellings from the year 2000 data shows that the majority of homes are located in the MFEB area (refer Table 11).

Table 11: Dwellings – Victoria

Brigade Coverage	**Number of Homes (year 2000)**	**Proportion of Victoria Housing**
CFA	736,846	42%
MFEB	997,613	58%
Total (Victoria)	**1,734,459**	

Analysis of population growth in the state of Victoria shows close to a 1% growth rate. Figure 11 shows the trend of population and dwelling growth for the CFA area over the years 1998 to 2000.

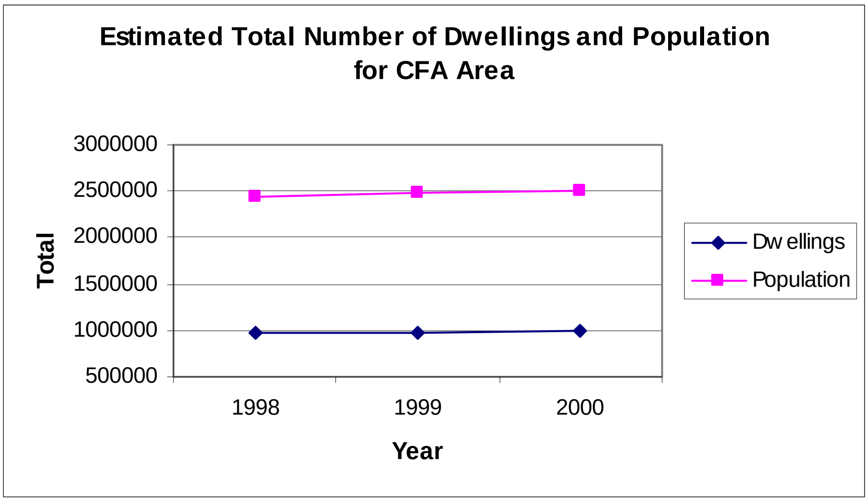


Figure 11: Population and Dwelling Growth Rate – CFA Area

Figure 12 shows the total number of house fires in Victoria for the years 1998 to 2000. Trends from the data are difficult to discern due to the limited sample size.

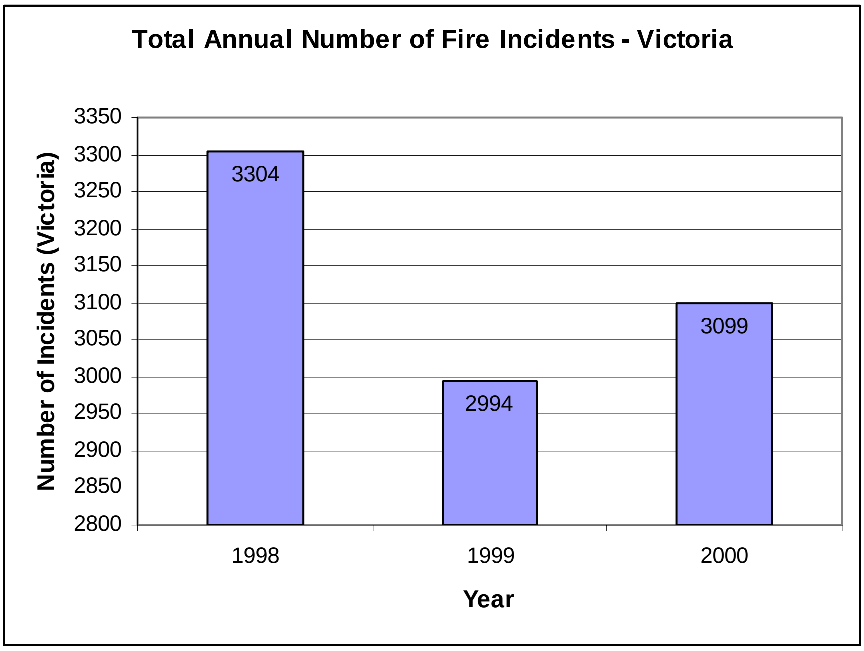


Figure 12: Annual Number of House Fires – Victoria (1998-2000)

The results of converting the number of fires in the home into a fire incident rate for Victoria is shown in Table 12. The average fire incident rate for the state of Victoria is found to be 0.00183 fires per household per year.

Table 12: Home Fire Incident Rate – Victoria

Year	Number of Homes	Total Number of Fire Incidents	Fire Incident Rate (fires per household per year)
1998	1,689,871	3,304	0.00196
1999	1,713,317	2,994	0.00175
2000	1,734,459	3,099	0.00179
Total	**5,137,647**	**9,397**	**0.00183**

(Source: WPI data [AFAC, 2001])

Figure 13 shows the total numbers of injuries and fatalities resulting from fire in the home for the state of Victoria. The limited data set makes trends in the data difficult to determine.

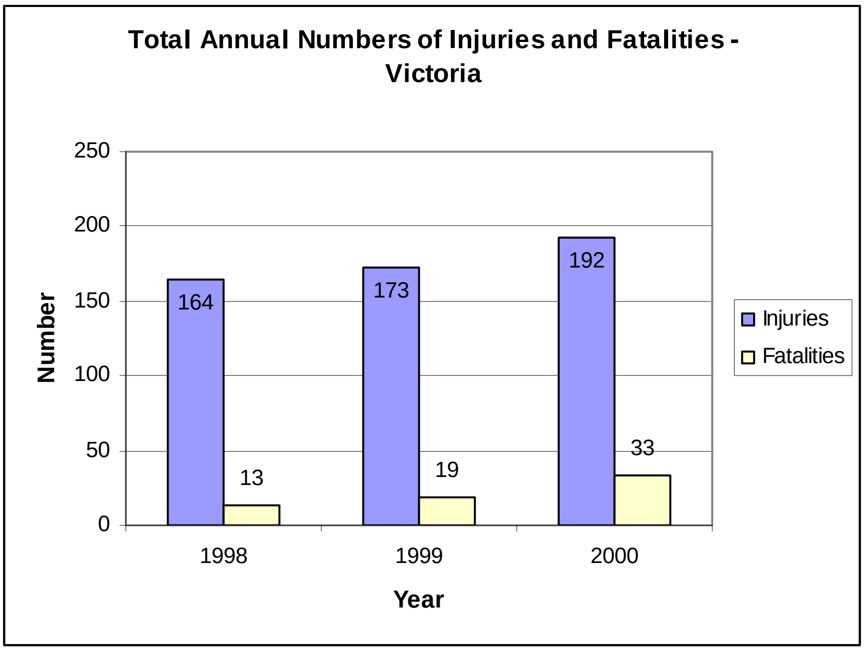


Figure 13: Home Fire Injuries and Fatalities – Victoria (1998-2000)

Table 13 and 14 calculate the injury and fatality rates from fires in the home for Victoria over the duration 1998 to 2000.

Table 13: House Fire Injury Rate – Victoria

Year	**Number of Injuries per Year**	**Total Number of Fire Incidents**	**Fire Injury Rate (injuries per fire incident per year)**
1998	164	3,304	0.050
1999	173	2,994	0.058
2000	192	3,099	0.062
Total	**529**	**9,397**	**0.056**

Table 14: House Fire Fatality Rate – Victoria

Year	Number of Fatalities per Year	Total Number of Fire Incidents	Fire Fatality Rate (fatalities per fire incident per year)
1998	13	3,304	0.004
1999	19	2,994	0.006
2000	33	3,099	0.011
Total	**65**	**9,397**	**0.007**

6.2 Overseas Statistics

Figure 14 shows a comparison of fire death rates between a variety of countries. The number of Australian fire deaths per million population is low by world standards.

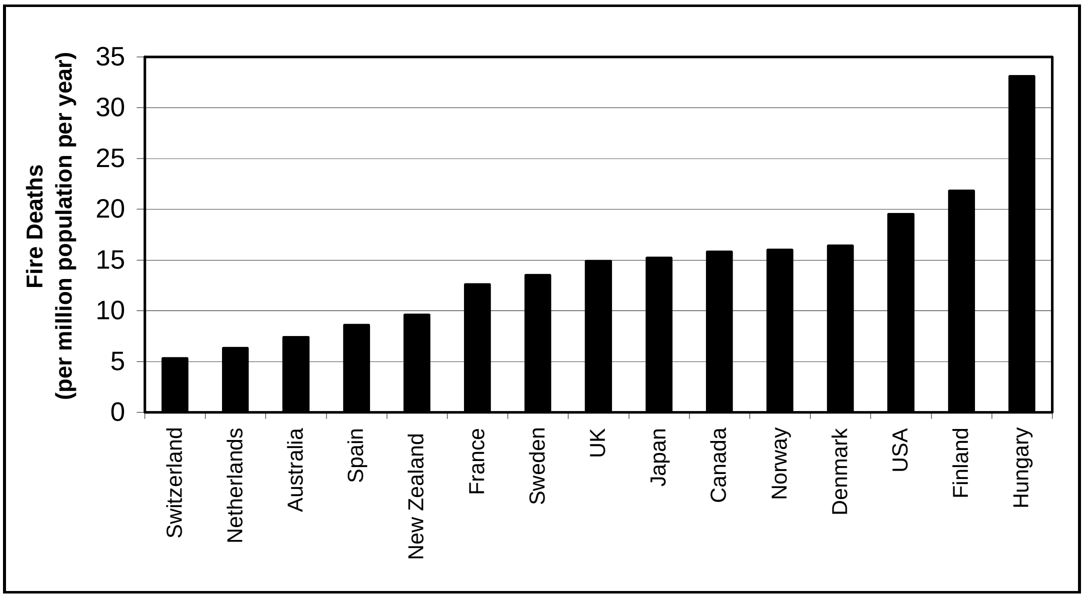


Figure 14: Comparison of International Fire Death Rates
(Source: Irwin, 1997)

6.2.1 United States

Statistics from the United States show trends for domestic fires to be similar to those of Australia. The kitchen, bedroom and living room (den) feature as the top three areas of fire origin (refer Figure 15).

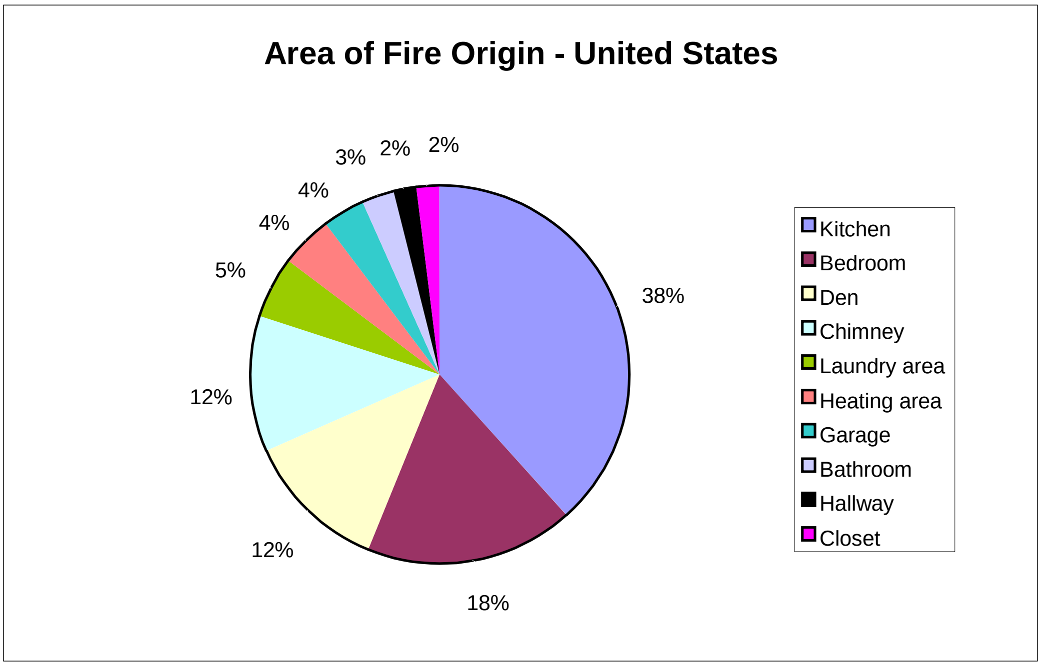


Figure 15: Area of Domestic Fire Origin – United States (Source Edison, 1999)

According to the United States Fire Administration (USFA, 1998-B), statistics show:

- Cooking is the leading cause of home fires in the U.S., and is also the leading cause of fire injuries.
- Careless smoking is the leading cause of overall fire deaths.
- Heating is the second leading cause of residential fires and ties with arson as the second leading cause of overall fire deaths.
- Arson is the third leading cause of residential fires and a leading cause of residential fire deaths.

In the United States about 5000 people die every year as the result of fire, and another 25,500 are injured. At least 80% of all fire deaths occur in private homes (USFA, 1998-B).

6.2.2 New Zealand

Fires in residential properties in Australia accounted for 59% of all structure fires in the period 1991-1992 (refer Figure 3). This highlights the same trend as for New Zealand where domestic fire incidents account for the majority of reported structure fire incidents.

Trends shown in New Zealand fire incident statistics indicate the leading area of fire origin in one- and two-family dwellings is the kitchen (34%) (Duncan et al, 2000). The lounge area (21%) rates second and sleeping areas (17%) rate third as the leading areas of fire origin. These statistics indicate that close to 75% of domestic structure fires in New Zealand start in the kitchen, lounge or bedroom (Duncan et al 2000).

6.2.3 United Kingdom

A paper published by Watson and Gamble (1999) analysed trends from fire incident data published for the years 1988 to 1998. Summarising this data from the UK shows (Watson & Gamble, 1999):

- In 1998, there were an estimated 643 deaths in the United Kingdom, compared with 723 in 1997, 709 in 1996, 736 in 1995 and 641 in 1994. Prior to this there had been a falling long term trend from the very high numbers of deaths recorded in the early 1970s (about 1,000 each year).

- There was a 2% fall in the number of non-fatal casualties to 18,170 in 1998 – the first fall since 1993 (mainly due to a fall in precautionary checks). Since 1988, there has been a rise of nearly 40% from 13,400, due mainly to a substantial rise in the number of precautionary checks. The number suffering from the effects of gas or smoke has increased from 3,500 in 1988 to 6,600 in 1998.

- Around three-quarters of all casualties occur in dwellings.

- The main sources of ignition were cooking appliances.

- The largest single cause of accidental death (32%) was careless handling (mainly careless disposal) of smoking materials.

- About one-fifth of all dwelling fires in the UK are malicious.

- Over the decade (1988-1998) various research shows that smoke alarm ownership has increased rapidly from under 10% in 1988 to 70% in 1994, but risen at a slower rate in recent years to 82% in 1998.

- Fires discovered by smoke alarms continued to be discovered more rapidly after ignition, be associated with lower casualty rates and cause less damage.

6.3 Summary of Statistics

In summary, Australian fire incident statistics reflect international trends with regards to:

- Area of fire origin – the majority of domestic fire incidents originate in kitchen, bedroom or living area.
- Area of fire origin which results in a fatality – the bedroom is the most likely fire origin which will result in a fatality. The living area and the kitchen follow next as most likely area of fire origin which would result in a fatality.
- Most structure fires occur in one- and two-family dwellings and hence most fatalities from fires occur in these structures.

7. CODES AND STANDARDS

7.1 Introduction

The objective of this research into reducing the loss of life, injury and amount of property loss caused by fires in domestic dwellings was to develop a proposal for a low-cost fire sprinkler system. A multi-purpose sprinkler system whereby the sprinkler system is integrated with the domestic plumbing system was designed.

Offering the multi-purpose sprinkler system design as a low-cost sprinkler option is based on the success of the design as applied to the New Zealand situation. The study undertaken in New Zealand for the New Zealand Fire Service (Duncan et al, 2000) identified the multi-purpose sprinkler system as a design option which successfully reduces the cost of domestic fire sprinkler systems when compared to those installed to the requirements of the New Zealand Standard, NZS 4515:1995 (SNZ, 1995). The multi-purpose fire sprinkler system design is based strongly on an option allowed in the National Fire Protection Association's Sprinkler Standard NFPA 13D:1999 (NFPA, 1999), therefore it has a precedent. This research is to assess whether the multi-purpose domestic fire sprinkler system can be applied to the Australian situation and result in a more cost-effective sprinkler system than those installed to the requirements of AS 2118.5:1995 (Standards Australia, 1995), the current standard for domestic fire sprinkler systems.

There are three standards referred to in this report specifically for domestic fire sprinkler systems: AS 2118.5:1995 (Standards Australia, 1995), NZS 4515:1995 (SNZ, 1995) and NFPA 13D:1999 (NFPA, 1999).

Other standards providing specifications for automatic sprinkler systems but not specifically for the domestic situation include:

- New Zealand – NZS 4541:1995 Automatic Fire Sprinkler Standard (SNZ, 1995).

- United States – NFPA 13:1996 Standard for the Installation of Sprinkler Systems (NFPA, 1996).

- United Kingdom – BS 5306: Part 2:1990 Fire Extinguishing Installation and Equipment on Premises – Specification for Sprinkler Systems, Technical Bulletin 14:1990 Sprinkler systems for dwelling houses, flats and transportable homes.

- Australia – AS 2118:1995 SAA Code for Automatic Fire Sprinkler System (Standards Australia, 1995 b).

The following provides and outline of the current Australian Sprinkler Standard, details of the proposed multi-purpose domestic fire sprinkler system as defined by NFPA 13D:1999 (NFPA, 1999). The Australian Standard, AS 2118.5:1995 (Standards Australia, 1995), is compared to NFPA 13D:1999 (NFPA, 1999), with deviations from the current Australian Standard, AS 2118.5:1995 (Standards Australia, 1995), outlined.

7.2 Australian Standard AS 2118.5:1995 – Domestic

The purpose of this standard is to provide a sprinkler system which will aid in the detection and control of residential fires in Class One buildings and thus provide improved protection against injury, life loss and property damage.

A sprinkler system installed in accordance with this Standard is expected to prevent flashover (total involvement) in the room of fire origin. The prime objective of a domestic life safety sprinkler system is to allow the occupant to escape in the event of fire (Standards Australia, 1995).

In preparing the Standard, the committee considered the US National Fire Protection Association (NFPA) 13D 'Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Mobile Homes' (NFPA, 1999). However, the design option allowing for a multi-purpose sprinkler system has been omitted.

AS 2118.5:1995 (Standards Australia, 1995) is divided into five sections: scope and general, design and installation requirements, marking and identification components and appendices.

The five sections of the domestic sprinkler standard outline:

Section 1 – Scope and General – outlines the objective of the standard and considers the potential to include new designs and innovations; a list of documents referenced in the standard are given, along with definitions and a description of the relevant application of the document.

Section 2 – Design and Installation Requirements – a list of sprinkler system components is provided and details of the criteria for the system's working drawings are given. The section outlines design and installation requirements for: water supply, design criteria, sprinklers, system types, pipe sizing, piping layouts and the extent of sprinkler protection.

Section 3 – Marking and Identification – requires the system to be identified, a site plan provided, details provided about replacement sprinklers, and operating instructions for the system.

Section 4 – Components – gives details of the following components: valves and drains, pressure gauges, piping, piping support, sprinklers, painting and ornamental finishes and alarms.

Section 5 – Appendix – including recommended smoke alarm requirements, a copy of the completion certificate for the sprinkler system and details of a recommended maintenance program.

7.3 NFPA 13D:1999 Multi-Purpose Sprinkler System

As noted, the multi-purpose domestic fire sprinkler system is a sprinkler system design option allowable by the National Fire Protection Association of the United States' domestic sprinkler standard, NFPA 13D:1999 (NFPA, 1999).

NFPA 13D:1999, Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes (NFPA, 1999) is an equivalent Standard to AS 2118.5:1995 (Standards Australia, 1995). This standard, published by the National Fire Protection Association (NFPA), was developed in recognition of the need to reduce the annual life loss from fire in residential occupancies in the United States. Fire deaths in residential occupancies in the United States make up, on average, over 60% of the total loss of life from fire (NFPA, 1999). The NFPA 13D:1999 (NFPA, 1999) Standard was first adopted in 1975 as sprinkler design requirements for the domestic situation. NFPA 13D:1999 (NFPA, 1999) recognises the need for sprinkler systems to be designed specifically for the domestic situation, as opposed to the use of systems appropriate for commercial situations.

The NFPA Standard defines a multi-purpose sprinkler system as:

A piping system within dwellings and manufactured homes intended to serve both domestic and fire protection needs (NFPA, 1999).

NFPA 13D:1999 (NFPA, 1999) states that a piping system serving both sprinkler and domestic needs shall be considered to be acceptable where the following conditions are met:

1. Addition of 19 litres per minute to the sprinkler system demand (to allow for domestic supply at the time of a fire).

2. Smoke alarms are installed.

3. 'Listed' piping materials are used.

4. Otherwise acceptable to the plumbing/health authorities.

5. A sign labelling the system is installed.

A cost-benefit analysis of the proposed sprinkler system is undertaken in order to assess its cost-effectiveness (refer Section 11). The results of the cost-benefit analysis are compared with the cost of a domestic sprinkler system constructed to current Australian standards, as outlined by the Beever and Britton (1999) research, and a system constructed to current New Zealand standards (Duncan et al, 2000).

7.4 NFPA 13D:1999 Comparison to AS 2118.5:1995

Design criteria for a multi-purpose sprinkler system which differ from that of a stand-alone sprinkler system installed to the requirements of AS 2118.5:1995 (Standards Australia, 1995) include:

(a) Design Discharge

NFPA 13D:1999 – The system shall provide a discharge of not less than 68 L/min to any single operating sprinkler and not less than 49 L/min per sprinkler to the number of design sprinklers, but the discharge shall not be less than the listing of the sprinkler. The minimum operating pressure of any residential sprinkler shall be 7 psi (0.5 bar).

AS 2118.5:1995 – The sprinkler coverage and minimum pressure and flow discharge requirements for approved residential sprinklers shall be in accordance with the sprinkler approval listing criteria as specified on the manufacturer's data sheets. This standard relies on product specifications as opposed to specifying design discharge.

(b) Sprinkler Coverage

NFPA 13D:1999 – Maximum area protected by a single sprinkler is 13.4 m^2. The maximum distance between sprinklers is 3.7 m on pipeline and maximum distance to the wall is 1.8 m. The minimum distance between sprinkler heads in a compartment is 2.4 m.

AS 2118.5:1995 – Clause 2.5.5 states that sprinklers shall be positioned so that the response discharge times are not unduly affected by such obstructions as ceiling slope, beams or light fixtures. Positioning of residential sprinklers shall comply with the sprinkler approval listing criteria as specified on the manufacturer's data sheets. Again, AS 2118.5:1995 (Standards Australia, 1995) relies on product specifications.

(c) Extent of Sprinkler Protection

NFPA 13D:1999 – Sprinklers shall not be required in bathrooms of 5.1 m^2 and less; sprinklers shall not be required in clothes closets, linen closets and pantries of 2.2 m^2 and less; sprinklers shall not be required in garages, open attached porches, carports and similar structures, attics and concealed spaces.

AS 2118.5:1995 – Clause 2.9 states that sprinklers shall be installed in all areas except –

(a) Dedicated water closets not exceeding 2.0 m^2 floor area

(b) Clothes closets, linen closets and pantries where the area of the space does not exceed 2.5 m^2 and the walls and ceiling are lined with non-combustible materials

(c) Open external (i) porches, (ii) balconies, (iii) walkways, (iv) stairs

(d) Roof spaces, crawl spaces, spaces below floor and above ceilings, and other concealed spaces that are not intended, nor used, for living purposes, storage or the installation of equipment such as flexible ductwork, heating and refrigeration equipment

(e) Scope

NFPA 13D:1999 – The scope of this Standard covers the design and installation of automatic sprinkler systems for protection against the fire hazards in one- and two-family dwellings and manufactured homes. An example of a manufactured home is a camper van.

AS 2118.5:1995 – the Australian Standard has scope to cover Class One buildings as defined by the Building Code of Australia (ABCB, 1996).

Class 1 buildings are one or more buildings, which in association constitute –

(a) Class 1a – a single dwelling being –

(i) a detached house, or

(ii) one or more attached dwellings each being a building, separated by a fire-resisting wall, including a row house, terrace house, town house or villa unit; or

(b) Class 1b – a boarding house, guest house, hostel or the like with a total floor area not exceeding 300 m^2 and in which not more than 12 persons would ordinarily be resident

Which is not located above or below another dwelling or another class of building other than a private garage.

The Australian Standard covers hostels and guesthouses (up to specific requirements) but excludes manufactured homes.

(f) System Types

NFPA 13D:1999 – Clause 4.3.2 allows for dry pipe systems. Where piping is located in unheated areas subject to freezing, a dry pipe or anti-freeze system shall be allowed to be used.

For the Australian situation, Clause 2.6.2 states that dry and pre-action sprinkler systems are not classified as domestic sprinkler systems.

7.5 Sprinkler Proposal

The proposed multi-purpose sprinkler system varies in the following ways from the current requirements of AS 2118.5:1995 (Standards Australia, 1995) for the installation of domestic fire sprinkler systems:

1. AS 2118.5:1995 (Standards Australia, 1995) requires the domestic sprinkler system to be a stand-alone system. The current Australian Standard has no provisions for alternatives to the stand-alone system. The concept of the multi-purpose system, whereby the sprinkler system is integrated with the domestic plumbing arises from the NFPA Standard 13D (NFPA, 1999).

2. A control valveset is not a requirement for the multi-purpose sprinkler system. A sprinkler system installed to the requirements of AS 2118.5:1995 (Standards Australia, 1995) requires:

    - A non-return valve at the property boundary at the branch take-off to the sprinkler system (Standards Australia, 1995).

    - Stop valve – where an additional sprinkler stop valve is provided downstream of the sprinkler branch take-off, the following shall apply –

        - The stop valve shall be located adjacent to the alarm-initiating device.

        - The stop valve shall be located in the open position and monitored with an anti-tampering device which is connected to the local aural alarm and which shall be initiated by a change in status of the valve, and;

        - A non-return valve shall be installed adjacent to the stop-valve

    These control valves are not required where the sprinkler system is integrated with the plumbing and water is continuously flowing through.

3. Because only potable water is flowing through the system, no backflow prevention to the sprinkler branches are required. Issues of backflow preventions and the implications associated are investigated in Section 12.

4. An alarm indicating sprinkler operation or the requirement to evacuate is not included in the multi-purpose sprinkler system. A sprinkler system installed to AS 2118.5:1995 (Standards Australia, 1995) requires local alarms, activated by the flow of water, to be provided on all sprinkler systems and be connected to the building fire alarm system when provided (Standards Australia, 1995).

5. In the case of a stand-alone sprinkler system installed to the specifications of AS 2118.5:1995 (Standards Australia, 1995), a flow switch would trigger an alarm to indicate the sprinklers were operating. In the case of the multi-purpose system, where water is continuously flowing through it, a flow switch would be an inappropriate mechanism. It is recommended that domestic smoke alarms be installed along with the multi-purpose sprinkler system.

6. Clause 2.9 of AS 2118.5:1995 (Standards Australia, 1995) states that sprinklers shall be installed in all areas except –

   (a) Dedicated water closets not exceeding 2.0 m^2 floor area;

   (b) Clothes closets, linen closets and pantries where the area of space does not exceed 2.5 m^2, and the walls and ceiling are lined with non-combustible materials;

   (c) Open external: (i) porches, (ii) balconies, (iii) walkways, (iv) stairs;

   (d) Roof spaces, crawl spaces, spaces below floor and above ceilings and other concealed spaces that are not intended, nor used, for living purposes, storage or the installation of equipment such as flexible ductwork, heating and refrigeration equipment.

   The statistical analysis indicates that the likelihood of a fire originating in these areas is minimal.

7. The domestic load for the hydraulic design is taken to be 12 litres per minute. This design flow is based on the requirements of AS 2118.5:1995 (Standards Australia, 1995) and has been used on the basis of evidence presented by Beever and Britton (1999) indicating that the average demand per household unit in Australia peaks at 6 litres per minute.

8. It is assumed that installation of the sprinkler system will be carried out by approved plumbers, sprinkler contractors or others who have demonstrated competency to carry out the work.

9. The proposed integrated sprinkler and domestic plumbing system has no specific ongoing maintenance requirements. AS 2118.5:1995 (Standards Australia, 1995) states that the owner is responsible for the condition of the sprinkler system. Likewise, this is recommended for the multi-purpose sprinkler system. With the sprinkler system integrated with the domestic plumbing, the possibility of unintentional shut off of the water supply is minimised.

10. The proposed multi-purpose sprinkler system does not need to be connected to the Fire Service.

8. HOUSE DESIGN

For the purposes of the cost-benefit analysis and in order to assess details of sprinkler system design and installation, two design homes were chosen: a low cost three-bedroom home and a four-bedroom two storey home.

8.1 Three-Bedroom Home

The three-bedroom house is representative of a low-cost home. This home is that used in the Wade and Duncan (2000) study and the Duncan et al study (2000) for the New Zealand scenario. This design home is used in the Australian study to enable comparison to the outcomes from the New Zealand study. It is also typical of a low-cost, three-bedroom home in Australia.

The low-cost three-bedroom home was used as the design home for the sprinkler installation (refer Figure 16). The three-bedroom design home was used as representative of a standard low-cost family home. It was assumed that the home is located in the suburbs with access to water services and public amenities such as fire hydrants. The home is a single-level dwelling constructed of timber frame with corrugated galvanised steel roof, weatherboard exterior walls, aluminium windows and interior lining of gypsum plasterboard walls with particleboard finished floors.

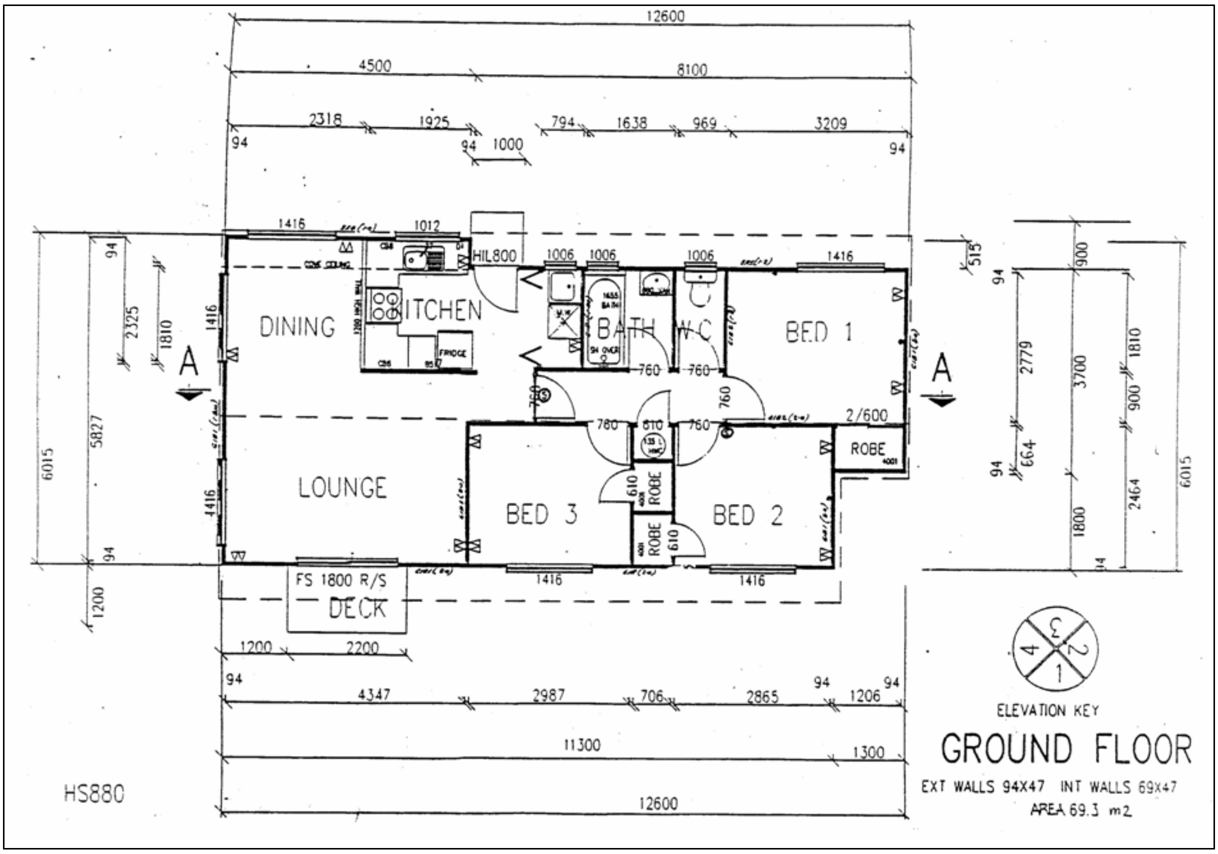


Figure 16: Floor Plan of Three-Bedroom Home

(Source – Wade and Duncan, 2000)

8.2 Four-Bedroom plus Family Room Home

In order to more accurately assess the cost-effectiveness of the proposed multi-purpose sprinkler system in other typical types of homes, a two-storey, four-bedroom plus family room home was used for an additional analysis. The four-bedroom house is based on an AVJennings pre-planned house design (the plans remain copyright to AVJennings).

As for the three-bedroom home, it is also assumed that the four-bedroom home is located in the suburbs with access to water services and public amenities such as fire hydrants. Features the AVJennings "The Manor" home include:

Four bedrooms	
Two bathrooms	
Powder room	
Family room	
Games room	
Double garage	
Living	286.6 m^2
Garage	40.3 m^2
Total Area	**326.9 m^2**
Width	13.68 m
Depth	21.04 m

Figure 17 is the floor plan for the four-bedroom home used for the sprinkler design.

Figure 17: Floor Plan of Four-Bedroom Design Home
(Source: AVJennings. Copyright to AVJennings Limited.)

To provide a three-dimensional perspective, Figure 18 is an artistic interpretation of the four-bedroom AVJennings home.

Figure 18: AVJennings Home
(Source: AVJennings. Copyright to AVJennings Limited.)

8.3 Multi-Purpose Sprinkler Design – Three-Bedroom Home

A multi-purpose sprinkler system design was carried out for a three-bedroom home. Details of the hydraulic calculations for the sprinkler design are included in Appendix I.

The design closely follows the specifications of NFPA 13D:1999 (NFPA, 1999) for the design of multi-purpose sprinkler systems and incorporates aspects of the current Australian Standard AS 2118.5:1995 (Standards Australia, 1995) for domestic sprinkler systems.

Figure 19 shows the layout for the sprinkler head placement in the three-bedroom home.

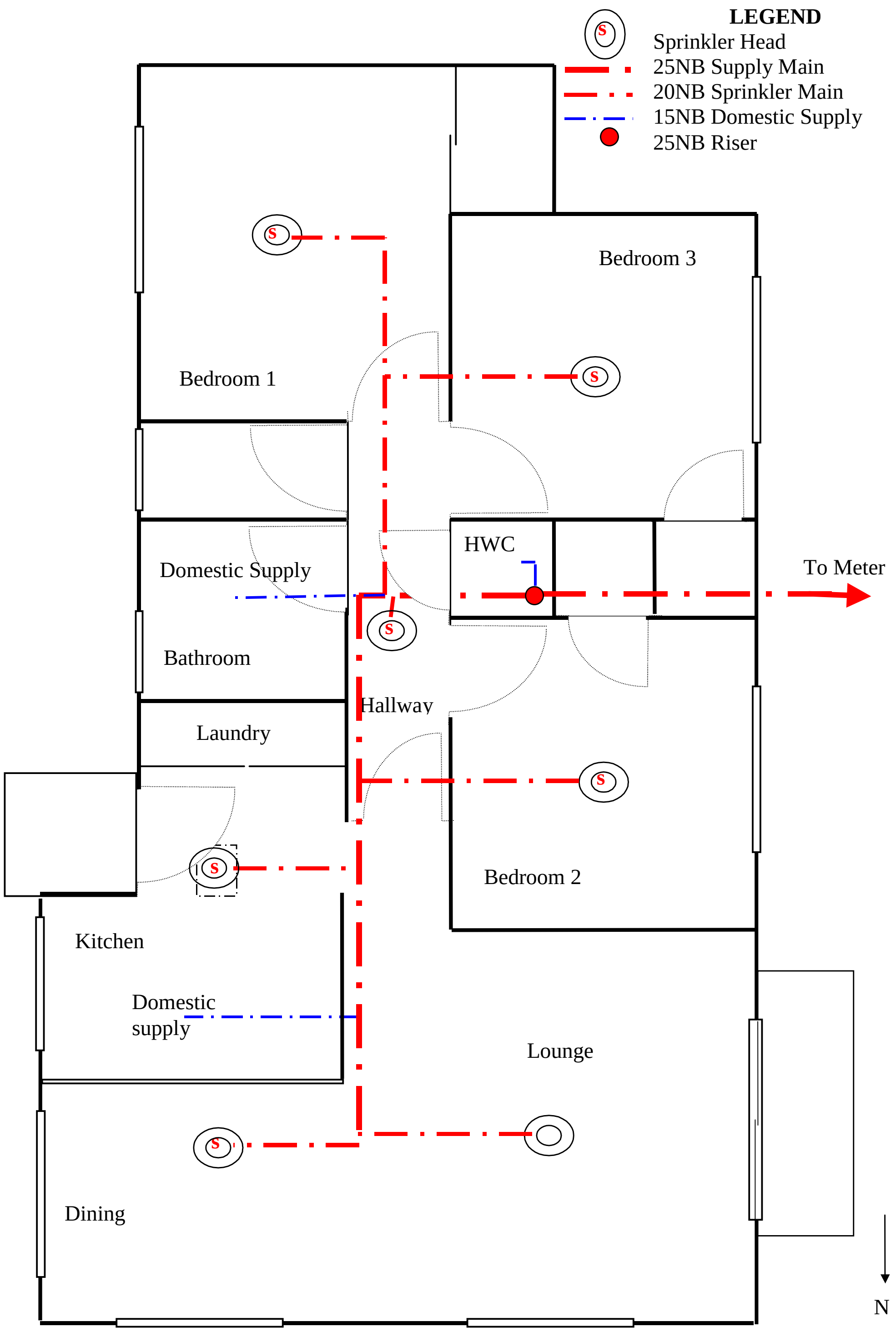


Figure 19: Plan View of Multi-Purpose Sprinkler System – Three-Bedroom Home

In summary, the specific details of the multi-purpose sprinkler system for the three-bedroom house are as follows:

- A single mains connection feeds both the sprinkler system and the domestic water supply.

- The multi-purpose sprinkler system designed to the described pipe sizes for the three-bedroom home requires a minimum pressure at the mains of 350 kPa to operate. Alterations to the pipe sizes would be required if mains pressure were less than the minimum.

- The domestic load for the hydraulic design of the combined plumbing and sprinkler system was taken to be 12 litres per minute, in accordance with AS 2118.5:1995 Clause 2.3.2.1 (Standards Australia, 1995).

- Pipe sizes for the mains feed, the plumbing features and the sprinkler branches are determined from the hydraulic calculations (refer Appendix I – Three-bedroom house design).

- For the three-bedroom house there are 7 sprinkler heads, each of residential listing; one in each of the three bedrooms, one in the hallway, one in each of the kitchen, lounge and dining room.

- The hydraulic calculations for the multi-purpose sprinkler system are based on two sprinkler heads operating.

8.4 Multi-Purpose Sprinkler Design – Four-Bedroom Home

A multi-purpose sprinkler system design was undertaken for the four-bedroom home. Criteria for the hydraulic design are similar to that of the three-bedroom home. Details of the hydraulic design for the three-bedroom design are included in the appendix (refer Appendix I – Four-bedroom house sprinkler design). The assumptions used in the design are the same as that used for the three-bedroom home sprinkler design. The design is based on a minimum pressure of 350 kPa at the mains due to a pressure loss of 320 kPa through the system based on the pipe sizes quoted and two sprinkler heads operating (refer Appendix I for details of the hydraulic calculations).

Figure 20 and Figure 21 show the layout for the placement of sprinkler heads in the four-bedroom home.

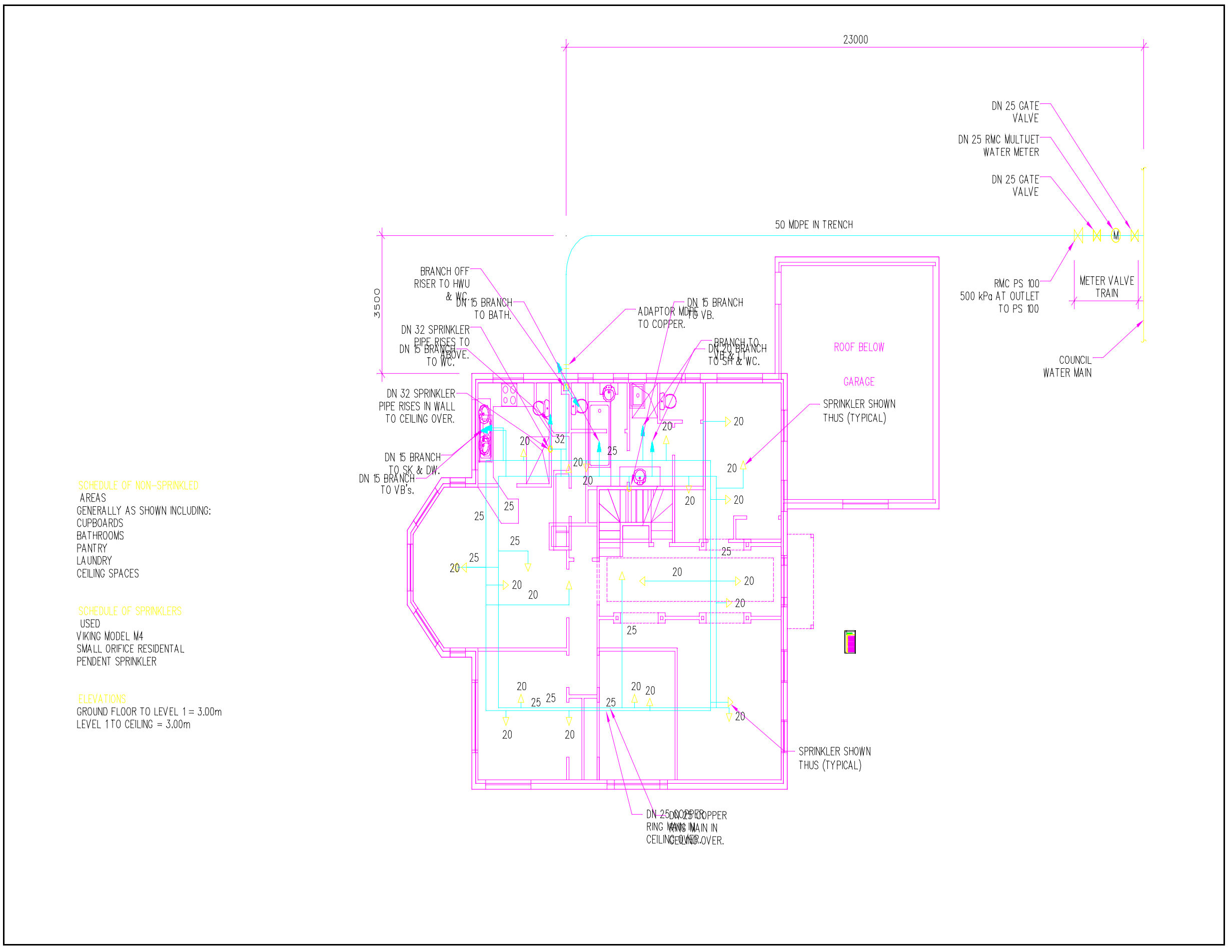


Figure 20: Sprinkler Plumbing – Plan View

(not to scale)

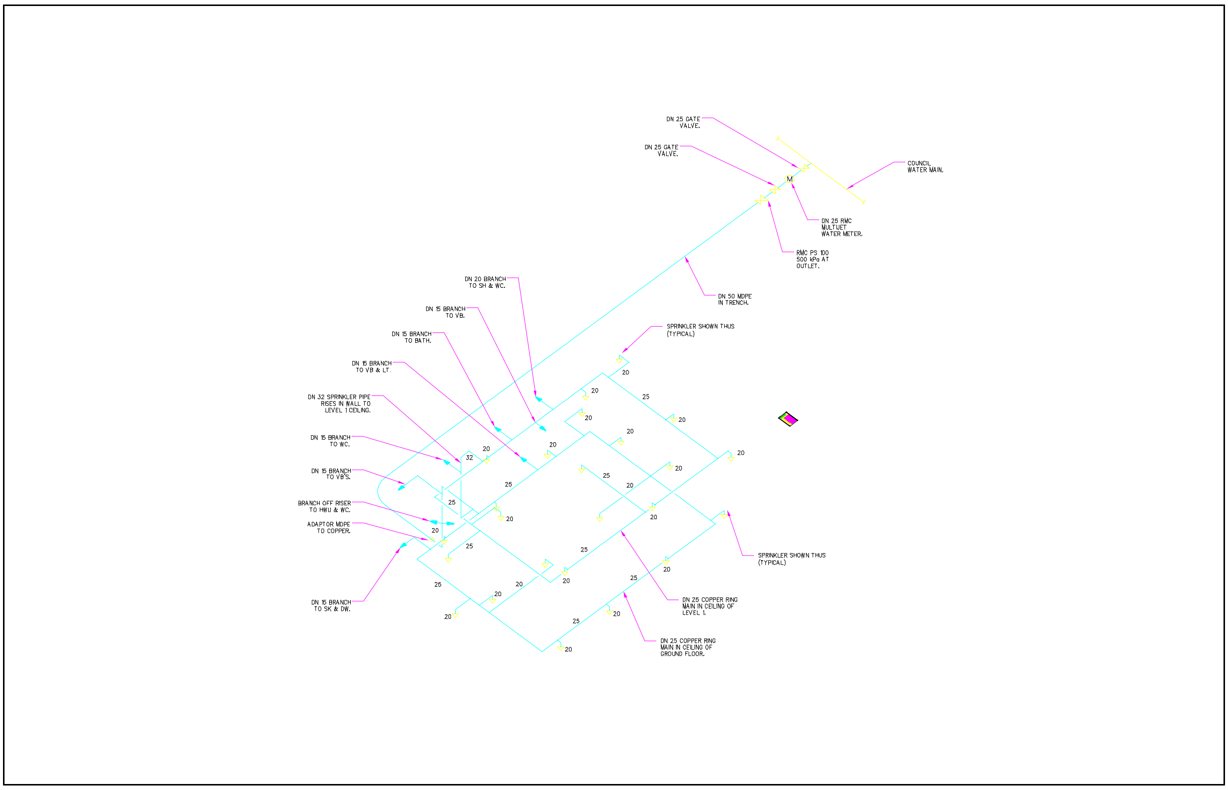


Figure 21: Sprinkler Plumbing – Isometric View

(not to scale)

8.5 Summary of Hydraulic Design

The following Table 15 is a summary of the pressure loss through the combined sprinkler and domestic plumbing system. The pressure loss through the system for the four-bedroom home is less than for the three-bedroom home due to the pipe configurations. The three-bedroom home sprinkler system has been designed using 'branches' and the four-bedroom home has been designed using a 'loop system' that is hydraulically more efficient.

Table 15: Pressure Requirements for Multi-Purpose Sprinkler System

Design	**Pressure Loss Through System**
Three-bedroom home	329 kPa
Four-bedroom home	321 kPa

The hydraulic calculations are based on two sprinkler heads operating simultaneously and hence the water-pressure requirements for the two. If the pressure at the mains varied above and below the pressure loss through the system, the result would be a variation in the pipe sizes of the system.

8.6 Alternative Multi-Purpose Sprinkler Design

Stand-alone sprinkler systems built to the requirements of AS 2118.5:1995 require backflow prevention devices to prevent stagnant water contained in the sprinkler piping contaminating the potable water. However multi-purpose systems, under most circumstances, will reduce the likelihood for the need for such protection because the water is continuously being drawn off by the domestic use and will not become stagnant. With this in mind, the water supply plumbing should be designed so that any 'dead legs' to sprinklers are kept as short as possible in order to restrict the amount of stagnant water in the system. Implications from stagnant water left in lengths of sprinkler piping are discussed in Section 12 of this report.

In circumstances where contamination and/or stagnant water is an issue, the multi-purpose system can be designed as a 'loop' with sprinklers on short droppers from the loop and branches from the loop to domestic outlets. Such a design will mean that there is very little static water in the system. Another advantage of this design is that the pressure losses in the 'loop' are considerably reduced because water is flowing to each sprinkler head from two directions, in fact the loss is a quarter of that in the same length of pipe at the same flow from one direction only. The additional pipe required for the 'loop' design will be an added cost to the system.

In the case of the four-bedroom home multi-purpose sprinkler design, it is envisaged that designing the system as a 'loop' would not excessively increase the installation costs.

9. RISK ASSESSMENT

A risk assessment approach whereby the influence on expected numbers of injuries and fatalities caused by a reduction in sprinkler coverage is used to assess the effectiveness of the multi-purpose sprinkler system for the Australian situation.

9.1 Risk Assessment Objectives

The risk assessment objectives are to:

(1) Investigate the number and location in the premises of injuries and fatalities as a result of domestic fires.

(2) Determine the impact on the number of injuries and fatalities as a result of installing combinations of domestic smoke alarms and sprinklers.

(3) Assess the impact on the number of injuries and fatalities as a result of omitting sprinkler heads from areas where fires are less likely to originate.

9.2 Event Tree

The event tree used to assess the objectives of the risk assessment is similar to that developed for the New Zealand analysis (Duncan et al, 2000). The event tree used for the New Zealand study is adapted for the Australian situation as determined by Australian fire incident statistics.

A sample of the event tree used in this analysis is included in Appendix II.

9.2.1 Nomenclature and statistics

Diagrammatic representations of event trees use symbols to represent where selections are made: squares represent decisions to be made and circles represent where selections are made (Clemen, 1991).

Conditional probabilities are associated with each chance event in the event tree. The probabilities are determined from Australian domestic fire incident statistics.

9.2.2 Detection and intervention combinations

Four combinations of detection and intervention are to be analysed (refer Table 16).

Table 16: Detection and Intervention Combinations

Option	Detection	Intervention
1	Smoke Alarm	Sprinkler
2	Smoke Alarm	No Sprinkler
3	No Smoke Alarm	Sprinkler
4	No Smoke Alarm	No Sprinkler

9.2.3 Analysis methodology

For analysis, probabilities are associated with each chance event. The likelihood of fire occurring per room is multiplied by the reliability of the sprinkler operating and effectively reaching the fire, then multiplied with the reliability of the smoke alarm activating and alerting the occupants, to achieve an estimate of the likelihood of this sequence of events occurring. The likelihood of this event sequence is in turn multiplied by the consequence (expected number of injuries and fatalities associated with the sprinkler and smoke alarm combinations) to provide an expected number of injuries and fatalities. The expected number of injuries and fatalities is multiplied by the probability of fire occurrence to determine the expected annual number of injuries and fatalities as a result of the sprinkler and smoke alarm combinations (refer Appendix II).

9.3 Statistics

Probabilities are associated with each chance event in the event tree. These probabilities are derived from domestic fire incident statistics.

9.3.1 Probability of fire occurrence

The New Zealand analysis (Duncan et al, 2000) used a fire incident rate of 0.004 fires per household per year. The analysis conducted by Beever and Britton (1999) stated the fire incident rate for Australia to be 0.00187 fires per household per year and the United States fire incident rate is found to be 0.0027 fires per household per year (FEMA, 1997). Statistics analysed in this study show the fire incident rate to be close to 0.0018 fires per household per year (refer Table 6).

For this analysis, a fire incident rate of 0.002 fires per household per year is used. A sensitivity analysis was undertaken to determine the influence the fire incident rate has on the cost-effectiveness of the proposed multi-purpose sprinkler system (refer Section 11.6.1). Choice of the incident rate is due to:

- Beever and Britton (1999) fire incident rate of 0.00187 is based on national statistics for a limited sample of fire incident statistics.

- The statistics provided by AFAC for this study are only for reported fire incidents. A proportion of fire incidents go unreported due to, for example, early detection by a smoke alarm. These unreported fires are subsequently considered by the slightly higher fire incident rate than that used in the Beever and Britton (1999) study.

9.3.2 Area of fire origin

For analysis of the number of injuries as a result of fires in the home, the following distribution of area of fire origin was used:

Egress	2.6%
Lounge	17.7%
Bedroom	28.3%
Other	7.4%
Kitchen / Dining	34.6%
Toilet / Bathroom	0.7%
Laundry	3.0%
Cupboard / Storage / Ceiling Cavity	2.2%
Garage / Carport	3.5%

The distribution of area of fire origin resulting in an injury originates from analysis of statistics provided by AFAC for this study.

For analysis of the number of fatalities as a result of fires in the home, the following distribution of area of fire origin was used:

Lounge	23.6%
Bedroom	31.1%
Kitchen / Dining	16.5%
Egress	1.4%
Toilet / Bathroom	1.2%
Laundry	1.3%
Cupboard / Storage / Ceiling Cavity	2.7%
Garage / Carport	2.4%
Other	19.8%

The proportion of fatal fires originating from fire in the kitchen, lounge or bedroom is determined from the statistics provided in Table 8. These three leading areas of fire origin which result in a fatality are consistent with those presented in the Beever and Britton (1999) study which, for the period 1989 to 1994, show the bedroom to be the most common origin for a fatal fire followed by the living room then the kitchen.

The proportion of fires distributed to egress, toilet/bathroom, laundry and cupboard/storage/ceiling cavity originate from United States statistics (source NFPA 13D:1999, Table A-1-2(b)).

Fatal fires originating in the garage (2.4%) is consistent with statistics used in the New Zealand analysis (Duncan et al, 2000) and is greater than the United States statistics which show 1.2% of fatal fire originating in the garage/carport area. The use of a proportion greater than shown by the United States statistics accounts for variation in garage construction techniques, particularly fire separation.

9.4 Assumptions

Australian domestic fire incident statistics were analysed and the following assumptions with respect to smoke alarm reliability, sprinkler head reliability, fatality rates and injury rates were made.

9.4.1 Smoke alarm reliability

There are several installation options for domestic smoke alarms, including: single battery-operated, single mains-powered, several interconnected and battery-operated, several interconnected and mains-powered. Based on the assumptions made by Wade and Duncan (2000), the estimated probabilities of detecting a fire range from approximately 60% for a single battery-operated alarm to around 90% for four interconnected alarms.

The analysis undertaken by Wade and Duncan (2000) take the smoke alarm reliability to be 74%, based on the installation of four battery-operated alarms.

Beever and Britton (1999) undertook a series of risk analyses to determine the likelihood of the smoke alarm not providing a warning. The risk analysis was undertaken for a selection of smoke alarm combinations and the results are as follows (refer Table 17):

Table 17: Reliability of Smoke Alarm

Smoke Alarm Configuration	Probability of Not Providing a Warning
Battery-powered smoke alarm in corridor	0.410
Mains-powered smoke alarm in corridor	0.272
Five interconnected battery-powered smoke alarms	0.163
Five interconnected mains-powered smoke alarms	0.127

(Source: Beever and Britton, 1999)

For the analysis, the reliability of a mains-powered smoke alarm is used. This smoke alarm configuration is the same as that required by the Building Code of Australia (ABCB, 1996). The probability of the smoke alarm not providing a warning is therefore 27.2%, hence the smoke alarm will activate effectively 72.8% of the time.

9.4.2 Sprinkler effectiveness

Marryatt (1988) states that fire sprinkler systems are 99.46% reliable. This reliability figure is based on New Zealand and Australian sprinkler system data from 1886-1986. The reliability figure of 99.46% represents cases where the sprinkler system has operated and successfully controlled the fire. The figure neglects to include instances where the sprinkler system has been disconnected from the water supply.

For the New Zealand analysis (Duncan et al, 2000), if a sprinkler head was installed in the room of fire origin, it was determined that it would operate and water successfully reach the fire 95% of the time. Reliability is not assigned to the entire sprinkler system, rather a likelihood of operation is worked out from the probability of water successfully reaching the fire, if there is a sprinkler in the room of origin.

In the case of the sprinkler system being integrated with the domestic plumbing, there is early warning of interruption to the water supply. In the case of the conventional, stand-alone sprinkler system built to the requirements of AS 2118.5:1995 (Standards Australia, 1995), disruption to the sprinkler water supply may go undetected until maintenance checks are made, or when the sprinkler system is required to operate. Whereas, it is immediately evident if water supply to domestic plumbing fixtures is interrupted in an occupied home. Therefore, it is assumed that the inherent reliability of the sprinkler head will be no less than for conventional sprinkler systems.

A reliability of 95%, as used for the New Zealand study (Duncan et al, 2000), is used in the risk assessment analysis. A sensitivity analysis was undertaken to determine the influence reliability has on the expected numbers of lives and injuries saved as a result of installation of the multi-purpose sprinkler system (refer Section 10.6).

9.4.3 Fatality rates

For the case of installation of sprinkler systems, Beever and Britton (1999) used 7 deaths per 1000 house fires where no sprinkler systems were present and between 1.46 and 3.89 deaths per 1000 house fires where sprinkler systems were present.

Fire incidents analysed in this report show the average fatality rate to be 7.8 fatalities per 1000 house fires in Australia (refer Table 7).

The Scottsdale study, where domestic sprinklers were installed in a community (Home Fire Sprinkler Coalition, 1997), states that the domestic sprinkler system has the potential to reduce the number of domestic fire fatalities by 80-90%.

Wade and Duncan (2000) conclude the following reductions in fatality rates as a result of the installation of smoke alarms (refer Table 18)

Table 18: Fatality Rates with Smoke Alarms

Installation Option	Fire Death Rate per 1000 House Fires
Four, battery (1-year) operated alarms	2.8
Four, battery (10-year) operated alarms	2.5
No alarm	6.0

(Source – Wade and Duncan, 2000)

The fire death rate of 2.8 deaths per 1000 house fires for the option of four battery (1-year) operated alarms, was used for the New Zealand risk assessment (Duncan et al, 2000).

Table 19 below shows the fire death rates for the configurations of smoke alarms and sprinklers as used for the New Zealand analysis (Duncan et al, 2000).

Table 19: Fatality Rates Used in Risk Assessment – New Zealand Analysis

Option	Consequence – Expected Deaths per 1000 House Fires	Reduction in Fatalities
No smoke alarm / no sprinkler	6	
Smoke alarm / no sprinkler	2.8	53%
No smoke alarm / sprinkler	1.2	80%
Smoke alarm / sprinkler	1	83%

(Source: Duncan et al, 2000)

Beever and Britton (1999) assessed the fatality rates for different alarm configurations to be (refer Table 20):

Table 20: Fatality Rates with Smoke Alarms

Smoke Alarm Configuration	Fatalities per 1000 Fires
Single battery-powered alarm	4
Single mains-powered alarm	3
Five interconnected battery-powered alarms	2
Five interconnected mains-powered alarms	2

(Source: Beever and Britton, 1999)

A risk analysis undertaken by Beever and Britton (1999) found the probability of a mains powered smoke alarm not being heard and resulting in a fire to be 0.004.

Australia has made it compulsory to install smoke alarms in one- and two-family homes (excluding Class 1a buildings in the Northern Territory) (ABCB, 1996). It is a requirement that the smoke alarms be connected to the mains power (if power is supplied to the building). It is not a requirement that the smoke alarms be interconnected. Therefore, the risk assessment is conducted on the basis of single, stand-alone mains-powered smoke alarms being installed.

Table 21 outlines the fatality rates used for the Australian analysis.

Table 21: Fatality Rates Used in Risk Assessment

Option	Consequence – Expected Deaths per 1000 House Fires	Reduction in Fatalities
No smoke alarm / no sprinkler	7	
Smoke alarm / no sprinkler	3	40%
No smoke alarm / sprinkler	1.4	80%
Smoke alarm / sprinkler	1	86%

The consequence of expected deaths per 1000 house fires originate from (refer Table 22):

Table 22: Origin of Fatality Rates

Option	Origin of Expected Deaths
No smoke alarm / no sprinkler	Beever and Britton (1999) used 7 deaths per 1000 house fires. AFAC statistics show the death rate to be 7.8 deaths per 1000 house fires (refer Table 7). 7 was chosen as the same as the Beever and Britton (1999) statistics and close to that determined from fire incident statistics provided for this report.
Smoke alarm / no sprinkler	Beever and Britton (1999) undertook a risk analysis which found that with a single mains-powered smoke alarm installed, the expected fatality rate would be 3 deaths per 1000 house fires. This is consistent with New South Wales fire brigades statistical analysis of fire incidents (Nicolopoulos, 1996)
No smoke alarm / sprinkler	The New Zealand study (Duncan et al, 2000) derived that the sprinkler system would reduce the fatality rate by 80%. The Scottsdale Study (Home Fire Sprinkler Coalition, 1997) stated that a sprinkler system alone is likely to reduce

	the expected number of deaths as a result of home fires by 80% to 90%. An 80% reduction is chosen for this study from the lower bound of the Scottsdale study.
Smoke alarm / sprinkler	The New Zealand study (Duncan et al, 2000) derived that the combination of a sprinkler system with a smoke alarm would reduce the number of deaths by 83%. The Scottsdale study (Home Fire Sprinkler Coalition, 1997) states sprinklers alone can reduce the death rate by 80% to 90%. An 86% reduction in death rate is chosen for this analysis to represent the upper range of the Scottsdale study where, as to the requirements of NFPA 13D, the homes had smoke alarms installed as well as sprinklers.

9.4.4 Injury rates

In relation to the installation of domestic sprinkler systems, Beever and Britton (1999) used 70 injuries per 1000 house fires where no sprinkler systems were present. Beever and Britton (1999) consider fire injury rates in the range of 15 to 30 per 1000 fires for sprinklered one- and two-family homes.

From the AFAC statistics provided for this study, the average injury rate resulting from fires in the home is calculated to be 40 injuries per 1000 house fires.

Wade and Duncan (2000) estimate that the presence of a domestic fire sprinkler system would reduce the number of injuries caused by domestic fires from 40 to 15 per 1000 fires – a 63% reduction.

Table 23 outlines the injury rates used for the Australian analysis.

Table 23: Injury Rates Used in Risk Assessment

Option	Consequence – Expected Deaths per 1000 House Fires	Reduction in Injuries
No smoke alarm / no sprinkler	60	
Smoke alarm / no sprinkler	30	50%
No smoke alarm / sprinkler	30	50%
Smoke alarm / sprinkler	15	76%

9.5 Risk Assessment Results

Figure 22 compares the results of the risk assessment for each combination of sprinkler system and smoke alarm option for the expected numbers of injuries and fatalities in the state of Victoria. The results are for total coverage where sprinkler heads are installed in every room, including, for example, in cupboards, which is in excess of the requirements of AS 2118.5:1995 (Standards Australia, 1995).

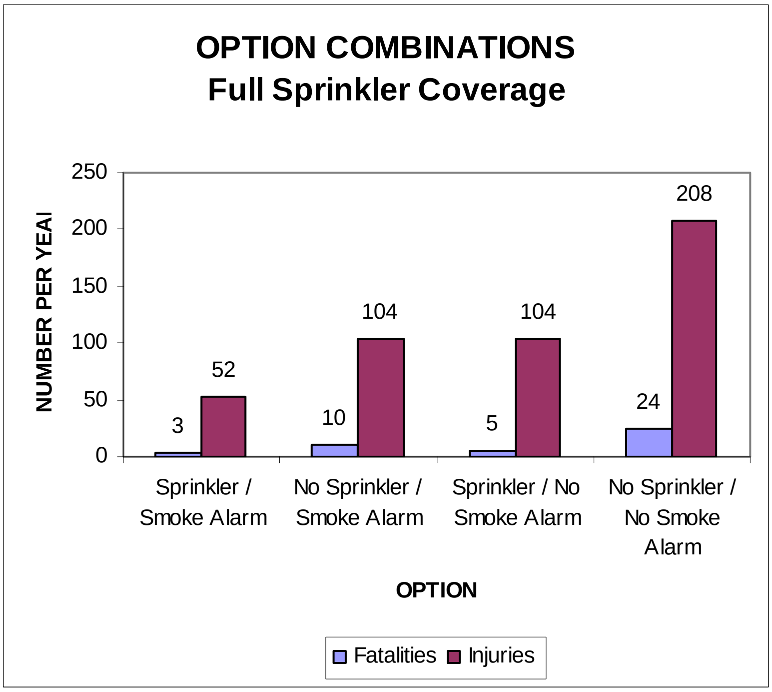


Figure 22: Results of the Risk Assessment – Total Sprinkler Coverage

9.5.1 Fatalities

Results of the risk assessment for total sprinkler coverage are as follows (refer Table 24).

Table 24: Results of Risk Assessment – Full Sprinkler Coverage

Option	Expected Fatalities/Year (Victoria)	Reduction
Sprinkler / smoke alarm	3	86%
No sprinkler / smoke alarm	10	57%
Sprinkler / no smoke alarm	5	80%
No sprinkler / no smoke alarm	24	

Results of the analysis show that the combination of sprinkler system and smoke alarm is likely to reduce the number of fatalities in domestic fires by 86% (refer Table 24). A sprinkler system alone has the potential to reduce the number of fatalities by 80%. A smoke alarm alone is likely to reduce the number of fatalities by 57%.

9.5.2 Injuries

Results of the risk assessment for total coverage are as follows (refer Table 25).

Table 25: Results of Risk Assessment – Injuries

Option	Expected Injuries/Year (Victoria)	Reduction
Sprinkler / smoke alarm	52	75%
No sprinkler / smoke alarm	104	50%
Sprinkler / no smoke alarm	104	50%
No sprinkler / no smoke alarm	208	

Results of the analysis show that the combination of a full coverage sprinkler system and smoke alarm is likely to reduce the number of injuries in domestic fires by 75% (refer Table 25). A sprinkler system alone has the potential to reduce the number of injuries by 50%. A smoke alarm alone is likely to reduce the number of injuries by 50%.

9.6 Sensitivity Analysis

The results reported in Section 10.5 rely on the assumption that the reliability of the sprinkler head operating and effectively reaching the fire is 95% given it is located within the room of fire origin. Figure 23 shows the influence that reduction of the likelihood that the sprinkler head operates and effectively reaches the fire has on the expected number of injuries and fatalities from domestic fires in Victoria.

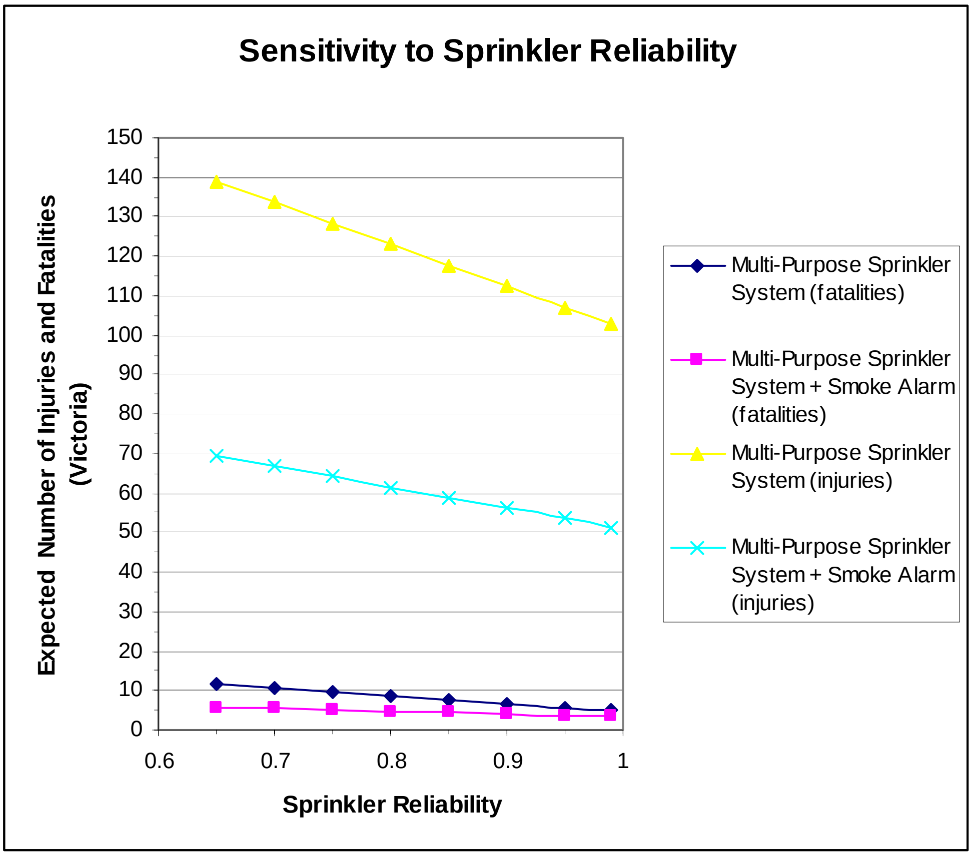


Figure 23: Influence on Number of Fatalities and Injuries as a Result of Reduction in Sprinkler Reliability

Reducing the reliability of the sprinkler to 70% still has the effect of approximately halving the expected number of injuries and fatalities as a result of a fire in the home.

9.7 Discussion

The risk assessment set out to: investigate the number and location of injuries and fatalities as a result of domestic fires; determine the impact on the number of injuries and fatalities as a result of installing combinations of domestic smoke alarms and sprinklers; and assess the impact on the number of injuries and fatalities as a result of omitting sprinkler heads from areas where fires are less likely to originate.

The assessment analysed four options for sprinkler system and smoke alarm combinations to determine their influence on injury rates and fatality rates as a result of fires in the home. Results show that the combination of sprinkler system and smoke alarm is the most successful at reducing the number of injuries and fatalities as a result of fire in the home.

9.7.1 Reduced sprinkler coverage

Figure 24 shows the number of injuries and fatalities resulting from fire in a home when the coverage of the sprinkler system has been reduced. Sprinkler heads have been removed from the bathroom, toilet, storage/cupboard/ceiling space.

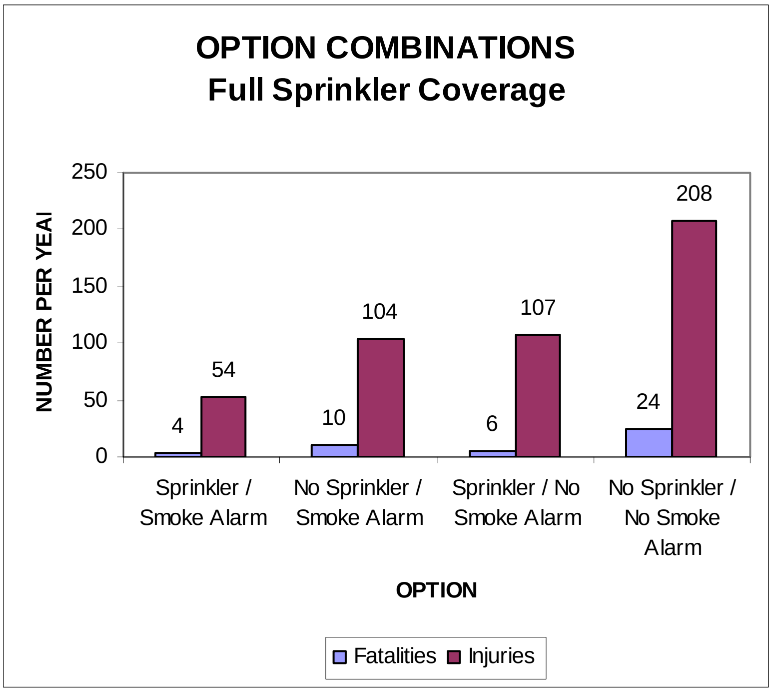


Figure 24:Comparison of Expected Injuries with Reduced Sprinkler Coverage – Victoria

Table 26: Comparison of Full Coverage Sprinkler System with Reduced Sprinkler Coverage

Option	Fatalities/Year (Victoria)		Injuries/Year (Victoria)	
	Full Coverage Sprinkler System	Reduced Coverage Sprinkler System	Full Coverage Sprinkler System	Reduced Coverage Sprinkler System
Sprinkler and Smoke Alarm	3	4	52	54
Sprinkler and No Smoke Alarm	5	6	104	107
No Sprinkler and No Smoke Alarm	24		208	

Table 26 compares the numbers of expected injuries and fatalities as a result of fire in the fully sprinklered home to the numbers as a result of reducing the sprinkler coverage. Removing sprinklers from toilets, bathrooms, and wardrobes/cupboards/ceiling cavities has minimal effect on the expected numbers of injuries and fatalities from fires in the home.

10. COST-BENEFIT ANALYSIS

10.1 Introduction

A cost-benefit analysis was undertaken for multi-purpose sprinkler systems installed in both the three-bedroom and the four-bedroom home. The analysis was undertaken to evaluate the cost-effectiveness of the proposed system. The cost-benefit analysis is based on the methodology undertaken by Beever and Britton (1999) and also used in the New Zealand study (Duncan et al, 2000).

The following describes the input variables to be used in the analysis. The results of the cost-benefit analysis are to be compared with the cost of a domestic sprinkler system constructed to current Australian Standards.

10.2 Methodology

The cost-effectiveness of the proposed home fire sprinkler system is assessed through calculation of a cost per life saved, where cost per life saved is defined as:

$$\text{Cost per life saved} = \frac{\text{(installation costs + maintenance costs - savings in injury costs - savings in property losses)}}{\text{expected number of lives saved}}$$

For the analysis, a nominal discount rate of 7.5% and an inflation rate of 2% was used. An analysis period of 20 years is considered, and where components have a different working life the replacement costs are included. The domestic sprinkler system is assumed to have a working life of 30 years.

For the multi-purpose sprinkler system, a net present cost is calculated by subtracting the net present value of savings such as injuries avoided and direct savings of property from the net present value of the purchase, installation and maintenance costs. The net present value (NPV) per household is calculated using the formula:

$$\text{NPV} = \sum_{t=1}^{n} \frac{\text{Net yearly cost}}{(1+\text{discount rate})^{t}}$$

Where t = time (years) and n = number of years

10.3 Input Variables

10.3.1 Installation costs

Installation costs for the sprinkler system were obtained from three Victorian plumbers. The quotes indicate the price for installing the 'normal' domestic plumbing as well as the additional cost to extend the plumbing into a multi-purpose sprinkler system. Each pricing itemises costs for materials, labour and maintenance (refer Table 29 and Table 30). The sprinkler system and mains-powered smoke alarm are assumed to be installed during the time of house construction.

10.3.2 Maintenance

The onus for maintenance of the multi-purpose fire sprinkler system is to be placed on the owner of the system and hence no third-party maintenance fees are charged. AS 2118.5:1995 (Standards Australia, 1995) provides a schedule of recommended checklist items. It is expected that home-owners would be provided with instructions to enable them to check the flow rate from time to time in the system for example by using a bucket.

10.3.3 Injury costs

Beever and Britton (1999) derived a value of A$21,000 as the cost per fire injury. This included pain and suffering, patient and visitor transportation and estimated lost earnings and is the input value for injury costs in the Australian cost-benefit analysis.

A value of NZ$30,000 was used in the New Zealand study (Duncan et al, 2000). The NZ$30,000 was based on earlier cost-benefit studies from the US (Ruegg and Fuller, 1984) which used US$20,000. The US study was also the basis for the studies done by Rahmanian (1995) and Strategos (1989).

The Beever and Britton (1999) $21,000 for injury costs, adjusted to $21,500 for inflation, was used in this cost-benefit analysis.

10.3.4 Direct property losses

According to Beever and Britton (1999), direct losses arising from property damage for one- and two-family dwelling fires average approximately $10,000 per fire as sourced from AFIRS (1992/3) database.

For the Beever and Britton (1999) cost-benefit analysis, the cost of an unsprinklered house fire in New South Wales is used together with the percentage reduction observed in Scottsdale of 84%. This gives figures of average property loss of $24,000 for unsprinklered fires and $3,900 for sprinklered fires.

For sprinklered fires, a value of A$4,000 in property loss is assumed for this study. With a single mains-powered smoke alarm included with the sprinkler system, $3,000 average property loss is expected. With the smoke alarm alone,

$9,500 in property losses is assumed. With no system present, the Beever and Britton (1999) $24,000 adjusted for inflation to $24,500, is used as the expected cost of property losses in the analysis.

10.3.5 Expected number of lives saved

The assumptions of 7 deaths per 1000 house fires for unsprinklered dwellings is made (refer Table 22). As determined from the risk assessment analysis for the partial coverage multi-purpose sprinkler system, the following expected deaths per 1000 house fires were used in the cost-benefit analysis (refer Table 27).

Table 27: Fatality Rates Input to Cost-Benefit Model

Option	**Expected Deaths per 1000 House Fires**
Single mains-powered smoke alarm installed in the hallway	3
Multi-purpose sprinkler system with mains-powered smoke alarm installed in the hallway	1.1
Multi-purpose sprinkler system only	1.6
No system	7

10.3.6 Expected number of injuries

An injury rate of 60 per 1000 house fires was assumed for this study where no fire protection measures are installed. The expected number of injuries from the fire for the smoke alarm and sprinkler combinations are determined from the risk assessment. Table 28 below shows the injury rates used in the cost benefit analysis.

Table 28: Injury Rates Input to Cost-Benefit Model

Option	**Expected Injuries per 1000 House Fires**
Single mains-powered smoke alarm installed in the hallway	30
Multi-purpose sprinkler system with mains-powered smoke alarm installed in the hallway	15.4
Multi-purpose sprinkler system only	30.9
No system	60

10.3.7 Rate of fire incidents

Beever and Britton (1999) based the fire incident rate on statistics from the period of 1989/90 to 1993/94. They estimated the fire incident rate to be 1.87 reported fires per 1000 households in Australia (Beever and Britton, 1999).

From the Australian fire statistics supplied by AFAC for this report, a fire incident rate of 1.8 fires per 1000 household is calculated, which is similar to the Beever and Britton (1999) estimate.

For the analysis, a fire incident rate of 2 fires per 1000 households in Australia is chosen.

10.4 Input Costs

10.4.1 Three-Bedroom Home

Three quotes for installing the sprinkler system in the three-bedroom home were obtained. The prices for the installation of the plumbing and sprinkler fixtures are as follows (refer Table 29.):

Table 29: Three-Bedroom Home – Prices for Multi-Purpose Sprinkler Installation

	Plumbing Only			Plumbing + Multi-Purpose Sprinklers			Marginal Cost to Multi-Purpose Sprinklers		
Quote*	**Labour**	**Materials**	**Total**	**Labour**	**Materials**	**Total**	**Labour**	**Materials**	**Total**
1	$623	$776	**$1,399**	$1,153	$1,150	**$2,302**	$530	$374	**$904**
2	$765	$992	**$1,757**	$1,530	$1,880	**$3,410**	$765	$888	**$1,653**
3	$866	$483	**$1,349**	$1,309	$1,149	**$2,458**	$443	$666	**$1,109**
Average	**$751**	**$750**	**$1,502**	**$1,331**	**$1,393**	**$2,723**	**$579**	**$643**	**$1,222**

*Prices quoted are for installation at time of house construction.

The average prices from the quotes for installation of the multi-purpose sprinkler system in the three-bedroom home were used in the cost-benefit analysis ($1,222).

10.4.2 Four-Bedroom Home

Three quotes for installing the sprinkler system in the four-bedroom home were obtained. The prices for the installation of the plumbing and sprinkler fixtures are as follows (refer Table 30):

Table 30: Four-Bedroom Home – Prices for Multi-Purpose Sprinkler Installation

	Plumbing Only			Plumbing + Multi-Purpose Sprinklers			Multi-Purpose Sprinklers Only**		
Quote*	**Labour**	**Materials**	**Total**	**Labour**	**Materials**	**Total**	**Labour**	**Materials**	**Total**
1	$730	$1,630	$2,360	$1,440	$4,418	$5,858	$710	$2,788	$3,498
2	$789	$670	$1,459	$2,583	$3,456	$6,039	$1,794	$2,786	$4,580
3	$879	$863	$1,742	$2,942	$2,548	$5,490	$2,063	$1,685	$3,748
Average	**$799**	**$1,054**	**$1,854**	**$2,322**	**$3,474**	**$5,796**	**$1,522**	**$2,420**	**$3,942**

*Prices quoted are for installation at time of house construction
**Prices do not include sprinklers installed in the garage

The average prices from the quotes for installation of the multi-purpose sprinkler system in the four-bedroom home were used in the cost-benefit analysis ($3,942).

The original sprinkler design did not incorporate sprinkler heads in the garage. On analysis of the fire incident statistics for Australia, the garage is an area of fire origin where a fire is likely to originate and result in an injury or fatality. Four additional sprinkler heads would be required to add sprinkler coverage to the garage. The additional cost of installing sprinklers in the garage, calculated on a per sprinkler head basis (average cost of close to $165), would be $657.

The marginal cost for installing a multi-purpose sprinkler system into the four-bedroom home including the garage is $4,599. This value is used in the cost-benefit model.

10.4.3 Smoke Alarm Options

It is assumed that all smoke alarm units are replaced after 10 years (Beever and Britton, 1999).

For the cost-benefit analysis used in this study, the option of single mains-powered smoke alarms are considered. The prices for installation and maintenance from the Beever and Britton (1999) study are adjusted for inflation (2% for one year) resulting in the input cost of A$170 and maintenance of A$15 for replacing the back-up battery and home-owner's time. The smoke alarms are assumed to be installed at the time of house construction and replaced after 10 years.

The four-bedroom home was on two levels so, two mains-powered smoke alarms were considered appropriate for the analysis using an installed cost of

$290, and an annual maintenance cost of $30. The maintenance cost includes replacing the back-up battery and a small allowance for the home-owner’s time.

10.5 Cost-Benefit Results

The cost-benefit analysis was undertaken for the multi-purpose sprinkler system installed in both a three-bedroom home and a four-bedroom home. The results from the analysis, compared to those of the Beever and Britton (1999) home, are as follows (refer Table 31).

Table 31: Cost-Benefit Analysis Results

Option	$ Cost Per Life Saved	
Multi-purpose sprinkler system – three-bedroom (70 m^2) home	$3.31 million	
Multi-purpose sprinkler system – three-bedroom (70 m^2) home + mains-powered smoke alarm	$4.69 million	
Multi-purpose sprinkler system – four-bedroom (327 m^2) home	$19 million	
Multi-purpose sprinkler system – four-bedroom (327 m^2) home + mains-powered smoke alarm at each level	$20.4 million	
New sprinkler system to AS 2118.5:1995*	Production 150 m^2 House	$30 to $53 million
	Custom Built 210 m^2 House	$34 to $60 million
	Retrofit 150 m^2 House	$34 to $60 million

*Source: Beever and Britton (1999)

It should be noted that the house sizes and styles used for cost-benefit analysis in the Beever and Britton (1999) study, differ from those used in this study. The following table shows the installation and maintenance costs used for the Beever and Britton (1999) cost-benefit analysis, the major difference being the input value for annual maintenance for the sprinkler system. Annual maintenance costs significantly influence the cost-effectiveness of the system and this is shown in the sensitivity analysis to maintenance costs (refer Section 11.6.3).

Table 32: Installation and Maintenance Costs – Beever and Britton (1999)

House	Area of House	Cost for Sprinkler system	Annual Maintenance
Production House to AS 2118.5	150 m^2	$2,550	$500
Custom Built House to AS 2118.5	210 m^2	$3,300	$500
Retrofit to AS 2118.5	150 m^2	$3,300	$500

10.6 Discussion

10.6.1 Sensitivity to fire incident rate

The cost-effectiveness of the proposed multi-purpose sprinkler system is strongly influenced by the probability of fire occurrence. A higher fire incident rate makes the installation of the proposed sprinkler system considerably more cost-effective. Figure 25 shows the effect that increasing the fire incident rate has on the cost per life saved of the system.

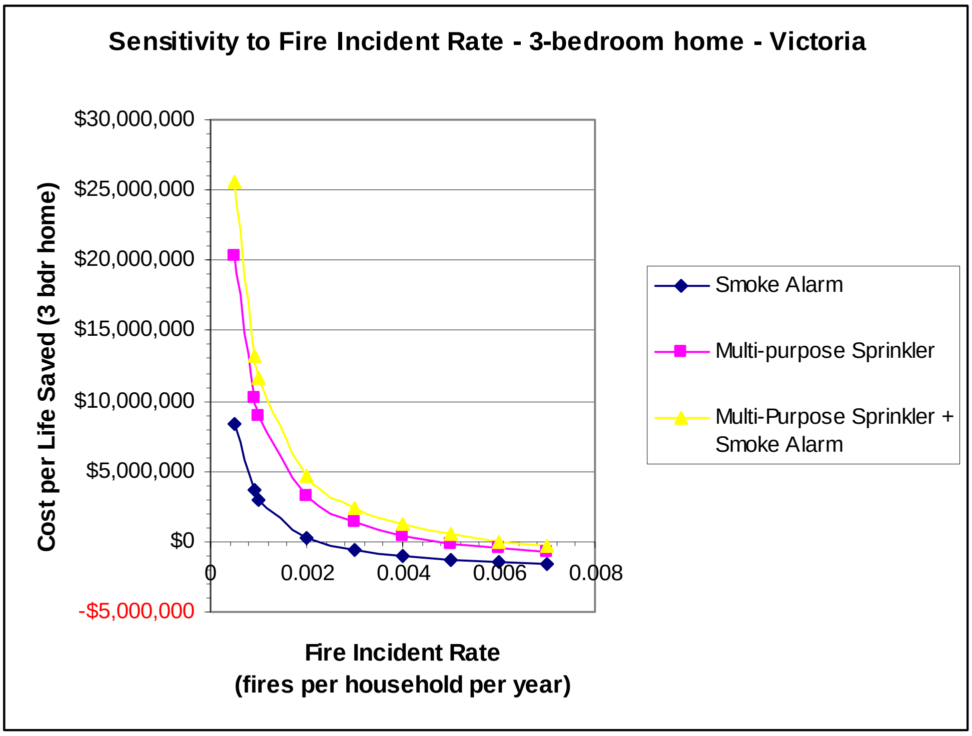


Figure 25: Sensitivity of Cost-Effectiveness to Fire Incident Rate

The sensitivity analysis shows that the installation of a multi-purpose sprinkler system becomes more cost-effective for risk groups, such as occupants of rental properties, where the likelihood of a fire occurring is greater than the Australian average.

10.6.2 Expected lives saved

For the state of Victoria, the expected annual number of fatalities as a result of home fires is 24. Table 22 shows the expected numbers of lives saved for Victoria due to the installation of multi-purpose sprinkler systems and smoke alarms.

Table 33: Expected Number of Lives Saved (Victoria)

Option	**Expected lives saved per year (Victoria)**	**Cost per life saved.** **3-bedroom home**	**Cost per life saved.** **4-bedroom home**
Mains-powered smoke alarm in hallway	13.9	$334,000	$2,523,000
Multi-purpose sprinkler system	18.7	$3,310,000	$19,000,000
Multi-purpose sprinkler system + mains-powered smoke alarm	20.5	$4,690,000	$20,400,000

The combination of the multi-purpose sprinkler system and smoke alarm has the greatest effect on reducing the number of fatalities as a result of fire in the home.

10.6.3 Sensitivity to annual maintenance costs

Figure 26 shows the influence annual maintenance costs have on the cost-effectiveness of the multi-purpose sprinkler system. Beever and Britton (1999) used an annual maintenance fee of A$500 for the sprinkler systems installed to AS 2118.5:1995 (Standards Australia, 1995), achieving costs per life saved in the range of $30 to $60 million. Using A$500 as the annual maintenance cost for the multi-purpose sprinkler system installed in the 4-bedroom home calculates the cost per life saved to be $47 million. This value is significantly more than the $19 million cost per life saved for a multi-purpose sprinkler system installed in the 4-bedroom home when no maintenance costs are incurred.

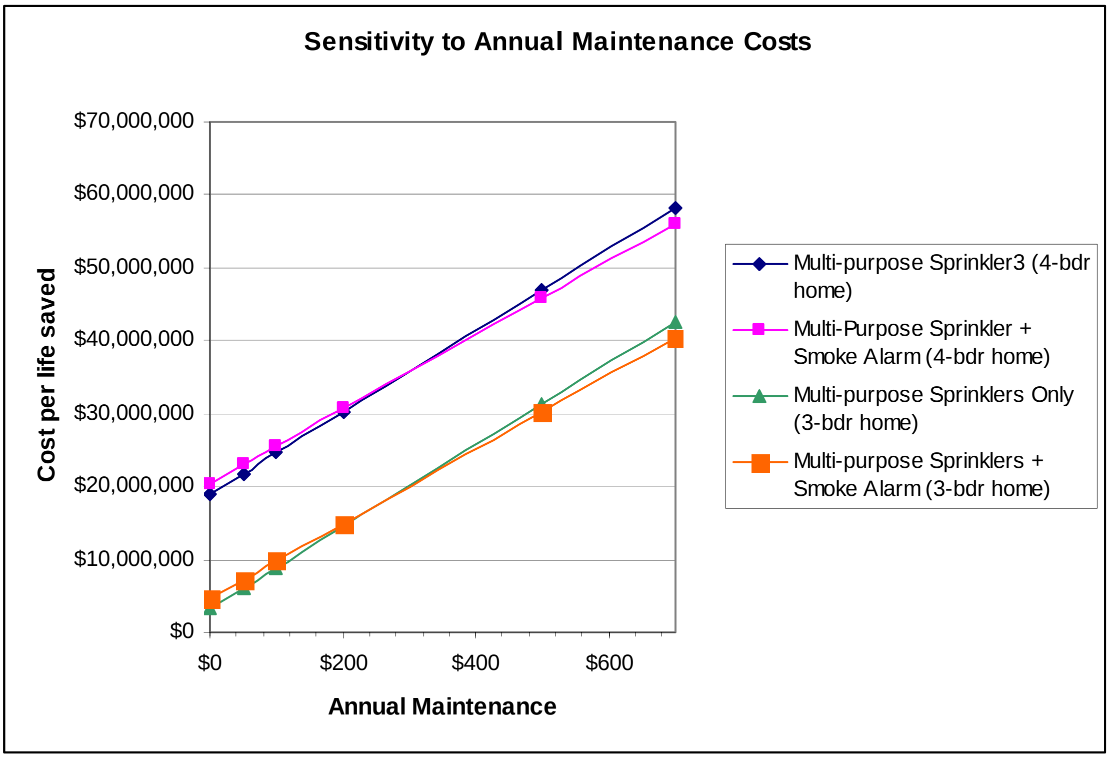


Figure 26: Sensitivity of Cost per Life Saved to Annual Maintenance Costs

10.6.4 Cost comparison of sprinkler systems

Table 34 compares the cost of the multi-purpose sprinkler system, on a per sprinkler head basis, with a sprinkler system installed to the requirements of AS 2118.5:1995 (Standards Australia, 1995).

Table 34: Comparative Cost of Sprinkler Systems

Sprinkler System Type	**Area of House**	**Total Cost of Sprinkler System**	**Number of Sprinkler Heads in System**	**Cost per Sprinkler Head**	**Cost of Annual Maintenance**
Production House to AS 2118.5*	150 m^2	$2,550	8	$320	$500
Custom Built House to AS 2118.5*	210 m^2	$3,300	10	$330	$500
3-Bedroom Home Multi-Purpose Design	70 m^2	$1,222	7	$175	$0
4-Bedroom Home Multi-Purpose Design	327 m^2	$3,942	21	$188	$0

(* Source: Beever and Britton, 1999)

Table 34 shows that the multi-purpose sprinkler system on a per sprinkler head basis costs approximately 2/3 the price of a sprinkler system installed to current Australia standards.

10.6.5 Comparative values of cost per life saved

A comparison of the cost per life saved for installation of the multi-purpose sprinkler system is made with similar values for 'cost of life' for other life saving initiatives, as provided by Beever and Britton (1999).

Table 35: Comparison of Life Saving Initiatives

Life Saving Initiative*	Cost per Life Saved
USA EPA Asbestos Regulations	$160,000,000
Domestic Sprinklers to AS 2118.5	$50,000,000
Residual Current Devices	$25,000,000
Multi-purpose Sprinkler System (4-bedroom home)	**$19,000,000**
Mandatory Airbags for New Cars	$7,000,000
Multi-purpose Sprinkler System (3-bedroom home)	**$3,300,000**
Interconnected Residential Smoke Alarms (5)	$3,200,000
Fences on Highway Central Reservations	$650,000
Influenza Vaccinations	$500,000
Malign Melanoma Awareness Campaign	$50,000
Suicide Prevention Program	<0

(* Source [excluding multi-purpose sprinkler system values]: Beever and Britton, 1999)

The cost per life saved as calculated for the installation of a multi-purpose sprinkler system in the three-bedroom home, was found to be $3.3 million, similar to that calculated by Beever and Britton (1999) for five interconnected smoke alarms.

The cost per life saved for a multi-purpose sprinkler system installed in the four-bedroom home was calculated to be $19 million which is less than the cost per life saved for installing residual current devices.

11. STAGNANT WATER

11.1 Introduction

Integrating the fire sprinkler system with the domestic plumbing results in the addition of extra lengths of dead-end pipe. Although the combined sprinkler and plumbing system can be designed so as to minimise the number of dead-end lengths, the addition of the sprinklers to the plumbing system does still result in an increase in their number. The issue was raised from the New Zealand research (Duncan et al, 2000) as to whether the stagnant water from these pipes is likely to decrease the quality of the potable water in the domestic plumbing system.

It is believed that water left stagnant in a pipeline used for potable water will deteriorate in terms of biological, physical and chemical properties. The question is whether this degradation will be significant enough to compromise the quality of the drinking water. It should be noted that all plumbing fixtures are required to be tested to the Standard, AS/NZS 4020:1999 *Products for use in contact with drinking water* (Standards Australia, 1999).

The literature search provided some information regarding the likelihood of water left stagnant in lengths of sprinkler pipe contaminating drinking water.

11.2 Experimental Data

Reference: Hart, F. L., Till, B., Nardini, C. & Bisson, D. (1993) ***Backflow Protection for Fire Sprinkler Systems,*** **United States Fire Administration, Grant Number EMW-93-G-4191, United States.**

This study attempted to predict risks and benefits that would likely result from the installation of residential sprinkler systems in one- and two-family residences in the United States, with and without backflow preventers. (**It should be noted that the sprinkler system referred to is a conventional, stand-alone system for use in one- and two-family dwellings, not a multi-purpose system.**)

The study set out to:

- Identify present waterborne illness risks through a literature review of publications of known waterborne outbreaks.
- Associate that illness risk to existing stagnant water conditions in home piping systems (potable pipe lines).
- Predict the increase in illness risk that would result from installing additional stagnant water piping systems (residential fire sprinkler pipelines).
- Based on reported backflow preventer failure rates, make calculations to determine how waterborne illness risks would be influenced by

installing different types of backflow preventers at residential fire sprinkler connections.

Findings from the risk assessment show:

- The risk of death or injury associated with unsprinklered residential dwellings is higher than the risk of waterborne illness associated with unprotected residential sprinkler systems, and

- Residential sprinkler systems protected by backflow preventors would result in approximately the same illness risk regardless of the type of backflow device used (Single Check Valve, Double Check Valve, or Reduced Pressure Principle Backflow Device).

A fundamental assumption to the risk assessment calculations was that water left stagnant over extended periods (such as wet pipe fire sprinkler pipe lines) would result in a similar degree of water deterioration as water typically left stagnant in potable lines over shorter periods. A subsequent study set out to determine whether this assumption is valid (refer to next section: *Water Deterioration from Extended Stagnation Conditions in Steel, Copper and CPVC Pipes*).

Reference: Hart, Frederick L., Anderson, Leonard & Murawski, Jeffery (February 1996) *Water Deterioration from Extended Stagnation Conditions in Steel, Copper and CPVC Pipes*, U.S. Fire Administration, Federal Emergency Management Agency, Grant Number EMW-94-G-4521, United States.

This study looks into the possible risks of contamination of drinking water as a consequence of stagnant water left in lengths of pipe.

The motivation for the research arose from the fact that water left stagnant in fire sprinkler pipe lines that are connected to municipal distribution systems is seen by water suppliers as a potential source of potable supply deterioration which could result in non-compliance with the Safe Water Drinking Act (SWDA) regulations in the United States. A common proposal for reducing this potential problem in the United States is to require backflow preventers and periodic flushing of the sprinkler systems. (It should be noted that this investigation investigated water left stagnant in stand-alone sprinkler systems. The situation is different to the multi-purpose sprinkler system whereby additional mixing between sprinkler water and drinking water will occur.)

The authors state that, the length of stagnation that occurs in fire sprinkler pipelines can be much longer than water left stagnant in potable distribution systems and building pipe systems (months instead of days). A deduction may be to conclude that longer stagnation conditions will result in poorer water quality. This would conclude that stagnant water in fire sprinkler lines represents a greater danger of contamination than stagnant water typically found in potable water lines.

The scope of this research was to monitor the effect of long-term stagnation (up to about eight months) on biological, chemical, and physical water quality parameters in steel, copper and CPVC pipes under controlled laboratory conditions.

The report states that data generated from the laboratory experiments describe kinetics of water degradation, while data generated by field sampling studies only show a single point on the deterioration curve. A more complete picture of the water deterioration phenomenon is therefore being presented. Other advantages of a laboratory approach include:

- The initial water quality is known. Field studies can compare only stagnant water quality to present condition potable water – not water that was originally placed in the sprinkler lines.

- All pipeline material (type and age) is controlled. Field systems may be mixtures of pipe types and ages.

- Environmental conditions throughout the stagnation period (for example, time duration, temperature variations and flushing) are known and under careful control.

The authors state that the objective of the study was to provide data and discussion for review by personnel from both the water supply industry and the fire protection industry. The laboratory study was designed to answer the following questions:

- What biological, chemical and physical changes occur during water stagnation?

- How does Extended Period Stagnation (EPS) compare to Short Period Stagnation (SPS) in terms of water quality deterioration?

- How does pipeline material influence water deterioration reactions?

In this study, Short Period Stagnation (SPS) was considered to be two weeks or less; Extended Period Stagnation (EPS) was considered to be up to eight months.

The authors state that some of the limitations to the research include:

- Pipeline materials were compared in terms of impacts to stagnant water deterioration reactions, other factors such as pressure capacities, structural properties, ease of installation and cost, were not considered.

- Possible impacts due to chemicals used in the installation process such as oils, solders, or solvents were not measured.

- Although initial water quality conditions were known, the effect of variations to initial water quality was not included in this study as it would enter too many variables to the experimental design.

- Only new pipe sections were used in the laboratory experiments. Changes to water deterioration due to interior pipe wall coatings, which may occur after long period use, were not considered in the experiments.

Conclusions and Recommendations

The objective of this laboratory study was to determine how extended periods of stagnation (expected to occur in fire sprinkler systems) compares with short periods of stagnation (expected to occur in potable distribution systems).

To generate information that applies to both potable systems and fire sprinkler systems, pipe materials selected for this study included steel, copper and CPVC. The authors state that information presented in this research report can be used to answer other questions regarding the appropriate operation of existing sprinkler systems and the potential for potable water deterioration when these two systems are connected.

The following is a summary of the data as presented in this paper (Hart et al, Feb 1996).

Steel Pipes
The laboratory experiments found:

- Steel pipes are not recommended for residential systems because of high deterioration reactions which may lead to potable water deterioration.

- For systems already equipped with steel pipes, routine flushing may not be appropriate as this could aggravate the deterioration reactions. It may be possible, however, that routine flushing may prevent build-up of solids to the extent that flow carrying capacities are influenced. Further investigation into this matter may be appropriate and was not an initial objective of this water quality study.

- High particulates are a cause for concern because of the potential for fouling backflow-preventer mechanisms.

- Water samples removed from pipe sections that were not mixed were found to be highly stratified due to settling of particulates to the bottom section.

Copper Pipe

- Data generated for the copper pipe shows that short periods of stagnation will result in high levels of deterioration that approach levels found after extended periods of stagnation.

- For water with a high corrosion potential, the use of copper may not be suitable because of the potential for water contamination.

- For systems already equipped with copper pipes, routine flushing is not recommended, as this would most likely only aggravate the deterioration reactions.

CPVC Pipe

- Very little deterioration occurred, even after extended periods of stagnation.

- With the absence of chemical corrosion reactions, the level of solids build-up was very low compared to the copper and steel pipe sections.

- No benefit is apparent from routine flushing of CPVC sprinkler lines.

Reference: Hart, Frederick l., Anderson, Leonard & Murawski, Jeffrey (1996) *Field Sampling Data of Water Taken from Fire Sprinkler Systems*, United States Fire Administration, Federal Emergency Management Agency, Grant Number EMW-94-G-4521, United States.

This field study is used to tie in the information from the risk assessment and laboratory study outlined in the previous two sections.

The risk assessment study concluded that the risk of death or injury from residential fires was greater than the potential risk of water-borne illness if residential sprinkler systems were installed without backflow preventers or with single check valve devices. A principal assumption to that risk assessment calculation was that water left stagnant in fire sprinkler pipes for very long periods represents the same degree of potential hazard as water left stagnant for shorter periods in potable pipelines. To test this assumption a laboratory study was conducted where pipe sections were filled with water from a potable supply and left stagnant for up to eight months. Steel, copper and CPVC pipe sections were used. Resulting data illustrated that stagnant water deteriorates rapidly.

During the laboratory study, samples of water taken from field sprinkler systems were also analysed to help determine if laboratory data was comparable to field conditions. This report presents that data and makes comparisons to the laboratory study results.

This report presents data from a water-sampling program of fire sprinkler systems in the Massachusetts area. The objective of this study was to determine if data produced by the laboratory study was comparable to field data. As indicated in the laboratory study report, data generated under controlled conditions has many obvious advantages.

- The initial water quality is known. Field studies can only compare stagnant water quality to present condition potable water – not water that was originally placed in the sprinkler lines.

- Data generated from laboratory experiments will describe kinetics if water is monitored over time. Data generated by field sampling studies only show a single point on the deterioration curve. Deterioration rates are needed if comparisons are to be made with potable water systems.

- All pipeline material (type and age) is controlled. Field systems may have a mix of pipe types and ages.

- Environmental conditions throughout the stagnation period (time duration, temperature variations, flushing etc) are known and under careful control. Field conditions have a host of uncontrolled environmental conditions.

- Field water samples may not represent true aliquots of all water in the system. (Pockets of water may contain high solids and other contaminants.) Laboratory samples can represent the entire water volume placed in a stagnant condition.

The objective of the field-sampling program was to provide validation of the laboratory results.

The authors state that various visual observations could be made concerning the quality of water found in fire sprinkler pipelines. The following is a summary of the findings from the research (Hart et al, 1996).

Steel Pipes

- The deteriorated physical quality of water in the steel piped fire sprinkler system was visible and quite pronounced.

- High turbidity and suspended solids.

- Oily smell to the sample as well as oily film on the top of some samples.

- Colour ranged from clear to rust to black depending on the sampling location.

- Formation of small gas bubbles on the side of the sample bottle.

- High variability in the appearance of the sample as a function of sampling time and between different locations within the pipe system. Highest solids sample was usually the first draw.

Copper Pipelines

- Moderate solids and turbidity that appeared to be oxidised iron was observed.

- All systems were connected to steel risers. The proximity of the sampling to these risers could contribute to discrepancies in some pipe material systems water parameters.

- Formation of small gas bubbles on the side of the sample bottle.

CPVC Pipelines

- Low turbidity and solids.
- Faint odour of plastic.

Discussion of Results

Table 36: Physical Parameter Averages from Laboratory and Field Study

Data Source	Turbidity (NTU)	Total Solids (mg/L)	Suspended Solids (mg/L)	Alkalinity (mg/L as $CaCO_3$ eq.)	Conductivity (μ-MHO)
Laboratory (Steel)	64.7	250	60	49	234
Laboratory (Copper)	19	172	11	88	246
Laboratory (CPVC)	0.4	114	9	35	193
Field (Steel)	8.4	185	127	24	96
Field (Copper)	19.3	134	18	51	274
Field (CPVC)	0.7	90	6	35	137

Table 37: Chemical Parameter Averages from Laboratory and Field Study

Data Source	pH	Fe/Cu (mg/L)	TKN (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)
Laboratory (Steel)	8.0	52.80	11.97	0.20	0.17
Laboratory (Copper)	8.0	1.50	7.80	0.07	0.07
Laboratory (CPVC)	6.9	---	0.70	0.20	0.00
Field (Steel)	8.9	9.54	8.16	0.21	0.24
Field (Copper)	7.3	1.22	0.90	0.23	0.48
Field (CPVC)	8.1	---	0.50	0.40	0.00

Table 38: Biological Parameter Averages from Laboratory and Field Study

Data Source	Mould & Yeast (CFU/100ml)	Coliform (CFU/100ml)	Heterotrophic (CFU/ml)
Laboratory (Steel)	0.7	0	30
Laboratory (Copper)	0	0	1,177
Laboratory (CPVC)	2.5	0	15,500
Field (Steel)	52.2	0	2,000
Field (Copper)	6.0	0	60
Field (CPVC)	5.5	0	1,100

CONCLUSIONS

Results from the field samples identified the following (Hart et al, 1996):

- Samples taken from the field steel pipe system consistently had lower turbidity levels than found in the laboratory samples. The authors offer that one explanation for this difference is that the laboratory study used new pipe sections and had maximum stagnation periods of about eight months. The field samples were suspected of having much higher periods of stagnation (up to 68 years), which may have resulted in a coagulation of small particles and a coating on the inside pipe wall.

- Samples taken from the field steel pipe systems consistently had higher suspended solids than found in the laboratory. Although this may seem like a contradiction to the above observation, it may be explained by the same phenomenon (coagulation of particles and coating on the inside pipe wall). During sampling, solids on the pipe wall (or coagulated in large deposits in the water) may enter the water flow and therefore be measured as suspended solids. These large particles would not influence the turbidity measurement to the same degree as smaller suspended materials would.

- Samples taken from the field steel pipe systems consistently had lower iron levels than found in the laboratory. This data may be directly related to the turbidity differences and may therefore be a result of the same phenomenon.

- Samples taken from all field systems typically had lower bacteria population levels than measured in the laboratory. Laboratory data generated before the eight-month sample was consistently higher.

- With the exception of suspended solids, it appears that field samples were typically lower in impurity concentrations than samples obtained under laboratory conditions. The authors offer that a likely explanation for this difference is that laboratory samples were obtained from agitated pipe sections while field samples could only receive pockets of water from the sprinkler system. Samples obtained from the laboratory study, therefore, should be viewed as true aliquots of the entire stagnant water system while samples from the field are subject to high variations.

Reference: Notarianni, Kathy A. and Jackson, Margaret A. (1994) *Comparison of Fire Sprinkler Piping Materials: Steel, Copper, Chlorinated Polyvinyl Chloride and Polybutylene, in Residential and Light Hazard Installations*, National Institute of Standards and Technology, United States.

This is a literature-based study which was conducted to compare characteristics and usage of steel, copper, chlorinated polyvinyl chloride (CPVC) and polybutylene (PB) fire sprinkler pipe primarily related to residential and light hazard installation. This report addresses key variables such as material properties, usage criteria and limitations, system design, installation requirements, economics and maintenance. Information selected from this paper is only with regards to sprinkler pipe impact on water quality.

Findings of the research show:

- CPVC and PB pipe are not susceptible to corrosion and scale build-up as are steel and copper fire sprinkler pipe.
- All piping materials are subject to sedimentation of debris in the water supply.

The information in this report is presented in terms of its usefulness in selecting a sprinkler pipe material.

11.3 Summary

From the literature search into the issue of stagnant water contaminating potable water when sprinkler pipe work is integrated with the domestic plumbing, the following information was found:

- In the normal domestic plumbing system, lengths of dead-end pipe exist. Lengths of pipe may be installed in the home, for example, for future extensions to the house or for the installation of additional appliances (e.g. dishwasher). There are also pipe branches within the normal plumbing system which are under-utilised, for example a garden tap. Stagnant water in these lengths are currently not a concern to home owners.
- There are currently regions in Australia where water filters are installed in homes where the water quality is below standard.
- The literature outlined above shows that stagnant water left in lengths of plastic pipe results in the least amount of water contamination. Water

quality in copper and steel pipe deteriorates greater than water left stagnant in plastic pipe.

- The risk assessment research outlined (Hart et al, 1993) indicates that the risk of death or injury associated with unsprinklered residential homes is over ten times higher (exactly 11.1) than the risk of waterborne illness associated with unprotected, stand-alone fire sprinkler systems.

- Residential sprinkler systems protected by backflow preventors would result in approximately the same illness risk regardless of the type of backflow device used (Single Check Valve, Double Check Valve, or Reduced Pressure Principle Backflow Device).

The increased risk of contaminated water which the additional lengths of dead-end pipe introduced to the domestic plumbing system by the multi-purpose sprinkler system adds, is difficult to quantify. The multi-purpose sprinkler can be designed so that any 'dead legs' to sprinklers are kept as short as possible in order to restrict the amount of stagnant water in the system.

The focus of this section was to highlight that there may be a concern by some authorities and to indicate that more investigation would be required to determine whether the increased risk of contamination is a life safety concern.

12. CONCLUSIONS

This report has shown that it is feasible for a combined home plumbing and fire sprinkler system to be installed into a new three-bedroom Australian home (of simple design) for a cost of approximately $1,200 over and above the cost of the domestic plumbing system. For a more complex four-bedroom, two-storey home (with garage), the additional cost was determined to be approximately $4,600. These costs represent savings on a per sprinkler head installation compared to the cost of installing a domestic fire sprinkler system to the current AS 2118.5 standard.

The cost-benefit analysis carried out and described in this report has resulted in an estimated cost per life saved of $3.3 million for the three-bedroom home based on average fire incident, fatality and injury rates. The estimated cost per life saved for the four-bedroom home was $19 million. Again, these represent a significant improvement on the cost per life saved of more than $30 million determined in earlier research for the Building Control Commission by Beever and Britton (1999) for Australian Standard complying systems. The estimated cost per life saved increases slightly for the installation of the proposed home fire sprinkler system together with the mains-powered smoke alarm currently required under Victorian building legislation for new homes.

This report has also shown that the estimated cost per life saved for a combined home plumbing and fire sprinkler system is sensitive to a number of factors. One of the more important of these factors is the number of fire incidents per 1000 households per year. The average fire incident rate for Australia based on available statistical records is close to 2 fire incidents per 1000 households per year. This is the rate reported to the fire brigades so the actual rate is likely to be higher. However, this fire incident rate is observed to be lower than for the USA (~2.7) and New Zealand (~4). The cost per life saved reduces significantly as the fire incident rate increases.

Therefore, it is recommended that selective targeting of at-risk communities, where the fire incident, fatalities and injury rates are generally higher than the Australian average rates, would result in significantly better cost-benefit outcomes than indicated in this study.

This report described a concept for developing a combined home plumbing and fire sprinkler system; provided cost estimates for installing such a system in two specific home designs and calculated cost-effectiveness measures by which the cost-benefit could be evaluated. It should not be used as a substitute for a detailed design guide, code of practice or installation manual as further considerations regarding installation procedures, adequacy of water supplies and hydraulic design must be confirmed in each case. There is an obvious need for a code of practice to be developed which will enable site-specific conditions to be accounted for and allow trained installers (including plumbers) to carry out a combined home plumbing and fire sprinkler system installation.

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14. APPENDIX I – SPRINKLER DESIGN

14.1 Three-Bedroom Home

The following outlines the hydraulic calculations, design specifications and plans for the multi-purpose sprinkler design for the three-bedroom home.

1 Job name:- Typical 3 bedroom house (FOR TWO SPRINKLES IN COMPARTMENT)
2 Location:- Suburbs (USING 12 L / M FOR DOMESTIC LOAD)

3

	Sprinkler Selected	Flow Rate Single (l/m)	Flow Rate Single (l/s)	Pressure Single (kPa)	Flow Rate Multiple (l/m)	Flow Rate Multiple (l/s)	Pressure Multiple (kPa
a)	Viking Microfast Model M-4	49.20	0.82	63.00	43.50	0.72	49.30
b)							
c)							
d)							

4 Piping material:- COPPER

5 Calculations for #:- 2 Sprinklers (single or multiple)

6 System Flow Rate:- 1.44 plus 0.2 equals 1.64 L per sec

Sprinkler l/s plus Plumbing l/s equals L per sec

7 Sprinkler pressure demand:- 49.3 kPa

8 Building supply pressure:- 500 kPa

9 Pressure losses

Velocity flow loss (kPa/m)

20 mm		kPa/m
25 mm		kPa/m
32 mm		kPa/m

10 Meter loss @ flow:- 100 kPa (10)

11 Backflow preventer loss:- 0 kPa (11)

12 Pipes, valves and fittings:-

Pipe Section C-D

Flow 0.72 L / sec

20 mm						
Pipe	1.8	metres	1	equals	1.80	metres
Valves		# @	0.30	equal lgth		metres
90 deg elbows	1	# @	0.90	equal lgth	0.90	metres
Tees run		# @	0.50	equal lgth		metres
Tees branch		# @	1.40	equal lgth	0.00	metres
Other		# @		equal lgth		metres

12.1 20 mm pressure loss 2.7 @ 3.68 equals 9.94 kPa (12.1)

Total lgth @ Press loss equals kPa

Pipes, valves and fittings:-

Pipe Section C-R

Flow 1.64 L / sec

25 mm						
Pipe	26.9	metres	1	equals	26.90	metres
Valves		# @	0.30	equal lgth		metres
90 deg elbows	4	# @	0.90	equal lgth	3.60	metres
Tees run		# @	0.50	equal lgth		metres
Tees branch	2	# @	1.40	equal lgth	2.80	metres
Other		# @		equal lgth		metres

12.2 25 mm pressure loss 33.3 @ 4.202 equals 139.93 kPa (12.1)

Total lgth @ Press loss equals kPa

13 Elevation loss:-

Highest sprinkler above source 3 metres @ 9.81 kpa / M = 29.43 kPa (13)

14 TOTAL SYSTEM PRESSURE LOSSES (10+11+12.1+12.2+13) 279.30 kPa (14)

15 Pressure available at sprinkler

500 less 279.2953 equals 220.7047 kPa

Building supply pressure (8) System pressure losses (14)

16 Minimum requirement 49.3 kPa

17 Pressure acceptable (or not); the pressure is greater than or equal to the required pressure for the sprinkler YES Y / N

1 Job name:- Typical 3 bedroom house (1 SPRINKLER IN COMPARTMENT, DN 25 PIPE)

2 Location:- Suburbs (USING 12 L / M FOR DOMESTIC LOAD)

3	Sprinkler Selected	Flow Rate Single (l/m)	Flow Rate Single (l/s)	Pressure Single (kPa)	Flow Rate Multiple (l/m)	Flow Rate Multiple (l/s)	Pressure Multiple (kPa
a)	Viking Microfast Model M-4	49.20	0.82	63.00	43.50	0.72	49.30
b)							
c)							
d)							

4 Piping material:- COPPER

5 Calculations for #:- 1 Sprinklers (single or multiple)

6	System Flow Rate:-	0.82	plus	0.2	equals	1.02	L per sec
		Sprinkler l/s	plus	Plumbing l/s	equals		L per sec

7 Sprinkler pressure demand:- 63 kPa

8 Building supply pressure:- 500 kPa

9 Pressure losses

Velocity flow loss (kPa/m)

20 mm		kPa/m
25 mm		kPa/m
32 mm		kPa/m

10	Meter loss @ flow:-	100	kPa (10)
11	Backflow preventer loss:-	0	kPa (11)

12 Pipes, valves and fittings:-

Pipe Section C-D

Flow 0.82 L / sec

20 mm						
Pipe	1.8	metres	1	equals	1.80	metres
Valves		# @	0.30	equal lgth	-	metres
90 deg elbows	1	# @	0.90	equal lgth	0.90	metres
Tees run		# @	0.50	equal lgth		metres
Tees branch		# @	1.40	equal lgth	0.00	metres
Other		# @		equal lgth		metres

12.1	20 mm pressure loss	2.7	@	4.68	equals	12.64	kPa (12.1)
		Total lgth	@	Press loss	equals	kPa	

Pipes, valves and fittings:-

Pipe Section C-R

Flow 1.02 L / sec

25 mm						
Pipe	26.9	metres	1	equals	26.90	metres
Valves		# @	0.30	equal lgth		metres
90 deg elbows	4	# @	0.90	equal lgth	3.60	metres
Tees run		# @	0.50	equal lgth		metres
Tees branch	2	# @	1.40	equal lgth	2.80	metres
Other		# @		equal lgth		metres

12.2	25 mm pressure loss	33.3	@	4.202	equals	139.93	kPa (12.1)
		Total lgth	@	Press loss	equals	kPa	

13 Elevation loss:-

Highest sprinkler above source 3 metres @ 9.81 kpa / M = 29.43 kPa (13)

14 TOTAL SYSTEM PRESSURE LOSSES (10+11+12.1+12.2+13) 282.00 kPa (14)

15 Pressure available at sprinkler

500	less	281.998	equals	218.002 kPa
Building supply pressure (8)		System pressure losses (14)		

16 Minimum requirement 63 kPa

17 Pressure acceptable (or not); the pressure is greater than or equal to the required pressure for the sprinkler YES Y/N

1	Job name:-	Typical 3 bedroom house (2 SPRINKLER IN COMPARTMENT, DN 20 PIPE)
2	Location:-	Suburbs (USING 12 L / M FOR DOMESTIC LOAD)

3	Sprinkler Selected	Flow Rate Single (l/m)	Flow Rate Single (l/s)	Pressure Single (kPa)	Flow Rate Multiple (l/m)	Flow Rate Multiple (l/s)	Pressure Multiple (kPa
a)	Viking Microfast Model M-4	49.20	0.82	63.00	43.50	0.72	49.30
b)							
c)							
d)							

4	Piping material:-	COPPER					
5	Calculations for #:-	2	Sprinklers (single or multiple)				
6	System Flow Rate:-	1.44	plus	0.2	equals	1.64	L per sec
		Sprinkler l/s	plus	Plumbing l/s	equals		L per sec

7	Sprinkler pressure demand:-	49.3	kPa
8	Building supply pressure:-	500	kPa
9	Pressure losses		
	Velocity flow loss (kPa/m)		
	20 mm		kPa/m
	25 mm		kPa/m
	32 mm		kPa/m

10	Meter loss @ flow:-	100	kPa (10)
11	Backflow preventer loss:-	0	kPa (11)

12 Pipes, valves and fittings:-

Pipe Section B-C

Flow 0.72 L / sec

20 mm						
Pipe	1.8	metres	1	equals	1.80	metres
Valves		# @	0.30	equal lgth		metres
90 deg elbows	1	# @	0.90	equal lgth	0.90	metres
Tees run		# @	0.50	equal lgth		metres
Tees branch		# @	1.40	equal lgth	0.00	metres
Other		# @		equal lgth		metres

12.1 20 mm pressure loss	2.7	@	3.681	equals	9.9387	kPa (12.1)
	Total lgth	@	Press loss	equals	kPa	

Pipes, valves and fittings:-

Pipe Section C-R

Flow 1.64 L / sec

20 mm						
Pipe	26.9	metres	1	equals	26.90	metres
Valves		# @	0.30	equal lgth		metres
90 deg elbows	4	# @	0.90	equal lgth	3.60	metres
Tees run		# @	0.50	equal lgth		metres
Tees branch	2	# @	1.40	equal lgth	2.80	metres
Other		# @		equal lgth		metres

12.2 20 mm pressure loss	33.3	@	16.88	equals	562.104	kPa (12.1)
	Total lgth	@	Press loss	equals	kPa	

13 Elevation loss:-

Highest sprinkler above source 3 metres @ 9.81 kpa / M = 29.43 kPa (13)

14 TOTAL SYSTEM PRESSURE LOSSES (10+11+12.1+12.2+13) 701.4727 kPa (14)

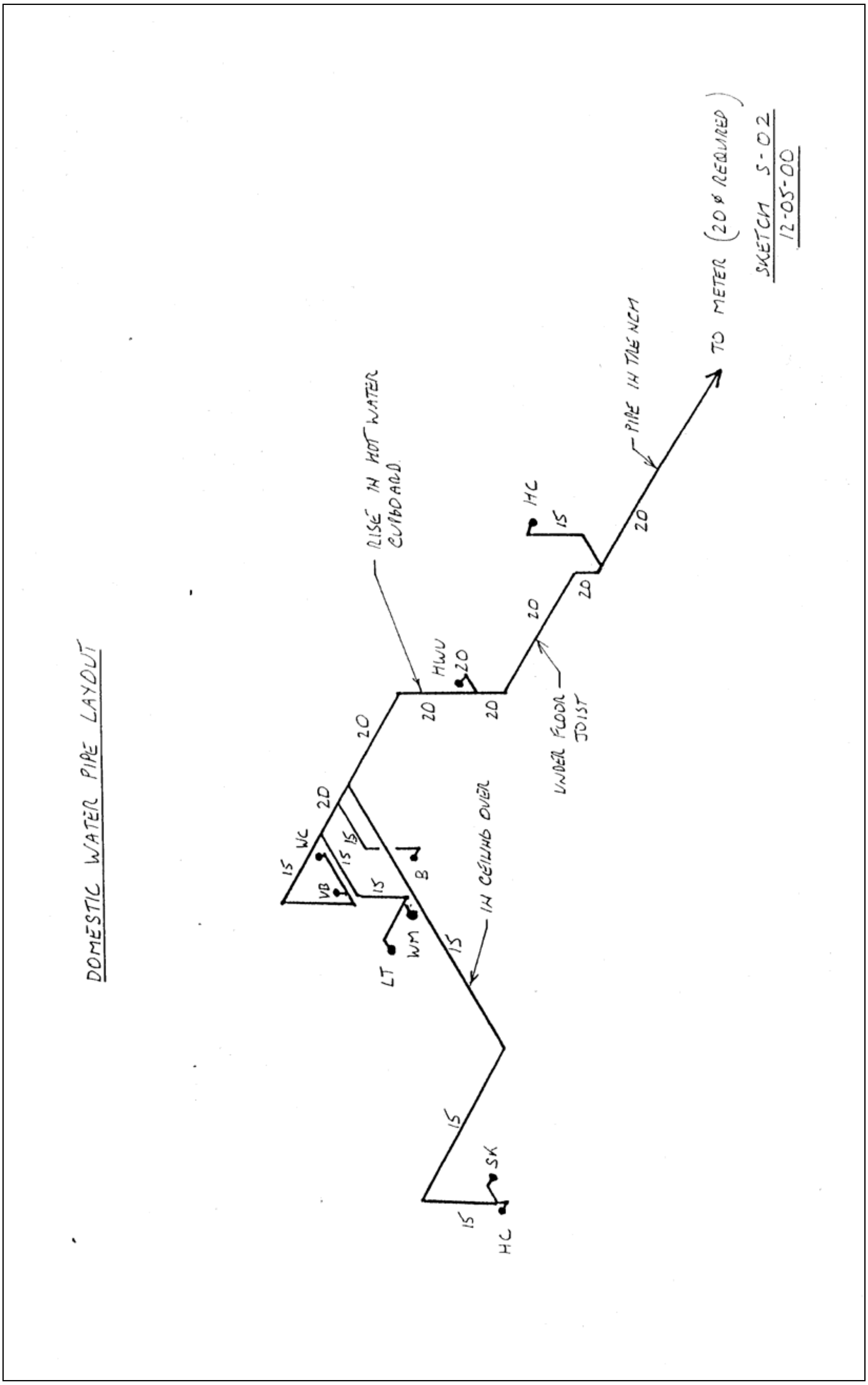
15 Pressure available at sprinkler

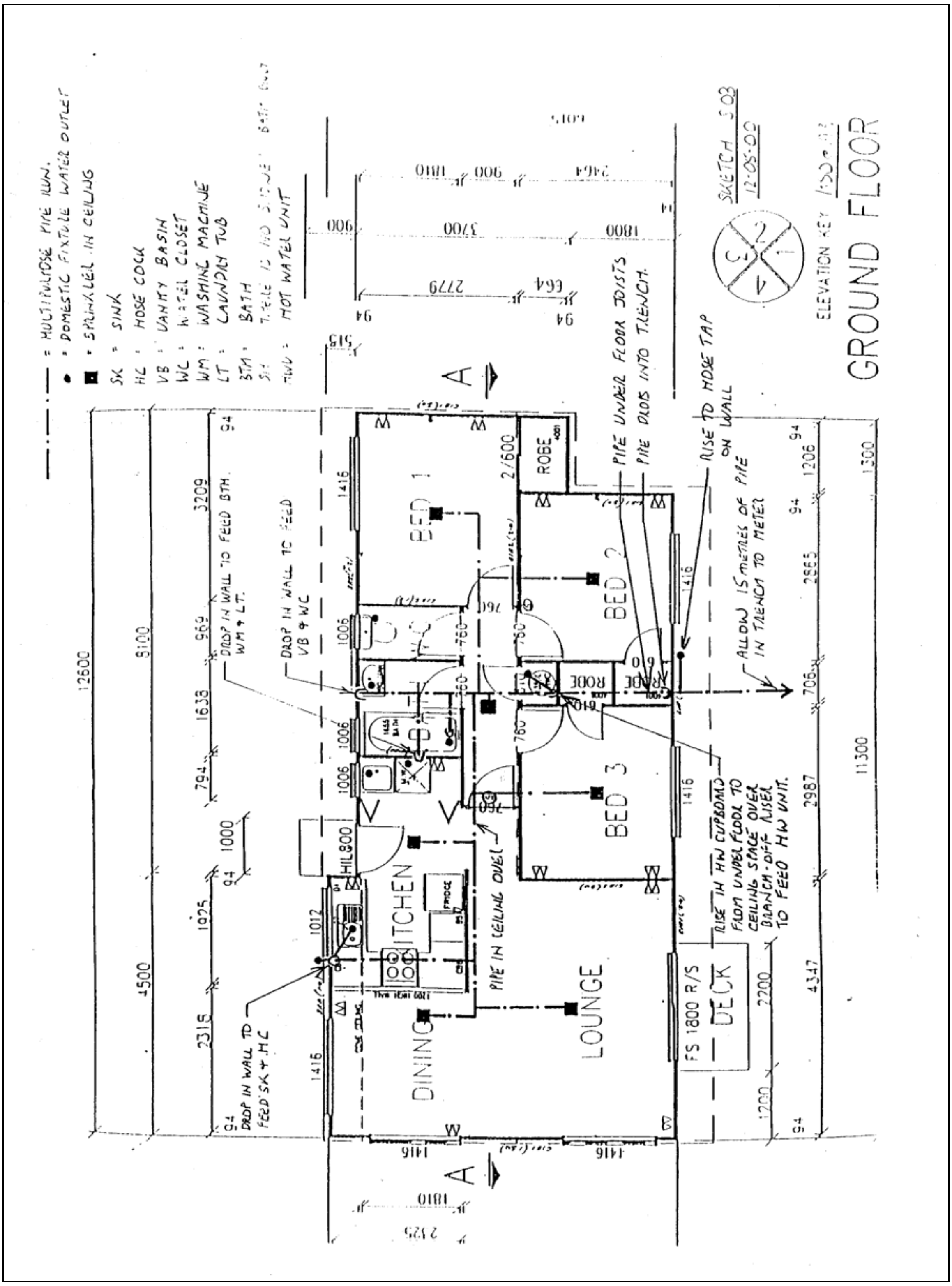
500	less	701.4727	equals	-201.4727 kPa
Building supply pressure (8)		System pressure losses (14)		

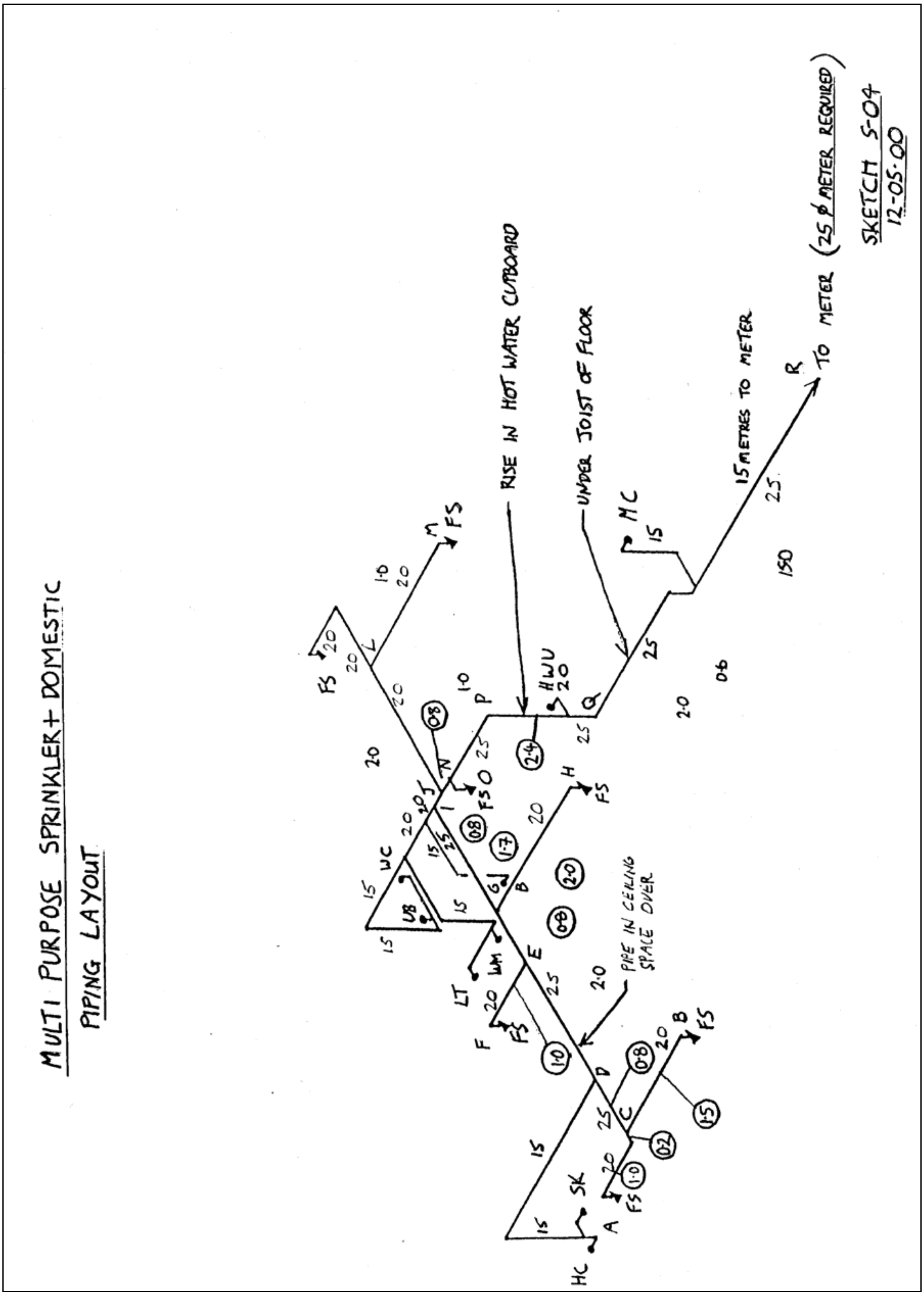
16 Minimum requirement 49.3 kPa

17 Pressure acceptable (or not); the pressure is greater than or equal to the required pressure for the sprinkler

NO Y / N


DOMESTIC WATER PIPE LAYOUT
RISE IN HOT WATER CUPBOARD
UNDER FLOOR JOIST
IN CEILING OVER
TO METER (20ø REQUIRED)
SKETCH S-02
12-05-00
HWU
HC
SK
WC
VB
LT
WM
B
20
15


GROUND FLOOR
ELEVATION KEY
SKETCH 3.03
12-05-00
= MULTIPURPOSE PIPE RUN.
= DOMESTIC FIXTURE WATER OUTLET
= SPRINKLER IN CEILING
SK = SINK
HC = HOSE COCK
VB = VANITY BASIN
WC = WATER CLOSET
WM = WASHING MACHINE
LT = LAUNDRY TUB
BTH = BATH
HWU = HOT WATER UNIT
BED 1
BED 2
BED 3
KITCHEN
DINING
LOUNGE
DECK
ROBE
FRIDGE
PIPE UNDER FLOOR JOISTS
PIPE DROPS INTO TRENCH.
RISE TO HOSE TAP ON WALL
ALLOW 15 METRES OF PIPE IN TRENCH TO METER
DROP IN WALL TO FEED BTH. WM + LT.
DROP IN WALL TO FEED VB + WC
DROP IN WALL TO FEED SK + HC
PIPE IN CEILING OVER
RISE IN HW CUPBOARD FROM UNDER FLOOR TO CEILING SPACE OVER BRANCH-OFF RISER TO FEED HW UNIT.
FS 1800 R/S
12600
8100
4500
11300


MULTI PURPOSE SPRINKLER + DOMESTIC
PIPING LAYOUT
RISE IN HOT WATER CUPBOARD
UNDER JOIST OF FLOOR
15 METRES TO METER
TO METER (25 φ METER REQUIRED)
SKETCH S-04
12-05-00
PIPE IN CEILING SPACE OVER

BRANZ Sample Sprinkler | Specification

Trade Specification for Installation of Domestic Sprinklers.

Name of Project:	Typical three bedroom home.
Type of System:	Based on NFPA 13 D.
Pipe Protection:	Not required.
Sprinklers:	Viking Microfast Model M-4
Sprinkler Spacing:	4.9 metres x 4.9 metres.
Sprinklers Omitted:	Bathroom, WC compartment, Robes, HW cupboard, Laundry Cubicle, Ceiling Space.
Escutcheons:	Semi-recessed,
Pipe Hangers and Clips:	Copper saddles or plastic uniclips.
Meter:	25 mm water meter (a 20 mm meter will not deliver the flow required) and isolating valve.
Backflow Valves:	Not required.
Pressure Gauges:	Not Required.
Flow Alarms:	Not Required.
Testing of pipework:	Allow to pressure test the entire multipurpose piping system to 1500 kPa for 15 minutes. Install sprinklers after testing.
Branches to Domestic Fixtures:	Work to be undertaken to normal standards

End of Specification

Hydraulic Services Consultants
HYDRAULIC SERVICES: Domestic Sprinkler Project

Reason for Issue Information, Date 12/5/00
Page 1

(Note: choice of either copper or plastic piping for design of the system)

VIKING® TECHNICAL DATA

Microfast® MODEL M-4 SMALL ORIFICE RESIDENTIAL PENDENT SPRINKLER

Sprinkler Temperature Classification	Nominal Sprinkler Temperature Rating (Fusing Point)	Ceiling Temperature at Sprinkler: Maximum Ambient Temperature Allowed[1]	Ceiling Temperature at Sprinkler: Maximum Recommended Ambient Temperature[2]	Bulb Color
Ordinary	155 °F (68 °C)	135 °F (46 °C)	100 °F (38 °C)	Red
Intermediate	175 °F (79 °C)	155 °F (68 °C)	150 °F (65 °C)	Yellow

Sprinkler Finishes: Brass, Bright Brass, Chrome-Enloy® (patents pending), White (paint), and Navajo White (paint)

[1] Based on National Fire Prevention and Control Administration, Contract No. 7-34860.
[2] Based on NFPA-13. Other limits may apply depending on fire loading, sprinkler location, and other requirements of the Authority Having Jurisdiction. Refer to specific installation standards.

Deflector Style	NPT Thread Size		Nominal K-Factor		Overall Length		Base Part Number[3]
	inch	mm	US	metric[11]	inches	mm	
Pendent	½	15	4.3	6,2	2.25	57,2	09530

Approval Chart[4]
Microfast Model M-4 Small Orifice Residential Pendent Sprinkler

KEY
A1X — A: Temperature; 1: Finish; X: Escutcheon (if applicable)

Maximum Areas of Coverage[9]	Minimum Water Supply Requirements: Single Sprinkler	Minimum Water Supply Requirements: Two or More Sprinklers	UL[5]	ULC[7]	NYC[8]
12' x 12' (3.7 m x 3.7 m)	11.5 gpm @ 7.2 psi (43.5 L/min @ 49,3 kPa	11.5 gpm @ 7.2 psi (43.5 L/min @ 49,3 kPa	A1X	A1X	-
14' x 14' (4,3 m x 4.3 m)	13.0 gpm @ 9.1 psi (49.2 L/min @ 63,0 kPa	11.5 gpm @ 7.2 psi (43,5 L/min @ 49,3 kPa	A1X	A1X	-
16' x 16' (4.9 m x 4,9 m)	13.0 gpm @ 9.1 psi (49,2 L/min @ 63,0 kPa	11.5 gpm @ 7.2 psi (43,5 L/min @ 49,3 kPa	A1X	A1X	-
18' x 18' (5.5 m x 5.5 m)	16.0 gpm @ 13.8 psi (60,6 L/min @ 95,6 kPa	13.5 gpm @ 9.9 psi (51,1 L/min @ 68,0 kPa	A1X	A1X	-
20' x 20' (6,1 m x 6,1 m)	19.0 gpm @ 19.5 psi (71,9 L/min @ 134,6 kPa	17.0 gpm @ 15.6 psi (64.4 L/min @ 107,8 kPa	A1X	A1X	-

Sloped Ceiling Approvals[10]

Maximum Area of Coverage[9,10]	Minimum Water Supply Requirements: Single Sprinkler	Minimum Water Supply Requirements: Two or More Sprinklers	UL[6]	ULC[7]	NYC[8]
16' x 16' (4,9 m x 4,9 m)	18.0 gpm @ 17.5 psi (68,1 L/min @ 120,7 kPa	13.0 gpm @ 9.1 psi (49,2 L/min @ 63,0 kPa	A1X	A1X	-

Approved Temperatures	Approved Finishes	Approved Escutcheons
A - 155 °F (68 °C) and 175 °F (79 °C)	1 - Brass, Bright Brass, Chrome-Enloy®, White (paint), and Navajo White (paint)	X - Standard surface-mounted escutcheons or Microfast® Model F-1 Adjustable Escutcheon[12], or recessed with the Micromatic® Model E-1 Recessed Escutcheon

Footnotes

[3] Base part number shown. For complete part number, see price list.
[4] This chart shows the listings and approvals available at the time of printing. Other approvals are in process. Check with the manufacturer for any additional approvals.
[5] Listing is for residential occupancies with smooth, flat, horizontal ceilings.
[6] Listing is for residential occupancies with smooth ceilings with slopes up to and including a 6/12 (26.6°) pitch.
[7] Listed by Underwriter's Laboratories, Inc. for use in Canada.
[8] Acceptance for use by City of New York Department of Buildings is pending.
[9] For areas of coverage smaller than shown, use the "Minimum Water Supply Requirement" for the next larger area listed with sprinklers of similar K-factor.
[10] Areas under sloped ceilings must be measured along the ceiling slope. Actual floor coverage under sloped ceilings will be less than the listed area of coverage.
[11] Metric K-factor shown is for use when pressure is measured in kPa. When pressure is measured in BAR, multiply the metric K-factor shown by 10.0.
[12] The Microfast® Model F-1 Adjustable Escutcheon is considered a surface-mounted escutcheon because it does not allow the fusible element of the sprinkler to be recessed behind the face of the wall or ceiling.

NOTE: Install residential pendent sprinklers with deflectors between 1" and 4" (25,4 mm and 102 mm) below the ceiling. For recessed sprinkler installations, locate the deflectors in a zone between 3/4" and 4" (19 mm and 102 mm) below the ceiling.

Table 1

Trade Specification for Installation of Domestic Sprinklers.

Name of Project:	Typical three bedroom home.
Type of System:	Based on NFPA 13 D.
Pipe Protection:	Not required.
Sprinklers:	Viking Microfast Model M-4
Sprinkler Spacing:	4.9 metres x 4.9 metres.
Sprinklers Omitted:	Bathroom, WC compartment, Robes, HW cupboard, Laundry Cubicle, Ceiling Space.
Escutcheons:	Semi-recessed,
Pipe Hangers and Clips:	Copper saddles or plastic uniclips.
Meter:	25 mm water meter (a 20 mm meter will not deliver the flow required) and isolating valve.
Backflow Valves:	Not required.
Pressure Gauges:	Not Required.
Flow Alarms:	Not Required.
Testing of pipework:	Allow to pressure test the entire multipurpose piping system to 1500 kPa for 15 minutes. Install sprinklers after testing.
Branches to Domestic Fixtures:	Work to be undertaken to normal standards

End of Specification

Ser	Item Description	Unit	Qnty	Mat $	Mat Ext	Lab Rt	Lab Ext
	Preamble						
*	Pipe-in-trench rates shall include for excavation, sand bedding and backfill.	Note					
*	Pipe-in-wall rates shall include for all boring, cutting and notching.	Note					
*	Pipe-on-joist rates shall include for all fixing clips and fastenings.	Note					
*	All pipe rates shall include for all running joints, fluxes, brazing rod, etc.	Note					
*	Rates for bends and tees can be either pulled or fabricated.	Note					
*	Following is a description of pipe and fittings for the reticulation of the sprinkler water pipe from and including the water meter to and including the wing back elbow and sprinkler.						
1	25 Cu in trench in sand bedding & backfill	Metres	15.60				
2	25 Cu under timber floor joist	Metres	2.00				
3	25 Cu in timber frame walls	Metres	2.40				
4	25 Cu in ceiling space on timber joist	Metres	6.90				
5	20 Cu in timber frame walls (to HWU)	Metres	1.00				
6	20 Cu in ceiling space on timber joist	Metres	12.50				
7	20 Cu dropper to Sprinklers	Metres	2.10				
8	15 Cu in ceiling space on timber joist	Metres	5.25				
9	15 Cu in timber frame walls	Metres	12.30				
10	15 brass wing back elbow on timber wall	No.	8				
11	20 brass wing back elbow on timber wall (HWU)	No.	1				
12	25 bend	No.	4				
13	20 bend	No.	9				
14	15 bend	No.	7				
15	25 x 20 tee	No.	6				
16	25 x 20 x 20 tee	No.	1				
17	25 x 15 tee	No.	2				
18	20 tee	No.	1				
19	20 x 15 x 15 tee	No.	1				
20	20 x 15 tee	No.	1				
21	15 tees	No.	3				
22	25 mm water meter	No.	1				
23	Connect 25 Cu to 25 water meter	No.	1				
24	Viking M-4 Sprinkler	No.	7				
25	Connect 15 sprinkler to 20 Cu pipe	No.	7				
26	Chrome plated escutcheon to sprinkler	No.	7				
	TOTALS (B) (To Summary)						

Ser	Item Description	Unit	Qnty	Mat $	Mat Ext	Lab Rt	Lab Ext
	SUMMARY						
*	Item A Enter the cost of the water reticulation to the domestic fixtures from TOTALS (A)						
*	Item B Enter the cost of the sprinkler water reticulation to the Multipurpose Piping from TOTALS (B)						
*	Subtract Item A from Item B						
*	Total the Mat $ and Lab Ext to show the extra cost to install the sprinkler system						

VIKING® **TECHNICAL DATA**

Microfast® MODEL M-4 SMALL ORIFICE RESIDENTIAL PENDENT SPRINKLER

Sprinkler Temperature Classification	Nominal Sprinkler Temperature Rating (Fusing Point)	Ceiling Temperature at Sprinkler: Maximum Ambient Temperature Allowed[1]	Ceiling Temperature at Sprinkler: Maximum Recommended Ambient Temperature[2]	Bulb Color
Ordinary	155 °F (68 °C)	135 °F (46 °C)	100 °F (38 °C)	Red
Intermediate	175 °F (79 °C)	155 °F (68 °C)	150 °F (65 °C)	Yellow

Sprinkler Finishes: Brass, Bright Brass, Chrome-Enloy® (patents pending), White (paint), and Navajo White (paint)

[1] Based on National Fire Prevention and Control Administration, Contract No. 7-34860.
[2] Based on NFPA-13. Other limits may apply depending on fire loading, sprinkler location, and other requirements of the Authority Having Jurisdiction. Refer to specific installation standards.

Deflector Style	NPT Thread Size		Nominal K-Factor		Overall Length		Base Part Number[3]
	Inch	mm	US	metric[11]	Inches	mm	
Pendent	½	15	4.3	6,2	2.25	57,2	09530

Approval Chart[4]
Microfast Model M-4 Small Orifice Residential Pendent Sprinkler

KEY
A1X — A: Temperature; 1: Finish; X: Escutcheon (if applicable)

Maximum Areas of Coverage[9]	Minimum Water Supply Requirements: Single Sprinkler	Minimum Water Supply Requirements: Two or More Sprinklers	UL[5]	ULC[7]	NYC[8]
12' x 12' (3,7 m x 3,7 m)	11.5 gpm @ 7.2 psi (43,5 L/min @ 49,3 kPa	11.5 gpm @ 7.2 psi (43,5 L/min @ 49,3 kPa	A1X	A1X	–
14' x 14' (4,3 m x 4,3 m)	13.0 gpm @ 9.1 psi (49,2 L/min @ 63,0 kPa	11.5 gpm @ 7.2 psi (43,5 L/min @ 49,3 kPa	A1X	A1X	–
16' x 16' (4,9 m x 4,9 m)	13.0 gpm @ 9.1 psi (49,2 L/min @ 63,0 kPa	11.5 gpm @ 7.2 psi (43,5 L/min @ 49,3 kPa	A1X	A1X	–
18' x 18' (5,5 m x 5,5 m)	16.0 gpm @ 13.8 psi (60,6 L/min @ 95,6 kPa	13.5 gpm @ 9.9 psi (51,1 L/min @ 68,0 kPa	A1X	A1X	–
20' x 20' (6,1 m x 6,1 m)	19.0 gpm @ 19.5 psi (71,9 L/min @ 134,6 kPa	17.0 gpm @ 15.6 psi (64,4 L/min @ 107,8 kPa	A1X	A1X	–

Sloped Ceiling Approvals[10]

Maximum Area of Coverage[9,10]	Minimum Water Supply Requirements: Single Sprinkler	Minimum Water Supply Requirements: Two or More Sprinklers	UL[6]	ULC[7]	NYC[8]
16' x 16' (4,9 m x 4,9 m)	18.0 gpm @ 17.5 psi (68,1 L/min @ 120,7 kPa	13.0 gpm @ 9.1 psi (49,2 L/min @ 63,0 kPa	A1X	A1X	–

Approved Temperatures	Approved Finishes	Approved Escutcheons
A - 155 °F (68 °C) and 175 °F (79 °C)	1 - Brass, Bright Brass, Chrome-Enloy®, White (paint), and Navajo White (paint)	X - Standard surface-mounted escutcheons or Microfast® Model F-1 Adjustable Escutcheon[12], or recessed with the Micromatic® Model E-1 Recessed Escutcheon

Footnotes

[3] Base part number shown. For complete part number, see price list.
[4] This chart shows the listings and approvals available at the time of printing. Other approvals are in process. Check with the manufacturer for any additional approvals.
[5] Listing is for residential occupancies with smooth, flat, horizontal ceilings.
[6] Listing is for residential occupancies with smooth ceilings with slopes up to and including a 6/12 (26.6°) pitch.
[7] Listed by Underwriter's Laboratories, Inc. for use in Canada.
[8] Acceptance for use by City of New York Department of Buildings is pending.
[9] For areas of coverage smaller than shown, use the "Minimum Water Supply Requirement" for the next larger area listed with sprinklers of similar K-factor.
[10] Areas under sloped ceilings must be measured along the ceiling slope. Actual floor coverage under sloped ceilings will be less than the listed area of coverage.
[11] Metric K-factor shown is for use when pressure is measured in kPa. When pressure is measured in BAR, multiply the metric K-factor shown by 10.0.
[12] The Microfast® Model F-1 Adjustable Escutcheon is considered a surface-mounted escutcheon because it does not allow the fusible element of the sprinkler to be recessed behind the face of the wall or ceiling.

NOTE: Install residential pendent sprinklers with deflectors between 1" and 4" (25,4 mm and 102 mm) below the ceiling. For recessed sprinkler installations, locate the deflectors in a zone between 3/4" and 4" (19 mm and 102 mm) below the ceiling.

Table 1

Replaces sprinkler page 140 a-c, dated June 4, 1998 (revised pip-cap materials) Form No. F_082095

14.2 Four-Bedroom Home

The following outlines the hydraulic calculations, design specifications and plans for the multi-purpose sprinkler design for the four-bedroom home.

Trade Specification for the Installation of Domestic Automatic Fire Sprinklers to a Multipurpose Piping System.

Name of Project:	Typical Australian House
Location:	Suburban Australia
Type of System:	Multipurpose fire/domestic supply
Pipe Materials:	Underground; Medium density polyethylene pipe (MDPE)
	Above ground; Copper to AS 1432, Type B.
Pipe Joints:	MDPE; mechanical joiners or push-lock.
	Copper; Silver brazed.
Pipe Fittings:	MDPE; Proprietary
	Copper; Pulled or fabricated tees or elbows
Pipe Protection:	Not required
Sprinkler Type:	Viking Model M4 residential pendant sprinkler with escutcheon
Sprinkler spacing:	4.3 x 4.3 metres maximum
Sprinklers Omitted:	Bathroom, WC Compartments, Robes, HW Cupboard, Laundry, Ceiling space.
Pipe Hangers & Clips:	Copper saddles or uniclips to AS 3500.1.2.
Meter:	25 mm water meter and assemble (note a DN 20 meter will not deliver the flow required).
Backflow Valves:	Not required.
Pressure Gauges:	Not required.
Flow Alarms:	Not required.
Sprinkler to Pipe Joiner:	15 mm BSP threaded connector (for sprinkler) x 20 or 25 copper brazing socket.
Liaison with Local Fire Service:	Do not allow for any liaison or discussion with the local fire service.
Testing of Pipework:	Allow to pressure the entire multipurpose piping system to 1500 kPa for 30 minutes.
Branches to Domestic Fixtures:	Work to be undertaken to normal standards as specified under AS 3500.1.2, and the Local Authority.

End of Specification

Multi-purpose sprinkler system + plumbing

Serial	Description	Unit	Qnty	Mat $	Mat $ Ext	Lab Hr Rt	Lab hr Ext
*	Pipe in trench rates shall include for all excavation , sand bedding & backfill.	Note					
*	Pipe-in-wall rates shall include for all boring, cutting & notching.	Note					
*	Pipe-in-ceiling rates shall include for all fixing clips & fastenings.	Note					
*	All pipe rates shall include for running joints, fluxes, brazing rod, etc.	Note					
*	Rates for bends & tees can be either pulled or fabricated.	Note					
*	The following is a description of pipe & fittings for the reticulation of the multipurpose sprinkler/water pipe from & including the meter to & including the sprinkler or branch to the potable supply.	Note					
1	DN 50 Medium Density Polyethylene pipe in trench (MDPE).	Metres	28.00				
2	Connect DN 50 MDPE to 32 CU	No	1				
3	Connect DN 50 MDPE to 25 CU	No	1				
4	DN 32 Cu in wall or ceiling	Metres	10.00				
5	DN 25 Cu in ceiling space	Metres	67.00				
6	DN 20 Cu in ceiling space	Metres	18.00				
7	DN 32 equal tee	No	1				
8	DN 32 x 25 x 25 tee	No	2				
9	DN 32 x 15 tee	No	1				
10	DN 25 equal tee	No	3				
11	DN 25 x 20 tee	No	23				
12	DN 25 x 15 tee	No	4				
13	DN 32 elbow	No	6				
14	DN 25 elbow	No	11				
15	DN 20 elbow	No	25				
16	DN 25 water meter assembly, including connection to the council main and lodgment of all fees	Item	1				
17	DN 25 RMC PS 100 pressure limiting valve	No	1				
18	Viking Model M4 residential pendant sprinkler	No	24				
19	Chrome plated escutcheon to sprinkler	No	24				
20	Connect DN 15 sprinkler to DN 20 or 25 Cu pipe	No	24				

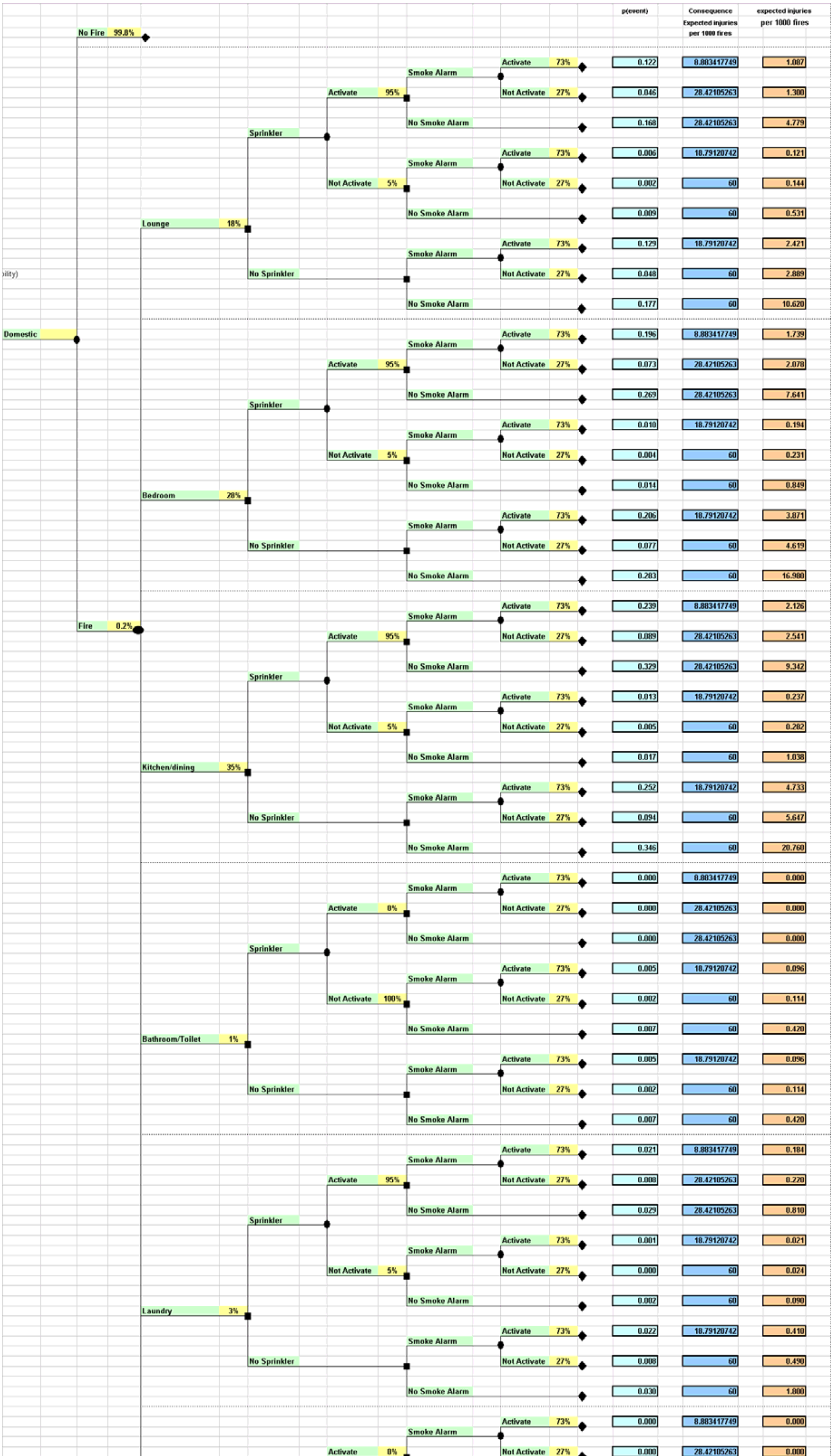
Plumbing Only

Serial	Description	Unit	Qnty	Mat $	Mat $ Ext	Lab Hr Rt	Lab hr Ext
*	Pipe in trench rates shall include for all excavation , sand bedding & backfill.	Note					
*	Pipe-in-wall rates shall include for all boring, cutting & notching.	Note					
*	Pipe-in-ceiling rates shall include for all fixing clips & fastenings.	Note					
*	All pipe rates shall include for running joints, fluxes, brazing rod, etc.	Note					
*	Rates for bends & tees can be either pulled or fabricated.	Note					
*	The following is a description of pipe & fittings for the reticulation of the potable water pipe from & including the meter to & including the branch to the fixture supply off the main spine. This is the area that would subtitute into the same run of multipurpose run.	Note					
1	DN 32 Medium Density Polyethylene pipe in trench (MDPE).	Metres	28.00				
2	Connect DN 32 MDPE to 20 CU	No	2				
3	DN 20 Cu in wall or ceiling	Metres	13.00				
4	DN 20 equal tee	No	4				
5	DN 20 x 25 tee	No	3				
6	DN 20 x 15 x 15 tee	No	1				
7	DN 20 elbow	No	4				
8	DN 20 water meter assembly, including connection to the council main and lodgment of all fees	Item	1				
9	DN 20 RMC PS 75 pressure limiting valve	No	1				

Hydraulic Calculation Sheet.					Sheet No. 1		Date. 31-01-01
For. MOST D/A SINGLE					By.		HEAD-VIKING M4
Sprinkler or Nozzle Location.	Flow. Lit/Min.	Pipe size. mm.	Pipe Fittings and Devices.	Equivalent Pipe Length. M.	Friction loss. C=	Pressure Summary. kPa.	SINGLE Notes 4.3×4.3m. 49.2 ℓ/m @ 63.0 kPa
A ↓ B	q 49.20 + 11.00 Q 61.20	50 HDPE	25T4 3e1.3	Lgth. 29.00 Fit. 3.90 Tot. 32.90	S/P = 0.22 C/F	Init. 245.14 Losses 7.24 Total 237.90	MAINS = 500.00 @ 80% = 400.00 METER @ 61.2 ℓ/m = 20.00 PRV 76.00 96.00 96.00 ~~304.00~~
B ↓ C	q Q 61.20	32 B.	3e2.00	Lgth. 1.00 Fit. 6.00 Tot. 7.00	B/F 1.00 C/F	Init. 237.90 Losses 7.00 Total. 230.90	ELEV 6m @ 9.81 = 58.86 = STARTING PRESSURE 245.14
C ↓ D.	q Q 61.20	32 B.	3+2 3e2.00	Lgth. 5.00 Fit. 6.00 Tot. 11.00	B/F 1.00 C/F	Init. 230.90 Losses 11.00 Total. 219.90	
D ↓ F	q Q 61.20	32 B	0.5+3.0+ 0.5+0.8 = 4e2.00	Lgth. 4.80 Fit. 8.00 Tot. 12.80	B/F 1.00 C/F	Init. 219.90 Losses 12.80 Total. 207.10	
UPPER LOOP.	q Q 61.20	25 B.	8.5×2 6.0×2 5e2.00 0.14×	Lgth. 29.00 Fit. 10.00 Tot. 39.00 =	B/F 3.30 × 5.46	Init. 207.10 Losses 18.02 Total. 189.08	@ ANY POINT ON LOOP.
G ↓ H	q Q 49.20	20 B	1.2+0.3 1e1.00	Lgth. 1.50 Fit. 4.00 Tot. 5.50	8.60	Init. 189.08 Losses 47.30 Total. 141.78	B/F LESS HEAD @ 63.0 = 78.78 (RESIDUAL) SYSTEM OK

15. APPENDIX II – RISK ASSESSMENT

The following is a sample of the event tree used in the risk assessment calculations.


p(event)
Consequence
Expected injuries
per 1000 fires
expected injuries
per 1000 fires
No Fire 99.8%
Activate 73% 0.122 8.883417749 1.087
Smoke Alarm
Activate 95%
Not Activate 27% 0.046 28.42105263 1.300
No Smoke Alarm 0.168 28.42105263 4.779
Sprinkler
Activate 73% 0.006 18.79120742 0.121
Smoke Alarm
Not Activate 5%
Not Activate 27% 0.002 60 0.144
No Smoke Alarm 0.009 60 0.531
Lounge 18%
Activate 73% 0.129 18.79120742 2.421
Smoke Alarm
bility)
No Sprinkler
Not Activate 27% 0.048 60 2.889
No Smoke Alarm 0.177 60 10.620
Domestic
Activate 73% 0.196 8.883417749 1.739
Smoke Alarm
Activate 95%
Not Activate 27% 0.073 28.42105263 2.078
No Smoke Alarm 0.269 28.42105263 7.641
Sprinkler
Activate 73% 0.010 18.79120742 0.194
Smoke Alarm
Not Activate 5%
Not Activate 27% 0.004 60 0.231
No Smoke Alarm 0.014 60 0.849
Bedroom 28%
Activate 73% 0.206 18.79120742 3.871
Smoke Alarm
No Sprinkler
Not Activate 27% 0.077 60 4.619
No Smoke Alarm 0.283 60 16.980
Activate 73% 0.239 8.883417749 2.126
Smoke Alarm
Fire 0.2%
Activate 95%
Not Activate 27% 0.089 28.42105263 2.541
No Smoke Alarm 0.329 28.42105263 9.342
Sprinkler
Activate 73% 0.013 18.79120742 0.237
Smoke Alarm
Not Activate 5%
Not Activate 27% 0.005 60 0.282
No Smoke Alarm 0.017 60 1.038
Kitchen/dining 35%
Activate 73% 0.252 18.79120742 4.733
Smoke Alarm
No Sprinkler
Not Activate 27% 0.094 60 5.647
No Smoke Alarm 0.346 60 20.760
Activate 73% 0.000 8.883417749 0.000
Smoke Alarm
Activate 0%
Not Activate 27% 0.000 28.42105263 0.000
No Smoke Alarm 0.000 28.42105263 0.000
Sprinkler
Activate 73% 0.005 18.79120742 0.096
Smoke Alarm
Not Activate 100%
Not Activate 27% 0.002 60 0.114
No Smoke Alarm 0.007 60 0.420
Bathroom/Toilet 1%
Activate 73% 0.005 18.79120742 0.096
Smoke Alarm
No Sprinkler
Not Activate 27% 0.002 60 0.114
No Smoke Alarm 0.007 60 0.420
Activate 73% 0.021 8.883417749 0.184
Smoke Alarm
Activate 95%
Not Activate 27% 0.008 28.42105263 0.220
No Smoke Alarm 0.029 28.42105263 0.810
Sprinkler
Activate 73% 0.001 18.79120742 0.021
Smoke Alarm
Not Activate 5%
Not Activate 27% 0.000 60 0.024
No Smoke Alarm 0.002 60 0.090
Laundry 3%
Activate 73% 0.022 18.79120742 0.410
Smoke Alarm
No Sprinkler
Not Activate 27% 0.008 60 0.490
No Smoke Alarm 0.030 60 1.800
Activate 73% 0.000 8.883417749 0.000
Smoke Alarm
Activate 0%
Not Activate 27% 0.000 28.42105263 0.000