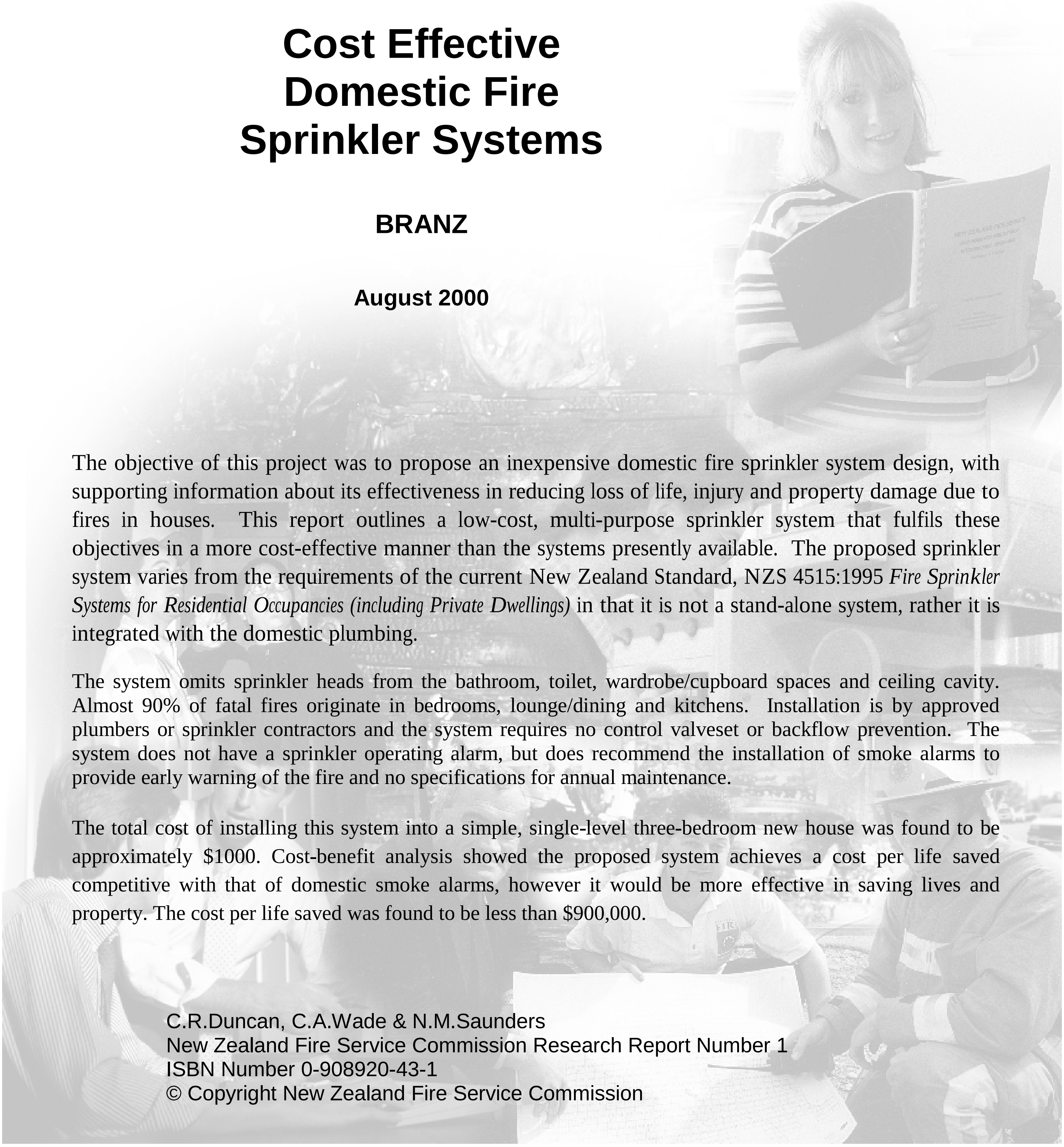
Fire Research
Report



Cost Effective Domestic Fire Sprinkler Systems

BRANZ

August 2000

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 report 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 4515:1995 *Fire Sprinkler Systems for Residential Occupancies (including Private Dwellings)* 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 originate in bedrooms, lounge/dining and kitchens. Installation 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, but does recommend the installation of smoke alarms to provide early warning of the fire and no specifications for annual maintenance.

The total cost of installing this system into a simple, single-level three-bedroom new house was found to be approximately $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 $900,000.

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THE RESOURCE CENTRE FOR BUILDING EXCELLENCE

BRANZ REPORT

(July 2000)

Prepared for the New Zealand Fire Service

Cost-Effective Domestic Fire Sprinkler Systems

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

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Viking Sprinklers, New Zealand supplied information on sprinkler heads and donated residential sprinkler heads for the purpose of demonstrating the sprinkler system.

COST-EFFECTIVE DOMESTIC FIRE SPRINKLER SYSTEMS

Abstract

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 report 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 4515:1995 *Fire Sprinkler Systems for Residential Occupancies (including Private Dwellings)* in that it:

1 Is not a stand-alone system, rather it is integrated with the domestic plumbing.

2 Omits sprinkler heads from the bathroom, toilet, wardrobe/cupboard spaces and ceiling cavity. Almost 90% of fatal fires originate in bedrooms, lounge/dining and kitchens.

3 Installation is by approved plumbers or sprinkler contractors.

4 Requires no control valveset or backflow prevention.

5 Does not have a sprinkler operating alarm, but does recommend the installation of smoke alarms to provide early warning of the fire.

6 Has no specifications for annual maintenance.

The total cost of installing this system into a simple, single-level three-bedroom new house was found to be approximately $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 $900,000.

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1. EXECUTIVE SUMMARY

The objective of this project was to propose an inexpensive domestic sprinkler system design, with supporting information about its effectiveness in reducing loss of life, injury and property damage due to fires in domestic dwellings.

The research adds to the international knowledge on the performance of domestic fire sprinkler systems. It highlights where sprinklers can be targeted within a dwelling 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.

A literature search and preliminary investigation into the cost and cost-effectiveness of domestic sprinkler systems concludes that sprinkler systems built to current New Zealand standards are not cost-effective. A review of the current New Zealand Standard for domestic sprinkler systems (NZS 4515:1995 [SNZ, 1995]) is attempting to reduce the cost and hence improve the cost-effectiveness of the system.

The literature search and preliminary investigation into the cost and cost-effectiveness of domestic sprinkler system concludes:

- Sprinkler systems built to current New Zealand standards are not cost-effective.
- Cost-benefit analysis has proven that there is scope to reduce the cost of the domestic sprinkler system. The scope comes predominantly from legislation, competition and design requirements.
- A risk assessment approach, where reductions in reliability are offset against increased coverage of sprinklers in the home, appears to offer possibilities for providing options to reduce the cost of the sprinkler system.
- Inconsistencies exist between areas where for example it costs more to connect water mains to serve the sprinklers than it does to install the sprinkler system.
- The review of the current New Zealand Standard for domestic sprinkler systems (NZS 4515:1995 [SNZ, 1995]) is attempting to reduce the costs of the system, but as shown by the cost-benefit analysis, the costs need to be reduced further. The attempts to have plumbers install the system and to reduce the maintenance requirements are a good start.
- Compulsory requirements for sprinkler systems in homes have been successful in the USA in reducing the costs of the system.

The review of literature and international sprinkler standards indicated that the multi-purpose sprinkler system offers significant cost reductions. A multi-purpose sprinkler system shares the same pipes as the domestic plumbing system; the sprinklers are integrated with the domestic plumbing. Using the same pipe for both systems means less pipe and less fittings.

The proposed design for a multi-purpose domestic sprinkler system is based strongly on the requirements of the National Fire Protection Association's residential sprinkler

Standard, NFPA 13D (NFPA, 1999). A risk assessment approach, where the influence on expected numbers of injuries and fatalities caused by a reduction in sprinkler coverage is assessed, and a cost-benefit analysis, based on the costs to install the proposed multi-purpose sprinkler system, is used to analyse the effectiveness of the system.

The risk assessment was undertaken through the use of event tree analysis. An event tree is a logic diagram which predicts the possible outcomes from an initial event (Charters, 1999). The likelihood of each outcome depends on other factors such as whether the fire is noticed at an early stage, whether it spreads or whether it is put out with fire extinguishers. The conditional probability of each of these other factors can be calculated and an estimate made of how often an event occurs (Charters, 1999).

The risk assessment objectives were to:

1. Investigate the number and location 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 reducing the reliability of the domestic fire sprinkler system.

4. 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 space.

The risk assessment analysed four options of sprinkler system and smoke alarm combinations. Outcomes from the 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%).

The proposed multi-purpose sprinkler system varies from the requirements of NZS 4515:1995 (SNZ, 1995) as it:

1. is not a stand-alone system
2. omits sprinkler heads from the bathroom, toilet, wardrobe/cupboard space and ceiling cavity
3. is assumed that the installation will be carried out by approved plumbers, sprinkler contractors or others who have demonstrated competency to carry out the work
4. requires no control valveset
5. does not have a sprinkler operating alarm, but does recommend the installation of smoke alarms to provide early warning of the fire
6. has no specifications for annual maintenance.

The cost per life saved for installation of the proposed multi-purpose sprinkler system was found to be $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 4515:1995 (SNZ, 1995).

Analysis shows that the draft Standard has increased the cost-effectiveness of the sprinkler system, reducing the cost per life saved from $34.8 million to $17.8 million (refer Table 15). 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 a new sprinkler system to the draft New Zealand Standard, DZ 4515/CD3 (SNZ, 1999). The comparison of these results show the proposed low-cost multi-purpose sprinkler system to be considerably more cost-effective than domestic sprinkler systems installed to current or draft standards.

Combining the smoke alarm with the multi-purpose 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 $2.8 million.

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 low-cost sprinkler system is considerably less than that of multiple smoke alarms.

2. INTRODUCTION

The objective of this project was to propose an inexpensive domestic sprinkler system design with supporting information about its effectiveness in reducing loss of life, injury and property damage due to fires in domestic dwellings.

The research adds to the international knowledge on the performance of domestic fire sprinkler systems. It highlights where sprinklers can be targeted within a dwelling 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.

Domestic sprinkler systems have the potential to reduce the number of fire deaths and the amount of property loss attributed to fire in the home. Close to 4,700 domestic structure fires occur annually in New Zealand, with around 23 deaths annually as a result of these fires (Irwin, 1997). Sprinkler systems have proven to be effective in the commercial situation. The systems built to current Standards have a success rate of around 99% (Marryat, 1988).

This report is an investigation into ways to reduce the cost of installing domestic sprinkler systems in New Zealand homes. The report provides statistics of domestic fires in New Zealand and puts these statistics into a global context by comparing them with international statistics. Details of previous research into the cost-effectiveness of domestic fire sprinkler systems are summarised. Codes and standards for domestic sprinkler systems are outlined, particularly the existing New Zealand Standard for residential sprinkler systems, NZS 4515:1995 (SNZ, 1995), and the domestic sprinkler standard from the National Fire Protection Association in the United States, NFPA 13D:1999. An investigation into the cost-effectiveness of domestic sprinkler systems for New Zealand homes is described. The cost-effectiveness study highlights the components of the system where potential cost savings can be made. To ensure clarity throughout the study, definitions of the key components of the sprinkler system are provided, along with a description of possible alternatives to the standard sprinkler system design, such as the multi-purpose and flow-through fire sprinkler system. Alternatives for the conventional, stand-alone sprinkler system are given. Case studies of the use and effectiveness of the domestic fire sprinkler system highlight some advantages and disadvantages.

The second half of the report focuses on assessing the effectiveness of alternatives to the conventional domestic sprinkler system. Risk assessment and computer modelling are used to evaluate the effectiveness of the proposed alternatives. 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. Computer modelling investigates the effect sprinklers have on increasing the duration of tenable conditions in the event of a fire in a dwelling. A cost-benefit analysis of the proposed alternative domestic sprinkler system is compared with the results from a cost-benefit analysis previously undertaken for a domestic sprinkler system installed to the requirements of the current New Zealand Standard, NZS 4515:1995 (SNZ, 1995). The report concludes with a proposal for an inexpensive (and cost-effective) domestic fire sprinkler system.

3. STATISTICS

3.1 Domestic Fire Problem

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 frequency and severity of domestic fires has illustrated a need to find ways to reduce the problem. Domestic smoke alarms have begun to increase fire safety, with more than 50% of homes in New Zealand installed with smoke alarms. The success of sprinklers in commercial applications for both life safety and property protection has indicated that domestic sprinklers may be an option for increasing protection from fire in the home.

3.1.1 Frequency

During the period 1986 to 1994 inclusive, the New Zealand Fire Service attended a total of 198,846 fire incidents (Irwin, 1997). This equates to an average of 22,100 fire incidents each year (Irwin, 1997). Domestic fires contribute to approximately 21% of the total fire incidents in New Zealand, equating to 4668 domestic structure fire incidents annually (Irwin, 1997). Figure 1 shows a distribution of the varieties of fire incidents occurring in New Zealand.

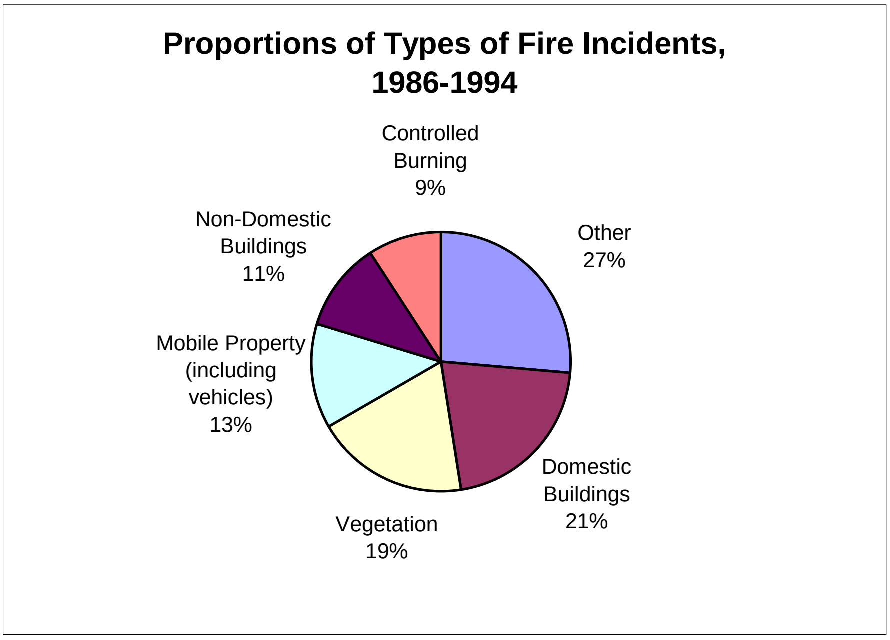

Figure 1: Proportions of Types of Fire Incidents (Source – Irwin, 1997)

The ‘other’ category includes fire incidents which were classified in the ‘fires involving chemicals, flammable liquids and gases’, and ‘miscellaneous’ sections of the incident reporting field (Irwin, 1997). The term ‘Domestic Building’ included one- and two-family dwellings, apartments, townhouses and flats.

3.1.2 Location

Statistics collected by the New Zealand Fire Service show that close to 75% of domestic structure fires start in the kitchen, lounge or bedroom (refer Figure 2).

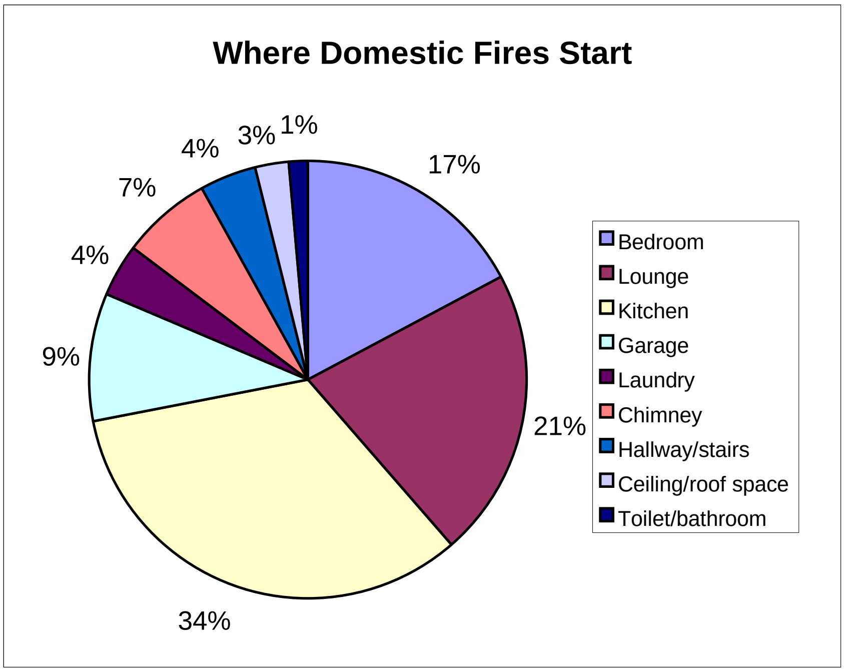

Figure 2: Where New Zealand Domestic Fires Start
(Source - NZFS, 1999)

The most frequent area of fire origin is the kitchen (34%), but the most frequent area of origin for fires which cause fatalities is the bedroom, comprising 38% (refer Figure 5).

3.1.3 Severity

The average number of fire deaths annually in houses and flats in New Zealand from 1986 – 1998 is 23 (Grieve, 1999). Figure 3 shows the number of fatalities caused by domestic structure fires. The number of fire deaths are small enough that variations from year to year can be significant and any overall trends are difficult to determine.

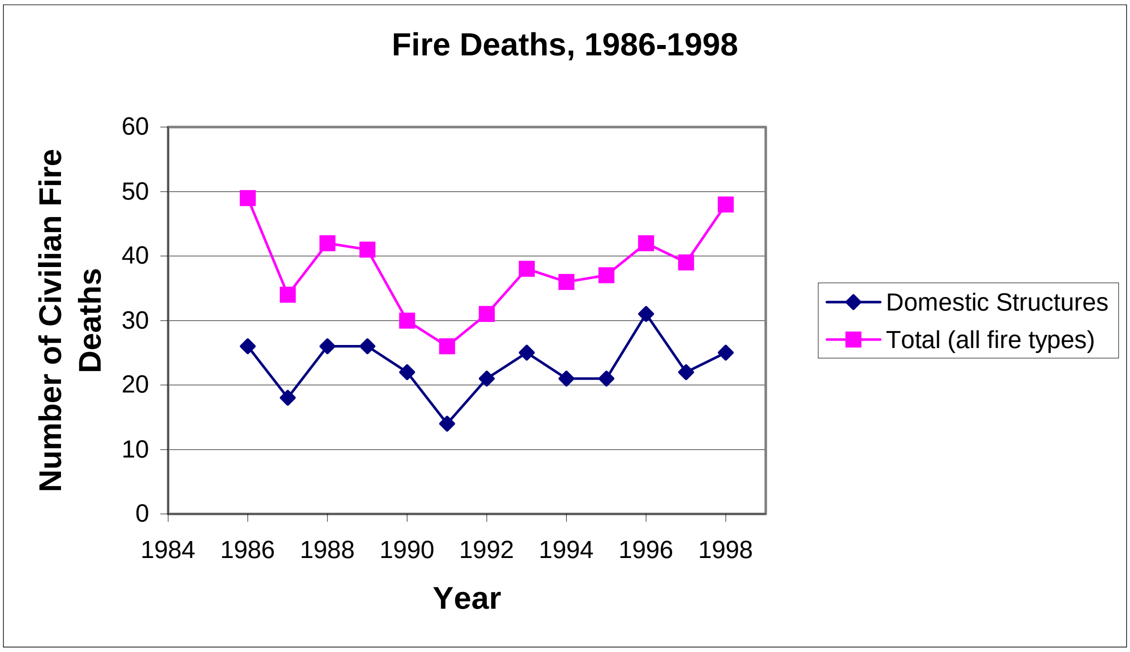

Figure 3: Fire Deaths in Houses and Flats, New Zealand 1986-1998
(Source – Grieve, 1999)

Figure 4 shows a comparison of fire death rates between a variety of countries. The number of New Zealand fire deaths per million population is low by world standards but is about equal to the average for all the developed countries (Wade and Duncan, 2000).

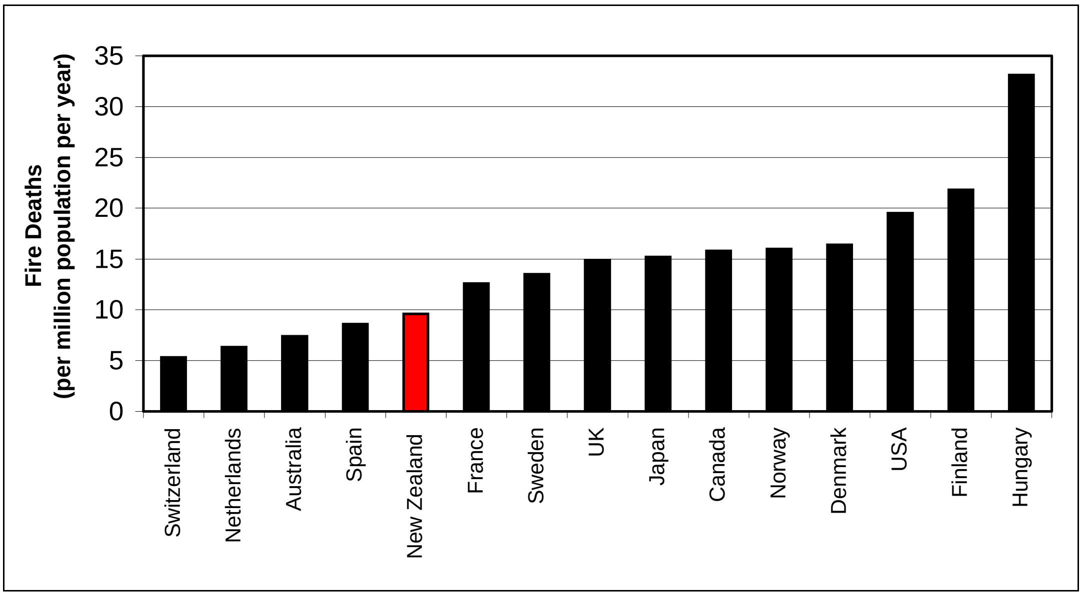

Figure 4: Comparison of International Fire Death Rates
(Source – Irwin, 1997)

Close to forty percent of fatal fires in New Zealand begin in the bedroom (refer Figure 5), with the majority occurring during sleeping hours, between 10 pm and 10 am (refer Figure 6).

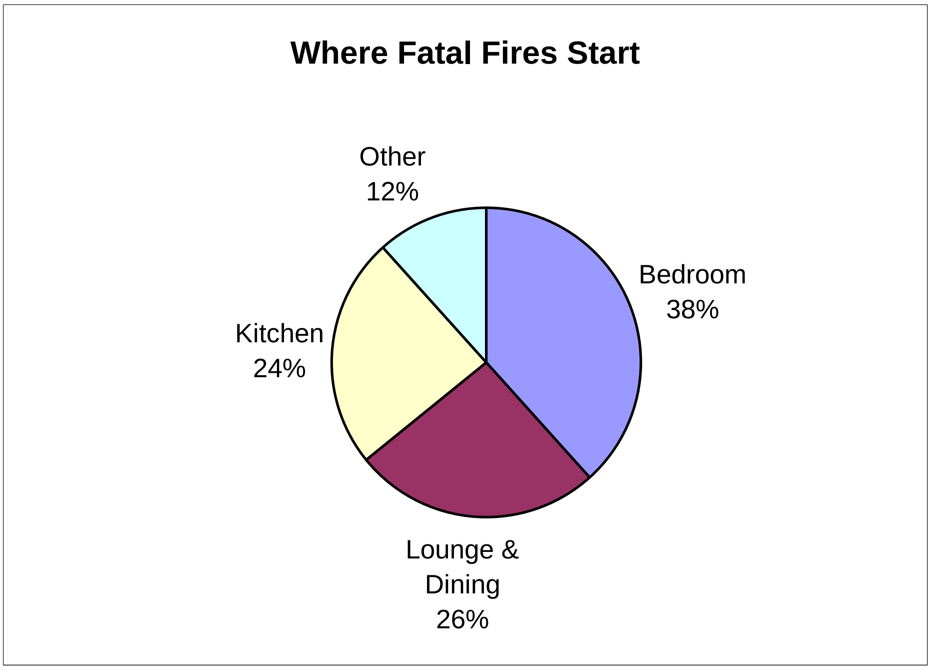

Figure 5: Where Fatal Fires Start
(Source – Irwin, 1997)

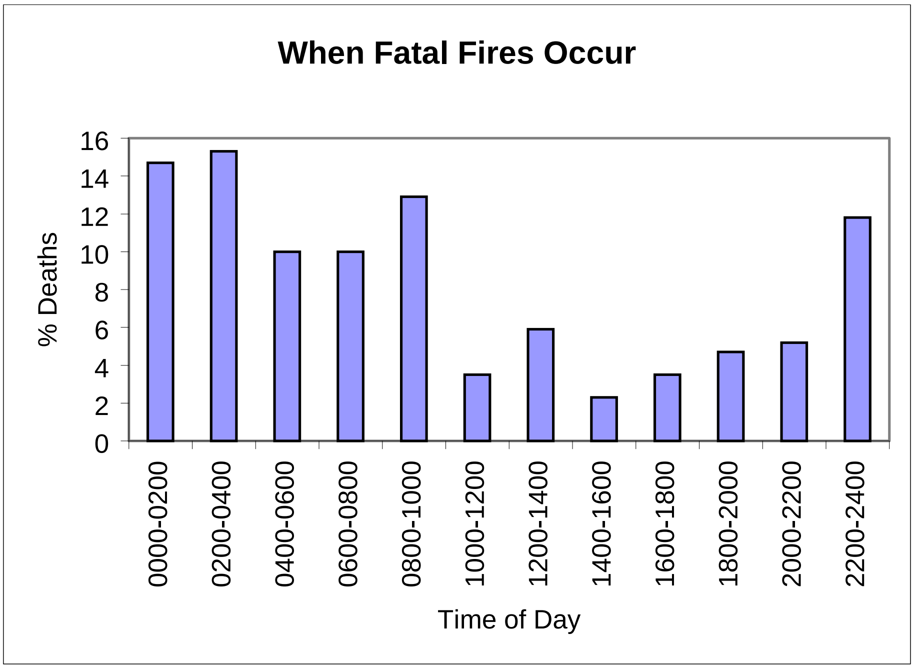

Figure 6: When Fatal Fires Occur
(Source – Irwin, 1997)

These statistics suggest that sleeping occupants are more at risk from fire. Early warning from a smoke alarm or suppression from a sprinkler system would be beneficial to further reduce the risk of fire for sleeping occupants.

3.2 Domestic Sprinklers in New Zealand

A cost-benefit analysis undertaken by BRANZ (refer Section 4.0) for domestic fire sprinkler systems installed in homes in New Zealand, shows that systems built to current standards are not cost-effective. Subsequently, there are very few domestic sprinkler systems installed in New Zealand homes. Cause for the low numbers of sprinkler systems could be the prohibitive cost and current legislation. Legislation in New Zealand does not require private homes to have sprinkler systems installed. Case studies from the United States indicate that laws requiring the compulsory installation of sprinklers in private homes are successful in achieving a reduction in reported domestic fire incidents and hence, the number of fatalities. Although the sprinkler systems are successful, it is only on a large scale, when the cost-benefit analysis is undertaken for the wider community, as opposed to per household, that the domestic fire sprinkler system become cost-effective (refer Section 6.0).

The New Zealand Standard NZS 4515:1995 (SNZ, 1995), is the current standard which outlines the requirements for fire sprinkler systems in residential and domestic occupancies.

A residential occupancy is defined as rooms arranged for the purposes of habitation or co-habitation, other than those defined as a domestic occupancy. Residential occupancies include hospitals, rest homes, care institutions, prisons, police cells, motels, hotels, hostels, residential boarding schools, flats and apartments.

A domestic occupancy is defined as a dwelling used as the home or residence of not more than one household and includes any attached self-contained unit.

NZS 4515:1995 (SNZ, 1995) is an auxiliary document to NZS 4541:1995 (SNZ, 1995-b) Automatic Fire Sprinkler Systems, which is used for sprinkler design in occupancies not defined as domestic or residential. This Standard is currently under review with a number of changes intended to be made resulting in cost-savings. The effect of these proposals are examined later in this report.

3.3 Overseas Statistics

Statistics from the United States show trends for domestic fires to be similar to those of New Zealand, with 8 out of 10 fire deaths occurring in the home (Home Fire Sprinkler Coalition, 1999). The kitchen, bedroom and living room (den) feature as the top three areas of fire origin (refer Figure 7).

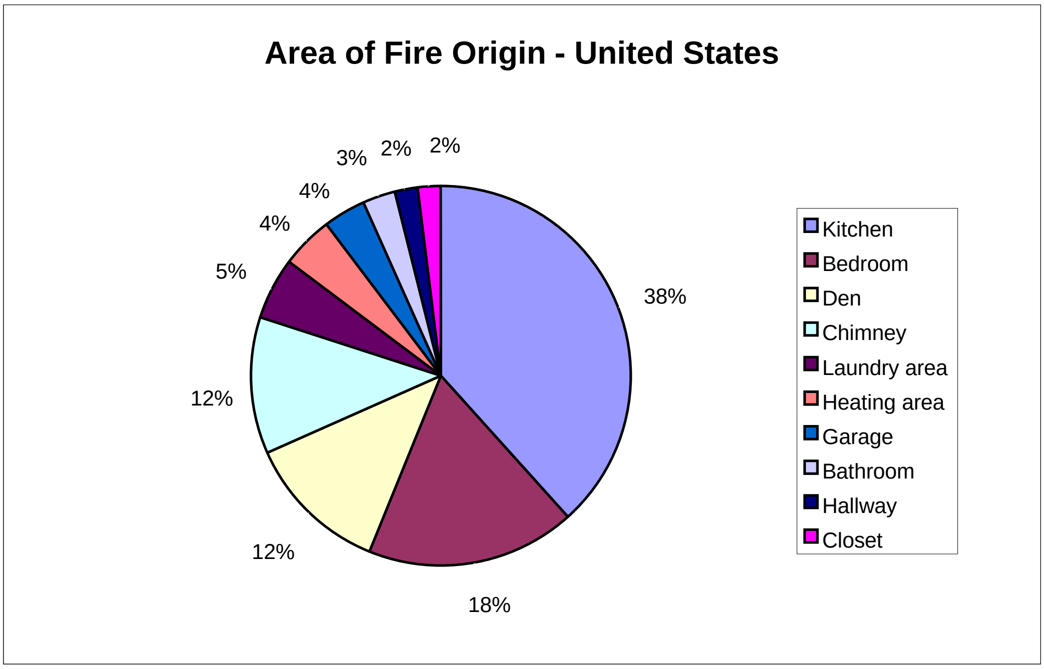

Figure 7: Area of Domestic Fire Origin – United States
(Source – Edison, 1999)

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

- Cooking is the leading cause of home fires in the U.S., it 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. Direct property loss due to fires is estimated at $9.4 billion annually (USFA, 1998-B).

Approximately 86% of U.S. homes have at least one smoke alarm (Edison, 1999). About 64% of the residential fire deaths occur in the 18% of the U.S. homes which have no smoke alarms (and presumably no sprinkler system) installed (Edison, 1999).

Changes to legislation making domestic sprinkler systems compulsory, illustrate how effective sprinklers are at reducing the number of fire incidents and fatalities. There are cities in the United States where laws have been passed, making sprinkler systems compulsory. A high percentage of fires involving residential sprinklers usually only result in the operation of a single sprinkler head (NFPA, 1994).

Smoke alarms have been successful at reducing the domestic fire risk, but with at least 5000 deaths from fire still occurring annually in the United States, consideration of alternative fire safety measures need to be made (Edison, 1999).

3.4 Previous Research

Previous research into the cost and cost-effectiveness of domestic sprinkler systems include studies by Beever and Britton (1999) and Rahmanian (1995).

3.4.1 Beever and Britton

A study by Beever and Britton (1999) for the Building Control Commission, Victoria, Australia, researched cost-effective fire safety measures for residential buildings. The research undertook a cost-benefit analysis for domestic sprinkler systems with the methodology for this analysis subsequently used for the BRANZ study of cost-effective fire safety measures (refer Section 4.0).

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. An overview of statistics provides an idea 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. Similar to New Zealand, around 30% of fire fatalities and fire injuries in Australia occur in one- and two-family dwellings (Beever and Britton, 1999).

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 designs varying from the conventional sprinkler system. The tests indicated:

‘*… that a 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 (above) 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*)

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

Findings from the Australian research into the cost-effectiveness of domestic sprinkler systems concluded:

- 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 domestic 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 a very cost-effective means.

‘*Based on the findings of this study, no recommendation can be made for extending building codes to require sprinklers to be installed in domestic dwellings in Australia at this given time. The adoption of sprinklers should however be reassessed in the future as their cost-effectiveness is expected to improve with predicted demographic changes (ageing population) and reducing costs.’ (Beever and Britton, 1999)*

3.4.2 Rahmanian

A study by Rahmanian (1995) documents an analysis of domestic fire sprinkler systems for use in New Zealand homes. The report evaluates the economics of domestic sprinkler systems installed to current standards in New Zealand homes and includes a literature search, review and comparison of international sprinkler codes, costs and benefits of domestic sprinkler systems and case studies for two single-family dwellings in New Zealand.

The study by Rahmanian (1995) concludes:

- NZS 4515:1995 (SNZ, 1995) is more conservative than any other equivalent domestic standard around the world. This results in higher installation costs for domestic sprinkler systems in New Zealand than in other countries, mainly due to the need for sprinkler heads in concealed spaces.

- In New Zealand, installing domestic sprinkler systems in new dwellings only, could save over 100 lives and $450 million worth of property damage over a 30-year period.

- In New Zealand, installing domestic sprinkler systems in 10% of existing dwellings each year, in addition to all new dwellings, could save about 550 lives and $1.8 billion worth of property damage over a 30-year period.

- At the present time (1995), the cost of installing domestic sprinkler systems in New Zealand homes is greater than the expected value of benefits, but the gap between its costs and benefits becomes narrower when benefits to the community as a whole are considered.

- From the results of this specific cost-benefit analysis for the New Zealand situation, a significant reduction in the present design and installation costs of domestic sprinkler systems and a large increase in value of life, injuries and insurance discount is required in order for the systems to become cost-effective.

- Because of the small number of systems being installed in New Zealand homes, there is not much competition within the sprinkler industry. The market would become more competitive if the demand for domestic sprinkler systems increased.

- Widespread use of domestic sprinkler systems is not very likely to markedly reduce the costs of operating the New Zealand Fire Service.

Rahmanian (1995) lists some recommendations for ways the cost of the domestic sprinkler system can be reduced. The recommendations give guidelines for city councils, insurance companies, the sprinkler industry, the Insurance Council of New Zealand and the Building Industry Authority. The recommendations focus on:

- City Council – reducing the water main connection fees, increasing the diameter of the domestic water supply pipe from 15 mm to 20 mm to enable the sprinkler system to be connected directly to the domestic water supply, as opposed to an additional water supply connection to the water mains for the sprinkler system.

- Insurance Companies – offering incentives to the home owner in the form of reductions in insurance premiums.

- Sprinkler Industry – design of a cheaper control valve set, encouragement of more installation of sprinkler systems in homes to make prices for installation and maintenance more competitive.

- Insurance Council of New Zealand – allowing non-specialised contractors, such as plumbers, to install sprinkler systems.

- Building Industry Authority – the approved documents should be modified to give trade-offs in passive fire protection where sprinkler systems are installed in multi-family dwellings.

The cost-benefit analysis undertaken by Rahmanian (1995) for a sprinkler system installed in a single-family home, concludes that domestic fire sprinkler systems installed to current standards are not cost-effective, confirming the findings of the Australian study (Beever and Britton, 1999) and the New Zealand study (Wade and Duncan, 2000).

4. CODES AND STANDARDS

Codes and standards for the installation of domestic sprinkler systems have been developed to ensure sprinklers maintain their standard of efficiency when used for the domestic situation.

There are three standards specifically for domestic fire sprinkler systems, NZS 4515:1995 , NFPA 13D:1999 and AS 2118:1995 – Part 5.

Other standards which provide specifications for automatic sprinkler systems which are not specifically for the domestic situation, include:

- New Zealand - NZS 4541:1996 Automatic Fire Sprinkler Systems
- United States - NFPA 13:1996 Standard for the Installation of Sprinkler Systems
- British - 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
- Australian - AS 2118:1995 SAA Code for Automatic Fire Sprinkler System

4.1 NZS 4515:1995

The current Standard outlining the requirements for installation of domestic sprinkler systems in New Zealand is:

NZS 4515:1995 FIRE SPRINKLER SYSTEMS FOR RESIDENTIAL OCCUPANCIES (including PRIVATE DWELLINGS).

NZS 4515:1995 (SNZ, 1995) complements the current New Zealand Standard for automatic sprinkler systems, NZS 4541:1996, which is used for commercial applications.

The eight chapters of the residential sprinkler Standard outline:

- General Requirements – such as scope, definitions and procedures.
- General Design Requirements – for the extent of protection, types of system, provision of hand operated fire fighting appliances, materials with a high spread of flame index.
- System Components – such as requirements for sprinkler heads, pipework, valves and alarms.
- Location of Sprinklers – cases of: rooms other than basements and garages; roof, ceiling and underfloor spaces; external sprinklers; basements and garages.
- Determination of Water Supply Requirements – the basis for calculations of design flows and pressures.
- Water Supply - such as town mains, storage tanks and pumps.

- Hydraulic Calculations – describes hydraulic calculations and calculation methods.

- Testing, Maintenance and Survey Inspection requirements.

At present, the New Zealand Standard for residential (including domestic) fire sprinkler systems is being reviewed. Amendments to the domestic sprinkler Standard are focusing on ways to reduce the cost of the system in an attempt to make domestic sprinkler systems for the domestic situation, more cost-effective. Changes being considered in the review include requirements for the control valve, qualifications of sprinkler installers and stipulations for maintenance.

4.2 NFPA 13D:1999

The equivalent standard to NZS 4515:1995 (SNZ, 1995) for domestic fire sprinkler systems installed in homes in the United States is:

NFPA 13D:1999 Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes.

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. Like New Zealand, fire deaths in residential occupancies make up, on average, over 60% of the total loss of life from fire. The Standard was first adopted in 1975 as sprinkler design requirements for the domestic situation (NFPA, 1999).

NFPA 13D: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 profile of NFPA 13D:1999 is as follows:

Chapter one of NFPA 13D:1999 outlines some general information on the scope, purpose and definitions for the Standard. The first chapter outlines requirements for maintenance, devices, materials, design and installation of the domestic sprinkler system.

Chapter two provides the requirements for water supply for the sprinkler system. Water supply requirements for the specific cases of the multi-purpose piping system and the mobile home are described.

The third chapter looks at the sprinkler system components. The components are split up and described in six sections: valves and drains, pressure gauges, piping, piping support, sprinklers, alarms.

Chapter four gives the requirements for system design. Details of the design criteria, position of sprinklers, system types, pipe sizing, piping configurations and location of sprinklers are provided.

The unique requirements of sprinkler systems for use in limited area dwellings are described separately by chapter five. A mobile home is an example of a limited area dwelling.

The final chapter provides a selection of references used to establish the Standard.

Some cities in the United States have enacted legislation requiring residential sprinklers to be installed in new residential buildings, and some have gone so far as to make the requirements retroactive to existing buildings. Scottsdale, Arizona is an example of a city where it has become compulsory to install sprinkler systems in new domestic dwellings. The Scottsdale example is described in the case study to follow (refer section 6.0).

4.2.1 NFPA 13D:1999 Multi-purpose sprinkler system

The National Fire Protection Association Standard for the installation of sprinkler systems in one- and two-family dwellings, NFPA 13D:1999 (NFPA, 1999), allows for the installation of multi-purpose sprinkler systems. The 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 states that a piping system serving both sprinkler and domestic needs shall be considered to be acceptable where the following conditions are met:

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

(b) Smoke alarms are installed.

(c) ‘Listed’ piping materials are used.

(d) Otherwise acceptable to the plumbing/health authorities.

(e) A sign labelling the system is installed.

Design criteria for a multi-purpose sprinkler system which differ from that of a stand alone sprinkler installed to the requirements of NZS 4515:1995 (SNZ, 1995) include:

(a) Design Discharge – 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).

(b) Sprinkler Coverage – 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.

(c) Sprinkler Location – 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.

NZS 4515:1995 (SNZ, 1995) has no provisions for a multi-purpose sprinkler system. The Standard requires an isolated run of pipe dedicated to the sprinkler system.

4.3 Code Comparison

Rahmanian (1995) concludes sprinkler systems installed to NZS 4515:1995 (SNZ, 1995) are more expensive to install than the equivalent system installed to requirements of NFPA 13D:1995, the Standard for domestic fire sprinkler systems in the United States. Rahmanian (1995) establishes that the requirements for sprinkler heads in concealed spaces are the major contribution to the price difference. Comparison of NZS 4515:1995 to NFPA 13D:1995 identifies the following differences (Rahmanian, 1995):

- Building Size Requirements - NZS 4515 provides the requirements for sprinkler systems installed in single family dwellings, homes up to two storeys with a maximum floor area of 500 m^2 and homes with a maximum floor area of 2000 m^2 and up to four storeys in height if the sprinkler system in the building has a fire service alarm connection and the water supply can provide a least 60 minutes flow at the design pressure for the sprinkler system. NFPA 13D provides the automatic fire sprinkler system design requirements for one- and two-family dwellings and manufactured homes. NFPA 13D has no limitations of floor area and number of storeys for family dwellings.

- Alarm – NZS 4515, section 3.9 states that '*Every installation shall include a "sprinkler operating" alarm and an evacuation alarm, except that for single family dwellings the sprinkler operating alarm may serve both functions provided it can be heard throughout the building. Such alarms shall be actuated by each of the following devices: (a) Water flow detector; (b) Low installation pressure detector;'* The requirements for alarms, as stated in section 3.6 of NFPA 13D, states '*Local waterflow alarms with facilities for flow testing such as alarm devices, shall be provided on all sprinkler systems with the exception of dwellings or manufactured homes having smoke detectors in accordance with NFPA 72 National Fire Alarm Code, shall not be required to be provided with a waterflow alarm.*' NZS 4515 states no requirements for smoke alarms, whereby NFPA 13D assumes homes are installed with domestic smoke alarms.

- Clause 4.1.2 of the New Zealand Standard requires sprinklers to be installed in concealed spaces such as cupboards and wardrobes. NFPA 13D allows sprinklers to be excluded from bathrooms of 5.1 m^2 or less, cupboards or areas of the space which does not exceed 2.2 m^2, attics, crawl spaces and other concealed spaces that are not used or intended for living purposes or storage plus sprinklers are not required in entrance foyers that are not the only means of egress (Clause 4-6 Location of Sprinklers).

- The design discharge for sprinklers designed to the requirements of NFPA 13D, requiring a maximum of two operating heads, is not less than 68 L/min for any single operating sprinkler (Clause 4-1.1, NFPA 13D:1995); the design discharge for sprinklers designed to the requirements of NZS 4515 is 100 L/min.

- Sprinkler systems designed to the requirements of NFPA 13D allow dry pipe systems to be installed in climates where there is potential for freezing. The New Zealand standard allows only wet pipe systems, with antifreeze added to the water where there is possibility of temperatures reaching below zero.

- Requirements for sprinkler coverage, according to NZS 4515, vary between rooms of different use. NFPA 13D works on a maximum area of coverage allowed for a sprinkler head and minimum distances between sprinkler heads.

5. COST-EFFECTIVENESS

It is recognised that cost is one of the reasons for the lack of endorsement for domestic sprinkler systems. Coughlin (1999) states that the high cost of the systems can be partially attributed to:

1. Accurate cost estimates for installing domestic sprinkler systems are not available because very few sprinkler installers are in the domestic market. Projected costs for the system can be distorted by commercial overhead from large commercial projects.

2. Requirements from local authorities and building regulators, such as backflow prevention, water connection charges and building consent fees, can add fixed costs to the sprinkler system. It is possible that charges for bringing a water line to a building may exceed the cost of the sprinkler system.

3. Absence of a competitive market due to a lack of installers. Experience in the United States has proven that with the establishment of a competitive market, prices for the installation of a domestic sprinkler system can reduce by as much as 50%, as shown by the Scottsdale case study (refer section 7.2).

5.1 Cost-Effectiveness of Domestic Sprinkler Systems

Research undertaken by BRANZ (Wade and Duncan, 2000), investigated the cost-effectiveness of domestic sprinkler systems installed in compliance with existing standards.

The methodology for the cost-effectiveness study followed that carried out by Beever and Britton (1999) for the Building Control Commission of Victoria, Australia. The study involved cost-benefit modelling to determine a dollar cost per life saved for the installation of specified fire safety measures. The cost per life saved was determined by calculating:

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

Each variable for the cost per life saved equation was derived from New Zealand Fire Service statistics and commercial costs.

For each fire safety measure, a net present cost was calculated by subtracting the net present value of savings (such as injuries avoided and direct loss of property) from the net present value of the purchase, installation and maintenance costs. The net present value (NPV) per household for the fire safety measure was calculated using the formula:

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

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

For analysis, a nominal discount rate of 8% and an inflation rate of 2% was used for an analysis period of twenty years. Where components of the safety measures had a different working life, the replacement costs were incorporated at the appropriate time during the analysis period.

The BRANZ cost-effectiveness study carried out a cost-benefit analysis for the following fire sprinkler options:

- A fire sprinkler system installed in a new dwelling to the requirements of NZS 4515:1995 and the draft Standard DZ 4515/CD3.
- A fire sprinkler system retrofitted to an existing dwelling.

A low-cost three-bedroom home was used as the design home for the sprinkler installations (refer Figure 8). 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. Costs for the fire safety measures were market value, in-situ prices provided by contractors.

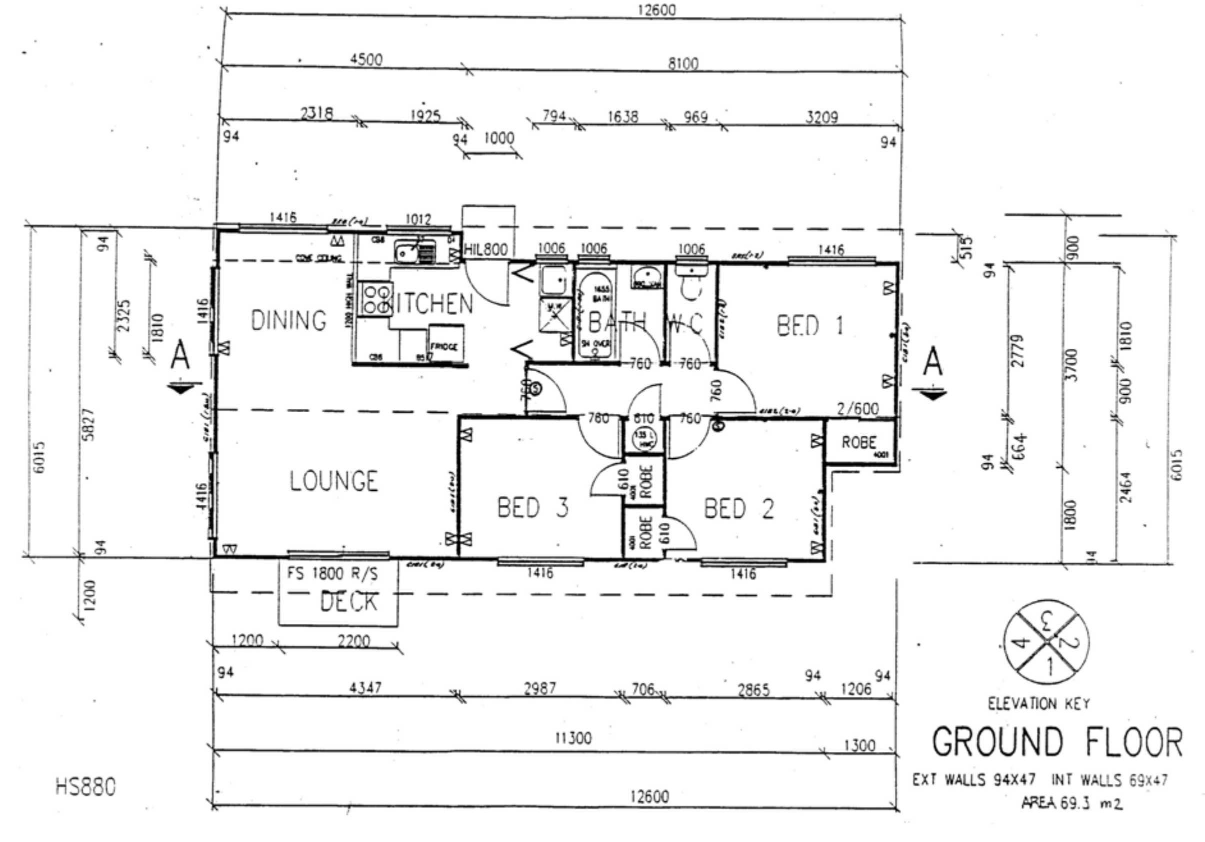

Figure 8: Floor Plan of Design Home
(Source – Wade and Duncan, 2000)

5.1.1 Input variables

In order to evaluate the cost per life saved, values for the installation costs, maintenance costs, injury costs, property losses, expected number of lives saved and the rate of fire incidents were required. The following describes the input 'cost' variables used in the cost-benefit analysis by Wade and Duncan (2000):

- Installation costs

Installation costs for the sprinkler system were taken from quotes provided by sprinkler contractors. The quotes were for installation of the sprinkler systems into the three-bedroomed design home, and were based on the requirements of NZS 4515:1995 (SNZ, 1995). Each pricing itemised costs for materials, labour and maintenance. Average values from the prices were used for the input value of installation costs (refer Table 1).

- Maintenance costs

The annual maintenance was assumed to be undertaken by a sprinkler contractor. A value of $635 was used to cover annual maintenance inspections and replacement of parts.

Table 1 is a summary of the installation and maintenance input values used for the cost-benefit analysis.

Table 1: Installation and Maintenance Input Values

Option	Design, Installation and Material Costs ($)	Connection to Street Mains	Annual Maintenance and Survey Costs ($)
Installed in new dwelling to requirements of NZS 4515:1995	6500**	200	635
Installed in new dwelling to requirements of DZ 4515/CD3 (Draft New Zealand Standard)	4070	200	280

**includes residential valve set ~ $3000 (source – Wade and Duncan, 2000)

Assumptions made for the input costs in the analysis for the domestic sprinkler system installed to the requirements of NZS 4515:1995 (SNZ, 1995) were:

- Analysis period for the study of 20 years, with a sprinkler system life of 50 years.
- The sprinkler system is not connected directly to the Fire Service.
- Annual maintenance is undertaken by a sprinkler contractor at a cost of $350.
- The sprinkler system is required to have an annual survey at a cost of $285.
- There is a water connection fee charged by the territorial authority of $2300 for a retrofit sprinkler system only. It is assumed the domestic water connection charge for a new home would incorporate the sprinkler connection, with an additional $200 cost for the upgrade of the water main to compensate for the additional water demand required by the sprinkler system.
- The system does not incorporate a separate backflow prevention device. Backflow prevention is provided by the check valves in the sprinkler valve set.
- It is assumed that the dwelling is supplied with adequate water pressure, hence no pump is required to boost the pressure for the sprinkler system.

The following describes the methodology for deriving the costs for injury, property loss, the expected number of lives saved and the rate of fire incidents:

- Injury costs

Beever and Britton (1999) assumed a value of A$21,100 as the cost per fire injury. This included pain and suffering, patient and visitor transportation, and estimated lost earnings.

Earlier cost-benefit studies from the U.S. (Ruegg and Fuller, 1984) used $US 20,000. This U.S. study was also the basis for the studies done by Rahmanian (1995) and Strategos (1989).

A value of $30,000 for the average cost of a fire injury was used in this study which is similar to the Australian value after accounting for exchange rates and inflation.

- Property losses

The value for property losses per household per fire was determined to be $17,200 with no sprinkler system or alarm present, and $3,000 with a sprinkler system present.

Data supplied by the Insurance Council of New Zealand (Gravestock, 1999) indicated that the average fire insurance claim over a recent 12 month period to be $13,300. This comprised both contents ($4,700) and building ($8,600) claims. However, the extent of smoke alarm or sprinkler coverage (if any) associated with these claims was not known.

Rahmanian (1995) analysed New Zealand insurance data applicable between 1990-1994. He estimated that the average property loss due to domestic fires in New Zealand to be $74 million per year. Assuming the average number of reported structure fires in domestic buildings to be 4668 fires per year (Irwin, 1997) gives the average property loss per fire as approximately $16,000.

From the analysis of Scottsdale data of property loss in sprinklered houses taken over a ten-year period, the average value for property loss was found to be $US 1,700 (Home Fire Sprinkler Coalition, 1997). A sprinkler system installed in a New Zealand home is assumed to reduce the amount of property loss caused by fire to $3,000.

- Expected number of lives saved

The number of deaths per 1000 house fires in the absence of any fire protection system was estimated to be six. The presence of a sprinkler system was taken to reduce this death rate to 1.2 deaths per 1000 house fires (Wade and Duncan, 2000).

- Expected number of injuries

The expected number of injuries per 1000 house fires in the absence of any fire protection system was estimated to be 40. The installation of a domestic sprinkler system is assumed to reduce the number of injuries to 15 per 1000 fires (Wade and Duncan, 2000).

- Rate of fire incidents

New Zealand Fire Service statistics show that over the five-year period from 1993 to 1997, the average number of fires in one- and two-family dwellings each year was 5,967. Assuming the average number of dwellings to be 1,318,800 over the same period provides an estimate of 0.0045 reported fires per year per household. This rate includes structure and non-structure fires.

Irwin (1997) also analysed New Zealand Fire Service data for the period 1986 to 1994, and determined the average number of reported structure fires in domestic buildings (1-2 family dwelling and apartments, flats) to be 4668 per year. Based on an average number of dwellings of 1,152,000 over that period provides an estimate of 0.0041 reported fires per year per household.

Therefore, a fire incident rate of 0.004 fires per year per household is used in this study based on current New Zealand data from NZFS Statistics 1993-1997 and Irwin's (1997) analysis. Although higher than the equivalent Australian data, this is still expected to provide a conservative estimate of the actual fire incident rate due to the number of fires that are discovered and extinguished without a call to the Fire Service.

5.1.2 Results

Results of the BRANZ cost-effectiveness study were consistent with the findings of the Australian study (Beever and Britton, 1999); domestic sprinkler systems, constructed to current standards, are not cost-effective at a cost per life saved calculated to be around $35 million (refer Table 2).

Prices quoted for the sprinkler systems installed in the design home ranged from around $6000 to around $10000. Items which contributed significantly to the cost of the system were the valve set and ongoing costs for maintenance and inspection.

Table 2: Results of Sprinkler Cost-Benefit Analysis

	Option	$cost/life saved
Sprinkler System	Installed in new dwelling to requirements of NZS 4515:1995	$35 million
	Installed in new dwelling to requirements of DZ 4515/CD3 (Draft New Zealand Standard)	$18 million

(source – Wade and Duncan, 2000)

5.1.3 Incentives

To encourage the wider use of domestic sprinkler systems, incentives are required. The Residential Fire Safety Institute of the United States (Residential Fire Safety Institute, 1999) identifies two types of incentives to encourage the use of domestic sprinkler systems. The first is economic, such as low-interest loans; the second is design alternatives like reduced compartmentation requirements or longer distances to exits. Design alternatives have also been called tradeoffs and are used in commercial applications when there is a sprinkler system installed.

Incentives which would encourage the homeowner to install a domestic sprinkler system include:

> Reduced insurance premiums, reduced fire resistance ratings, no separate water meter for the sprinkler system, no charge for the connection of the sprinkler system to the water mains, check valves instead of low-pressure-principle backflow preventer, property tax (rates) reductions, reducing installation labour costs, placing the onus of maintenance on the homeowner instead of requirements for specialist maintenance inspectors.

On a town planning scale, if all private homes had sprinkler systems installed, there would be the potential for the following cost savings:

- Increased density of housing, greater fire hydrant spacing, longer access road distance, longer distance from fire stations, reduced access to building sides, narrower streets, longer cul-de-sacs, reduced turnaround radius, reduced fire fighting water supply requirements.

- Most of the town planning issues relate to reviewing the access and facility requirements for the fire service. These town planning issues are exemplified by the case studies in the United States where towns have developed legislation making the installation of domestic sprinkler systems compulsory.

Town planning incentives would become attractive to the homeowner if the reduction in community spending on fire safety and protection, filtered down to them. The cost savings could be reflected in reduced rates or the increased quality of community-provided services.

5.1.4 Recommendations

Investigation of domestic sprinkler systems installed to current standards in New Zealand homes shows costs are too high to achieve general acceptance, but potential exists for a reduction in costs and an increase in installations (BRANZ, 1989).

The cost-effectiveness study identified areas where there are options available to reduce the cost of the domestic sprinkler system. Potential cost saving measures manifest as economic and design incentives.

Basic principles of economics indicate that economies of scale will help with the reduction of the cost of domestic sprinkler systems. The more demand for the products and services associated with domestic sprinkler systems, the more competitive the prices will become. On the town planning scale, requirements for domestic sprinkler systems will reduce the funds required for providing access and facilities for the Fire Service.

The results from the cost-benefit analysis show that domestic sprinkler systems installed to current New Zealand standards are not cost-effective. Reinvention of the approach towards domestic sprinkler system codes, standards and installation is required in order to make the systems more cost-effective.

6. DOMESTIC SPRINKLER SYSTEMS

6.1 Definitions

The following are key definitions used for domestic sprinkler systems. The definitions originate from NZS 4515:1995, the New Zealand Standard for the installation of fire sprinkler systems in residential occupancies and private dwellings (SNZ, 1995), and will help clarify references in the text to the components of the sprinkler system.

A sprinkler installation is defined as *'that part of the system downstream from and including the main stop valve.'* A sprinkler system is *'a system including:*

(a) The water supply pipes from the boundary of the protected premises to the sprinkler valves;

(b) Any static water supply on the protected premises;

(c) Any pump providing water supply and its driving engine, motor and control equipment;

(d) The control valves and all appurtenances thereto;

(e) The main stop valve anti-interference devices;

(f) Any fire alarm signalling device;

(g) All pipework, sprinklers and appurtenances downstream of the control valves;

(h) First aid fire fighting appliances;

(i) *Any fire rated wall, door or partition required by this Standard.'*

Of primary importance to the sprinkler system are the sprinkler heads. Sprinkler heads are required to be listed. Listing *'means that such (specific makes and models of equipment, materials, procedures, organizations and facilities required or permitted by this Standard) has been examined by the authority having jurisdiction and found to meet relevant standards and/or has otherwise been demonstrated to be adequate for the intended application. Listings are limited in effect to the tenor and qualifications of the listing document issued by the authority having jurisdiction and cease to have effect from the date that the authority having jurisdiction issues any signed notice of withdrawal of listing.'*

Particular sprinkler heads have been manufactured for specific use in the residential and domestic situation. A residential sprinkler head differs from a quick response sprinkler head due to the higher than usual spray pattern. NZS 4515 defines a residential sprinkler as, *'an automatic sprinkler head designed and listed as a residential sprinkler for the protection of residences and featuring a very low response time index and a higher than usual discharge trajectory.'*

There are applications in the domestic situation for:

Standard response sprinkler heads – *'a sprinkler of spray pattern, conventional pattern or sidewall pattern of 10 mm or 15 mm nominal bore in which the operating element will produce a response time index of greater than 200* $ft^{1/2}sec^{1/2}$ *(110* $m^{1/2}sec^{1/2}$*).'*

Intermediate response sprinkler heads – *'a standard response sprinkler in which the operating element has been replaced by the original manufacturer with an operating element that will produce a response time index of 80 to 200* $ft^{1/2}sec^{1/2}$ *(44 to 110* $m^{1/2}sec^{1/2}$*).'*

6.1.1 Sprinkler heads

Sprinkler heads, which respond automatically to the heat generated by a fire, have been designed uniquely for the domestic situation. Sprinklers with a residential listing differ from normal quick response heads due to their spray pattern. The residential heads direct water high on the walls instead of the typical 'umbrella' spray pattern (Coughlin, 1999). The spray pattern was developed to ensure coverage of walls and ceilings, often constructed of combustible material.

The New Zealand Standard, NZS 4515:1995 (SNZ, 1995), specifies residential sprinklers for use in the domestic situation. The argument used for specifying residential sprinkler heads by the New Zealand Standard is as follows:

- *Firstly, the amount of smoke and toxic gases produced by the fire is typically well below life threatening threshold levels.*

- *Secondly, the amount of heat produced by the fire is smaller and less water is needed to cool the fire. This provides substantial cost benefits by way of reduced pipe sizing, easier installation and smaller system water demand. In many cases, it will be possible to use the domestic water supply to feed the system.*

Quick response residential heads can have response times as low as 20-30 seconds. According to the BRANZ information bulletin on domestic sprinkler systems (BRANZ, 1989), the effectiveness of the quick response residential heads is based on having a thermal link with a larger surface area (to absorb heat at a faster rate) and a lower mass (so less heat needs to be absorbed), so that they activate quicker than standard heads. The speediness of the response provides the occupants with additional time to escape. The sprinkler heads are required to be listed to ensure they respond as required for the domestic situation.

New domestic sprinkler technology are the "on-off" sprinkler heads. At approximately eight times the cost of standard quick-response residential sprinkler heads (Mak, 1999), the "on-off" sprinkler heads do not add to the cost-effectiveness of the system. What the "on-off" heads provide is control and moderation of the amount of water supplied to the fire.

The "on-off" sprinkler head is activated when the temperature of its bimetallic disc is exceeded; the disc will reverse its curvature and allow flow-through the sprinkler. When the temperature around the sprinkler decreases to approximately 38°C, the curvature of the disc reverses and shuts off the flow-through the sprinkler (Beever and Britton, 1999).

The “on-off” heads provide the option to exclude the sprinkler alarm which activates by sensing flow in the system. The “on-off” sprinkler heads would mean that the system would not necessarily be required to be monitored. The advantage for using an “on-off” style sprinkler head is particularly for buildings which are unoccupied at the time of the fire. The use of the automatic switch off would reduce the amount of water damage caused by sprinklers discharging in the unoccupied building.

6.1.2 Piping

The use of plastic piping, as opposed to steel or copper piping, has influenced the cost of the domestic sprinkler system. Plastic piping costs less and has been proven to be more versatile, particularly for use in retrofitting sprinklers for an existing home.

The versatility of the plastic piping system originates from the pipe’s flexibility and jointing characteristics. The flexibility of particularly polybutylene pipe, has aided installation as smaller holes are required in the existing structure to position the pipe. Plastic fittings are used for joining the system and plastic welding or simple gluing can be used to weld pipe lengths together.

Hydraulic calculations are influenced by the roughness coefficient for the plastic piping. The plastic piping is smoother than the metal and hence for the same water pressure and pipe diameter, more water can flow (BRANZ, 1989).

New Zealand Standards (SNZ, 1995; SNZ, 1995-b) approve polybutylene (PB) and chlorinated polyvinyl chloride (cPVC) for use in domestic sprinkler systems. Again, the pipe work is required to be listed before certification of use.

6.2 Multi-Purpose Sprinkler System

6.2.1 Cost reductions

A multi-purpose sprinkler system shares the same pipe as the domestic plumbing system. Using the same pipe for both systems means less pipe and less fittings. The sprinkler heads are designed to operate from the pressures of the domestic water supply.

The biggest cost saving the multi-purpose sprinkler systems offer is the deletion of the backflow prevention devices and control valve-set from design requirements. The purpose of the backflow prevention device is to prevent the stagnant water in the sprinkler system from backflowing into the potable water supplied by the mains (Coughlin, 1999). In the BRANZ cost-effectiveness study (Wade and Duncan, 2000), the backflow prevention device included in the valve set, contributed approximately $300 to the total cost of the sprinkler system. Exclusion of the backflow prevention device would contribute towards making the sprinkler system more cost-effective.

With the sprinkler system incorporated into the house plumbing, there is potential for plumbers or trained professionals to install the system (Coughlin, 1999). Installing the sprinkler system in conjunction with the standard domestic plumbing would also reduce the costs for piping and fittings.

The multi-purpose system alters the maintenance requirements for the sprinkler system. Faults within the system would be more readily identified as there would be a constant flow of water through the piping. Current maintenance requirements from the New Zealand Standard for domestic and residential sprinkler systems, NZS 4515:1995, require six-monthly and annual checks of the system. These checks involve routine maintenance such as pressure checks and alarm activation, and are undertaken by sprinkler contractors. The BRANZ cost-effectiveness study identified maintenance requirements as costing approximately $635 annually (Wade and Duncan, 2000). The annual fees for maintenance are a disincentive for the homeowner to install a sprinkler system. For the case of the multi-purpose system, an initial certificate of compliance could be issued at completion of the sprinkler installation, and further official inspections left to the discretion of the homeowner.

6.2.2 Design requirements

Adaptations to parts of the stand-alone sprinkler system are required in order for the multi-purpose system to provide the same amount of protection from fire.

Since multi-purpose systems share the same pipe as domestic plumbing, a normal flow switch would trigger an alarm whenever high-flow plumbing fixtures were opened. Flow switches would not be an appropriate mechanism to activate the sprinkler alarm. It could be possible for a smoke alarm to provide the early warning of the fire, in replace of an alarm activated by flow in the sprinkler pipe system. The smoke alarm would alert occupants to a fire so a flow switch could be eliminated. Coughlin (1999) indicates that some homeowners want a flow switch so their home can be monitored in their absence. In this case, the installer can set the delay mechanism in the flow switch for a time period longer than a normal flow. The switch could also be placed on a security system so that it can be activated when the homeowners are not home (Coughlin, 1999).

An independent fire sprinkler shut-off valve would not be available for the multi-purpose sprinkler system. The control valve for the domestic water supply would need to be accessed for sprinkler control and shut-off. With the water supply for the sprinkler system linked to the domestic supply, the possibility of unintentional shut-off of the water supply is reduced and therefore reliability is improved.

The American Fire Sprinkler Association (AFSA) offers a guide to ensure multi-purpose sprinkler systems are installed correctly (SprinklerNet, 1999). The purpose of the guide is to provide a structure for the multi-purpose sprinkler installation and to identify some of the differences between a stand-alone, dedicated sprinkler and an multi-purpose sprinkler system. NFPA 13D:1999 provides minimal guidance on the installation of multi-purpose sprinkler systems, with this guide building on the NFPA 13D requirements (SprinklerNet, 1999). The multi-purpose system must provide automatic sprinkler protection in all areas as required by NFPA 13D:1999; design requirements for the number of sprinkler heads remains the same as that for a conventional stand-alone sprinkler system.

The AFSA states that the fire sprinklers are the driving system for the initial pipe layout since it presents the greatest water demand, is a life safety system for which sprinkler locations are critical, and must be supported by hydraulic calculations (SprinklerNet, 1999). The sprinkler system must be designed before the domestic plumbing system.

With the sprinkler system incorporated into the domestic plumbing system, alterations to the plumbing system may compromise the design of the sprinkler system. Multi-purpose sprinkler systems in the United States are required to be labelled with:

‘This is a multi-purpose fire sprinkler system, no modifications should be made to the plumbing or fire sprinkler system without contacting a qualified contractor’ (SprinklerNet, 1999).

Multi-purpose fire sprinkler systems in the United States are not required to be directly connected to the Fire Service (SprinklerNet, 1999).

6.3 Flow-Through Sprinkler System

A flow-through sprinkler system functions on similar principles to the multi-purpose system. According to information published by the City of Burnaby Building Department in the United States (1999), flow in the flow-through sprinkler system is achieved by taking a connection from the most remote sprinkler head in the system and extending the piping to serve the toilet. Potable water is allowed to flow-through the main sprinkler distribution piping each time the toilet is flushed. With fresh water flowing through the system, the degree of backflow hazard is reduced, thereby allowing the use of a simpler, less expensive back flow device in place of the double check valve assembly. The flow-through system is provided with a vane-type water flow indicator alarm which will activate when the water flow rate exceeds a certain rate, indicating that a sprinkler head is activated.

Unlike the multi-purpose sprinkler system, the flow-through system has its own unique set of piping. The system is not incorporated into the piping network for the domestic plumbing system. Water flows from a separate mains supply and is circulated through the system every time the toilet flushes.

Like the multi-purpose sprinkler system, the flow-through system eliminates many of the maintenance requirements.

The flow-through system is potentially more expensive than the multi-purpose sprinkler system due to the stand-alone piping network, but because of the potential for relaxed maintenance requirements and reduced installation costs, there are possibilities for the flow-through systems to further reduce the cost of domestic sprinkler systems.

7. CASE STUDIES

7.1 Domestic Sprinkler Legislation

The United States is proactive 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. 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).

7.2 Scottsdale Case Study

The process for adopting compulsory requirements for domestic sprinkler systems in Scottsdale, Arizona was initiated by people in the fire protection community understanding that there is not only one single method of protection that can provide the answers to all the variables associated with providing effective fire protection (Home Fire Sprinkler Coalition, 1997).

This sequence of events looks specifically at the community of Scottsdale and the steps used to research, adopt, implement and evaluate the benefits to the community from compulsory installation of domestic sprinkler systems.

Some background information for the city of Scottsdale is as follows (Home Fire Sprinkler Coalition, 1997):

- The City of Scottsdale is located in Central Arizona in the United States and is a member 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 attributing to a 54% population increase in ten years.
- The city area encompasses 182.5 square miles (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.

The Scottsdale study identified six major areas that should be evaluated to better address the issue of fire loss in the United States:

1. The need to place more emphasis on fire prevention.
2. The fire service needs better training and education.
3. Americans must be educated about fire safety, in both design and materials.
4. The environment in which Americans live and work presents unnecessary hazards.
5. The fire protection features in buildings need to be improved.
6. Important areas of research are being neglected.

7.2.1 Sequence of events

From the inception of the idea to adopt requirements for domestic sprinkler systems, it took around 10 years to develop the law and implement it. Between the years of 1974 and 1995 there were many milestones that illustrate the process of designing, adopting and assessing the effectiveness of compulsory domestic sprinkler systems.

SEQUENCE OF EVENTS

SCOTTSDALE RESIDENTIAL SPRINKLER PROJECT – Saving Lives, Saving Money Automatic Sprinklers – a 10 year study (Home Fire Sprinkler Coalition, 1997).

In September 1974 the city of Scottsdale enacted its first major sprinkler code. City Ordinance #829 adopted the 1973 Uniform Fire Code and amended the document 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 two primary beliefs:

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.

In 1977, Scottsdale was first introduced to the residential sprinkler concept when the Fire Chief of San Clemente, California requested the Fire Chief of Scottsdale be present when the San Clemente residential sprinkler ordinance and protection concept was presented to its City Council. Several other recognised leaders in the sprinkler protection field were in attendance of the Council meeting to provide assistance and support. Specifically, their support was related to identifying the advantages and disadvantages of built-in fire protection. When the Fire Chief of Scottsdale returned home from the San Clemente Council meeting, the task of developing a comprehensive sprinkler ordinance for the City of Scottsdale was assigned to the City's Fire Marshal.

It was decided that in order for the implementation of a law to make domestic sprinklers compulsory, there were critical issues that still needed to be addressed. The critical issues identified were:

1. Some additional real life scenario testing of the new sprinkler technology would need to be established;

2. Further development and research of the design freedom concept for sprinkler systems to help address the economic impact of this built-in protection.

It was recognized that in the late 1970's and early 1980's 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. Contacts with communities such as Cobb County, Georgia, who had successfully developed laws for compulsory installation of domestic sprinkler systems, gave insight into how to make the sprinkler ordinance for Scottsdale more cost effective. The focus of the research was to identify which of the passive development code guidelines could be changed or modified to help reduce the initial cost of the required sprinkler protection.

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 32 feet (10 metres) to 28 feet (8.5 metres) was approved.

- Cul-de-sac lengths were increased from 600 feet (183 metres) to 2,000 feet (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 rated doors separating single family homes from garages was also eliminated.

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

> Fire hydrant spacing was increased from 330 feet (100 metres) to 700 feet (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.

On June 4, 1985 the Scottsdale Sprinkler Ordinance #1709 was adopted for the community and was fully implemented on January 1, 1986. Effective July 5, 1985, all new multi-family and commercial structures for which building permits are issued will be sprinklered. The ordinance also requires that, effective January 1, 1986, all new single-family residences for which building permits are issued be sprinklered.

7.2.2 Ten years of domestic sprinklers

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 the domestic sprinkler standard. The average house was taken to be a 2000 square foot (186 square metres) single-family home. The two primary areas this study focused on were the total costs and allowed design freedoms for both on-site and off-site changes. The findings of the 1986 study undertaken by Reese-Carr (Home Fire Sprinkler Coalition, 1997), indicated the total costs would be $US 1.14 per square foot ($US12.27 per square metre) to install a domestic sprinkler system in a new 2000 square foot (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 tradeoffs 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 the same proportion. Interestingly, the area of the city did not expand, remaining at 183 square miles (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 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 $US 1.14 sq ft ($US 12.27 per square metre) to $US 0.59 sq ft ($US 6.35 per square metre), a close to 50% reduction in cost.

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

- Estimated water flows were substantially reduced for the community.

- When the city finally 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 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.

7.3 Domestic Sprinkler Activation

Media reports illustrate graphic details of domestic fires and fatalities. More recently, due to the New Zealand Fire Service campaign to promote domestic smoke alarms, there have been reports of the success of smoke alarms at saving lives, but the reports still show pictures of property damage. Very rarely are there reports telling of where domestic sprinklers have successfully protected life and property. The lack of reports of the success of domestic sprinkler systems in New Zealand homes is possibly due to the small number of installed systems.

To emphasise the effectiveness of domestic sprinkler systems, reports of their success are published. Reports show pictures of how a sprinkler head can contain a fire and contrast this with the damage caused if the home were not sprinklered. The reports describe how efficient sprinklers are at containing and extinguishing the fires.

In all cases, the argument for the installation of domestic sprinkler systems becomes emotive. Statements such as:

‘You do have a choice – a puddle of water or a pile of ashes’ (Sprinkler success stories, 1997-B).

‘Had there been NO sprinklers, the outcome of this fire could have been worse including the loss of one’s most valued possessions ……….. human life.’ (Sprinkler success stories, 1997-A.)

Smoke alarms are generally accepted as a form of early warning from a fire; they are relatively inexpensive, easy to install and maintain, plus they have a proven record of success at effectively warning occupants of fire. The argument for the inclusion of a domestic sprinkler system is that, with only a smoke alarm installed, the occupant must have the skills, knowledge and ability to escape the structure on their own (Home Fire Sprinkler Coalition, 1997). A domestic sprinkler system would provide suppression as well as early warning.

8. EXPERIMENTAL DATA FROM RESIDENTIAL SPRINKLER TESTS

The literature search provided a variety of comprehensive experiments which investigate the performance and benefits of residential sprinklers. The following is a summary of the relevant experiments.

8.1 Experimental Data

Reference: Notarianni, K. 1993. Measurement of room conditions and response of sprinklers and smoke detectors during a simulated two-bed hospital patient room fire. NISTIR 5240, Gaithersburg, MD.

A series of experiments was reported in which a wood crib was burned in a simulated two-bed hospital patient room in order to measure the activation times of various types of quick- and standard-response sprinkler heads and smoke alarms. The fire was selected to be of a small enough size to challenge the tenability of the space by burning for a long enough period to allow the accumulation of smoke and gases before the temperature beneath the ceiling was sufficient to activate the sprinklers. It was determined that a 60 kW steady state fire with the door closed posed the greatest challenge to the tenability of the space. The gas temperature at the time of sprinkler activation for the quick response sprinklers was at or below 77ºC at a height of 5 feet (1.14 metres) above the floor, and at or below 48ºC at a height of 3 feet (0.7 metres) above the floor. Of the parameters measured, temperature was the best indicator of tenability. Sprinklers in all locations tested actuated before this nominally 60 kW fire would threaten the patient's life, except in the case of a shielded fire test, where sidewall sprinklers operated after the life safety criterion in the computer model HAZARD 1, with regard to temperature, was exceeded. Ionisation and photoelectric smoke alarms in all locations, for all fire scenarios conducted, alarmed before the patient's life would be threatened.

The outcomes from these full-scale tests were used as validation of the outcomes from the computer model BRANZFIRE (Wade, 1996; Wade and Barnett, 1997; Wade et al, 1997; Wade, 1999) (refer Section 11).

Reference: P. Beever and M. Britton. 1999. Research into cost-effective fire safety measures for residential buildings. Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Australia.

An experimental series was designed to examine sprinkler and smoke alarm effectiveness in Building Code of Australia Class 1 buildings. Class 1 buildings are classified as follows (ABCB, 1996):

> 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*.

Nine full-scale experiments were conducted in a burn room designed to represent a typical domestic lounge room, being approximately 20 m^2. A fire load comprising of mixed plastics and timber to produce a "fast" fire growth rate. The fuel load was approximately 30 kg/m^2 wood equivalent. The door to the room was open during the experiments. Fast-response domestic sprinklers with a response time index in the range 22 to 33 $(ms)^{1/2}$ were used, except for one test where an on/off sprinkler was used. The experiments showed that tenable conditions could be maintained with a 20% reduction in the current domestic sprinkler discharge requirements (to Australian Standards) and with an increased spacing of sprinkler to wall distance.

Reference: Sekizawa, A., Takemoto, A., Kozeki, D., Yanai, E. and Suzuki, K. 1997. Experimental study on fire hazard of residential fires before and after sprinkler activation. Thirteenth meeting of the UJNR Panel on Fire Research and Safety March 13-20, 1996. Volume 2. National Institute of Standards and Technology, Gaithersburg, MD.

Fire experiments were carried out in a full-scale room (3.8 m x 3.6 m x 2.4 m), assumed to be a residential living room. Ventilation conditions and the location of a 20 kg wood crib fuel source were varied. Concentrations of oxygen and carbon monoxide, smoke density and temperature were measured. The activation of residential sprinklers (operating temperature = 72°C) (and other fire detectors) was investigated.

When the fire source was placed in the centre of the room, the response of the sprinklers were quick and the fire was extinguished early. The CO concentration was 200 ppm before sprinkler activation and 500 ppm afterwards. Another test was done with the sprinkler and fire source horizontally offset to be the most unfavourable configuration. In this experiment, the sprinkler activated 7 minutes after ignition and the water discharge controlled the fire. However, when a door to the room was opened 15 minutes after ignition, the fire started to grow again. This indicated incomplete combustion even after the sprinkler operated. CO gas concentration rose drastically following the activation of the sprinkler. It was 2000 ppm at 13 minutes after ignition, and 3500 ppm at the end of the experiment.

This confirmed that in some unfavourable cases for the activation of sprinklers, a person inside the room of origin could be exposed to untenable conditions.

Reference: Budnick, E. 1984. Estimating the effectiveness of state-of-the-art detectors and automatic sprinklers on life safety in residential occupancies. NBSIR 84-2819. National Bureau of Standards, Washington, DC.

Budnick reviewed the results of full-scale tests and the statistics on residential fire fatalities from the NFIRS database. He claimed that approximately 20-30% of the fatalities in residential occupancies appeared unsavable by current (1984) smoke alarm or sprinkler technology. These fatalities occurred primarily because of intimate exposure of the person to the fire, or exposure to a very rapidly developing shielded fire. In both cases, he claimed that hazardous conditions frequently occur prior to smoke alarm or sprinkler activation.

Criteria for hazardous levels of gas temperature, carbon monoxide, oxygen and smoke density were given as:

Temperature > 100 ^{o}C

Carbon monoxide > 8000 ppm or 50% COHb

Oxygen < 12%

Smoke density > 0.25-0.50 OD/m

Reference: Kung, H et al. 1980. Sprinkler performance in residential fire tests, prepared for Federal Emergency Management Agency, US Fire Administration, Factory Mutual Research, Norwood, MA.

Full-scale sprinkler system testing indicated that for many residential fire scenarios, suppression was initiated before conditions hazardous to life safety were reached.

Reference: Kung, H et al. 1982. Field evaluation of residential prototype sprinkler − Los Angeles Fire Test Program, Factory Mutual Research, Norwood, MA.

Tests were conducted in a large two-storey dwelling that was instrumented to measure the development of hazardous conditions in the rooms and along the escape routes. Data were collected on gas temperatures and toxic gas production both before and after sprinkler activation. Peak levels for temperatures, carbon monoxide and oxygen concentration at eye level indicated that hazardous conditions were not reached in the room of origin, at the top of the stairs, or in the bedroom on the second floor for either smouldering or flaming upholstered furniture fires initiated in the living room. The residential sprinkler responded before hazardous conditions were reached.

The results from the living room upholstered chair fires were typical of the performance of the residential rapid-response sprinklers for most of the other scenarios tested, except for a flaming fire in an unsprinklered walk-in closet in a bedroom and a smouldering fire in a closed bedroom. In the case of the unsprinklered closet, hazardous conditions were substantially exceeded in the bedroom, along the escape path and in the living room. In the case of the bedroom smouldering fire, the fire did not reach a flaming state. However, the sprinkler eventually activated more than 5 hours after smouldering ignition and controlled the fire, but CO concentrations exceeded 5000 ppm more than two hours prior to sprinkler activation. Such a concentration for that time period would be lethal.

Reference: Cote, A. 1983. Final report on field test of a retrofit sprinkler system. National Fire Protection Research Foundation.

This was a series of 11 full-scale hotel room fire tests to evaluate the effectiveness of quick-response sidewall sprinklers used in conjunction with a polybutylene piping system in a retrofit system installation. In the eight fast-flaming and flaming start fires, the quick-response sprinklers controlled the fire and critical limits for survivability were not exceeded. In the fast-flaming start fire without sprinklers, critical limits for survivability were exceeded.

9. RISK ASSESSMENT

The literature review and analysis undertaken in this research concludes, 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 is 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.

The risk assessment was undertaken through the use of event tree analysis. An event tree is a logic diagram which predicts the possible outcomes from an initial event (Charters, 1999). The likelihood of each outcome depends on other factors such as whether the fire is noticed at an early stage, whether it spreads or whether it is put out with fire extinguishers. The conditional probability of each of these other factors can be calculated and an estimate made of how often an event occurs (Charters, 1999).

9.1 Risk Assessment Objectives

The risk assessment objectives are to:

5. Investigate the number and location of injuries and fatalities as a result of domestic fires.

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

7. Assess the impact on the number of injuries and fatalities as a result of reducing the reliability of the domestic fire sprinkler system.

8. 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 space.

9.2 Event Tree Development

The event tree used for analysing the effectiveness of the domestic fire sprinkler system evolves from the combination of two event trees: the complete event tree and the sprinkler reliability event tree.

9.2.1 Complete event tree

There are four significant stages in the sequence of events from fire ignition to outcome: the event, detection, intervention and outcome (refer Figure 9).

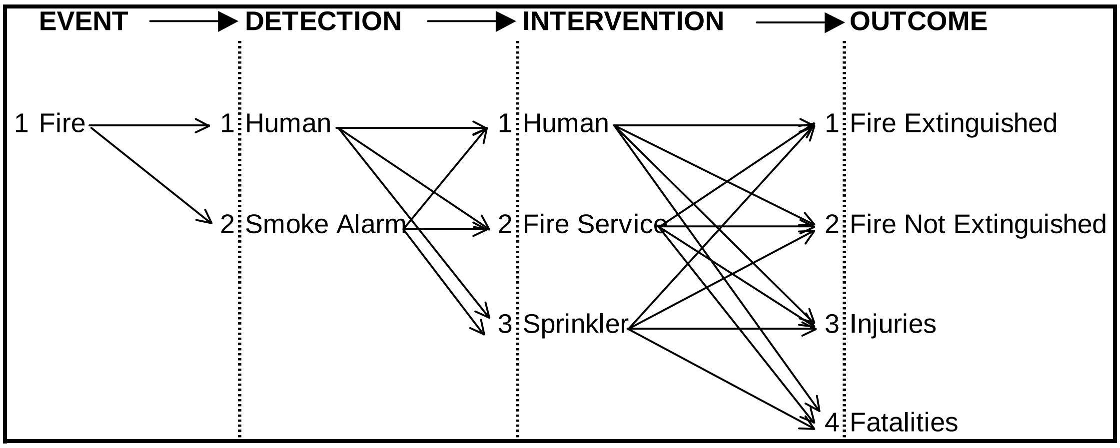

Figure 9: Complete Event Tree

The complete sequence of events varies according to the sequence of the detection and intervention stages. Uncertainties arise when trying to quantify human influences on the sequence – for example, whether the fire is first detected by the occupant or smoke alarm, whether the smoke alarm cue is recognised, whether intervention with fighting the fire is successful and the timing of calling the fire service. Uncertainties also arise when identifying the type of domestic fire.

The uncertainties associated with the sequence of detection and intervention stages, choice of fire type and the difficulty in quantifying human influences make the event tree unwieldy. As the conditional probabilities are difficult to measure, the complete event tree has to be simplified to reduce the amount of uncertainty in the calculation.

9.2.2 Sprinkler reliability event tree

The reliability of the domestic sprinkler system can be determined from first principles. Assuming that a fire develops in a domestic situation, the domestic sprinkler event tree assesses the ability of the sprinkler system to successfully control or extinguish the fire.

The operation of the domestic fire sprinkler system involves five factors which combine to determine whether the water expelled from the sprinkler head will successfully reach the fire. These five factors are:

1. Availability of water supply

2. Functionality of valve set

3. Reliability of pipework

4. Operation of the sprinkler head

5. Effectiveness of the spray discharged from the sprinkler head

The availability of the water supply for the proposed domestic fire sprinkler system refers to the supply from the town mains. This supply is as reliable as the potable water supply to the home. An estimate would assume that the water supply to the home would be disrupted, on average, two days per year for reasons such as routine maintenance. Assuming this two-day disruption, the reliability of the water supply is 99.5%.

Annual maintenance inspections of sprinkler system control valvesets are required by NZS 4515:1995 (SNZ, 1995). The checks are a requirement to ensure water is supplied to the sprinkler system and that the water reaches the sprinkler heads at the correct pressure. Factors which may cause the control valveset to be non-operational include faulty installation and accidental closure of the valve. The design for both the proposed low-cost multi-purpose sprinkler system and the flow-through sprinkler system do not require a control valveset. Similarly, for the two proposed systems, backflow prevention is not required as only potable water is flowing through the system.

Pipe used for domestic sprinkler systems is required to be listed (refer Section 6.1.2). Uncertainties arise, particularly for plastic piping, due to the location of the fire; if the fire is intimate with the pipe work, the reliability can be reduced.

Residential sprinkler heads are required to be listed. Listing ensures that the sprinkler head is manufactured and operates as correctly at the specified pressures and flows.

The type and location of the fire influences the effectiveness of the sprinkler system. For example, a shielded fire is sheltered from the extinguishing effects of the water from the sprinkler head. Human influences need to be factored into whether the spray from the sprinkler head is effective at reaching the fire. For example, obstructions to the sprinkler head, such as attaching ornaments, can alter the spray pattern.

The conditional probability of each of the five factors which jointly determine the sprinkler effectiveness can be calculated, and an estimate made of whether the water discharged from the sprinkler head is successful in reaching the fire.

The uncertainties associated with the human influences and fire characteristics make the reliability of the sprinkler system difficult to quantify from first principles. Statistics from the operation of sprinkler systems were used as reliability input data for the final event tree.

9.3 Event Tree

From the combination of the complete event tree and the sprinkler reliability event tree, four stages in the sequence of events were identified: probability of fire occurrence, area of fire origin, smoke alarm detection and sprinkler intervention. These four factors fit into the categories of event, detection and intervention, as characterised by the complete event tree (refer Figure 10). The outcomes in the event tree are identified as the numbers of injuries and fatalities as a result of the fire.

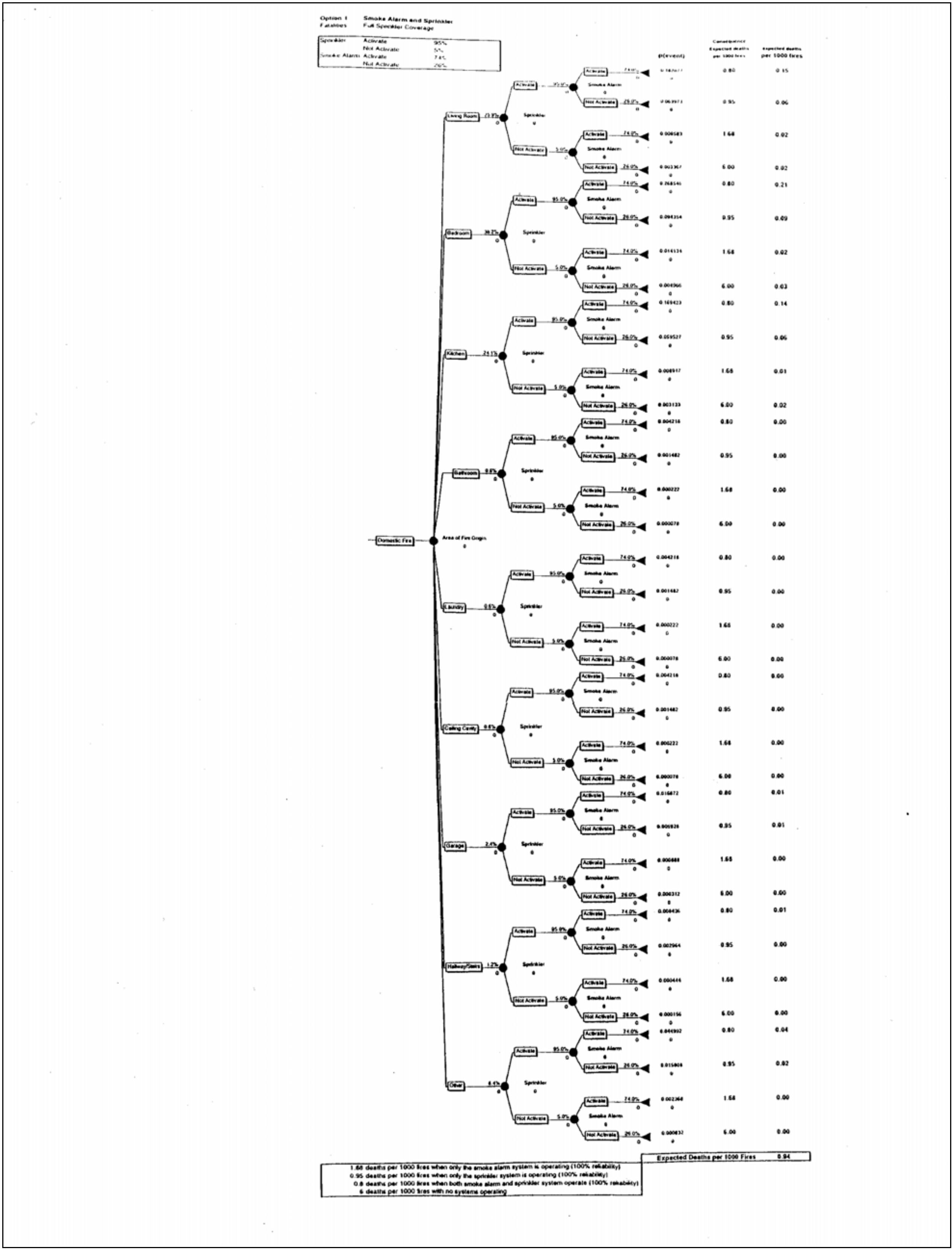

Figure 10: Sample Event Tree

9.3.1 Nomenclature

The event tree diagram represents the sequence of events developed to assess the objectives of the risk assessment (refer Figure 10). Diagrammatic representations of event trees use symbols to represent where selections are made. Squares represent decisions to be made and circles represent chance events. The branches emanating from a square correspond to the choices available to the decision maker and the branches from a circle represent the possible outcomes of a chance event. Diamonds symbolise the end of the event process. The third decision element, the value of the outcomes, is specified at the ends of the branches (Clemen, 1991).

9.3.2 Detection and intervention combinations

Four combinations of detection and intervention were analysed (refer Table 3):

Table 3: Detection and Intervention Combinations

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

9.3.3 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 system, then multiplied with the reliability of the smoke alarm to achieve an estimate of the likelihood of this sequence of events occurring. The likelihood of this event sequence is in turn multiplied with 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 (refer Figure 10). 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 I – Event Tree Including Calculations).

The outcomes, in terms of numbers of injuries and fatalities, from each combination option of sprinkler and smoke alarm are compared for analysis of the risk assessment objectives.

9.4 Statistics

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

9.4.1 Probability of fire occurrence

As discussed in section 5.1.1, a fire incident rate of 0.004 fires per year per household is used in this study.

9.4.2 Areas of fire origin

For analysis of the influence on injuries and fatalities as a result of removing sprinkler heads from the ceiling cavity, bathroom and wardrobes/cupboards, the distribution of area of fire origin is required.

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

Living Room	16.1 %
Bedroom	30.8 %
Kitchen	37.2 %
Bathroom	1.2 %
Laundry	1.2 %
Ceiling Cavity	1.1 %
Garage	2.0 %
Hallway/Stairs	2.2 %
Other	8.2 %

The likelihood (%) of the fire occurring in the living room, bedroom, kitchen, bathroom, laundry and garage are taken from New Zealand Fire Service statistics (Irwin, 1997). The likelihood of fires originating in the ceiling cavity, hallway/stairs and ‘other’, which result in injuries, is based upon United States fire statistics. The United States data is based on 13,691 injuries and 3,589 deaths over the period 1973-1983 (NFPA, 1999). The proportion of incidents remaining is distributed according to the United States statistics provided in Table A-1-2(a) of NFPA13D:1999 (NFPA, 1999). Table 4 presents the United States data.

Table 4: United States Statistics - Area of Fire Origin Causing Injuries and Fatalities

Area of Origin	Civilian Deaths	Civilian Percent	Fires	Percent	Injuries	Percent
Living Room, family room or den	1330	37.1	42600	10.5	2546	18.6
Bedroom	919	25.6	50200	12.4	3250	23.7
Kitchen	541	15.1	92670	22.9	3987	29.1
Dining Room	83	2.3	3780	0.9	189	1.4
Heating equipment room or area	62	1.7	15130	3.7	374	2.7
Hallway or corridor	48	1.3	3690	0.9	155	1.1
Laundry room or area	47	1.3	15370	3.8	363	2.7
Garage or carport	45	1.2	14580	3.6	524	3.8
Bathroom	44	1.2	8040	2.0	271	2.0
Unclassified structural area	43	1.2	4530	1.1	104	0.8
Crawl space or substructure space	41	1.2	11200	2.8	317	2.3
Multiple areas	41	1.1	3350	0.8	96	0.7
Ceiling/floor assembly or concealed space	32	0.9	3470	0.9	64	0.5
Wall assembly or concealed space	27	0.8	7090	1.8	93	0.7
Closet	23	0.6	5020	1.2	186	1.4
Exterior balcony or open porch	22	0.6	5570	1.4	121	0.9
Exterior wall surface	22	0.6	14620	3.6	118	0.9
Unclassified area	21	0.6	2590	0.6	87	0.6
Attic or ceiling/roof assembly or concealed space	21	0.6	10740	2.7	98	0.7
Tool room or other supply storage room or area	20	0.5	4160	1.0	133	1.0
Lobby or entrance way	17	0.5	1410	0.3	44	0.3
Interior stairway	17	0.5	1100	0.3	41	0.3
Chimney	17	0.5	60530	14.9	75	0.5
Unclassified function area	17	0.5	1090	0.3	43	0.3
Unclassified storage area	14	0.4	2460	0.6	80	0.6
Area not applicable	11	0.3	1180	0.3	22	0.2
Exterior stairway	8	0.2	1090	0.3	25	0.2
Lawn or field	7	0.2	1670	0.4	24	0.2
Trash room or area	5	0.1	1140	0.3	14	0.1
Product storage area	5	0.1	780	0.2	23	0.2
Unclassified means of egress	5	0.1	610	0.2	15	0.1
Unclassified service or equipment area	4	0.1	380	0.1	12	0.1
Library	3	0.1	180	0.0	11	0.0
Other known area	26	0.7	12880	3.2	195	1.4
TOTAL	**3589**	**100**	**404900**	**100**	**13691**	**100**

(Source – NFPA 13D:1999, Table A-1-2(b) [NFPA, 1999])

The United States data reflects similar distribution of the areas of fire origin which result in injuries and fatalities. Over 80% of injuries and fatalities as a consequence of fire in the domestic situation occur in the kitchen, living room and bedroom.

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

Living Room	25.9 %
Bedroom	38.2 %
Kitchen	24.1 %
Bathroom	0.6 %
Laundry	0.6 %
Ceiling Cavity	0.6 %
Garage	2.4 %
Other	6.4 %
Hallway/Stairs	1.2 %

Based on statistics from the New Zealand Fire Service, fatal fires are more likely to originate in the bedroom (38.2%), living room (25.9%) and kitchen (24.1%) (Irwin, 1997). The supplied statistics show that the remaining 12% of fatal fires originate in ‘other’ areas (garages and carports, 2.4%; bathroom, 0.6%; laundry, 0.6%) (Irwin, 1997). For the purpose of this analysis, the remaining areas of fire origin which result in fatalities are distributed according to the United States statistics (refer Table 4).

9.5 Assumptions

Domestic fire statistics were analysed and the following assumptions with respect to smoke alarm reliability, sprinkler system reliability, fatality rates and injury rates were made.

9.5.1 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. For detached dwellings, the Building Industry Authority of New Zealand have proposed the mandatory installation of stand-alone battery operated smoke alarms.

Each smoke alarm installation option has an associated probability of detecting the fire. The estimated probabilities range from approximately 60% for a single battery-operated alarm to around 90% for four interconnected alarms (Wade and Duncan, 2000).

For the purposes of determining a reliability for use in the risk assessment, the option of four battery-operated alarms was used. This option was the closest to the recommendations of the Building Industry Authority.

The smoke alarm was taken to be 74% reliable and hence does not alert the occupants, for various reasons, 26% of the time (Wade and Duncan, 2000).

9.5.2 Sprinkler system reliability

Historical data as shown in Figure 4 indicates about 4 deaths per 1000 domestic structure fires. However this rate includes all fires in the presence of smoke alarms or not. It is necessary to estimate what the fatality rate would be if smoke alarms are installed and what it would be if no alarms exist, and similarly for cases where sprinklers are installed or not.

Because of the difficulty of determining the reliability of the sprinkler system from first principles, statistics on the ability of sprinkler systems across all building types to reduce the number of fatalities are used to quantify the reliability of domestic sprinkler systems.

Marryatt (1988) states that sprinkler systems are 99.45% reliable. This figure is based on New Zealand and Australian sprinkler system data from 1886-1986. The reliability figure of 99.45% is optimistic as it represents cases where the sprinkler system has operated and successfully controlled the fire. It neglects to include instances where the sprinkler system has failed to operate.

In the case of commercial sprinkler systems installed in New Zealand, Mak (personal comment, 2000) states:

"…as far as can be ascertained, there have been three lives lost in sprinklered buildings in New Zealand:

- *Paremoremo Prison (1998) – inmate tampered with sprinklers*
- *Rangipo Prison (1998) – accelerant thrown over inmate*
- *Kaikohe Rest Home (1996) – resident set fire to armchair and was intimate with the source of ignition."*

These statistics indicate that operative sprinkler systems are successful at preventing fatalities as a result of fire.

The reliability of the sprinkler system for use in the risk assessment was taken to be 95%. With the sprinkler system integrated with the domestic plumbing, there is early warning of interruption to the water supply. In the case of a sprinkler system installed to the requirements of NZS 4515:1995 (SNZ, 1995), disruption to the water supply may go undetected until maintenance checks are made, or when the sprinkler system is required to operate. It is immediately evident if water supply to domestic fixtures is interrupted in an occupied dwelling. Therefore it is assumed that the inherent reliability will be no less than for conventional sprinkler systems.

9.5.3 Fatality rates

For the case of installation of a sprinkler system, Beever and Britton (1999) used seven 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. The figures representing the expected reduction in death rates are based on examination of 1994 USA data. The value of seven deaths per 1000 house fires when no sprinkler system is present is based on AFIRS data for the period 1989-1993 as presented by Beever and Britton (1999).

A study by Rahmanian (1995) suggests that sprinklers in domestic dwellings can reduce the number of deaths by 50% or more. Ruegg and Fuller (1984) estimated 1.46 deaths per 1000 house fires for houses with sprinklers and alarms.

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%.

From the analysis of statistics for the reduction in fatalities as a result of installing a domestic smoke alarm, Wade and Duncan (2000) conclude the following reductions for the installation options (refer Table 5):

Table 5: Fatality Rates with Smoke Alarms

Installation Option	**Fire Death Rate per 1000 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 for the option of four battery (1-year) operated alarms was used in the risk assessment. Therefore the fire death rates per 1000 house fires were taken to be 2.8.

Table 6 provides the fatality rates used in the risk assessment for analysing the combination of smoke alarm and sprinkler scenarios. The consequence of the expected number of deaths per 1000 house fires presented in Table 6 is based on the outcome if the sprinkler system and the smoke alarm are operational.

Table 6: Fatality Rates used in Risk Assessment

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%

9.5.4 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. Injuries were defined as those recorded at the scene of the fire. For the number of injuries in sprinklered fires, Beever and Britton (1999) found the data they used from the NFIRS database for 1995 to be inconsistent, stating 100 injuries per 1000 fires, which is greater than that for unsprinklered fires in Australia. A study by Ruegg and Fuller (1984) estimated civilian injury rates to be 14 per 1000 fires for one- and two-family houses protected by sprinklers and smoke alarms (Beever and Britton, 1999). Beever and Britton (1999) consider fire injury rates in the range of 30 to 15 per 1000 fires for sprinklered one- and two-family dwellings.

New Zealand Fire Service statistics indicate that, on average, 40 injuries per 1000 domestic fires occur annually as a result of domestic 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 house fires − a 63% reduction.

Table 7: Assumed Fire Injury Rate with Smoke Alarms

Installation Option	**Fire Injury Rate per 1000 Fires**
Four battery (1-year) operated alarms	12
Four battery (10-year) operated alarms	12
No alarm	40

(source - Wade and Duncan, 2000)

For the purposes of the risk assessment, a rate of 12 injuries per 1000 house fires was used corresponding to four battery operated alarms (Wade and Duncan, 2000).

Table 8 provides the injury rates used in the risk assessment to analyse the combination of smoke alarm and sprinkler scenarios. The consequence of the expected number of injuries per 1000 house fires is based on the sprinkler system and smoke alarm being operational.

Table 8: Injury Rates used in Risk Assessment

Option	**Consequence – expected injuries per 1000 house fires**	**Reduction in injuries**
No smoke alarm / no sprinkler	40	
Smoke alarm / no sprinkler	12	70%
No smoke alarm / sprinkler	15	63%
Smoke alarm / sprinkler	10	75%

9.6 Results

The results of the risk assessment event tree analysis follow.

Figure 11 compares the results of the risk assessment for each sprinkler system and smoke alarm option. The results are for sprinkler heads installed in each room in accordance with NZS 4515:1995 (SNZ, 1995).

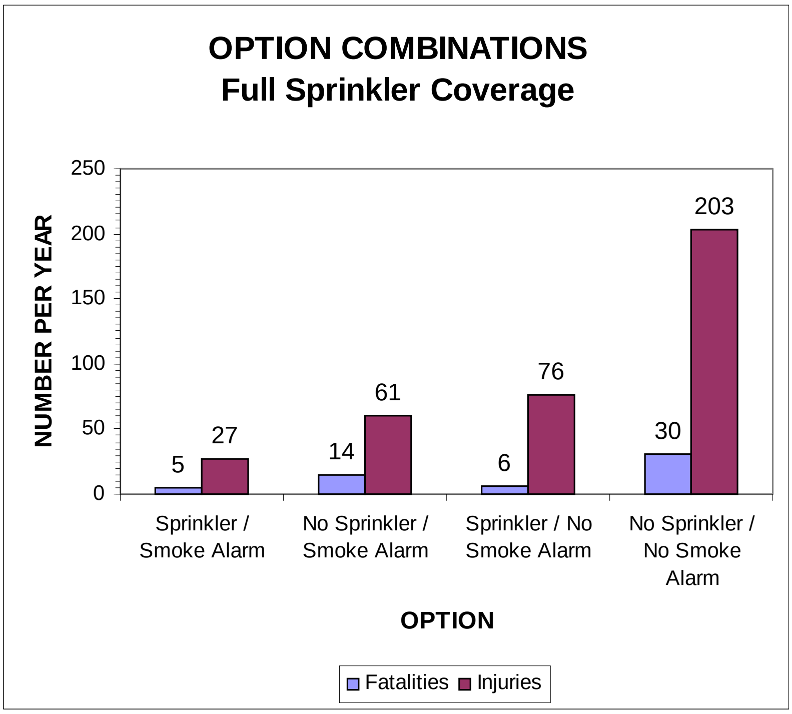

Figure 11: Results of Risk Assessment

9.6.1 Fatalities

Table 9: Results of Risk Assessment – Full Sprinkler Coverage

Option	Expected Fatalities/Year	Reduction
Sprinkler / Smoke Alarm	4.8	84%
No Sprinkler / Smoke Alarm	14.2	53%
Sprinkler / No Smoke Alarm	6.1	80%
No Sprinkler / No Smoke Alarm	30.5	

Results of the event tree analysis show that the combination of sprinkler system and smoke alarm is likely to reduce the number of fatalities in domestic fires by 84% (refer Table 9). 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 53%.

9.6.2 Injuries

Table 10: Results of Risk Assessment - Injuries

Option	Injuries/Year	Reduction
Sprinkler / Smoke Alarm	27.3	87%
No Sprinkler / Smoke Alarm	60.9	70%
Sprinkler / No Smoke Alarm	76.1	63%
No Sprinkler / No Smoke Alarm	203.0	

Results of the event tree analysis show that the combination of sprinkler system and smoke alarm is likely to reduce the number of injuries in domestic fires by 87% (refer Table 10). A sprinkler system alone has the potential to reduce the number of injuries by 63%. A smoke alarm alone is likely to reduce the number of injuries by 70%.

9.7 Sensitivity Analysis

The results reported in Section 9.6 rely on the assumption that the reliability of the domestic sprinkler system is 95%. Figures 12 and 13 show the influence that reducing the reliability of the sprinkler system has on the numbers of injuries and fatalities.

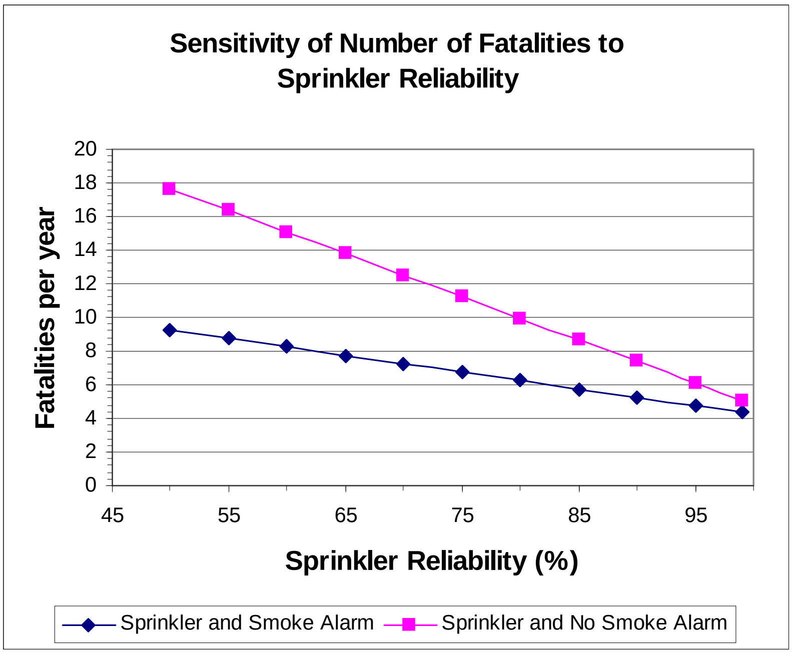

Figure 12: Influence on number of fatalities as a result of reduction in sprinkler system reliability

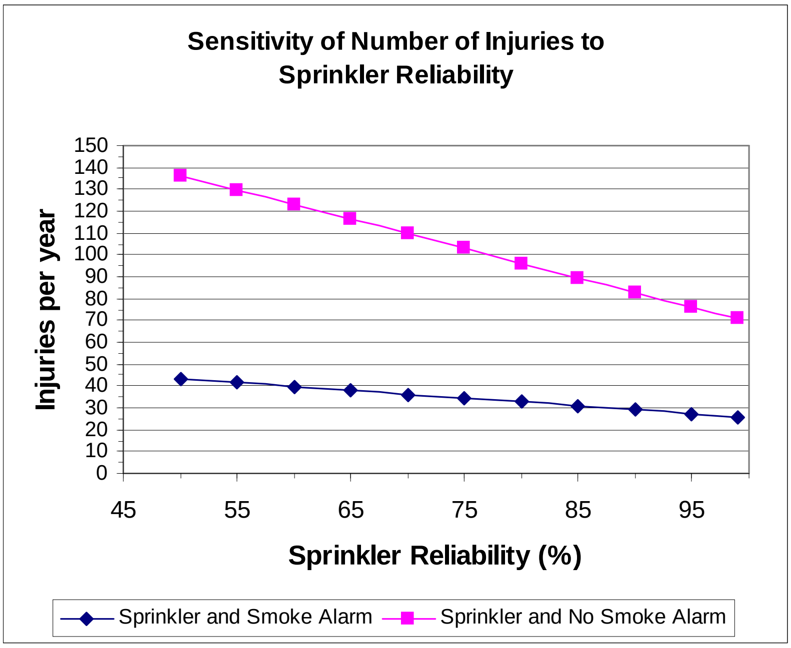

Figure 13: Influence on number of injuries as a result of reduction in sprinkler system reliability

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

9.8 Discussion

The risk assessment set out to investigate the number and location of injuries and fatalities as a result of domestic fires. Reflecting the statistics, the majority of fatalities and injuries occur as a result of fire originating in the living room, bedroom or kitchen.

The risk assessment analysed four options of sprinkler system and smoke alarm combinations in an attempt to determine their impact on the number of injuries and fatalities. Results show that the combination of sprinkler system and smoke alarm is the most successful at reducing the number of injuries and fatalities. The sprinkler system alone is likely to reduce the number of fatalities by around 80% and the number of injuries by around 63%. The smoke alarm alone can potentially reduce the number of injuries by around 70% and the number of fatalities by approximately one half.

A sensitivity analysis assessed the impact on the number of injuries and fatalities of reducing the reliability of the domestic fire sprinkler system. Results of the sensitivity analysis show that reducing the reliability of the sprinkler system from 95% to 75% still has the impact of reducing the number of fatalities and injuries by more than one half (refer Figures 12 and 13).

9.8.1 Reduced sprinkler coverage

Figure 14 shows the number of injuries and fatalities resulting from a fire in a home where the coverage of the sprinklers has been reduced. The sprinklers have been removed from the bathroom, toilet, ceiling cavity and wardrobe/cupboard space.

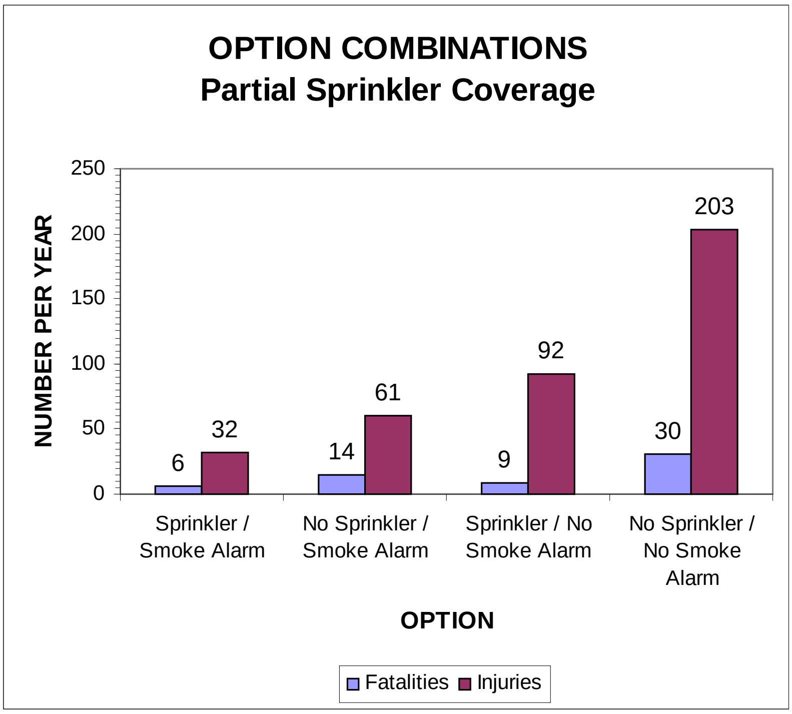

Figure 14: Comparison of Injuries and Fatalities with Reduced Sprinkler Coverage

For the option of the combined domestic 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%). The following Table 11 compares the numbers of injuries and fatalities as a result of fire in the fully sprinklered home to the numbers as a result of reducing the sprinkler coverage.

Table 11: Comparison of Full Coverage Sprinkler System 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

10. COMPUTER MODELLING

10.1 Introduction

To assess the effectiveness of the proposed domestic sprinkler system, a computer model was used.

The computer model chosen for analysis was BRANZFIRE Version 2000.09 (Wade, 1996; Wade and Barnett, 1997; Wade et al, 1997; Wade, 1999). The details of the modelling are summarised below. In general the model results should be treated as indicative as there are many uncertainties in the assumptions and input data. Full results of this determination are included as Appendix II.

10.2 Model Verification

Before using BRANZFIRE, it was decided that additional verification was required to confirm that the model would produce credible results for the scenario proposed to be modelled. A scenario based on a full-scale residential compartment was modelled. This scenario mirrored some experiments conducted by the National Institute of Standards and Technology, USA on a two-bed hospital patient room fire (Notarianni, 1993).

Room Description: As shown in Figure 15, the walls and ceiling were 13 mm calcium silicate board over 16 mm gypsum plasterboard; the floor was 100 mm concrete.

Sprinklers: Quick-response extended coverage (QR-EC) pendant sprinkler on ceiling in the centre of the patient room. Orifice 12.7 mm, K-factor = 0.79 $(l/min/kPa)^{1/2}$ glass bulb, operating temperature 68ºC, Response Time Index (RTI) 39 $(ms)^{1/2}$. Assumed conduction factor = 0. Radial distance from sprinkler S4 = 1.6 m. Assumed distance of glass bulb below ceiling = 25 mm.

Fuel: Wood crib measuring 0.61 m x 0.46 m x 0.15 m high ignited by a 100 mm diameter tray of burning heptane (refer Figure 15). It was previously determined that a 60 kW steady state fire with the door closed posed the greatest challenge to the tenability of the space.

10.2.1Results of verification modelling

The comparison shown here is for the “closed door test” (refer Table 12). Full results are included as Appendix II to this report.

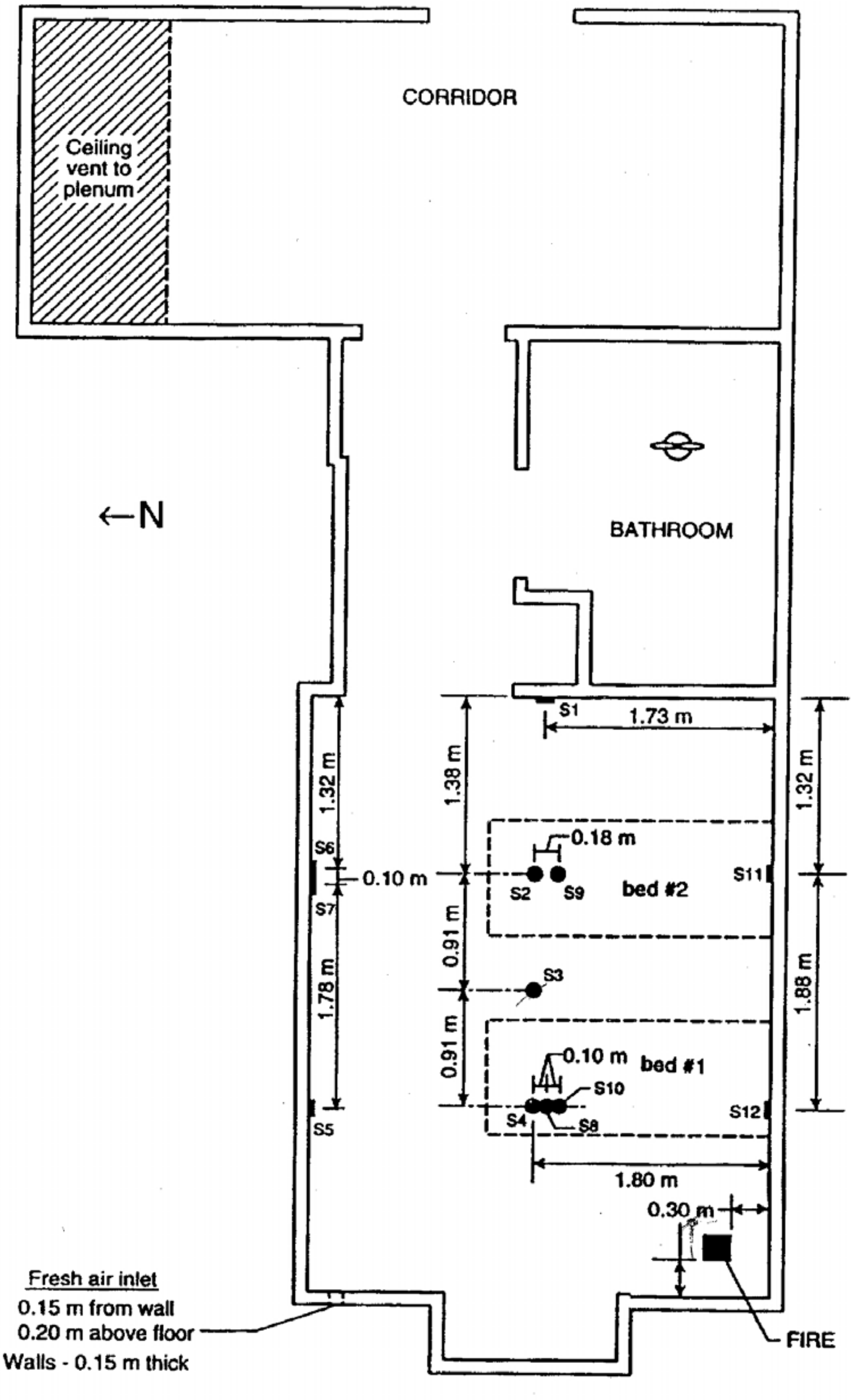

Figure 15: Model Verification Room

Table 12: Comparison of Fire Test and Computer Model Outputs for Verification

	Reference From Test	Fire Test	BRANZFIRE Predicted	Difference
Sprinkler Actuation	S4	422s	523s	+101s
Ionisation detector in room of origin	D8	36s	41s	+5s
Detector in Bathroom	D4	133s	149s	+16s
Gas Temperature	1.5 m above the floor, centre of room @ 440s	52°C	61°C	+9°C
Gas Temperature	0.91m above the floor, centre of room @ 440s	30°C	37°C	+7°C
Maximum Concentration of CO_2	In room of origin, measured at 1.5m above the floor	0.64%	1.6%	+0.96%
Maximum Concentration of CO	In room of origin at 1.5m above the floor	0ppm	156ppm	+156ppm

10.2.2Summary of model verification

In general, the results above indicate that BRANZFIRE Version 2000.09 (Wade, 1996; Wade and Barnett, 1997; Wade et al, 1997; Wade, 1999) predictions are conservative when compared to the full-scale test that they were modelling. Therefore, the model is likely to give a reasonable estimate (conservative) for the other similar fire scenarios and be a useful tool for undertaking a fire hazard analysis of a domestic-scale building. Other verification data for the model can be found in model documentation and supporting references.

10.3 Predictions for Domestic Sprinkler Systems

Two single-storey three-bedroom houses, representative of typical low-cost New Zealand properties, were modelled using the two-layer zone model BRANZFIRE (Wade, 1996; Wade and Barnett, 1997; Wade et al, 1997; Wade, 1999). The plan views of the houses are shown as Figures 16 and 17.

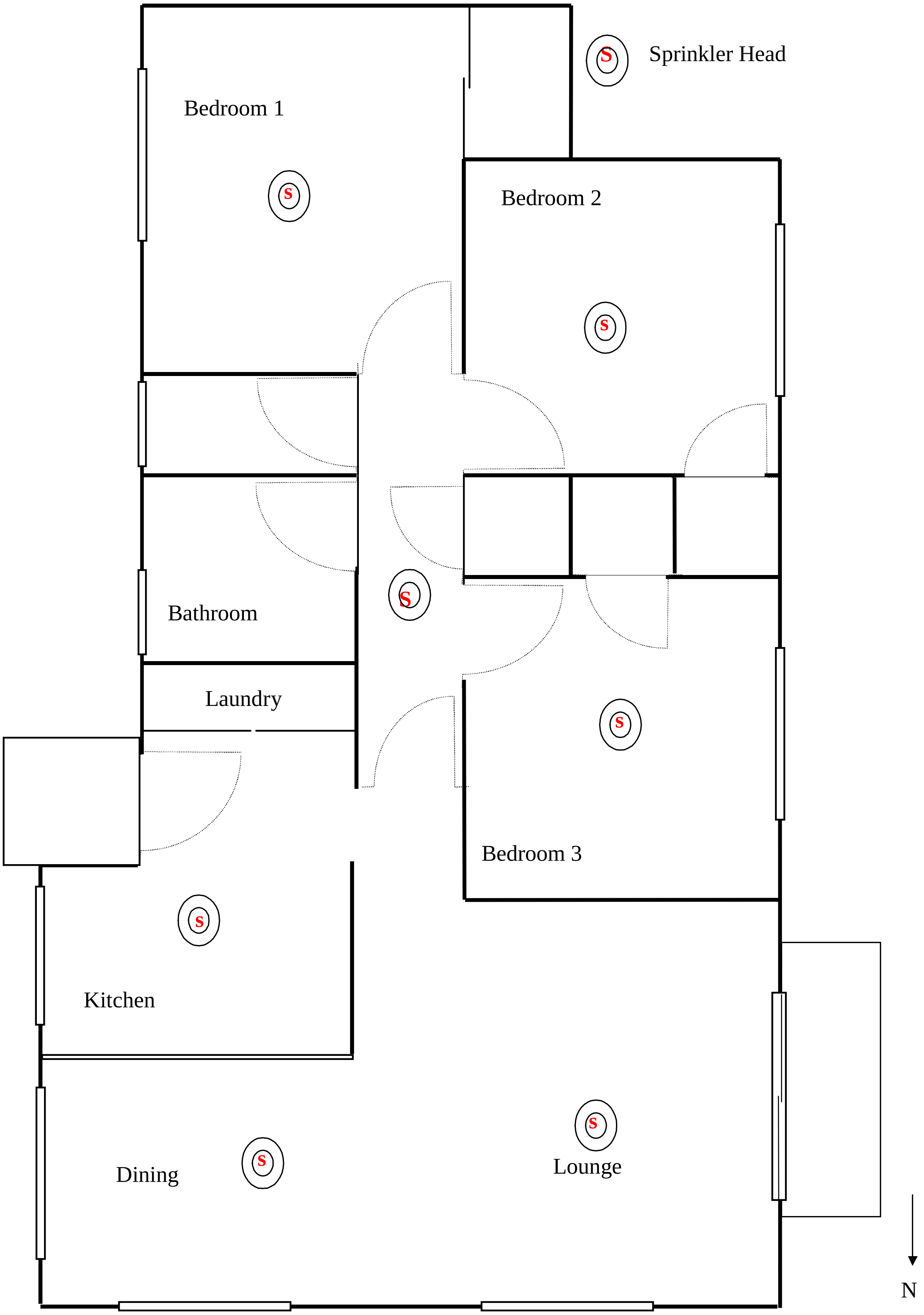

Figure 16: BRANZ Low-Cost Design House

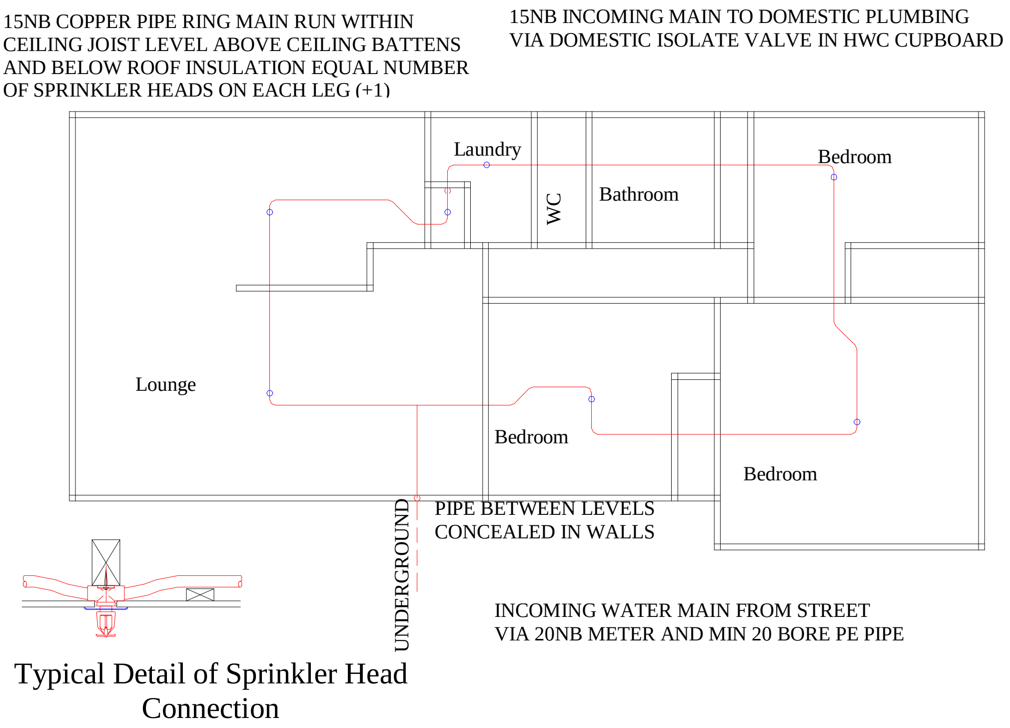

Figure 17: Low-Cost Three-Bedroom Design House
(Source – D. Gillespie, Fire Engineering Solutions Limited)

For modelling purposes, each of the homes was reduced to either three or four compartments. In order to simplify the model, the lounge and dining areas of each home were modelled as a single space and an equivalent volume used; in the case of the second house the kitchen was also included and a part partition wall was omitted.

The wall and ceiling linings were input as 9.5 mm gypsum plasterboard and the floor linings as 20 mm high-density particleboard.

In each house three scenarios were modelled as representative of the most likely fire scenarios. The scenarios modelled were:

Fire in Kitchen
Fire in Lounge
Fire in a Bedroom

For each fire scenario the case was modelled as sprinklered and unsprinklered in order to ascertain the likely effects of sprinkler suppression. A residential sprinkler head was used as the installed device. Details of the sprinkler head are:

RTI	35 $(ms)^{1/2}$
C factor	0.6
Actuation Temp	68ºC
Density	4 mm/min

The radial distance from the fire to the sprinkler head was assumed to be the distance from the head to the furthest point in the room.

The position of sprinkler heads is shown in Figures 16 and 17. It can be seen that a single sprinkler head is assumed to cover each compartment.

The design fires used were taken from real test data of typical free-burning items such as beds and furniture (Lee, 1985).

An example input file is shown in Appendix II. A typical results file is shown in Appendix II.

10.4 Results of Modelling

Each of the scenarios modelled showed that the sprinkler system as described above increased the time to untenable conditions within the room of fire origin and the connected spaces. Table 13 below shows the mean time to specified tenability limits (Purser, 1995) for all the modelled scenarios.

Table 13: Times to Specified Tenability Limits

Tenability in Room of Origin			
Parameter	**Assumed Tenability Limit**	**Sprinklered Room Time to Untenable Conditions (Average) (seconds)**	**Unsprinklered Room Time to Untenable Conditions (Average) (seconds)**
Temperature	80^oC	Did not occur within duration of model	207
CO Content	0.1%	Did not occur within duration of model	378
CO_2 Content	5%	Did not occur within duration of model	297
O_2 Content	12%	Did not occur within duration of model	295
Fractional Effective Dose of Narcotic Gases	1	210	165
Radiation to Floor	$2.5\ kWm^{-2}$	Did not occur within duration of model	210
Fractional Effective Dose of Radiation	1	Did not occur within duration of model	232
Visibility	3m	111	85

The sprinkler decreased temperatures and the evolution of toxic products, although there was little or no effect on visibility. The model assumes no interaction between the water spray and the hot upper layer following operation of the sprinkler, therefore the results may not be valid at that time.

Detailed results in the form of output of the model and associated indicative graphical representations are included as Appendix II. However, in summary, the modelling predicted the following:

1. Sprinkler actuation times varied from 49 seconds to 205 seconds, depending on the fire growth rate used. It should be noted that some of the real fire data used showed little or no heat release in the first 170 seconds from ignition (refer Figure 18). In the case where the heat release is delayed, the sprinkler actuated 35 seconds after the growth became exponential. With reference to the verification modelling described previously, these times to sprinkler activation can be assumed to be conservative.

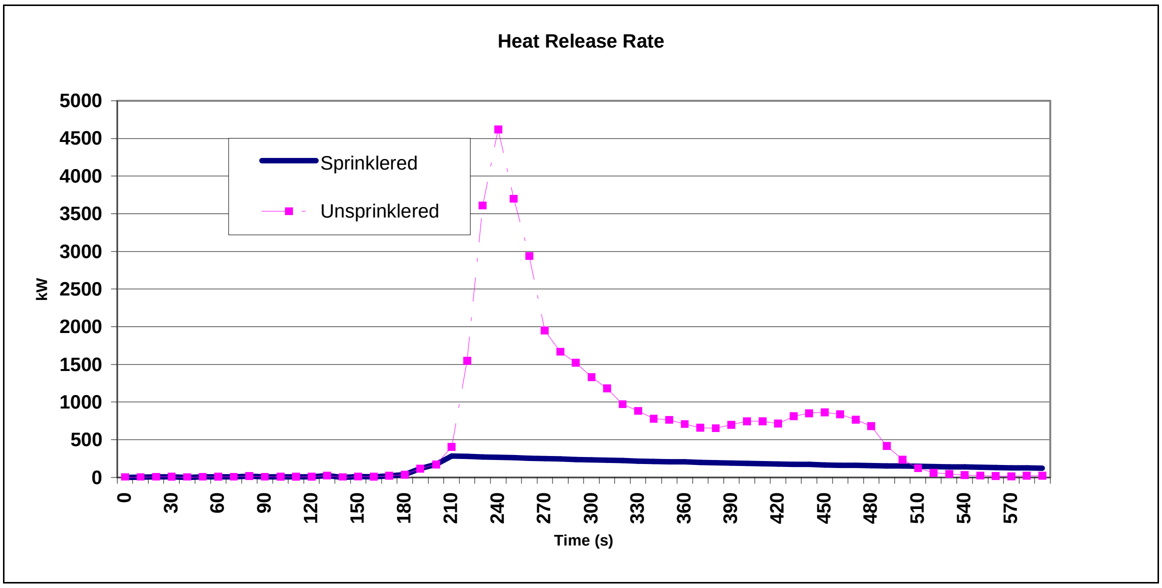

Figure 18: Comparison of Heat Release Rates for a Modelled Sprinklered and Unsprinklered Bedroom Fire Scenario

2. Temperatures were decreased by the sprinkler system to tenable conditions, in some instances by as much as 480ºC (refer Figure 19).

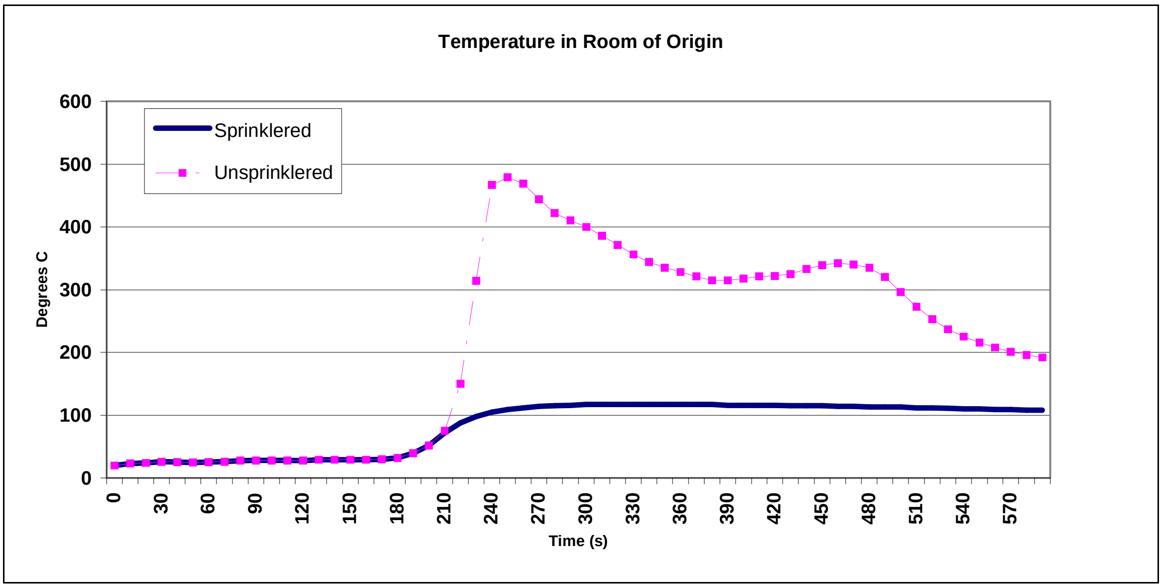

Figure 19: Comparison of Temperatures in the Upper Layer for Modelled Sprinklered and Unsprinklered Scenarios

3. Carbon monoxide and carbon dioxide concentrations were decreased by the sprinkler system to within tenable limits. The fractional effective dose of narcotic gases was maintained below the limit of 1 for periods long enough following sprinkler activation, for escape to be effected from the room of fire origin (refer Figures 20, 21 and 22). This result in particular should be considered with caution with respect to concentrations following activation of the sprinkler, as experimental data from tests have shown increases in CO and other toxic products following activation.

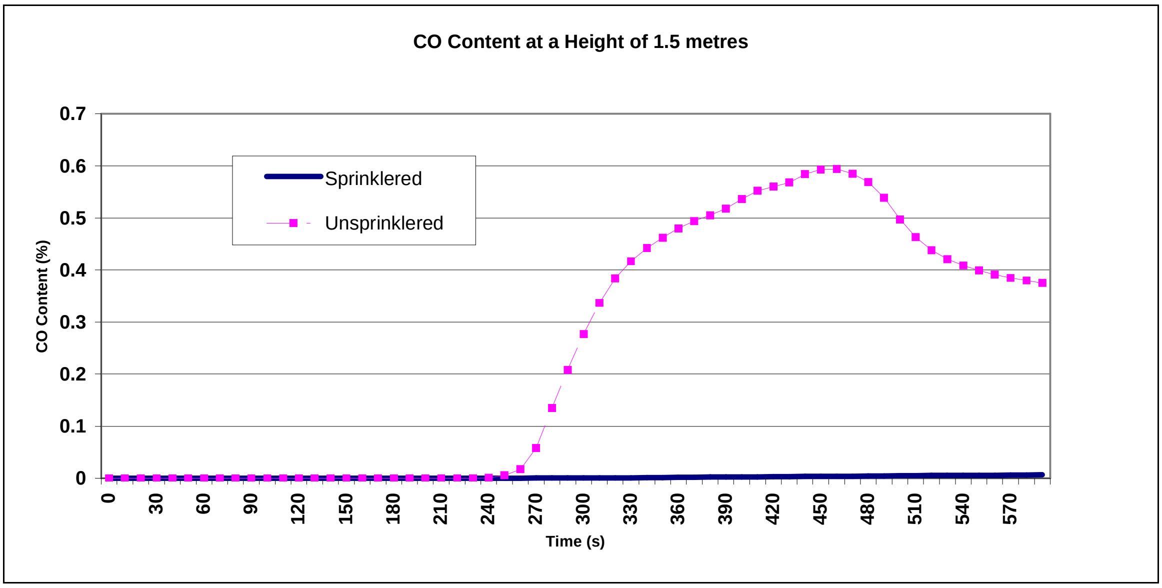

Figure 20: Comparison of CO Content in the Lower Layer of Modelled Sprinklered and Unsprinklered Scenarios

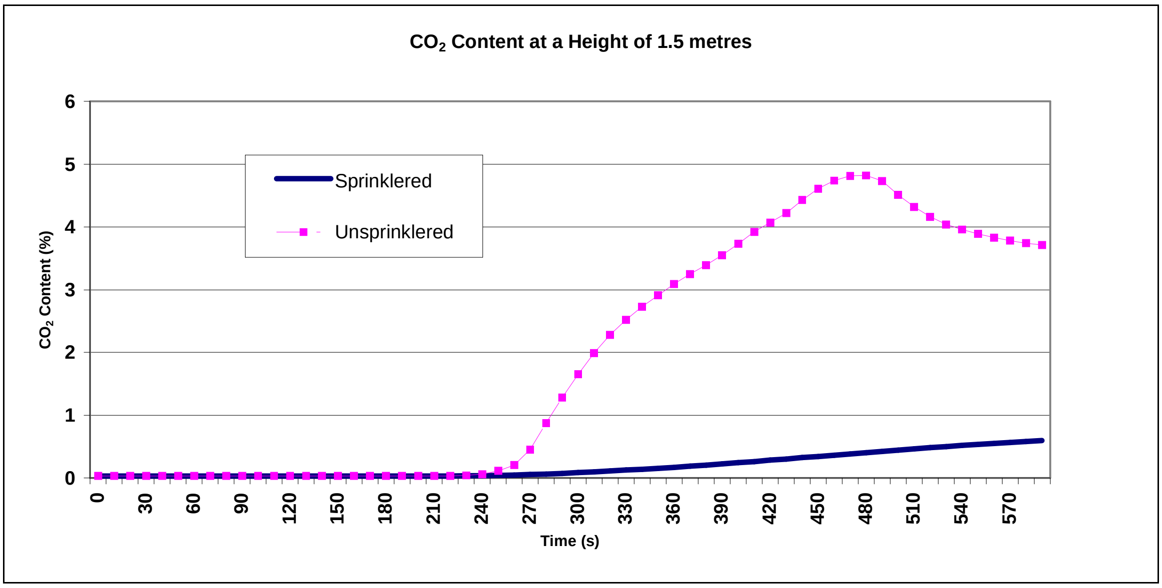

Figure 21: Comparison of CO_2 Content in the Lower Layer of Modelled Sprinklered and Unsprinklered Scenarios

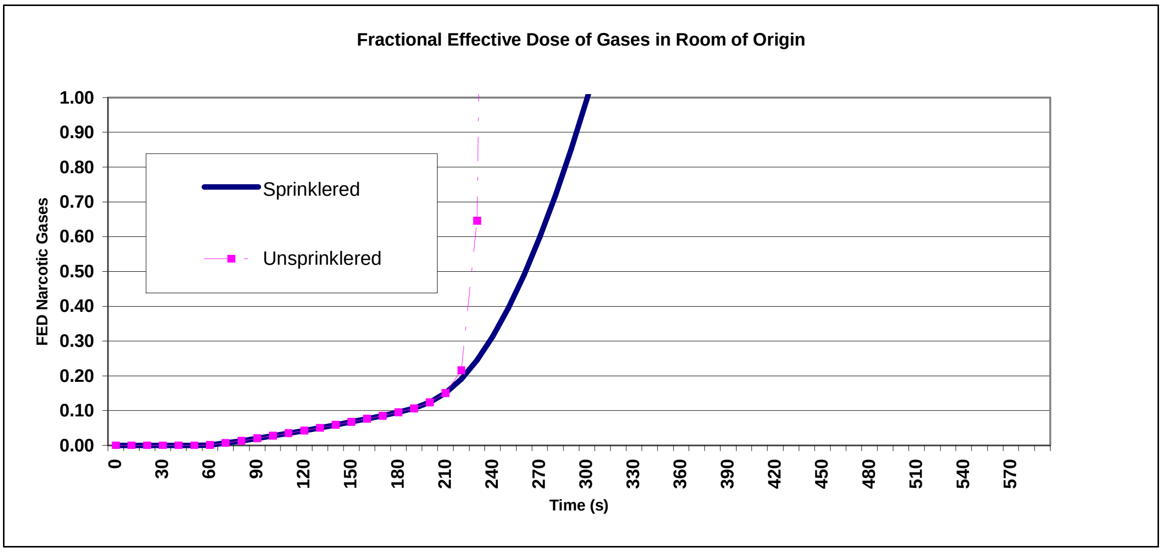

Figure 22: Comparison of Fractional Effective Dose of Narcotic Gases for a Modelled Sprinklered and Unsprinklered Room of Origin

4. In spaces adjacent to the room of origin (i.e. the hall and other bedrooms):

   In the case of a fire in a bedroom, with all bedroom doors assumed to be ajar, the tenability in terms of fractional effective dose, at a height of 1.5 m, of narcotic gases is increased. In the hall, on sprinkler actuation the increase is by margins of three to six minutes, and in an adjacent bedroom from one minute up to a situation where untenable conditions never occur (refer Figure 23). Thus, when compared with the unsprinklered scenarios, the model predicts increased time available for escape in the sprinklered situation.

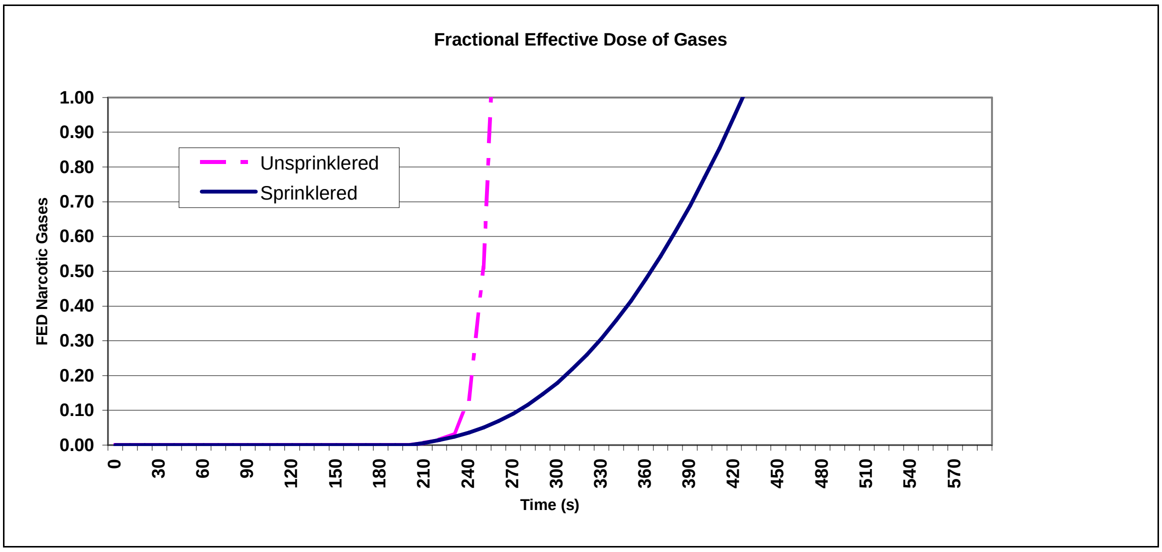

Figure 23: Comparison of Fractional Effective Dose of Narcotic Gases in Adjacent Space for Modelled Sprinklered and Unsprinklered Scenarios

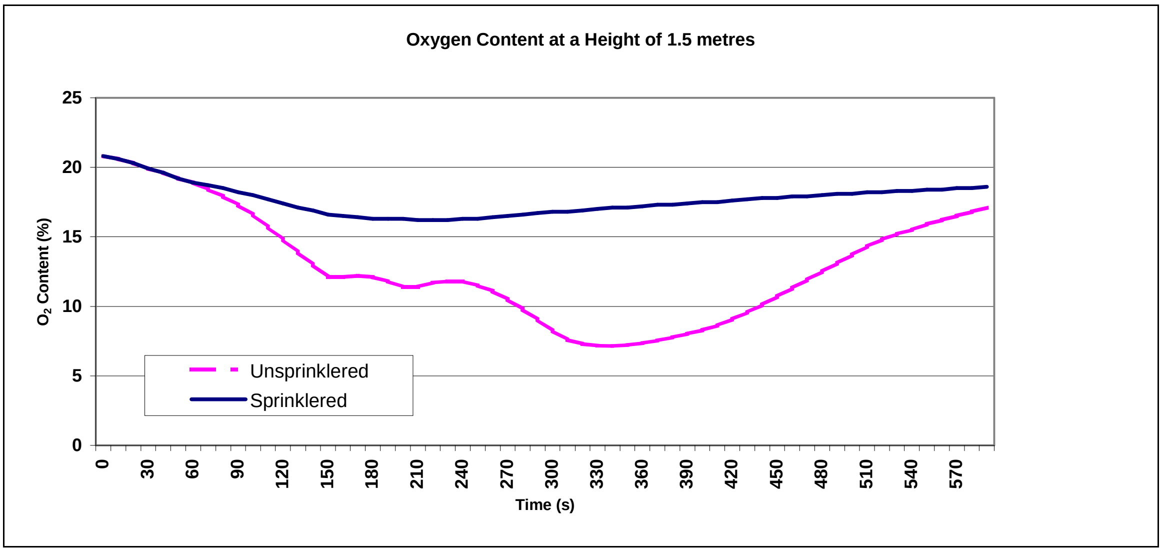

Figure 24: Comparison of the O_2 Content of the Modelled Sprinklered and Unsprinklered Scenarios

5. Similarly, the sprinkler system maintains oxygen concentrations above tenable limits (refer Figure 24).

6. Radiation from the upper layer in the room of fire origin is maintained by the sprinkler system well below an acceptable tenable limit of 2.5 kW/m^2. However, in the unsprinklered scenario, levels of radiation at floor level exceed the tenable limit (refer Figure 25). As a result, the Fractional Effective Dose of Radiation never exceeded zero for the sprinklered scenarios, but for the unsprinklered scenarios the limit of one was attained at times of between three and five minutes from ignition (refer Figure 26).

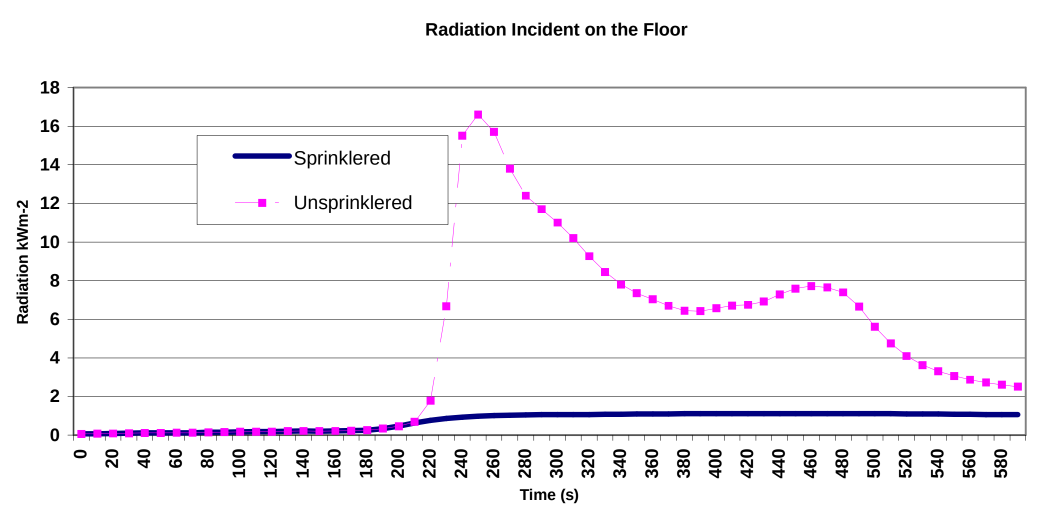

Figure 25: Comparison of Radiation Incident on the Floor for Modelled Sprinklered and Unsprinklered Scenarios

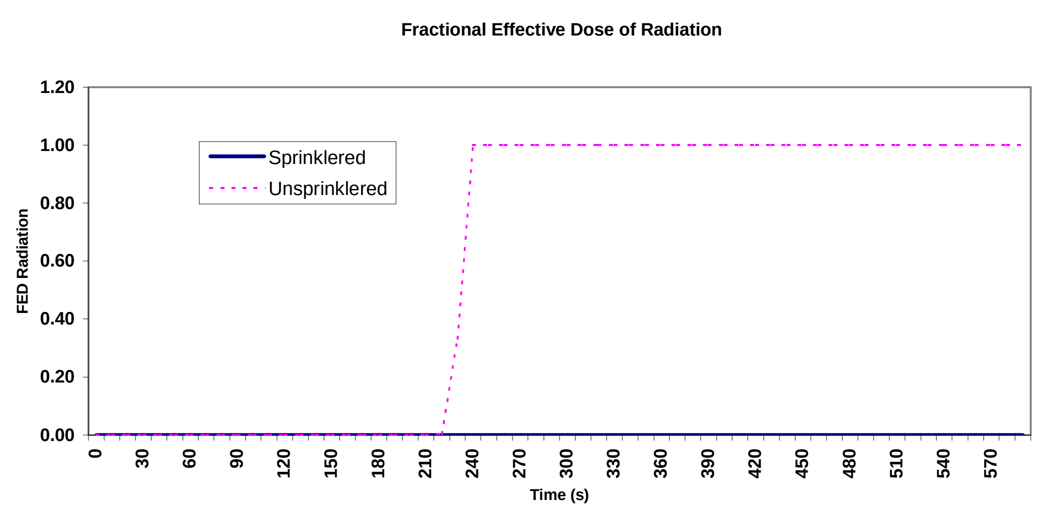

Figure 26: Comparison of Fractional Effective Dose of Radiation for Modelled Sprinklered and Unsprinklered Scenarios

7. The smoke layer is maintained above 1 metre in most cases for the sprinklered scenarios (refer Figure 27) but visibility, at a height of 1.5 m, is not affected at all by the sprinkler (refer Figure 28).

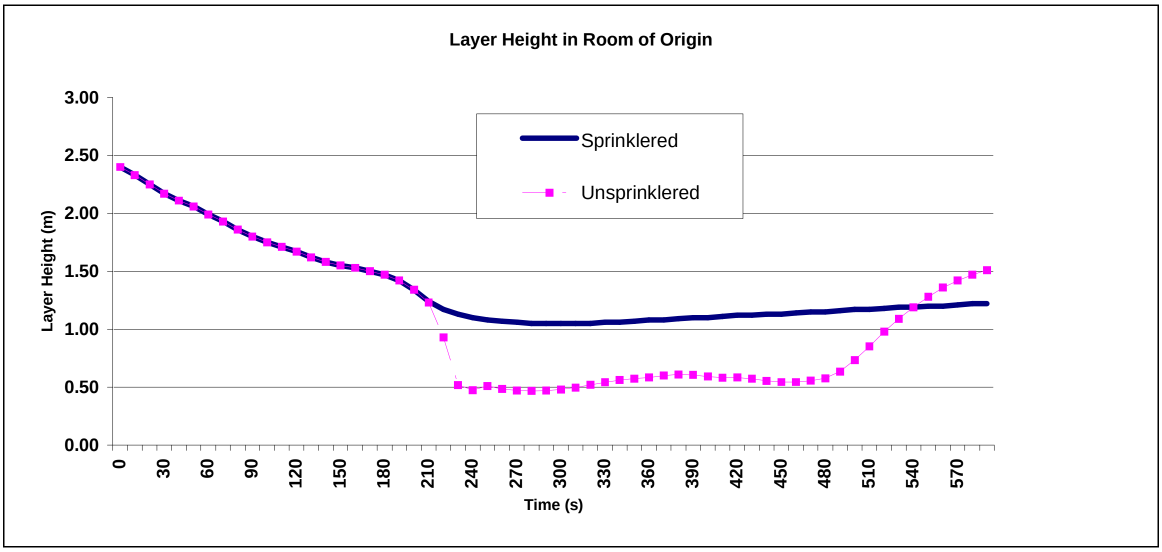

Figure 27: Comparison of Smoke Layer Height for Modelled Sprinklered and Unsprinklered Scenarios

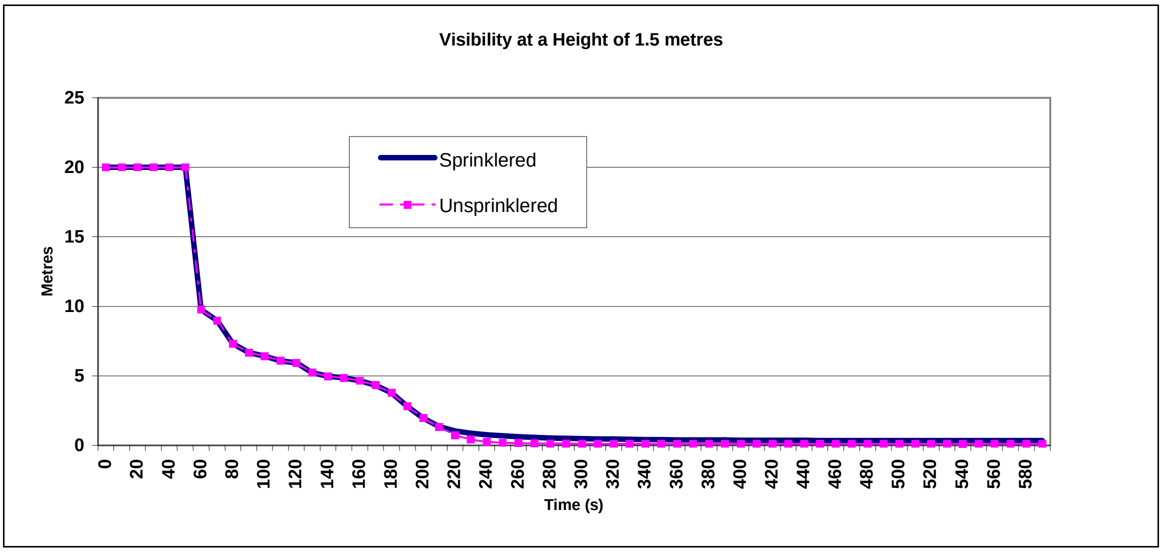

Figure 28: Comparison of Visibility for Modelled Sprinklered and Unsprinklered Scenarios

10.5 Sensitivity Analysis

A sensitivity analysis was conducted in order to establish the validity of the results, and whether and to what extent the results may have been affected by the sprinkler parameters input into the model. Generally, variation of the C factor and Response Time Index parameters of the sprinkler head only caused a maximum variance in the parameters (temperatures, CO content, CO_2 content etc) of $\underline{+}$ 1% (Figure 29).

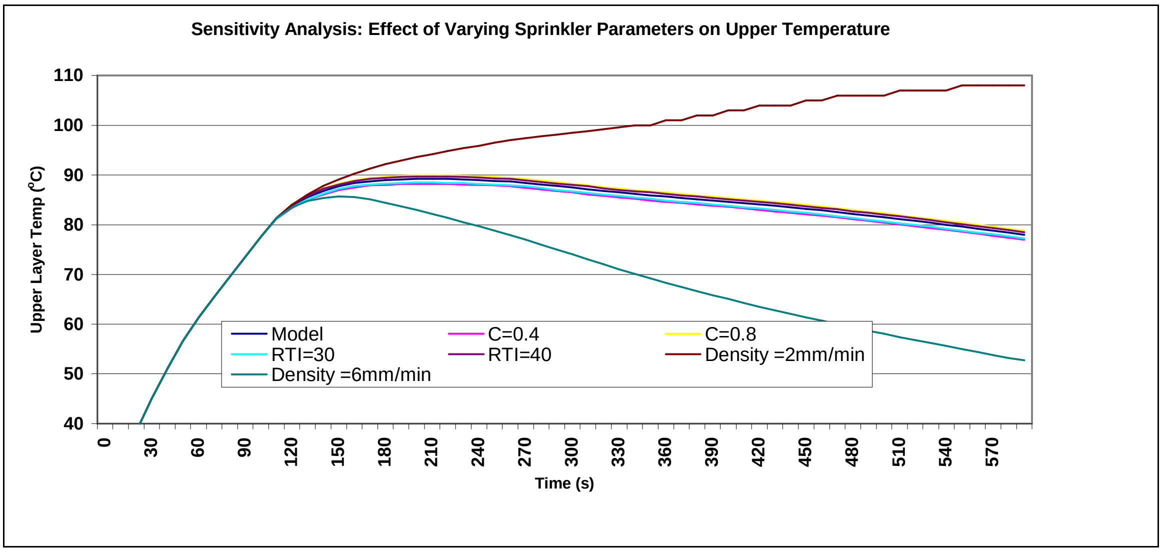

Figure 29: Chart Showing the Effect on Temperature of the Upper Layer of Varying the C factor, RTI and Minimum Design Density of the Sprinkler Head

However, variation of the minimum design density of the sprinkler head caused significant variances in the outputs − the mean variance found was –24% to +33%. The largest variance was in the Heat Release Rate of the sprinkler controlled fire, varying from +119% to –71% of the Heat Release Rate at Ignition +600s (refer Figure 30).

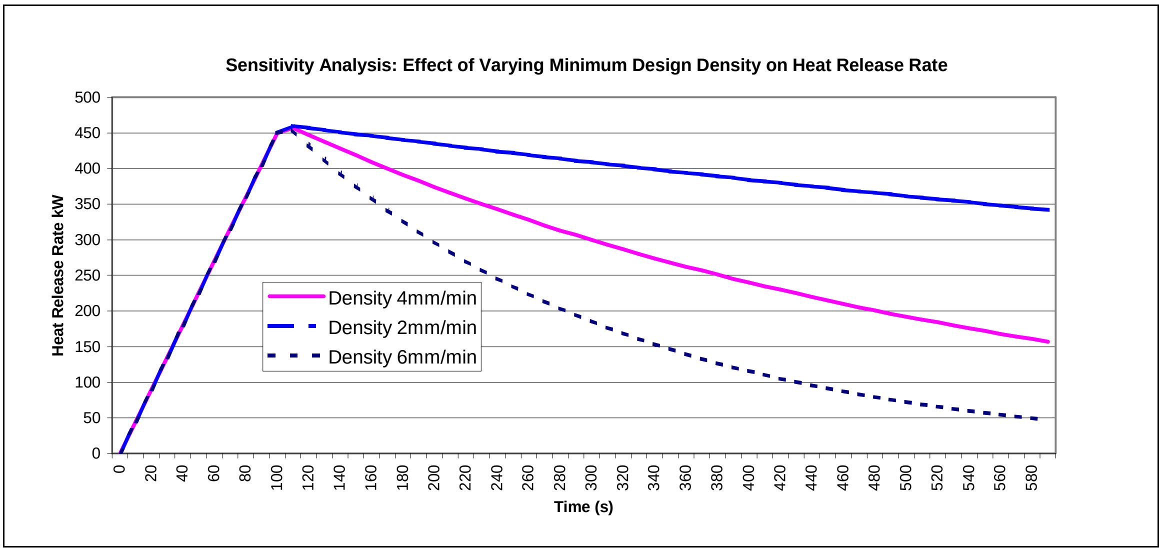

Figure 30: Effect of Varying the Minimum Design Density of the Sprinkler Head on the Heat Release Rate of the Sprinkler Controlled Fire

This variance is expected as the quantity of water on the fire is being halved (4 mm/min to 2 mm/min) or increased by 50% (4 mm/min to 6 mm/min). It is significant in terms of residential sprinkler heads − these are designed to spray 20% of the water they expel onto the four walls of the compartment they are protecting, thus reducing the density of water on the floor and consequently the fire (Underwriters Laboratories, 2000)

Full results of the outputs of the sensitivity analysis, including graphs, are included as Appendix II.

11. LOW-COST DOMESTIC SPRINKLER SYSTEM

11.1 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 sprinkler system. A multi-purpose sprinkler system whereby the sprinkler system is integrated with the domestic plumbing system was designed.

The following provides details of the proposed multi-purpose domestic sprinkler system, with deviations from the current New Zealand Standard for domestic fire sprinkler systems NZS 4515:1995 (SNZ, 1995), outlined. A cost-benefit analysis of the proposed sprinkler system is undertaken in order to assess its cost-effectiveness. The results of the cost-benefit analysis are compared with the cost of a domestic sprinkler system constructed to current New Zealand standards. An alternative low-cost sprinkler system is proposed for use in retrofit situations.

11.2 Design

A multi-purpose sprinkler system design was carried out by Hydraulic Services Consultants for the BRANZ house (refer Appendix III: Hydraulic Services Consultants) (refer Part 1 Figure 8 – Floor Plan of Design Home). The design closely follows the specifications of NFPA 13D for the design of multi-purpose sprinkler systems (NFPA, 1996) and incorporates aspects of the Australian Standard, AS 2118.5 (Standards Australia, 1995) for domestic sprinkler systems.

Full details of this low-cost, multi-purpose sprinkler system design are included in Appendix III – ‘Report on the Installation Costs of Fire Sprinklers into a Standard Three-Bedroom Dwelling’. Figures 31 and 32 are diagrammatic representations of the sprinkler system design.

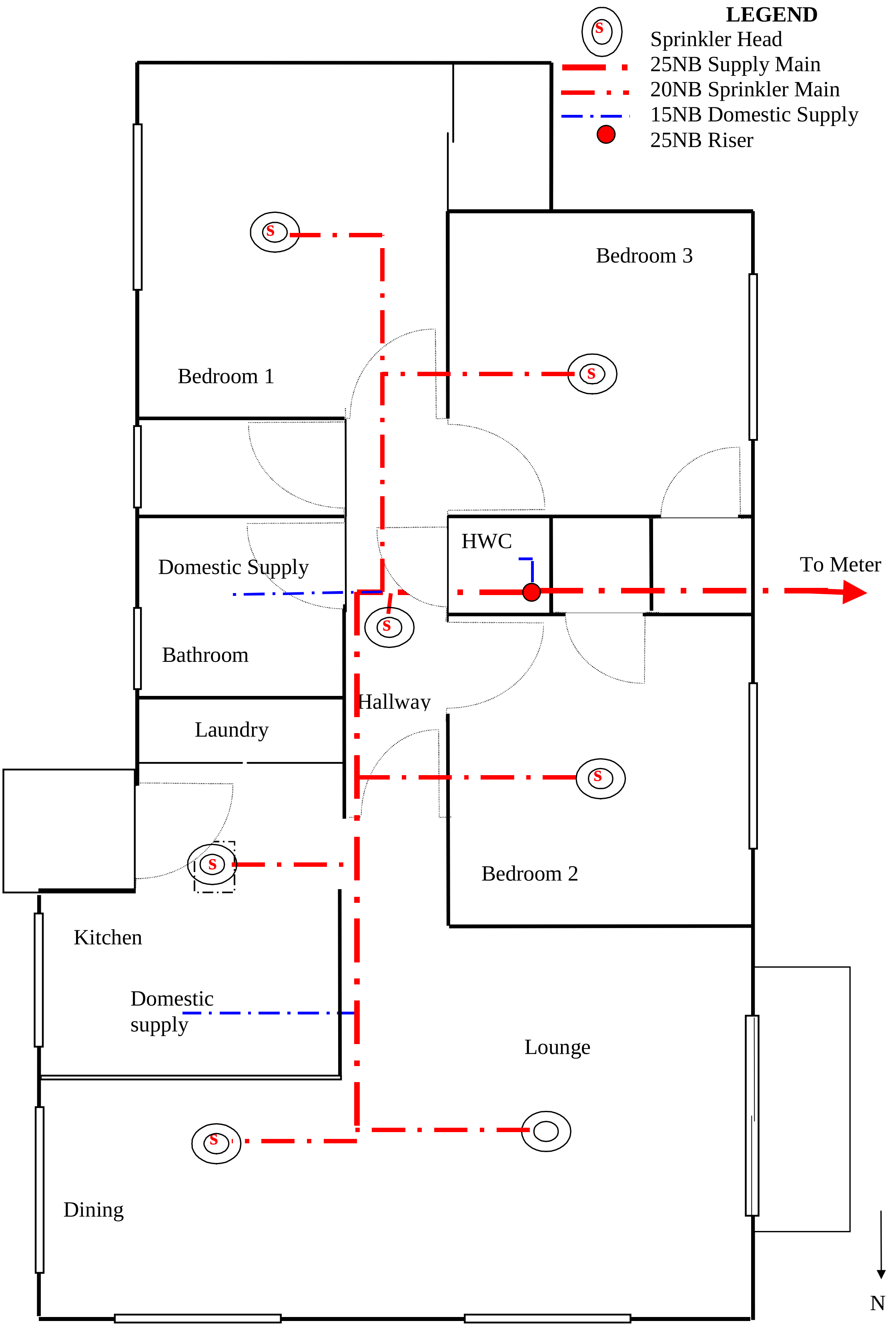

Figure 31: Plan View of Multi-purpose Sprinkler System
(Source – P. Downey, Hydraulic Services Consultants)

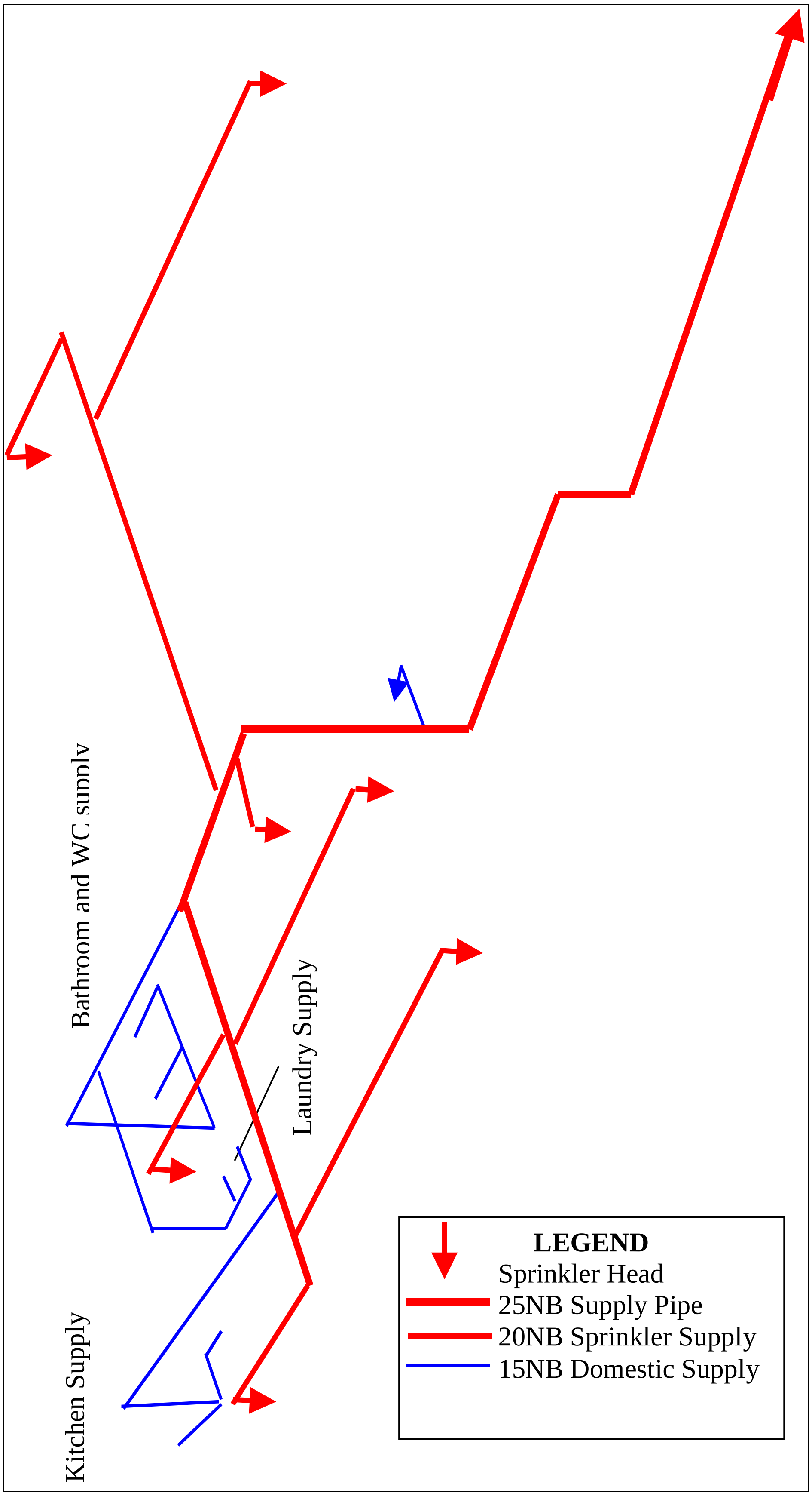

Figure 32: Pipe Layout of Multi-purpose Sprinkler System
(Source – P. Downey, Hydraulic Services Consultants)

In summary, the specific details of the low-cost sprinkler system design for the BRANZ house are as follows:

- 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 (refer Appendix III – Hydraulic Calculations).
- 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 water supply enters the house at the location of the domestic hot water cylinder, which is the standard location of water supply entry (Downey, 2000).
- The main run of water supply pipe is 25 mm diameter; the branches serving the sprinklers are 20 mm diameter; the branches supplying the domestic services are 15 mm diameter (refer Figures 31 and 32).
- 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 are based on two sprinkler heads operating.
- The entire multi-purpose system is designed using copper piping.

Refer to Section 11.3 below for justifications of the design assumptions and details of variations from NZS 4515:1995 (SNZ, 1995).

11.3 Deviations from NZS 4515:1995

The proposed low-cost 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 (NFPA, 1996).
2. A control valveset is not a requirement for the low-cost 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 backflow prevention is required.

4. An alarm indicating sprinkler operation or the 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 low-cost sprinkler system. The smoke alarm would provide the early warning of the fire. The risk assessment confirms the benefits of installing a smoke alarm along with the sprinkler system. Computer modelling indicates the extended time for evacuation achieved by installation of a domestic smoke alarm.

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

6. 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 (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. The requirements of NZS 4515:1995 (SNZ, 1995) state that the domestic load should be 57 litres per minute.

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

8. The integrated sprinkler and domestic plumbing system has no specific ongoing maintenance requirements. The maintenance requirements are specific to the control valveset. The proposed low-cost 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.

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

11.4 Cost-Benefit Analysis

11.4.1Methodology

The cost-benefit analysis methodology applied to the proposed low-cost domestic sprinkler system follows that carried out for the BRANZ cost-benefit analysis for domestic fire sprinkler systems (Wade and Duncan, 2000). The methodology for the cost-benefit modelling used in the Wade and Duncan (2000) study is based on Australian research undertaken by Beever and Britton (1999), which investigates the cost-effectiveness of a variety of domestic fire-safety features. The cost-effectiveness is assessed through calculation of a cost per life saved, where cost per life saved is defined as:

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

For the analysis, a nominal discount rate of 8% 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 low-cost 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:

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

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

The same low-cost three-bedroom home as used for the cost-effectiveness study for the standard domestic sprinkler systems (Wade and Duncan, 2000), was used as the design home for the prototype sprinkler system installations (refer Figure 8). Section 5 provides a summary of the Wade and Duncan (2000) study investigating the cost-effectiveness of domestic fire sprinkler systems, including a description and floor plan of the design home.

Variations from the input data used in the Wade and Duncan (2000) study are:

1. Number of fatalities per 1000 house fires was determined from the risk assessment. For the case where a multi-purpose sprinkler system was present without a smoke alarm, 1.68 fatalities per 1000 house fires are predicted; for the case where four battery-powered smoke alarms and a multi-purpose sprinkler system is present, 1.12 fatalities per 1000 house fires are predicted.

2. Number of injuries per 1000 house fires was determined from the risk assessment. For the case where a multi-purpose sprinkler system was present without a smoke alarm, 18.1 injuries per 1000 house fires are predicted; for the

case where four battery-powered smoke alarms and a multi-purpose sprinkler system is present, 6.21 injuries per 1000 house fires are predicted.

3. The proposed low-cost sprinkler system relies on the use of qualified persons to install the system. The design specifications were distributed to plumbing contractors for pricing. The pricing included costs for design, materials, installation and maintenance (refer Appendix III: Costs). Table 14 is a summary of the prices quoted for installation of the prototype sprinkler systems into the design home.

Table 14: Costs of the Sprinkler System

Tender	Option	Materials	Labour	Total
1	Plumbing only	$1,252.00	$546.00	$1,798.00
	Plumbing + Sprinklers	$1,805.00	$966.00	$2,771.00
	Difference (extra to install sprinklers)			**$973.00**
2	Plumbing only	$1,656.00		$1,656.00
	Plumbing + Sprinklers	$2,742.00		$2,742.00
	Difference (extra to install sprinklers)			**$1,086.00**
3	Plumbing only	$1,102.60	$525.00	$1,627.60
	Plumbing + Sprinklers	$1,759.26	$714.00	$2,473.26
	Difference (extra to install sprinklers)			**$845.66**
Average cost for installation of sprinkler system				**$968.22**

(source: see Appendix III)

11.4.2Results

The cost-benefit analysis was carried out for the low-cost multi-purpose sprinkler system. Table 15 compares a summary of the results of this cost-benefit analysis with the findings of the Wade and Duncan (2000) study for the installation of a sprinkler system only.

Table 15: Cost-Benefit Analysis Results

Option	**$ cost per life saved**
Low-cost multi-purpose sprinkler system	$891,000
New sprinkler system (to NZS 4515:1995)	$34.8 million*
New sprinkler system (to DZ 4515/CD3)	$17.8 million*

*source: Wade and Duncan (2000)

11.4.3Discussion

The cost per life saved for installation of the proposed multi-purpose sprinkler system was found to be $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 4515:1995 (SNZ, 1995). A review of the current New Zealand Standard for the installation of domestic fire sprinkler systems is attempting 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 $34.8 million to $17.8 million (refer Table 15). 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 a new sprinkler system to the draft New Zealand Standard, DZ 4515/CD3 (SNZ, 1999). The comparison of these results show the proposed low-cost multi-purpose sprinkler system to be considerably more cost-effective than domestic sprinkler systems installed to current or draft standards.

Reducing the cost of the domestic sprinkler system has achieved a cost-effectiveness in the range close to that of a domestic smoke alarm (refer Table 16). The cost per life saved for the low-cost sprinkler system is considerably less than that of multiple smoke alarms.

Table 16: Cost-Benefit of Fire Protection Options

	Installation costs (NPV $)	Maintenance costs over 20 years (NPV $)	Savings on injuries and property loss ($)	Net cost per household ($)	Deaths per household	Expected deaths per year	Lives saved per year	$ net cost per life saved
Four stand-alone ionisation 1 year battery	212	973	405	780	0.000224	14.2	16.2	$3 million
Four stand-alone ionisation 10 year battery	340	741	414	667	0.0002	12.7	17.8	$2.4 million
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 million
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 million
DZ 4515/CD3 complying domestic sprinkler system	4270	3242	693	6,820	0.000096	6.1	24.4	$17.8 million
No system	0	0	0	0	0.00048	30.5		

*assumes sprinklers omitted from bathrooms, ceiling spaces, wardrobes etc.

The integrated plumbing and sprinkler system reduces the amount of materials required for the sprinkler system. A stand-alone system constructed to NZS 4515:1995 (SNZ, 1995) requires piping and fixtures to extend to the entire house; the multi-purpose system only requires piping extensions for the sprinkler branches (refer Figures 31 and 32).

The residential valveset required by NZS 4515:1995 (SNZ, 1995) for stand-alone sprinkler systems contributes around $3000 to the cost of the system. The multi-purpose system does not incorporate a valveset and hence this cost is saved.

Table 16 shows a comparison of a variety of fire protection options. 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 $2.8 million, similar to the Transit New Zealand criterion for value of human life.

Addition of a $200 fee for design to the cost of the multi-purpose system increases the cost per life saved from $891,000 to $1,469,467 (61%) (refer Figure 33).

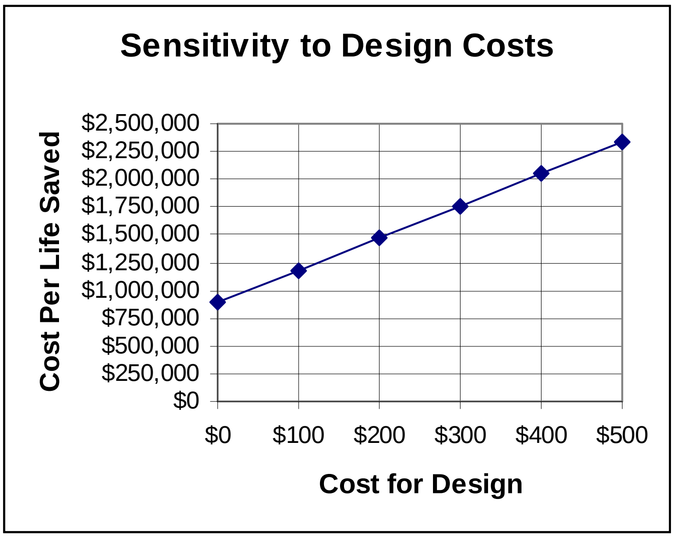

Figure 33: Sensitivity to Design Costs

The multi-purpose system does not require annual maintenance inspections. Addition of an annual maintenance fee to the system has a significant effect on the cost-effectiveness. Figure 34 represents the sensitivity of the cost per life saved for the multi-purpose sprinkler system as a result of adding a maintenance fee.

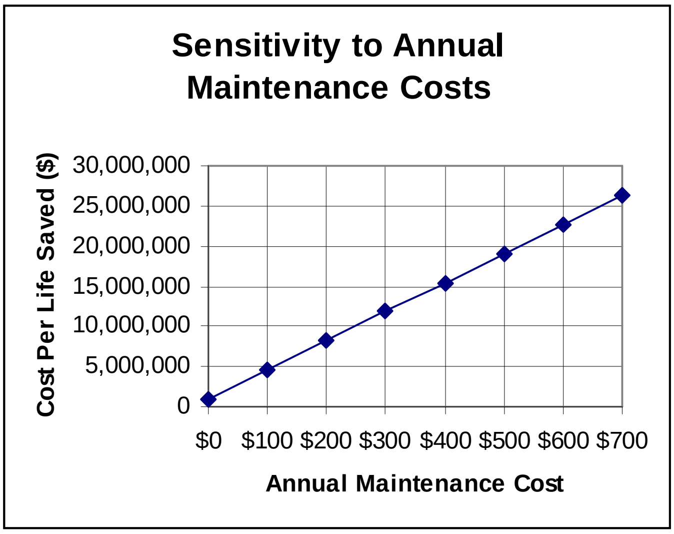

Figure 34: Sensitivity to Maintenance Costs

Similar to the findings of the Wade and Duncan (2000) study, increasing the analysis period and the fire incidence probability has the effect of reducing the cost per life saved and hence increasing the cost-effectiveness of the system.

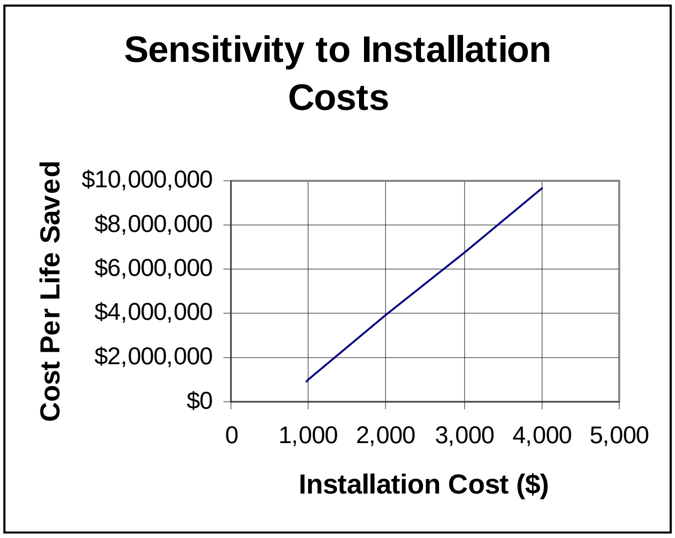

Figure 35: Sensitivity to Installation Costs

The cost for the proposed multi-purpose sprinkler system is less than $1,000 as determined from quotes provided by plumbers for materials and installation. Increasing the cost of the sprinkler system has a significant effect on the cost-effectiveness of the system. Doubling the cost of the system to $2,000 has the effect of increasing the cost per life saved from $891,000 to $3.9 million (refer Figure 35).

11.5 Alternative Low-Cost Domestic Sprinkler System for Retrofitting

The proposed low-cost multi-purpose domestic sprinkler system is appropriate for installation in new dwellings where the design can be integrated with the plumbing design.

Consideration was also given to options for retrofitting domestic sprinkler systems to existing homes. A low-cost option considered appropriate for retrofitting purposes is the flow-through sprinkler system.

11.5.1Flow-through sprinkler system

The flow-through sprinkler system functions on similar principles to the multi-purpose sprinkler system. The sprinkler system is designed in sequence with the domestic plumbing system, with water flowing through the sprinkler piping then on to the plumbing fixtures.

Full details of this low-cost, flow-through sprinkler system design are included in Appendix III – ‘Details of the flow-through sprinkler system’. Figure 36 shows the layout of the flow-through sprinkler system.

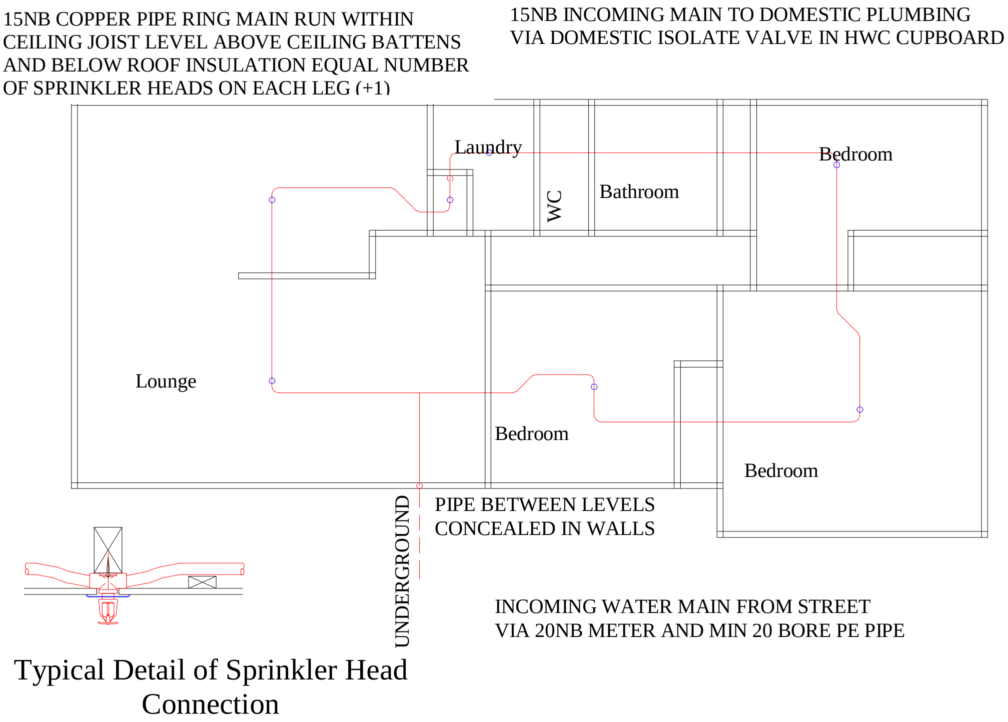

Figure 36: Flow-Through Sprinkler System

In summary, a conceptual design of a flow-through sprinkler system for the BRANZ house is as follows:

- A single mains connection feeds the sprinkler system then flows on in sequence to the domestic water supply.

- Design pressure from the mains was taken to be 500 KPa (an assumed average for the residential situation in New Zealand) and hence a 25 mm diameter feed from the mains to the house was required to achieve the design pressures at the sprinkler heads (refer Appendix III − Hydraulic Calculations for Flow-Through System).

- 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 incoming water main to the home rises to the ceiling cavity from within an external wall.

- The main run of water supply pipe is 25 mm diameter; the mains supply is split to two branches of 20 mm to serve as a ring main; the ring main then feeds the domestic piping via an isolating valve at the location of the hot water cylinder (refer Figure 36).

- There are seven sprinkler heads, each of residential listing: one in each of the three bedrooms, one in each of the kitchen, lounge and dining room and one in the hot water-cylinder cupboard.

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

The sprinkler design varies from NZS 4515:1995 (SNZ, 1995) in the same way as the multi-purpose sprinkler design with respect to requirements for the control valveset, backflow prevention, monitoring alarm, exclusion of sprinkler heads, domestic load calculations, plumbing contractors and connection to the fire service (refer Section 11.3).

The following points detail some advantages of the flow-through sprinkler system:

1. Unlike the multi-purpose sprinkler system, the flow-through sprinkler system has its own unique set of piping − the system is not integrated with the domestic plumbing. This stand-alone system is a similar principle to the stand-alone sprinkler system required by NZS 4515:1995 (SNZ, 1995). The main difference between the flow-through and the Standard sprinkler system is that the latter requires the system to be charged with stagnant water which is pressure maintained by the control valveset. The flow-through system has no requirement for the control valveset and pressure control as water is continuously flowing through the system.

2. The design of the flow-through sprinkler system can be adapted for retrofitting into an existing dwelling because of its stand-alone piping. The domestic plumbing can be disconnected and the sprinkler system installed in sequence from the mains and connected into the plumbing.

3. The flow-through system incorporates no dead-end branches so issues of water stagnating in sprinkler branches are resolved.

4. Similarly to the multi-purpose system, issues of reliability of water supply to the sprinkler heads are resolved because the same water supplies the domestic plumbing and lack of water supply to the sprinklers would be immediately detected.

5. The stand-alone system provides the ability to isolate the domestic plumbing while still having water supply to the sprinkler system.

12. CONCLUSION

12.1 Case for Domestic Sprinkler Systems

The literature search and preliminary investigation into the cost and cost-effectiveness of domestic sprinkler system concludes:

- Sprinkler systems built to current New Zealand standards are not cost-effective.

- Cost-benefit analysis has proven that there is scope to reduce the cost of the domestic sprinkler system. The scope comes predominantly from legislation, competition and design requirements.

- With the strict requirements for sprinkler heads to be listed, and considerable research into the likes of spray patterns and system pressures, repetition of experiments into ways of modifying these parts of the sprinkler system appear to be redundant. A risk assessment approach, where reductions in reliability are offset against increased coverage of sprinklers in the home, appears to offer possibilities for providing options to reduce the cost of the sprinkler system.

- Inconsistencies exist between areas where for example it costs more to connect water mains to serve the sprinklers than it does to install the sprinkler system.

- The review of the current New Zealand Standard for domestic sprinkler systems (NZS 4515:1995 [SNZ, 1995]) is attempting to reduce the costs of the system, but as shown by the cost-benefit analysis, the costs need to be reduced further. The attempts to have plumbers install the system and to reduce the maintenance requirements are a good start.

- Compulsory requirements for sprinkler systems in homes have been successful in the USA in reducing the costs of the system.

- The multi-purpose sprinkler system offers significant cost reductions and advantages and should be investigated further.

12.2 Risk Assessment Analysis

Outcomes from the 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%).

12.3 Low-Cost Sprinkler System

The research set out to establish a low-cost sprinkler system appropriate for domestic use. For installation in a new house, a multi-purpose sprinkler system, whereby the sprinkler piping is integrated with the domestic plumbing, is proposed.

The proposed multi-purpose sprinkler system varies from the requirements of NZS 4515:1995 (SNZ, 1995) as it:

7. is not a stand-alone system
8. omits sprinkler heads from the bathroom, toilet, wardrobe/cupboard space and ceiling cavity
9. is assumed that the installation will be carried out by approved plumbers, sprinkler contractors or others who have demonstrated competency to carry out the work
10. requires no control valveset
11. does not have a sprinkler operating alarm, but does recommend the installation of smoke alarms to provide early warning of the fire
12. has no specifications for annual maintenance.

The cost per life saved for installation of the proposed multi-purpose sprinkler system was found to be $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 4515:1995 (SNZ, 1995). A review of the current New Zealand Standard for the installation of domestic fire sprinkler systems is attempting 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 $34.8 million to $17.8 million (refer Table 15). 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 a new sprinkler system to the draft New Zealand Standard, DZ 4515/CD3 (SNZ, 1999). The comparison of these results show the proposed low-cost multi-purpose sprinkler system to be considerably more cost-effective than domestic sprinkler systems installed to current or draft standards.

The option of a multi-purpose sprinkler system offers the most cost effective solution.

Combination of the smoke alarm with the multi-purpose 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 $2.8 million.

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 low-cost sprinkler system is considerably less than that of multiple smoke alarms.

Consideration was also given to options for retrofitting domestic sprinkler systems to existing homes. A low-cost option considered appropriate for retrofitting purposes is the flow-through sprinkler system.

The flow-through sprinkler system is designed in sequence with the domestic plumbing system, with water flowing through the sprinkler piping then on to the plumbing fixtures. The sprinkler design varies from NZS 4515:1995 (SNZ, 1995) in the same way as the multi-purpose sprinkler design but also offers advantages, including the ease of retrofit installation and the ability to isolate the sprinkler system from the domestic plumbing.

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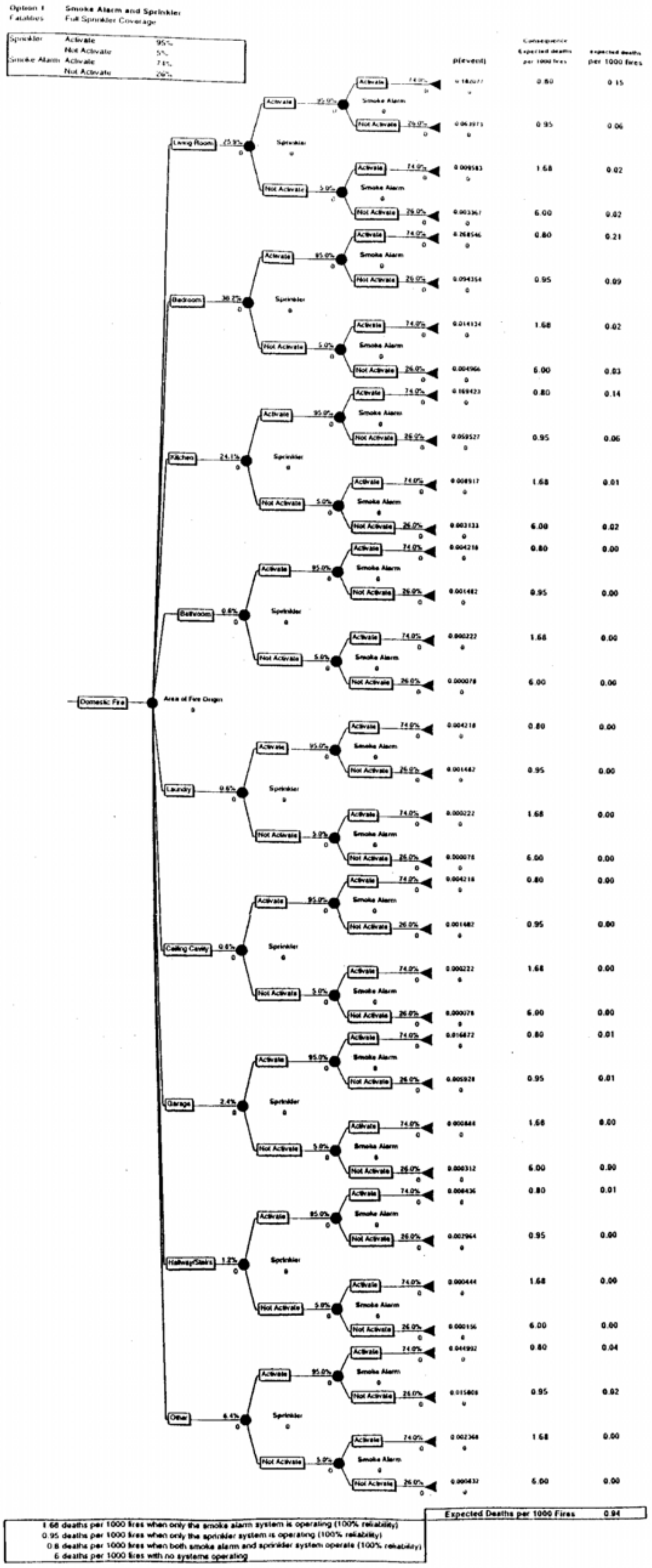
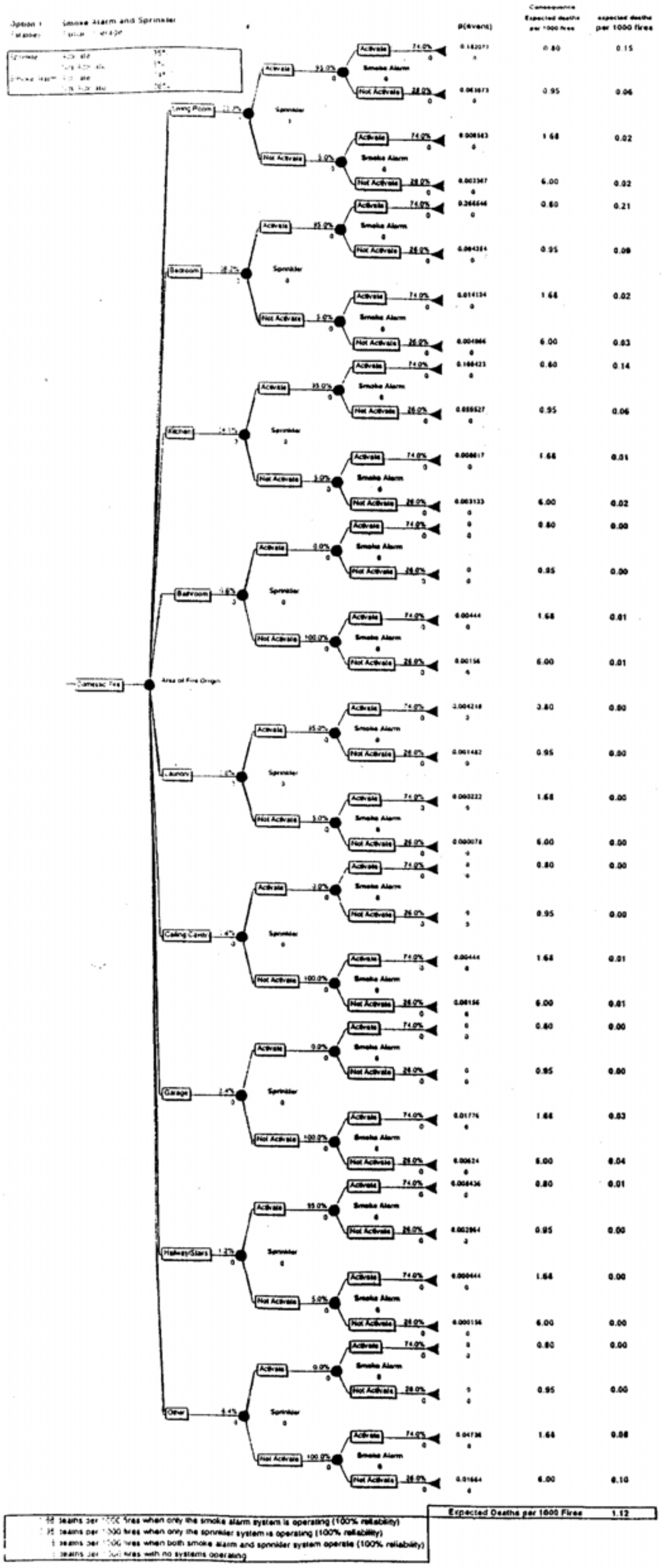
14. APPENDIX I – RISK ASSESSMENT

The following are examples of the event trees used in the risk assessment. The first event tree is to calculate the expected deaths per 1000 house fires where there is a full coverage sprinkler system and smoke alarms present. The second event tree calculates the expected deaths per 1000 house fires where there is a partial coverage sprinkler system and smoke alarms present.


Option 1 Smoke Alarm and Sprinkler
Fatalities Full Sprinkler Coverage
Sprinkler Activate 95%
Not Activate 5%
Smoke Alarm Activate 74%
Not Activate 26%
p(event)
Consequence Expected deaths per 1000 fires
expected deaths per 1000 fires
Domestic Fire
Area of Fire Origin
Living Room 25.9%
Bedroom 38.2%
Kitchen 24.1%
Bathroom 0.6%
Laundry 0.6%
Ceiling Cavity 0.6%
Garage 2.4%
Hallway/Stairs 1.2%
Other 6.4%
Sprinkler
Activate 95.0%
Not Activate 5.0%
Smoke Alarm
Activate 74.0%
Not Activate 26.0%
0
0.182077 0.80 0.15
0.063973 0.95 0.06
0.009583 1.68 0.02
0.003367 6.00 0.02
0.268546 0.80 0.21
0.094354 0.95 0.09
0.014134 1.68 0.02
0.004966 6.00 0.03
0.169423 0.80 0.14
0.059527 0.95 0.06
0.008917 1.68 0.01
0.003133 6.00 0.02
0.004218 0.80 0.00
0.001482 0.95 0.00
0.000222 1.68 0.00
0.000078 6.00 0.00
0.004218 0.80 0.00
0.001482 0.95 0.00
0.000222 1.68 0.00
0.000078 6.00 0.00
0.004218 0.80 0.00
0.001482 0.95 0.00
0.000222 1.68 0.00
0.000078 6.00 0.00
0.016872 0.80 0.01
0.005928 0.95 0.01
0.000888 1.68 0.00
0.000312 6.00 0.00
0.008436 0.80 0.01
0.002964 0.95 0.00
0.000444 1.68 0.00
0.000156 6.00 0.00
0.044992 0.80 0.04
0.015808 0.95 0.02
0.002368 1.68 0.00
0.000832 6.00 0.00
Expected Deaths per 1000 Fires 0.94
1.68 deaths per 1000 fires when only the smoke alarm system is operating (100% reliability)
0.95 deaths per 1000 fires when only the sprinkler system is operating (100% reliability)
0.8 deaths per 1000 fires when both smoke alarm and sprinkler system operate (100% reliability)
6 deaths per 1000 fires with no systems operating


Option 1 Smoke Alarm and Sprinkler
p(event)
Consequence Expected deaths per 1000 fires
expected deaths per 1000 fires
Domestic Fire
Area of Fire Origin
Living Room
Bedroom
Kitchen
Bathroom
Laundry
Ceiling Cavity
Garage
Hallway/Stairs
Other
Sprinkler
Smoke Alarm
Activate
Not Activate
95.0%
5.0%
0.0%
100.0%
74.0%
26.0%
0.80
0.95
1.68
6.00
0.15
0.06
0.02
0.02
0.21
0.09
0.02
0.03
0.14
0.06
0.01
0.02
0.00
0.00
0.01
0.01
0.00
0.00
0.00
0.00
0.00
0.00
0.01
0.01
0.00
0.00
0.03
0.04
0.01
0.00
0.00
0.00
0.00
0.00
0.08
0.10
Expected Deaths per 1000 Fires 1.12
deaths per 1000 fires when only the smoke alarm system is operating (100% reliability)
deaths per 1000 fires when only the sprinkler system is operating (100% reliability)
deaths per 1000 fires when both smoke alarm and sprinkler system operate (100% reliability)
deaths per 1000 fires with no systems operating

15. APPENDIX II – COMPUTER MODELLING

```
Thursday,June 01,2000,09:43 PM
Input Filename : A:\bedroomsp.mod

BRANZFIRE Multi-Compartment Fire Model (Ver 2000.09)
```

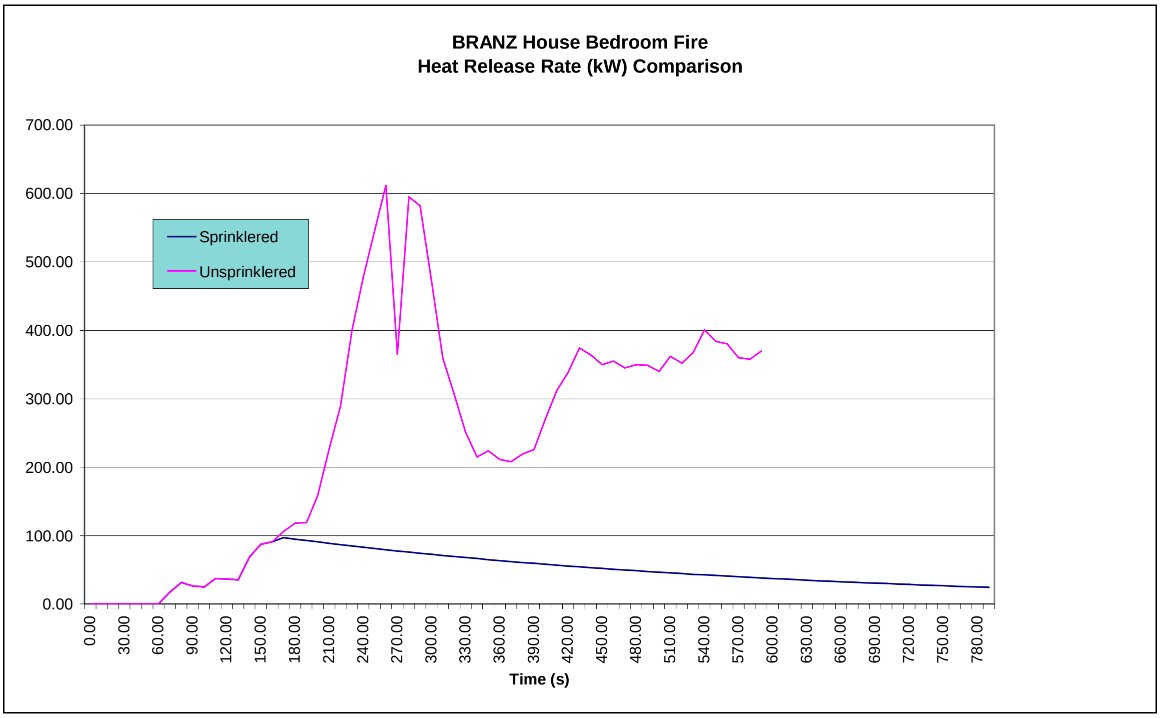
Sprinklered Bedroom BRANZ House

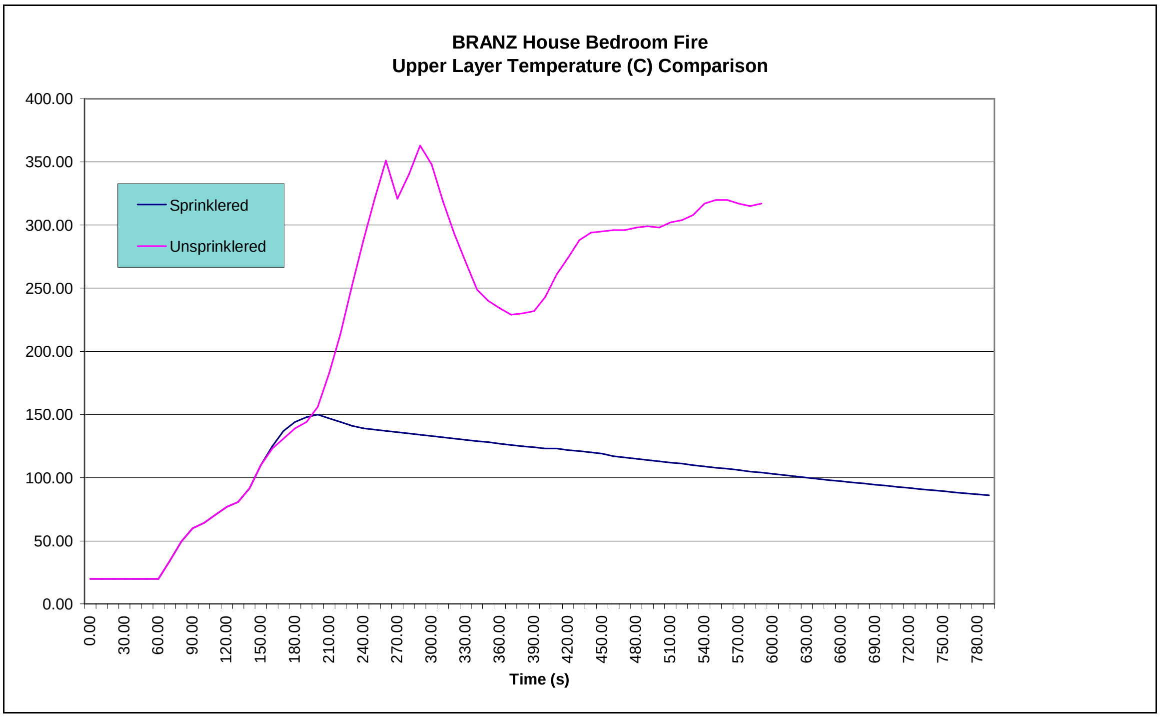
```
====================================================================
Description of Rooms
====================================================================
Room  1  : Hall
         Room Length (m) =                                 3.40
         Room Width (m) =                                  0.80
         Maximum Room Height (m) =                         2.40
         Minimum Room Height (m) =                         2.40
         Floor Elevation (m) =                             0.000
         Room  1  has a flat ceiling.

         Wall Surface is Plasterboard, Gypsum paper-faced
         Wall Density (kg/m3) =                            760.0
         Wall Conductivity (W/m.K) =                       0.160
         Wall Emissivity =                                 0.88
         Wall Thickness (mm) =                             10.0

         Ceiling Surface is Plasterboard, Gypsum paper-faced
         Ceiling Density (kg/m3) =                         760.0
         Ceiling Conductivity (W/m.K) =                    0.160
         Ceiling Emissivity =                              0.88
         Ceiling Thickness (mm) =                          10.0

         Floor Surface is Particleboard, high density
         Floor Density (kg/m3) =                           1000.0
         Floor Conductivity (W/m.K) =                      0.170
         Floor Emissivity =                                0.88
         Floor Thickness = (mm)                            25.0

Room  2  : Bedroom
         Room Length (m) =                                 3.21
         Room Width (m) =                                  2.78
         Maximum Room Height (m) =                         2.40
         Minimum Room Height (m) =                         2.40
         Floor Elevation (m) =                             0.000
         Room  2  has a flat ceiling.

         Wall Surface is Plasterboard, Gypsum paper-faced
         Wall Density (kg/m3) =                            760.0
         Wall Conductivity (W/m.K) =                       0.160
         Wall Emissivity =                                 0.88
         Wall Thickness (mm) =                             10.0

         Ceiling Surface is Plasterboard, Gypsum paper-faced
         Ceiling Density (kg/m3) =                         760.0
         Ceiling Conductivity (W/m.K) =                    0.160
         Ceiling Emissivity =                              0.88
         Ceiling Thickness (mm) =                          10.0

         Floor Surface is Particleboard, high density
         Floor Density (kg/m3) =                           1000.0
         Floor Conductivity (W/m.K) =                      0.170
         Floor Emissivity =                                0.88
         Floor Thickness = (mm)                            25.0

Room  3  : Bedroom2
         Room Length (m) =                                 2.87
```

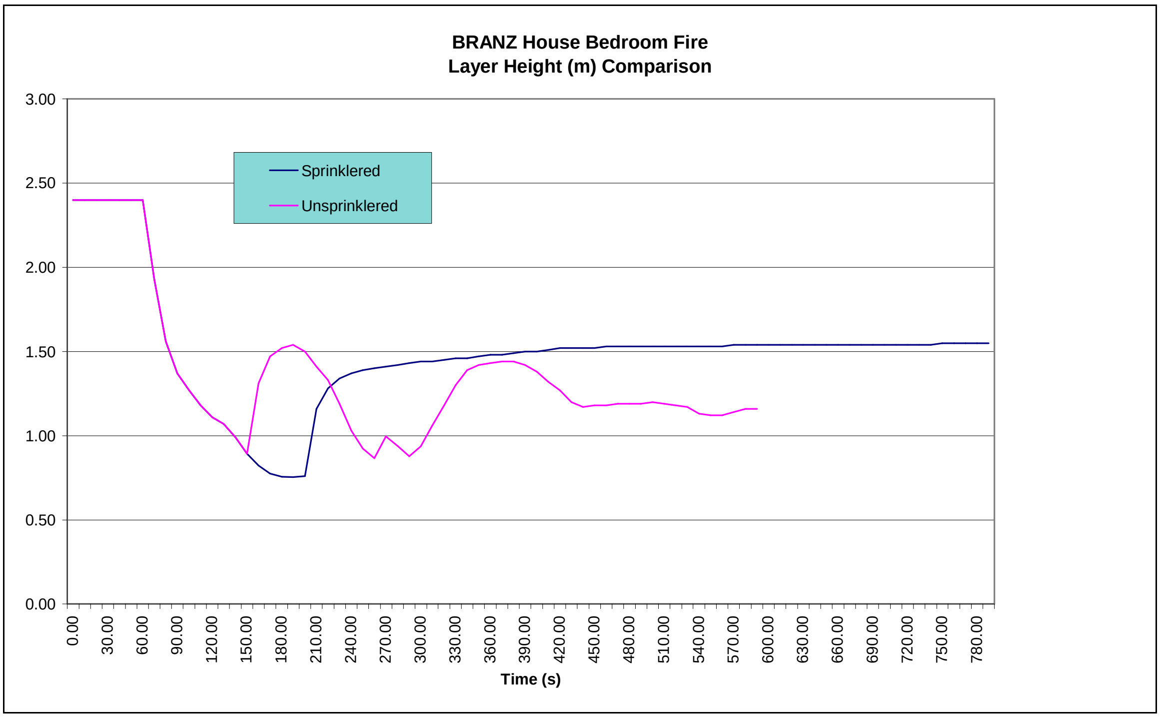
```
         Room Width (m) =                                  2.46
         Maximum Room Height (m) =                         2.40
         Minimum Room Height (m) =                         2.40
         Floor Elevation (m) =                             0.000
         Room  3  has a flat ceiling.

         Wall Surface is Plasterboard, Gypsum paper-faced
         Wall Density (kg/m3) =                            760.0
         Wall Conductivity (W/m.K) =                       0.160
         Wall Emissivity =                                 0.88
         Wall Thickness (mm) =                             10.0

         Ceiling Surface is Plasterboard, Gypsum paper-faced
         Ceiling Density (kg/m3) =                         760.0
         Ceiling Conductivity (W/m.K) =                    0.160
         Ceiling Emissivity =                              0.88
         Ceiling Thickness (mm) =                          10.0

         Floor Surface is Particleboard, high density
         Floor Density (kg/m3) =                           1000.0
         Floor Conductivity (W/m.K) =                      0.170
         Floor Emissivity =                                0.88
         Floor Thickness = (mm)                            25.0

Room  4  : Bedroom3
         Room Length (m) =                                 3.00
         Room Width (m) =                                  2.46
         Maximum Room Height (m) =                         2.40
         Minimum Room Height (m) =                         2.40
         Floor Elevation (m) =                             0.000
         Room  4  has a flat ceiling.

         Wall Surface is Plasterboard, Gypsum paper-faced
         Wall Density (kg/m3) =                            760.0
         Wall Conductivity (W/m.K) =                       0.160
         Wall Emissivity =                                 0.88
         Wall Thickness (mm) =                             10.0

         Ceiling Surface is Plasterboard, Gypsum paper-faced
         Ceiling Density (kg/m3) =                         760.0
         Ceiling Conductivity (W/m.K) =                    0.160
         Ceiling Emissivity =                              0.88
         Ceiling Thickness (mm) =                          10.0

         Floor Surface is Particleboard, high density
         Floor Density (kg/m3) =                           1000.0
         Floor Conductivity (W/m.K) =                      0.170
         Floor Emissivity =                                0.88
         Floor Thickness = (mm)                            25.0

====================================================================
Description of Wall Vents
====================================================================
From room  1  to  2 , Vent No 1
                   Vent Width (m) =                        0.200
                   Vent Height (m) =                       2.100
                   Vent Sill Height (m) =                  0.000
                   Vent Soffit Height (m) =                2.100
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0

From room  1  to  3 , Vent No 1
                   Vent Width (m) =                        0.200
                   Vent Height (m) =                       2.100
                   Vent Sill Height (m) =                  0.000
                   Vent Soffit Height (m) =                2.100
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0

From room  1  to  4 , Vent No 1
                   Vent Width (m) =                        0.200
                   Vent Height (m) =                       2.100
```

```
                   Vent Sill Height (m) =                  0.000
                   Vent Soffit Height (m) =                2.100
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0

From room  2  to outside, Vent No 1
                   Vent Width (m) =                        0.002
                   Vent Height (m) =                       2.400
                   Vent Sill Height (m) =                  0.000
                   Vent Soffit Height (m) =                2.400
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0

From room  3  to outside, Vent No 1
                   Vent Width (m) =                        0.002
                   Vent Height (m) =                       2.400
                   Vent Sill Height (m) =                  0.000
                   Vent Soffit Height (m) =                2.400
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0

From room  4  to outside, Vent No 1
                   Vent Width (m) =                        0.002
                   Vent Height (m) =                       2.400
                   Vent Sill Height (m) =                  0.000
                   Vent Soffit Height (m) =                2.400
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0

From room  4  to outside, Vent No 2
                   Vent Width (m) =                        0.700
                   Vent Height (m) =                       0.800
                   Vent Sill Height (m) =                  1.300
                   Vent Soffit Height (m) =                2.100
                   Opening Time (sec) =                    200
                   Closing Time (sec) =                    0

====================================================================
Description of Ceiling/Floor Vents
====================================================================
====================================================================
Ambient Conditions
====================================================================
Interior Temp (C) =                                        20.0
Exterior Temp (C) =                                        15.0
Relative Humidity (%) =                                    65

====================================================================
Tenability Parameters
====================================================================
Monitoring Height for Visibility and FED (m) =             2.00
Occupant Activity Level =                                  Light
Visibility calculations assume:                            reflective signs
FED Start Time (sec)                                       0
FED End Time (sec)                                         600

====================================================================
Sprinkler / Detector Parameters
====================================================================
Sprinkler installed in Room                                4
         Sprinkler suppression is simulated.
         Response Time Index (m.s)^1/2 =                   35.0
         Sprinkler C-Factor (m.s)^1/2 =                    0.6
         Radial Distance (m) =                             2.0
         Actuation Temperature (C) =                       68.0
         Water Spray Density (mm/min) =                    4.0
         Distance below ceiling (mm) =                     3
         Ceiling Jet model used is NIST JET.

====================================================================
Mechanical Ventilation (to/from outside)
====================================================================
```

```
Mechanical Ventilation not installed in Room 1
Mechanical Ventilation not installed in Room 2
Mechanical Ventilation not installed in Room 3
Mechanical Ventilation not installed in Room 4

===================================================================
Description of the Fire
===================================================================
Radiant Loss Fraction =                                     0.35
Smoke Emission Coefficent (1/m) =                           0.80
Characteristic Mass Loss per Unit Area (kg/s.m2) =          0.035
Air Entrainment in Plume uses McCaffrey (recommended)

Burning Object No 1

              Located in Room                               4
              Energy Yield (kJ/g) =                         12.4
              CO2 Yield (kg/kg fuel) =                      1.270
              Soot Yield (kg/kg fuel) =                     0.015
              H2O Yield (kg/kg fuel) =                      0.442
              Fire Height (m) =                             0.500
              Fire Location (m) =                           Wall


===================================================================
Summary of End-Point Conditions in Room of Fire Origin
===================================================================
FED Radiation (incap) of 1  Not Reached.
An Upper Layer Temperature of 600 deg C Not Reached.
Visibility at 2m above floor reduced to 5 m at 80.0 Seconds.
Temperature at 2m above floor has reached 80 deg C at 128.0 Seconds.
FED Narcotic Gases (incap) Exceeded 1 at 191.0 Seconds.
Sprinkler/Detector Actuated at 165.0 Seconds.

===================================================================
Initial Time-Step = 1.00 seconds.
Computer Run-Time = 1137.1 seconds.
===================================================================
```


BRANZ House Bedroom Fire
Heat Release Rate (kW) Comparison
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
Sprinklered
Unsprinklered
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00
300.00
330.00
360.00
390.00
420.00
450.00
480.00
510.00
540.00
570.00
600.00
630.00
660.00
690.00
720.00
750.00
780.00
Time (s)


BRANZ House Bedroom Fire
Upper Layer Temperature (C) Comparison
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Sprinklered
Unsprinklered
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00
300.00
330.00
360.00
390.00
420.00
450.00
480.00
510.00
540.00
570.00
600.00
630.00
660.00
690.00
720.00
750.00
780.00
Time (s)


BRANZ House Bedroom Fire
Layer Height (m) Comparison
Sprinklered
Unsprinklered
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00
300.00
330.00
360.00
390.00
420.00
450.00
480.00
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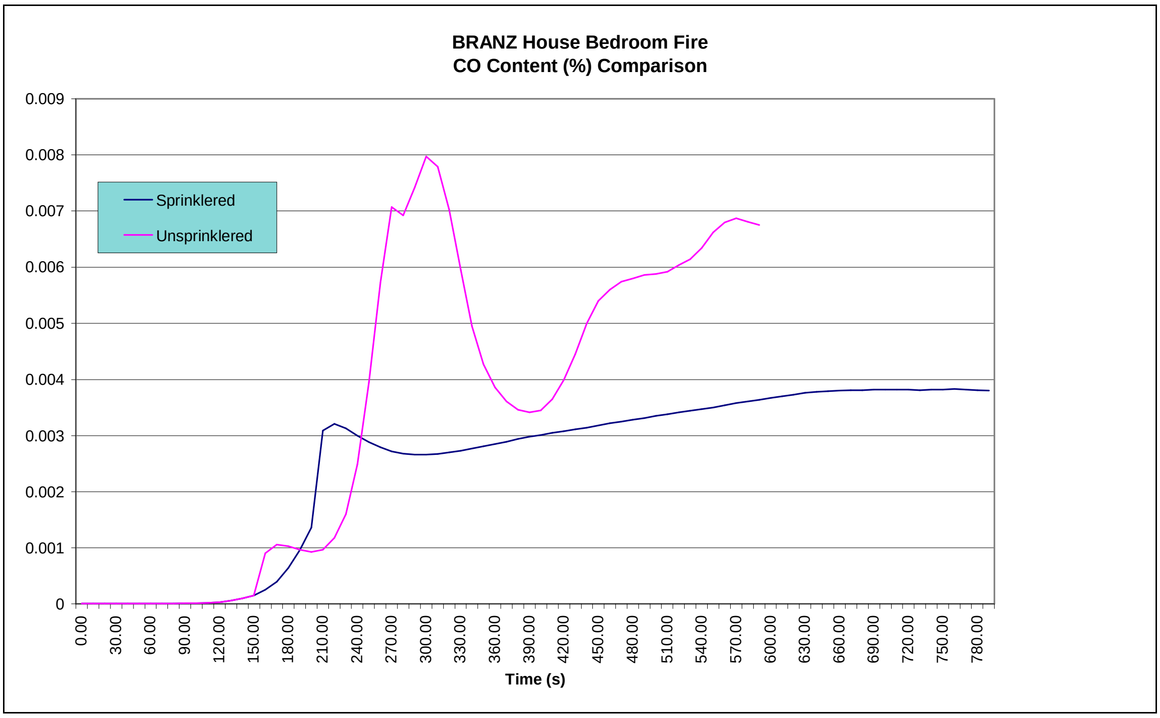
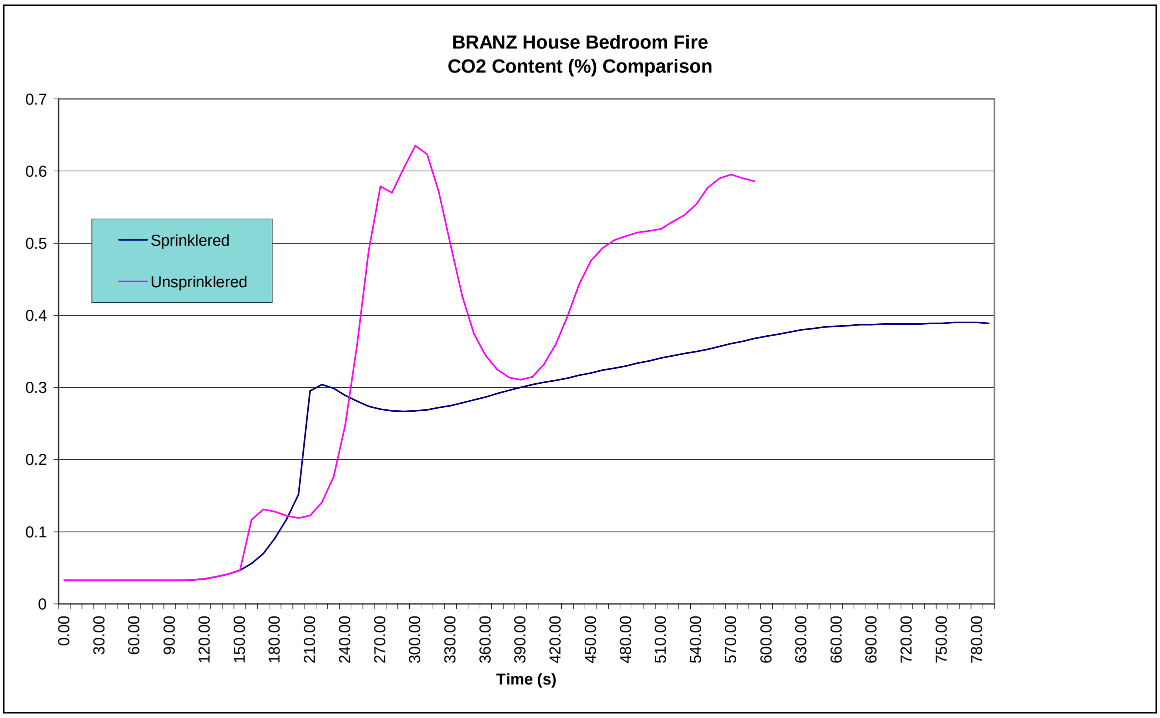
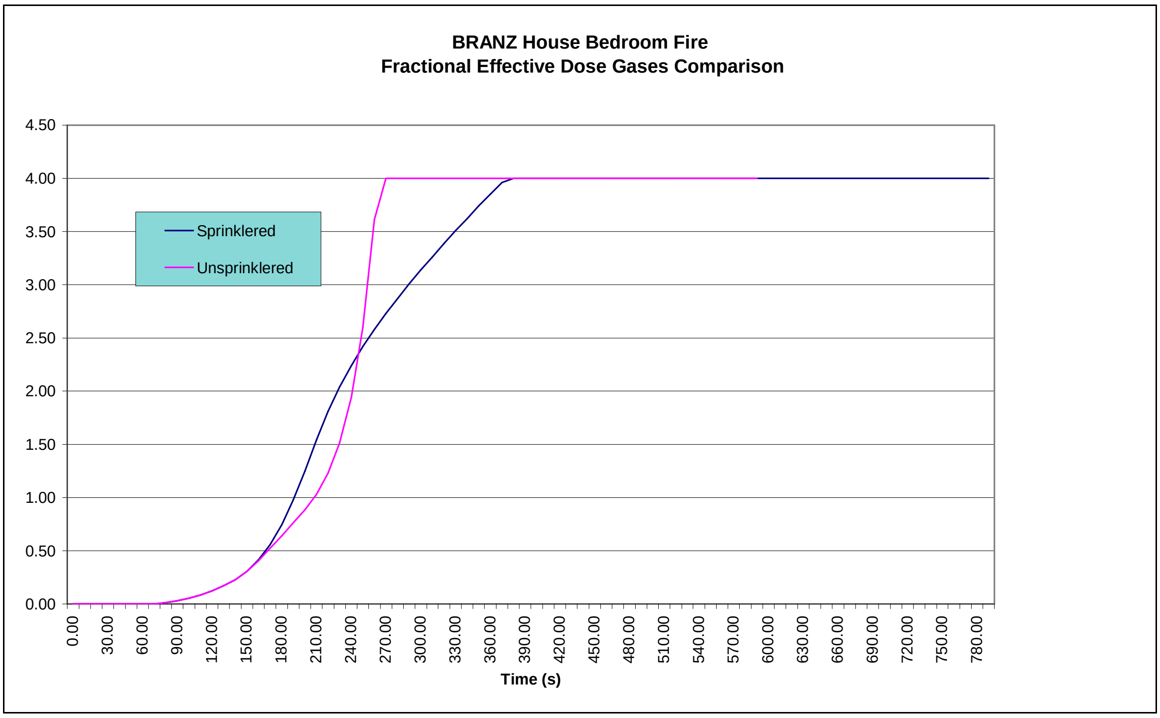
690.00
720.00
750.00
780.00
Time (s)


BRANZ House Bedroom Fire
CO Content (%) Comparison
Sprinklered
Unsprinklered
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00
300.00
330.00
360.00
390.00
420.00
450.00
480.00
510.00
540.00
570.00
600.00
630.00
660.00
690.00
720.00
750.00
780.00
Time (s)


BRANZ House Bedroom Fire
CO2 Content (%) Comparison
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Sprinklered
Unsprinklered
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00
300.00
330.00
360.00
390.00
420.00
450.00
480.00
510.00
540.00
570.00
600.00
630.00
660.00
690.00
720.00
750.00
780.00
Time (s)


BRANZ House Bedroom Fire
Fractional Effective Dose Gases Comparison
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Sprinklered
Unsprinklered
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00
300.00
330.00
360.00
390.00
420.00
450.00
480.00
510.00
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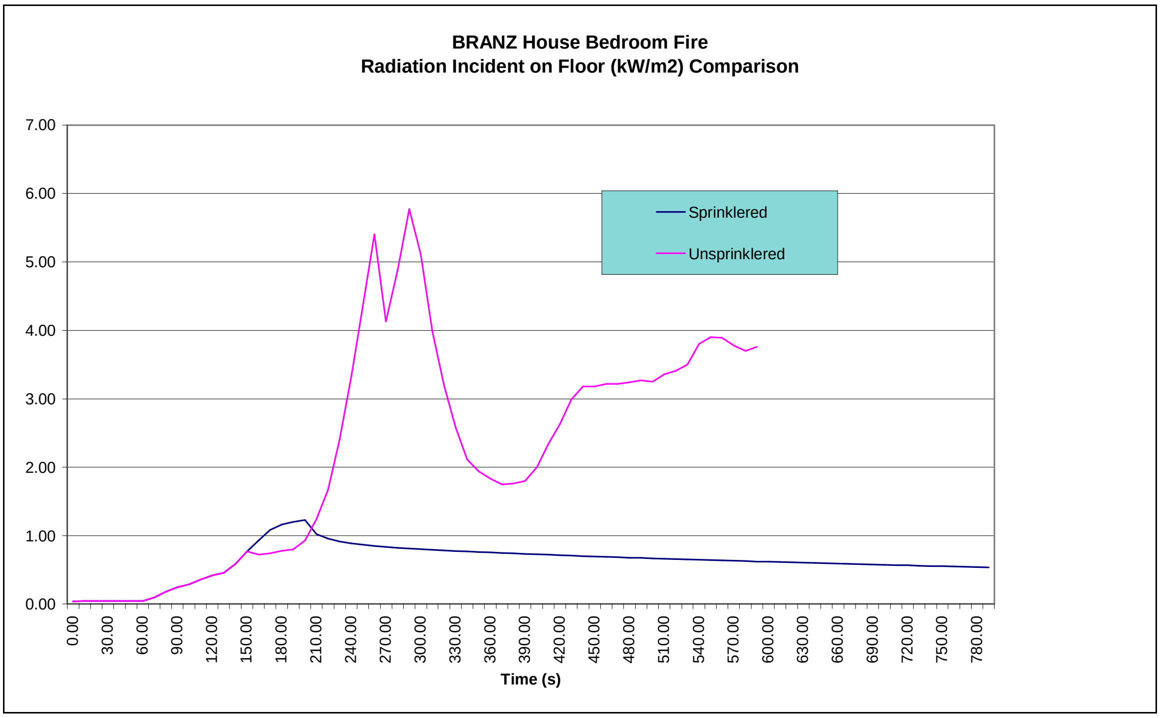
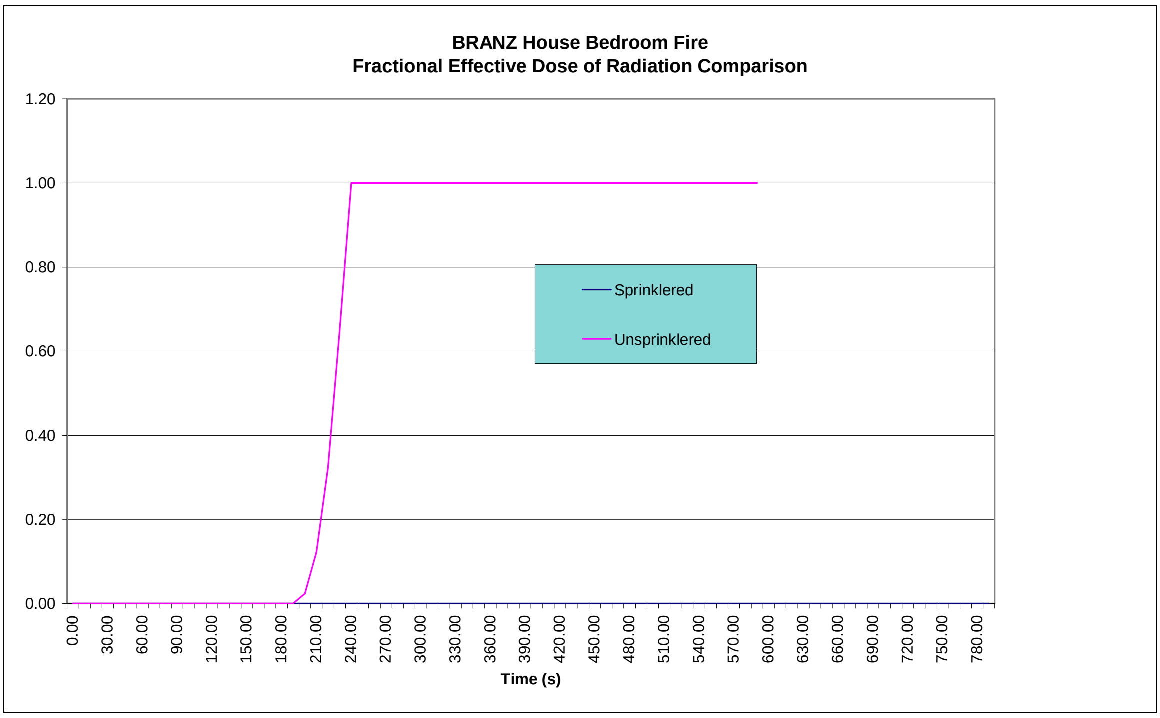
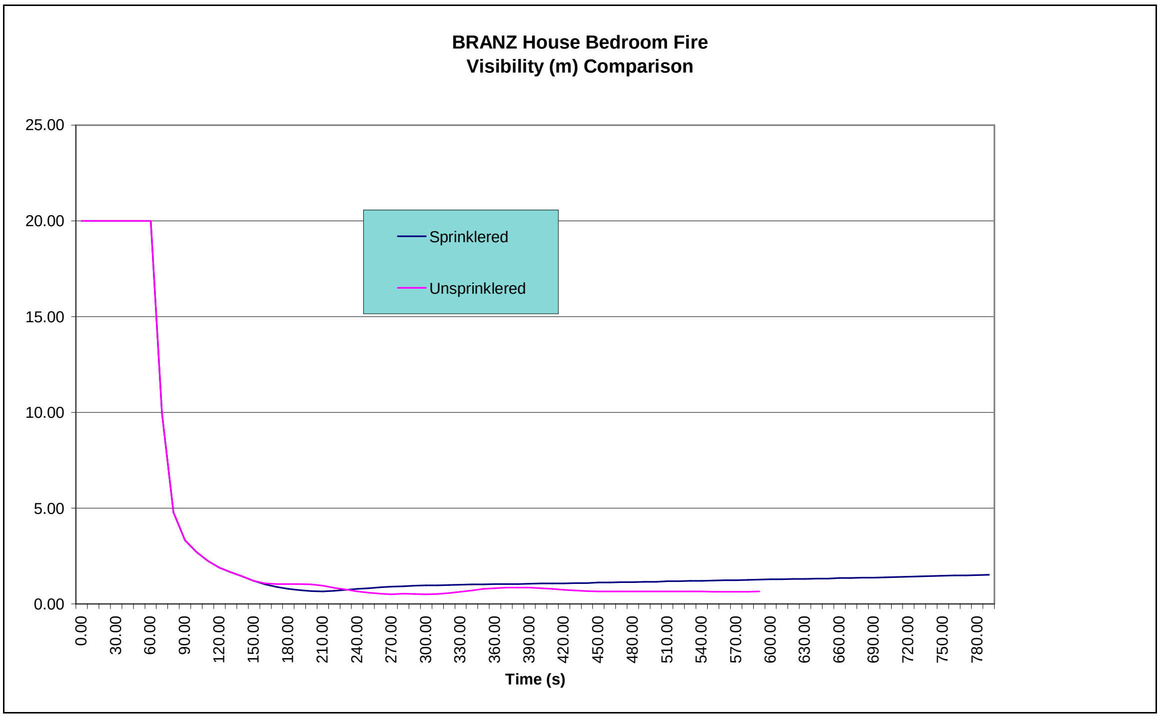
570.00
600.00
630.00
660.00
690.00
720.00
750.00
780.00
Time (s)


BRANZ House Bedroom Fire
Radiation Incident on Floor (kW/m2) Comparison
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Sprinklered
Unsprinklered
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00
300.00
330.00
360.00
390.00
420.00
450.00
480.00
510.00
540.00
570.00
600.00
630.00
660.00
690.00
720.00
750.00
780.00
Time (s)


BRANZ House Bedroom Fire
Fractional Effective Dose of Radiation Comparison
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Sprinklered
Unsprinklered
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00
300.00
330.00
360.00
390.00
420.00
450.00
480.00
510.00
540.00
570.00
600.00
630.00
660.00
690.00
720.00
750.00
780.00
Time (s)



```
Monday,June 05,2000,08:55 PM
Input Filename : A:\uniteccloungesp.mod

BRANZFIRE Multi-Compartment Fire Model (Ver 2000.09)
```

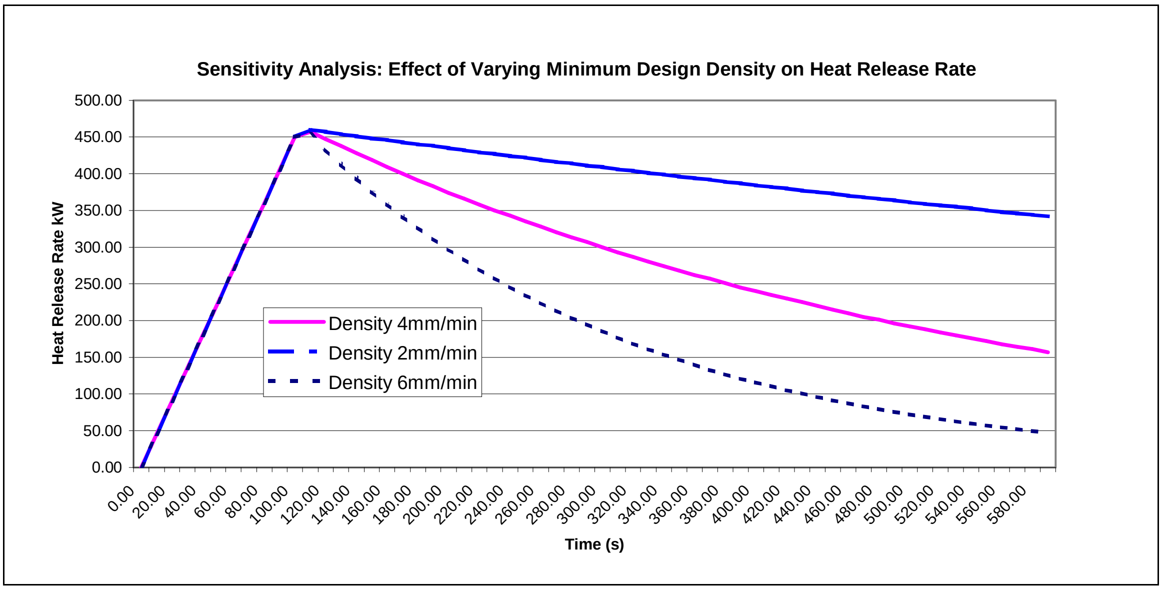
Sprinklered Lounge Unitec House
Sensitivity Analysis Higher Density of Application

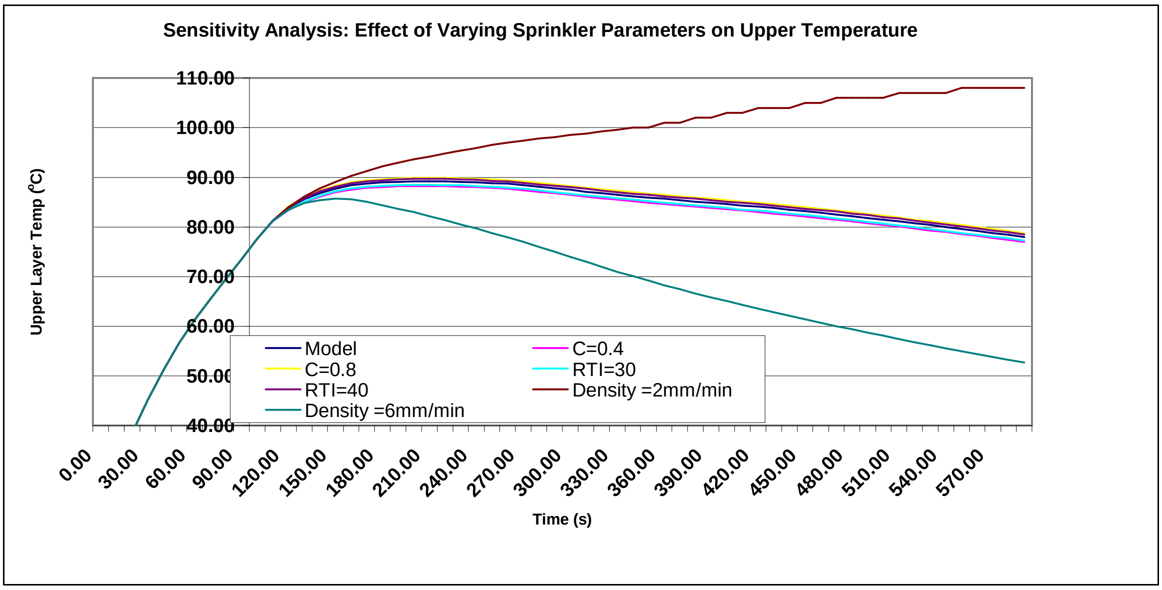
```
====================================================================
Description of Rooms
====================================================================
Room  1  : Kitch/lounge/dining
         Room Length (m) =                                 12.80
         Room Width (m) =                                  12.50
         Maximum Room Height (m) =                         2.40
         Minimum Room Height (m) =                         2.40
         Floor Elevation (m) =                             0.000
         Room  1  has a flat ceiling.

         Wall Surface is Plasterboard, Gypsum paper-faced
         Wall Density (kg/m3) =                            760.0
         Wall Conductivity (W/m.K) =                       0.160
         Wall Emissivity =                                 0.88
         Wall Thickness (mm) =                             10.0

         Ceiling Surface is Plasterboard, Gypsum paper-faced
         Ceiling Density (kg/m3) =                         760.0
         Ceiling Conductivity (W/m.K) =                    0.160
         Ceiling Emissivity =                              0.88
         Ceiling Thickness (mm) =                          10.0

         Floor Surface is Particleboard, low density
         Floor Density (kg/m3) =                           590.0
         Floor Conductivity (W/m.K) =                      0.078
         Floor Emissivity =                                0.88
         Floor Thickness = (mm)                            20.0

Room  2  : Hall
         Room Length (m) =                                 8.60
         Room Width (m) =                                  1.50
         Maximum Room Height (m) =                         2.40
         Minimum Room Height (m) =                         2.40
```

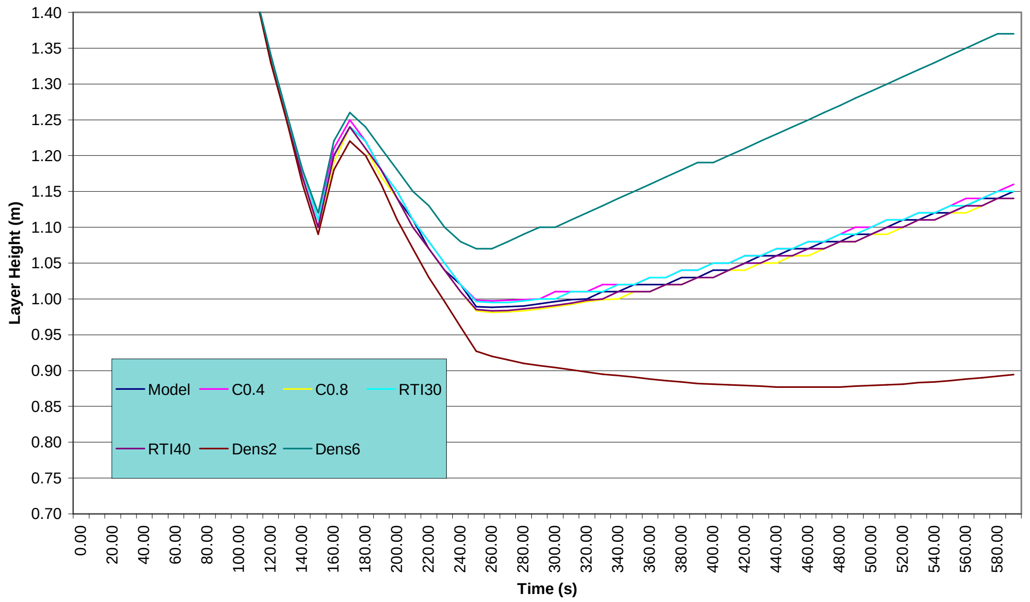
```
         Floor Elevation (m) =                             0.000
         Room  2  has a flat ceiling.

         Wall Surface is Plasterboard, Gypsum paper-faced
         Wall Density (kg/m3) =                            760.0
         Wall Conductivity (W/m.K) =                       0.160
         Wall Emissivity =                                 0.88
         Wall Thickness (mm) =                             10.0

         Ceiling Surface is Plasterboard, Gypsum paper-faced
         Ceiling Density (kg/m3) =                         760.0
         Ceiling Conductivity (W/m.K) =                    0.160
         Ceiling Emissivity =                              0.88
         Ceiling Thickness (mm) =                          9.5

         Floor Surface is Particleboard, low density
         Floor Density (kg/m3) =                           590.0
         Floor Conductivity (W/m.K) =                      0.078
         Floor Emissivity =                                0.88
         Floor Thickness = (mm)                            20.0

Room  3  : Bedroom
         Room Length (m) =                                 7.50
         Room Width (m) =                                  6.50
         Maximum Room Height (m) =                         2.40
         Minimum Room Height (m) =                         2.40
         Floor Elevation (m) =                             0.000
         Room  3  has a flat ceiling.

         Wall Surface is Plasterboard, Gypsum paper-faced
         Wall Density (kg/m3) =                            760.0
         Wall Conductivity (W/m.K) =                       0.160
         Wall Emissivity =                                 0.88
         Wall Thickness (mm) =                             10.0

         Ceiling Surface is Plasterboard, Gypsum paper-faced
         Ceiling Density (kg/m3) =                         760.0
         Ceiling Conductivity (W/m.K) =                    0.160
         Ceiling Emissivity =                              0.88
         Ceiling Thickness (mm) =                          9.5

         Floor Surface is Particleboard, low density
         Floor Density (kg/m3) =                           590.0
         Floor Conductivity (W/m.K) =                      0.078
         Floor Emissivity =                                0.88
         Floor Thickness = (mm)                            20.0

====================================================================
Description of Wall Vents
====================================================================
From room  1  to  2 , Vent No 1
                   Vent Width (m) =                        0.002
                   Vent Height (m) =                       2.100
                   Vent Sill Height (m) =                  0.000
                   Vent Soffit Height (m) =                2.100
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0

From room  1  to  2 , Vent No 2
                   Vent Width (m) =                        0.800
                   Vent Height (m) =                       0.001
                   Vent Sill Height (m) =                  2.100
                   Vent Soffit Height (m) =                2.101
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0

From room  1  to  2 , Vent No 3
                   Vent Width (m) =                        0.800
                   Vent Height (m) =                       0.002
                   Vent Sill Height (m) =                  0.000
                   Vent Soffit Height (m) =                0.002
                   Opening Time (sec) =                    0
```

```
                   Closing Time (sec) =                    0

From room  1  to outside, Vent No 1
                   Vent Width (m) =                        0.003
                   Vent Height (m) =                       2.400
                   Vent Sill Height (m) =                  0.000
                   Vent Soffit Height (m) =                2.400
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0

From room  1  to outside, Vent No 2
                   Vent Width (m) =                        1.000
                   Vent Height (m) =                       0.900
                   Vent Sill Height (m) =                  1.300
                   Vent Soffit Height (m) =                2.200
                   Opening Time (sec) =                    150
                   Closing Time (sec) =                    0

From room  1  to outside, Vent No 3
                   Vent Width (m) =                        1.000
                   Vent Height (m) =                       0.900
                   Vent Sill Height (m) =                  1.300
                   Vent Soffit Height (m) =                2.200
                   Opening Time (sec) =                    250
                   Closing Time (sec) =                    0

====================================================================
Description of Ceiling/Floor Vents
====================================================================
====================================================================
Ambient Conditions
====================================================================
Interior Temp (C) =                                        20.0
Exterior Temp (C) =                                        15.0
Relative Humidity (%) =                                    65

====================================================================
Tenability Parameters
====================================================================
Monitoring Height for Visibility and FED (m) =             2.00
Occupant Activity Level =                                  Light
Visibility calculations assume:                            reflective signs
FED Start Time (sec)                                       0
FED End Time (sec)                                         600

====================================================================
Sprinkler / Detector Parameters
====================================================================
Sprinkler installed in Room                                1
         Sprinkler suppression is simulated.
         Response Time Index (m.s)^1/2 =                   35.0
         Sprinkler C-Factor (m.s)^1/2 =                    0.6
         Radial Distance (m) =                             8.0
         Actuation Temperature (C) =                       68.0
         Water Spray Density (mm/min) =                    6.0
         Distance below ceiling (mm) =                     25
         Ceiling Jet model used is NIST JET.

====================================================================
Mechanical Ventilation (to/from outside)
====================================================================
Mechanical Ventilation not installed in Room 1
Mechanical Ventilation not installed in Room 2
Mechanical Ventilation not installed in Room 3

====================================================================
Description of the Fire
====================================================================
Radiant Loss Fraction =                                    0.35
Smoke Emission Coefficent (1/m) =                          0.80
Characteristic Mass Loss per Unit Area (kg/s.m2) =         0.011
Air Entrainment in Plume uses McCaffrey (recommended)
```

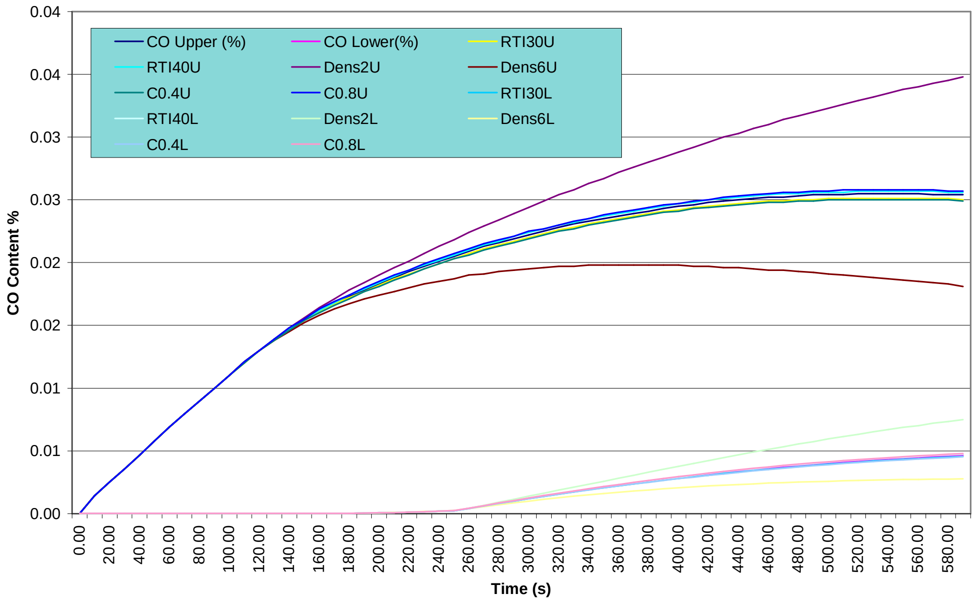
```
Burning Object No 1

              Located in Room                              1
              Energy Yield (kJ/g) =                        12.4
              CO2 Yield (kg/kg fuel) =                     1.270
              Soot Yield (kg/kg fuel) =                    0.015
              H2O Yield (kg/kg fuel) =                     1.000
              Fire Height (m) =                            0.300
              Fire Location (m) =                          Centre



====================================================================
Summary of End-Point Conditions in Room of Fire Origin
====================================================================
FED Radiation (incap) of 1  Not Reached.
An Upper Layer Temperature of 600 deg C Not Reached.
Visibility at 2m above floor reduced to 10 m at 54.0 Seconds.
Temperature at 2m above floor has reached 80 deg C at 107.0 Seconds.
FED Narcotic Gases (incap) Exceeded 1 at 201.0 Seconds.
Sprinkler/Detector Actuated at 107.0 Seconds.

====================================================================
Initial Time-Step = 1.00 seconds.
Computer Run-Time = 329.7 seconds.
====================================================================
```


Sensitivity Analysis: Effect of Varying Minimum Design Density on Heat Release Rate
Heat Release Rate kW
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Density 4mm/min
Density 2mm/min
Density 6mm/min
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00
240.00
260.00
280.00
300.00
320.00
340.00
360.00
380.00
400.00
420.00
440.00
460.00
480.00
500.00
520.00
540.00
560.00
580.00
Time (s)

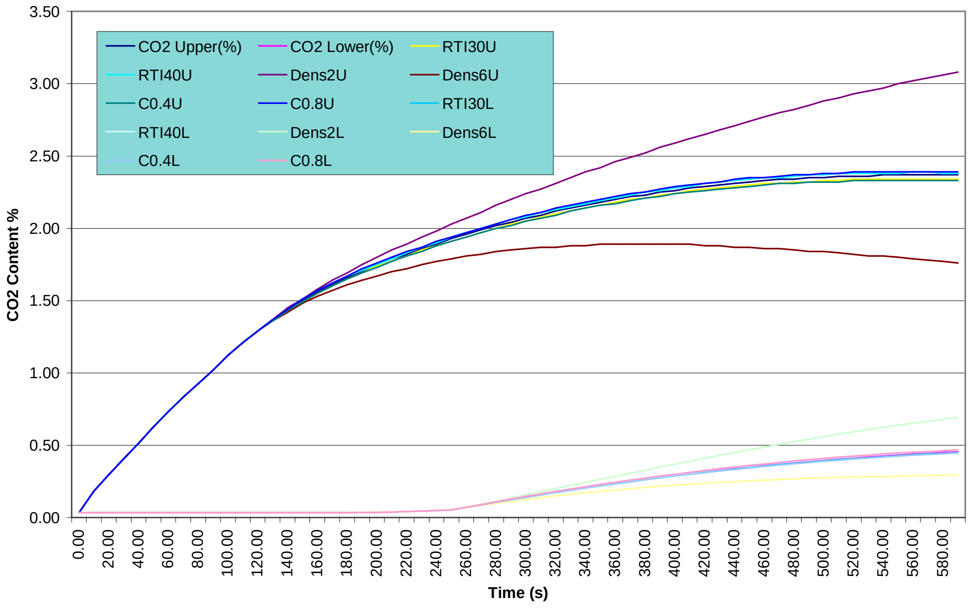

Sensitivity Analysis: Effect of Varying Sprinkler Parameters on Upper Temperature
Upper Layer Temp (ºC)
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
Model
C=0.8
RTI=40
Density =6mm/min
C=0.4
RTI=30
Density =2mm/min
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00
300.00
330.00
360.00
390.00
420.00
450.00
480.00
510.00
540.00
570.00
Time (s)



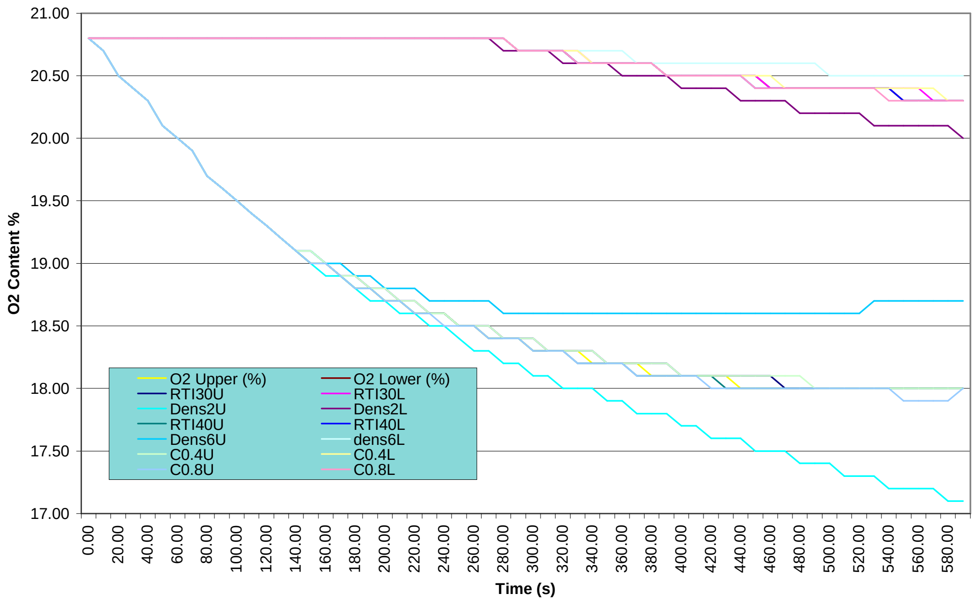
Sensitivity Analysis: Effect of Varying Sprinkler Parameters on Layer Height



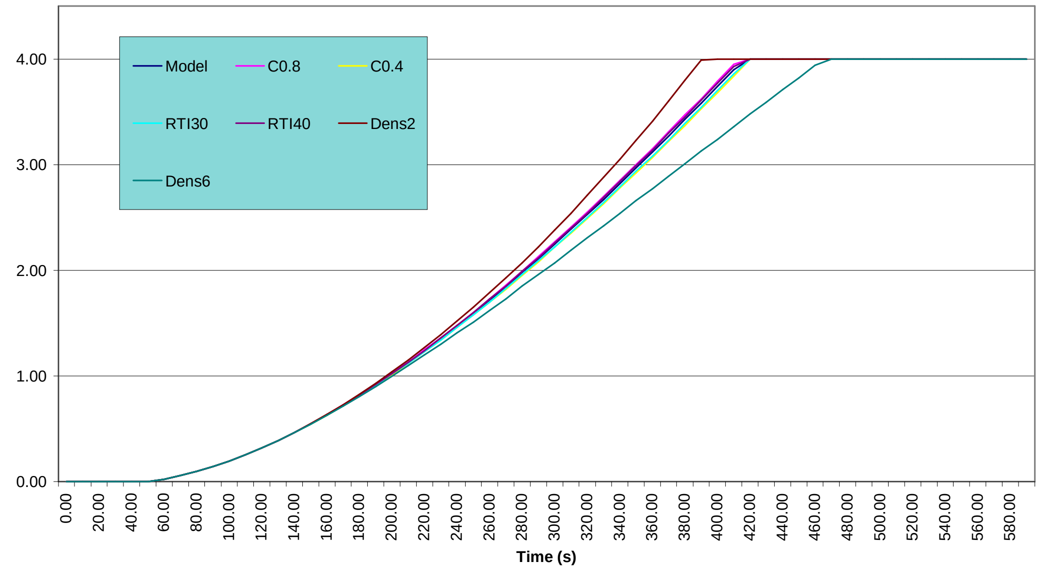
Sensitivity Analysis: Effect of Varying Sprinkler Parameters on CO Concentrations



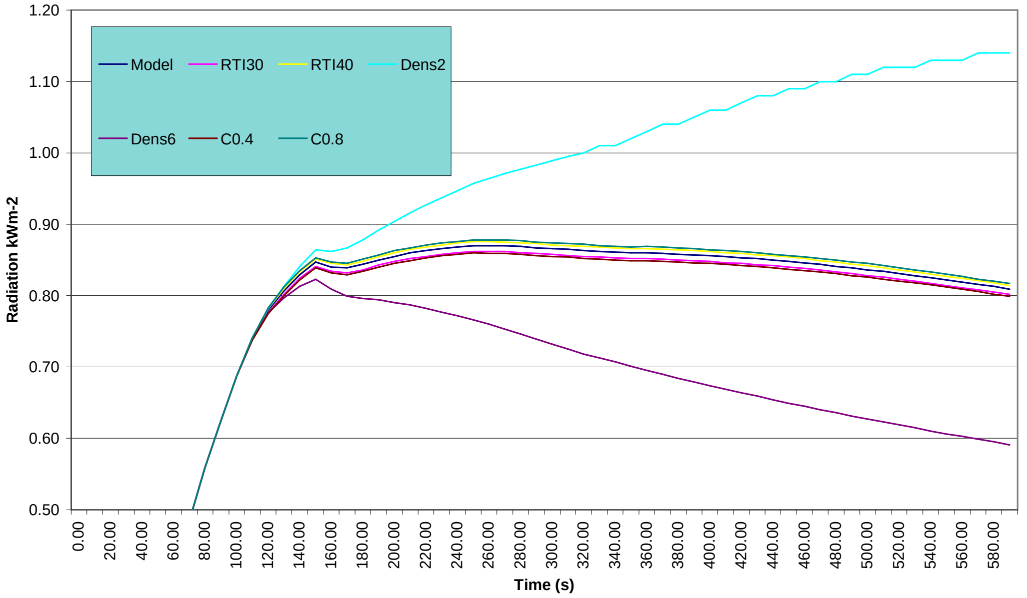
Sensitivity Analysis of Effects of Sprinkler Parameters on CO2 Content (%)



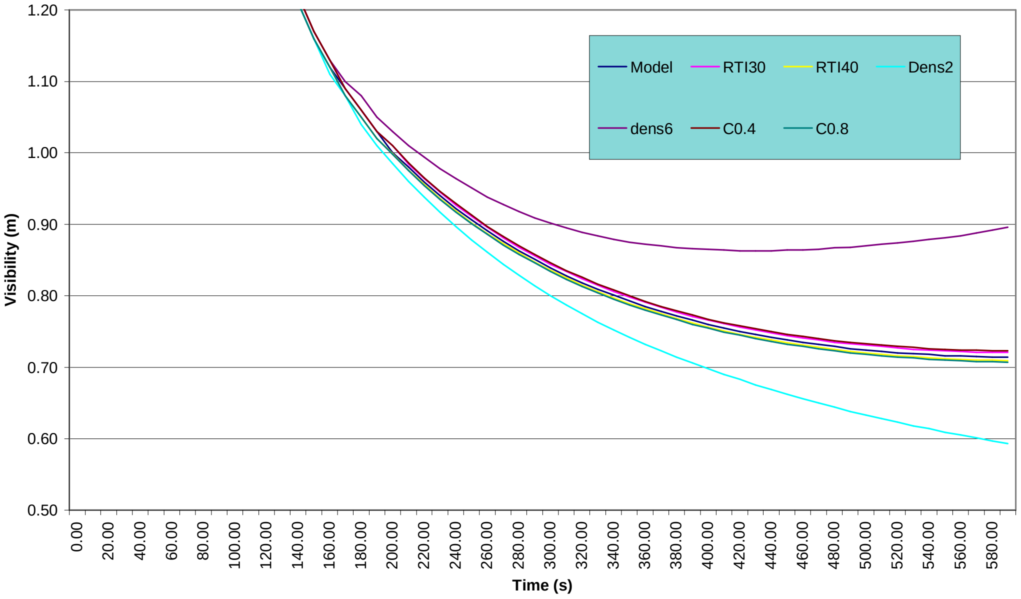
Sensitivity Analysis: Effect of Varying Sprinkler Parameters on Oxygen Content



Sensitivity Analysis: Effect of Varying Sprinkler Parameters on Fractional Effective Dose of Narcotic Gases



Sensitivity Analysis: Effect of Varying Sprinkler Parameters on Radiation To the Floor



Sensitivity Analysis: Effect of Varying Sprinkler Parameters on Visibility

16. APPENDIX III – COST-BENEFIT ANALYSIS

Hydraulic Calculations for the Flow-Through Sprinkler System

Job Name:-	Typical 3 Bedroom House (2 Sprinklers in Compartment)			
Location:-	Suburbs	Domestic Load 12 L\min		
Sprinkler Selected	Flow Rate Single l\min	Pressure Single (kPa)	Flow rate Multiple l/min	Pressure Multiple (kPa)
Viking Microfast Model M-6	37.9	70.9	32.2	51.2

Piping Materials	Copper					
Calculations for	2	Sprinklers				
System Flow Rate	Sprinkler Load	+	Domestic Load	=		L/min
	64.4	+	12	=	76.4	L/min
Sprinkler Pressure Demand	51.2	kPa				
Building Supply Pressure	500	kPa				
Pressure Losses						
Meter Loss @ flow					100	kPa (10)
Backflow Preventer Loss					0	kPa (11)
Pipes, Valves and Fittings;						
Pipe section	Ring Main					
Flow	76.4 L\min		Equivalent Lgth		Equiv Lgth	
15mm Pipe	28	metres	28	=	28	metres
Valves	0	@	0.3	=	0	metres
90 deg Elbows	0	@	0.9	=	0	metres
Tees Run	0	@	0.5	=	0	metres
Tees Branch	0	@	1.4	=	0	metres
Other	0	@		=	0	metres
	Equiv Lgth		Pressure Loss per metre			
20mm Pressure Loss	28	*	21.23	=	594.44	kPa (12.1)
Pipes, Valves and Fittings;						
Pipe Section	Supply					
Flow	76.4 L\min		Equivalent Lgth		Equiv Lgth	
20mm Pipe	19	metres	19	=	19	metres
Valves	0	@	0.3	=	0	metres
90 deg Elbows	2	@	0.9	=	1.8	metres
Tees Run	0	@	0.5	=	0	metres
Tees Branch	0	@	1.4	=	0	metres
Other	0	@		=	0	metres
25mm Pressure Loss	Total Length	@	Pressure Loss per metre			
	20.8	*	10.57	=	219.856	kPa (12.2)
Elevation Loss:-						
Highest Sprinkler above source			3 metres @ 9.81 kPa/m	=	29.43	kPa (13)
Total System Pressure Losses (10+11+12.1+12.2+13)					943.726	
Pressure Available at Sprinkler						
	Building Supply Pressure		System Pressure Losses			
	500	-	943.726	=	-443.726	
			Minimum Requirement		51.2	kPa

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

No Y\N

Hydraulic Calculations for the Flow-Through Sprinkler System

Job Name:-	Typical 3 Bedroom House (2 Sprinklers in Compartment)			
Location:-	Suburbs	Domestic Load 12 L\min		
Sprinkler Selected	Flow Rate Single l\min	Pressure Single (kPa)	Flow rate Multiple l/min	Pressure Multiple (kPa)
Viking Microfast Model M-6	37.9	70.9	32.2	51.2

Piping Materials		Copper					
Calculations for		2	Sprinklers				
System Flow Rate		Sprinkler Load	+	Domestic Load	=		L/min
		64.4	+	12	=	76.4	L/min
Sprinkler Pressure Demand		51.2	kPa				
Building Supply Pressure		500	kPa				
Pressure Losses							
Meter Loss @ flow						100	kPa (10)
Backflow Preventer Loss						0	kPa (11)
Pipes, Valves and Fittings;							
Pipe section		Ring Main					
Flow		76.4 L\min		Equivalent Lgth		Equiv Lgth	
20mm	Pipe	28	metres	28	=	28	metres
	Valves	0	@	0.3	=	0	metres
	90 deg Elbows	0	@	0.9	=	0	metres
	Tees Run	0	@	0.5	=	0	metres
	Tees Branch	0	@	1.4	=	0	metres
	Other	0	@		=	0	metres
		Equiv Lgth		Pressure Loss per metre			
	20mm Pressure Loss	28	*	2.95	=	82.6	kPa (12.1)
Pipes, Valves and Fittings;							
Pipe Section		Supply					
Flow		76.4 L\min		Equivalent Lgth		Equiv Lgth	
25mm	Pipe	19	metres	19	=	19	metres
	Valves	0	@	0.3	=	0	metres
	90 deg Elbows	2	@	0.9	=	1.8	metres
	Tees Run	0	@	0.5	=	0	metres
	Tees Branch	0	@	1.4	=	0	metres
	Other	0	@		=	0	metres
	25mm Pressure Loss	Total Length	@	Pressure Loss per metre			
		20.8	*	2.601	=	54.1008	kPa (12.2)
Elevation Loss:-							
Highest Sprinkler above source			3	metres @ 9.81 kPa/m =		29.43	kPa (13)
Total System Pressure Losses (10+11+12.1+12.2+13)						266.1308	
Pressure Available at Sprinkler							
		Building Supply Pressure		System Pressure Losses			
		500	-	266.1308	=	233.8692	
				Minimum Requirement		51.2	kPa

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

Yes	Y\N

HYDRAULIC
SERVICES
CONSULTANTS
LIMITED
Level 1
8 Melrose Street
Newmarket
PO Box 62 081
Mt Wellington
Auckland
Ph 64 9 520 7738
Fax 64 9 520 7739

Dear

***Subject*: Domestic Fire Sprinkler System
Prices for Installation**

Further to our discussion, we attach herewith drawings and specifications of the proposed layouts. Could you please calculate and submit a price for the supply and installation of all pipework and sprinklers as indicated.

The purpose of this exercise is to compare the cost difference between the pipe arrangement shown for an ordinary domestic layout and the combined domestic and fire sprinkler system.

What we are trying to establish is; how much extra is it to install a sprinkler system into an ordinary KIWI home?

By way of explanation, please note the following:-

There are four drawings @ A 3 size, one building section @ A4 size, one specification page, two pages of technical data relating to the proposed sprinkler, two Schedules of Quantities relating to each layout and one summary page.

I've given all the necessary measurements in the Schedule of Quantities, but you can scale off the A3 plans at 1:50 scale or look at the numbers in the circles on the Diagrammatic Sketch S-04 for my linear measurements.

Copper piping is used for both layouts. This is so a realistic comparison can be made at the end of the exercise.

Piping Layout 1 - The Domestic Piping Layout

Sketches S-01 and S-02 show the proposed run of domestic copper piping, excluding the sprinkler system. A DN 20 meter is all that is required to service the domestic load, so please allow the standard METROWATER charge of $580.00 for the installation of this meter. DN 20 copper is run in a trench to rise in the Hot Water cupboard, then reticulate through the ceiling space to drop in various walls to the domestic fixtures. You will note the largest size pipe is DN 20, with DN 15 droppers and run-outs to each individual fixture or hose tap.

Please prepare a price for the labour and material necessary to complete this Domestic piping arrangement.

Piping Layout 2 - The Multipurpose Piping Layout

Sketches S-03 and S-04 show the proposed run of multipurpose copper piping, including the sprinkler system. A DN 25 meter is required to service the combined fire and domestic load, so please allow the standard METROWATER charge of $710.00 for the installation of this meter. Please also note that due to the sprinkler load, the main pipe run is increased to DN 25. Generally, DN 25 copper is run in a trench to rise in the Hot Water cupboard, then reticulate through the ceiling space to carry to each sprinkler and drop in various walls to the domestic fixtures. You will note the largest size pipe is DN 25, with DN 20 required to each sprinkler and DN 15 droppers and run-outs to each individual fixture or hose tap.

The value of the sprinklers are fixed at $ 16.25 each and the escutcheon are fixed $2.33 each.

Please prepare a price for the labour and material necessary to complete this Multipurpose piping arrangement.

Could you please return your prices on your official company letter head with as much breakdown as you feel you can supply. It would be good if you could at least show a bottom line labour and material content for each type of system.

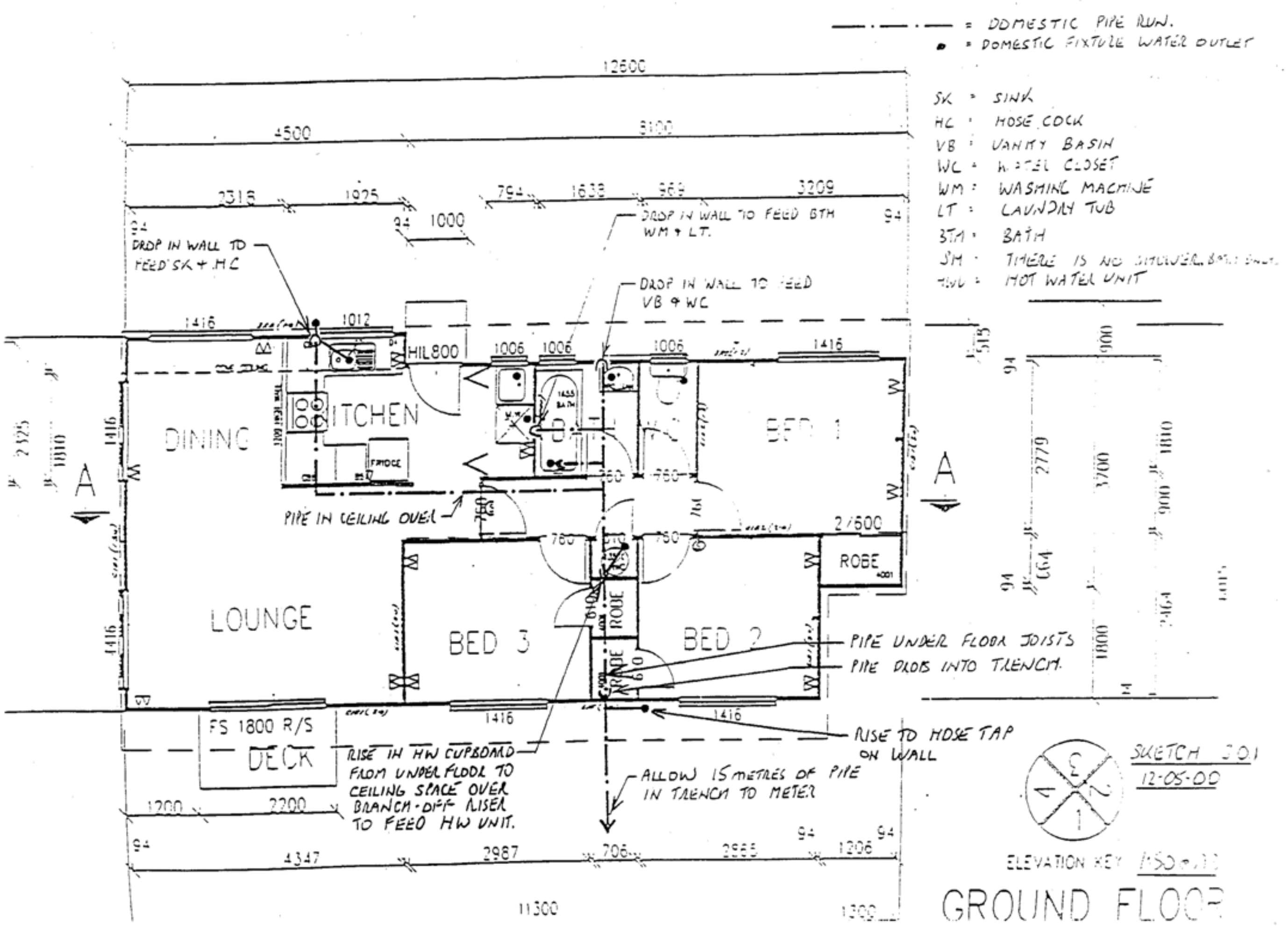
Please don't allow for liaison with the Fire Service of New Zealand or the Insurance Council of New Zealand, I'll allow an appropriate amount of money when I summarise the exercise.

Fitting the sprinkler is a simple exercise of screwing the sprinkler into a DN 15 BSP (it's actually NPT, but BSP works at DN 15) socket welded onto the end of a piece of DN 20 copper pipe. It's no more complicated than fixing a wing back.

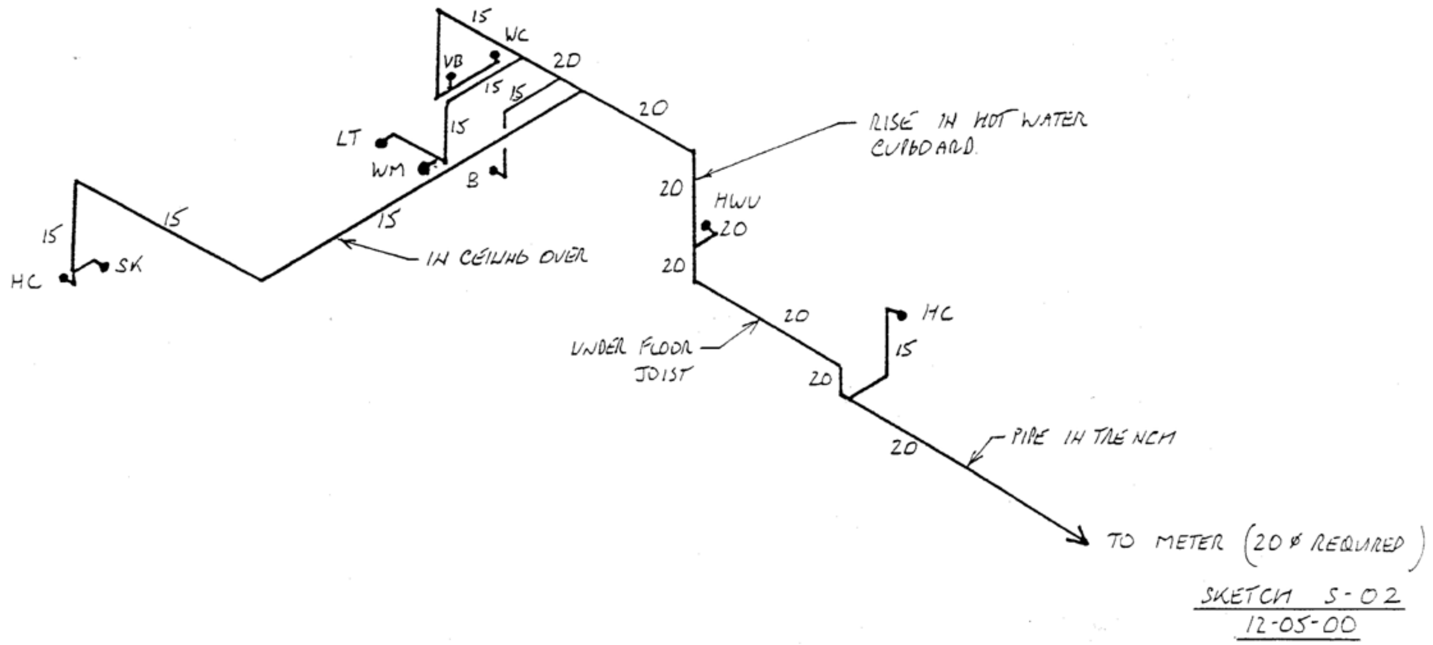
Thank you for assisting in this exercise, I appreciate it. Please come back to me if you need any assistance.

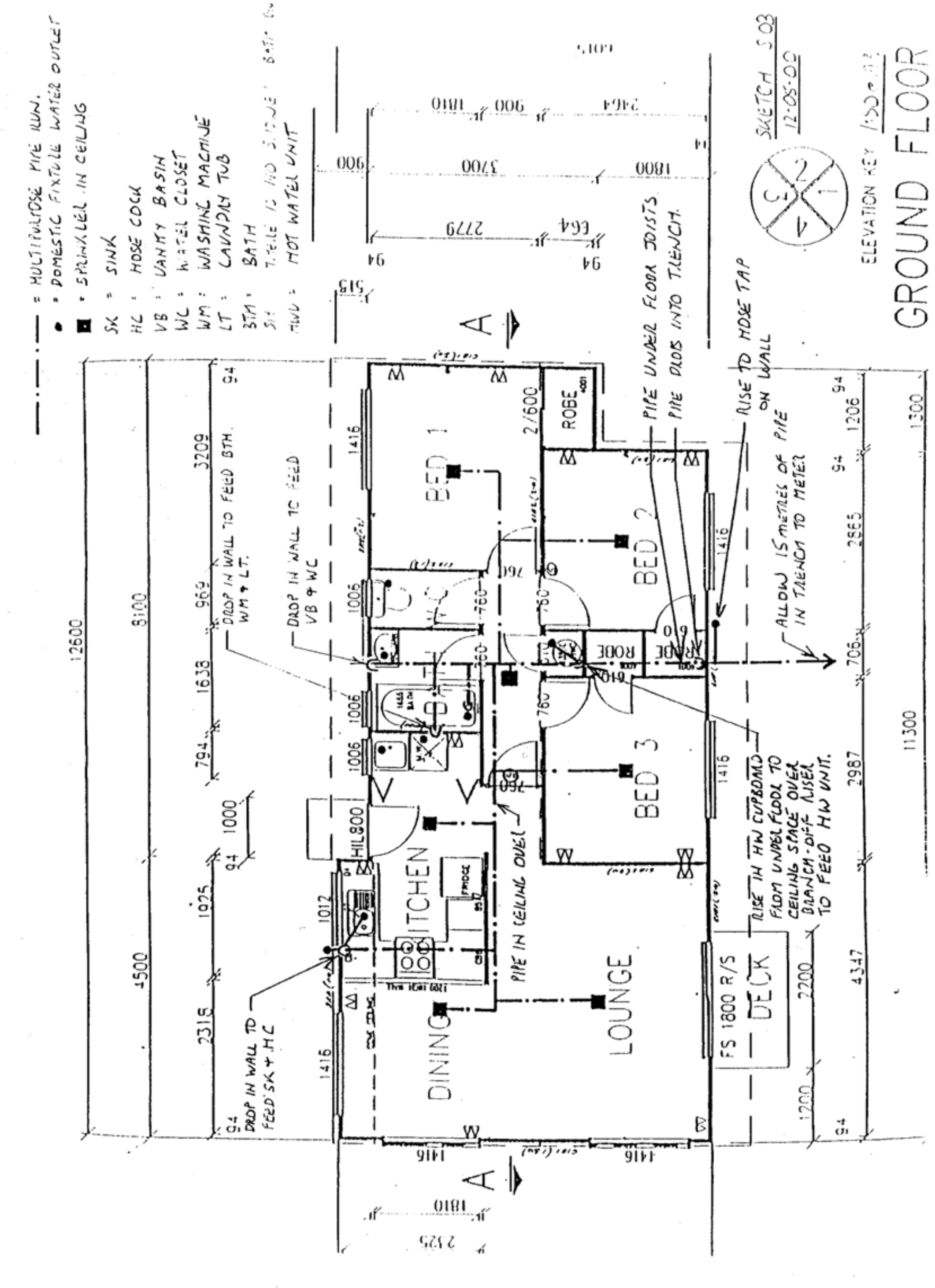
Yours Faithfully

Peter Downey
Hydraulic Services Consultants Limited


= DOMESTIC PIPE RUN.
● = DOMESTIC FIXTURE WATER OUTLET
SK = SINK
HC = HOSE COCK
VB = VANITY BASIN
WC = WATER CLOSET
WM = WASHING MACHINE
LT = LAUNDRY TUB
BTH = BATH
SH = THERE IS NO SHOWER, BATH ONLY.
HWU = HOT WATER UNIT
12600
4500
8100
2316
1925
794
1638
969
3209
94
1000
DROP IN WALL TO FEED SK + HC
DROP IN WALL TO FEED BTH WM + LT.
DROP IN WALL TO FEED VB + WC
1416
1012
HIL800
1006
DINING
ITCHEN
FRIDGE
BED 1
A
PIPE IN CEILING OVER
760
2/600
ROBE
LOUNGE
BED 3
BED 2
PIPE UNDER FLOOR JOISTS
PIPE DROPS INTO TRENCH.
FS 1800 R/S
DECK
RISE IN HW CUPBOARD FROM UNDER FLOOR TO CEILING SPACE OVER BRANCH-OFF RISER TO FEED HW UNIT.
RISE TO HOSE TAP ON WALL
ALLOW 15 METRES OF PIPE IN TRENCH TO METER
1200
2200
4347
2987
706
2955
1206
11300
1300
2325
1810
2779
3700
900
664
1800
2464
SKETCH 301
12-05-00
ELEVATION KEY
GROUND FLOOR

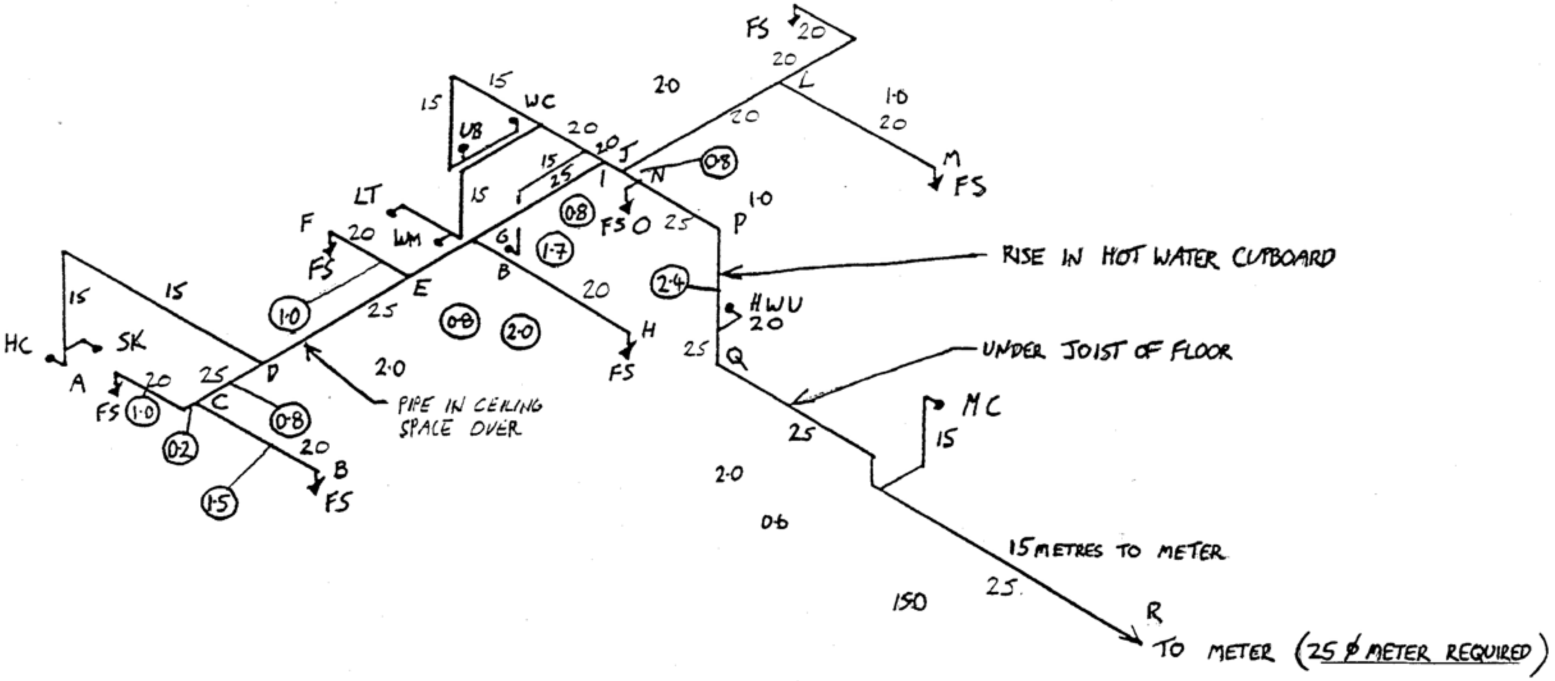
DOMESTIC WATER PIPE LAYOUT





= 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
ROBE
KITCHEN
DINING
LOUNGE
DECK
FS 1800 R/S
FRIDGE
DROP IN WALL TO FEED BTH. WM + LT.
DROP IN WALL TO FEED VB + WC
DROP IN WALL TO FEED SK + H.C
PIPE IN CEILING OVER
PIPE UNDER FLOOR JOISTS
PIPE DROPS INTO TRENCH.
RISE TO HOSE TAP ON WALL
ALLOW 15 METRES OF PIPE IN TRENCH TO METER
RISE IN HW CUPBOARD FROM UNDER FLOOR TO CEILING SPACE OVER BRANCH-OFF RISER TO FEED HW UNIT.
12600
8100
4500
3209
969
1638
794
1000
1925
2316
11300
4347
2987
2965
1206
1300
1200
2200
706
1416
1006
1012
760
610
2779
3700
1800
664
2464
900
1810
2525
515
94
A
ELEVATION KEY
SKETCH 3 03
12-05-02
GROUND FLOOR

MULTI PURPOSE SPRINKLER + DOMESTIC PIPING LAYOUT



SKETCH S-04
12-05-00

Trade Specification for Installation of Domestic Sprinklers.

Name of Project:	Typical three bedroom home.
Location:	Suburban New Zealand.
Type of System:	Based on NFPA 13 D.
Pipe Material:	Copper.
Pipe Joints:	Silver brazed.
Pipe Fittings:	Fabricated, pulled or manufactured tees and elbows.
Pipe Protection:	Not required.
Sprinklers:	Viking Microfast Model M-4 (you are to allow $16.25 each).
Sprinkler Spacing:	4.9 metres x 4.9 metres.
Sprinklers Omitted:	Bathroom, WC compartment, Robes, HW cupboard, Laundry Cubicle, Ceiling Space.
Escutcheons:	Semi-recessed, (you are to allow $2.33 each sprinkler).
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.
Sprinkler to Pipe Joiner:	15 BSP threaded connector (for sprinkler) x 20 CU brazing socket.
Liaison with NZ Fire Service:	Do not allow for any liaison or discussion with the NZ Fire Service.
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 as specified under Clause G 12 of the NZBC.

End of Specification

VIKING® **TECHNICAL DATA**

Microfast® MODEL M-4
SMALL ORIFICE RESIDENTIAL PENDENT SPRINKLER

1. PRODUCT NAME

Viking Microfast® Model M-4 Small Orifice Residential Pendent Sprinkler

- Base Part Number 09530

2. MANUFACTURER

The Viking Corporation
210 N. Industrial Park Road
Hastings, Michigan 49058, USA
Telephone: (616) 945-9501
(877) 384-5464
Fax: (616) 945-9599
e-mail: techsvcs@vikingcorp.com

3. PRODUCT DESCRIPTION

The Viking Microfast® Model M-4 Small Orifice Residential Pendent Sprinkler is a small, high-sensitivity, glass-bulb spray sprinkler. The sprinkler is available in several finishes, with temperature ratings to meet design requirements. **The sprinkler is listed for use below smooth, flat, horizontal ceilings and ceilings with slopes up to and including a 6/12 (26.6°) pitch.**

The small orifice design, with a K-factor of 4.3, allows efficient use of available water supplies for the hydraulically designed fire-protection system. The small, rugged, 3 mm glass-bulb and special deflector combine speed of operation and areas of coverage to meet residential sprinkler standards. During fire conditions, the heat-sensitive liquid in the glass bulb expands, causing the glass to shatter, releasing the pip-cap and sealing spring assembly. The water flowing through the sprinkler orifice strikes the sprinkler deflector, forming a uniform spray pattern to extinguish or control the fire.

4. TECHNICAL DATA

LISTINGS AND APPROVALS

Refer to Table 1 on page 140 d.

See chart for minimum water supply requirements and maximum areas of coverage.

Glass-bulb fluid temperature rated to -65 °F (-55 °C).

Rated to 175 psi (1 207 kPa) water working pressure.

Factory tested hydrostatically to 500 psi (3 448 kPa)

Spring: USA Patent No. 4,167,974
Bulb: USA Patent No. 4,796,710
Testing: USA Patent No. 4,831,870
Thread Size: ½" (15 mm) NPT
K-factor: 4.3 (6,2 Metric*)

* 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.

SPRINKLER MATERIALS

Frame: Brass Castings UNS-C84400
Deflector: Brass UNS-C26000
Bulb: Glass, nominal 3 mm diameter
Seal: Teflon® Tape
Spring: Nickel Alloy
Screw: Brass UNS-C36000
Pip Cap: Copper UNS-C11000 and Stainless Steel UNS-S30400

ACCESSORIES

Refer to the "SPRINKLER ACCESSORIES" section of the *Viking Engineering and Design Data* book for approved sprinkler wrench and other accessories.

5. AVAILABILITY AND SERVICE

Viking sprinklers are available through a network of domestic, Canadian, and international distributors. See the Yellow Pages of the telephone directory for a local distributor (listed under "Sprinklers-Automatic-Fire") or contact Viking.

> **Viking Technical Data may be found on The Viking Corporation's Web site at http://www.vikingcorp.com. The Web site may include a more recent edition of this technical data page.**

6. GUARANTEES

For details of warranty, refer to Viking's current list price schedule or contact The Viking Corporation directly.

7. INSTALLATION

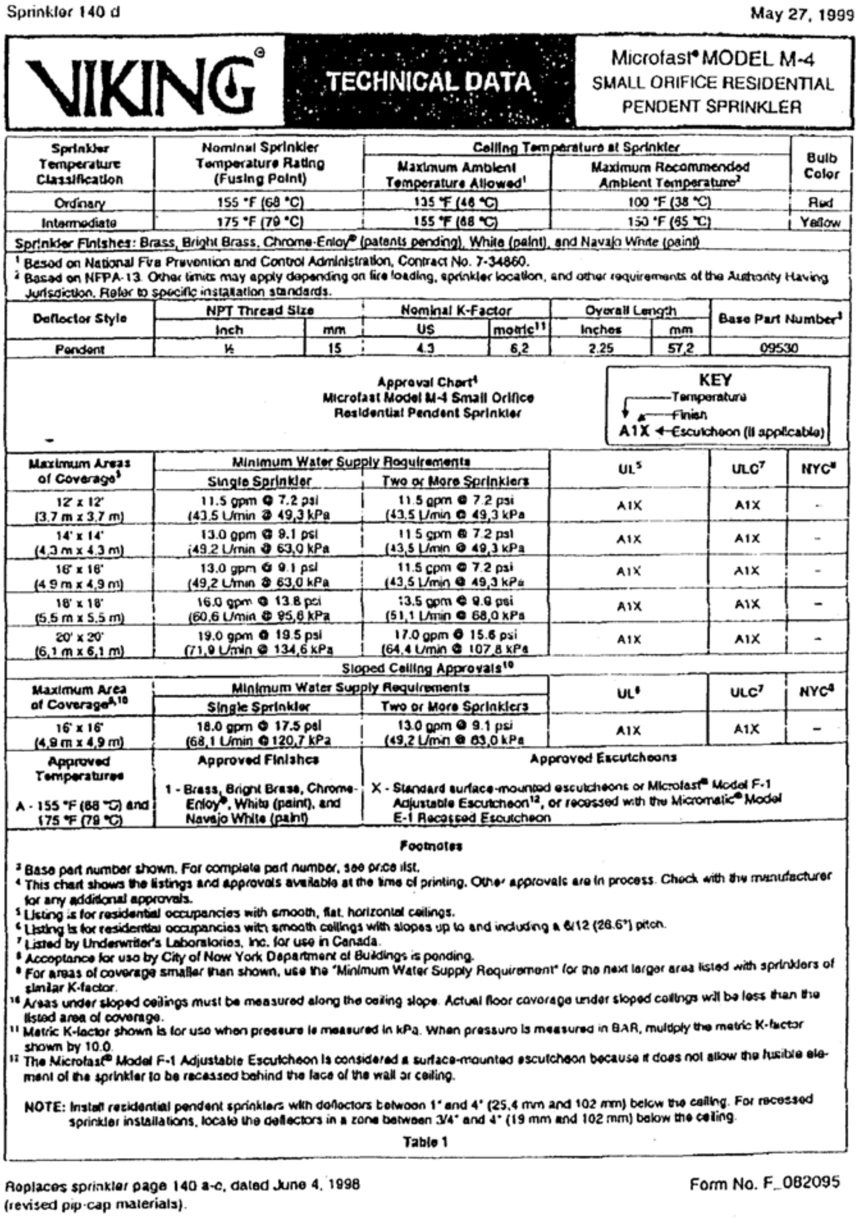
WARNING: Viking sprinklers are manufactured and tested to meet the rigid requirements of approving agencies. The sprinklers are designed to be installed in accordance with recognized installation standards. Deviation from the standards or any alteration to the sprinkler after it leaves the factory including, but not limited to: painting, plating, coating, or modification, may render the sprinkler inoperative and will automatically nullify the approval and any guarantee made by The Viking Corporation.

A. Sprinklers are to be installed in accordance with the latest published standards of the National Fire Protection Association, Factory Mutual, Loss Prevention Council, Assemblee Pleniere, Verband der Sachversicherer or other similar organizations, and also with provisions of governmental codes, ordinances, and standards whenever applicable. For conditions not specifically covered by the Standards, refer to the "Viking Residential Installation Guide".
Final approval and acceptance of all residential sprinkler installations must be obtained from the Authority Having Jurisdiction. Residential sprinklers are special-service sprinklers for use in one- and two-family dwellings, mobile homes, and residential portions of other occupancies where allowed. The use of residential sprinklers may be limited due to occupancy and hazard. The minimum flow rate indicated for a listed area of coverage must be provided at the sprinkler. Therefore, the system must be hydraulically calculated. Refer to the Authority Having Jurisdiction prior to installation.

B. Sprinklers must be handled with care. They must be stored in a cool, dry place in their original container. Never install sprinklers that have been dropped or damaged in any way. Never install any glass-bulb sprinkler if the bulb is cracked or if there is a loss of liquid from the bulb. If a glass bulb lacks the appropriate amount of fluid, it should be set aside and returned to Viking (or an authorized Viking distributor) for analysis as soon as possible. If the sprinkler is not returned to Viking, it should be destroyed immediately. Never install sprinklers that have been exposed to temperatures in excess of the maximum ambient temperature allowed. Such sprinklers should be destroyed immediately.

C. Corrosion-resistant sprinklers must be installed when subject to corrosive atmospheres. Viking Microfast® Model M-4 Residential Pendent

Replaces sprinkler page 140 a-c, dated June 4, 1998 (revised pip-cap materials).



Sprinkler 140 d

May 27, 1999

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		Bulb Color
		Maximum Ambient Temperature Allowed[1]	Maximum Recommended Ambient Temperature[2]	
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
Temperature
Finish
A1X ← Escutcheon (if applicable)

Maximum Areas of Coverage[9]	Minimum Water Supply Requirements		UL[5]	ULC[7]	NYC[8]
	Single Sprinkler	Two or More Sprinklers			
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		UL[6]	ULC[7]	NYC[8]
	Single Sprinkler	Two or More Sprinklers			
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.

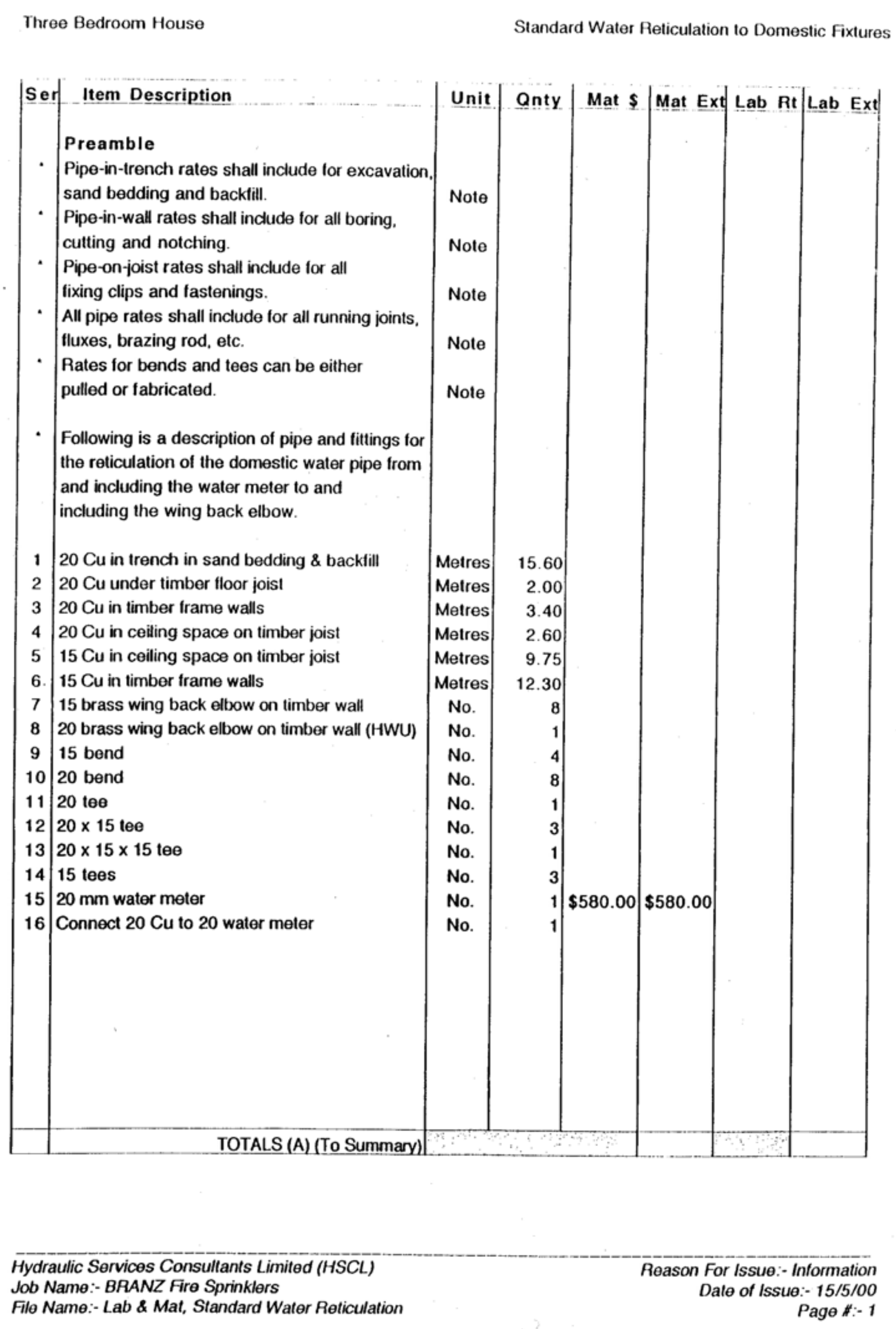
[12] The Microfast® Model F-1 Adjustable Escutcheon is considered a surface-mounted escutcheon because it does not allow the fusible element of the sprinkler to be recessed behind the face of the wall or ceiling.

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



Three Bedroom House

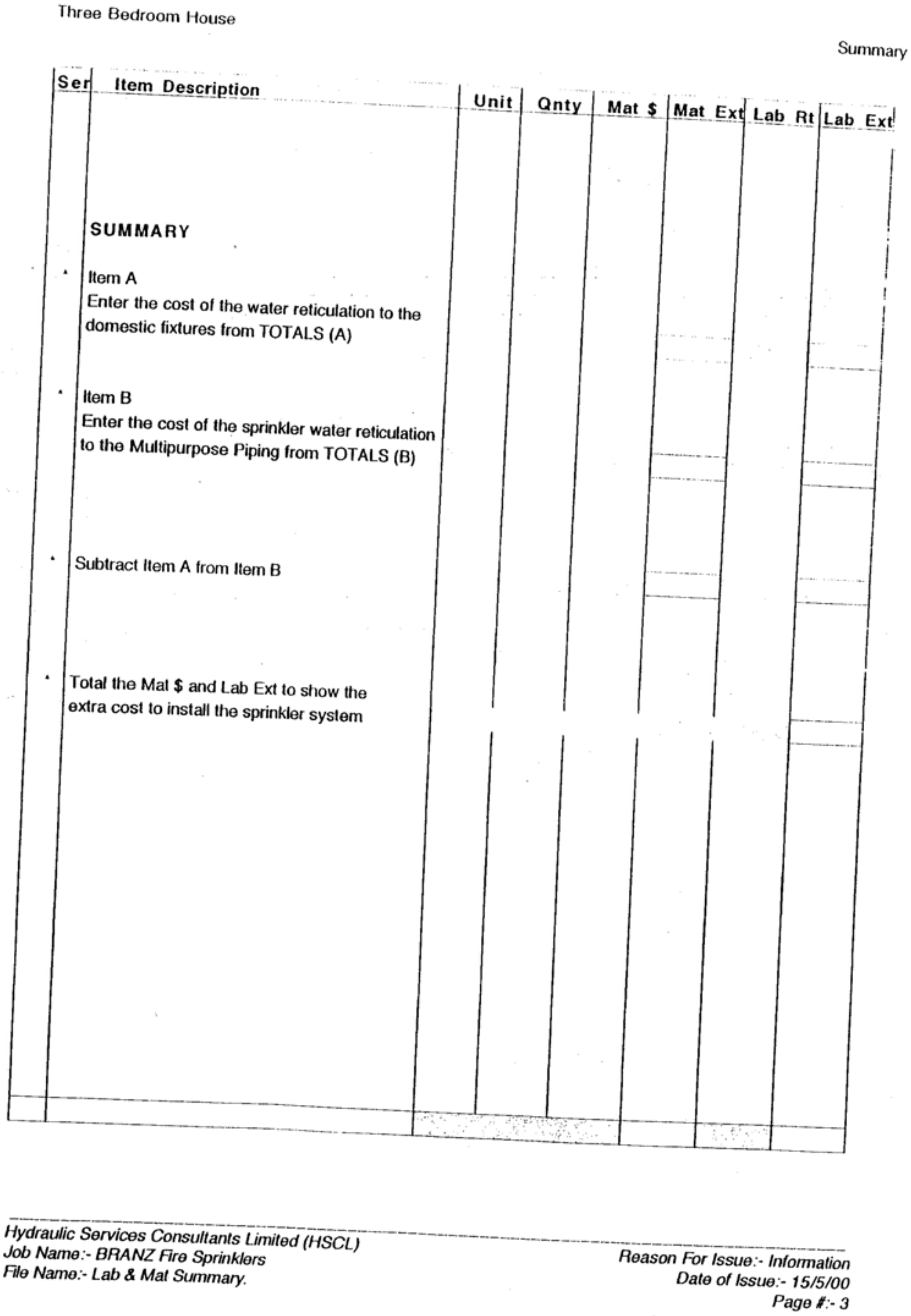
Standard Water Reticulation to Domestic Fixtures

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 domestic water pipe from and including the water meter to and including the wing back elbow.						
1	20 Cu in trench in sand bedding & backfill	Metres	15.60				
2	20 Cu under timber floor joist	Metres	2.00				
3	20 Cu in timber frame walls	Metres	3.40				
4	20 Cu in ceiling space on timber joist	Metres	2.60				
5	15 Cu in ceiling space on timber joist	Metres	9.75				
6	15 Cu in timber frame walls	Metres	12.30				
7	15 brass wing back elbow on timber wall	No.	8				
8	20 brass wing back elbow on timber wall (HWU)	No.	1				
9	15 bend	No.	4				
10	20 bend	No.	8				
11	20 tee	No.	1				
12	20 x 15 tee	No.	3				
13	20 x 15 x 15 tee	No.	1				
14	15 tees	No.	3				
15	20 mm water meter	No.	1	$580.00	$580.00		
16	Connect 20 Cu to 20 water meter	No.	1				
	TOTALS (A) (To Summary)						

Hydraulic Services Consultants Limited (HSCL)
Job Name:- BRANZ Fire Sprinklers
File Name:- Lab & Mat, Standard Water Reticulation

Reason For Issue:- Information
Date of Issue:- 15/5/00
Page #:- 1

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	$710.00	$710.00		
23	Connect 25 Cu to 25 water meter	No.	1				
24	Viking M-4 Sprinkler	No.	7	$16.25	$113.75		
25	Connect 15 sprinkler to 20 Cu pipe	No.	7				
26	Chrome plated escutcheon to sprinkler	No.	7	$2.33	$16.31		
	TOTALS (B) (To Summary)						



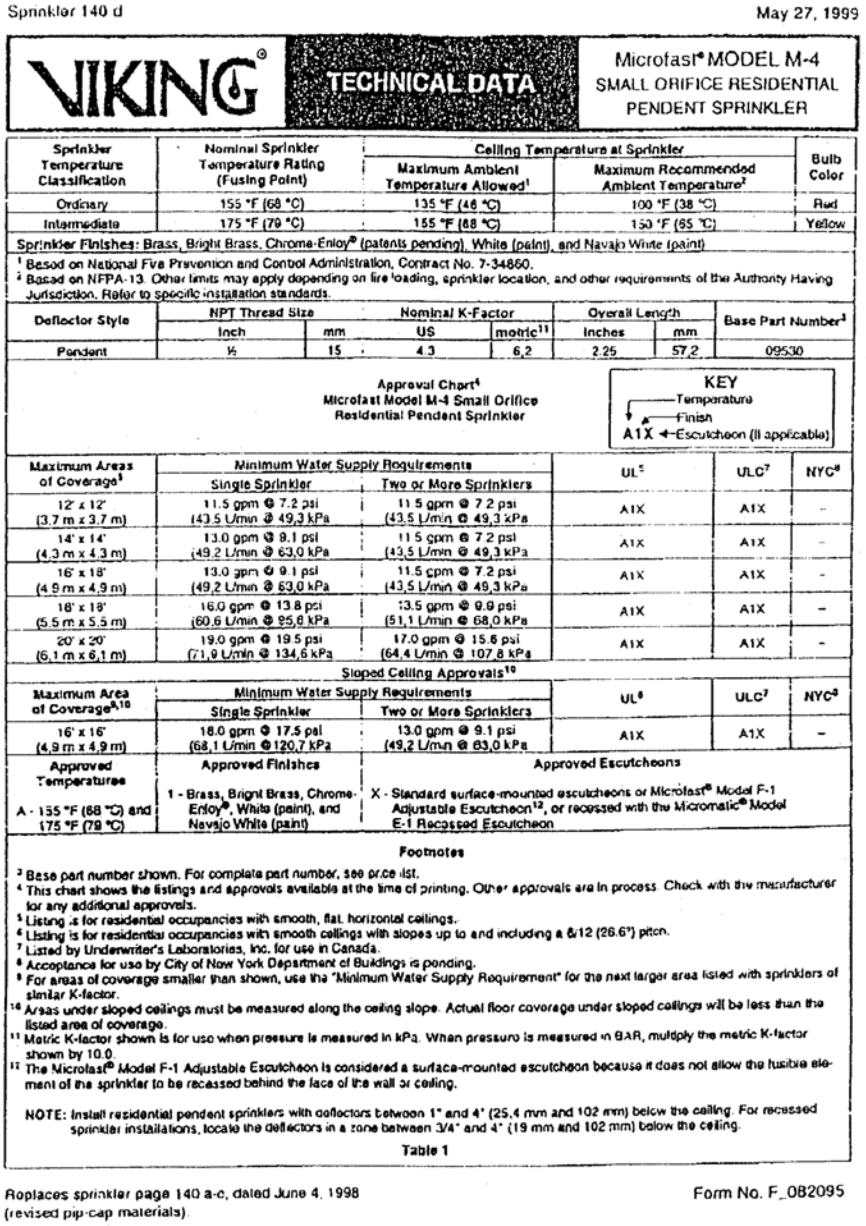
Three Bedroom House

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						

Hydraulic Services Consultants Limited (HSCL)
Job Name:- BRANZ Fire Sprinklers
File Name:- Lab & Mat Summary.

Reason For Issue:- Information
Date of Issue:- 15/5/00
Page #:- 3



Sprinkler 140 d May 27, 1999

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		Bulb Color
		Maximum Ambient Temperature Allowed[1]	Maximum Recommended Ambient Temperature[2]	
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		UL[5]	ULC[7]	NYC[8]
	Single Sprinkler	Two or More Sprinklers			
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		UL[6]	ULC[7]	NYC[8]
	Single Sprinkler	Two or More Sprinklers			
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

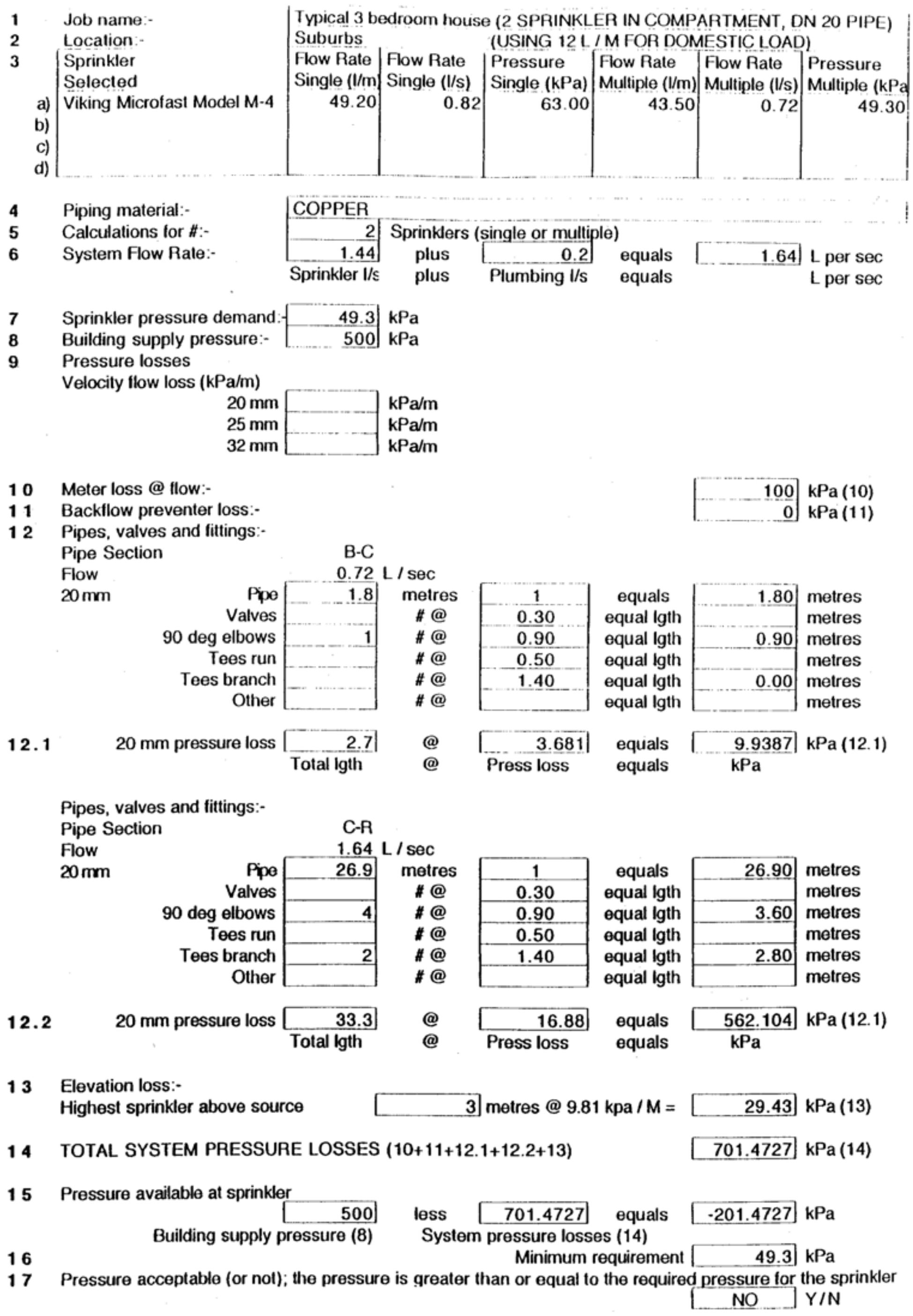
[3] Base part number shown. For complete part number, see price list.
[4] This chart shows the listings and approvals available at the time of printing. Other approvals are in process. Check with the manufacturer for any additional approvals.
[5] Listing is for residential occupancies with smooth, flat, 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



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

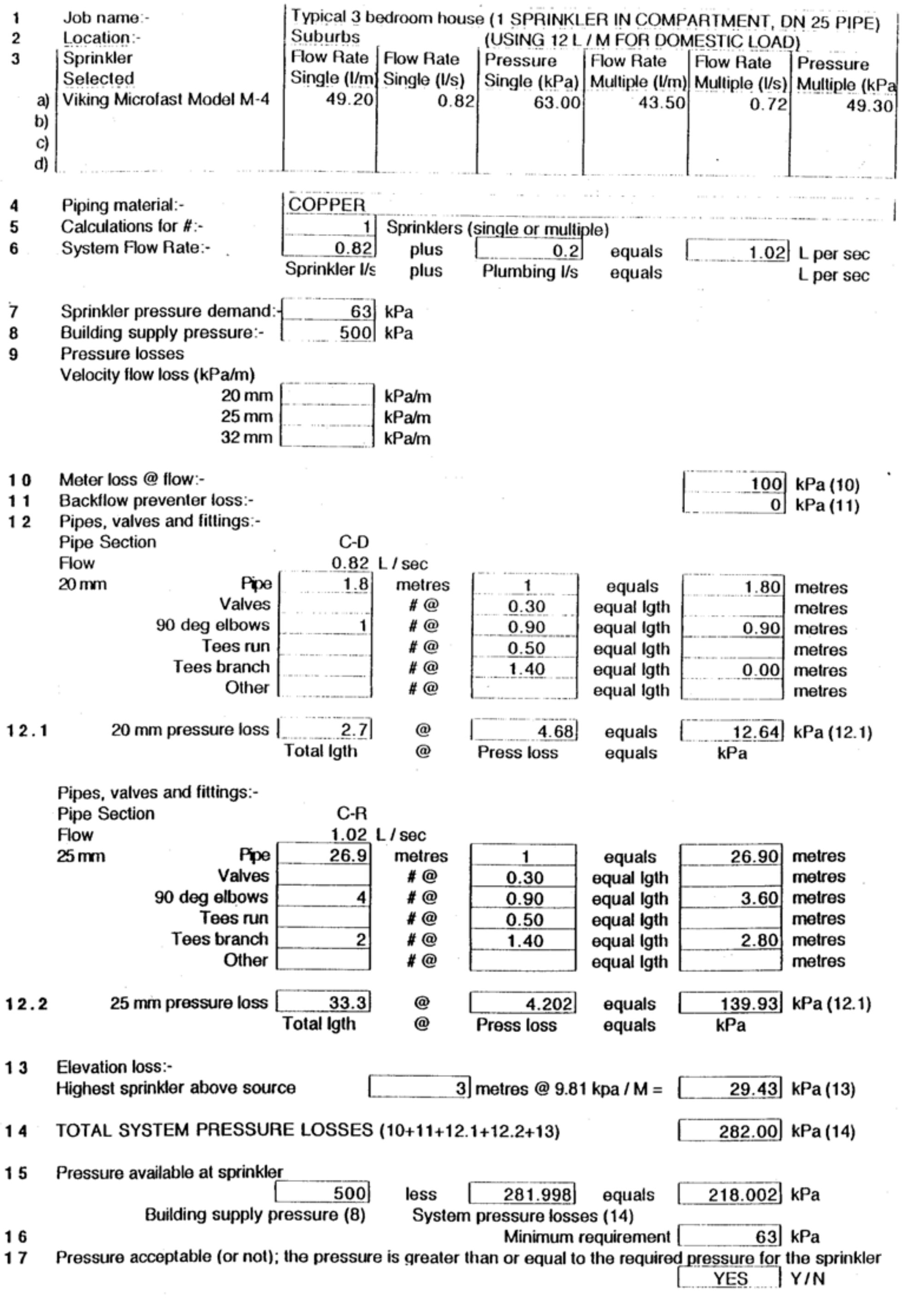
500 less 701.4727 equals -201.4727 kPa

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



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)

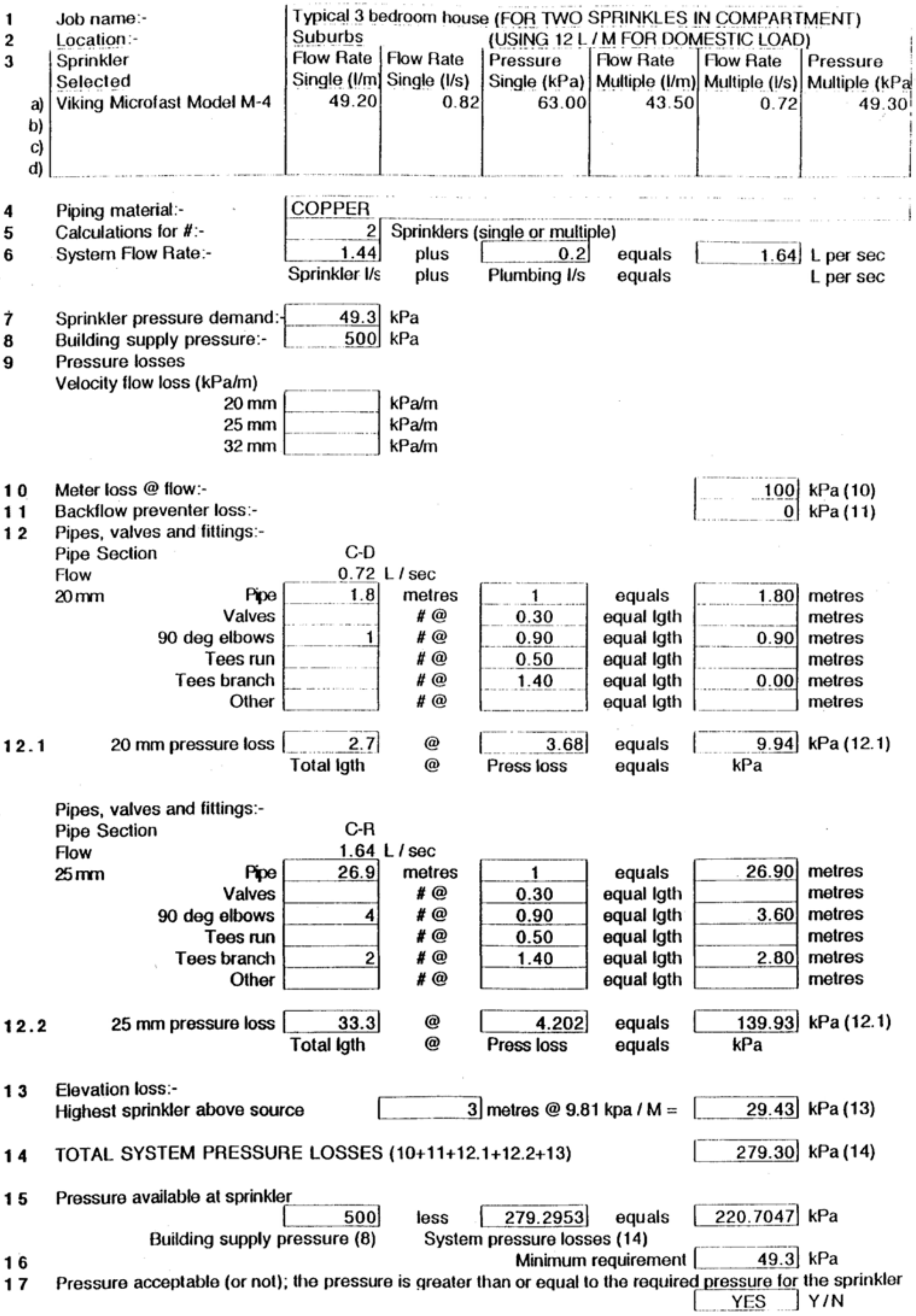
14 TOTAL SYSTEM PRESSURE LOSSES (10+11+12.1+12.2+13) 282.00 kPa (14)

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 (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