Fire Research Report

Revision of the Cost Effectiveness Analysis of Home Sprinkler Systems including Sustainability

BRANZ

August 2008

This report summarises the results of a research project investigating the cost effectiveness of home sprinkler systems incorporating sustainability aspects. A life cycle assessment approach was used to evaluate sustainability issues focusing on environmental impacts. The previous model for the cost effectiveness analysis for home sprinklers was revised to account for input parameter uncertainty by including input distributions instead of single value inputs and by conducting simulations that sampled the input distributions. Overall, incorporation of sustainability issues into the cost effectiveness analysis for home sprinkler systems provided a broader insight into the overall costs and benefits, including aspects that currently have no monetary equivalent.

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REPORT

No. FQ0682/1

Revision of the Cost Effectiveness Analysis of Home Sprinkler Systems including Sustainability

A.P. Robbins, C.A. Wade, M.J. Bengtsson, N.P. Howard and E. Soja

The work reported here was funded by the New Zealand Fire Service Commission.

Preface

This report describes a project that reviewed and updated a cost-benefit methodology and data from a previous BRANZ study for the installation of a home sprinkler system. The incorporation of the impact of sustainability aspects into a cost effectiveness model has been investigated.

Acknowledgments

This work was funded by the New Zealand Fire Service Commission from the Contestable Research Fund.

Note

This report is intended for regulators, researchers, engineers and others interested in the economic implications of fire safety strategies using home sprinkler systems.

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Abstract

This report summarises the results of a research project investigating the cost effectiveness of home sprinkler systems incorporating sustainability aspects.

Approaches to combine the impact of sustainability aspects in a quantitative cost benefit assessment were investigated. A Life Cycle Assessment approach, in accordance with ISO 14040, was selected as being the most appropriate to incorporate a wide range of environmental impacts as a single measure. The results were demonstrated by evaluating sustainability issues, focusing on environmental impacts, related to home fire sprinklers and successfully developing a sustainability impacts module for the cost effectiveness model.

The previous model for the cost effectiveness analysis for home sprinklers was revised to account for input parameter uncertainty by including input distributions instead of single value inputs and by conducting simulations that sampled the input distributions. In addition, input data for the analyses was reviewed and updated where recent or more appropriate data could be located.

Distributions for the monetary cost per life saved and the sustainability benefits per life saved were produced for categories of residential building stock occupiers, where home sprinklers would be appropriate.

Overall, incorporation of sustainability issues into the cost effectiveness analysis for home sprinkler systems provided a broader insight into the overall costs and benefits, including aspects that currently have no monetary equivalent. The development of the cost effectiveness model using distributed values for input parameters also provided a better understanding of the results of the model and the impact of inputs compared to previous models that used single input parameter values. In addition, considering sectors of the buiding stock for potential targeting of home sprinkler systems provided a more thorough understanding of the potential costs and benefits of the application of home sprinkler systems. This approach would be useful in identifying appropriate sectors within the total residential building stock to provide the maximum monetary and sustainability related benefits. Futhermore any category or sector for which fire statistics are available can be investigated.

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Abbreviations

2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin
ABI	Association of British Insurers
AGO	Australian Greenhouse Office
avg.	average
BEES	BRANZ Building Energy End-use Study
BRE	Building Research Establishment
CFPA	Confederation of Fire Protection Associations (Europe)
CO_2	carbon dioxide
Co-PCBs	non-ortho coplanar PCBs
dmg.	Damage
EU	European Union
GWP	global warming potential
instal.	installation
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MAF	Ministry of Agriculture and Forestry
mat.	Materials
MfE	Ministry for Education
NPI	National Pollutant Inventory
NZ	New Zealand
NZFS	New Zealand Fire Service
ODP	Ozone Depletion Potential
ODPM	Office of the Deputy Prime Minister
OECD	Organisation for Economic Co-operation and Develeopment
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PCCD/F	
PCDD/F	
PCDDs	polychlorinated dibenzo-p-dioxins
PCDFs	polychlorinated dibenzofurans
PVC	polyvinyl chloride
QVNZ	Quotable Value New Zealand
sprnk.	sprinklered
TEQ	toxic equivalence quantity
UK	United Kingdom
UNEP	United Nations Environment Program
unsprnk.	Unsprinklered
US$	United States of America dollar
USA	United States of America
VOCs	volatile organic compounds
VoSL	Value of a Statistical Life
WRI	World Resources Institute

1. EXECUTIVE SUMMARY

This report summarises the results of a research project, for which the objective was to revise a previous cost effectiveness analysis for home sprinkler systems by:

- investigating how the impact of sustainability could be included in a quantitative cost-benefit analysis for home sprinklers,
- demonstrating the quantitative incorporation of sustainability aspects by developing a new module for home sprinklers for inclusion in the cost-benefit model,
- accounting for input parameter uncertainty by including input distributions instead of single value inputs whenever possible and by conducting simulations that sampled from the input distributions, and
- revising input data for the analyses by including the current estimated value of a statistical human life based on recent research and also reviewing and updating other input data, where more up to date or appropriate data can be located.

A Life Cycle Assessment approach, in accordance with ISO 14040, was selected as the most useful way to provide a single measure of a wide range of environmental impacts for comparison with a cost effectiveness analysis. As a demonstration of this approach, sustainability issues associated with residential structure fires were successfully incorporated into the cost effectiveness analysis for home sprinkler systems.

The approach to incorporating environmental issues into this model considers the cradle to gate impact for sprinkler systems and loss and replacement of flame damaged average building stock. That is, the environmental related effects of fire and the loss and replacement of home contents was not included in the assessment. It is expected that the inclusion of these additional aspects would produce an even more positive contribution to the measure of environmental benefits. Therefore the results from this study are conservative.

A single metric for the measure of the environmental related ‘costs’ and ‘benefits’ was used: NZ Ecopoints. The use of NZ Ecopoints as a metric provided a measure of the sustainability issues, incorporating a wide range of environmental impacts. 100 NZ Ecopoints represents the average yearly environmental impact of a New Zealander. In addition, the incorporation of NZ Ecopoints-base module for use in parallel to the cost effectiveness analysis of home sprinkler systems was designed to allow direct comparison with net present values for monetary estimates, when they become available. Furthermore this study represents the first use in New Zealand of Ecopoints for the quantitative metric for environmental impact, which is currently commonplace in the UK and elsewhere.

The environmental related results for all scenarios considered indicated gross environmental benefits (i.e., a saving of NZ Ecopoints) for each life saved with the inclusion of home sprinklers in New Zealand residential properties. That is, for the monetary cost associated with each life saved, environmental issues considered here were reduced compared to the scenario of smoke alarms only present.

The results for environmental benefits per life saved were presented as distributions to account for input parameter uncertainty (e.g. for the base case, considering sprinklers and smoke alarms present, Figure 1 and summarised in Table 57).

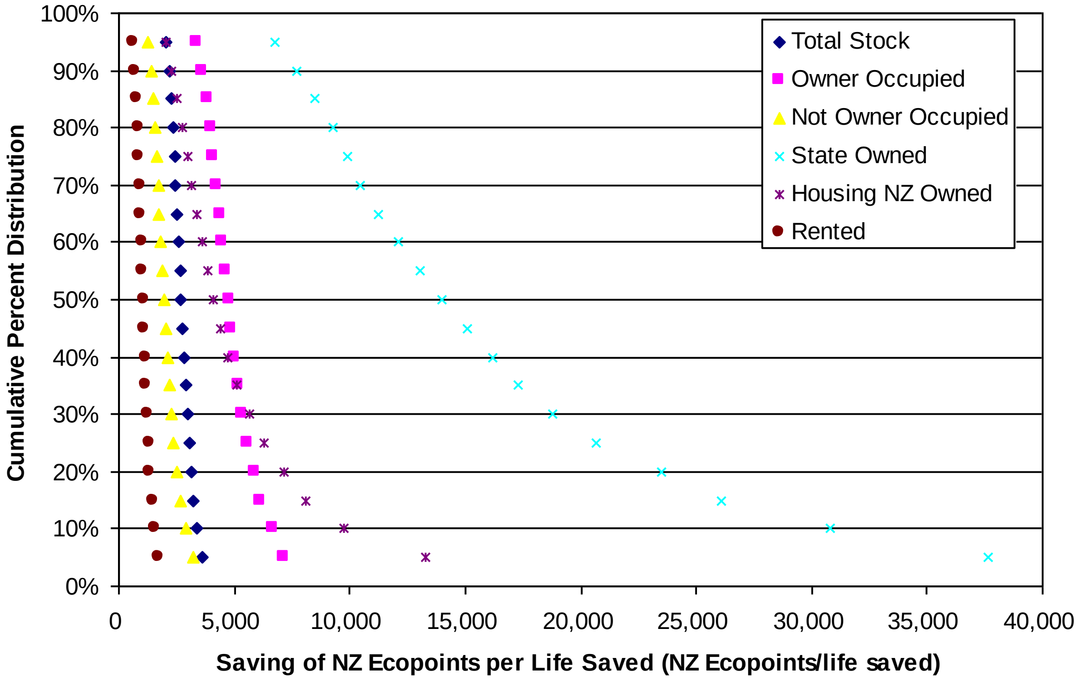


Figure 1: Cumulative percent distribution for the NZ Ecopoint savings per life saved for the total residential building stock when considering sprinklers and smoke alarms present.

The model results for the base case, considering sprinklers and smoke detectors present, indicate a range of mean environmental benefits per life saved of approximately 11 to 170 equivalent years of average environmental impact of a New Zealander (i.e., 1,100 to 17,000 NZ Ecopoints, Table 68 and Figure 76) depending on the category of residential building stock occupier considered. Specifically, ranking the mean model results from the base case for when both sprinklers and smoke alarms are present in terms of the greatest environmental impact avoided per life saved associated with home sprinkler systems for the categories of residential occupier considered produces:

1. State owned (and council) building stock (170 eqv. years of environmental impact/life saved),
2. Housing NZ owned building stock (56 eqv. years of environmental impact/life saved),
3. Owner occupied residential building stock (50 eqv. years of environmental impact/life saved),
4. Not owner occupied residential building stock (21 eqv. years of environmental impact/life saved),
5. Rented residential building stock (11 eqv. years of environmental impact/life saved),

The results for monetary costs per life saved were presented as distributions to account for input parameter uncertainty (e.g. for the base case (Figure 2), considering sprinklers and smoke alarms present, as shown in Figure 54 – Figure 57, Figure 58, respectively and summarised in Table 56).

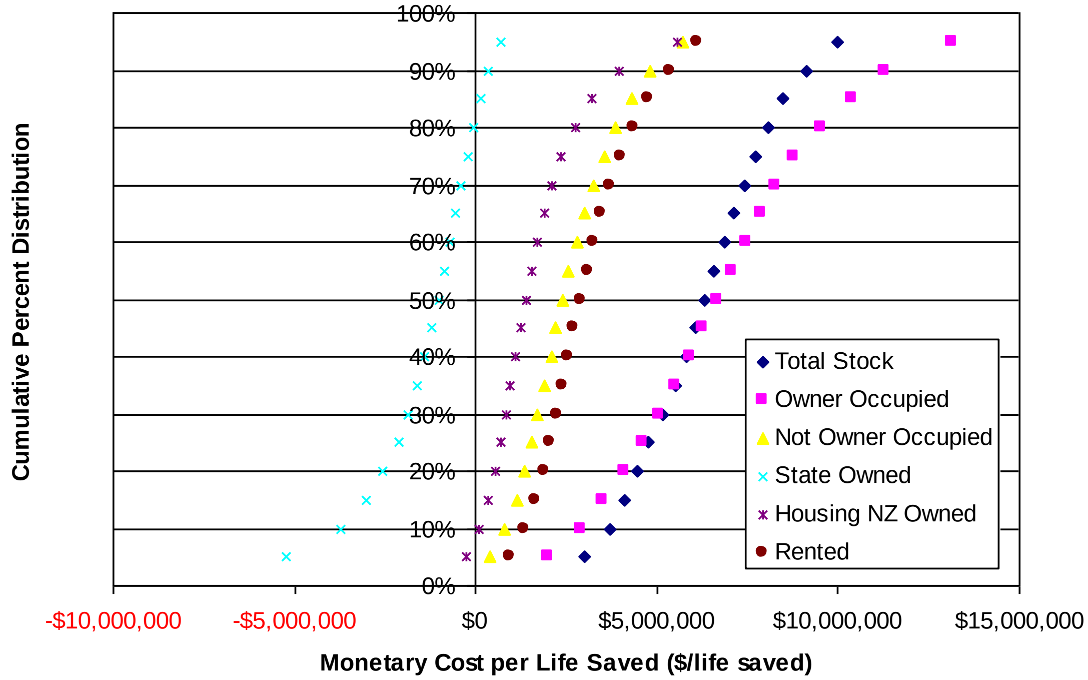


Figure 2: Cumulative percent distribution for the monetary cost per life saved for the total residential building stock when considering sprinklers and smoke alarms present for the base case.

The model results for the base case, considering sprinklers and smoke detectors present, indicate a range of mean monetary benefits per life saved of approximately -$1.5 to $ 7.0 million (Table 68 and Figure 76) depending on the category of residential building stock occupier considered. Specifically, ranking the mean model results from the base case for when both sprinklers and smoke alarms are present in terms of the greatest monetary benefit per life saved associated with home sprinkler systems for the categories of residential occupiers considered produces:

Occupier group	Mean Cost per life saved	Lives saved (50 years)
State owned	- $1.5 million /life saved	13
Housing NZ owned	$1.9 million /life saved	33
Not owner occupied	$2.7 million /life saved	560
Rented	$3.1 million /life saved	800
Owner occupied	$7.0 million /life saved	200

Considering categories of the residential building stock occupier as well as the total residential building stock for home sprinkler systems provided a wide range of monetary costs per life saved. This also indicated that a target application may also produce more concentrated benefits. However, the relative proportions of the building stock and numbers of fire incidents applicable to each occupier group need to be considered to determine the national impact (e.g. total number of lives saved).

The important assumptions for the base case scenario included:

- rate of retrofit of home sprinkler systems in existing housing stock of an average of 10%p.a., with a minimum of 7%p.a. and a maximum of 15%p.a.,

- proportion of new households with home sprinkler systems of 100%,
- increase of new households follows the average trends based on the last 3 New Zealand censuses,
- discount rate of an average of 8%p.a., with a minimum 7%p.a. and a maximum of 9%p.a.,
- inflation rate of an average of 2.1%p.a., with a minimum of 2%p.a. and a maximum of 3%p.a., and
- analysis period of 50 years.

A discussion of the assumptions for the model input parameter values is presented in Section 7, and a summary of the input values is presented in Table 54 and Table 55. Variation of the model input parameter values would result in variations from the model output that is presented here.

The model results are presented in a form designed to allow direct comparison with net present value estimates of the value of a statistical life.

Overall, incorporation of sustainability issues into the cost effectiveness analysis for home sprinkler systems provided a broader insight into the overall costs and benefits, including aspects that currently have no monetary equivalent. The development of the cost effectiveness model using distributed values for input parameters also provided a better understanding of the results of the model and the impact of inputs compared to previous models that used single input parameter values. In addition, considering sectors of the initial target population for potential application of home sprinkler systems provided a more thorough understanding of the potential costs and benefits of the application of home sprinkler systems. Furthermore any category or sector for which fire statistics are available can be investigated.

2. INTRODUCTION

This document reports the results of the research project to update and extend the previous cost benefit studies carried out by BRANZ (Duncan et al., 2000) ensuring that the analysis methods and data used reflect current thinking and new information. The review includes consideration of the implications of sustainable development in alignment with the Building Act 2004. Therefore, particular emphasis is given to demonstrating the effects of fire sprinkler use both in terms of potential reductions in direct fire losses but also in relation to the wider measures of sustainability such as environmental impacts.

Aspects of the previous methodology considered for improvement were:

- investigating how the impact of sustainability can be included in a quantitative cost-benefit analysis with particular emphasis on evaluating the use of fire sprinklers and developing a means of including sustainability impacts.
- development of a module for the quantative measure of sustainability impact to run parallel to a cost benefit analysis.
- accounting for input parameter uncertainty by including input distributions instead of single value inputs whenever possible.
- revising input data for the analyses by reviewing and updating input data, where more recent or appropriate data can be located.

2.1 Objective

The overall aim of this document is to report the results of the research project for the home sprinkler system cost effectiveness analysis review incorporating sustainability aspects.

The specific objectives of this report are to:

1. To revise and update cost-benefit studies for the installation of home sprinklers (Duncan et al., 2000);
2. To provide initial guidance for incorporating the impact of sustainability in cost-benefit studies of fire protection features in buildings; and
3. To provide the first demonstration of the potential cost-benefit impacts of sustainability considerations using sprinkler protection, as far as practicable.

2.2 Motivation

The cost-effectiveness of installing a home sprinkler system integral with domestic plumbing in New Zealand was explored in 2000 by BRANZ for the New Zealand Fire Service (Duncan et al., 2000) and the analysis found that the estimated cost per life saved to be about $900k. At that time the home sprinkler design was new and costing information was based on a hypothetical design for a very simple single-level 3-bedroom house design. Following publication of a New Zealand Standard for Home Sprinklers (NZS 4517, 2002), the plumbing industry has gained more experience with their installation and more trained installers are now available. Better quality and more accurate costing information was expected to be obtainable with regards to the home sprinkler system.

The cost-benefit results are also re-evaluated in anticipation of a revised value of a statistical life (VoSL) for fire. These earlier studies assessed the cost of the fire intervention measures against the benefits of a reduced number of deaths and injuries and less property damage. The ‘cost per-life saved’ was determined and compared to the VoSL. A current project by Business Economic Research Ltd (BERL) for the New Zealand Fire Service is investigating what value of statistical life is appropriate for use in New Zealand cost benefit studies for evaluating fire-related intervention measures. It was envisaged that the results of this work would be available for use in this project.

Furthermore, The Building Act 2004 includes, as a purpose, a requirement that ‘buildings are designed, constructed, and able to be used in ways that promote sustainable development’ (New Zealand Building Act, 2004). Changes to the Building Code are being considered to meet the requirements of the new Act. There are currently no established methodologies for how the sustainability aspects of fire sprinklers should be quantified for inclusion in a larger cost benefit analysis other than reductions in the direct financial fire losses. The New Zealand Fire Service, in line with their strategic priorities, have recognised the contribution that fire sprinklers can make toward improving ‘community fire outcomes through fire prevention, fire safety and better response’ and therefore have identified, in the CRF briefing documents, the research topic of sprinkler protection and sustainability as being of significant interest. The original cost-benefit studies did not include the broader impact of sustainability – encompassing economic, social and environmental considerations.

Central in moving towards sustainable development is the recognition that traditional decision-making is heavily biased towards economic considerations. This has proven insufficient to achieve and ensure desirable environmental and social outcomes. Often environmental and social costs/benefits are not readily available in monetary terms and means for economic valuations are required. In order to value environmental benefits and costs economists often rely upon "contingent valuation" surveys as we cannot go to the supermarket to find the value of clean air, of peace and quiet, or of open space. For example, ways of establishing environmental and social values include directly asking people what they are willing to pay for a benefit and/or are willing to receive in compensation for tolerating a cost through a survey or questionnaire. Values can also be estimated by studying property values and wages (and other phenomena) and deriving environmental value of an asset depending on the stream of benefits derived, including environmental amenities.

3. FIRE AND SUSTAINABILITY

3.1 Literature Review

This section reviews the literature relating to incorporation of sustainability into policy making about fire protection measures. A preliminary literature review prior to the project start did not locate any satisfactory sustainability cost-benefit analyses emphasising sustainability matters related to sprinklers in New Zealand or internationally.

3.1.1 Background

3.1.1.1 Environmental Damage from Fire

Fires generally have negative impacts on the environment, and fire suppression and firefighting activities occur to avoid and reduce these and other types of impacts (i.e. threats to life and property). However, fire-fighting activities can have environmental impacts in their own right (e.g., the use of chemical foams or retardants for control of some fires, water abstraction from natural waterways, and toxicity due to chemicals released from burning activities), and these impacts need to be evaluated to minimise the overall impact of fires on the environment, with due regard for other priorities. In terms of environmental impacts, a useful distinction may be between extensive fires (e.g., wildland fires) in which the fires and fire-fighting impacts cover large areas, and fires that occur at a single location (e.g., fires of structures or mobile properties) in which the products of fires and fire-fighting disperse from the fire into the surrounding unburnt environment (Moore et al., 2007) – this review focuses on fires in structures only, i.e. single location.

3.1.1.2 Considering Sustainable Development

There is growing international pressure on all sectors of industry and commerce to transition rapidly to new models of sustainable development. This is driven by emerging concerns over Climate Change, pollution and ecosystem degradation, collapse of marine ecosystems and fish stocks and the depletion of scarce resources especially fossil fuels and the associated vulnerability of many economies to the available fossil fuel resources especially oil.

This has become a major focus of change in the real estate and construction industries as both public and private sector clients increasingly demand “Green” buildings as a public statement of their own environmental commitments to their customers, to their investors and to their staff. This has proved a powerful business driver as companies adopting this ethic achieve superior investment performance and efficiency by better attracting and retaining staff and housing them in more productive buildings. Individuals also identify strongly with this ethic and eco-labeled products and services and environmentally rated homes provide the means to inform individual purchasing/tenant decisions.

The building material and product sectors are now engaging proactively to improve the methods of assessment of building materials and products available in Australia and New Zealand with widespread acceptance that the technique of Life Cycle Assessment (LCA) should be used.

3.1.1.3 Sprinkler Fire Protection

Sprinklers are very important elements of building in terms of fire protection – allowing fire damage to be mitigated at an early stage, hence limiting economic loss, social disruption, ecological damage, and arguably most importantly saving human lives and injuries.

There is substantial evidence that sprinkler systems increase a person's chances for survival in a fire in his home. Estimates range from 80 to 96% increase in the survival rate if the dwelling is equipped with sprinklers and smoke detectors (Fuller, 1991).

It has been suggested that the main reason why homeowners do not elect to install sprinklers is the perceived relatively high purchase and installation costs. An investment decision about fire protection should take account of many factors. Some of the factors, such as installation price, maintenance and replacement costs, and impact on property taxes (if any) and insurance rates, can be easily determined directly. Other factors, such as the probability of fire occurrence and probability of death, injury and property damage caused by fire are difficult to determine for a given house and a particular family. Attitudes towards risk and aesthetics of a fire protection systems vary between individuals and are difficult to estimate.(Fuller, 1991) Furthermore the impact of a fire event on the occupants, and the boarder sense the community, businesses, emergency services and infrastructure and the environment are difficult to quantify.

3.1.1.4 Traditional Assessment of Fire Related Costs

Fire represents a significant cost to the economy in terms of its direct impact on individuals and property, extra protection installed in buildings, the administration of fire insurance and the resources required to provide fire cover through the Fire and Rescue Service. Estimates of the economic cost of fire provide a useful tool to assist policy-makers with policy appraisal and evaluation. Through use in cost benefit analysis, they can help to provide answers to questions such as:

- What would be the saving to the economy of preventing a given number of fires?
- How scarce resources can be used most effectively to tackle the most significant costs.
- What is the optimal balance of resources that should be allocated to fire safety education, fire protection and fire response? What are the trade-offs?

Of course, cost benefit analysis does not provide the definitive answer to these questions, and is just one of a range of tools that can be applied to consider the impacts of a policy. (Office of the Deputy Prime Minister, 2005)

3.1.1.5 Sustainability Framework

Fires generally have negative social, cultural, environmental and economic impacts, and fire suppression and fire fighting activities occur to avoid and reduce these impacts and threats to life and property. In terms of environmental impacts, a useful distinction may be made between extensive fires (e.g., bush fires) in which the fires and fire-fighting impacts cover large areas, and fires that occur at a relatively confined location (e.g., fires in structures or mobile properties) in which the products of fires and fire-fighting disperse from the fire into the surrounding unburnt environment (Moore et al., 2007). This study focuses on residential fires only, i.e. single location.

Fire-fighting activities can have environmental impacts in their own right (e.g., the use of chemical foams or retardants for control of some fires, water abstraction from natural waterways, and toxicity due to chemicals released during burning), and these impacts need to be evaluated to assess and then minimise the overall impact of fires on the environment, with due regard for other priorities.

3.1.2 Impacts and Implications of Residential Fires

This section presents documented environmental, social and economic implications and impacts from residential fires from a sustainability viewpoint. Particular focus is on the environmental concerns surrounding polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) from burning of plastic products and waste wood including paint, glue etc. Social and economic impacts and implications are highly interlinked and will be discussed in combination. Cultural impacts are not considered.

3.1.2.1 Environmental Impact from Structural Fires

It has been stated that "Every fire represents some threat to the environment" (CFPA, 1990). Fowles et al. (2001) reports that international studies suggest that chemical contamination of the environment from fire-fighting activities present a serious hazard to aquatic ecosystems in certain situations. Locally, this is also of concern to the New Zealand Fire Service as well as Regional and District Councils, who have a responsibility to protect the environment from adverse effects. However, uncertainty lies in that little is known about the nature or magnitude of ecological risks from fires and fire-water runoff generally, apart from a number of case reports from internationally occurring ecological catastrophes. This being the case, it is difficult to effectively factor in ecological risks into the decision making process about managing fire fighting activities. Uncertainty lies in deciding what preventative measures should be taken at high risk facilities, or during fire fighting, so as to ensure minimal ecological risk from fire-run-off.

Chemicals may be released into the environment, either discharged into the air during burning, or in the form of run-off from fire-water used during suppression efforts. Contaminants in fire-water run-off may include non-specific chemicals typically associated with combustion, as well as stored industrial or biocidal chemicals. Some industrial chemicals and many agrichemicals are highly toxic to aquatic or soil ecosystems and therefore present a large range of acute and chronic toxicity as well as environmental persistence (Fowles et al., 2001). There is increasing awareness that "ordinary" fires in premises containing seemingly innocuous materials can also present a threat to the surrounding soil and aquatic environment (FPA, 1990). The majority of these types of fires would contribute runoff into the storm drainage system, which can result in discharge into coastal marine and surface waters. It is thought that in most of these cases, the ecological impacts are fairly low, however as the ecological consequences of these releases have not been widely studied, little is known of the potential impacts these events have on the ecological environment (Fowles et al., 2001).

Marlair et al. (2004) categorise the interaction between a fire and its surrounding environment (Figure 3) as:

- Direct gaseous and particulate emissions to the atmosphere (fire plumes);
- Spread of atmospheric emissions;
- Deposition of atmospheric emissions;
- Soil contamination; and
- Aquifer contamination

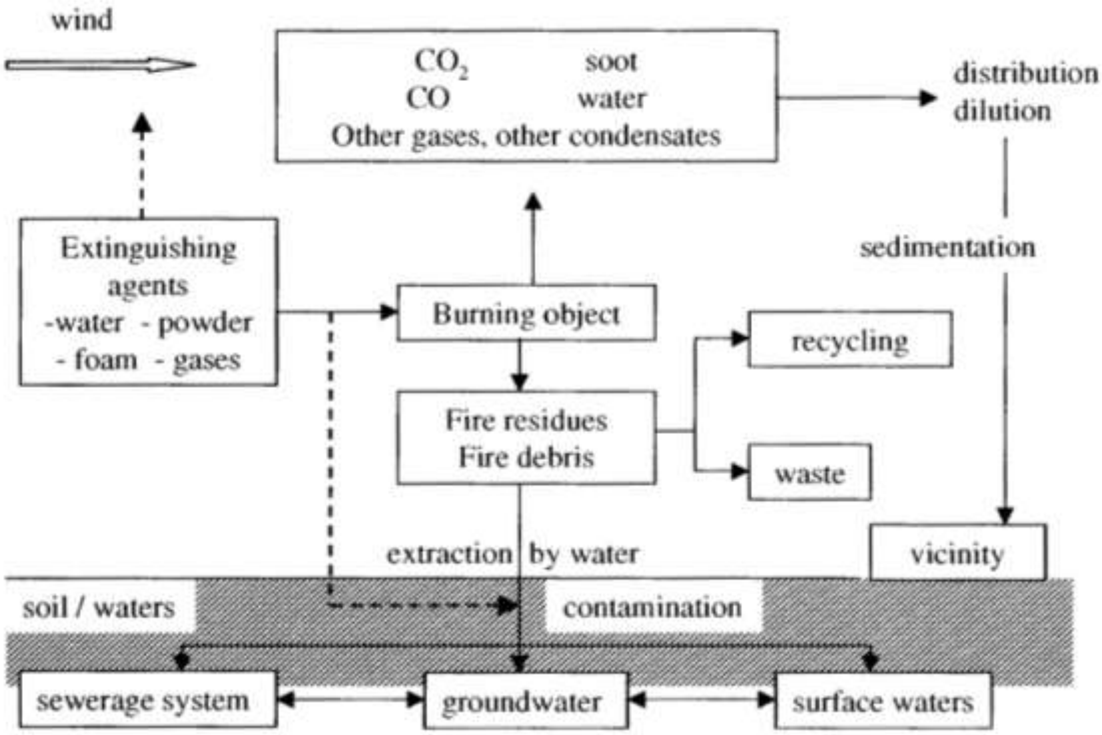


Figure 3: Emissions pathway from fires (extracted from Marlair et al., 2004)

Moore et al. (2007) argue that the chemicals and heat developed in fires and during fire-fighting can affect the environment through:

- Smoke particles transported in a fire plume carrying products from the fire to surrounding locales downwind, where they may be deposited dry or dissolved in rainwater.
- Chemicals contained in fire-water or leached from fire residues can enter soil beneath the site of the fire.
- Fire-fighting involving water or other liquids can dissolve chemicals or transport ash developed at the site of the fire and heated by the fire, and this heated fire-water, if not contained, can leave the site of the fire and enter local waterways.

This latter process can carry substantial quantities of heat and chemicals to sensitive adjacent ecosystems and is probably the most important dispersal process to be considered (Moore et al., 2007).

3.1.2.2 Emissions of PCDD and PCDF from House Fires

The environmental concerns surrounding polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) include their high toxicity, resistance to biological and chemical breakdown, and their ability to bioaccumulate in organisms. They are particularly potent developmental toxicants at low concentrations and can disrupt the development of endocrine, reproductive, immune and nervous system of the offspring of fish, birds, and mammals when exposed from conception through postnatal or post hatching stages (National Dioxin Program, 2004).

It is well known that PCDDs, PCDFs and non-ortho coplanar PCBs (Co-PCBs) are generated in the combustion process of waste scraps[1]. Combustion from house fires and backyard waste has recently been identified in various national inventories as a

[1] They are treated as so-called ‘dioxin analogues’ due to their similar biological toxic effects.

large potential source of PCDD and PCDF (UNEP, 1999; Gullett et al., 1999; Lemieux et al., 2000). Other examples of evidence of emission contamination include:

- Soil samples from the incineration sites with waste electric wire have been found to be heavily polluted by dioxin analogs (Huang et al., 1992);
- Burning of waste wood including paint, glue, plastic, etc. produces a high level of PCDDs and PCDFs, showing the 2,3,7,8-TCDD toxic equivalence quantity (TEQ) level in bottom ash samples to be 155 times on the average, as large as natural wood (5.3 pgTEQ/g) (Wunderli et al., 1996); and

The authors have not found conclusive research on PCCD/F emissions from house fires. For instance Carroll (1996) demonstrated that PVC in house fires was not likely to be a comparatively major source of PCDD/F. However, PVC is not the only material in houses that can generate PCDD/F when burned. Further, no speculation was made with respect to contents, roofing or other materials of construction, and also it is not clear that total emissions can be estimated by summing emissions from materials burned separately. In theory, there can be interaction effects in combustion or the fire plume, but treating these materials as though they were burning separately in uncontrolled combustion is a useful first approximation (Carroll, 1996 & 2001).

Case Study

Formation of dioxin analogues by open-air incineration of waste wood and by fire of buildings and houses concerning Hanshin Great Earthquake in Japan (Nakao et al., 2002):

"In the early morning of 17 January 1995, Hanshin Great Earthquake occurred in the wide area of Hyogo and Osaka prefectures, western Japan, where about 10 million people live. Over 5000 people were killed by the earthquake and the continuous fire, and a lot of destroyed and burned buildings and houses were generated by these in the area. A bulk of waste wood from the broken buildings and houses was consequently open-air incinerated during the period from February to May in five sites in Takaradzuka, Nishinomiya, Kobe and Amagasaki cities of Hyogo prefecture. After the prohibition of open-air incineration on local government recommendation, 7700 t of wood scrap were also incinerated in temporal incinerators in Nishinomiya and Amagasaki cities during the period from June 1995 to October 1996.

It is well known that polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and non-ortho coplanar PCBs (Co-PCBs) generate in the combustion process of waste scraps. They are treated as so-called dioxin analogs due to their similar biological toxic effects. Huang et al. (1992) reported that the soil samples from the incineration sites only with waste electric wire were heavily polluted by dioxin analogs in Taiwan, Republic of China. Wunderli et al. (1996) also found that the burning of waste wood including paint, glue, plastic, etc. formed considerably a high level of PCDDs and PCDFs, showing the 2,3,7,8-TCDD toxic equivalence quantity (TEQ) level in bottom ash samples to be 155 times on the average, as large as natural wood (5.3 pgTEQ/g). This suggests that a large amount of dioxin analogs might be released to environment by open-air incineration and fire concerning Hanshin Great Earthquake."

3.1.2.3 Air Pollution

By world standards, air quality in New Zealand is comparatively very good. This is mainly attributed to: the country's geographical location in the South Pacific Ocean; the constantly blowing westerly winds; the coastal location of most large cities; and the limited amount of heavy industry. However, in some urban areas, levels of contaminants in the outdoor air occasionally, and sometimes frequently, exceed New Zealand's Ambient Air Quality Guidelines, with the potential for impact on human health. There is also increasing pressure on air quality from emission sources. Overall, traffic is the biggest source of air pollution in New Zealand, followed by home-heating fires (burning of wood and coal) (Statistics New Zealand, 2002).

Fire smoke carries fire products including chemicals and particulates. The introduction of synthetic polymers in household furnishings has meant that a range of inorganic acids and hydrogen cyanide are amongst those contaminants commonly carried by smoke (Alarie, 2002). Smoke plumes from fires carry these contaminants and gases downwind where they eventually disperse into the atmosphere or precipitate out into the environment. The effects of these smoke plumes on surrounding environments are relatively unknown although dispersion from small one-off events probably dilutes the contaminants to such an extent that they probably have little effect (Trewin 2003; Fowles et al. 2000).

In a literature review of data reporting emissions of organic air toxics from open burning sources, including structural fires, Lemieux et al. (2004) found that several sources[2] appear to have the potential for being significant sources of pollutants, and for some of the compounds that are considered persistent bioaccumulative toxics[3]. No data on air toxic emissions from structural fires could be found, and although generic emission factors were not reported, references were made to emissions data from some of the components that might be found in structures (e.g. insulation, wood, plastic). Lemieux et al. reported that there are potentially important data gaps that should be filled by additional research.

It shall be noted that fires release greenhouse gases, but the contribution from house fires is not included in this assessment.

3.1.2.4 Soil Contamination

Products of fire combustion may also enter soils at the site of the fire through leaching or from infiltration of fire-water. The effects on soils at sites of smaller scale fires (e.g., house fires) have not been widely examined. There is little information available on the level of contamination of soils following fire events and how long contaminants persist (Moore et al., 2007). In comparison with industrial fires that involve hazardous chemicals, typical suburban house fires are not thought to pose a significant environmental threat (Fowles, 2001). However, there is an increasing awareness that all fire-water runoff contains combustion products including phosphates, sulphates, nitrates, dioxins and furans, and PAHs, small organic compounds and metals (Trewin, 2003).

3.1.2.5 Aquatic Ecotoxicity

> *"Water runoff from fire scenes is generally acutely toxic to aquatic ecosystems. The magnitude of the hazards posed by different types of buildings and facilities varies substantially, depending on the size of the structure, the extent of the burn, and the materials contained within it"*
>
> (Fowles, 2001)

International studies suggest that chemical contamination of the environment from fire-fighting activities presents a serious hazard to aquatic ecosystems in certain situations. Locally, this is also of concern to the New Zealand Fire Service as well as Regional

[2] Including: Accidental Fires, Agricultural Burning of Crop Residue, Agricultural Plastic Film, Animal Carcasses, Automobile Shredder Fluff Fires, Camp Fires, Car–Boat–Train (the vehicle not cargo) Fires, Construction Debris Fires, Copper Wire Reclamation, Crude Oil and Oil Spill Fires, Electronics Waste, Fiberglass, Fireworks, Grain Silo Fires, Household Waste, Land Clearing Debris (biomass), Landfills/Dumps, Prescribed Burning and Savanna/Forest Fires, Structural Fires, Tire Fires, and Yard Waste Fires.

[3] Including PBTs, PCDDs/Fs, PAHs, and hexachlorobenzene.

and District Councils, who have a responsibility to protect the environment from adverse effects (Fowles et al., 2001).

Fire-water could be hazardous even without any contaminants because of the temperature of water draining from a fire scene. The potential for fire-water temperature and toxicity to cause problems in receiving waters will relate to the concentrations of contaminants and the temperature of water leaving the fire scene, the duration of fire-water discharge, any dilution from other stormwater or groundwater sources, and the dilution provided by the receiving waters. The sensitivity of the receiving environment will also vary from place to place, depending on the quality of the habitat and the types of aquatic species present (Moore et al., 2007).

Runoff from even small commonly encountered fires poses a toxic threat to aquatic ecosystems. However, the impacts of common combustion products from a typical urban house fire on municipal storm water systems are unlikely to pose a significant ecological threat. In most cases, these drainage systems contain water that is already toxic to aquatic life, and the dilution factor involved at the final reservoir is expected to be sufficient to reduce concentrations to near ambient levels in a short span of time (Fowles, 2001; Office of the Deputy Prime Minister, 2005; Noiton et al., 2001). However as the ecological consequences of these releases have not been widely studied, little is known of the potential impacts these events have on the ecological environment (Fowles et al., 2001).

In an experiment reported in Moore et al. (2007) the fire-water collected from two control burns had levels of toxic compounds and heavy metals much higher than those previously reported for house fires in New Zealand and higher than freshwater quality criteria. This suggests a precautionary approach to prevent fire-water from house fires from entering stormwater systems whenever possible. Moore et al. further noted that the fire-water collected was hazardous even without any other contaminants because of the heat of water draining from a fire scene.

3.1.2.6 Fire Suppressant Foams

Fire suppressant foams are primarily detergent based and act by increasing water efficiency (Adams & Simmons 1999). Studies of the toxicity of these foams suggest they have toxic effects in aquatic ecosystems but few effects to terrestrial ecosystems. Fire suppressant foams have shown toxic effects to fish (Gaikowski et al. 1996a, 1996b) and to some aquatic invertebrates (McDonald et al. 1996, 1997). Impacts on terrestrial vegetation communities, however, may be minor. Larson et al. (2000) found that plant species richness declined immediately after application of suppressant foam to shrub steppe vegetation in northern Nevada, but recovered by the end of one growing season. Hartskeerl et al. (2004) found that applications of foam to seedlings of seven Australian plant species showed no detectable impacts on a range of vegetative growth characteristics.

3.1.3 Climate Change Impact on Fire Prevention

Global warming and climate change in particular have become a central challenge in the development of a sustainable society. Climate change is likely to impact fire management practices in New Zealand in regions where fire risks are projected to increase and where water availability may decrease due to increase in drought frequency and severity.

3.1.3.1 Increase in Fire Risk

Results from a study by Pearce et al. (2005) indicate that New Zealand is likely to experience more severe fire weather and general fire danger, especially in the Bay of Plenty, the east of both islands and the central (Wellington/Nelson) regions. This will result in increased fire risk including:

- easier ignition, and therefore a greater number of fires;
- drier and windier conditions, resulting in faster fire spread, greater areas burned, and increased fire suppression costs and damages;
- longer fire seasons and increased drought frequency, and associated increases in fuel drying, greater fuel availability and increased fire intensities, more prolonged mop-up, increased resource requirements and more difficult fire suppression;
- increased frequency of thunderstorms and lightning.

There is a general expectation for increase in intensity and frequency of extreme rainfall events which may offset some of the increased fire risk from climate change.

Although the increased general fire risk from predicted climate changes discussed here relates predominantly to external threats when considering structure fires, the general implication of the changed conditions stand with the added issues of a potentially different pattern of fires (e.g. more pressure from vegetation fires, fire spread between property, etc) and the complexity of correlating fire starts to the potential change in occupant behaviour (e.g., less home heating and use of more air conditioners, etc).

3.1.3.2 Increase in Droughts and Water Availability

In consideration of the potential impact of climate change on fire suppression, more frequent drought conditions would mean less water available in general, including for fire-fighting activities. Even though fire-fighting uses relatively little water compared with total current combined domestic and industrial usage, a holistic approach to water conservation would see fit to include all uses. For example, New Zealand Fire Service figures estimate 27,500 litres for an average house structure-fire compared with 800 litres for a house sprinkler system (Saunders & Conder, 2002; NZFS, 2006b) and approximately 4,000 residential structure fire incidents per year (NZFS, 2005). Therefore a cost benefit analysis taking into account the impact of the predicted climate change may prove the future value of sprinkler systems to be even more beneficial than currently perceived.

Furthermore, the value of potable water may provide sufficient motivation to evaluate potential alternatives to current fire fighting and fire prevention practices. For conventional sprinkler systems that do not form part of the potable water supply it could be worth evaluating whether water other than potable water could be used in some situations (e.g. gray water systems or salt water fire fighting systems for coastal areas); or whether water-saving fire-fighting methods are more prevalent than current practices, e.g. more sprinkler systems in buildings, or more or new substances used in conjunction with water to maximize the fire-fighting effectiveness per unit of water or instead of water, or novel applications of other methods. Therefore there is potential scope for research and development of new and improved water-saving built-in and mobile fire-fighting technologies for both structure fire and vegetation fire scenarios.

However, the driving force behind the home sprinkler system that is the subject of this study, are the cost savings that can be made by combining the potable domestic plumbing supply with a fire sprinkler system.

3.1.4 Ecosystems at Risks

3.1.4.1 General Considerations

Fowles et al. (2001) state that each high risk facility should have an ecological risk assessment carried out to assess the impact of fire on the surrounding aquatic environment. The susceptibility of different species to runoff toxicity will be dependent upon the chemicals involved at the facility and upon the species exposed, and therefore these considerations also need to be addressed in the assessment. However, some generalisations can be made regarding sensitive ecosystems. These include (Fowles et al., 2001):

1. slow-moving or still waterways or wetlands are more sensitive
2. small water volumes in the receiving waterway giving less dilution to the runoff increases the system's vulnerability
3. a low biological filtration capacity resulting in greater pH changes (lower buffering capacity) and less binding of chemicals to organic matter increases bioavailability of the substances
4. the presence of threatened or endangered species is always a major concern
5. pre-existing or chronic environmental impacts from pollution from other sources may make the system particularly sensitive to added inputs

Moore et al. (2007) report that Regional Council records of fire related pollution incidents concentrate on those from industrial complexes where other contaminants occur on site. There were none that recognised that fire-water from fires of non-industrial buildings can also carry significant levels of toxic compounds as shown by their analyses of fire-water collected from controlled burns. Regional Council records of fire-related pollution incidents reflect the wide diversity of contaminants that can be carried by fire-water from industrial complexes or vehicles, into stormwater systems and eventually to streams. Fire-water in these instances was highly toxic and considerable efforts were expended to prevent it reaching water courses. Nevertheless, in several instances, significant negative effects to stream life were noted.

3.1.4.2 Biodiversity

New Zealand has 29 indigenous and 20 introduced species of freshwater fish. Of these, 10 indigenous species are listed as threatened (MfE, 1997). The distribution of these species in inland lakes ranges throughout New Zealand from Northland to Southland, and from coastal to alpine habitats. There are some indications that native New Zealand species may be more susceptible than conventional laboratory species to acute toxic effects from pollutants. Generally, the faster moving, high volume waters in major rivers are much better able to sustain and recover from a single contaminant episode than are slower moving waters of such as that observed for a swamp, wetland, or inland lake (Fowles et al., 2001).

New Zealand has a particularly diverse set of vertebrate life, including one third of the world's known species of cockabullies, in rockpools, as well as a range of plant, native bird, and other animal life in estuaries. A sizeable percentage of these species are threatened and these habitats are very fragile and susceptible to permanent damage from a contaminant exposure event (Fowles et al., 2001).

In an experiment reported in Moore et al. (2007) the fire-water collected from two control burns had levels of toxic compounds and heavy metals much higher than those previously reported for house fires in New Zealand and higher than freshwater quality criteria. This suggests fire-water from house fires should be prevented from entering stormwater systems whenever possible. Fire-water collected was hazardous even without any other contaminants because of the heat of water draining from a fire scene. Habitat maps showing the presence of significant native fish can be created with sufficient urban detail to help the Fire Service pinpoint a fire scene in relation to stormwater networks and likely fish habitat values. The Fire Service and Council pollution control officers can use such maps to assess the likely significance of fish populations affected by a discharge, and to locate opportunities to intercept contaminants (Moore et al., 2007).

It is recommended that a comprehensive preventive strategy for fire-water runoff include links to other groups such as the Department of Conservation and Regional Councils that are able to provide a biological inventory of the most critical aquatic systems in a specific region (Fowles et al., 2001).

3.1.5 Valuation of Natural Resources in New Zealand

3.1.5.1 Water Resources

According to the freshwater allocation conference held by the Ministry of Agriculture and Forestry (MAF, 2002) and MfE in 2002, water is valued by New Zealanders for many reasons:

- economic – for irrigation and industry
- environmental – maintaining life in streams
- health – for water supply and safe swimming
- cultural – mahinga kai and mauri
- recreation – for fishing, boating and canoeing

According to a report based on contributions by over 175 scientists (WRI, 2000):

"The world's national economies are based on the goods and services derived from ecosystems …"

Freshwater is a primary or vital part of most of these ecosystems and provides a variety of goods and services of benefit to the economy and humankind (Statistics New Zealand, 2004).

In August 2002, The Government's Approach to Sustainable Development stated that (MfE, 2002):

"the sustainable management of fresh water is one of New Zealand's most significant environmental challenges …"

The Government's 2003 Sustainable Development for New Zealand: Programme of Action has made water one of the four key issues (Department of Prime Minister and Cabinet, 2003):

"Freshwater allocation and use, water quality issues, and water bodies of national importance are fundamental elements for New Zealand's sustainable development. There are a number of water-resource management issues that must be addressed for us to sustain our economic growth, natural environment and heritage, and the health and wellbeing of our people. … The programme of action seeks to achieve the following outcomes:

- *freshwater is allocated and used in a sustainable, efficient and equitable way*
- *freshwater quality is maintained to meet all appropriate needs*
- *water bodies with nationally significant natural, social or cultural heritage values are protected."*

3.1.5.2 Economic Valuation of Water

The economic value of freshwater is not fixed but depends on location, time, circumstance and individual preference. Where market prices or values cannot be obtained, alternative valuation methods, such as travel cost or people's willingness to pay, can be used. Values may be either directly measured or else calculated by multiplying volumes and prices together (Statistics New Zealand, 2004).

Methods for valuing water use are generally not applicable for determining non-use values. Estimates of total water value typically combine several valuation methods. However, valuation of water non-use involves such notions as aesthetic beauty, cultural importance, recreational quality and maintenance of biodiversity and can be difficult and costly to accurately and unambiguously measure (Statistics New Zealand, 2004).

Valuation of Direct Water Use

Statistics New Zealand (2004) discusses the following methods for valuing water use:

- Market value – rates and fees charged by water suppliers to users. Market values may also include trading water rights. Market prices, by their nature, are based on human use or exploitation potential and may be ideal for valuing the economic use of water but are unsuitable for determining the non-use or preservation value of water.
- Cost of acquiring water rights – where market values for water, such as irrigation water, are not available, one of the alternative methods is to use the cost of acquiring water rights as a proxy for the value of the water itself.
- Cost of abstraction and distribution - This method assumes that the value of water is equal to the cost of abstraction and distribution. It is an unsatisfactory method because it sets the intrinsic value of water to zero. Price effects from water scarcity and changes in supply and demand are ignored. The cost of abstraction and distribution, by itself, cannot realistically represent the value of water.
- Resource rent - Resource rent is the economic value of a resource and is attributable not to the users of the resource but to the limited supply of the resource. It is a measure of the scarcity value of a resource.
- Economic activity - This method relates economic activity, such as value-added or gross profit, to the water used. It can be regarded as a productivity measure.

Valuation of Water Non-use

Statistics New Zealand (2004) also discusses methods for valuing water non-use. Several methods can be used. Revealed preference pricing techniques use direct observations or actual prices and include travel cost, hedonic pricing and market valuation of economic losses. Stated preference or non-behavioural pricing techniques involve asking questions of people and include contingent valuation and conjoint analysis. The following methods are presented:

- Travel cost - Recreation and aesthetic values of lakes, river, wetlands and other water resources can be calculated in monetary terms by examining the travel cost to visit such sites. Travel costs have three components: direct transport costs (such as bus fares or fuel and vehicle wear); entrance fees (if applicable); and time (the cost of opportunities forgone).
- Hedonic pricing - Hedonic pricing is a statistical technique for assessing the contribution that each quality characteristic of a product makes towards the overall price of the product. The assessments are derived from analysis of similar products with differing quality characteristics. Proximity of a subdivision site to a scenic lake, for example, provides environmental amenity value that boosts land prices above those for comparable sites that are not close to such a lake.

- Market valuation of economic losses - Measuring the economic effects of environmental damage to water resources can provide an indication of the economic worth of similar undamaged resources.
- Contingent valuation - This method involves asking people directly how much they would be willing to pay for specific environmental attributes (or alternatively how much they would be willing to accept for the loss of such attributes).
- Conjoint analysis - Conjoint analysis is similar to contingent valuation but is less direct. Instead of collecting values directly, the values are inferred (using discrete choice techniques) from the hypothetical choices, rankings or matches that survey respondents make. For example, a householder may be asked to state a preference between a nitrate-polluted water source at $10 per month and a cleaned-up water source that costs an extra $20 per month.
- Benefit transfer - This is not a pricing method in itself. It is a means of valuing an ecosystem, for example, by using unit values or information from studies done elsewhere.

In the absence of market prices, there is no single alternative method that appears suitable for efficient nationwide valuation of all types of water resource. Market prices, if they were available, would be the best means of determining the value of water used in the economy. For water that is not directly used in the economy, however, there would be no market prices, and alternative valuation methods would be unlikely to fully take future generations, biodiversity and ecosystem values into account (Statistics New Zealand, 2004)

3.1.5.3 Valuation of water quality

Pure water, for most uses, has higher value than polluted water. Valuation of water quality would ideally use market prices or values but, in their absence, values can be measured using alternative methods. Contingent valuation has been used in various studies in New Zealand (e.g., Kerr et al. (2004)). Other methods include conjoint analysis and hedonic pricing. The cost of treatment is also a possible pricing differential between pure and polluted water. The value that water users place on quality can be considerable, according to a contingent valuation survey in 2000 (Statistics New Zealand, 2004). For Christchurch households (White et al., 2001):

“the in-situ value of the groundwater resource (water quality aspects only) is estimated as $535 million …“

Valuation of water quality on an accurate, ongoing basis across every region in New Zealand would involve extensive data collection and analysis and is outside the present scope of the monetary stock accounts (Statistics New Zealand, 2004).

3.1.5.4 The Price of New Zealand’s Fresh Water Resources

The present water management regime is largely based on:

- non-compulsory water metering in most regions
- treatment of water as a ‘free’ good (intrinsically free but with abstraction and supply costs and fees)
- ‘first in, first served’ issuing of water rights

The result for water accounting is that data is lacking for physical volumes and mostly unavailable for monetary values (Statistics New Zealand, 2004). However, a number of regional valuations have been attempted and according to a study in 2001 (White et al., 2001):

"the economic value of groundwater to abstractive users in the Waimea Plains, Nelson, is estimated to be approximately $250 million. ... The economic value of New Zealand's total consumptive water allocation would be estimated at $24 billion to $25 billion if the unit economic value of Waimea Plain's groundwater could be applied to all of New Zealand's water allocation."

The estimated $24 billion to $25 billion for national freshwater assets is for consumptive use and excludes the economic value of water for waste disposal, freshwater fisheries, recreation, hydroelectric generation and gravel replenishment.

In 2002, the economic value of freshwater assets in the Manawatu-Wanganui Region alone was assessed at approximately $2.6 billion by GNS. This figure includes $146 million for non- consumptive uses (hunting, boating, fishing and recreation) and $137 million for existence value to householders (White and Sharp, 2002). The Manawatu-Wanganui Region has 8 percent of New Zealand's land area and 6% of its population, suggesting, by extrapolation, that the economic value of all freshwater assets across New Zealand could be about $30 billion to $45 billion (Statistics New Zealand, 2004).

The preceding extrapolation is consistent with a national benefit of about $2 billion per annum from freshwater assets, if a discount rate of 6 percent is assumed.

Values for ecosystem services in the Waikato Region are shown in the following table, for the 1997 calendar year. Applying the relevant values per hectare to the estimated surface area of New Zealand's lakes, rivers and wetlands would give a value of about $15 billion per year. If ecosystem services from aquifers, glaciers and snow were added, the national value would likely reach several tens of billions of dollars per year (Patterson and Cole, 1998).

Table 1: Ecosystem values. Extracted from Patterson & Cole (1998).

Ecosystem Type	Value per Hectare/Year ($)	Total Value ($million)	Percent of total Value
Lakes and Rivers	19,700	1,856	19.8
Forests	2,400	1,848	19.8
Agricultural/Horticultural	1,100	1,460	15.6
Freshwater Wetlands	39,800	1,211	12.9
Coastal Marine Area (CMA)	500	1,113	11.9
Near Coastal Zone	8,000	915	9.8
Estuarine	46,400	863	9.2
Other:			
Scrub/Shrub	500	55	0.6
Seagrass/Algal Beds	38,900	21	0.2
Cropland	140	9	0.1
Mangrove	19,000	3	0.1
Total		**9,360**	**100**

Note: Ecosystem services of lakes and rivers include hydrological cycles, flow regulation and flood control, water supply, recreation and food. Ecosystem services of freshwater wetlands include storm protection, flood control, habitat, nutrient recycling and waste treatment.

3.1.5.5 Air Quality

By world standards, air quality in New Zealand is comparatively very good. This is mainly because of: the country's geographical location in the South Pacific Ocean; the constantly blowing westerly winds; the coastal location of most of our large cities; and the limited amount of heavy industry. However, in some urban areas, levels of contaminants in the outdoor air occasionally, and sometimes frequently, exceed New Zealand's Ambient Air Quality Guidelines, with the potential for impact on human health. There is also increasing pressure on air quality from emission sources. Overall, traffic is the biggest source of air pollution in New Zealand, followed by home-heating fires (burning of wood and coal). New Zealand has relatively little industrial air pollution, although there are regional differences in all forms of air pollution (Statistics New Zealand, 2002).

3.1.5.6 Natural and Heritage Resources

Fire causes damage to areas or sites that are valued by society either for their strong environmental or heritage value. These losses are difficult to value in monetary terms and, depending on severity, can range across a wide band on a year-by-year basis. (National Center for Environmental Assessment, 2000)

The costs associated with the loss of vegetation (particularly non-commercial forest and other vegetation) from wildfires have not been assessed in this report due to the reasons cited above. However, previous work in this area has assumed a cost $1,500/ha plus environmental costs associated with carbon emissions, and further research in this area could build on this work (National Center for Environmental Assessment, 2000).

Natural or historical areas can also generate income based on recreational use and tourism, and the loss of this income leads to indirect losses to businesses in the area. For example, the impacts of the Yellowstone National Park fires were based on this analytical approach. However, these impacts are only relevant for significant fires in major tourism spots, and extrapolation for all fires is impractical. (National Center for Environmental Assessment, 2000)

3.1.6 Environmental Impact Measures for Buildings and Materials

3.1.6.1 Life Cycle Assessment

There have been rapid advancements in the way building materials, elements and components have been environmentally profiled in the last decade. Prior to this, many green building claims and strategies were based on a single life-cycle stage or a single environmental impact. A product is claimed to be green simply because it has recycled content, or claimed not to be green because it emits volatile organic compounds (VOCs) during its installation and use. These single-attribute claims may be misleading because they ignore the possibility that other life-cycle stages, or other environmental impacts, may yield offsetting impacts (BEES, 2002; Page, 2006). Life Cycle Assessment (LCA) is an established and increasingly popular method for comparing the environmental impacts between products and services.

The most significant change in the way building products are measured is in the application of cradle to the grave or cradle to cradle LCA tools. These tools broaden the environmental discussion by accounting for the whole life cycle on a wide range of environmental issues – not just concentrating on issues such as embodied energy and embodied carbon dioxide (CO_2). Thus, issues such as climate change, fossil fuel depletion, pollution to water, minerals extraction and waste disposal are recognised and analysed. The benefit of this approach is in implementing a trade-off analysis to achieve a genuine reduction in overall environmental impact, rather than a simple shift of impact. Life cycle assessment includes the pollution associated with obtaining, using and disposing of products, and the extent to which resources are depleted or the environment is damaged in the product's manufacture, use and disposal. Thus, by providing a more holistic approach, a better representation of a building material's environmental attributes (and therefore environmental profile) can be gained (Page, 2006).

LCA is the process of evaluating the potential effects that a product, process or service has on the environment over the entire period of its life cycle. The International Organization for Standardization (ISO) has defined LCA as a technique for assessing the environmental aspects and potential impacts associated with a product by (ISO 14040, 2006):

- Compiling an inventory of relevant inputs and outputs of a product system;
- Evaluating the potential environmental impacts associated with those inputs and outputs; and
- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

The technical framework for LCA consists of four components, each interrelated and having a vital role in the assessment. In accordance with the current terminology of ISO 14040, the components are: goal and scope definition, inventory analysis, impact assessment and interpretation (AGO, 2006).

3.1.6.2 Selected International Developments

Extensive reviews of international tools have been undertaken by various international authors. For further information on rating tools generally, reference should be made in particular to Ashe et al. (2003).

Early LCA tools with detailed provision for building materials were used by Dutch local governments and municipalities for prescriptive specifications in the early 1990s. In the UK, early steps were taken towards a Green Guide specification initiative as early as 1993, with the BRE Environmental Profiles Methodology published in 1999. Developments in the US and Canada occurred in parallel, with the launch of Environmental Building News' first GreenSpec in 1992, the Canadian ATHENA sustainable materials project in 1991 (which was carried forward to become the ATHENA Sustainable materials institute in 1997) and BEES in 1998. Today, the range of tools and systems in both the EU and USA markets is continuing to expand.

A summary of selected initiatives in the area of tools and systems for evaluating sustainability of building materials is shown in Table 2.

Table 2: Summary of selected international initiatives in the area of tools and systems for addressing building materials sustainability (AGO, 2006)

Tool or system	Category	Comment
LEED	Building design rating tool	The dominant building rating tool in the US. Voluntary. Allocates approx 20% of credits to materials selection, addressing issues such as recycled content, regional materials, reuse and certified timber. Ratings are not currently based on quantifiable metrics, but are now moving towards LCA through the 'LCA into LEED' initiative.
GreenSpec	Product information dataset/decision tool	Long-running and highly regarded US green specification and decision-support tool. Addresses criteria such as recycled content, reduced emissions and low toxicity with discrete pass/fail criteria. Does not currently reference LCA quantification or attempt to weight benefits, but credits are closely aligned with LEED credits.
eLCIe	Product information dataset/ decision tool	A recently developed US LCA-based decision-support tool that aims to give clear ranking of product options using a weighted methodology. For individual products only (e.g. carpet), rather than assemblages (e.g. floor finish incorporating underlay, adhesive etc). An example of a market-led response to the demand for assessment quantification.
GreenCalc	Building design rating tool	A Dutch-developed whole-building design tool incorporating an LCA dataset for impact assessment of building materials used. There is evidence that EU member countries, after developing a wide range of building rating tools, are moving towards consolidation and inter-operability, with LCA and Type III environmental labels forming an important part of this. GreenCalc is indicative of the emerging generation of building design tools.
IBIS	Product information dataset/ decision tool	Developed for a Dutch government agency as a decision-support tool to augment ecolabels that do not explicitly address biodiversity impacts for products and services. IBIS appears to be unique in its development in many ways, including in the use of a predictive approach. Not currently capable of being integrated into LCA.
MOSUS, Mass Balance	Regulatory requirement	A number of EU jurisdictions now have requirements for tracking materials flows through the economy. The German MOSUS project is one of these (Mass Balance, along similar lines, although is a UK initiative not a regulatory reporting requirement). Implementation of materials flows reporting appears to be growing rapidly.
RoHS, REACH	Regulatory requirement	The EU Restriction of Hazardous Substances Directive (RoHS) restricts the use of six hazardous materials in the manufacture of various types of electronic and electrical equipment. The Registration, Evaluation and Authorisation of Chemicals (REACH, 2005) requires manufacturers of large quantities of chemicals to demonstrate they will not prove hazardous. Although RoHS does not currently apply to construction materials, and REACH has yet to come into effect, it is anticipated that these measures will be adopted in other jurisdictions. REACH and RoHS are already having an impact on supply chains globally (Pollet 2005a, 2005b).
Eco-labels (variety of)	Product information/ decision tool	There is now a very large and expanding range of eco-labels covering building products. These fall under Type I, II and III approaches.
BRE Green Guide to Specification	Product information dataset/ decision tool	A combined assembly approach and weighted LCA analysis to produce single-score results for generic building assemblies. A range of third-party providers are delivering accreditation to the BRE methodology.
BREEAM	Building design rating tool	A whole-building rating tool that uses LCA-based criteria for materials credits. Credits are based on a set percentage of an assemblage (e.g. exterior cladding) achieving an 'A' or 'B' rating. These ratings are set through the BRE methodology used in the Green Guide (refer above).
Envest	Design tool	A UK design tool that provides an easy-to-use interface. Allows rapid evaluation of overall environmental performance of building envelope and materials choices, based broadly on LCA-derived data.

3.1.7 Analysis

Based upon what is known about the nature of chemicals and of fire incidents where ecological impacts have been identified, it may be concluded that fire-water runoff can pose a threat to nearby aquatic environments. In cases of large industrial fires, it has been shown that rivers, streams, and lakes near to large fires bear the brunt of the ecological impact, and can sustain long-lasting damage. For most common house fires, this threat is comparatively minor. The type and magnitude of damage that occurs during a fire is a complex product of the type of fire, the emergency planning measures in place, and the location of the fire with respect to susceptible ecological resources.

- The environmental damage and consequence is dependent on the sensitivity of the surrounding environment, i.e. typically higher sensitivity in rural areas than in urban where the stormwater runoff may already be contaminated.
- The toxicity of the fire residuals into the air, water and ecosystems are highly variable and poorly understood. The general focus in the literature is on the dioxins; polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF), and the metals copper and zinc, which are highly toxic to aquatic ecosystems.
- The valuation of the environmental and social impacts from building fires are less investigated and poorly explored compared to the economic valuations of building fire loss.
- Methods for estimating the cost from building fire losses vary internationally and incorporate to varying degrees, what could be defined as, sustainability aspects.
- From the available literature it is not possible to assign a generic/average/total price on the environmental damage from a building fire for two reasons:
  - The environmental impacts from fires are not well documented; and
  - Even if they were available; associated economic values are not readily available for the impacts.
- Indicative valuations for freshwater resources are available for various geographic regions in NZ.
- Internationally Life Cycle Assessment is the most widely accepted tool for assessing environmental impacts from building products and materials.
- A Life Cycle Assessment approach is increasing its foothold in building rating tools.

3.1.8 Conclusions

3.1.8.1 Sprinkler Protection

Fires generally have negative social, cultural, environmental and economic impacts, and fire suppression and fire fighting activities occur to avoid and reduce these impacts and threats to life and property. Fire-fighting activities can have environmental impacts in their own right (e.g., the use of chemical foams or retardants for control of some fires, water abstraction from natural waterways, and toxicity due to chemicals released during burning), and these impacts need to be evaluated to assess and then minimise the overall impact of fires on the environment, with due regard for other priorities.

Sprinklers can be very important elements of a building in terms of fire protection. Mitigating fire damage at an earlier stage follows on to limiting economic loss, social disruption, ecological damage, and arguably most importantly saving human lives and injuries. There is substantial evidence that sprinkler systems increase a person's chances for survival in a home fire. Estimates range from 50 to 90% if equipped with a sprinkler system.

3.1.8.2 Environmental Impacts

In general there are many remaining uncertainties regarding the environmental impacts from house fires. Toxicity and the heat from firewater runoff are considered larger concerns than soil contamination and air pollution from house fires. Fire-water runoff in urban environments, where the fire-water is assumed to be drained into stormwater systems, is considered to be a lesser issue than in rural environments where the fire-water runoff can have potentially more severe consequences on sensitive ecosystems.

The main concern documented in the literature researched for this project is concerning emissions of PCDD and PCDF. Attempts to quantify the concentrations of these substances place emissions from house fires at relatively low levels.

As a generalisation it can be said that house fires are only likely to have apparent and direct consequence to the environment when they occur close enough to impact on sensitive ecosystems. It is difficult to quantify the adverse environmental impacts from house fires, especially considering the impacts vary significantly between sites and the need for additional research regarding the nature of the impacts.

3.1.8.3 Cost of Water

Water resources and water quality have a value that is higher than the current market value. That is, water has a user value as reflected in market prices; value derived from ecosystem services and intrinsic value. A number of local valuations of freshwater resources and ecological services have been attempted in New Zealand. However, it is found difficult to relate the valuations to environmental impacts from fires with the current incomplete understanding of the magnitude of environmental degradation from house fires. The valuation results could be used on a case by case basis for house fires where there has been quantifiable negative environmental impacts.

3.1.9 Recommendations

- Use Life Cycle Assessment methodology
- Focus on impacts on sensitive ecosystems
- Use existing valuation of environmental resources as a proxy for environmental impacts.

3.2 Life Cycle Assessment Methodology

3.2.1 Scope

It shall be noted that the previous review and discussion is at this point separate from the update of cost-benefit methodology and data used in the previous BRANZ study, as explained in the project objectives of this report. In this section we will compare the cradle to gate environmental impacts associated with the materials for:

a) Sprinkler installations; and

b) Replacement fire damage that would be avoided with sprinklers installed

It shall be noted that the cradle to gate Life Cycle Assessment (LCA) will not include overall environmental and human impacts from fires, nor will it include end of life impacts (gate to grave or gate to cradle, covering such issues as disposal, etc.) of the sprinkler systems.

In essence the comparison is between environmental impacts associated with installing sprinkler systems in a relatively large number of houses compared to the reduced amount of fire damage that would occur in a comparatively smaller number of houses subject to a fire incident with a sprinkler system present.

3.2.2 Project Life Cycle Assessment Methodology

This entailed the following key steps (Howard et al., 2007):

- Selection of an LCA application protocol
- Estimation of material quantities for:
    - sprinkler installation
    - avoided damage from sprinkler protection
- Use of Simapro to derive/compile Life Cycle Inventory data for each material
- Adaptation of Simapro inventory data for consistent methodology and New Zealand relevance
- Estimation of the total embodied impacts for
    - sprinkler installation
    - avoided damage from sprinkler protection
- Impact assessment
- Characterisation
- Normalisation
- Weighting
- Collation of results from all phases

3.2.2.1 Selection of Life Cycle Assessment Application Protocol

We have selected an LCA approach that is both ISO 14040 compliant and consistent for all materials and products at all life cycle stages and points on the supply chain.

In this work, we have used the BRE Environmental Profiles Methodology (Howard et al., 1999) and attempted to bring all the data used to a common economic basis for allocation between co-products, adapt any data that originates from overseas to a New Zealand relevant context and ensure that the scope used for different data sources is, as far as possible, consistent and compatible and appropriate for this project.

3.2.3 Sustainability Life Cycle Assessment Variables

3.2.3.1 Water Use

The current extent of environment impact reduction having been incorporated into fire safety systems cost effectiveness analysis is limited. For sprinkler systems, this is limited to analysis of the Scottsdale data (Jelenewicz, 2005), which only considered the average reduction in water volume of 11,700 litres used for a sprinklered house fire compared to an unsprinklered house fire and similar estimates for New Zealand by Saunders and Condor (2002) of 26,700 litres, as presented in Table 3.

Table 3: Estimated average volume of water used for home fire suppression.

Average Volume of Water Used without Sprinkler System	Average Volume of Water Used with Sprinkler System	Reference
11,000 l	1,300 l	Based on Scottsdale data (Jelenewicz, 2005)
27,500 l	800 l	(Saunders and Condor, 2002)

3.2.3.2 Sprinklers

The approach taken comprised estimating the material quantities used for sprinkler installations. This was done by determining the material weights for additional plumbing required (see the examples presented in Table 4) and for the sprinkler components (see Table 5, from the specified plumbing materials it was assumed that 70% is extra over domestic cold water reticulation). The sprinkler system specifications sent to a number of plumbing firms for cost estimates are presented in **Error! Reference source not found.**.

Table 4: Material masses for sprinkler system components.

Pipe Material		Pipe Dia. (mm)	Small House				Large House			
			Length (m)	Quantity (#)	kg/m	Mass (kg)	Length (m)	Quantity (#)	kg/m	Mass (kg)
Polybutylene (PB)	Pipe	25	23	1	0.215	3.11	47	1	0.215	10.12
		20	16	1	0.135	3.45	8	1	0.135	1.08
	Tee	25		5	0.110	0.55		22	0.110	2.42
		20		3	0.063	0.19				
		20 - 25						3	0.110	0.33
	Elbow	25		3				11		
		20		4	0.049	0.20				
	Valve	25								
		20								
MDPE (PE80B)	Pipe	32			0.72		8	1	0.72	5.76
		25	10	1	0.17	1.70			0.17	
	Tee	32								
		25								
	Elbow	32								
		25		1	0.1					
Brass	Valve	32						1	1	1.00

		25		1	0.7	0.70				

Table 5: Sprinkler head component masses.

Physical Characteristic	Mass (g)		
	Sprinkler Head Type A	Sprinkler Head Type B	Sprinkler Head Type C
Frame	51.2	51.2	
Deflector	6.08	10.5	11.86
Bulb	0.254	0.254	
Tape	0.035	0.035	
Spring	0.347	0.0347	0.27
Screw	1.76	1.76	0.69
Pip Cap	1.66	1.66	1.81
Body			60.0
Saddle			4.14
Sealing Assembly			0.36
Soldered Link Halves			1.14
Lever			2.22
Guide Pin Housing			23.18
Guide Pins			5.10
Support Cup			40.82
Cover Plate			14.70
Retainer			36.17

3.2.3.3 Avoided Property Loss in Fire

The approach taken comprised estimating the material quantities representing avoided damage due to sprinkler protection. This was done by determining:

a) Material quantities in a typical house constructions based on the Exemplar House (Willson, 2002);

b) Estimating average quantities per material based on materials in the existing building stock;

c) Determining proxy materials for which LCI data is available when necessary;

d) Estimating the amount of house damage incurred each year from fires; and

e) Estimating the amount of damage avoided by installing sprinklers.

3.2.3.4 Material Quantities in a Typical House

The life cycle impacts from replacement materials for fire damage which could have been avoided with sprinkler fire protection are estimated. The quantities are estimated based on material schedules for an archetypical house type built with different construction material combinations. The archetypical house is based on the Exemplar House (Willson, 2002) (see Figure 4) and the material schedule are presented in Table 6 and **Error! Reference source not found.**, Appendix F.

The Exemplar House is a schedule of quantities for a typical 1.5 storey house. The schedule is rearranged into various categories of materials. The floor areas are 149 m^2 ground, 46 m^2 upper floor, 3 bedrooms, double garage (included in 149 m^2), elevations attached. Ground floor dimensions 14.4 m x 14.1 m. Lot size 624 m^2.

The material schedules from the Exemplar House were averaged to produce a single list of material quantities which was used to provide input into the LCA (Table 7). For cases where life cycle impact characterisation is not available representative proxy materials can be used, however this was required for this case.

The model for estimating the amount of material saved by sprinkler protection was developed in combination with the cost effeciveness model, presented in Section 6.

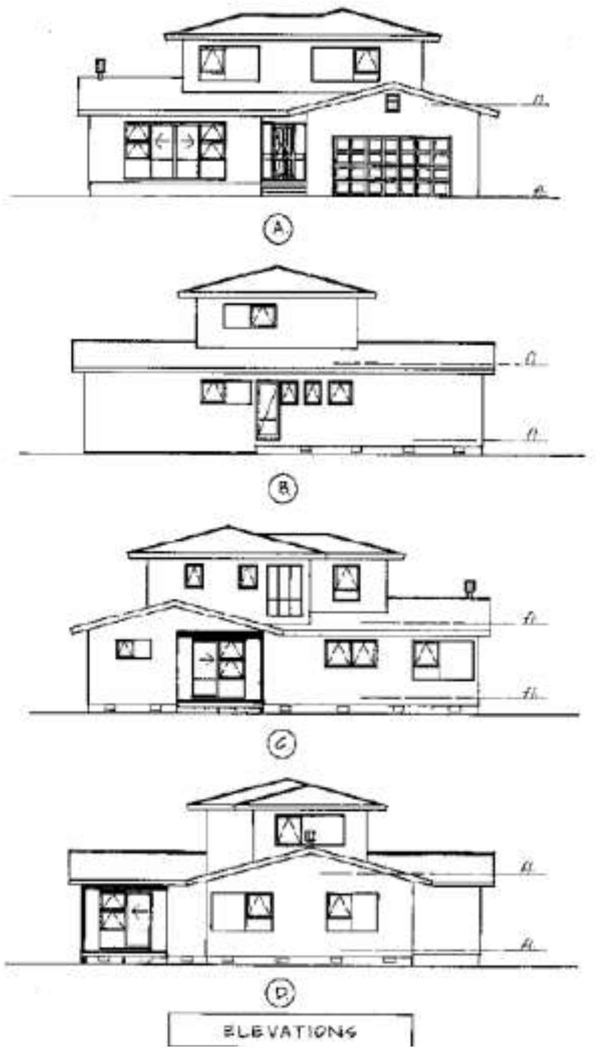


Figure 4: The exemplar house (Willson, 2002).

Table 6: House type summary

House Type	Cost ($Jun02)	Sawn Timber Products (m^3)				Cavity battens	Weather board	Other [a]	Total
		Piles	Framing	Decking	Exterior finish				
Slab/Fib Cmt plank/Steel sheet	178,220	0.00	18.43	0.00	0.65	0.41	0.00	4.39	23.87
Slab/ Brick/ Concrete tile	180,918	0.00	19.02	0.00	0.59	0.14	0.00	4.39	24.14
Slab/ Brick/ Steel sheet	181,645	0.00	18.43	0.00	0.59	0.14	0.00	4.39	23.55
Timber/Fib Cmt plank/Steel sheet	182,104	0.53	22.34	1.11	0.65	0.41	0.00	4.39	29.43
Slab/Timber		0.00	18.43	0.00	0.65	0.41	4.59	4.39	28.47

WB/Steel sheet	185,964								
Timber/Timber WB/Steel sheet	189,849	0.53	22.34	1.11	0.65	0.41	4.59	4.39	34.03

Note: [a] Other includes: Interior finish (1.07) + Jambs/window liners (0.72) + Landscape (2.60) = 4.39 m^3

Table 7: Average house structural content (adapted from Wilson, 2002)

Material	**Average Content**	**Units**
Hardfill	10.17	**m3**
Sand blinding	123.88	**m2**
Re-steel	602.21	**kg**
Concrete blocks	1027.71	**kg**
Concrete readymix	30.36	**m3**
Steel bolts/plates/straps	26.90	**kg**
PVC	93.64	**kg**
Fibre cmt basebd & soffits	430.77	**kg**
Timber piles H5	0.18	**m3**
Sawn timber H3.2 (deck)	0.37	**m3**
Framing timber H1.2	8.46	**m3**
Framing timber UT	11.10	**m3**
Deck planks H3.2	0.37	**m3**
Exterior H3.1 finish/battens	0.95	**m3**
Particle Board sheets	1.69	**m3**
Polythene DPC	128.88	**m2**
Foil insulation (floors)	35.33	**m2**
FC Plank	980.00	**kg**
Brick	1373.33	**kg**
Timb WB	882.00	**kg**
Sht Steel	873.30	**kg**
Conc tile	1725.05	**kg**
Paint	105.89	**litres**
Retain wall/fence timber H4	0.95	**m3**
Half round retain wall H4	1.12	**m3**
Sawn timber H3.2 (fences etc)	0.59	**m3**
Interior UT mould, jamb, liner	1.79	**m3**
Fibre cmt basebd & soffits	392	**kg**
Building paper	355	**m2**
Windows glass	450	**kg**
Windows aluminium	144	**kg**
Insulation Fibreglass	294	**kg**
Plasterboard	4518	**kg**
Wet wall lining(coated HB)	59	**kg**
Doors	19	**no**
Wallpaper	346	**m2**
Carpet	132	**m2**
Vinyl	15.0	**m2**
Nails	60	**kg**

3.2.4 Life Cycle Inventory Data

For the Life Cycle Inventory (LCI) data phase of the project, we used the Simapro v7.1.4 software to compile the inventory data for the materials and products used and to characterise the data (discussed below).

BRANZ are committed to consistency in their LCA assessment of all materials and products. However, the commonly available sources of materials LCA/LCI data internationally (mainly European) and for Australian/NZ have been compiled by different researchers at different times working for different industry sectors where different methodological choices are considered the norm. This problem is compounded because it also applies to the upstream supply chain for any product being manufactured and to any downstream products fabricated.

This means that the data used for the different components may have very different rules applied to the allocation of burdens between co-products and the data may have a different geographic relevance, a different scope and a different timeframe.

Many materials are also recyclable or carry a proportion of recycled content or both. This implies the need for rules which provide a discount from recyclable primary products because they are going to be available for recycling, whilst transferring the discount to the recycled product spread over its recyclable lives to account for the fact that the recycled material can only be available if it has previously been produced from primary manufacture.

Some components (plastics) are derived from fossil fuel resources. These need to be treated differently for their emissions to the fossil fuel resources that are consumed by combustion.

Timber materials are renewable resources that sequester carbon dioxide from the atmosphere and sequester solar energy as the timber is being grown. If the scope of the methodology used to derive the data is drawn from the point of harvest of the timber, then the benefits of sequestered carbon and solar energy in the timber are not accounted for. For this study, sequestered carbon was taken into account, with the scope being drawn from the point of seeding the trees.

Finally, some materials have significant transport components. For example the sprinklers are manufactured in Europe or the US and shipped by ship to New Zealand. Although the greatest distances are transported by ship, the most impact is quite likely from lorry transports to and from the ports.

3.2.5 Data Sources

The main data source used for the LCA was Australian dataset provided with the Simapro v7.1.4 software. This data mostly originates from RMIT. Where required data is not available, BRANZ will use data from the Ecoinvent database which originates from the Ecoinvent Center in Switzerland and compiles data for most European countries.

The main adaptations made to the data for this project were as follows:

1. Universal and consistent application of economic allocation between all co-products and recycled wastes from all processes, including to end-of-life recycled materials going to recycled products. This affects all components and energy sources and feedstocks either directly or indirectly from their upstream supply chain.
2. Provision of discounts to the primary products that are recyclable on the basis of the value and quantity of scrap recycled compared to the value and quantity of primary product produced.

3. Transfer of this discount and spreading it between the recycled materials that derive from the primary product in proportion to their value and quantity.
4. Review of the unit process data for all material inputs (except PVC) to ensure consistency of feedstock emissions accounting. (The only raw PVC resin data available was from the Ecoinvent data and presented as a System process which prevented adaptation to the Australian/NZ context and to consistency of methodology with the other materials – it is hard to determine either the extent or direction (larger or smaller impact) of the error that this implies).
5. Review of the unit process data for all renewable material inputs (mainly timber, but also some vegetable oils) to ensure that the scope accounted for sequestered CO2 and solar energy – this was not the case in the basic Australian/NZ data set. In doing so, the data reflects a significant difference in CO2 sequestration from fast-growing plantation species compared to slower growing but more durable broad-leaved timber.
6. Adoption of LCA data for timber species that were considered closest to those used for manufacture of timber framed windows – data for the specific species and Australian/NZ forestry practices could not be found.
7. Numerous minor changes to maximise consistency of assessment.

Voids in the data are currently being identified, and form part of the next stage of this project.

3.2.6 Impact Assessment

It is very common for LCA practitioners to use impact assessment methods (e.g. Ecoindicator 99 NL and Europe) that come packaged within tools like Simapro without adapting them to country context. The approach to impact assessment taken by BRANZ to generate a New Zealand ecopoint is discussed below.

3.2.6.1 Characterised Data

In this project, in line with the BRE ecoprofiles methodology, BRANZ used the characterisation data from CML Leiden updated to the 2002 dataset. These are considered appropriate internationally for global impacts but should be adapted to a national context (or better still to a climate region or bioregion context) for local impacts.

Using the CML 2002 characterisation factors, life cycle data is characterised under the following headings:

- Abiotic Depletion
- Global Warming (GWP100 years)
- Ozone Depletion Potential (ODP)
- Human Toxicity
- Fresh Water Aquatic Ecotoxicity
- Marine Aquatic Ecotoxicity
- Terrestrial Ecotoxicity
- Photochemical Oxidation
- Acidification
- Eutrophication

Most are clearly defined, but the abiotic depletion factors relate to resource depletion issues including water, fossil fuel depletion etc. This data has very much a European context and is probably not appropriate to the New Zealand and Australian context. For New Zealand, it would have been better to have broken down the abiotic depletion category into separate sub-categories of:

- Landfill Waste
- Water Consumption
- Oil & Gas Depletion
- Solid Fuel Depletion
- Deforestation
- Productive Farmland lost
- Habitat & Ecosystem

For this work, the abiotic depletion category is considered to be excluded and the results renormalised excluding this factor. If future work provides appropriate characterisation factors for this class of impacts, the results can be refined to take them into account.

3.2.6.2 Normalisation New Zealand

Commensurate with these impact categories, we have compiled the data for New Zealand and Australia and these were used to normalise the characterised data for the materials, energy and water consumption associated with each of the archetypes, as presented in Table 8.

Table 8: Normalisation factors for New Zealand

Normalisation Factor	Units	Value
Abiotic Depletion	kg Sb eq	0.0075
Global Warming (GWP100 years)	kg $CO_{2\ eq}$	21198
Ozone Depletion Potential (ODP)	kg CFC-11 eq	0.0092
Human Toxicity	kg 1,4-DB eq	45662
Fresh Water Aquatic Ecotoxicity	kg 1,4-DB eq	1494
Marine Aquatic Ecotoxicity	kg 1,4-DB eq	262343
Terrestrial Ecotoxicity	kg 1,4-DB eq	121
Photochemical Oxidation	kg C_2H_4 eq	6.8
Acidification	kg SO_2 eq	23
Eutrophication	kg PO_4 eq	13.49

Where available, New Zealand specific emissions data was used (MfE, 2003 & 2007; Ozone Secretariat, 2007; Secretariat for the Stockholm Convention on Persistent Organic Pollutants, 2007). The remaining data was compiled from the Australian national pollutant emissions inventory (NPI, 2007) and scaled to take account of differences between New Zealand and Australia in:

- Population;
- Energy mix;
- Mineral mining;
- Iron, steel and coal production;

The scaling was based on information published by Statistics New Zealand, International Iron and Steel Institute, International Energy Agency, OECD and the New Zealand Ministry for the Environment.

3.2.6.3 Weighting New Zealand

The weightings exercise was conducted as part of an LCA introductory course for designers in 5 cities around New Zealand – Christchurch, Dunedin, Auckland, Hamilton and Wellington. The audience ranged in numbers from 27 to 95 participants with a total participation of 332. In an opening session, LCA was introduced to the audience and the different stages of goal and scope definition, inventory analysis, classification and characterization of impacts and weighting the impacts to reach a final ecopoint score. The purpose of weighting was outlined and the results from 7 different practitioner groups in the UK and from a similar exercise in the USA were briefly presented to the audience.

The weightings exercise was then introduced to the audiences. Lists of environmental impact issues were issued to each participant comprising short phrases describing each issue, e.g. "Climate Change", Ozone Depletion", "Fossil Fuel Depletion", "Ecological Diversity", etc. The weightings list used is included in **Error! Reference source not found.**. The audience were then invited to individually assign weightings to each of the issues presented. Each person was permitted to allocate a total of 100 points between the issues according to how important they considered the issue. They were allowed to distribute the weightings in any way that they wished. If they felt that just one issue was overwhelmingly important, they could assign all 100 points to that issue. If they felt that all of the issues were equally important, they could assign their weightings equally. If they wished to score an issue not on the list, they were asked to assign this score to the nearest equivalent and write a qualifying remark next to their score. If they felt that any issue was not important, then they could assign a zero score.

This exercise was conducted over the participants' coffee break and discussion about the meaning of the key phrases or their importance was encouraged, however, the facilitators were not allowed to answer any questions. All answers had to come from within the participants with no external bias. The results were collected at the end of the coffee session and analysed. In the final session of the workshop, the results were presented back to each group to reveal the groups' results and how they compared with different practitioner groups in the UK and USA and how the groups' results compared with the other New Zealand Cities studied.

The audience was asked to comment on the results, whether they felt they accurately reflected the opinions of the audience, whether they were surprised by the results and any other observations. The audiences at all centres confirmed that they felt the exercise accurately reflected their collective opinions and the main point of surprise was the degree of consistency between results from the different practitioners and from the different locations both inside New Zealand and overseas.

Table 9 Average weighting of environmental issues for New Zealand.

Impact Category	All Impact Categories	Re-normalised to Limited Categories
Abiotic depletion	9%	-
Global warming (GWP100)	12%	26%
Ozone layer depletion (ODP)	6%	12%
Human toxicity	6%	13%
Fresh water aquatic ecotox.	4%	9%
Marine aquatic ecotoxicity	6%	14%
Terrestrial ecotoxicity	3%	6%

Photochemical oxidation	3%	7%
Acidification	4%	8%
Eutrophication	3%	5%
Landfill Waste	7%	-
Water Consumption	2%	-
Oil & Gas Depletion	5%	-
Solid Fuel Depletion	1%	-
Natural Forest lost	2%	-
Productive Farmland lost	2%	-
Habitat & Ecosystem	10%	-

3.2.7 Summary

The LCA comparison is between environmental impacts from installing sprinkler systems in a large number of houses compared to estimates of the reduced fire damage that would otherwise need to be replaced in a comparatively smaller number of houses.

BRANZ uses the BRE Environmental Profiles Methodology and attempted to bring all the data used to a common economic basis for allocation between co-products, adapt any data that originates from overseas to a New Zealand relevant context and ensure that the scope used for different data sources is, as far as possible consistent and compatible and appropriate for this project. BRANZ uses Ecopoints to measure the total environmental life cycle impact, such that 100 Ecopoints correspond to the annual impacts of an average New Zealand citizen.

The inputs for the LCA were established and the results were incorporated into the cost effectiveness assessment as a sustainability module. A summary of the LCA values for the materials assumed to be used in the average residential building stock are presented in **Error! Reference source not found.**, Appendix F and the LCA values for sprinkler materials are presented in **Error! Reference source not found.**, Appendix F.

The cost effectiveness model results, including the results for the sustainability module, are presented in Section 8.3.

4. RESIDENTIAL FIRE INCIDENT, FATALITY AND INJURY STATISTICS

Duncan et al (2000) and Wade & Duncan (2000) used both structure and non-structure residential fires (with an average of approximately 6000 incidents per year) for estimation of fire incident rates per year per household (approximately 0.004).

"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". (Duncan et al., 2000)

The simple correlation of statistics where sprinklers are present compared to where sprinklers are not present may understate the potential value of sprinklers "because it lumps together all sprinklers, regardless of type, coverage or operational status, and is limited to fires reported to fire departments". (Rohr & Hall, 2005)

In addition to the usual differences in demographics, fire safety standards, etc that influence international fire statistics, it is important to note that different sprinkler standards will also influence the statistics. Therefore international statistics are included in this study as a general reference and are not intended to be directly representational of the New Zealand situation.

4.1 Summary of New Zealand Statistics

The New Zealand statistics discussed here relate to residential structure fire incidents. More information is included in Appendix B.1.

4.1.1 All Residential Properties

The numbers of fire incidents per year for 1986 – 2005 and 1995 – 2005 are shown in Figure 5 and Figure 6 respectively. The statistics for the years 1986 – 2005 (as shown in Figure 5) shows a minor trend of a generally increasing number of recorded fire incidents per year with increasing year, which may be impacted by the change in recording processes of the statistics. However the statistics for the years 1995 – 2005 (as shown in Figure 6) show no overall chronological trend. Therefore the statistic for the years 1995 – 2005 were used in analysis. The bin size used in the analysis was 100 incidents per year and a beta distribution (as shown in **Error! Reference source not found.**) was fitted based on the mean of 2,850, minimum of 2,770, maximum of 3,450 and a standard deviation of 224 incidents per year (as presented in Table 10).

The numbers of civilian fire fatalities per year for 1995 – 2005 and the number of fatalities per thousand fires are shown in Figure 8 and Figure 9 respectively. The statistics for the years 1995 – 2005 (as shown in Figure 8 and Figure 9) show no simple chronological correlation. For the analysis of fatalities per year, the bin size of 1 fatality per year was used and a beta distribution (as shown in **Error! Reference source not found.**) was fitted based on the mean of 21, minimum of 18, maximum of 28 and a standard deviation of 4.2 fatalities per year (as presented in Table 10). For the analysis of fatalities per thousand fires per year, the bin size used was 0.5 fatalities per thousand fires per year and a beta distribution (as shown in **Error! Reference source not found.**) was fitted based on the mean of 6.8, minimum of 4.7, maximum of 9.5 and a standard deviation of 1.3 fatalities per thousand fires per year (as presented in Table 10).

The numbers of civilian fire injuries per year for 1995 – 2005 and the number of injuries per thousand fires are shown in Figure 10 and Figure 11 respectively. The statistics for the years 1995 – 2005 (as shown in Figure 10 and Figure 11) show no simple chronological correlation. For the analysis of injuries per year, a bin size of 10 injuries per year was used and a beta distribution (as shown in **Error! Reference source not found.**) was fitted based on the mean of 240, minimum of 180, maximum of 300 and a standard deviation of 38 injuries per year (as presented in Table 10). For the analysis of injuries per thousand fires per year, the bin size used was 4 injuries per thousand fires per year and a beta distribution (as shown in **Error! Reference source not found.**) was fitted based on the mean of 77, minimum of 57, maximum of 88 and a standard deviation of 9.9 injuries per thousand fires per year (as presented in Table 10).

The number of residential structures, based on New Zealand consensus data, is shown in Figure 12 and is summarised for the range of years under consideration for fire statistics in Table 10.

Table 10: Summary of New Zealand residential fire statistics (assuming a normal distribution)

	Range of Years	Min.	Mean	95th Percentile	Max.	Standard Deviation
Fire Incidents/year	1995-2005	2,770	3,140	3,450	3,450	224
Fire Incidents/year	1986-2005	1,862	2,850	3,450	3,450	470
Fire Incidents/ 1000 residential structures/year [a]	1995-2005	1.9	2.7	3.3	3.4	0.5
Residential Structures (1000's) [a]	1995-2005	910	1,176	1,447	1,483	190
Fatalities/year	1995-2005	15	21	28	28	4.2
Fatalities/1000 Fires/year	1995-2005	4.7	6.8	8.9	9.5	1.3
Injuries/year	1995-2005	180	240	300	300	38
Injuries/1000 Fires/year	1995-2005	57	77	88	88	9.9

Note:
[a] This residential building stock values are based on New Zealand consensus data from 1991, 1996, 2001 and 2006.

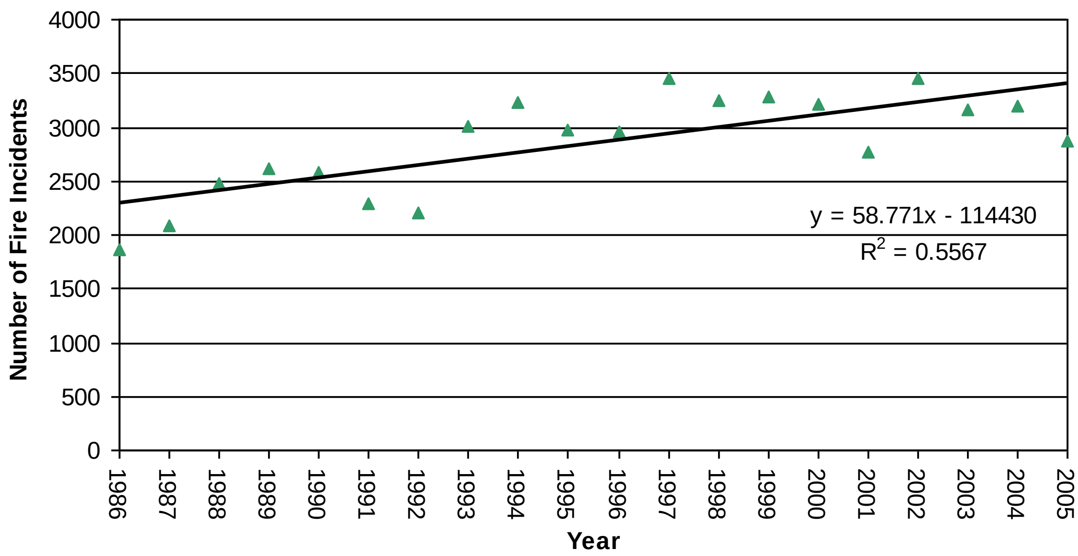


Figure 5: Number of fire incidents per year for New Zealand residential fires from 1986 to 2005.

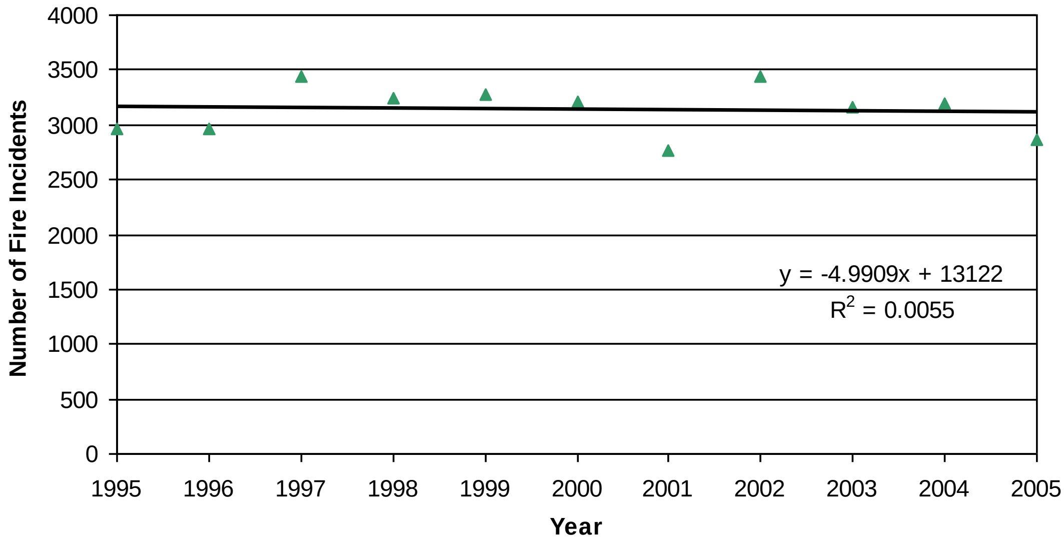


Figure 6: Number of fire incidents per year for New Zealand residential fires from 1995 to 2005.

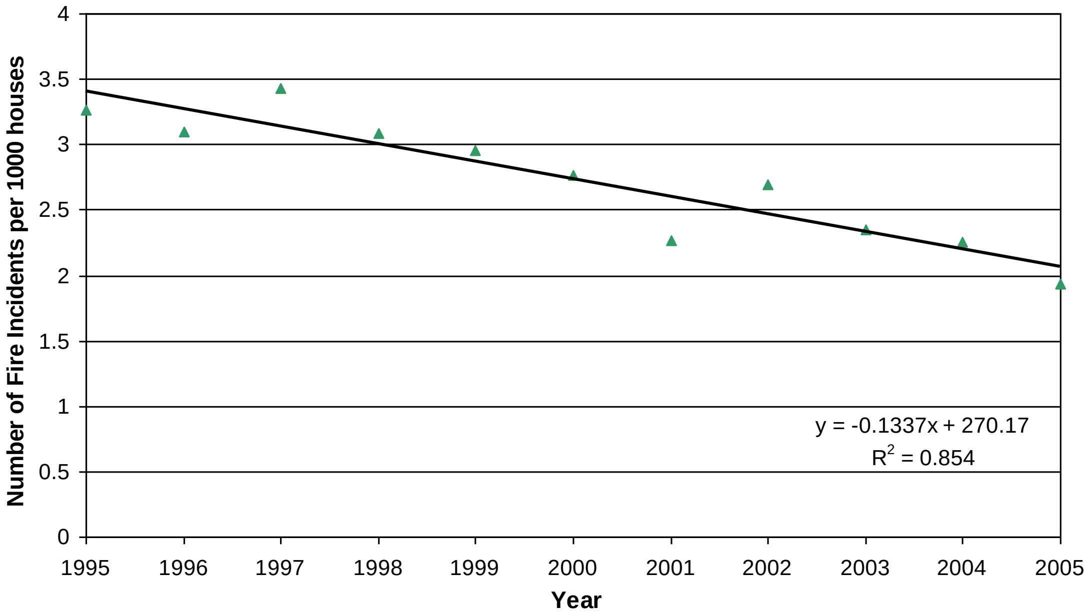


Figure 7: Number of fire incidents per 1000 houses per year for New Zealand residential fires from 1995 to 2005.

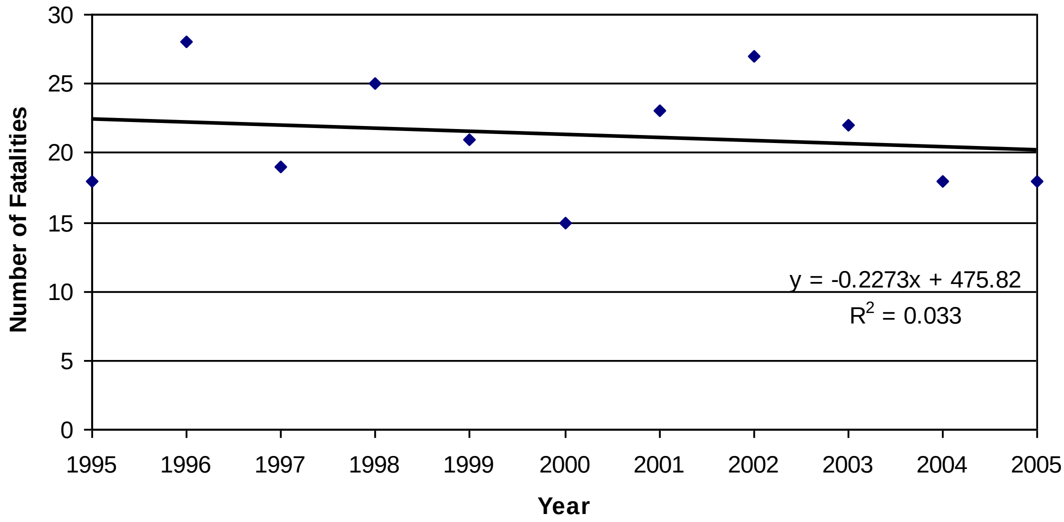


Figure 8: Number of civilian fire fatalities per year for New Zealand residential fires from 1995 to 2005.

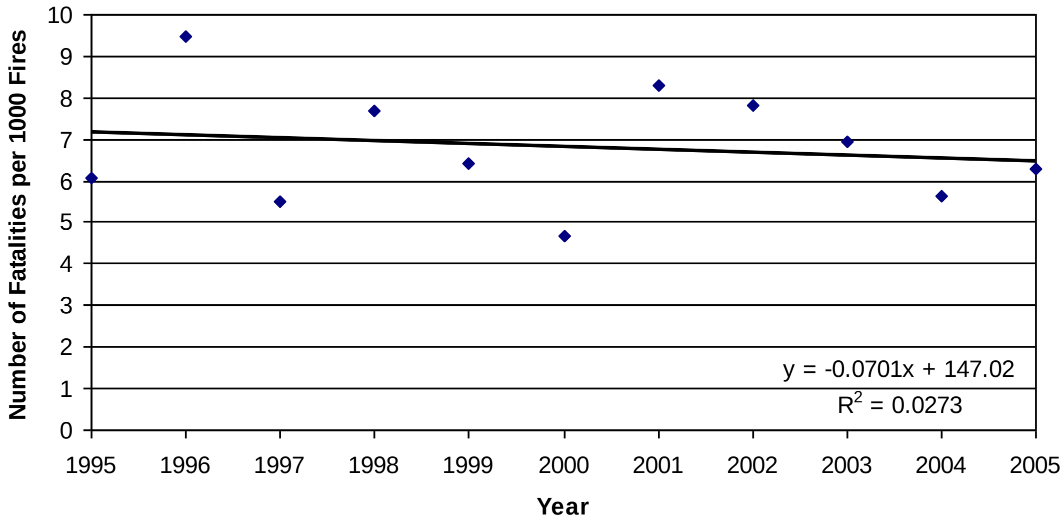


Figure 9: Number of civilian fire fatalities per 1000 fires per year for New Zealand residential fires from 1995 to 2005.

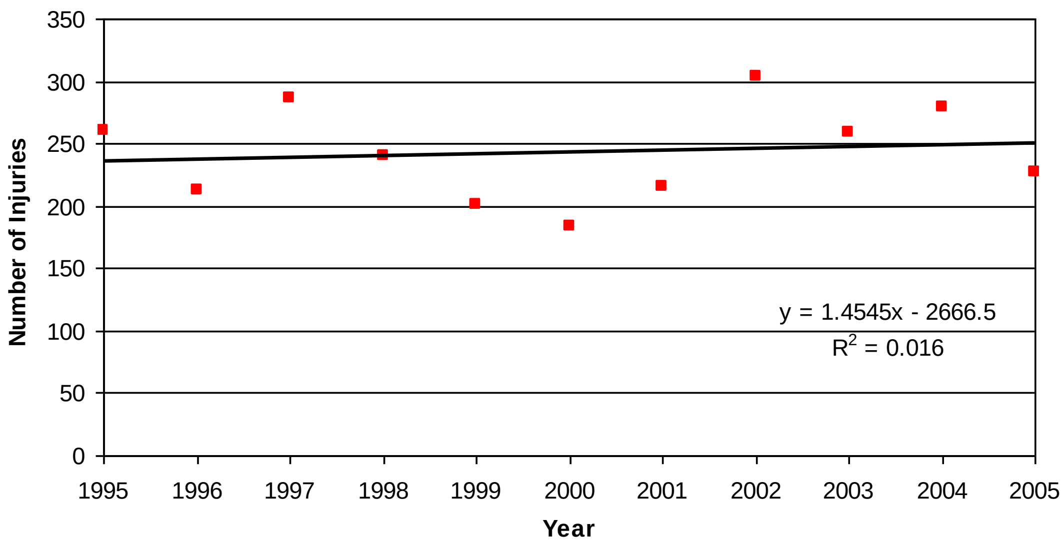


Figure 10: Number of civilian fire injuries per year for New Zealand residential fires from 1995 to 2005.

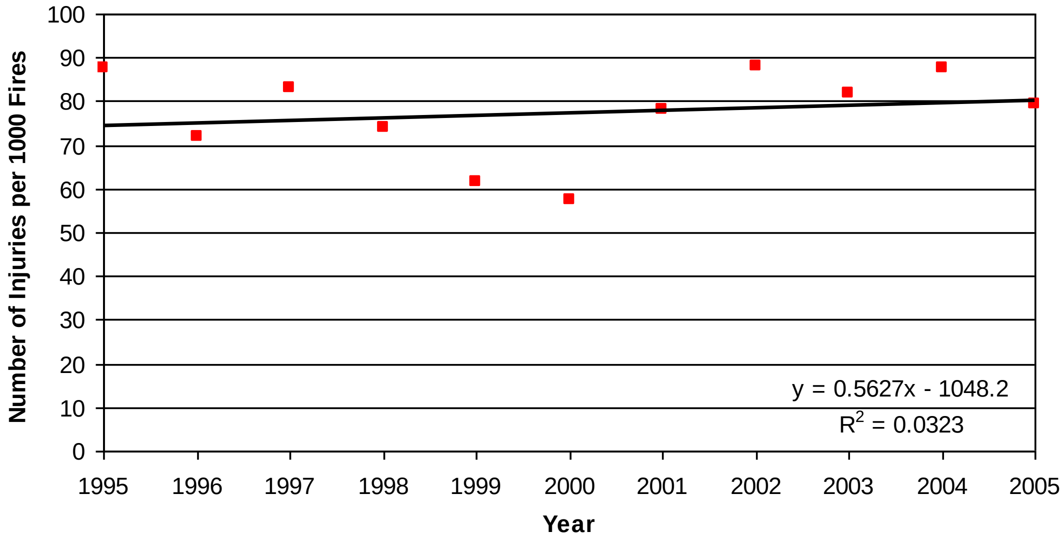


Figure 11: Number of civilian fire injuries per 1000 fires per year for New Zealand residential fires from 1995 to 2005.

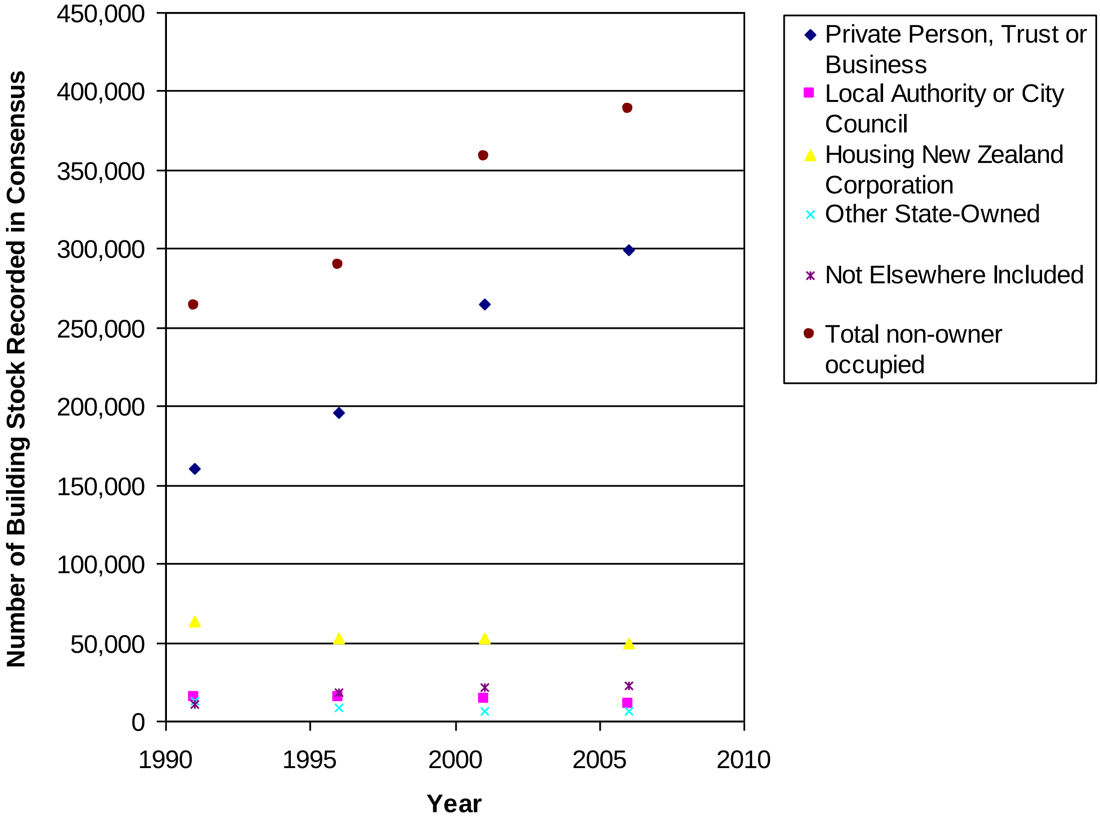


Figure 12: Number of residential building stock recorded in New Zealand consensuses for non-owner occupied properties (1991, 1996, 2001 and 2006).

4.1.2 Residential Properties by Occupier Type

The statistics were also analysed based on property occupier type. The types available were: owner occupied, and several ranges of non-owner occupied including state or local council owned, Housing New Zealand Ltd owned, and rented properties. Also there were categories for where the information was not recoded or recorded as ‘unknown’. The number of residential structure fires per year for each of the categories of occupier type considered is shown in Figure 13. The number of residential structure fire civilian fatalities per year for each occupier category is shown in Figure 14. The number of residential structure fire civilian injuries per year for each occupier category is shown in Figure 15. Detailed statistics are included in Appendix B1.1 for completeness.

The results of the analyses for simplified occupier categories are presented in the following sections.

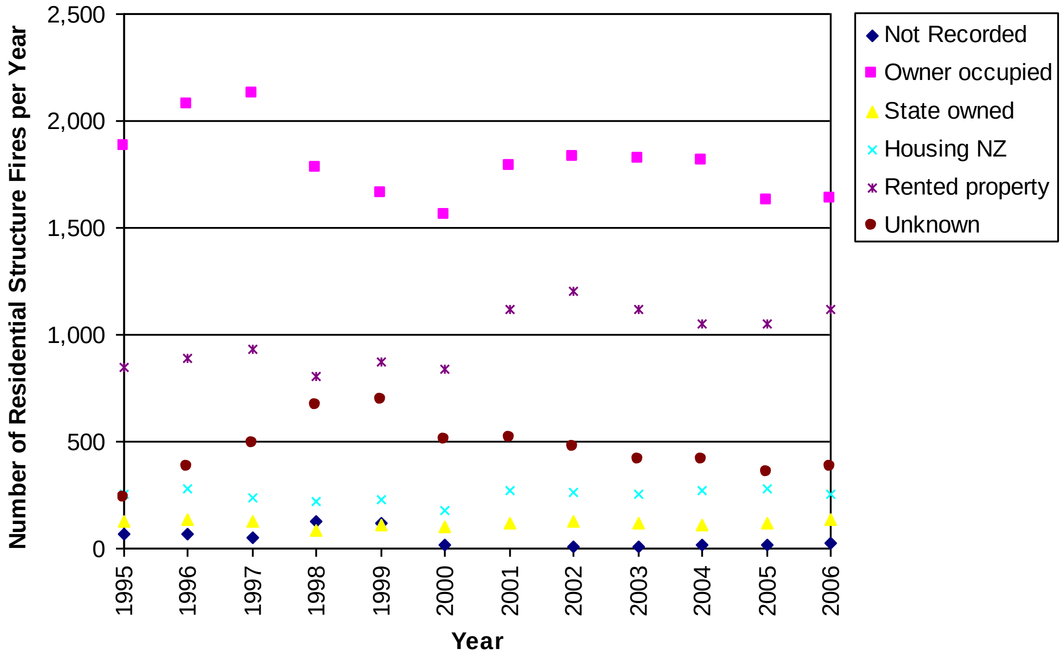


Figure 13: Number of residential structure fire incidents per year based on occupier category.

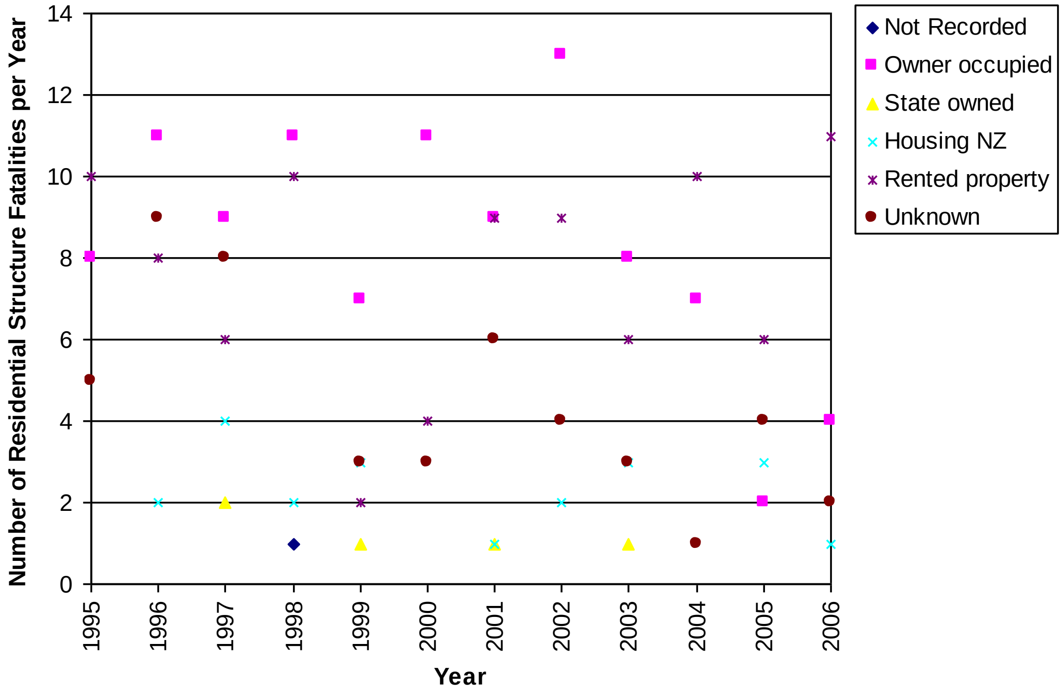


Figure 14: Number of residential structure fire civilian fatalities per year based on occupier category.

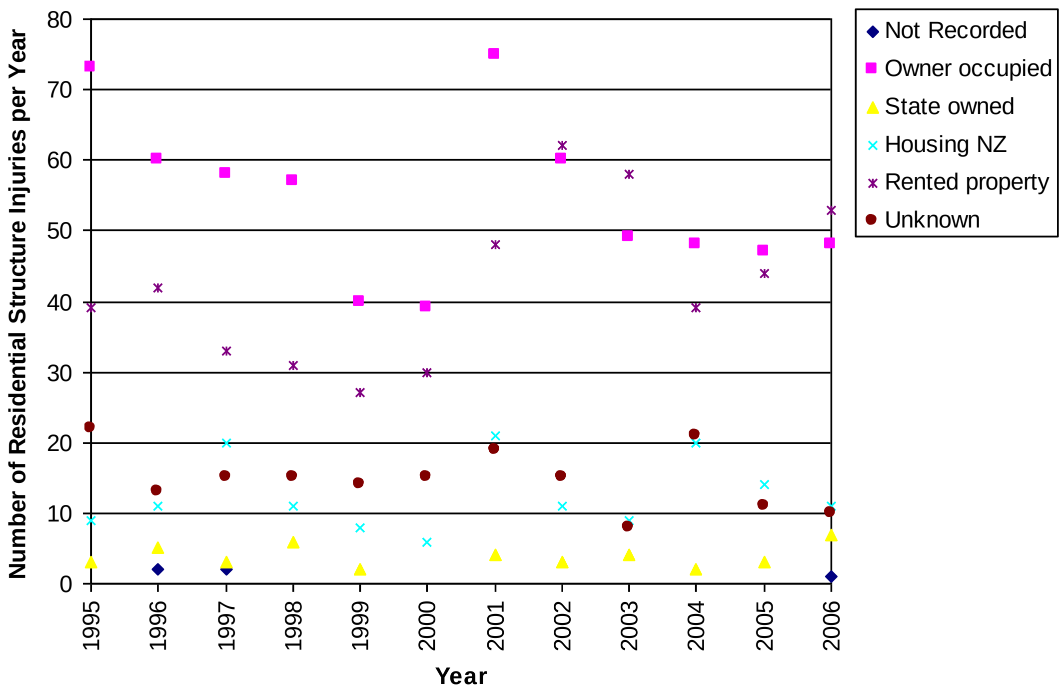


Figure 15: Number of residential structure fire civilian injuries per year based on occupier category.

4.1.2.1 Simplified Property Categories

A simplified approach was applied to the occupier types where by only two categories were considered: owner occupied and not owner occupied. The category for the not owner occupied residential properties includes rentals, and government owned, council owned and Housing NZ owned residential building stock. A summary of the statistics are presented in Table 11. The minimum, mean and maximum values are presented. The calculated 95th percentile and standard deviation, assuming a normal distribution, are also presented. The “unknown” and “not recorded” categories were removed from the data set by assuming that they are proportionally distributed over the remaining categories.

Table 11: Summary of the NZFS statistics for residential structure fires based on simplified occupancy of property (1995 – 2006) and interpolated censes data (1991, 1996, 2001, 2006).

	Simplified Occupier Category	Min.	Mean	95th Percentile	Max.	Standard Deviation
Average No. Households	Owner occupied	485,538	782,216	1117281	1,168,472	211803
	Not owner occupied	263,283	324,985	383865	388,272	44878
Fire Incidents/year	Owner occupied	722	1,946	2358	2,416	409
	Not owner occupied	657	1,531	1815	1,867	320
Fire Incidents/ 100,000 properties/ year	Owner occupied	156	249	346.8	349	67.2
	Not owner occupied	382	470	538.7	551	51.0
Fatalities/year	Owner occupied	3	9	14.5	15	3.9
	Not owner occupied	1	10	14.0	16	3.9
Fatalities/ 1000 Fires/year	Owner occupied	1.4	4.8	7.1	7.2	1.7
	Not owner occupied	1.5	6.4	10.1	10.2	2.3
Fatalities/ 100,000 properties/ year	Owner occupied	0	1	1.9	2	0.6
	Not owner occupied	1	3	4.6	5	1.0
Injuries/year	Owner occupied	21	58	83.7	84	16.7
	Not owner occupied	38	65	85.5	86	17.4
Injuries/ 1000 Fires/year	Owner occupied	22.7	29.7	41.0	41.3	5.5
	Not owner occupied	28.8	42.9	51.9	57.5	7.6
Injuries/ 100,000 properties/ year	Owner occupied	4	7	11.6	13	2.8
	Not owner occupied	11	20	23.8	24	4.1

Consistently more fire incidents occurred in owner occupied properties between 1995 and 2006. The trend of fire incidents per year is shown in Figure 16. However more fire incidents occurred in properties not owned by the occupier per type of property. That is, the occurrence of fire incidents per property type was higher for properties not were occupied by the owner of the property. The trend of fire incidents per 100,000 properties per year is shown in Figure 17.

On average, the same number of civilian fire fatalities occurred each year for each property occupier type and a similar number of civilian fatalities occurred per 1000 fire incident for each occupier type. The trend of civilian fire fatalities per year and of civilian fire fatalities per 1,000 fire incidents per year are shown in Figure 18 and Figure 19 respectively. However the number of fatalities per number of properties was consistently higher for non-owner occupied property each year (Figure 20), which is consistent with the higher numbers of fire incidents per number of properties not occupied by the owner (Figure 17).

On average a similar number of total civilian fire injuries occurred in both owner occupied and non-owner occupied properties each year. The trend of civilian fire injuries per year is shown in Figure 21. Consistently more injuries per fire incident were reported for non-owner occupied properties. The trend of civilian fire injuries per 1000 fire incidents per year is shown in Figure 22. Significantly more injuries occurred per non-owner occupier property than for owner occupied properties. The trend of civilian fire injuries per 100,000 properties per year is shown in Figure 23.

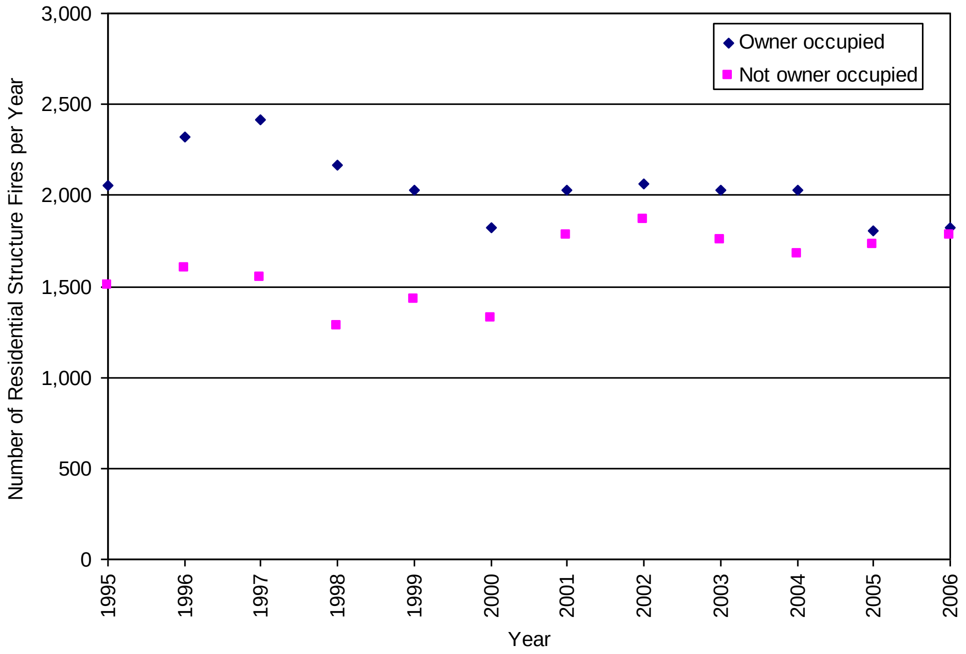


Figure 16: Number of residential structure fire incidents per year based on simplified occupier categories.

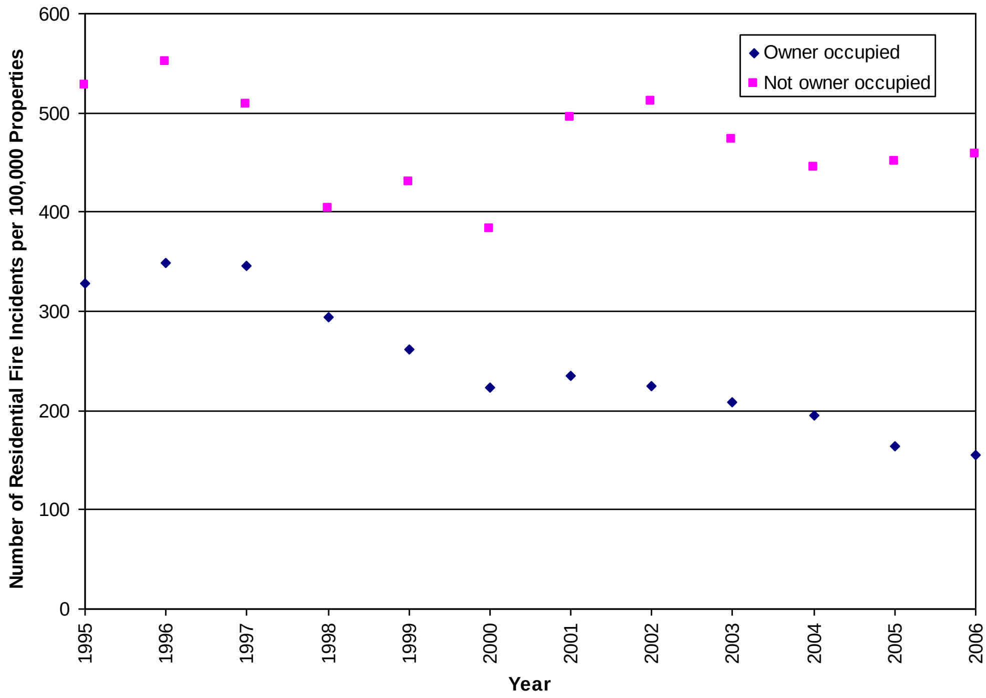


Figure 17: Number of residential structure fire incidents per 100,000 properties per year based on simplified occupier categories.

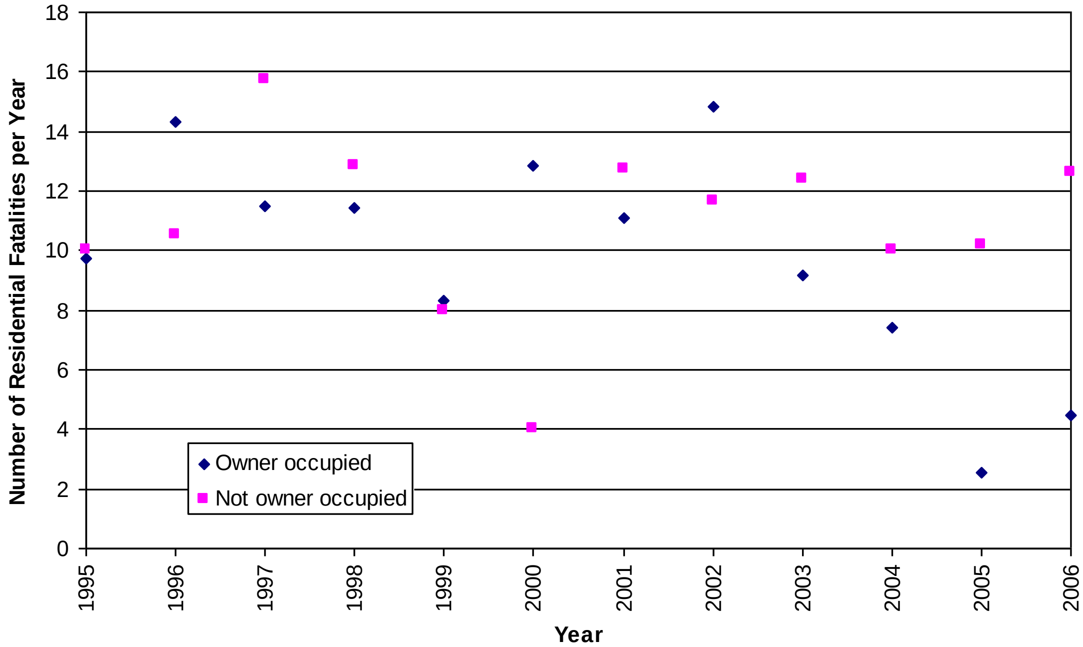


Figure 18: Number of residential structure fire civilian fatalities per year based on simplified occupier categories.

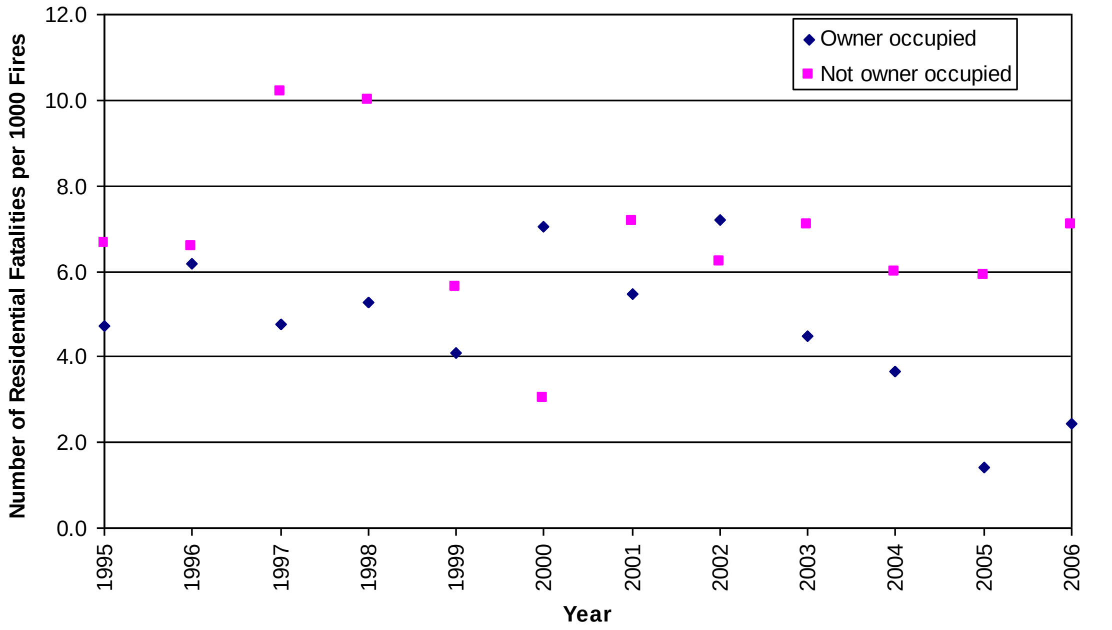


Figure 19: Number of residential structure fire civilian fatalities per 1000 fire incidents per year based on simplified occupier categories.

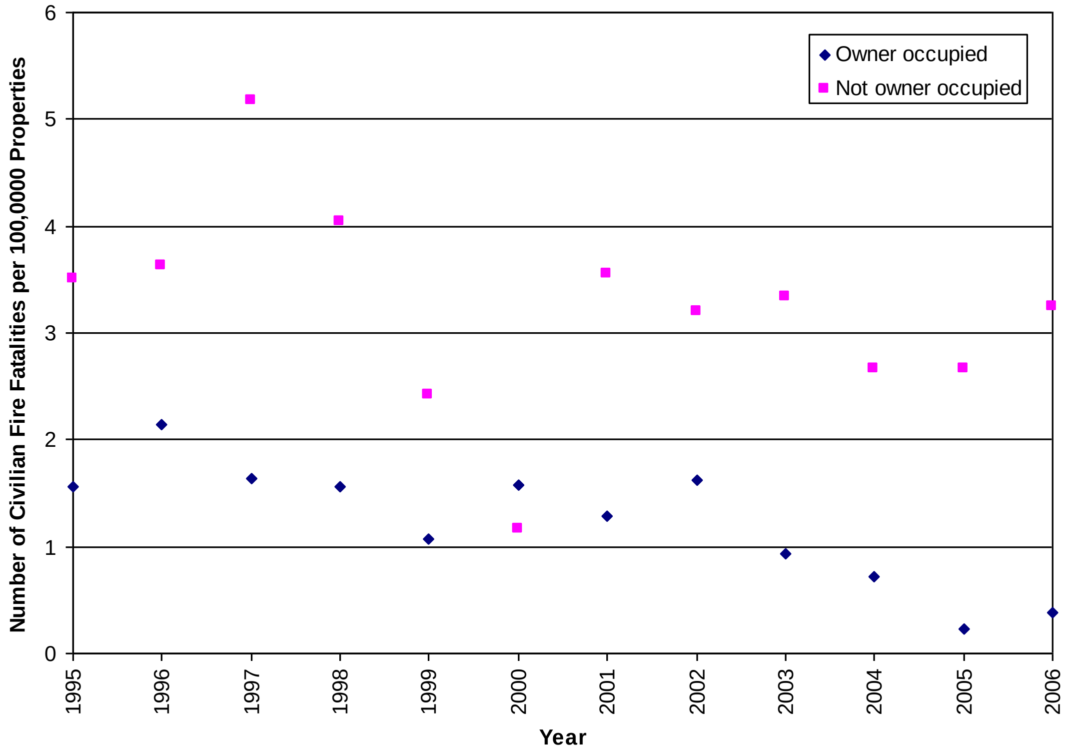


Figure 20: Number of residential structure fire civilian fatalities per 100,000 properties per year based on simplified occupier categories.

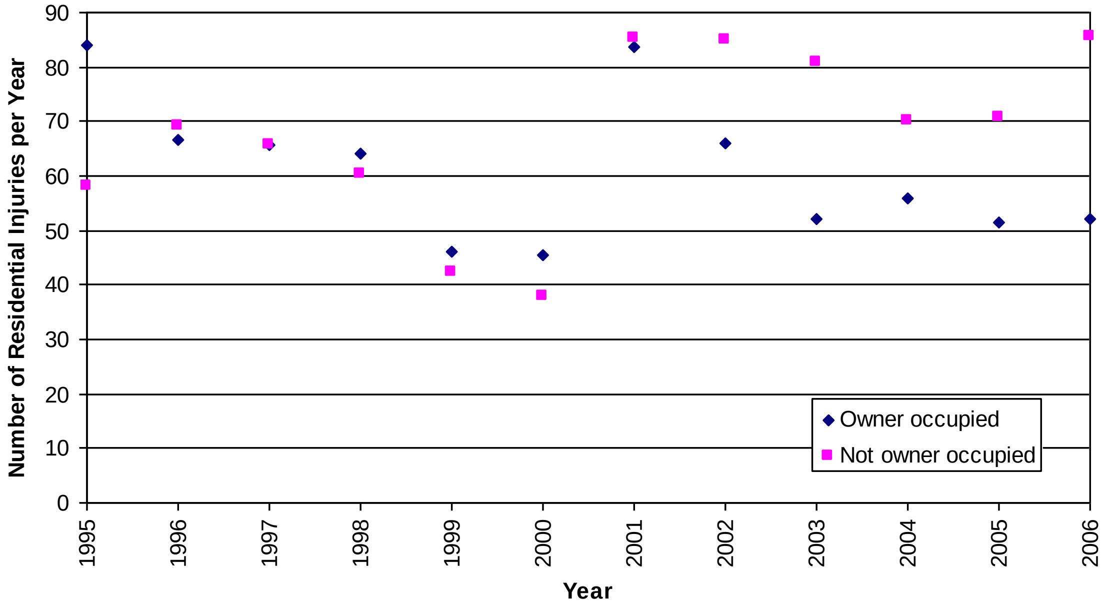


Figure 21: Number of residential structure fire civilian moderate & life threatening injuries per year based on simplified occupier categories.

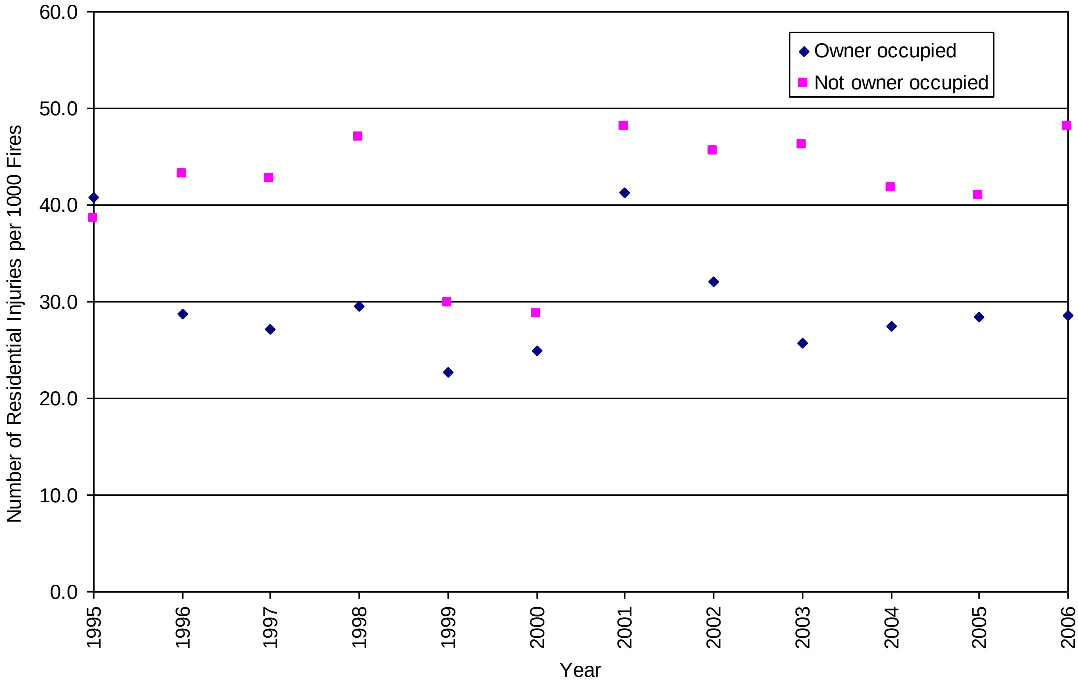


Figure 22: Number of residential structure fire civilian moderate & life threatening injuries per 1000 fire incidents per year based on simplified occupier categories.

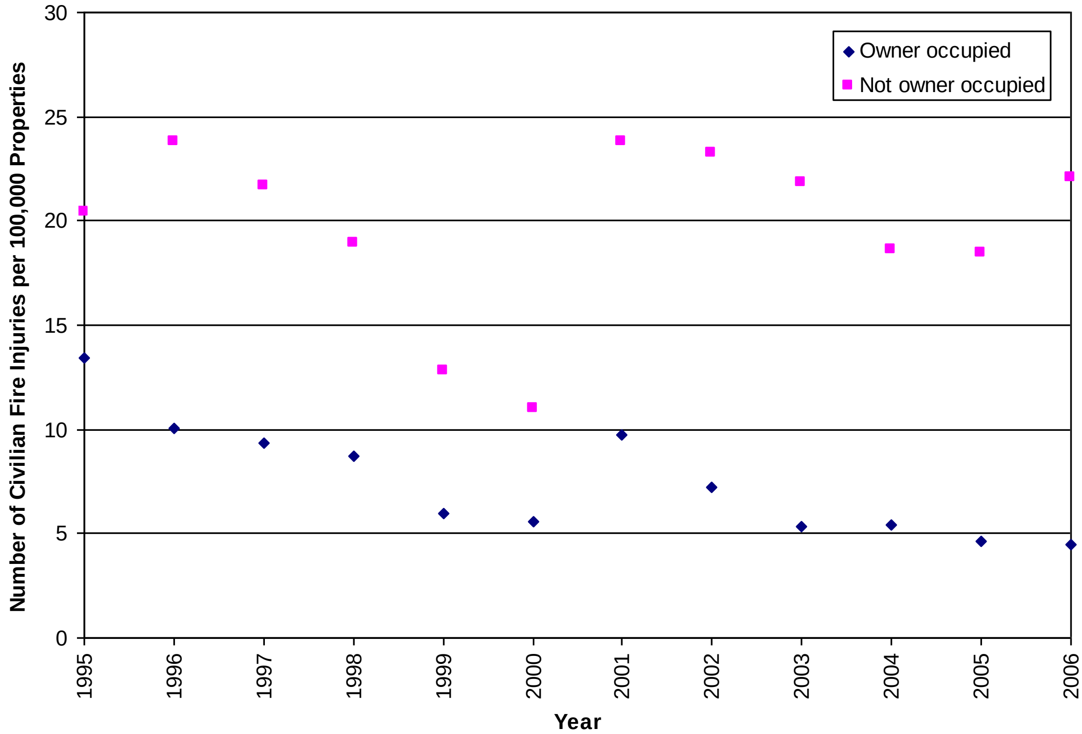


Figure 23: Number of residential structure fire civilian moderate & life threatening injuries per 100,000 properties per year based on simplified occupier categories.

4.1.2.2 Detailed Property Categories

This section provides results from analysis using more detailed categories for the properties that were not owner occupied. This analysis was performed assuming 'unknown' and 'not recorded' categories are proportionally distributed between the remaining categories. A summary of the statistical analysis is presented in Table 12. The calculated 95th percentile and standard deviation were calculated assuming a normal distribution.

Table 12: Summary of the NZFS statistics for residential structure fires based on detailed occupancy of property (1995 – 2006) and interpolated censes data (1991, 1996, 2001, 2006).

	Property Occupier Category	Min.	Mean	95th Percentile	Max.	Standard Deviation
Average No. Households	Owner occupied	485538	782216	1168472	1117281	211803
	State owned *	18204	23552	29799	29054	3531
	Housing NZ	52398	57267	66281	64810	4022
	Rented property	167202	244167	317670	312207	51877
Fire Incidents/year	Owner occupied	722	1,946	2358.2	2,416	409.4
	State owned *	119	281	339.2	351	62.1
	Housing NZ	105	245	290.0	290	51.4
	Rented property	433	1,006	1231.3	1,285	223.6
Fire Incidents/ 100,000 properties/ year	Owner occupied	156	249	346.8	349	67.2
	State owned *	886	1,353	1679.8	1,785	236.0
	Housing NZ	332	466	532.2	546	60.6
	Rented property	333	399	455.0	458	43.1
Fatalities/year	Owner occupied	3	9	14.5	15	3.9
	State owned *	0	1	3.3	5	1.5
	Housing NZ	0	2	3.6	4	1.5
	Rented property	1	8	11.1	12	3.3
Fatalities/ 1000 Fires/year	Owner occupied	1.4	4.8	7.1	7.2	1.7
	State owned *	0.0	3.0	11.4	14.5	5.0
	Housing NZ	0.0	6.5	15.2	17.7	5.8
	Rented property	2.3	7.3	11.7	12.7	3.1
Fatalities/ 100,000 properties/ year	Owner occupied	0	1	1.9	2	0.6
	State owned *	0	4	15.0	19	6.8
	Housing NZ	0	3	6.6	8	2.6
	Rented property	1	3	4.7	5	1.2
Injuries/year	Owner occupied	21	58	83.7	84	16.7
	State owned *	0	8	15.5	17	4.5
	Housing NZ	6	13	20.9	22	4.9
	Rented property	21	44	63.9	67	13.5
Injuries/ 1000 Fires/year	Owner occupied	22.7	29.7	41.0	41.3	5.5
	State owned *	0.0	30.0	59.1	71.2	17.4
	Housing NZ	32.3	55.1	98.4	118.8	25.9
	Rented property	31.7	43.7	51.9	52.1	6.1
Injuries/ 100,000 properties/ year	Owner occupied	4	7	11.6	13	2.8
	State owned *	0	39	75.7	91	22.9
	Housing NZ	11	23	38.1	39	9.5
	Rented property	12	17	22.3	23	3.8

Note: * 'State owned' refers to government department owned residential building stock (such as the Police and Education) and council owned residential building stock.

The total number of fire incidents per year was consistently greatest for owner occupied properties for 1995 – 2006, as shown in Figure 24. The number of fire incidents per property was significantly higher for state owned properties, as shown in Figure 25.

The highest total number of civilian fire fatalities per year was for owner occupied properties, with rented properties only slightly less, as shown in Figure 26. The results for the number of civilian fatalities per number of fires for each occupier type were mixed between each of the categories considered, as shown in Figure 27. However the fatalities per incident results associated with the owner occupied properties were relatively less than each of the non-owner occupied properties per year. The number of civilian fire fatalities per property was consistently higher for state owned and Housing NZ owned properties, as shown in Figure 28.

The results for civilian injuries were similar to those discussed for civilian fatalities. The total number of civilian injuries was slightly higher for owner occupied properties, however rented properties were close behind, as shown in Figure 29. The number of civilian injuries per fire incident was similar for each of the categories considered, except for a few years where state owned and Housing New Zealand properties recorded much higher injuries per incident than the other categories, as shown in Figure 30. The results for state owned and Housing New Zealand owned properties for injuries per number of properties were consistently the highest of the categories considered and owner occupied properties had the least number of injuries per number of properties, as shown in Figure 31.

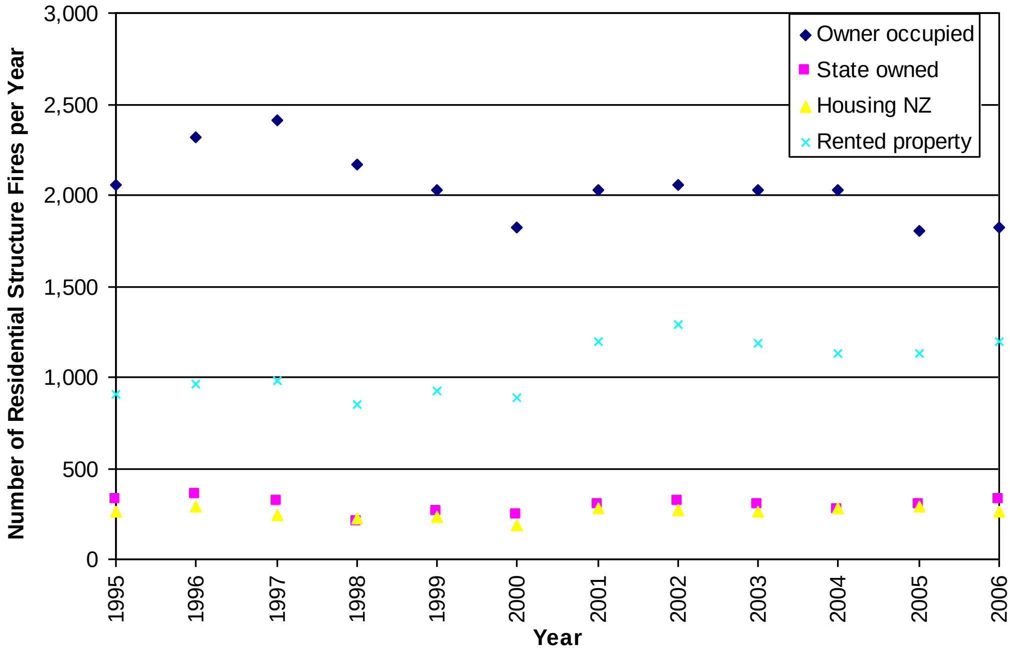


Figure 24: Number of residential structure fire incidents per year based on detailed occupier categories.

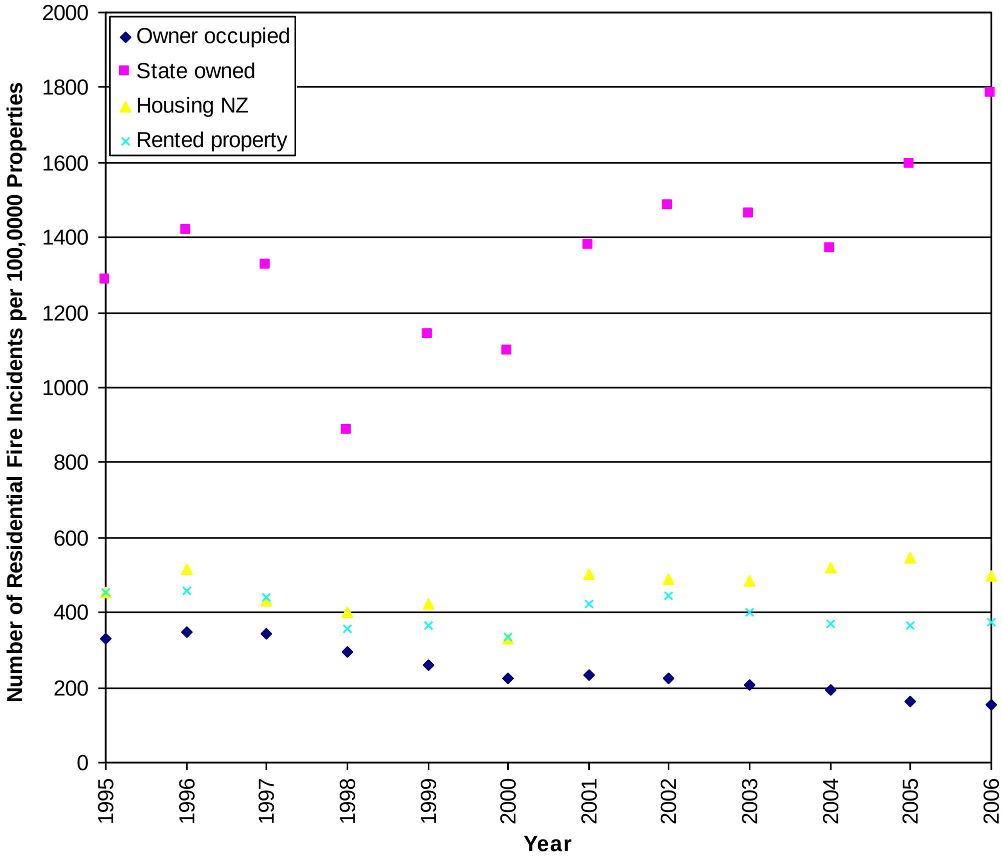


Figure 25: Number of residential structure fire incidents per 100,000 properties per year based on detailed occupier categories.

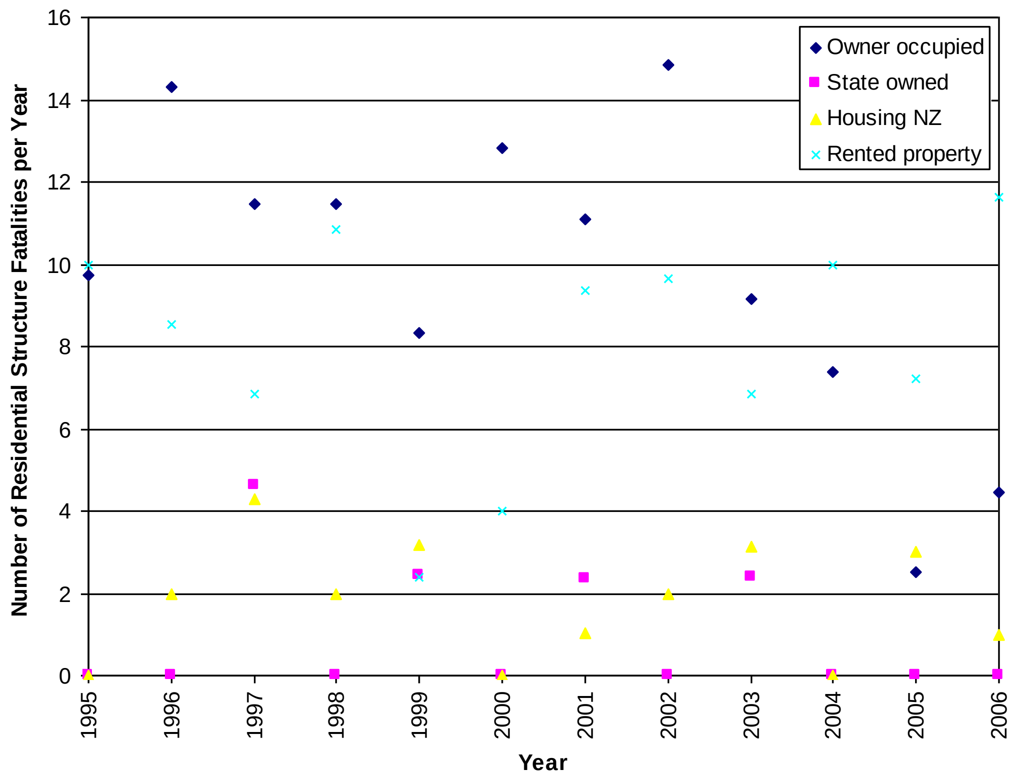


Figure 26: Number of residential structure fire civilian fatalities per year based on detailed occupier categories.

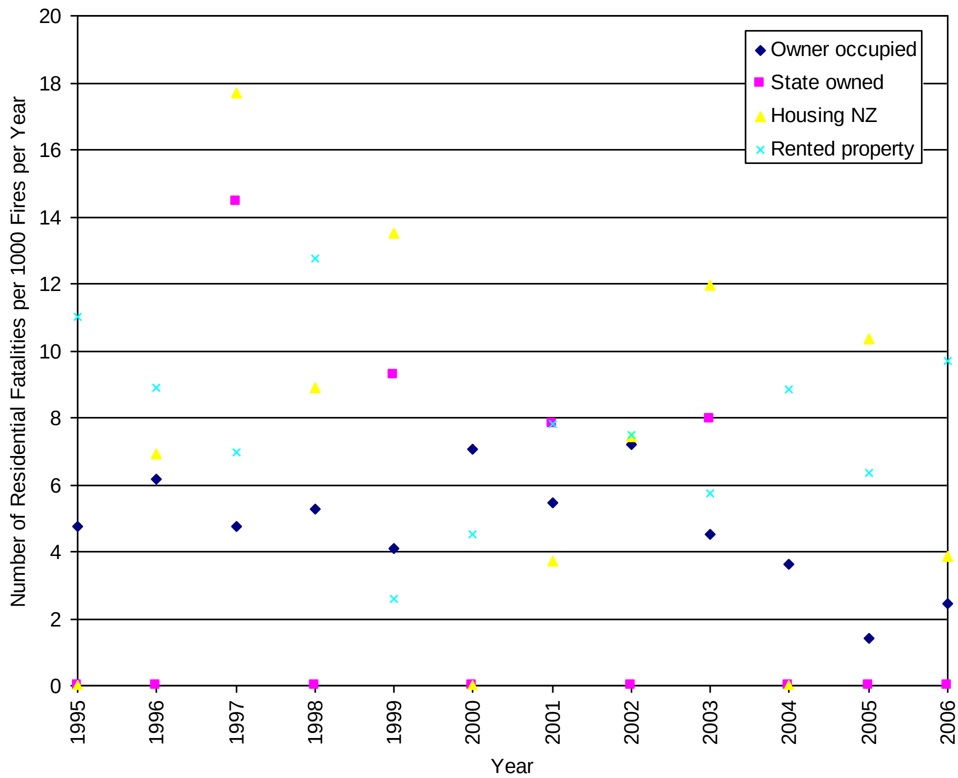


Figure 27: Number of residential structure fire civilian fatalities per 1000 fire incidents per year based on detailed occupier categories.

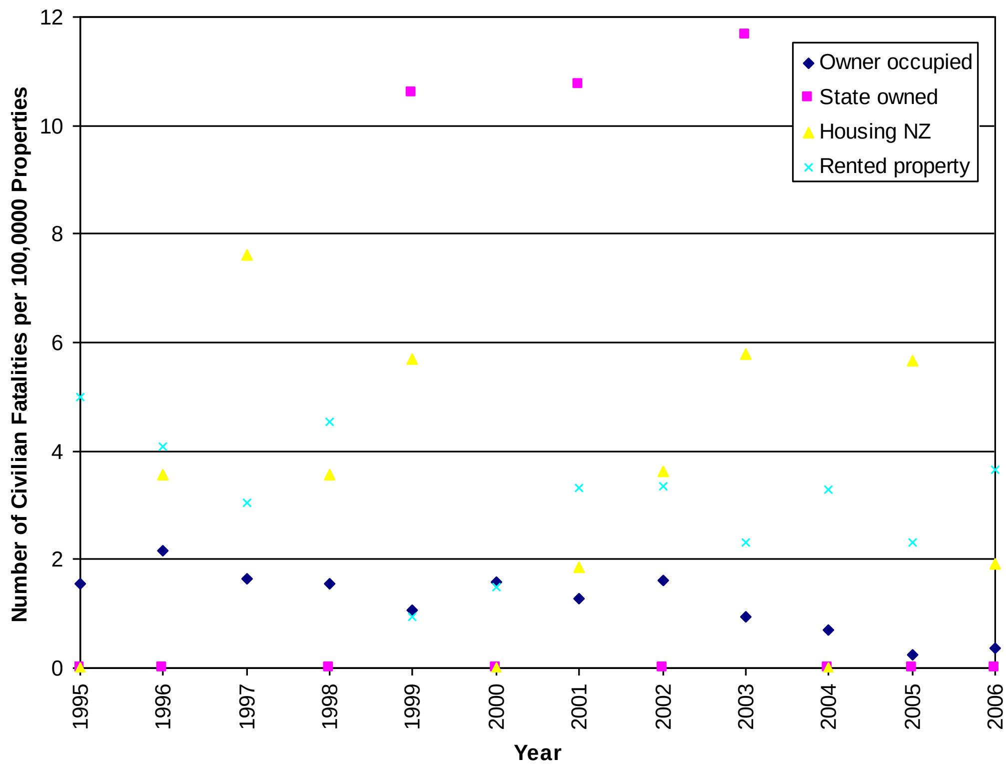


Figure 28: Number of residential structure fire civilian fatalities per 100,000 properties per year based on detailed occupier categories.

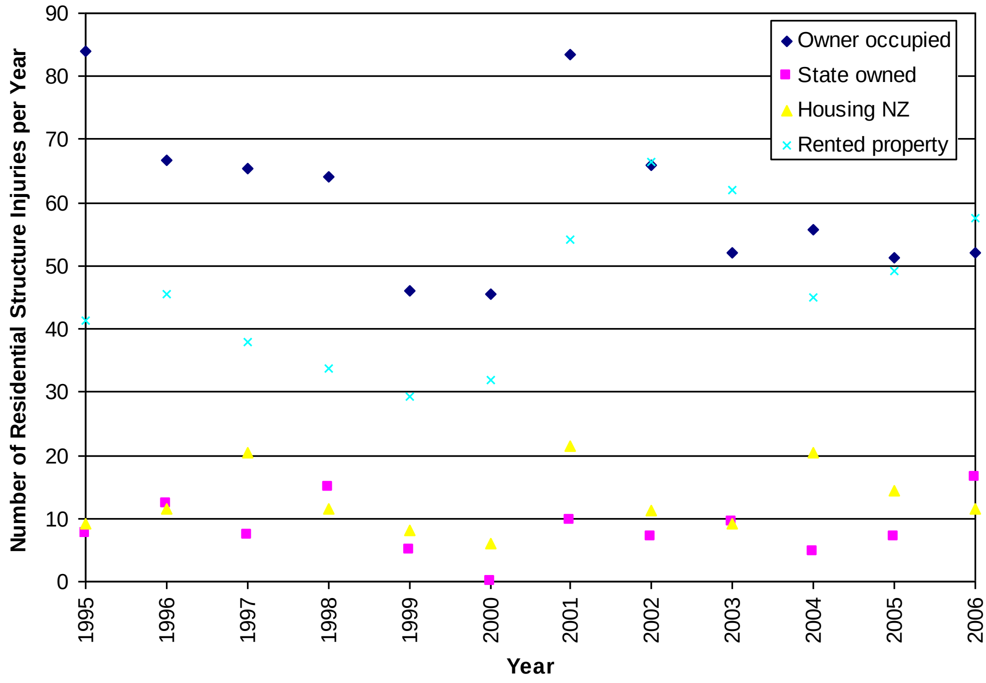


Figure 29: Number of residential structure fire civilian moderate & life threatening injuries per year based on detailed occupier categories.

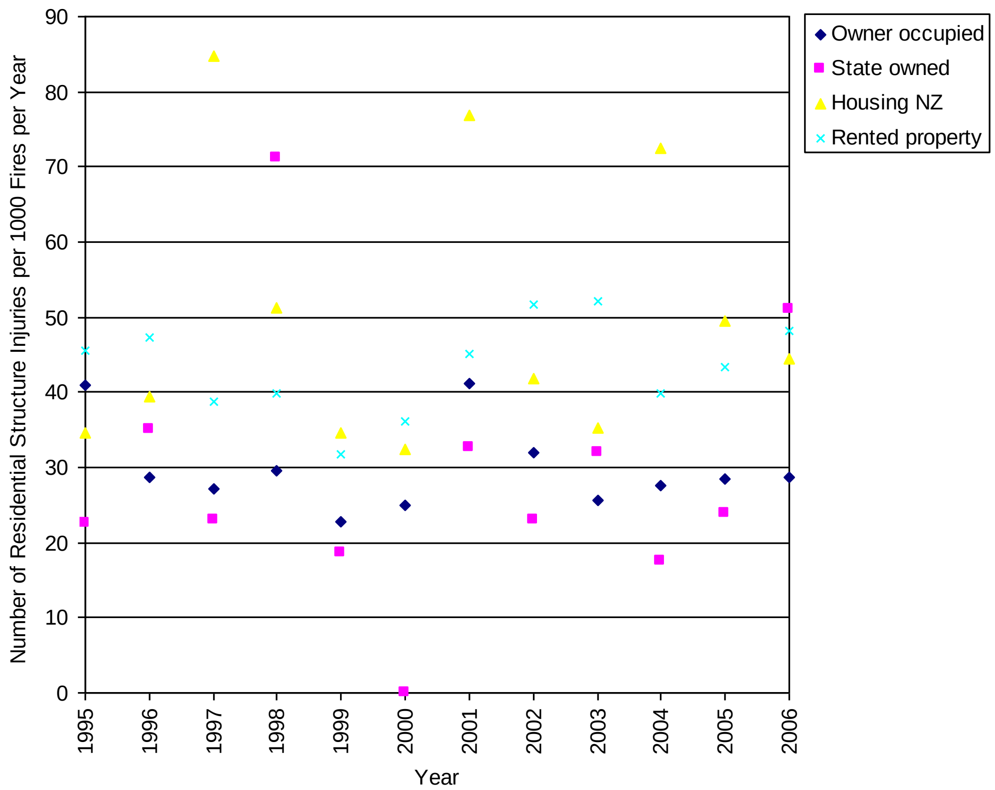


Figure 30: Number of residential structure fire civilian moderate & life threatening injuries per 1000 fire incidents per year based on detailed occupier categories.

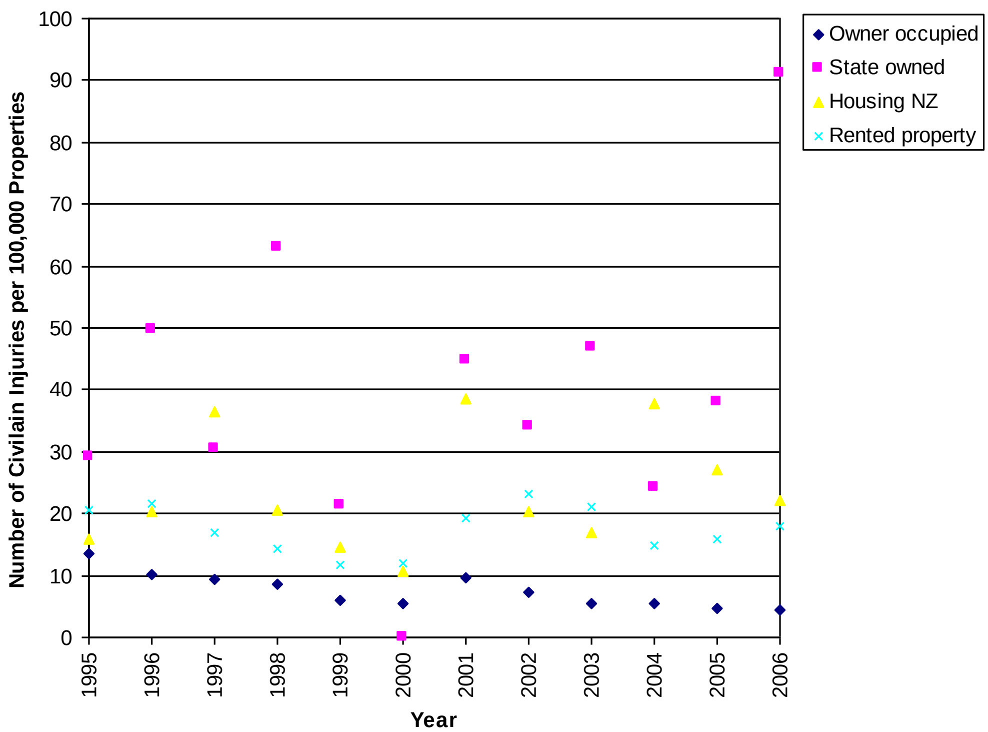


Figure 31: Number of residential structure fire civilian moderate & life threatening injuries per 100,000 properties per year based on detailed occupier categories.

4.1.3 Proportion of Structure Damage

For single house damage from fire in New Zealand the majority is saved with <10% damage (1,949), but that on average 184 houses sustain >90% losses (i.e. 0-10% of the structure was saved) to fires per year (see Table 13). In Figure 32 it can be seen that for structural damage from fire in New Zealand the majority of residential structure fires is saved with <10% damage, but also that approximately 600 structures per year (589 in 2005/06) are between 90 – 100% lost in fire.

Table 13: Single house fires by amount of structure saved (Challands, 2007).

Year	Percentage of structure saved										No structural damage (100% saved)	Total
	0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
2002/03	179	29	18	42	60	36	54	83	132	685	1,415	2,736
2003/04	220	22	16	30	76	41	55	95	134	732	1,283	2,704
2004/05	193	27	21	28	59	27	60	82	143	725	1,231	2,596
2005/06	154	32	25	39	62	37	61	78	135	721	1,087	2,421
2006/07	175	22	19	39	81	30	46	72	155	762	1,105	2,506
Average	184	26	20	34	68	35	55	82	140	725	1,224	2,593

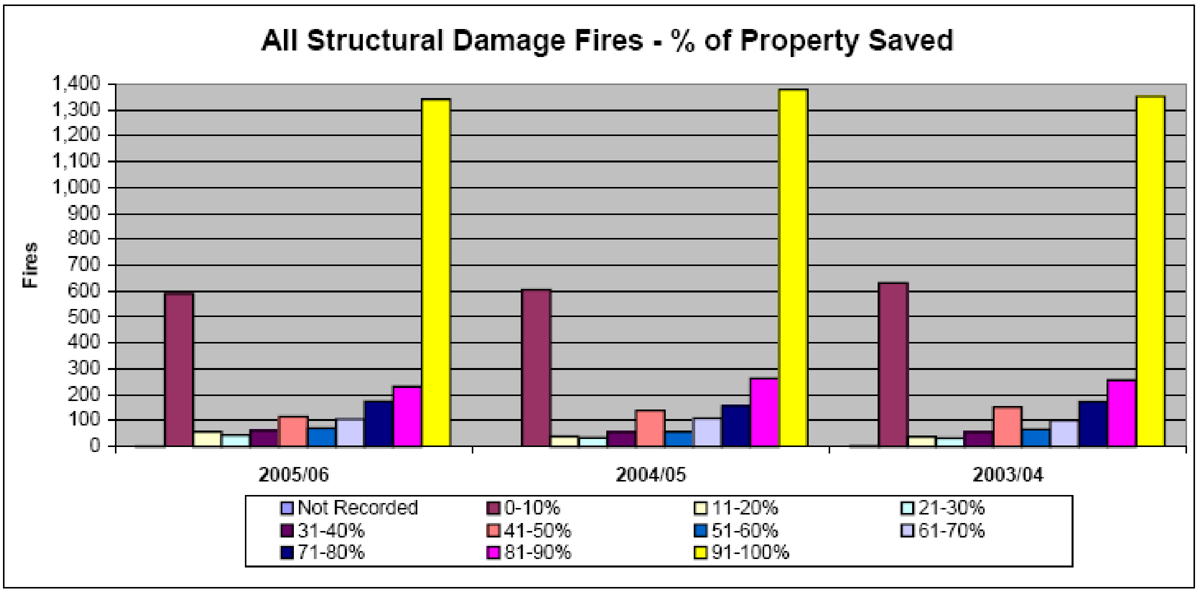


Figure 32: Proportions of property saved for all structural fires (NZFS, 2006a)

4.1.4 Detector and Suppression System Activation – All Structure Fires

Sprinklers were a very small portion of the detector/alarm systems activated at structure fires in 2005/2006 (149 out of 6109), as presented in Table 14. These results are for all structure fires in New Zealand. There are very few home sprinkler systems installed in New Zealand homes.

Table 14: Type of detector or suppression system activated at structure fires over the period 2005/06 (NZFS, 2006a)

Detector and/or Suppression System Type	Number of Fires where Detector/System Activated
Domestic (Home) Sprinkler	16
Sprinkler	128
Residential Sprinkler	5
CO2	2
Inert Gas	2
Halons (BCF, BTM, etc)	1
Dry Powder	2
Foam	1
Domestic Smoke Alarm	847
Smoke Detector System (monitored)	534
Smoke Detector/ Security Alarm System	80
Smoke Sampling System	6
Heat Detector, Thermal Detector	65
Flame Detector	2
Flammable Vapour Detector	1
Deluge System	4
Drencher System	4
Water Spray Projection System	2
Not recorded	4387
Unable to classify	20
Total	**6109**

Note: the 'not recorded' category includes all structure fires where no alarm was activated.

4.2 Summary of USA Statistics

The percentage of fires in buildings with automatic suppression system was approximately 2% in home (including detached dwellings, duplexes, row houses, apartments, townhouses, manufactured housing, etc) structure fires 1994 – 1998 annual averages. (Aherns 2007) This constitutes a relatively small sample size, furthermore the percentage of fires in one- and two-family dwelling structure fires is smaller than this estimate.

The USA statistics discussed here relate to one- and two-family structure fire incidents, as presented by Aherns (2007). More information is included in Appendix B.2.

The numbers of fire incidents per year for 1980 – 2005 and 1995 – 2005 are shown in Figure 33 and Figure 34 respectively. The statistics for the years 1980 – 2005 (as shown in Figure 33) show a reasonable direct chronological correlation of decreasing number of recorded fire incidents per year with increasing year, which may have been impacted by the change in recording processes of the statistics when NFIRS version 5.0 was introduced in 1999. However the statistics for the years 1995 – 2005 (as shown in Figure 34) show no overall direct chronological trend, and have a smaller range and sample standard deviation than the statistics for 1980 – 2005. Therefore the statistic for the years 1995 – 2005 were used in the analysis. The bin size used in the analysis was 2,000 incidents per year and a beta distribution (as shown in **Error! Reference source not found.**) was fitted based on the mean of 289,000, minimum of 281,000, maximum of 3254,000 and a standard deviation of 14,400 incidents per year (as presented in Table 15).

The numbers of civilian fire fatalities per year for 1980 – 2005 and the number of fatalities per thousand fires are shown in Figure 35 and Figure 36 respectively, and for 1995 – 2005 in Figure 37 and Figure 38 respectively. The statistics for the years 1995 – 2005 (as shown in Figure 37 and Figure 38) show no simple chronological correlation. The statistics for the years 1980 – 2005 show a reasonable direct chronological correlation with decreasing number of fatalities per year (as shown in Figure 35), and a slight direct chronological correlation with increasing numbers of fatalities per thousand fires (as shown in Figure 36). Therefore the statistics for 1995 – 2005 were used for analysis. For the analysis of fatalities per year (1995 – 2005), the bin size of 50 fatalities per year was used and a beta distribution (as shown in **Error! Reference source not found.**) was fitted based on the mean of 2,700, minimum of 2,300, maximum of 3,300 and a standard deviation of 320 fatalities per year (as presented in Table 15). For the analysis of fatalities per thousand fires per year, the bin size used was 0.1 fatalities per thousand fires per year and a beta distribution (as shown in **Error! Reference source not found.**) was fitted based on the mean of 9.2, minimum of 6.7, maximum of 11 and a standard deviation of 0.9 fatalities per thousand fires per year (as presented in Table 15).

The numbers of civilian fire injuries per year for 1980 – 2005 and the number of injuries per thousand fires are shown in Figure 39 and Figure 40 respectively, and for 1995 – 2005 in Figure 41 and Figure 42 respectively. Similar to the results for residential fire fatalities, the injury statistics for the years 1980 – 2005 show a reasonable direct chronological correlation with decreasing number of fatalities per year (as shown in Figure 39), and a slight direct chronological correlation with increasing numbers of fatalities per thousand fires (as shown in Figure 36). The statistics for the years 1995 – 2005 (as shown in Figure 41 and Figure 42) show no simple chronological correlation. Therefore the statistics for 1995 – 2005 were used for analysis. For the analysis of injuries per year, the bin size of 100 injuries per year was used and a beta distribution (as shown in **Error! Reference source not found.**) was fitted based on the mean of 2,700, minimum of 2,300, maximum of 3,300 and a standard deviation of 320 injuries per year (as presented in Table 15). For the analysis of injuries per thousand fires per year, the bin size used was 0.2 injuries per thousand fires per year and a beta distribution (as shown in **Error! Reference source not found.**) was fitted based on the mean of 39, minimum of 33, maximum of 44 and a standard deviation of 3.9 injuries per thousand fires per year (as presented in Table 15).

Table 15: Summary of USA one- and two-family dwelling structure fire statistics (from analysis of data presented by Aherns (2007)).

	Range of Years	Min.	Mean	95th Percentile	Max.	Standard Deviation
Fire Incidents/year	1995-2005	281,000	298,000	322,000	324,000	14,400
Fire Incidents/year	1980-2005	281,000	386,000	565,000	591,000	100,000
Fatalities/year	1995-2005	2,300	2,700	3,300	3,500	320
Fatalities/year	1980-2005	2,300	3,300	4,200	4,400	620
Fatalities/ 1000 Fires/year	1995-2005	7.6	9.2	11	11	0.9
Fatalities/ 1000 Fires/year	1980-2005	6.5	8.6	10	11	1.0
Injuries/year	1995-2005	10,000	11,600	14,000	14,000	1,300
Injuries/year	1980-2005	10,000	14,000	16,000	17,000	2,200
Injuries/ 1000 Fires/year	1995-2005	33	39	43	44	3.9
Injuries/ 1000 Fires/year	1980-2005	26	37	44	44	5.7

Over the period 2002 to 2005, on average 36 per 10,000 households recorded a fire large enough to be reported each year (Table 16, Butry et al. 2007). For every 10,000 house fires, 87 civilians died, 344 were injured and US$180.5 million in property losses sustained.

Table 16: National estimates of fires and probability of ignition occurrence in one- and two-family dwellings (adapted from Butry et al, 2007)

Year	Fires [a]	Houses [b]	Fires per Household per year
2002	300,500	81,660,500	0.0037
2003	297,000	82,143,000	0.0036
2004	301,500	83,446,000	0.0036
2005	287,000	84,749,000	0.0034
Mean	296,500	82,999,625	0.0036

Notes:
[a] As reported by NFPA for one- and two-family dwellings
[b] As reported by U.S. Census Bureau, American Housing Survey (U.S. Census 2007) for single family structures. Years 2002 and 2004 were linearly interpolated using 2001 and 2003, and 2003 and 2005 data, respectively.

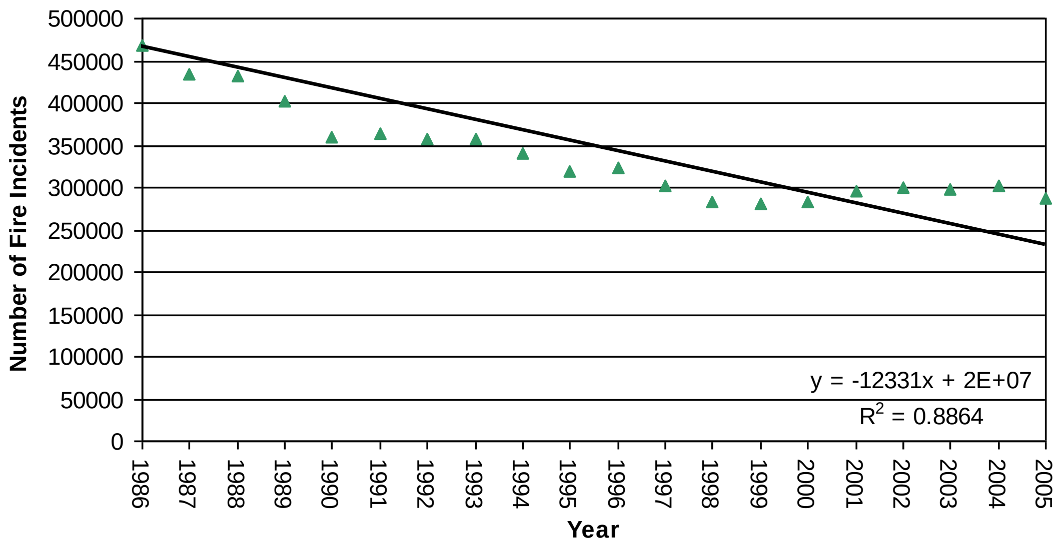


Figure 33: Number of fire incidents per year for the 1980 – 2005 USA one- and two-family dwelling structure fire statistics. (Adapted from data extracted from Aherns (2007))

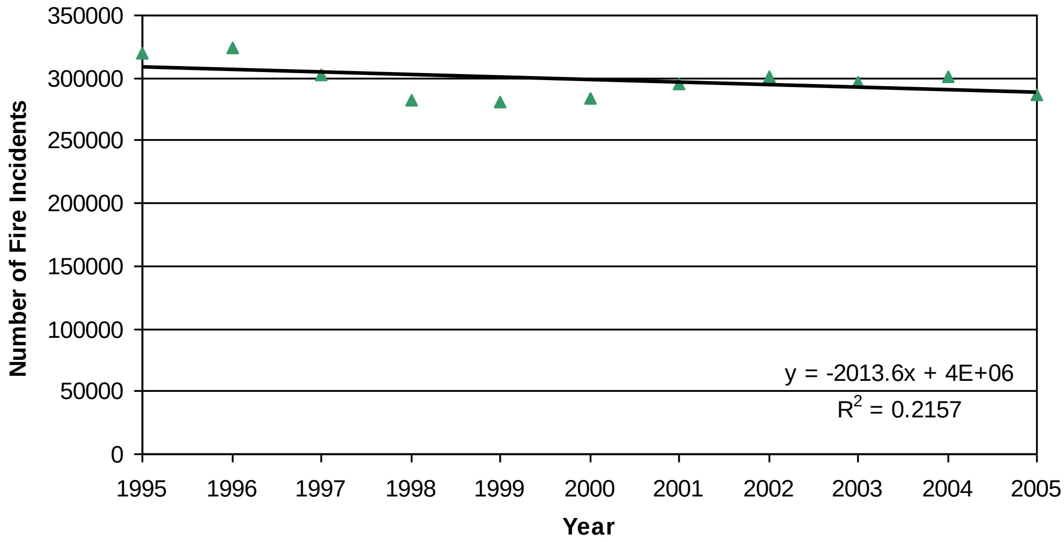


Figure 34: Number of fire incidents per year for the 1995 – 2005 USA one- and two-family dwelling structure fire statistics. (Adapted from data extracted from Aherns (2007))

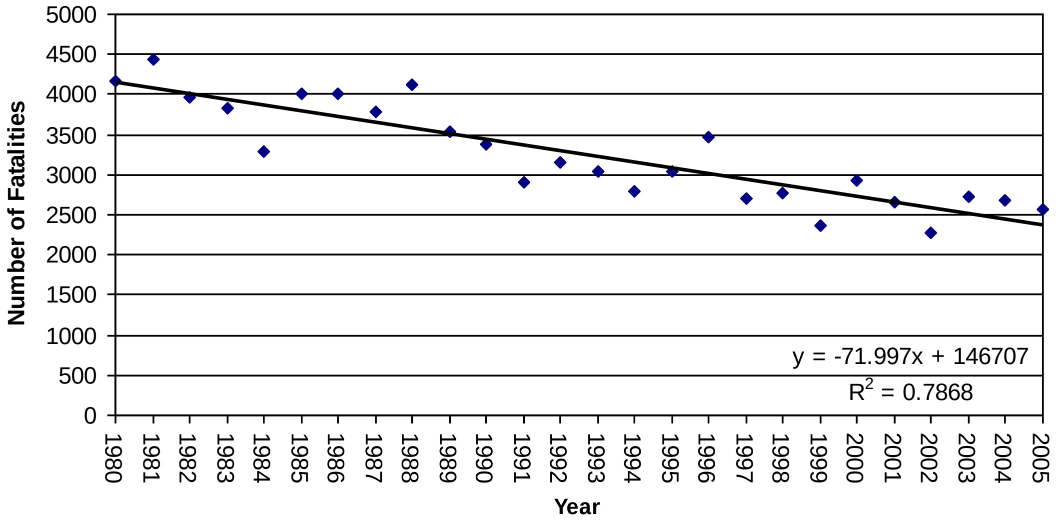


Figure 35: Number of civilian fire fatalities per year for the 1980 – 2005 USA one- and two-family dwelling structure fire statistics. (Adapted from data extracted from Aherns (2007))

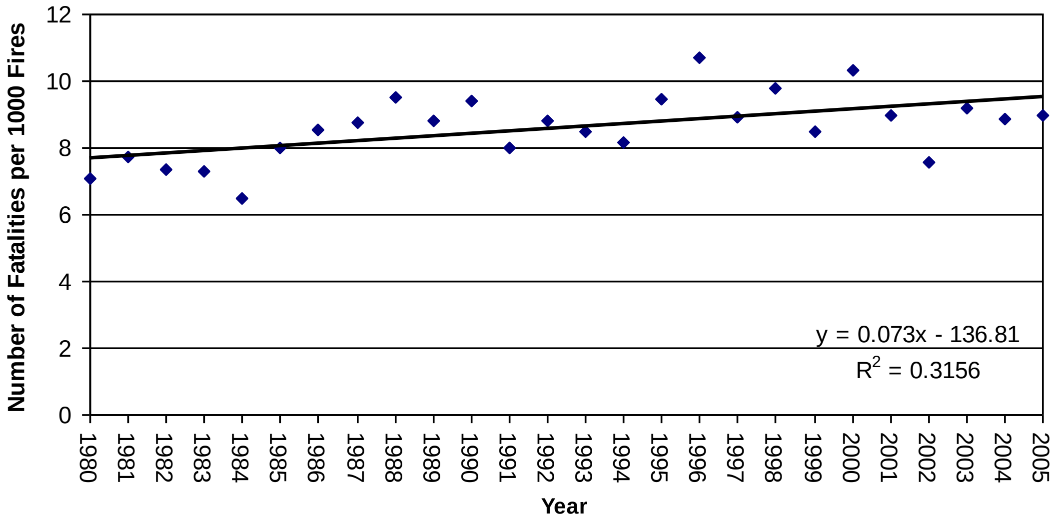


Figure 36: Number of civilian fire fatalities per 1000 fires per year for the 1980 – 2005 USA one- and two-family dwelling structure fire statistics. (Adapted from data extracted from Aherns (2007))

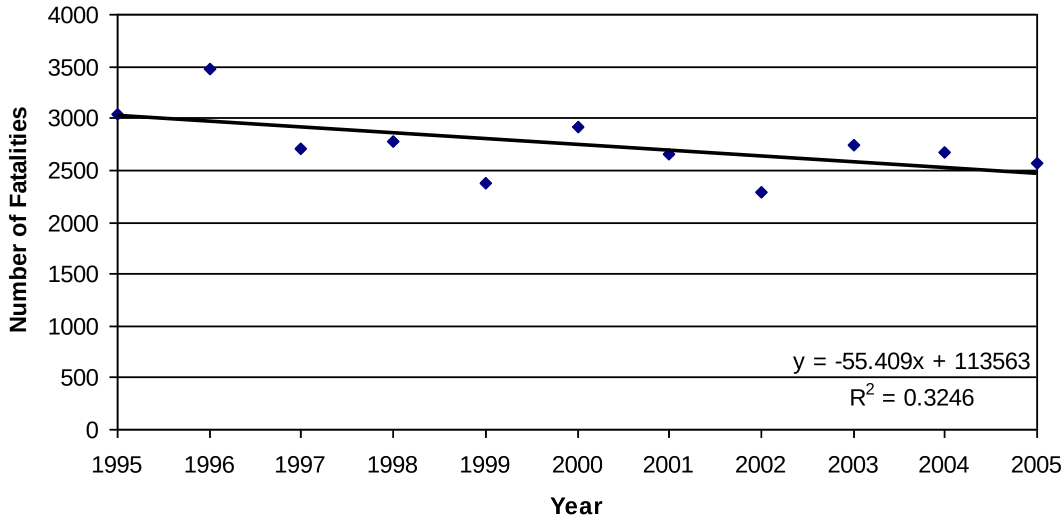


Figure 37: Number of civilian fire fatalities per year for the 1995 – 2005 USA one- and two-family dwelling structure fire statistics. (Adapted from data extracted from Aherns (2007))

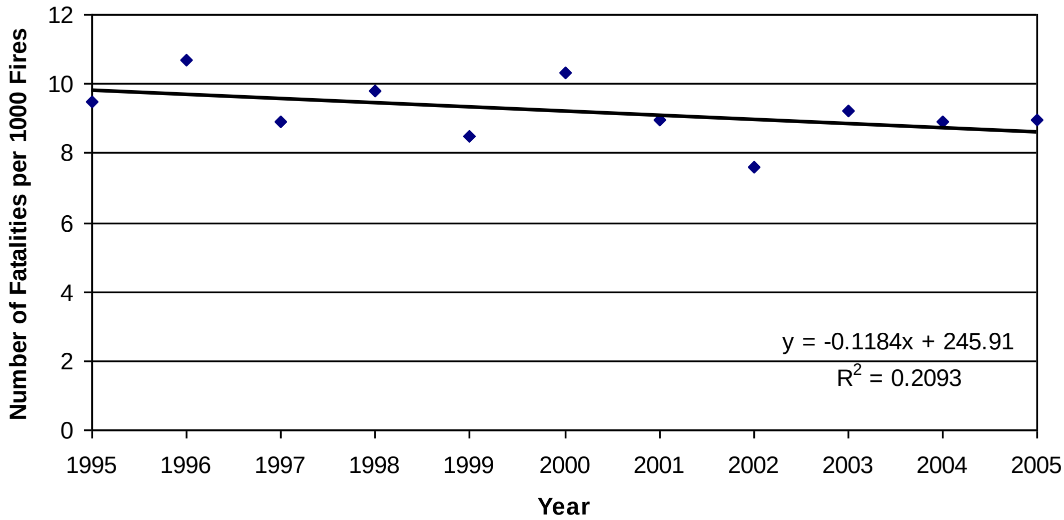


Figure 38: Number of civilian fire fatalities per 1000 fires per year for the 1995 – 2005 USA one- and two-family dwelling structure fire statistics. (Adapted from data extracted from Aherns (2007))

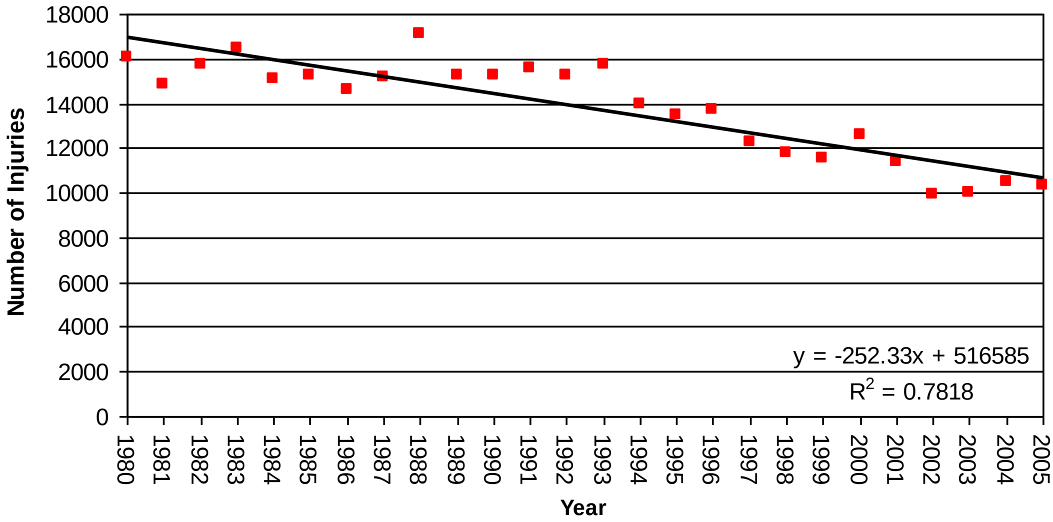


Figure 39: Number of civilian fire injuries per year for the 1980 – 2005 USA one- and two-family dwelling structure fire statistics. (Adapted from data extracted from Aherns (2007))

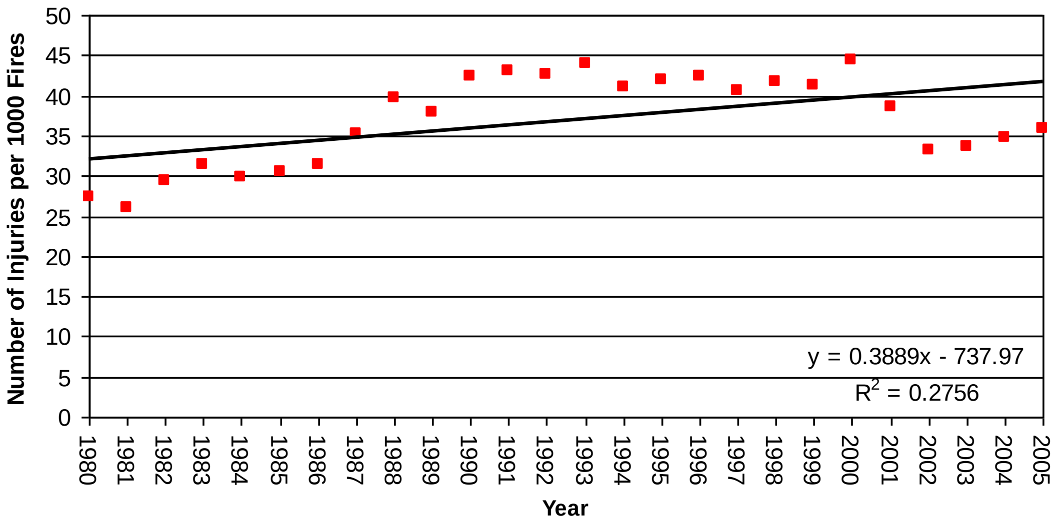


Figure 40: Number of civilian fire injuries per 1000 fires per year for the 1980 – 2005 USA one- and two-family dwelling structure fire statistics. (Adapted from data extracted from Aherns (2007))

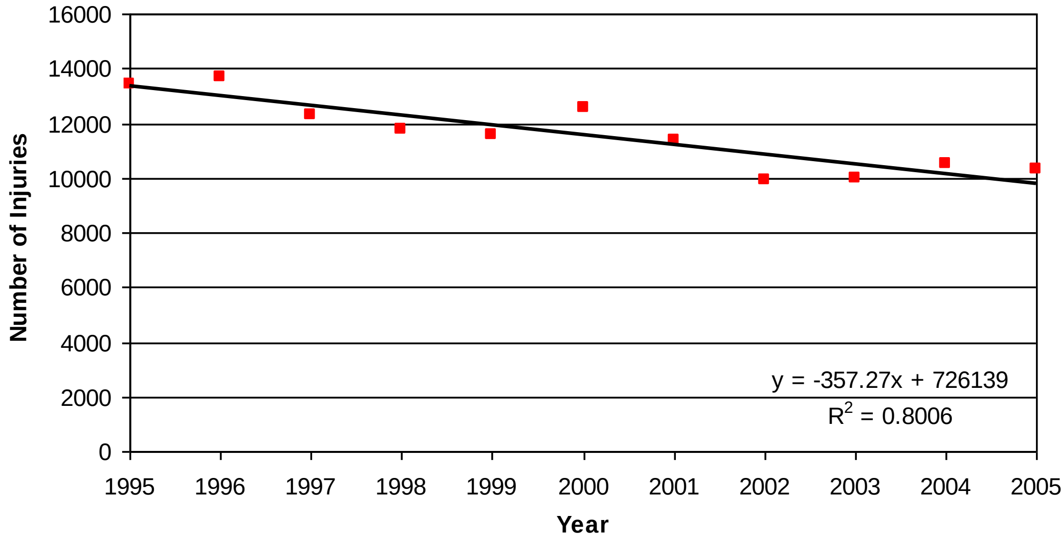


Figure 41: Number of civilian fire injuries per year for the 1995 – 2005 USA one- and two-family dwelling structure fire statistics. (Adapted from data extracted from Aherns (2007))

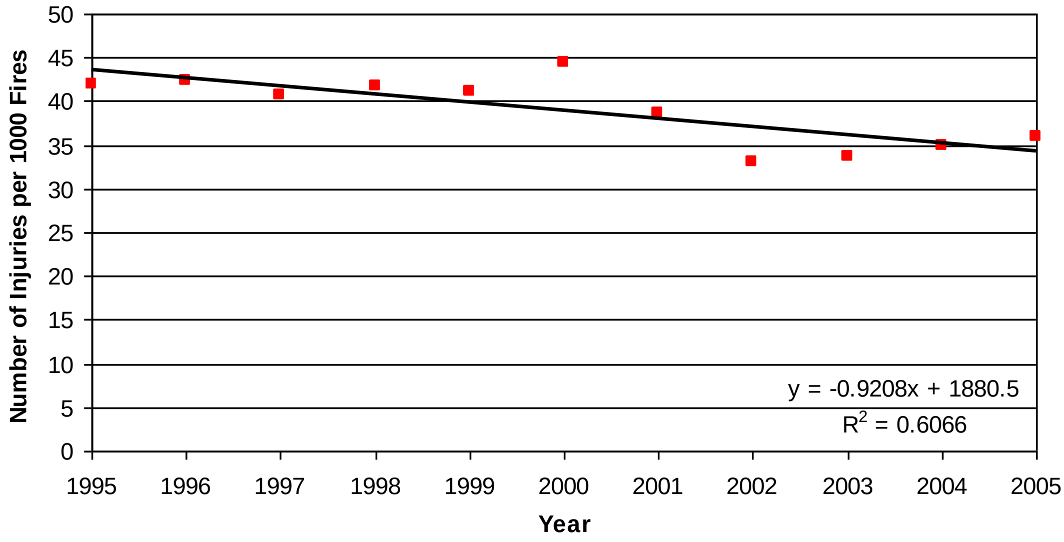


Figure 42: Number of civilian fire injuries per year for the 1995 – 2005 USA one- and two-family dwelling structure fire statistics. (Adapted from data extracted from Aherns (2007))

4.3 Summary of UK Statistics

Fatalities per thousand fires relating to residential building heights were between 10 and 14 for houses (1 to 3 floors high), 6 for blocks of flats 1 to 3 floors high and 10 for blocks of flats greater than 5 floors high (as shown in Figure 43). The number of fires per building for residential buildings by number of floors is shown in Figure 44. One storey flats had the largest number of fires per type of building (30 fires per thousand buildings). Whereas 1 to 3 floor houses had 3 to 4 fires per thousand buildings and 4 & 5 floor houses had 15.5 fires per thousand buildings. The number of fires decreases with increasing maximum fire size (as shown in Figure 45). However the number of fatalities per fire increases with increasing maximum fire size (as shown in Figure 46). (Williams et al., 2004)

Williams et al (2004) reported that the then current sample size available for residential sprinklered fires in the UK was insufficient to be used directly in any meaningful statistical analysis. Therefore an alternative approach was taken to indirectly estimate the effectiveness of sprinkler systems. The number of fire fatalities per thousand fires was correlated to the maximum fire size (which was based on the reported horizontal area of fire damage) (Figure 46). The effectiveness of a sprinkler system was then estimated by assuming a fire area that the sprinkler system could control the fire within and considering the potential number of fatalities adverted. Keeping the fire size as small as possible saves lives as well as reducing the risk per fire (as shown schematically in Figure 47). This approach was applied to estimate the reduction in the number of injuries and number of rescues needed if the fire size is restricted. It was assumed that if sprinklers were present they would "either extinguish the fire or at least prevent it from spreading further" (Williams et al., 2004), i.e. assuming 100% effectiveness of the sprinkler system if present. The results for the estimated percentage of reductions in number or fatalities, injuries and rescues for houses and flats are presented in Table 17, Table 18 and Table 19 respectively. The error estimates in these tables is presented as one standard deviation. The 95% confidence limits were estimated as twice the given standard deviations. More information is included in Appendix B.3.

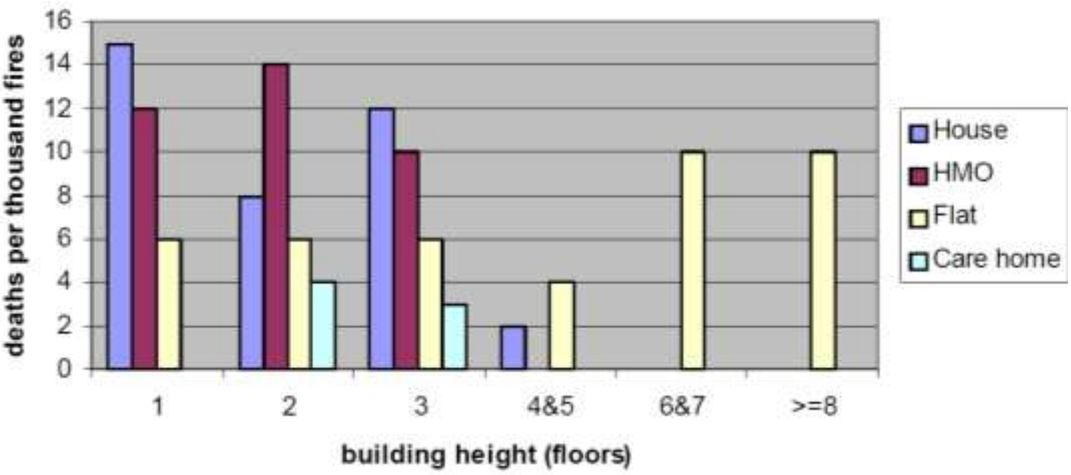


Figure 43: Number of fatalities per thousand fires versus building height for various sleeping purpose occupancies. Extracted from Williams et al. (2004).

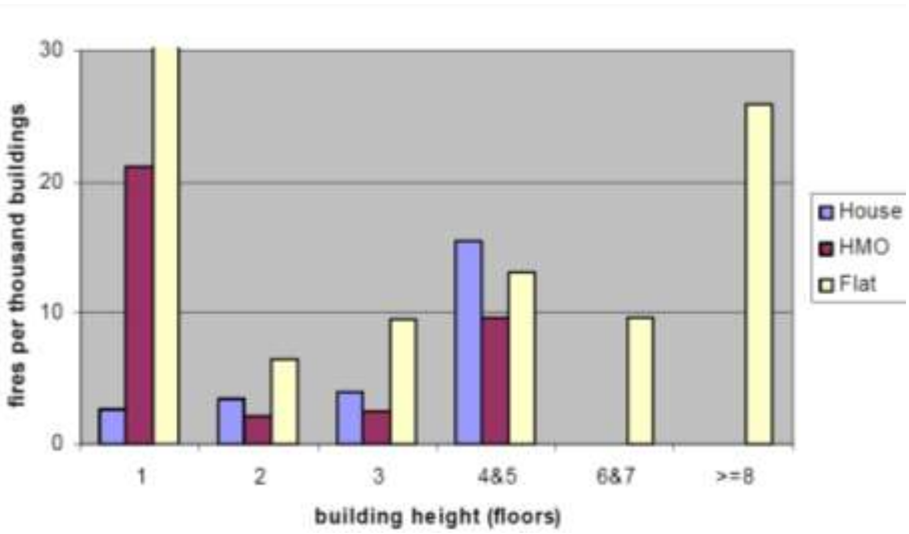


Figure 44: Building height versus number of fires per thousand of buildings for various sleeping occupancies. Extracted from Williams et al (2004).

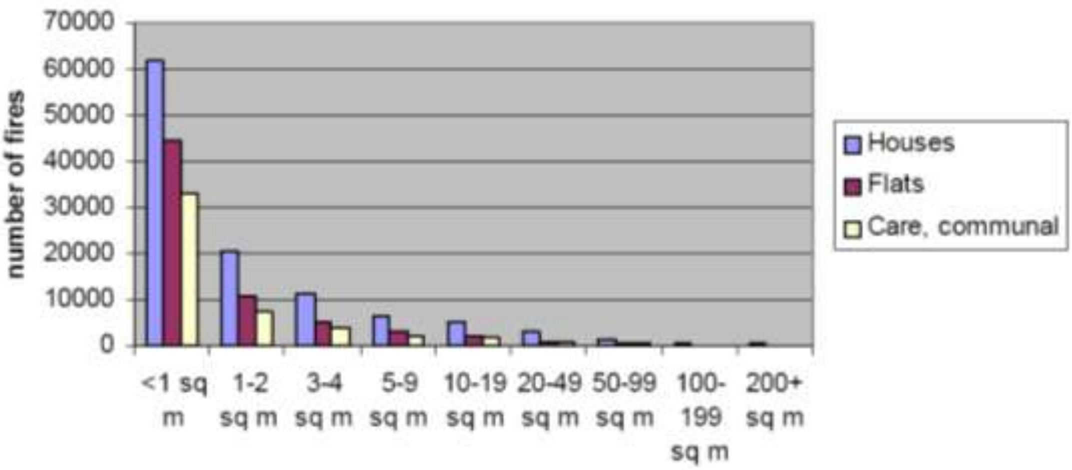


Figure 45: Number of fires versus maximum fire size. Extracted from Williams et al (2004).

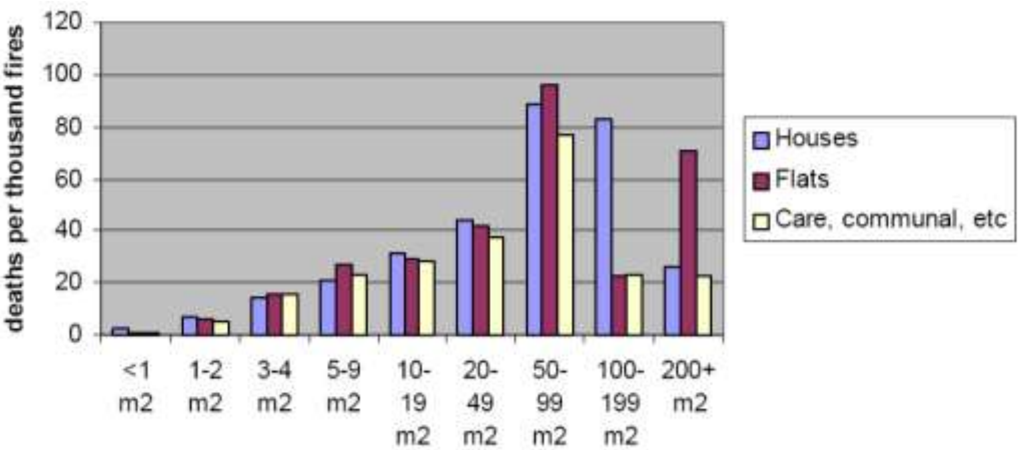
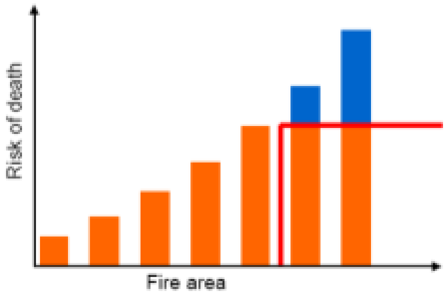
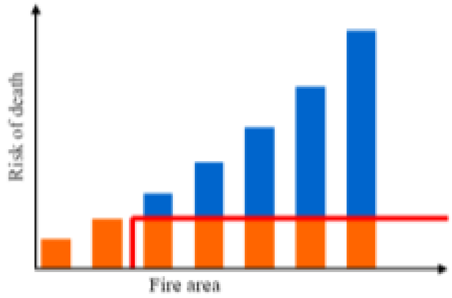


Figure 46: Number of fatalities per thousand fires versus maximum fire size. Extracted from Williams et al (2004).



(a)



(b)

Figure 47: Schematic of the estimated effectiveness of limiting the maximum fire size to different values (e.g. (b) shows the theoretical effect of limiting the maximum fire size to a smaller value than (a), where the blue coloured sections represent the theoretical fatalities prevented). Extracted from Williams et al (2004).

Table 17: Summary of estimated percentage reduction in the number of fatalities for an assumed maximum fire size. Adapted from Williams et al (2004).

Property Type	Estimated Percentage Reduction for Maximum Fire Area ± one standard deviation			
	< 1 m²	< 2 m²	< 4 m²	< 9 m²
House, single	84±4%	59±3	38±3	28±3
House, multiple	92±17	53±14	47±13	25±11
Flat, purpose-built	82±6	55±5	30±4	11±4
Flat, converted	72±13	51±10	18±9	10±7

Table 18: Summary of estimated percentage reduction in the number of injuries for an assumed maximum fire size. Adapted from Williams et al (2004).

Property Type	Estimated Percentage Reduction for Maximum Fire Area ± one standard deviation			
	< 1 m²	< 2 m²	< 4 m²	< 9 m²
House, single	40±1	14±1	7±1	4±1
House, multiple	41±4	24±4	12±3	7±3
Flat, purpose-built	30±1	16±1	9±1	4±7
Flat, converted	41±3	20±3	12±3	5±2

Table 19: Summary of estimated percentage reduction in the number of rescues for an assumed maximum fire size. Adapted from Williams et al (2004).

Property Type	Estimated Percentage Reduction for Maximum Fire Area ± one standard deviation			
	< 1 m^2	< 2 m^2	< 4 m^2	< 9 m^2
House, single	44±3	21±3	11±2	5±2
House, multiple	56±10	27±8	37±8	13±7
Flat, purpose-built	64±4	46±3	13±3	17±2
Flat, converted	59±7	37±6	5±5	10±4

5. HOME SPRINKLER COSTS

5.1 Introduction

To determine the costs of installing a combination home sprinkler system estimated costs were requested from plumbers and previous students of the BRANZ CITE home sprinkler design course who had successfully completed the course.

5.2 Design

Two house designs were provided including sprinkler system specifications. The request was to provide labour and material costs for the installation of the sprinkler systems and a standard domestic reticulation system appropriate for the house. This enabled the marginal cost of the sprinkler system to be determined.

Costs were to exclude the following:

- Design
- Supply of sprinkler heads
- Costs associated with the water supply (connection to town mains, and any requirements for backflow preventers and water meters)
- Costs associated with consent applications or negotiations with the building consent authorities or water authorities
- Ongoing maintenance

To be included were:

- Supervision costs
- Final commissioning cost

Assumptions made were:

- the towns main water supply is sufficient to supply the sprinkler system without the need for a pump
- roof spaces are unobstructed
- sprinklers can be placed anywhere in the room with unobstructed ceilings

The sprinkler pipework chosen was polybutylene (PB) as it is a common plumbing pipe which plumbers are used to dealing with. Two other possible pipe materials were rejected because of cost (copper) and complexity of installation requiring specialist equipment to make the joints (polypropylene).

5.3 Houses

Two house plans were used in the study. The two properties were as follows:

1. Single storey house used in the previous home sprinkler study approximately 70 m² with no garage, as shown in Figure 48.
2. Single storey house 135 m² with an attached double garage as shown in Figure 49. This is a much larger property and would be typical of the middle of the domestic housing market.

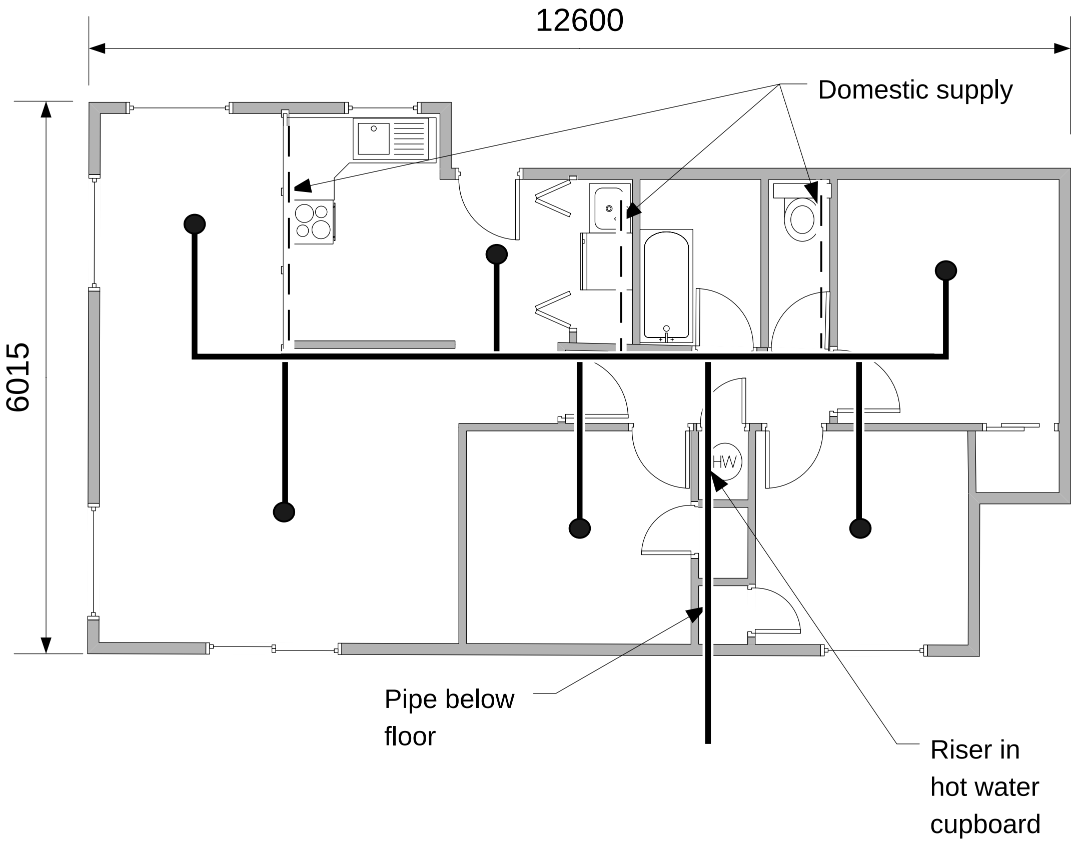


Figure 48: Floor Plan of Building of small house used for sprinkler system design.

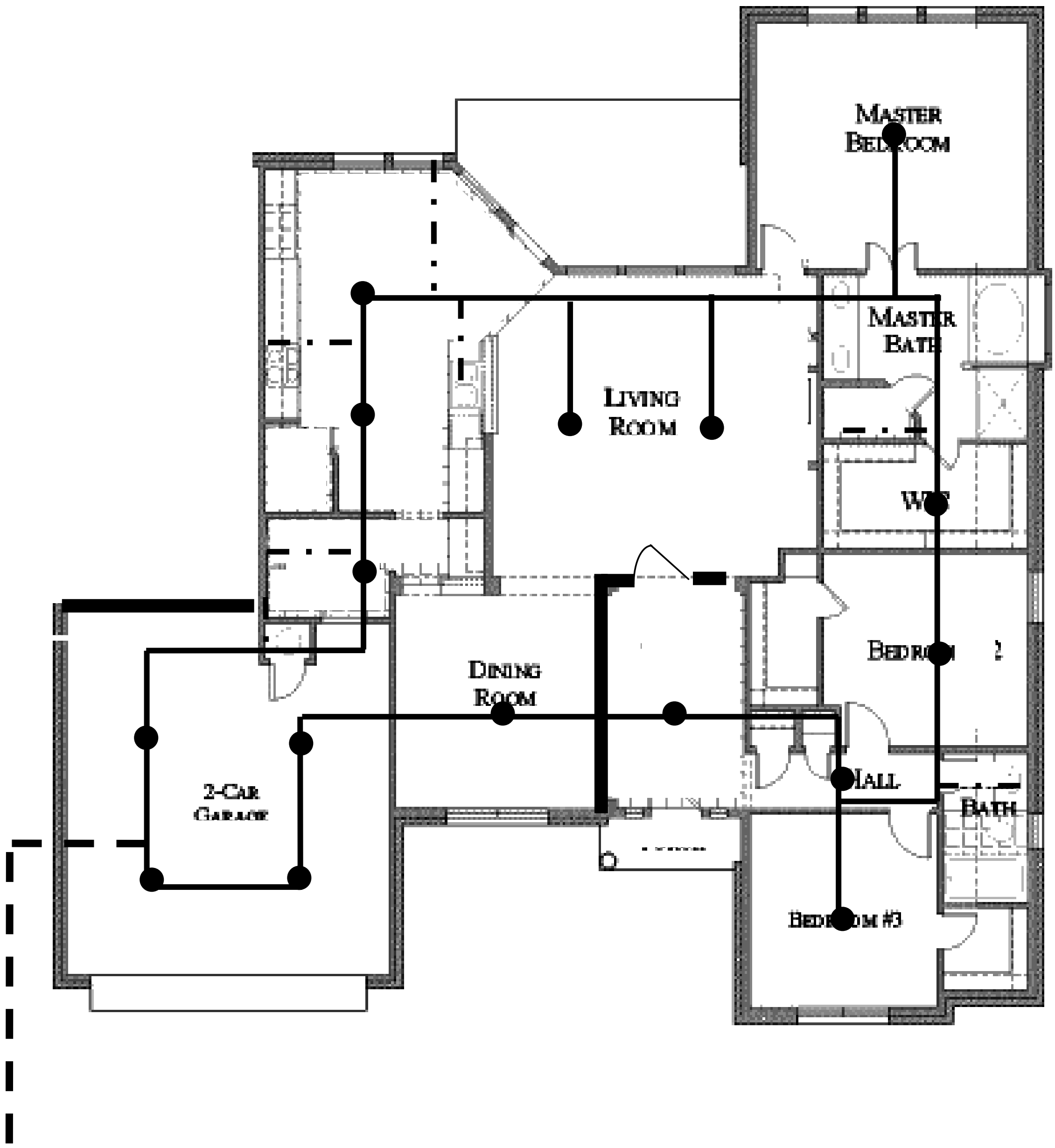


Figure 49: Floor plan of building of large house used for sprinkler system design.

5.4 Design Calculation

A combination sprinkler design, in accordance with NZS 4517 (SNZ, 2002) was carried out by BRANZ for the two houses.

The design details of the low-cost sprinkler system design for the houses are as follows:

- A single mains connection feeds both the sprinkler system and the domestic water supply.
- Design pressure from the mains was taken conservatively to be 400 kPa (a typical mains pressure for residential areas).

- 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 NZS 4517(SNZ, 2002).

- The water supply enters the houses at the location of the domestic hot water cylinder (small house), or garage (large house) which are typical locations of water supply entry.

- The main run of water supply pipe to the house is 25 mm ND diameter polyethylene PE80B for the small house and 32 mm ND for the large house. All sprinkler pipework is 28 mm ND polybutylene with push-on fittings.

- The sprinkler heads are concealed residential on a discharge area of 4.9 m x 4.9 m with a flow of 49.2 L/min and required pressure of 48 kPa. Approximately $65 per sprinkler head retail cost.

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

5.5 Cost Data – Sprinkler System included during initial Construction

Costs for the sprinkler systems were provided by six respondents. These quotes are presented in Table 20 and include the cost of the sprinkler heads. The cost attributed to the addition of a home sprinkler system during the construction of the house is the marginal cost. Mean marginal cost and 95th and 99th percentile (assuming a normal distribution) cost of sprinkler system are presented in Table 21 and the cost per unit area is presented in Table 23. The minimum and maximum marginal cost estimates are presented in Table 22 and Table 24.

Table 20: Costs for the large house and small house sprinkler systems

House	Domestic Supply Only ($)	Combination System ($)	Marginal Cost* ($)	Location
Large House Small House	1356 942	2760 1580	2444 1093	Porirua[1]
Large House Small House	2671 1253	4875 2336	3245 1538	Napier
Large House Small House	1356[2] 942[2]	3794 1840	2438 898	Hamilton
Large House Small House	1356[2] 942[2]	4640 2030	3284 1088	Nationwide[3] (lower Hutt)
Large House Small House	2760 1853	7493 4026	5343 3135	Rotorua
Large House Small House	4146[4]	6738	2591 1400[5]	Wanganui

Notes:

* The marginal cost is the cost associated with the addition of a home sprinkler system to the initial design of a new house.

1. Plumbing company only. No home sprinkler designers on staff.
2. Estimate based on costs from Porirua.
3. The company is a plastic piping supplier and offers nationwide support for design and supply of materials at a cost per square meter. It has a suggested maximum cost per square meter based on installations they have been involved with.
4. Based on costs for a house with 260 m² floor area.
5. The company only provided costs for the increase in costs over a domestic water supply.

Table 21: Summary of mean marginal cost and 95th and 99th percentile (assuming a normal distribution) cost for inclusion of a home sprinkler system in a new house

House	Area (m^2)	Mean Marginal Cost ($)	Sample Standard Deviation ($)	95th Percentile ($)	99th Percentile ($)
Large house	135	3224	1106	4828	5240
Small house	70	1525	822	2736	3055

Table 22: Summary of the maximum and minimum marginal costs for inclusion of a home sprinkler system in a new house

House	Area (m^2)	Minimum Marginal Cost ($)	Maximum Marginal Cost ($)
Large house	135	2438	5343
Small house	70	898	3135

Table 23: Summary of mean marginal cost and 95th and 99th percentile cost for the inclusion of a home sprinkler system in a new house per unit area of house

House	Area (m^2)	Mean Marginal Cost ($\$/m^2$)	Sample Standard Deviation ($\$/m^2$)	95th Percentile ($\$/m^2$)	99th Percentile ($\$/m^2$)
Large house	135	24	8	36	39
Small house	70	22	12	39	44

Table 24: Summary of the maximum and minimum marginal costs for inclusion of a home sprinkler system in a new house per unit area of house

House	Area (m^2)	Minimum Marginal Cost ($\$/m^2$)	Maximum Marginal Cost ($\$/m^2$)
Large house	135	18	40
Small house	70	13	45

6. COST EFFECTIVENESS METHODOLOGY

A list of the general factors considered in a cost benefit analysis of home sprinklers in one- and two-family dwellings for a range of studies is presented in Table 25.

Table 25: Factors considered in a domestic or residential sprinkler system cost-benefit analyses for accidental fires.

Cost	USA [a]	UK [b]	Vancouver, Canada [c]	Scottsdale, AZ, USA [d]	NZ [e]	Considered in this Study
Installation (including water supply)	✗	✓	✓	✓	✓	✓
Annual inspection & maintenance	✗	✓	✓	✓	✓	✓
Environmental impact & sustainability aspects of manufacture & installation of sprinkler system	✗	✗	✗	✗	✗	✓
Accidental Water damage	✓	✗	✗	✗	✗	✗
Benefit						
Fatalities prevented	✓	✓	✓	✓	✓	✓
Injuries prevented	✗	✓	✗	✗	✓	✓
Property loss prevented	✓	✓	✓	✓	✓	✓
Reduced impact on the environment due to fire effects & sustainability aspects	✗	✗	✗	✓	✗	✓
Fire service cost savings	✗	✗	✓	✓	✗	?
Insurance premium reduction	✗	✗	✗	✓	✗	✗
Reduction in construction costs associated with trade off	✗	✗	✓	✓	✗	✗
Reduction of intangible losses from homes (e.g. pets, family heirlooms, etc.)	✗	✗	✗	✗	✗	✗

Notes:
[a] Study performed for USA perspective (Rohr & Hall, 2005; Hall, 2007).
[b] Study performed for UK perspective (Fraser-Mitchell, 2004).
[c] Study performed pre- and post-mandatory residential sprinkler legislation in Vancouver, Canada (Robertson, 2001; Williams et al., 2004).
[d] Study performed for Scottsdale, AZ, USA (Ford, 1997; Williams et al., 2004).
[e] Study performed for New Zealand perspective (Wade and Duncan, 2000; Duncan et al., 2000).

6.1 Methodology

The home sprinkler cost effectiveness input parameters are listed with a brief description in Table 26. A list of the home sprinkler cost effectiveness output variables is presented in Table 27 and the calculation methods employed are presented in Table 29. The background and subsequent values used for these input parameters are discussed in detail in Section 7.

Table 26: List of home sprinkler cost effectiveness assessment input parameters.

Name	Symbol	Brief Description
Sprinkler effectiveness	η_{sprink}	A measure, based on statistics, for a sprinkler system to activate and control a fire according to the design of the system, assuming the fire is large enough to activate the sprinkler system.
Smoke alarm effectiveness	η_{smoke}	A measure, based on statistics, for a smoke alarm to activate and alert occupants, assuming the fire is sufficient to activate the sprinkler system. This variable includes a measure of the operation ability of the device, e.g. state of batteries (replaced and connected), appropriateness of placement of the device, etc.
Limit of flame damage for effective sprinkler system	L_{sprink}	An assumed percentage of the total structure to which an effective sprinkler system would control the fire from spreading beyond.
Limit of %structure damage for total loss	L_{total_loss}	An assumed threshold percentage of total structure damage above which the entire structure is deemed to be lost (i.e. the remainder is assumed to be demolished and 100% would be replaced).
Deaths per 1000 fires, no spr, no alarms	$D_{0,0}$	Current average number of civilian fatalities per 1000 residential fires where no sprinkler system and no smoke alarms are present.
Deaths per 1000 fires, no spr, with alarms	$D_{0,smoke}$	Current average number of civilian fatalities per 1000 residential fires where no sprinkler system is present but smoke alarms are present.
Deaths per 1000 fires, with spr, no alarms	$D_{srpink,0}$	Current average number of civilian fatalities per 1000 residential fires where a sprinkler system is present but no smoke alarms are present.
Deaths per 1000 fires with spr, with alarms	$D_{sprink,smoke}$	Current average number of civilian injuries per 1000 residential fires where both a sprinkler system and smoke alarms are present.
Injuries per 1000 fires, no spr, no alarms	$I_{0,0}$	Current average number of civilian injuries per 1000 residential fires where no sprinkler system and no smoke alarms are present.
Injuries per 1000 fires, no spr, with alarms	$I_{0,smoke}$	Current average number of civilian injuries per 1000 residential fires where no sprinkler system is present but smoke alarms are present.
Injuries per 1000 fires, with spr, no alarms	$I_{sprink,0}$	Current average number of civilian injuries per 1000 residential fires where a sprinkler system is present but no smoke alarms are present.

Table 26 continued: List of home sprinkler cost effectiveness assessment input parameters.

Name	Symbol	Brief Description
Injuries per 1000 fires with spr, with alarms	$I_{sprink,smoke}$	Current average number of civilian injuries per 1000 residential fires where both a sprinkler system and smoke alarms are present.
Initial number of house structure fires per year	F_0	The current number of household fires per year, where households represent buildings where NZS4517 could be applied, i.e. single- and two-family dwellings, single storey of flats, townhouses, etc. The number of house fires each year is assumed to be proportional to the number of houses, $F_t = \frac{H_{t,all}}{H_{0,all}} F_0$
Current number of households	$H_{0,all}$	The current number of households where a NZS4517 would be applicable. The number of houses is assumed to increase at a uniform rate, $H_t = H_{0,all} t r_{house}$
Increase in households per year	r_{house}	An estimate of the average percentage increase of the number of households per year over the chosen analysis period.
Initial number of sprinklered households	$H_{0,sprink}$	The current number of NZS4517 sprinklered households. The number of sprinklered houses each year is both retrofitted and new sprinkler systems, $H_{t,sprink} = r_{retrofit}(H_{t-1,all} - H_{t-1,sprink}) + p_{new\_sprink}(H_{t,all} - H_{t-1,all})$
Proportion of new households sprinklered	$p_{new,sprink}$	The proportion of new households built with a NZS4517 fire sprinkler system.
Rate of retrofit of sprinkler in households	$r_{retrofit}$	An estimate of the average rate of retrofit of systems in households with no fire sprinkler system currently present.
Proportion of existing housing with smoke alarms	$p_{old,smoke}$	This distinction is made to account for some households that currently do not comply with the mandatory requirement for smoke alarms, without complicating the effectiveness value of smoke alarms to incorporate the statistics regarding fire incidents where smoke alarms have not been present.
Proportion of new households with smoke alarms	p_{new_smoke}	Expected to be 100%.
Discount rate	$r_{discount}$	Estimated discount rate
Inflation rate	$r_{inflation}$	Estimated inflation rate
Analysis period	$Y_{analysis}$	Number of years considered for this analysis.
Sprinkler system life	Y_{sprink}	Number of years for the design life of the sprinkler system.
Room of fire origin – distribution of fire incident	$p_{fire,ROO}$	Proportions of fire incidents according to statistics for room of fire origin.

Table 26 continued: List of home sprinkler cost effectiveness assessment input parameters.

Name	Symbol	Brief Description
Proportion of fire incidents covered by an NZS4517 system	$p_{fire,NZS4517}$	A proportion of the total incidents, to take into account that a NZS4517 system does not necessarily cover every room.
Room of fire origin – distribution of fatalities	$p_{fatal,ROO}$	Proportions of civilian fatalities according to statistics for room of fire origin.
Proportion of fatalities covered by an NZS4517 system	$p_{fatal,NZS4517}$	A proportion of the total fatalities, to take into account that a NZS4517 system does not necessarily cover every room.
Room of fire origin – distribution of injuries	$p_{injury,ROO}$	Proportions of civilian injuries according to statistics for room of fire origin.
Proportion of injuries covered by an NZS4517 system	$p_{injury,NZS4517}$	A proportion of the total injuries, to take into account that a NZS4517 system does not necessarily cover every room.
Materials & installation (new household)	$C_{0,newsprink}$	Average current cost of materials and installation of a NZS4517 system during the construction of a new house.
Materials & installation (retrofit)	$C_{0,retrofitsprink}$	Average current cost of materials and installation of a NZS4517 system for the retrofit of an existing house.
Design	$C_{0,deisgn}$	Average current cost for designing a NZS4517 for a typical New Zealand household.
Annual Maintenance	$C_{i,maintenanc}$	Average current cost of annual maintenance. Currently no cost is attributable.
Initial regulatory costs	$C_{0,regulatory}$	Estimate of the initial regulatory costs required.
Yearly regulatory costs	$C_{i,annualregulator}$	Estimate of the average annual regulatory costs required.
Cost per fire injury	$C_{0,injury}$	Estimate of the current average cost per civilian fire injury.
Property loss per unsprinklered fire	$C_{0,propertyunsrpir}$	Estimate of the current average cost of property loss per unsprinklered residential fire.
Reduction in property loss per sprinklered fire	$p_{propertysrpink}$	Estimate of the average reduction in property loss where an effective sprinkler system is present.
Cost of Fire Service per unsprinklered fire	$C_{0,fireservice,unspr}$	Estimate of the current average mixed-cost for Fire Service attendance of an unsprinklered residential fire.
Reduction in cost of Fire Service per sprinklered fire	$p_{fireservice,sprink}$	Estimate of the average reduction in mixed-cost for Fire Service attendance of residential fire where an effective sprinkler system is present.
Fire Service fatalities at unsprinklered residential properties	$D_{FS,unsprink}$	Current average number of Fire Service fatalities sustained at unsprinklered residential property fire incidents.
Fire Service fatalities reduction for home sprinklered properties	$r_{FS,fatalitysprink}$	Estimate of the percentage reduction in Fire Service injuries at residential property fire incidents attributable to home sprinkler systems.
Fire Service injuries	$I_{FS,unsprink}$	Current average number of Fire Service injuries sustained at unsprinklered residential property fire incidents.

Table 26 continued: List of home sprinkler cost effectiveness assessment input parameters.

Name	Symbol	Brief Description
Fire Service injury reduction for home sprinklered properties	$r_{FS,injury,sprink}$	Estimate of the percentage reduction in Fire Service injuries at residential property fire incidents attributable to home sprinkler systems.
Average Insurance Premium	$C_{0,insurance,unsprink}$	Estimate of the current average household insurance premium without home sprinklers installed.
Insurance Premium Savings	$r_{insurance,sprink}$	Estimate of the reduction in household insurance premiums for installation of a home sprinkler system
Threshold %structure damage for total loss	$L_{\%struct,thresh}$	Estimate of the threshold value for the percentage of structural damage beyond which the entire structure is replaced.
%structural damage	$D_{\%struct}$	Average percentage of structural damage for each of the ranges used as input for the estimates of the percentage of fire incidents.
%fire incidents with %structure damage	$I_{\%fires,\%damg}$	Estimate of the percentage of fire incidents for each range of percentage of structure damage.
Cost of water per litre	$C_{water/litre}$	Estimate of the cost per litre in terms of water metered cost.
Volume of water used in a sprinklered house	$V_{water,sprink}$	Estimate of the average volume of water used to extinguish a fire within a house with a home sprinkler system present.
Volume of water used in an unsprinklered house	$V_{water,unsprink}$	Estimate of the average volume of water used to extinguish a fire within a house with no sprinkler detection present.
Cost of NZ Ecopoints for 100% structure damage	$C_{NZEco,100\%struct,house\_dmg}$	Estimate of the average number of NZ Ecopoints for 100% loss of an average household.
Cost of NZ Ecopoints for a percentage of structure damage	$C_{NZEco,\%struct,house\_dmg}$	Estimate of the average number of NZ Ecopoints for a percentage loss (less than 100%) of an average household.
Cost of NZ Ecopoints for the total replacement a percentage of a house structure	$C_{NZEco,100\%struct,house\_replace}$	Estimate of the average number of NZ Ecopoints for 100% replacement of an average household.
Cost of NZ Ecopoints for the replacement a percentage of a house structure	$C_{NZEco,\%struct,house\_replace}$	Estimate of the average number of NZ Ecopoints for replacement of a percentage (less than 100%) of an average household.
Cost of NZ Ecopoints for a litre of potable water	$C_{NZEco,fire\_water}$	Estimate of the average number of NZ Ecopoints for a litre of potable water that is used as fire water.
Proportion of small or large houses of the housing stock	$p_{house,<small\,or\,large>}$	Estimate of the proportions of large and small houses for the existing stock. New houses are assumed to have the same proportions.
Cost of NZ Ecopoints for a sprinkler system	$C_{sprink,<small\,or\,large>,<new\,or\,retrofit>}$	Estimate of the average number of NZ Ecopoints for a <small or large> and <new or retrofit> home sprinkler system.

Table 27: List of home sprinkler cost effectiveness assessment output variables and descriptions.

Name	Symbol	Brief Description
Lives saved per year	$S_{life,avg}$	Number of lives saved per year attributed to installation of sprinklers in houses.
Lives saved per household per year	$S_{life,avg,household}$	Number of lives saved per year per new Zealand household attributed to the installation of sprinklers in houses.
Fire Service Lives saved per year	$S_{FS\_life,avg}$	Number of Fire Service lives saved per year attributed to installation of sprinklers in houses.
Fire Service Lives saved per household per year	$S_{FS\_life,avg,household}$	Number of Fire Service lives saved per year per new Zealand household attributed to the installation of sprinklers in houses.
Savings in injury costs per household per year	$S_{injury\$,avg,household}$	Estimation of the monetary savings per injury adverted by a home sprinkler system per year per New Zealand household.
Savings in property loss per household per year	$S_{property\$,avg,household}$	Estimation of the monetary savings of property loss adverted by a home sprinkler system per year per New Zealand household.
Savings in Fire Service costs per household per year	$S_{fire\_service\$,avg,household}$	Estimation of the monetary savings of the Fire Service attributed to home sprinkler SYSTEMS per year per New Zealand household.
Savings in Insurance Premiums	$S_{insurance\$,avg,household}$	Estimation of the monetary savings of insurance premiums when a reduction is offered for installation of home sprinkler systems.
Savings in Fire Water per household per year	$S_{water\$,avg,household}$	Estimation of the monetary savings from potable water averted from fire water use attributed to home sprinkler systems per year per New Zealand household.
Total savings per household per year	$S_{total\$,avg,household}$	Estimation of the total monetary savings attributed to home sprinkler systems per year per New Zealand household.
Design, installation and maintenance costs per household per year	$C_{design\&install\&maint\$,avg,household}$	Estimation of the monetary costs attributed to the design, installation and maintenance of home sprinkler systems per year per New Zealand household.
Regulatory costs per household per year	$C_{regulatory\$,avg,household}$	Estimation of the monetary costs attributed to the regulation of home sprinkler systems per year per New Zealand household.
Total cost per household per year	$C_{total\$,avg,household}$	Estimation of the total monetary costs attributed to home sprinkler systems per year per New Zealand household.
Cost per life saved	$C_{\$/life}$	Estimation of the total monetary costs per life saved attributable to home sprinkler systems.

The life cycle assessment used some of the cost effectiveness analysis inputs. The additional input parameters used are summarised in Table 28. The output variables and descriptions are presented in Table 28 and the calculation methods are summarised in Table 30.

Table 28: List of home sprinkler life cycle assessment output variables and descriptions.

Name	Symbol	Brief Description
Savings of NZ Ecopoints for the number of fire adverted fire damaged households per household per year	$S_{house\_dmgNZEco,avg,household}$	Estimate of the NZ Ecopoints saved because of the equivalent number of houses saved attributed to home sprinklers from fire damage per household per year.
Savings of NZ Ecopoints for the averted replaced fire damaged households per household per year	$S_{house\_replaceNZEco,avg,household}$	Estimate of the NZ Ecopoints saved because of averted replacement of fire damaged households attributed to home sprinklers per household per year.
Savings of NZ Ecopoints for the averted fire water per household per year	$S_{fire\_waterNZEco,avg,household}$	Estimate of the NZ Ecopoints saved because of the savings in potential volume of water attributed to home sprinklers per household per year.
Total NZ Ecopoints saved per household per year	$S_{totalNZEco,avg,household}$	Estimate of the total NZ Ecopoints saved attributed to home sprinklers per household per year.
Cost of NZ Ecopoints for sprinkler system per household per year	$C_{sprinkNZEco,avg,household}$	Estimate of the cost of NZ Ecopoints for home sprinkler systems (based on components) per household per year.
Cost of NZ Ecopoints for sprinkler systems lost in sprinklered housing fire per household per year	$C_{sprink\_lostNZEco,avg,houshold}$	Estimate of the cost of NZ Ecopoints for home sprinklers systems lost to fire per household per year.
Cost of NZ Ecopoints for replacement sprinkler systems lost in fire per household per year	$C_{sprink\_replaceNZEco,avg,household}$	Estimate of the cost of NZ Ecopoints for the replacement of home sprinklers systems lost to fire per household per year.
Total NZ Ecopoints Cost per household per year	$C_{totalNZEco,avg,household}$	Estimate of the total cost of NZ Ecopoints per household per year.
NZ Ecopoints per life saved	$C_{NZEco/life}$	Estimate of the total cost of NZ Ecopoints per life saved. Note: a negative value here for NZ Ecopoints indicates a saving of points.
Monetary cost per 100 NZ Ecopoints saved	$C_{\$/100NZEco}$	Estimate of the monetary cost per 100 NZ Ecopoints attributed to the installation & operation of home sprinklers.

Table 29: List of home sprinkler cost effectiveness assessment calculation methods.

Name	Calculation Method
Lives saved per year	$S_{life,avg} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(S_{life,t} \right)$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{H_{t,sprink}}{H_{t,all}} p_{fatal,NZS4517} \left[\left(D_{0,0} - D_{sprink,0} \right) \eta_{sprink} \left(1 - \eta_{smoke} p_{new\_smoke} \right) + \left(D_{0,smoke} - D_{srpink,smoke} \right) p_{new\_smoke} \eta_{sprink} \eta_{smoke} \right] \right)$
Lives saved per household per year	$S_{life,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{S_{life,t}}{H_{t,all}} \right)$
Fire Service Lives saved per year	$S_{FS\_life,avg} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(S_{FS\_life,t} \right)$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{H_{t,sprink}}{H_{t,all}} r_{FS,fatality,sprink} D_{FS,unsprink} \eta_{sprink} \right)$
Fire Service Lives saved per household per year	$S_{FS\_life,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{S_{FS\_life,t}}{H_{t,all}} \right)$
Savings in injury costs per household per year	$S_{injury\$,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{r_{discount} C_{0,injury} S_{injury,t}}{H_{t,all}} \right)$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{r_{discount} C_{t,injury} H_{t,sprink}}{\left(H_{t,all} \right)^2} p_{injury,NZS4517} \left[\left(I_{0,0} - I_{sprink,0} \right) \eta_{sprink} \left(1 - \eta_{smoke} p_{new\_smoke} \right) + \left(I_{0,smoke} - I_{srpink,smoke} \right) p_{ne}$

Table 29 continued: List of home sprinkler cost effectiveness assessment calculation methods.

Name	Calculation Method
Savings in property loss per household per year	$S_{property\$,avg,household}=\frac{1}{Y_{analysis}}\sum_{t=1}^{Y_{analysis}}\left(\frac{r_{discount}C_{property,0}S_{t,property}}{H_{all,t}}\right)$ $=\frac{1}{Y_{analysis}}\sum_{t=1}^{Y_{analysis}}\left(\frac{r_{discount}C_{0,property}F_t\,p_{property,sprink}\,p_{fire,NZS4517}}{\left(H_{t,all}\right)^2}\right)$
Savings in Fire Service costs per household per year	$S_{fire\_service\$,avg,household}=\frac{1}{Y_{analysis}}\sum_{t=1}^{Y_{analysis}}\left(\frac{r_{discount}C_{fire\_service,0,unsprink}\,r_{fire\_service,sprink}\,\eta_{sprink}\,p_{fire,NZS4517}F_tH_{sprink,t}}{\left(H_{t,all}\right)^2}\right)$
Savings in insurance premiums	$S_{insurance\$,avg,household}=\frac{1}{Y_{analysis}}\sum_{t=1}^{Y_{analysis}}\left(\frac{H_{t,sprink}\,r_{discount}\,p_{insurance\_reduction}\,C_{t,insurance\_premimums}}{H_{t,all}}\right)$
Savings in Fire Water per household per year	$S_{water\$,avg,household}=\frac{1}{Y_{analysis}}\sum_{t=1}^{Y_{analysis}}\left(\frac{S_{water\$,t}}{H_{t,all}}\right)$ $=\frac{1}{Y_{analysis}}\sum_{t=1}^{Y_{analysis}}\left(\frac{1}{H_{all,t}}r_{discount}C_{water/litre}\frac{H_{t,sprink}F_t}{H_{t,all}}\left[V_{water,unsprink}-V_{water,sprink}\right]\right)$
Total savings per household per year	$S_{total\$,avg,household}=S_{injury\$,avg,household}+S_{property\$,avg,household}+S_{fire\_service\$,avg,household}+S_{insurance\$,avg,household}+S_{water\$,avg,household}$

Table 29 continued: List of home sprinkler cost effectiveness assessment calculation methods.

Name	Calculation Method
Design, installation and maintenance costs per household per year	$C_{design\&install\&maint,\$,agv,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{r_{discount} \left(H_{new\_sprink,t} \left(C_{t,design,new} + C_{t,installation,new} \right) + H_{retrofit,t} \left(C_{t,design,retrofit} + C_{t,installation,retrofit} \right) + H_{srpink,t-1} C_{t,maintenance} \right)}{H_{all,t}} \right)$
Regulatory costs per household per year	$C_{regulatory,\$,avg,household} = \frac{C_{0,regulatory}}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{r_{discount} C_{t,annual\_regulatory}}{H_{t,all}} \right)$
Net cost per household per year	$C_{total,\$,avg,household} = C_{design\&install\&maint,\$,agv,household} + C_{regulatory,\$,avg,household}$
Cost per life saved	$C_{\$/life} = \frac{C_{total,\$,avg,household} - S_{total,\$,avg,household}}{S_{life,avg,household}}$

Table 30: List of home sprinkler life cycle assessment calculation methods (for savings).

Name	Calculation Method
Savings of NZ Ecopoints for the number of fire adverted fire damaged households per household per year	$S_{house\_dmg,NZEco,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{S_{t,eqv\_house\_dmg}}{H_{all,t}} \right)$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{1}{H_{t,all}} \frac{H_{t,sprink} F_t}{H_{t,all}} \sum_{D_{\%struct}=0\%}^{100\%} if\ D_{\%struct} > L_{\%struct,thresh} \begin{Bmatrix} then\ I_{\%fire,\%damg} C_{NZEco,100\%struct,house\_dmg} \\ else\ I_{\%fire,\%damg} D_{\%struct} C_{NZEco,\%struct,house\_dmg} \end{Bmatrix} \right)$
Savings of NZ Ecopoints for the averted replaced fire damaged households per household per year	$S_{house\_replace,NZEco,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{S_{t,eqv\_house\_replace}}{H_{all,t}} \right)$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{1}{H_{t,all}} \frac{H_{t,sprink} F_t}{H_{t,all}} \sum_{D_{\%struct}=0\%}^{100\%} if\ D_{\%struct} > L_{\%struct,thresh} \begin{Bmatrix} then\ I_{\%fire,\%damg} C_{NZEco,100\%struct,house\_replace} \\ else\ I_{\%fire,\%damg} D_{\%struct} C_{NZEco,\%struct,house\_replace} \end{Bmatrix} \right)$
Savings of NZ Ecopoints for the averted fire water per household per year	$S_{fire\_water,NZEco,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{S_{t,fire\_water,NZEco}}{H_{all,t}} \right)$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{H_{sprink,t} F_t}{H_{all,t}\ \ 2} \left(V_{fire\_water,unsprink} - V_{fire\_water,sprink} \right) C_{NZEco,fire\_water} \right)$
Total NZ Ecopoints saved per household per year	$S_{total,NZEco,avg,household} = S_{house\_dmg,NZEco,avg,household} + S_{house\_replace,NZEco,avg,household} + S_{fire\_water,NZEco,avg,household}$

Table 31: List of home sprinkler life cycle assessment calculation methods (for costs & totals).

Cost of NZ Ecopoints for sprinkler system per household per year	$C_{sprinkNZEco,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{C_{t,sprink,NZEco}}{H_{all,t}} \right) = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{1}{H_{all,t}} \left[H_{sprink\_new,t} \left(p_{house,small} C_{sprink\_small\_new,NZEco} + p_{house,large} C_{sprink\_large\_new,NZEco} \right) + H_{sprink\_retrofit,t} \left(p_{house,small} C_{sprink\_small\_retrofit,NZEco} + p_{house,large} C_{sprink\_large\_retrofit,NZEco} \right) \right] \right)$
Cost of NZ Ecopoints for sprinkler systems lost in housing fire per household per year	$C_{sprink\_lost,NZEco,avg,houshold} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{C_{t,sprink\_lost,NZEco}}{H_{all,t}} \right) = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{1}{H_{all,t}} \frac{F_t H_{sprink,t}}{H_{all,t}} \left(1 - \eta_{sprink} p_{fire,NZS4517}\right) \left(p_{house,large} C_{sprink\_large\_new} + p_{house,small} C_{sprink\_small\_new} \right) \right)$
Cost of NZ Ecopoints for replacement sprinkler systems lost in fire per household per year	$C_{sprink\_replace,NZEco,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{C_{t,sprink\_replace,NZEco}}{H_{all,t}} \right) = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{1}{H_{all,t}} \frac{F_t H_{sprink,t}}{H_{all,t}} \left(1 - \eta_{sprink} p_{fire,NZS4517}\right) \left(p_{house,large} C_{sprink\_large\_retrofit} + p_{house,small} C_{sprink\_small\_retro}$
Total NZ Ecopoints Cost per household per year	$C_{totalNZEco,avg,household} = C_{sprinkNZEco,avg,household} + C_{sprink\_lost,NZEco,avg,household} + C_{sprink\_replace,NZEco,avg,household}$
NZ Ecopoints per life saved	$C_{NZEco/life} = \frac{C_{totalNZEco,avg,household} - S_{totalNZEco,avg,household}}{S_{life,avg,household}}$
Monetary cost per 100 NZ Ecopoints saved	$C_{\$/100NZEco} = \frac{\left(C_{total\$,avg,household} - S_{total\$,avg,household} \right)}{100 \left(C_{totalNZEco,avg,household} - S_{totalNZEco,avg,household} \right)}$

6.2 Previously Identified Sensitive Variables

Previous cost benefit analyses (Williams et al., 2004) were found to be highly sensitive to future changes, which cannot be predicted with any level of confidence. These future related variables included (Williams et al., 2004):

- demographics (specifically an aging population),
- societal perceptions regarding personal safety,
- behaviour such as smoking and intoxication,
- construction technology and benefits of scale that may reduce sprinkler costs,
- impact on the costs of providing public fire services, and
- interest rates and inflation.

7. COST EFFECTIVENESS ANALYSIS VARIABLES

The background and subsequent choice of values used for the input variables, as described in Table 26, are discussed here.

7.1 Sprinkler Effectiveness

When present and fire conditions were larger enough to activate them, sprinklers operated in 94% of the one-and two-family dwelling fires and 98% of the apartment fires (using 1999 – 2002 US data). It was noted that when sprinkler systems failed it was due to the “system being shut-off before the fire or to manual interventions defeating the system”. (Aherns 2007)

A NIST study estimated that due to poor installation or maintenance, the sprinkler system would not operate effectively 8% of the time. (Ruegg & Fuller, 1984)

The estimated percentage of fire with sprinklers were the sprinkler system operated was 84.6% (based on 87,500 fires) for all residential properties, 80.0% (based on 16,900 fires) for one-and two-family dwellings, and 87.6% (based on 50,000 fires) for apartments, based on US fire statistics from 1989 – 1998. Similarly, based on USA fire statistics from 1999, the estimated percentage of fire with sprinklers were the sprinkler system operated was 86.3% (based on 15,871 fires) for all residential properties, 81.8% (based on 6,620 fires) for one-and two-family dwellings, and 89.2% (based on 8,770 fires) for apartments. Similarly, based on USA fire statistics from 1999 – 2002, the estimated percentage of fire with sprinklers were the sprinkler system operated was 88% (based on non-adjusted data, and 97% based on NFPA adjusted data) for all residential properties, 94% (based on NFPA adjusted data) for one-and two-family dwellings, and 98% (based on NFPA adjusted data) for apartments. (Koffel, 2005)

Although it is noted that the design intent of a sprinkler system is fire control and not extinguishment, the estimated number of fires extinguished by sprinkler systems was 19% for all residential properties, 18% for one- and two-family dwellings and 20% for apartments, based on USA fire statistics for 1989 – 1998. (Koffel, 2005)

There was insufficient statistical UK residential data for analysis of the effectiveness of sprinklers. Therefore a theoretical approach was taken based on limiting the area of fire damage. Fatality, injury and rescue statistics were considered in terms of the reported area of fire damage. (Williams et al., 2004)

7.2 Limit of Flame Damage for Effective Sprinkler Operation

A maximum limit for flame damage of a residential structure was estimated, assuming effective operation of a home sprinkler system. There is currently no published literature that specifically relates to such a limit, therefore a conservative estimate was made of a mean damage limit of 5% of a structure, with a minimum of 2% and a maximum of 7%. These estimates are expected to be conservative, i.e. greater than would be expected for an effective home sprinkler system.

7.3 Threshold Total Structure Loss

A threshold percentage value was estimated for total structure loss, equal to or above which the fire damaged structure would be demolished and completely replaced. Since no published literature directly relating to this topic is currently available, a conservative estimation was made of a best estimate of 70%, with a minimum of 60% and a maximum of 80% structure damage for the threshold above which the structure would be demolished.

Table 32: Sprinkler system effectiveness.

Sprinkler System Description & Building Type	Effectiveness when Operates (%)	Operational Reliability	Overall Effectiveness Reliability	Country	Years Statistics are Based on	Reference
Residential Sprinklers						
One- and two-family dwellings	94			US	1999 – 2002	(Aherns, 2007)
Apartments	98			US	1999 – 2002	(Aherns, 2007)
All sprinkler system types						
All building types	99.45			Australia & New Zealand	1886 – 1986	(Marryatt, 1988) [a]
All building types	93			US	1999 – 2002	(Rohr & Hall, 2005) [b]
All residential properties		84.6		US	1989 – 1998	(Hall, 2003) [c]
All residential properties		86.3		US	1999	(Hall, 2003) [c]
One- and two-family dwellings		80.0		US	1989 – 1998	(Hall, 2003) [c]
One- and two-family dwellings		81.8		US	1999	(Hall, 2003) [c]
Apartments		87.6		US	1989 – 1998	(Hall, 2003) [c]
Apartments		89.2		US	1999	(Hall, 2003) [c]
Wet pipe sprinkler systems						
All residential properties	98 [d]	96 [e]	94 [f]	US	2002 – 2004	(Hall, 2007)
Home sprinkler System (NZS 4517)						
BRANZ 2000 CBA estimate	95 (min =90% & max = 99%)					(Wade & Duncan, 2000)
Current cost benefit study			95 (min = 90 & max = 99)			

Notes:
[a] Not including systems that failed to operate.
[b] Based on NFIRS Version 5.0 data.
[c] Excluding structure fires coded as being too small to activate sprinklers.
[d] Based on non-confined structure fires NFIRS Version 5.0 data, where the sprinklers operated and the fire was reported as large enough to activate sprinklers, for 3,400 residential fires.
[e] Based on NFIRS Version 5.0 data, where the fire was large enough to activate sprinklers and where the effectiveness was the qualitative judgement of people completing incident reports, reduction in loss of life or property loss per fire, and reduction in likelihood of large fire size or severity.
[f] Combined effectiveness reliability = (operational reliability x effectiveness when operational =96% x 98%)
[g] Assuming reliability is no less than NZS 4515:1995.

7.4 Smoke Alarm Effectiveness

Smoke alarms required by Warning Systems Compliance Document F7/AS1 (Amd 4 April, DBH, 2003) may be battery powered and are not required to be interconnected. Effectiveness for a range of smoke alarms is presented in Table 33.

Table 33: Smoke alarm effectiveness.

Smoke Alarm Description	Effectiveness (%)	Reference
Single battery-operated alarm	60	(Wade & Duncan, 2000)
Four interconnected alarms	90	(Wade & Duncan, 2000)
Single battery-operated alarm operates	72	(Aherns, 2007)
Single battery-operated alarm operates & alerts occupants	65	(Aherns, 2007)
BRANZ 2000 cost benefit analysis estimate	74 (min =50% & max = 90%)	Assuming four battery-operated alarms (Wade & Duncan, 2000)
Current cost benefit study	62 (min =50% & max = 90%)	Assuming battery-operated alarms that are not interconnected.

7.5 Distribution of Rooms of Fire Origin

The percentage distributions of the room of fire origin for civilian fatalities, civilian injuries and residential fire incidents based on recorded statistics are presented in Table 34 for a range of countries. A comparison of the percentage distributions for civilian fatalities for various countries is shown in Figure 50. Note that the line connecting the average values is only for ease of identification, and no trend or connection is implied between the considered categories. A comparison of the percentage distributions for civilian injuries for various countries is shown in Figure 51. A comparison of the percentage distributions for fire incidents for various countries is shown in Figure 52. A summary of the values assumed for the current study is presented in Table 35. The values used for the current study were primarily based on the New Zealand statistics, included in Table 34.

Table 34: Distribution of fire incidents, fatalities and injuries by room of fire origin for residential structure fire incidents.

Room of Fire Origin	Percentage of Civilian Fatalities						Percentage of Civilian Injuries				Percentage of Fire Incidents			
	NZ [a]	NZ [b]	USA [c]	USA [d]	Canada [e]	England & Wales [f]	NZ [a]	USA [c]	USA [d]	England & Wales [f]	NZ [a]	USA [c]	USA [d]	Canada [e]
Living Room [h]	31	19	24	39	45	40	17	10	20	16	16	4	11	13
Bedroom	33	34	23	26	20	31	26	22	24	18	14	8	12	11
Kitchen	25	29	15	15	17	21	44	35	29	59	41	38	23	29
Bathroom	0	0	-	1	-	2	1	-	2	2	1	-	2	-
Laundry	0	2	-	-	-	1	1	-	-	1	3	-	-	-
Ceiling Space	0	0	-	2	-	1	1	-	1	1	4	-	4	-
Hallway [i]	2	2	-	2	-	2	2	-	2	2	3	-	2	-
Garage	2	6	-	1	-	-	3	-	4	-	4	-	4	-
Other	7	8	38	14	18	2	5	33	18	1	4	50	42	47
Total Number [g]	**234**	**108**	**13265**	**3589**	**717**	**375**	**2668**	**54425**	**13691**	**10804**	**33025**	**1478000**	**404900**	**6739**

Notes:
[a] from analysis of New Zealand Fire Service statistics for residential properties 1995 – 2005. More detail of numbers of incidents, fatalities and injuries are provided in Appendix A.
[b] from analysis of New Zealand death inquest records of fire victims from 1997 – 2002 (Heimdall, 2005)
[c] from USA home structure fire statistics 2000 – 2004. (Aherns 2007)
[d] from NFPA 13D (1999), Table A-1-2(b). The statistics are from 1973 – 1983.
[e] form Ontario residential fires between 1995 – 2003 (Heimdall, 2005).
[f] from England and Wales accidental dwellings statistics for 2002/03. (DCLG 2007)
[g] Total number that the percentages in the column above are based on.
[h] Living Room includes family room, den and dining room.
[i] Hallway includes corridors, lobbies, entrance ways and interior stairs, i.e. escape routes.

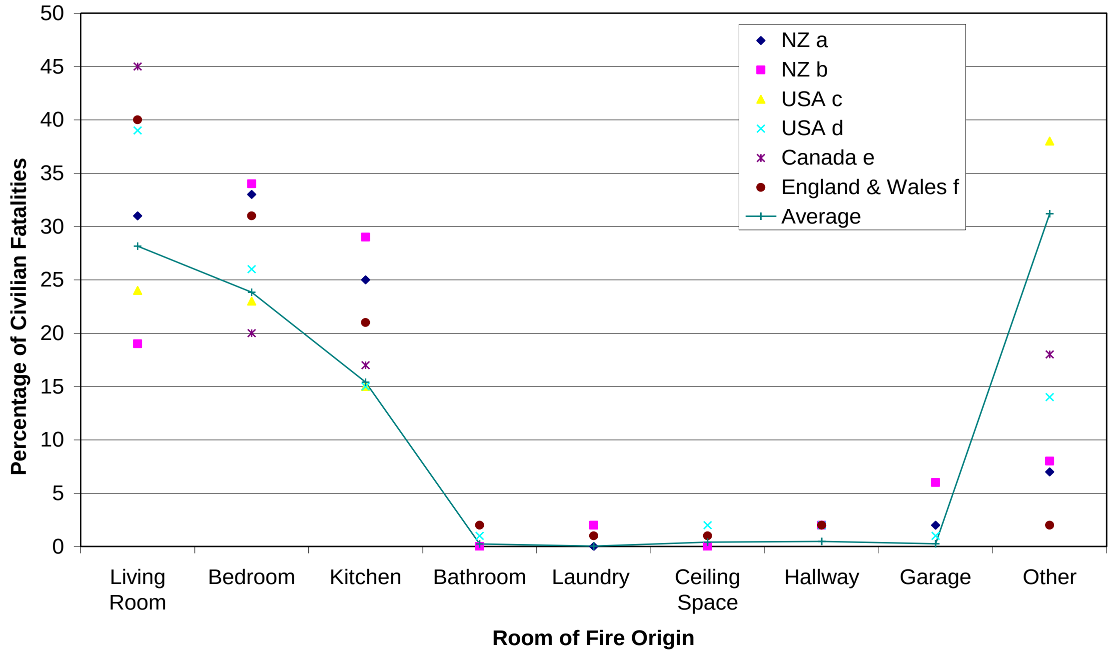


Figure 50: Percentages of civilian fatalities for various countries over various periods. (Details are presented in Table 34 and Error! Reference source not found.**.)**

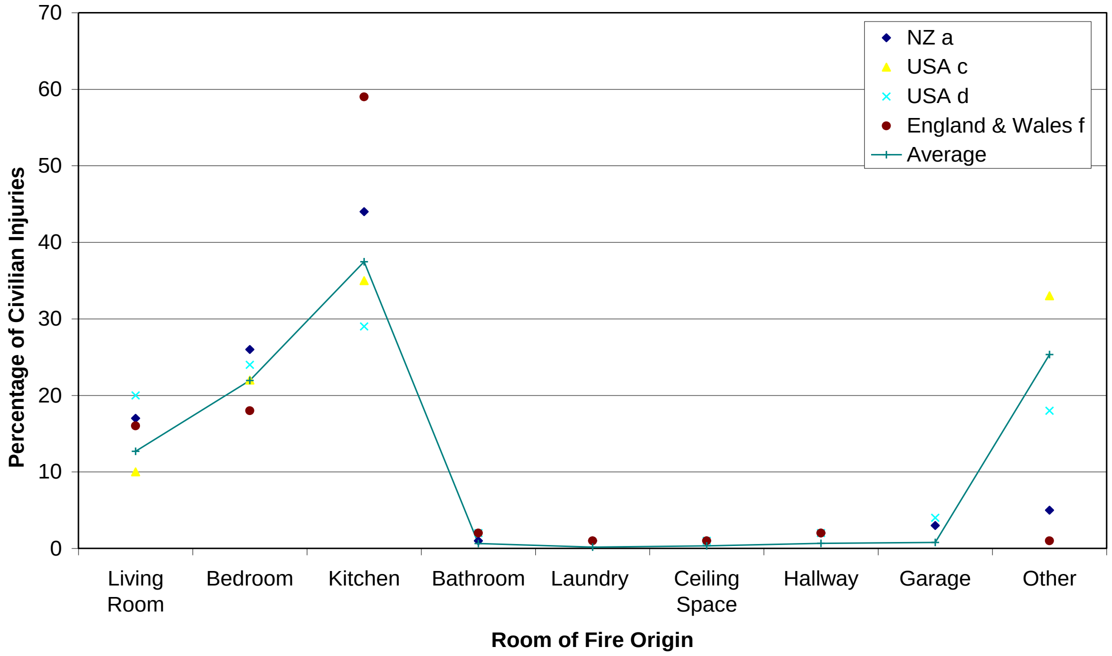


Figure 51: Percentages of civilian injuries for various countries over various periods. (Details are presented in Table 34 and Error! Reference source not found.**.)**

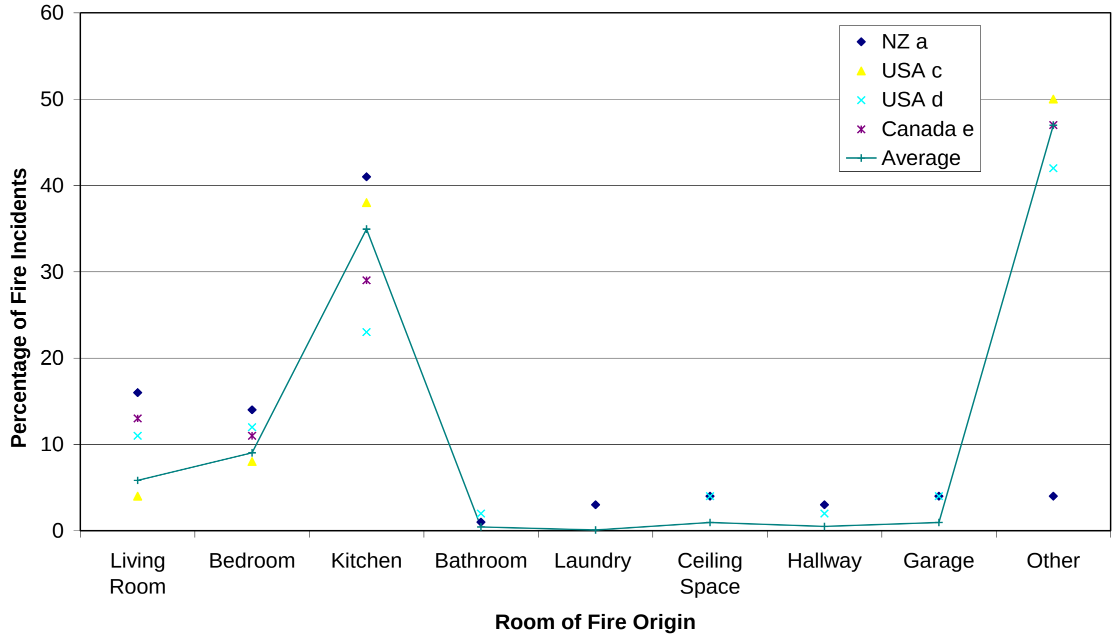


Figure 52: Percentages of residential structure fire incidents for various countries over various periods. (Details are presented in Table 34 and Error! Reference source not found.**.)**

Table 35: Distribution of fire incidents, fatalities and injuries by room of fire origin used in the cost benefit analyses.

Room of Fire Origin	Percentage of Civilian Fatalities		Percentage of Civilian Injuries		Percentage of Fire Incidents	
	BRANZ (2000) [a]	Current Analysis	BRANZ (2000)	Current Analysis	BRANZ (2000)	Current Analysis
Living Room	25.9	19	16.1	17	-	16
Bedroom	38.2	34	30.8	26	-	14
Kitchen	24.1	29	37.2	44	-	41
Bathroom	0.6	1	1.2	1	-	1
Laundry	0.6	2	1.2	1	-	3
Ceiling Space	0.6	1	1.1	1	-	4
Hallway	1.2	2	2.0	2	-	3
Garage	2.4	6	2.2.	3	-	4
Other	6.4	6	8.2	5	-	14

Notes:
[a] Values were based on a combination of New Zealand statistics (Duncan et al., 2000; Irwin, 1997) and from NFPA 13D (1999), Table A-1-2(b), where the statistics were from 1973 – 1983. (Wade & Duncan, 2000)

7.6 Proportion of Structure Covered by NZS 4517

Since NZS 4517 does not require full coverage of all areas of a structure for which it is designed, a conservative approach was taken by including a coverage parameter. That is the coverage parameter for averting potential fatalities, injuries or fire incidents is related to the proportion of the rooms covered by NZS 4517. For example, bathrooms and ceiling spaces do not have mandatory sprinkler coverage according to NZS 4517. Therefore when considering the coverage of home sprinklers, these spaces are excluded. As a conservative approach the 'other' category, as shown in Table 35, was also not included in the coverage of a NZS 4517 system.

The estimated values of coverage of a NZS 4517 system used for room of fire origin for fire incidents was 81% ± 5%, for fatalities was 92% ± 5%, and for injuries was 93% ± 5%.

7.7 Expected Number of Lives Saved

From analysis of 1997 – 2002 New Zealand fire death inquest records, where information was available (93 fatal fire incidents), 71% of fatal fires occurred in properties without smoke alarms. Another 9.7% of fatal fires occurred in properties where alarms were present but inoperative or disabled. (Heimdall, 2005) This constitutes a reduction in fatalities of approximately 60%.

Rohr (2003) reported that analysis of 1989 – 1999 US statistics for average civilian fatalities per thousand fires showed the reduction associated with automatic suppression equipment was 60% for manufacturing properties, 74% for stores and offices, 75% for aged and health care properties, and 91% for hotels and motels. Rohr suggested that the statistics underestimate the value of sprinklers, because only incidents reported to the fire departments are recorded. An estimate of the impact of residential sprinkler systems in USA homes was 74% reduction in death rate.

Incidents in New Zealand where loss of life has been incurred in sprinklered buildings have involved tampering of the sprinkler heads, the victim being intimate with the ignition of the fire and/or the victim being covered in accelerant. (BRANZ, 2000) According to NFPA incident reports properly operating sprinklers have assisted in preventing large loss-of-life incidents where the building was completely sprinklered, except in situations involving explosions or flash fires or where people have been killed during fire suppression activities. (Rohr, 2003)

Loss of life may be expected where the victim is intimate with the ignition of the fire, some fires with substantial smouldering periods where the victim is immobile and there is no quick rescue, where the fire starts in combustibles in a concealed space, or some shielded fast-flaming fires. (Rohr, 2003)

A summary of the published values for reduction for adverted fatalities are presented in Table 36.

Table 36: Summary of the expected number of fatalities associated with domestic fire protection systems.

Expected number of fatalities per 1000 fires & Percentage reduction compared to expected value in the absence of any fire protection system				Source
In the absence of any fire protection system (fatalities/ 1000 fires)	**Where smoke alarms are present (% reduction)**	**Where sprinklers are present (% reduction)**	**Where smoke alarms & sprinklers are present (% reduction)**	
-	60%			(Heimdall, 2005) [a]
-	53%	69%	82% (1.46 fatalites/ 1000fires)	(Ruegg & Fuller, 1984) [b]
-	-	50%	-	(Rahmanian, 1995)
-	-	80 – 90%	-	(Ford, 1997)
-	-	55 – 85%	-	(Fraser-Mitchell, 2004; Williams et al., 2004) [c]
-	-	74%	-	(Rohr, 2003) [d]
-	53%	70 – 80%	83%	(DCLG, 2007) [e]
-	-	77%	-	(Hall, 2007) [f]
-	-	57%	-	(Hall, 2007) [g]
9.8	-	40% (5.9 fatalites/ 1000fires)	-	(Rohr, 2003) [h]
9.7	-	52% (4.7 fatalites/ 1000fires)	-	(Rohr, 2003) [i]
6.0	53% (2.8 fatalites/ 1000fires)	80% (1.2 fatalites/ 1000fires)	83% (1.0 fatalites/ 1000fires)	Initial BRANZ 2000 study estimate (Duncan et al., 2000)

Notes:

[a] From analysis of NZ fire death incidents.

[b] Estimate based on relative frequency of different fire types and proximity of victims to these fires.

[c] Estimate based on UK statistics correlations, independent of property type.

[d] Estimate for US sprinklers in homes (inc. apartments & townhouses).

[e] Summary of consensus values.

f Estimate based on all residential (including apartments. hotels or motels, dormitories and barracks) non-confined structure fires 2002 – 2004

[g] Estimate based on all apartments non-confined structure fires 2002 – 2004.

[h] Based on US 1999 statistics for reported one- and two-family dwelling fires.

[i] Based on US 1989 – 1999 statistics for reported one- and two-family dwelling fires.

Considering the total population, to estimate values for the deaths per 1000 fires with no sprinklers and no fire alarms present the New Zealand statistics for average number of fatalities per year (approximately 21, with a minimum of 15 and a maximum of 28) and fatalities per 1000 fires (approximately 6.8, with a minimum of 4.7 and a maximum of 9.5), as presented in Table 10, were used in combination with an assumed reduction in residential fire fatalities of 53% when smoke alarms were present. Therefore the estimate used for the values for the number of deaths per 1000 fires when no sprinkler system and no smoke alarm system is present was an average of 8.7, with a minimum value of 6 and a maximum value of 12.

Using the same approach as applied for the total population, sectors of the residential property stock was considered according to occupier type using the results of the statistical analysis presented in Table 11 and Table 12. The results are summarised for each of the property occupier types in Table 38.

The reductions for adverted fatalities assumed for this study are summarised in Table 39.

Table 37: Summary of the statistics used to calculate the expected number of fatalities associated with domestic fires in the absence of any fire protection system for each property occupier type considered in this study.

	Fatalities/ year		
	Average	**Minimum**	**Maximum**
All residential properties	21	15	28
Owner occupied properties	9	3	15
Not owner occupied properties	10	1	16
State owned	1	0	5
Housing NZ	2	0	4
Rented properties	8	1	12

Table 38: Summary of the expected number of fatalities associated with domestic fires in the absence of any fire protection system for each property occupier type considered in this study.

Fatalities/ 1000 fires/ year	**All residential properties**	**Owner occupied properties**	**Not owner occupied properties**	**State owned**	**Housing NZ**	**Rented properties**
Average	8.5	6.5	9	4	10	11
Minimum	6	3	3	1	0	5
Maximum	12	9	13	15	27	15

Table 39: Summary of the percentage reduction from the conditions where no domestic fire safety is present in fatalities for smoke alarms and sprinklers used for the current study for all types of property occupier considered.

Where smoke alarms are present (% reduction)	Where sprinklers are present (% reduction)	Where smoke alarms & sprinklers are present (% reduction)
53%	80%	83%

7.8 Expected Number of Injuries

A summary of published values for reductions in civilian injuries where combinations of smoke alarms and sprinklers are present is presented in Table 40. The estimates of the reduction in civilian injuries attributed to smoke alarms and sprinkler systems used for this study are presented in Table 45.

For the total building stock considered, to estimate values for the injuries per 1000 fires with no sprinklers and no fire alarms present the New Zealand statistics for average number of fatalities per year (approximately 240, with a minimum of 180 and a maximum of 300) and fatalities per 1000 fires (approximately 77, with a minimum of 57 and a maximum of 88), as summarised in Table 41, were used in combination with an assumed reduction in residential fire fatalities of 70% when smoke alarms were present. Therefore the estimates used for the study for the number of injuries per 1000 fires when no sprinkler system and no smoke alarm system is present was an average of 110, with a minimum value of 70 and a maximum value of 120, as presented in Table 42.

A similar approach was used for each of the categories of property occupier. A summary of the values used in the current study is presented in Table 42.

Since the statistical data set for the property occupier type did not include minor injuries, whereas the data sets associated with the cost of fire related injuries and the statistics for the overall residential building stock did include minor injuries, minor injuries were approximated for the property occupier fire incident statistics. Details of the assumptions used for this approximation are included in Appendix **Error! Reference source not found.** and **Error! Reference source not found.**. The associated values used in the current study are presented in Table 44.

Table 40: Summary of the expected number of injuries associated with domestic fire protection systems.

Expected number of injuries per 1000 fires				Source
In the absence of any fire protection system	**Where smoke alarms are present (% reduction)**	**Where sprinklers are present (% reduction)**	**Where smoke alarms & sprinklers are present (% reduction)**	
70	-	-	-	(Beever & Britton, 1999) [a]
-	-	46%	46% (14 injuries/ 1000fires)	(Ruegg & Fuller, 1984) [b]
-		30 – 15%	-	(Beever & Britton, 1999) [c]
40	70% (12 injuries/ 1000fires)	-	-	(Wade & Duncan, 2000) [d, e]
-	-	30±15%	-	(Fraser-Mitchell, 2004) [f]
-	70%	45 – 65%	45 – 85%	(DCLG, 2007) [g]
40	70% (12 injuries/ 1000fires)	62% (15 injuries/ 1000fires)	75% (10 injuries/ 1000fires)	Initial BRANZ 2000 study estimate (Duncan et al., 2000)

Notes:
[a] Based on Australian statistics.
[b] Estimate based on relative frequency of different fire types and proximity of victims to these fires.
[c] Estimate for one- and two-family dwelling fires.
[d] Based on NZFS statistics.
[e] Estimate based on four battery operated alarms (for 1- and 10- year battery life).
[f] Estimate based on UK statistics correlations.
[g] Summary of consensus values.

Table 41: Summary of the statistics used to calculate the expected number of injuries associated with domestic fires in the absence of any fire protection system for each property occupier type considered in this study.

	Injuries/ year		
	Average	**Minimum**	**Maximum**
All residential properties	77	57	88
Owner occupied properties	58	21	84

Not owner occupied properties	65	38	86
State owned	8	0	17
Housing NZ	13	6	22
Rented properties	44	21	67

Table 42: Summary of the expected number of injuries associated with domestic fires in the absence of any fire protection system for each property occupier type considered in this study.

Injuries/ 1000 fires/ year	All residential properties	Owner occupied properties	Not owner occupied properties	State owned	Housing NZ	Rented properties
Average	110	44	65	40	75	65
Minimum	70	30	40	0	40	45
Maximum	120	60	90	95	130	75

Table 43: Summary of the statistics including the approximations for minor injuries used to calculate the expected number of injuries associated with domestic fires in the absence of any fire protection system for each property occupier type considered in this study.

	Injuries/ year		
	Average	**Minimum**	**Maximum**
Owner occupied properties	113	84	155
Not owner occupied properties	128	69	209
State owned	16	0	30
Housing NZ	24	11	39
Rented properties	89	54	158

Table 44: Summary of the expected number of injuries including the approximations for minor injuries associated with domestic fires in the absence of any fire protection system for each property occupier type considered in this study.

Injuries/ 1000 fires/ year	Owner occupied properties	Not owner occupied properties	State owned	Housing NZ	Rented properties
Average	85	120	75	135	125
Minimum	65	80	0	85	85
Maximum	115	180	180	230	195

Table 45: Summary of the percentage reduction from the conditions where no domestic fire safety is present in injuries for smoke alarms and sprinklers used for the current study for all types of property occupier considered.

Where smoke alarms	Where sprinklers	Where smoke alarms &

are present (% reduction)	are present (% reduction)	sprinklers are present (% reduction)
70%	62%	75%

7.9 Number 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. It was assumed the average number of dwellings to be 1,318,800 over the same period provide an estimate of 0.0045 reported fires per year per household. This rate included both 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.

A fire incident rate of 0.004 fires per year per household was assumed for the previous home sprinkler (Wade & Duncan, 2000) study, based on the then current New Zealand data from NZFS statistics 1993 – 1997 and Irwin's (1997) analysis. Although higher than the equivalent Australian data, this was assumed 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 and therefore not included in fire service statistics.

Future growth or reduction of the number of fire incidents per year was not included in the initial cost benefit analysis (Wade & Duncan, 2000).

For this study, structure fires only were considered. This reduced the number of fire incidents per year compared to the previous study (Wade & Duncan, 2000). Based on the analysis of New Zealand Fire Service statistics summarised in Section 4.1, the average number of structure fire incidents per year was estimated to be 3,200, with a minimum of 2,700 fire incidents and a maximum of 3,500 fire incidents. The values for the number of fire incidents per household per year are similar for both New Zealand statistics (0.002 – 0.0035, Figure 7) and USA statistics (0.003 – 0.004, Table 16). The New Zealand statistics show a slight decrease with time over the period from 1995 to 2005, however the values are still within a small range. For this study, the number of residential structure fire incidents was assumed to be proportional to number of households.

Considering properties where the occupier is not the owner of the property (as discussed in Section 4.1.2), the average number of fire incidents per property is more than twice that reported for owner occupied properties (Table 11). Therefore it is considered of use to assess the various categories of property occupier, for which there are statistics for comparison. A summary of the number of fire incidents per year for the various occupier categories considered in this study is presented in Table 46.

Table 46: Summary of the number of fire incidents per year used for the first year of the study for each property occupier type considered in this study.

Property Occupier Category	Fire Incidents/ year		
	Average	Minimum	Maximum
All residential properties	3,200	2,700	3,500

Owner occupied properties	1,950	700	2,400
Not owner occupied properties	1,550	650	1,850
State owned	280	120	350
Housing NZ	250	110	290
Rented properties	1,000	430	1,300

7.10 Number of Households

The total number of detached dwellings and flats (including unoccupied properties) was 1,435,000 in 2001. (QVNZ As at March 2001) The distribution of the decade built for the building stock, as at the 2001 consensus is shown in Figure 53. Houses and other single-storey dwellings accounted for approximately 85% of the total stock of residential dwellings, as indicated in the 2001 consensus. (BERL 2005)

The previous home sprinkler cost benefit analysis (Wade & Duncan, 2000) did not include future growth of the building stock.

The initial number of houses used in the study for each category of property occupier is presented in Table 47. The average increase in building stock for each of the occupier categories considered in this study is presented in Table 48. These values are based on analysis of the New Zealand consensus data for the years 1991, 1996, 2001 and 2006. These number for the categories of building stock by occupier type may include some multistorey buildings where NZS 4515 or NZS 45 41 would apply instead of NZS 4517. Therefore this should be taken into consideration when analysing the model results.

An average increase in the total building stock of 0.5% per annum was assumed for the current study.

It should be noted that for each of the combined categories of households (i.e., total residential stock and not owner occupied residential building stock) the model results reflect the implied assumption of the homogeneity of the categories included. That is, each sub-category within either the total building stock or the not owner occupied categories are assumed to proportionally increase or decrease over the period considered for analysis, whereas in reality they are not proportional (as indicated by consideration of Table 48).

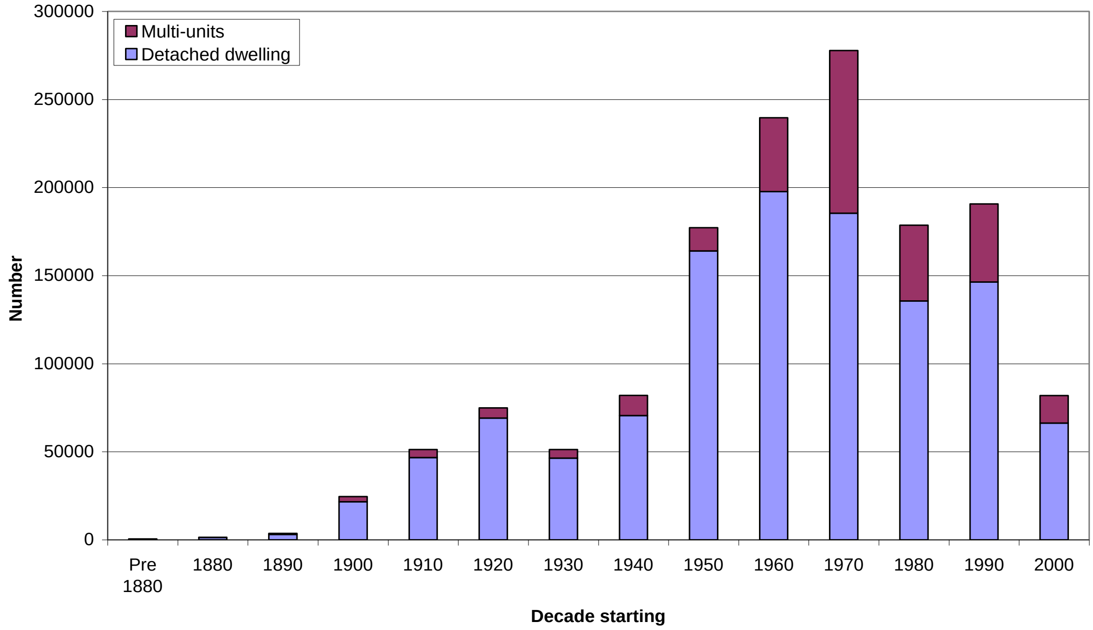


Figure 53: New Zealand housing stock by decade built. (QVNZ, as at March 2001)

Table 47: Summary of the number of households used for the first year of the study for each property occupier type considered in this study (based on the average number of houses reported in the New Zealand consensus over the years considered in Section 4.1).

Property Occupier Category	Number of Households
All residential properties	1,500,000
Owner occupied properties	782,000
Not owner occupied properties	325,000
State owned	23,500
Housing NZ	57,300
Rented properties	244,000

Table 48: Average percentage increase per year of the building stock by each category of residential property occupier considered in this study.

Property Occupier Category	Average Percentage Increase per Year in Building Stock	Minimum Percentage Increase per Year	Maximum Percentage Increase per Year
Owner occupier	-0.3%	-0.9%	0.1%
Not owner occupied	2.6%	1.5%	4.7%
State owned	-3.2%	-4.1%	-2.3%
Housing NZ	-1.5%	-3.6%	-0.1%
Rented property	4.4%	2.3%	6.9%

7.11 Discount Rate

"The real, after-tax annual rate of return in large-cap stocks over the period 1925 – 2005… is 4.8%, and the average yield rate for municipal bonds over the period 1919 to 2004 is 1.3%." (Brown, 2005)

For a previous BERL cost benefit study (2003) it was recognised that there is no 'standard' or agreed discount rate. Therefore estimates of 10, 5 and 3 and zero% were considered for the sensitivity analysis. These estimates for the discount rate were considered to be within the range suggested as appropriate in the context of health research. (BERL, 2003)

The discount rate assumed for this study was an average of 8%, with a minimum of 7% and a maximum of 9%.

7.12 Inflation Rate

The inflation rate assumed for this study was an average of 2.1%, with a minimum of 2% and a maximum of 3%.

7.13 Discounting of Lives and NZ Ecopoints

Lives and NZ Ecopoints were not discounted in this study.

That is, it was assumed that one life today is equal to one life in the future. This allows direct comparison with net present values for estimated values of a statistical life, since it would be the monetary value that would change with the assumed real discount rate over the period of analysis, whereas the number of lives saved would not be discounted in addition.

Similarly it was assumed that the monetary value assigned to a NZ Ecopoint would be affected by the real discount rate, and therefore the NZ Ecopoints would not be discounted within this study. Again this allows estimated net present values for the monetary value of 100 NZ Ecopoints to be compared directly from the results of this study.

7.14 Sprinkler System Life

The home sprinkler system life was assumed to be the same as that of domestic plumbing. This was assumed to be 50 years.

7.15 Analysis Period

The analysis period considered was the equivalent of the assumed value for a sprinkler system life.

7.16 Sprinkler Installation Costs

Considering the monetary aspects of sprinkler installation costs as listed in ASTM E917-05 Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, the aspects included are costs of:

- designing,
- purchasing/leasing,
- constructing/ installing,
- operating,
- maintaining, repairing, replacing, and
- disposal.

Another factor for consideration is the potential reduction in sprinkler installation costs when an ordinance is adopted. For example, the estimated installation cost in Scottsdale was approximately 7 cents per square meter, whereas the national average cost is approximately 9 to 14 cents per square meter. (Ford, 1997)

An example for USA residential sprinkler systems was presented by Brown (2005) for a range of house sizes. A summary for the results is included in Table 49.

The costs assumed for design and installation costs for this study are presented in Table 50.

Table 49: Summary of estimated system design and installation costs, including water supply costs.

Fully Furnished House (Retrofit)		New Build		Source
Quoted Value	**NZ 2008 Monetary Equivalent ***	**Quoted Value**	**NZ 2008 Monetary Equivalent ***	
£1,050 – 2,080	$2,800 – 5,500	£480	$1,300	(DCLG, 2007) [a]
		£1,650 ±150	$5,900 ±600	(Fraser-Mitchell, 2004) [b]
		US$700 – 1,600 (avg. US$1,100)	$1,200 – 2,600 (avg. $1,800)	(Brown, 2005) [c]
		US$1,500 – 2,200 (avg. US$1,800)	$2,400 – 3,600 (avg. $2,900)	(Brown, 2005) [d]
		US$1,600 – 2,500 (avg. US$2,000)	$2,600 – 4,000 (avg. $3,200)	(Brown, 2005) [e]
	$900 – 3,200 (avg, $3,200)		$700 – 2,200 (avg. $1,100)	Small house [f]
	$2,500 – 5,400 (avg. $3,600)		$1,400 – 4,800 (avg. $3,300)	Large house [f]

Notes:
* The New Zealand monetary equivalent was estimated simply using currency conversions and the same assumed values for discount rate and inflation rate as used throughout the study, as detailed in Appendix A.
[a] Lower cost UK home sprinkler system that assumes single sprinkler operation.
[b] UK residential sprinkler system.
[c] US residential sprinkler systems estimated for 6 different sprinkler systems (using a 30% material markup) in a representative example of a single family home: a 109 m² one-storey ranch.
[d] US residential sprinkler systems estimated for 6 different sprinkler systems (using a 30% material markup) in a representative example of a single family home: a 210 m² three-storey townhouse.

[e] US residential sprinkler systems estimated for 6 different sprinkler systems (using a 30% material markup) in a representative example of a single family home: a 310 m² two-storey colonial with basement.
[f] Averages estimated from local New Zealand survey. Details included in and Appendix C.

Table 50: Assumed design and installation costs used for this study.

	Average Cost	Minimum Cost	Maximum Cost
Retrofit	2400	900	5400
New Build	2100	700	4800

7.17 Fire Injury and Mortality Costs

It is often argued that it is not possible to place a value on casualties in fire, or any other situation. However, such values are implicit in choices that policy-makers face every day. The decision on whether to fund a road improvement against a new school, or to target domestic over other types of fire requires a judgement by a decision-maker and places an implicit value on casualties. There are research techniques that are increasingly being used to place objective values on the cost of casualties. These values include three elements (Office of the Deputy Prime Minister, 2005):

- *Healthcare costs*. Fire casualties tend to result in costs to the NHS. Reducing these casualties will free money and time to be used on other conditions.
- *Lost output*. Fire victims will often have to take time off work. This represents a reduction in production in the economy. Preventing fatalities and injuries will increase the output of the economy.
- *Emotional and physical suffering*. The emotional and physical suffering of victims is a significant cost and the hardest to value. It is not possible to value the cost to the individual of experiencing an incident, since different people will be affected in very different ways. To attempt to value this would demean the trauma suffered. However, it is possible to derive the value society places in preventing this incident occurring.

A variety of organisations around the world have attempted to value casualties. The values used in this study are published by the Department for Transport and have been used for a number of years in the appraisal of road schemes. (Department for Transport, 2004)

A significant element of the value of avoiding fatalities is the gain made by society in terms of increased output. This is a function of the age profile of those at risk and their potential years in work. There is likely to be a significant difference in the age profile of those most at risk of fatality in road accidents and in fires and therefore we would expect the value of lost output and thus the statistical value of life to differ between the two hazards. There is also some evidence to suggest that people place different values on suffering injury or ill health from different causes. Further research may provide more appropriate estimates for use in estimates of the cost of fire.

The DfT research also provides guidance on valuing serious and slight injuries. In order to apply these figures to fire casualties it is therefore necessary to classify injuries by severity, which is an area that fire statistics do not currently record in much detail. General categories of burns, smoke inhalation, physical injuries and other injuries are recorded, but within these categories there can be significant variation in the severity of injuries. The assumptions used by Roy (1997) are retained. All injuries involving burns and 25 per cent of injuries involving smoke inhalation are classified as serious injuries. The remainder are assumed to be slight.

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 USA 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 the BRANZ (2000) study which was similar to the Australian value after accounting for exchange rates and inflation.

BERL (2005) estimated the direct costs of fire-related injuries based on Health Information Service (HIS) and Accident Compensation Corporation (ACC) records for the period between 1999 and 2003. An average of 467 apparent fire-related injuries per annum was estimated. Hospital costs were on average $4825 per injury. Average ACC costs were approximately $3.7 million per annum, where 95% of this cost was attributed to compensation of on-going claimants.

BERL (2005) estimated average indirect fire-related injury costs based on New Zealand Land Transport Safety Authority (LTSA) estimates for Value of Statistical Life (VoSL). The NZFS combined categories of slight & moderate fire-related injury were estimated to be equivalent to the LTSA category of minor injury, with an indicative monetary value of $102,000. The NZFS category of life threatening fire-related injury was estimated to be equivalent to the LTSA category of serious injury, with an indicative monetary value of $255,000. The indirect cost of mortality was estimated as $2,550,000.

Estimates based on 1999 UK fire statistics suggested 37% of all residential (including care homes) civilian injuries were serious. (Fraser-Mitchell, 2004)

Table 51: Summary of indirect costs associated with fire-related injuries.

Indirect cost per slight or moderate injury		**Indirect cost per life-threatening injury**		**Indirect cost for mortality**		**Source**
Quoted Value	**NZ 2008 Monetary Equivalent ***	**Quoted Value**	**NZ 2008 Monetary Equivalent ***	**Quoted Value**	**NZ 2008 Monetary Equivalent ***	
$102k (2005)	$136k	$255k (2005)	$340k	$2,550k (2005)	$3,400k	(BERL 2005)
				US$2,700k (1998)	$8,500k	From a FAA funded report (Hoffer et al. 1998; Porter, 2002)
				US$400k – 4,000k (1981)	$6,400k – $64,000k	(Fischhoff et al., 1981; Porter, 2002)
		£58.3k ±6.7% (2002)	$2,500k ±6.7%	£1,243k ±5% (2002)	$5,300k ±5%	(Fraser-Mitchell, 2004)
$102k (2005)	$136k	$255k (2005)	$340k	For comparison with analysis results [a]		Estimates assumed for

					current study

Notes:
* The New Zealand monetary equivalent was estimated simply using currency conversions and the same assumed values for discount rate and inflation rate as used throughout the study, as detailed in Appendix A.
[a] For comparison with assessment results, see Section 8.4.

Table 52: Summary of direct costs associated with fire-related injuries.

Direct cost per injury		Source
Quoted Value	**NZ 2008 Monetary Equivalent ***	
NZ$13,000 (2005)	$17,400	Based on hospital & ACC costs (BREL 2005)
A$21,100 (1999)	$55,700	Including pain and suffering (Beever and Britton 1999)
US$20,000 (1984)	$240,000	(Ruegg and Fuller, 1984; Rahmanian, 1995; Strategos,1989)
NZ$30,000 (2000)	$64,800	Initial BRANZ 2000 study estimate (Duncan et al 2000)
	$17.4k – 64.8k (avg. $30k)	Estimate assumed for the current study

Notes:
* The New Zealand monetary equivalent was estimated simply using currency conversions and the same assumed values for discount rate and inflation rate as used throughout the study, as detailed in Appendix A.

7.18 Property Fire Damage Costs

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 (Ford, 1997).

Data supplied by the Insurance Council of New Zealand (Gravestock, 1999) indicated that the average home 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.

BERL (2005) have estimated the average cost of building and contents damage per dwelling fire to be $18,000 – $20,000. The average value of household fire-related insurance claims was approximately $16,000 per fire. (BERL 2005)

Rohr (2003) reported that analysis of 1989 – 1999 US statistics for average value of direct property damage per fire showed the reduction associated with automatic suppression equipment was 64% for manufacturing properties, 53% for stores and offices, 66% for aged and health care properties, and 70% for hotels and motels. An estimate of the impact of residential sprinkler systems in homes was 74% reduction in death rate. Rohr suggested that the statistics underestimate the value of sprinklers, because only incidents reported to the fire departments are recorded.

The percentage of fires confined to the room of fire origin (excluding structures under construction and sprinklers not in fire area) was 57% when no automatic extinguishing system was present and 67% when sprinklers of any type were present for one- and two-family dwellings, and 74% when no automatic extinguishing system was present and 92% when a sprinkler of any type was present (based on 2002 – 2004 US non-confined structure fire statistics). (Hall, 2007)

The published values and the assumed values for this study are summarised in Table 53.

Table 53: Summary of property loss values for various fire safety systems present

Average loss per fire when automatic suppression was present		Average loss per fire when automatic suppression was not present		Source
Quoted Value	Percentage Reduction from when no automatic suppression was present	Quoted Value	NZ 2008 Monetary Equivalent	
US$1,700				(Ford, 1997).[a]
US$2,200	95%	US$45,000 (2001)	$106k	(Jelenewicz, 2005) [b]
US$3,700	88%	US$32,000 (2003)	$62.1k	(Jelenewicz, 2005) [c]
US$5,400	50%	US$10,900	$14.4k	(Aherns 2007) [e]
		NZ$18,000-$20,000	$24k – 27k	(BERL 2005) [f]
	50±15%			(Fraser-Mitchell, 2004) [g]
US$5,400	42%	US$9,400	$18.2k	(Rohr, 2003) [h]
US$10,300	24%	US$13,500	$26.2k	(Rohr, 2003) [i]
	50 – 66%			(Rohr & Hall, 2005) [j]
US$7,800	19%	US$9,600	$18.6k	(Rohr, 2003) [k]
US$4,400	49%	US$7,800	$15.2k	(Rohr, 2003) [m]
US$11,000	17%	US$13,200	$25.6k	(Rohr, 2003) [n]
US$6,000	45%	US$10,800	$21.0k	(Rohr, 2003) [o]
US$14,700	42%	US$25,100	$33.2k	(Hall, 2007) [p]
US25,900	40%	US$15,600	$20.6k	(Hall, 2007) [q]
NZ$3,600	79%	NZ$17,200	$37.1k	Initial BRANZ 2000 study estimate (Duncan et al., 2000)
	20% – 95% (avg. 50%)		$15k – 100k (avg. $30k)	Estimate assumed for current study

Notes:

[a] From the analysis of Scottsdale data over a 10-year period.
[b] Based on Scottsdale home data.
[c] Based on Prince George's County single-family home data.
[d] From the analysis of New Zealand insurance data.
[e] US home structure fires, 1994-1998 annual averages.
[f] Estimated the average cost of building and contents damage per dwelling fire.
[g] Estimate based on US statistics.
[h] Estimate based on US average direct property damage per residential (including one-& two-family dwellings, apartments, hotels, motels, dormitories, barracks) fire 1989 – 1998.
[i] Estimate based on US average direct property damage per residential (including one-& two-family dwellings, apartments, hotels, motels, dormitories, barracks) fire 1999.
[j] Estimate based on US 1989 – 1998 all building statistics.
[k] Based on US 1989 – 1998 one- & two-family dwellings statistics.
[m] Based on US 1989 – 1998 apartment statistics.
[n] Based on US 1999 home (including one-& two-family dwellings, apartments, and townhouses) statistics.
[o] Based on US 1999 apartments statistics.
[p] Based on US 2002 – 2004 residential (including apartment, hotel and motel) statistics.
[q] Based on US 2002 – 2004 residential apartment statistics.

7.19 Cost Savings of Fire Service

Fire Service costs were not included in the 2000 home sprinkler CBA (Duncan and Wade 2000).

Roy (1997) used the number of various types of call-outs to allocate associated costs. Weiner (2001) and BERL (2002) used the average number of 'appliance-hours' attending each type of call-out to take into account differences of resource usage or consumption. These incident-based approaches assume the cost of operational readiness is equally distributed between all types of incidents. That is, the cost of time spent on response and suppression is treated the same as non-fire incidents.

TriData (1995) assumed an incremental approach, where the majority of operational readiness costs are associated with fire protection risk. Therefore costs of equipment, personnel and capital not used for fire protection (which was estimated as less than 5% of the overall costs of associated with fire services) were deducted.

BERL (2005) used an approach that combined both of these methodologies to produce a result comprising of mixed and fixed costs that was more conservative than the incremental approach. Using the 2004 NZFS and rural service budgets (including an estimated monetised contribution of volunteers) and statistics, considering all fire incidents (including vegetation fires, etc.), the average appliance time per fire (average number of appliances per incident multiplied by the average elapsed time per incident) was 93 hours, which related to approximately $5,100 of mixed costs and $2,700 of fixed costs per fire.

Cost savings for the fire service may include reduction in rescues required (estimated as a 20 – 50% reduction for all UK residential properties, and 40 – 65% reduction for flats), or shorter call-out times. (Fraser-Mitchell, 2004; Williams et al., 2004) However it was suggested that the value to place on rescues may be difficult assign an appropriate monetary value, and Jelenewicz (2005) suggested that it should not be included in a pure cost-benefit analysis, but instead be used to provide some qualitative insight.

A study estimated the savings of the Vancouver fire department costs to in the order of 20 – 30% of the cost of the sprinkler installation. (Williams et al., 2004)

The assumed values for fire service costs for unsprinklered fires used for this study were an average of $5,900, with a minimum of $5,000 and a maximum of $6,500. The assumed values for the reduction in cost of the fire service for sprinklered fires was an average of 30%, with a minimum of 20% and a maximum of 50%.

Another aspect of benefits that may be added in future analyses is the reduction of fire service fatalities and injuries attributed to home sprinkler systems.

7.20 Insurance Savings

An average insurance premium reduction of approximately 10% was offered by the majority of local (to the Scottsdale area) insurance agencies for the installation of home sprinklers. (Ford, 1997)

The Office of the Deputy Prime Minister (2005) considered that the payment of insurance premiums did not represent a cost of fire to the economy since they were transfer payments rather than a welfare loss to society. However, the administration cost of insurance is a genuine welfare loss and was therefore included as a cost of fire. It was reasoned that if there were no need for fire insurance, the capital and labour used by insurance companies to administer policies and claims could be used elsewhere. The Association of British Insurers (ABI) records the value of 'commissions and expenses' for commercial properties, domestic properties and vehicles. It is assumed that the proportion of these expenses that are attributable to fire is equal to the proportion of fire claims to total claims. The public sector was assumed to be self-insured and so no insurance administration was attributable to these fires. ABI data is recorded for the UK, but is scaled to England and Wales using their share of UK gross value added. (Office of the Deputy Prime Minister, 2005)

A conservative estimate of reduction in insurance premiums of an average 5%, with a minimum of 2% and a maximum of 7% was assumed for this study.

8. MODEL EXAMPLE

This section describes the scenarios considered for analysis, summarises the input variables used in the model scenarios, and presents the results and associated discussion for the scenarios considered.

8.1 Scenario Descriptions

Two alarm combinations were analysed:

1. With home sprinklers & smoke alarms, and
2. With home sprinklers but without smoke alarms.

Six residential property occupier categories were considered:

1. Total population,
2. Owner occupied properties,
3. Not owner occupied properties,
4. State and council owned properties,
5. Housing New Zealand owned properties, and
6. Rented properties.

Individual input parameters of potential monetary benefits were removed for analyses. These benefits were:

1. fire service costs,
2. insurance premium reductions, and
3. indirect costs from civilian fire injuries.

The ‘base case’ used to throughout this report refers to the case considering home sprinkler systems with smoke alarms, including all input parameters, and for all property occupier categories.

8.2 Summary of the Input Variable Values

A summary of the base input parameter values that are common for the scenarios discussed in Section 8.1, for both the cost effectiveness analysis and the environmental impact module, is presented in Table 54. A summary for the differences between property occupier types is presented in Table 55.

Discussion of the background and selected values for each of the input parameters is presented in Section 7.

Table 54: Summary of the base inputs for the cost effectiveness analysis and the environmental impact modulecommon for all scenarios considered

Input Description	Minimum Value	Average	Maximum Value
Sprinkler effectiveness	0.90	0.95	0.99
Smoke alarm effectiveness *	0.50	0.62	0.90
Limit of flame damage for effective sprinkler system	2%	5%	7%
Limit of %structure damage for total loss	60%	70%	80%
Reduction in deaths per 1000 fires, no sprinklers, with alarms		53%	
Reduction in deaths per 1000 fires, with sprinklers, no alarms		80%	
Reduction in deaths per 1000 fires with sprinklers, with alarms		83%	
Reduction in injuries per 1000 fires, no sprinklers, with alarms		70%	
Reduction in injuries per 1000 fires, with sprinklers, no alarms		62%	
Reduction in injuries per 1000 fires with sprinklers, with alarms		75%	
Proportion of new households sprinklered		100%	
Rate of retrofit of sprinkler in households	7%	10%	15%
Proportion of existing housing with smoke alarms	50%	60%	70%
Proportion of new households with smoke alarms		100%	
Proportions of current building stock:			
Type A [a]		5%	
Type B [a]		15%	
Type C [a]		10%	
Type D [a]		30%	
Type E [a]		10%	
Type F [a]		30%	
Proportions of new building stock:			
Type A [a]		5%	
Type B [a]		15%	
Type C [a]		10%	
Type D [a]		30%	
Type E [a]		10%	
Type F [a]		30%	
Proportions of sprinkler types:			
Type A [b]		33%	
Type B [b]		33%	
Type C [b]		34%	

Notes:
* For the cases of no smoke alarms, the smoke alarm effectiveness was set to zero.
[a] The types of building stock are as described in **Error! Reference source not found.**.
[b] The types of sprinkler system are as described in **Error! Reference source not found.**.

Table 54 continued: Summary of the base inputs for the cost effectiveness analysis and the environmental impact modulecommon for all scenarios considered

Input Description	Minimum Value	Average	Maximum Value
Proportion of house sizes			
Large houses		60%	
Small houses		40%	
Discount rate	7%	8%	9%
Inflation rate	2%	2.1%	3%
Analysis period (years)		50	
Sprinkler system life (years)		50	
Room of fire origin – distribution of fire incidents			
Living room		16%	
Bedroom		14%	
Kitchen		41%	
Bathroom		1%	
Laundry		3%	
Ceiling space		4%	
Hallway		3%	
Garage		4%	
Other		14%	
Proportion of fire incidents where roomcoverage is required by an NZS4517 system	-5%	81%	+5%
Room of fire origin – distribution of fatalities			
Living room		19%	
Bedroom		34%	
Kitchen		29%	
Bathroom		1%	
Laundry		2%	
Ceiling space		1%	
Hallway		2%	
Garage		6%	
Other		6%	
Proportion of fatalities where the room of fire origin coverage is required by an NZS4517 system	-5%	92%	+5%
Room of fire origin – distribution of injuries			
Living room		17%	
Bedroom		26%	
Kitchen		44%	
Bathroom		1%	
Laundry		1%	
Ceiling space		1%	
Hallway		2%	
Garage		3%	
Other		5%	
Proportion of injuries where room of fire origin coverage is required by an NZS4517 system	-5%	93%	+5%
Materials & installation & design (new household)	$700	$2,100	$4,800
Materials & installation & design (retrofit)	$900	$3,850	$5,400
Annual Maintenance		$0	

Table 54 continued: Summary of the base inputs for the cost effectiveness analysis and the environmental impact modulecommon for all scenarios considered

Input Description	Minimum Value	Average	Maximum Value
Cost per fire injury - direct	\$17,000	\$30,000	\$64,800
Cost per fire injury – indirect	\$136,000	\$200,000	\$340,000
Property loss per unsprinklered fire	\$15,000	\$30,000	\$100,000
Reduction in property loss per sprinklered fire	20%	52%	95%
Cost of Fire Service per unsprinklered fire	\$5,000	\$5,900	\$6,000
Reduction in cost of Fire Service per sprinklered fire	20%	30%	50%
Cost of a litre of potable water (considering local monetary charges only)	0.7 c/ℓ	11 c/ℓ	1.5 c/ℓ
Average Insurance Premium	\$300	\$600	\$900
Insurance Premium Savings	2%	5%	7%
Volume of fire-fighting water used in a sprinklered house		27,500 ℓ	
Volume of fire-fighting water used in an unsprinklered house		800 ℓ	
NZ Ecopoint cost for the total replacement of a house structure [c]			
Type A [a]		77	
Type B [a]		107	
Type C [a]		73	
Type D [a]		78	
Type E [a]		69	
Type F [a]		70	
NZ Ecopoint cost for a litre of potable water [c]		9×10^{-11}	
NZ Ecopoint cost for a sprinkler system [c]			
Type A [b]			
New Build, Large sprinkler system		0.1	
New Build, Small sprinkler system		0.03	
Retrofit, Large sprinkler system		0.2	
Retrofit, Small sprinkler system		0.08	
Type B [b]			
New Build, Large sprinkler system		0.1	
New Build, Small sprinkler system		0.03	
Retrofit, Large sprinkler system		0.2	
Retrofit, Small sprinkler system		0.08	
Type C [b]			
New Build, Large sprinkler system		0.1	
New Build, Small sprinkler system		0.04	
Retrofit, Large sprinkler system		0.2	
Retrofit, Small sprinkler system		0.09	

Notes:

[a] The types of building stock are as described in **Error! Reference source not found.**.

[b] The types of sprinkler system are as described in **Error! Reference source not found.**.

[c] A more detailed description of the NZ Ecopoints is included in **Error! Reference source not found.**.

Table 55: Summary of the base inputs for the cost effectiveness analysis and the environmental impact modulecommon for all scenarios considered

Input Description	Minimum Value	Best Value	Maximum Value
Deaths per 1000 fires, no sprinklers, no alarms			
Total population	6	8.7	12
Owner occupied properties	3	6.5	9
Not owner occupied properties	3	9	13
State and council owned properties	1	4	15
Housing New Zealand owned properties	0	10	27
Rented properties	5	11	15
Injuries per 1000 fires, no sprinklers, no alarms			
Total population	70	110	120
Owner occupied properties	65	85	115
Not owner occupied properties	80	120	180
State and council owned properties	0	75	180
Housing New Zealand owned properties	85	135	230
Rented properties	85	125	195
Initial number of house structure fires per year			
Total population	2,700	3,200	3,500
Owner occupied properties	700	1,950	2,400
Not owner occupied properties	650	1,550	1,850
State and council owned properties	120	280	350
Housing New Zealand owned properties	110	250	290
Rented properties	430	1,000	1,300
Current number of households			
Total population		1,500,000	
Owner occupied properties		782,000	
Not owner occupied properties		325,500	
State and council owned properties		23,500	
Housing New Zealand owned properties		57,300	
Rented properties		244,000	
Increase in households per year			
Total population	0.1%	0.5%	1%
Owner occupied properties	-0.9%	-0.3%	0.1%
Not owner occupied properties	1.5%	2.8%	4.7%
State and council owned properties	-4.1%	-3.2%	-2.3%
Housing New Zealand owned properties	-3.6%	-1.5%	-0.1%
Rented properties	2.3%	4.5%	6.9%
Initial number of sprinklered households			
Total population		1,000	
Owner occupied properties		1,000	
Not owner occupied properties		0	
State and council owned properties		0	
Housing New Zealand owned properties		0	
Rented properties		0	

8.3 Results – Summary

A summary of the model results are presented in this section. Detailed model results are presented in **Error! Reference source not found.**.

The results for the distributions of the monetary cost per life saved considering the presence of smoke alarms and home sprinkler systems in residential properties:

- For the base case are shown in Figure 54,
- For the case excluding potential monetary fire service savings attributable to the presence of home sprinkler systems are shown in Figure 55,
- For the case excluding potential monetary savings from the reduction of indirect costs of civilian fire injuries attributable to home sprinklers are shown in Figure 56, and
- For the case excluding potential reductions in insurance premiums are shown in Figure 57.

The mean, minimum, maximum and standard deviation for the calculated monetary cost per life saved are summarised in Table 56.

The results for the distributions of the NZ Ecopoint cost per life saved for the base case are shown in Figure 58. The mean, minimum, maximum and standard deviation for the calculated NZ Ecopoint cost per life saved are summarised in Table 57.

The results for the distributions of the monetary cost per life saved considering the presence of only home sprinkler systems in residential properties:

- For the base case are shown in Figure 59,
- For the case excluding potential monetary fire service savings attributable to the presence of home sprinkler systems are shown in Figure 60,
- For the case excluding potential monetary savings from the reduction of indirect costs of civilian fire injuries attributable to home sprinklers are shown in Figure 61, and
- For the case excluding potential reductions in insurance premiums are shown in Figure 62.

The mean, minimum, maximum and standard deviation for the calculated monetary cost per life saved are summarised in Table 58.

The results for the distributions of the NZ Ecopoint cost per life saved for the base case are shown in Figure 63. The mean, minimum, maximum and standard deviation for the calculated NZ Ecopoint cost per life saved are summarised in Table 59.

It should be noted that the total residential building stock category results cannot be directly compared to the other categories, since the total building stock category assumes that the proportions of each of the sub-categories remains proportional throughout the analysis period. Whereas the various individual sub-categories are assumed to increase or decrease, based on the observed trend from New Zealand consenses data. In addition, the fire statistics used for the total residential building stock model inputs included statistics reported with “unknown” and “not recorded” statistical categories (as discussed in Section 4.1.2.1), whereas these were removed from the other property occupier categories since they could not be classified.

Similarly, the category for not owner occupied residential properties assumes that the proportion of state owned, Housing NZ owned and rental properties remains the same over the analysis period. However the impact for the not owner occupied category is minor compared to the compounded assumptions for the total residential building stock previously discussed.

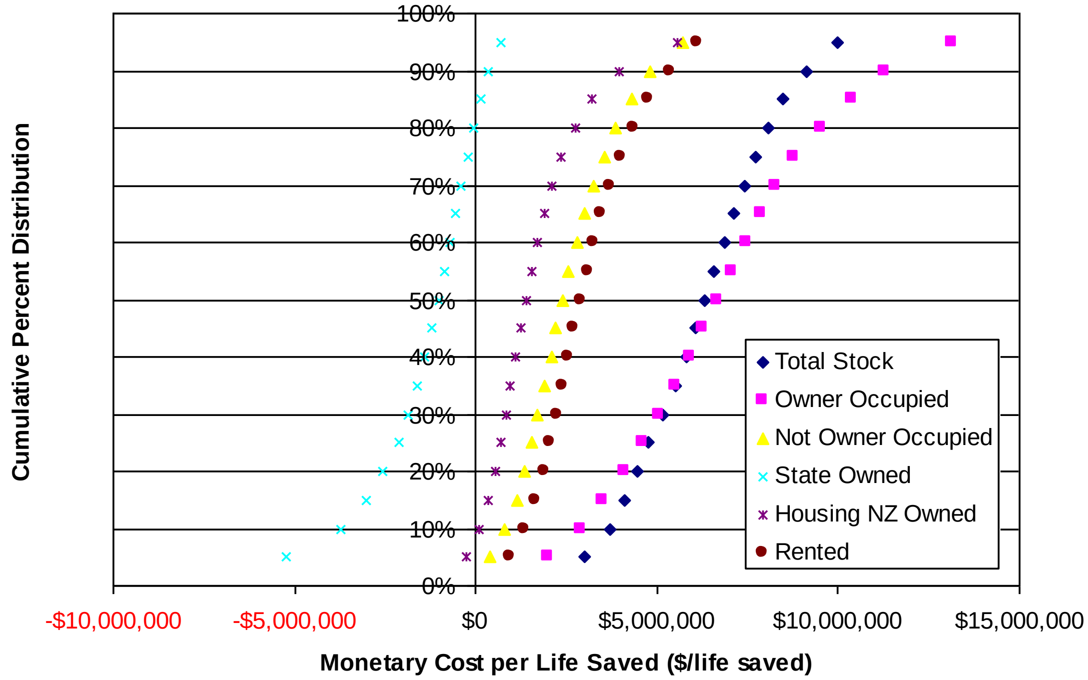


Figure 54: Cumulative percent distribution for the monetary cost per life saved when considering sprinklers and smoke alarms present for the base case.

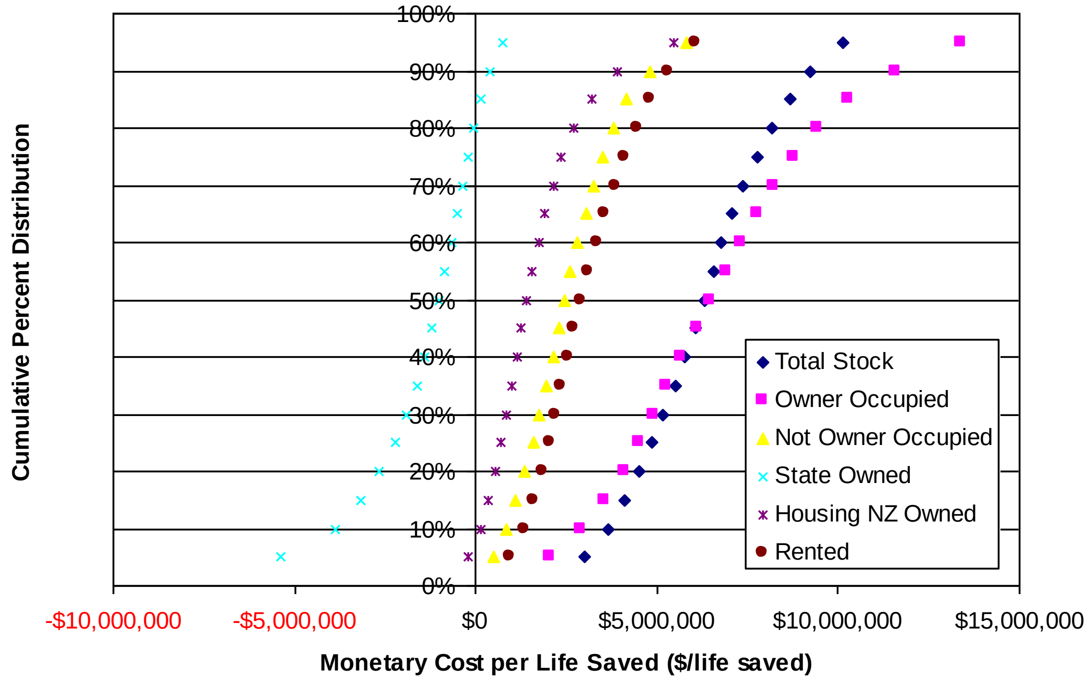


Figure 55: Cumulative percent distribution for the monetary cost per life saved when considering sprinklers and smoke alarms present excluding fire service costs.

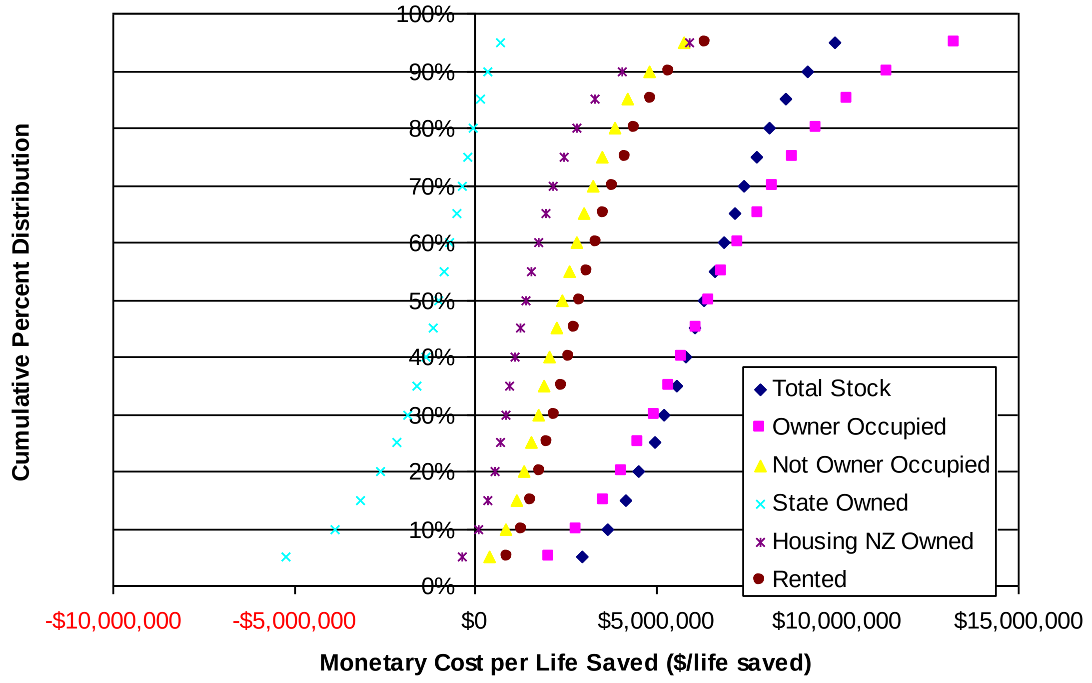


Figure 56: Cumulative percent distribution for the monetary cost per life when considering sprinklers and smoke alarms present excluding indirect injury costs.

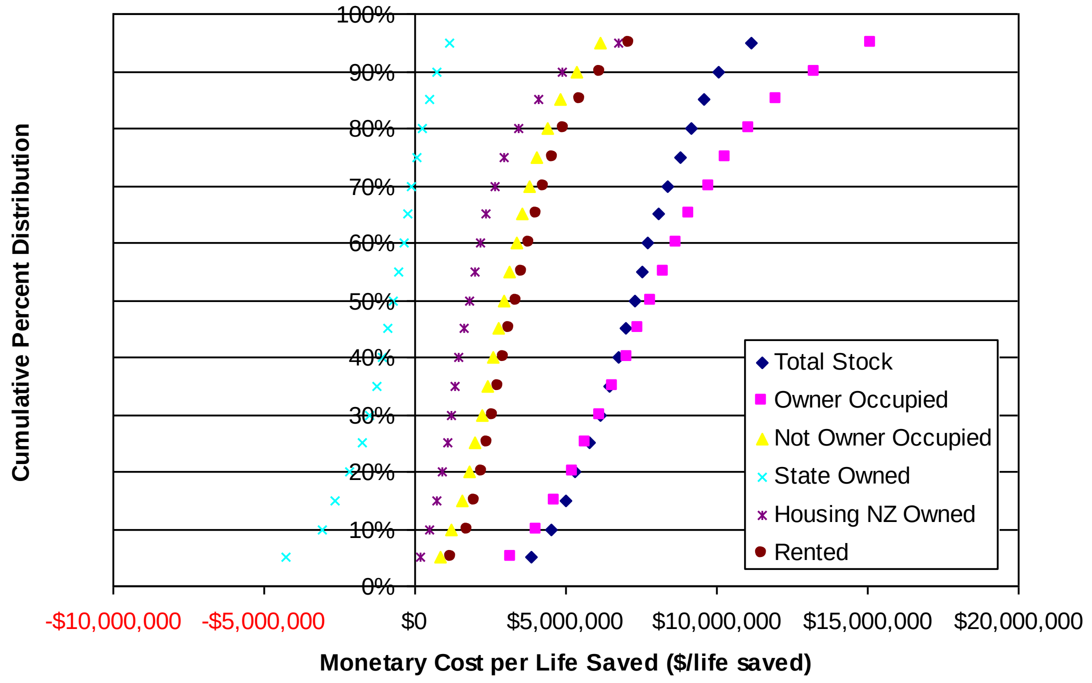


Figure 57: Cumulative percent distribution for the monetary cost per life saved when considering sprinklers and smoke alarms present excluding reductions in insurance premiums.

Table 56: Summary of the minimum, mean, maximum and standard deviation results for the monetary cost per life saved for the various cases considered for sprinklers and smoke alarms being present.

Base Case						
Residential Building Stock	**Total Stock**	**Owner Occupied**	**Not Owner Occupied**	**State Owned**	**Housing NZ Owned**	**Rented**
Minimum	-$32,000	-$2,300,000	-$1,900,000	-$18,000,000	-$7,400,000	-$1,500,000
Mean	$6,300,000	$7,000,000	$2,700,000	-$1,500,000	$1,900,000	$3,100,000
Maximum	$13,000,000	$23,000,000	$10,000,000	$4,700,000	$49,000,000	$11,000,000
Standard Deviation	$2,100,000	$3,400,000	$1,600,000	$2,000,000	$2,600,000	$1,600,000
Excluding Fire Service Costs						
Residential Building Stock	**Total Stock**	**Owner Occupied**	**Not Owner Occupied**	**State Owned**	**Housing NZ Owned**	**Rented**
Minimum	$35,000	-$2,600,000	-$2,200,000	-$17,000,000	-$4,600,000	-$690,000
Mean	$6,400,000	$6,900,000	$2,700,000	-$1,500,000	$2,000,000	$3,200,000
Maximum	$15,000,000	$30,000,000	$11,000,000	$4,200,000	$120,000,000	$12,000,000
Standard Deviation	$2,200,000	$3,600,000	$1,600,000	$2,000,000	$3,400,000	$1,700,000
Excluding Indirect Injury costs						
Residential Building Stock	**Total Stock**	**Owner Occupied**	**Not Owner Occupied**	**State Owned**	**Housing NZ Owned**	**Rented**
Minimum	$370,000	-$2,900,000	-$1,400,000	-$20,000,000	-$7,700,000	-$1,200,000
Mean	$6,400,000	$6,900,000	$2,700,000	-$1,500,000	$1,900,000	$3,200,000
Maximum	$15,000,000	$24,000,000	$13,000,000	$4,700,000	$57,000,000	$11,000,000
Standard Deviation	$2,100,000	$3,600,000	$1,700,000	$2,000,000	$2,600,000	$1,700,000
Excluding Reductions in Insurance Premiums						
Residential Building Stock	**Total Stock**	**Owner Occupied**	**Not Owner Occupied**	**State Owned**	**Housing NZ Owned**	**Rented**
Minimum	$920,000	-$1,100,000	-$940,000	-$24,000,000	-$2,100,000	-$290,000
Mean	$7,300,000	$8,300,000	$3,200,000	-$1,100,000	$2,500,000	$3,700,000
Maximum	$15,000,000	$28,000,000	$14,000,000	$4,100,000	$48,000,000	$12,000,000
Standard Deviation	$2,200,000	$3,800,000	$1,700,000	$1,900,000	$3,000,000	$1,800,000

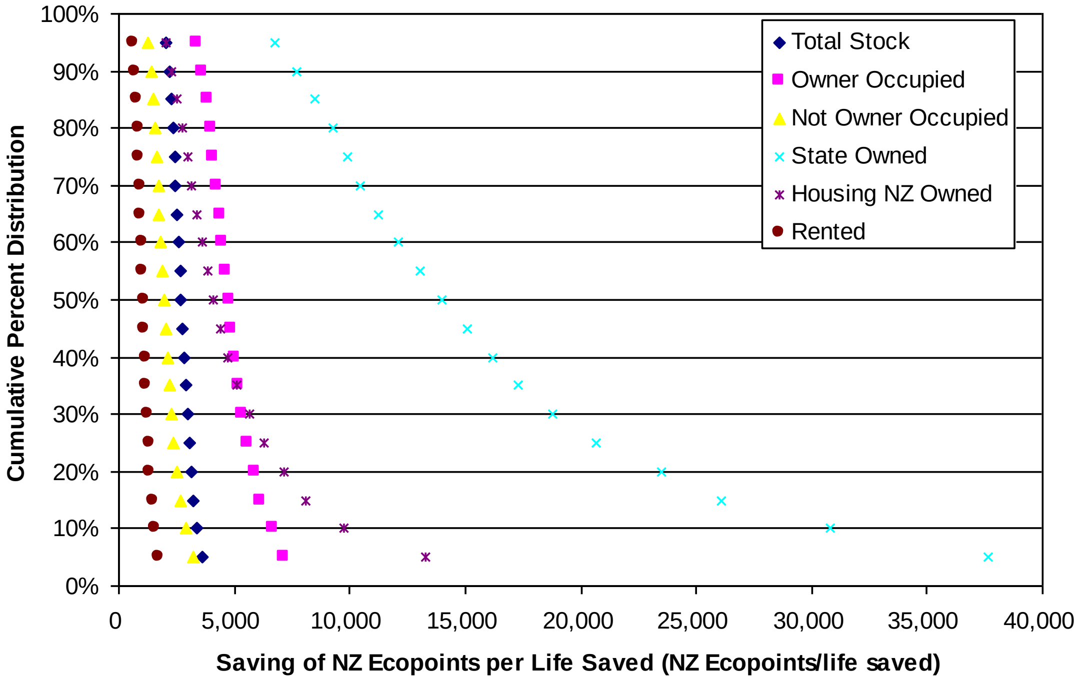


Figure 58: Cumulative percent distribution for the NZ Ecopoint savings per life saved for the total residential building stock when considering sprinklers and smoke alarms present.

Table 57: Summary of the minimum, mean, maximum and standard deviation results for the NZ Ecopoint cost per life saved for the various cases considered for sprinklers and smoke alarms being present. *

Residential Building Stock	Total Stock	Owner Occupied	Not Owner Occupied	State Owned	Housing NZ Owned	Rented
Minimum	-4,800	-11,000	-5,900	-91,000	-130,000	-3,100
Mean	-2,800	-5,000	-2,100	-17,000	-5,600	-1,100
Maximum	-1,700	-2,500	-820	-4,400	-1,300	-190
Standard Deviation	470	1,200	620	10,000	5,400	340

Note: * The results relating to the base case are presented here, since the cases considering excluding various monetary benefits does not affect the NZ Ecopoint results.

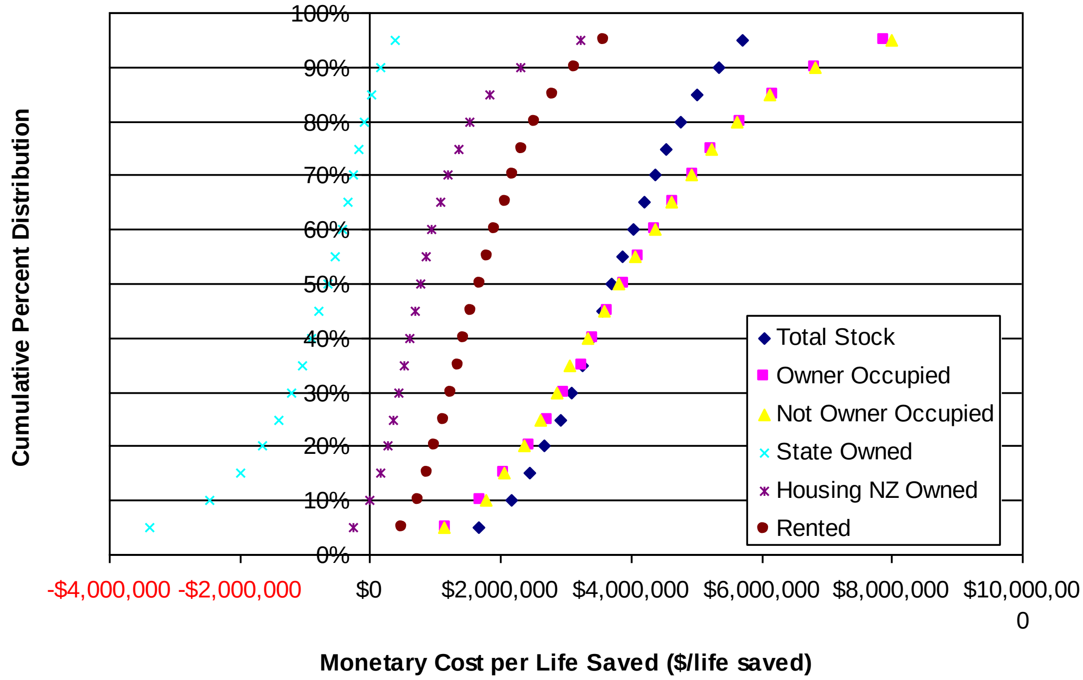


Figure 59: Cumulative percent distribution for the monetary cost per life saved for the total residential building stock when considering only sprinklers being present for the base case.

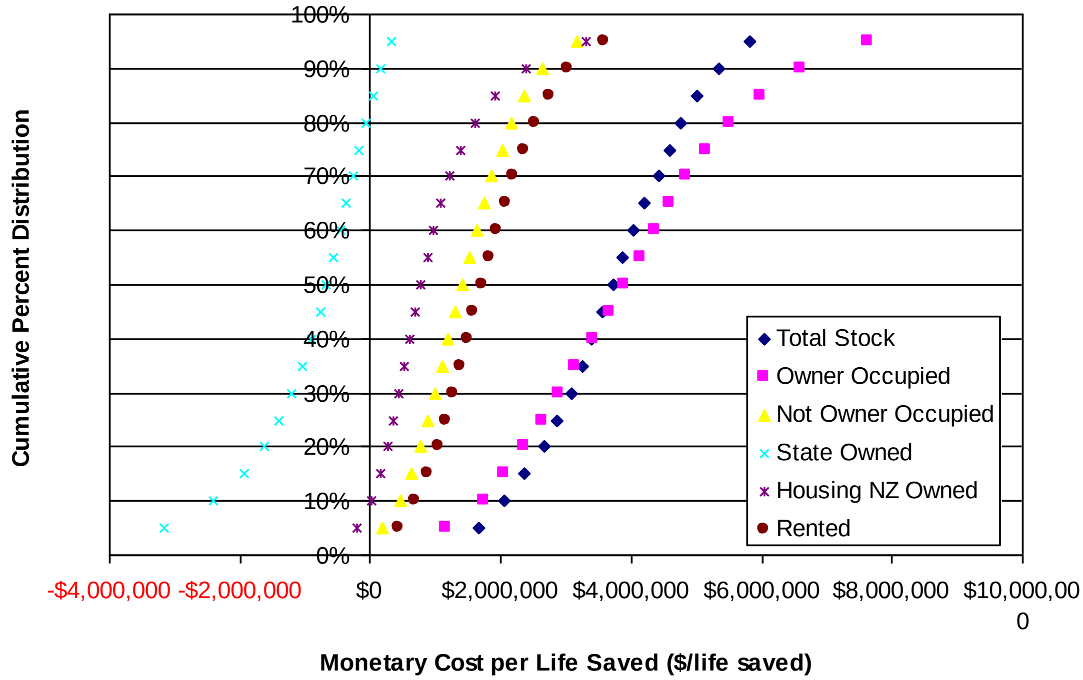


Figure 60: Cumulative percent distribution for the monetary cost per life saved for the total residential building stock when considering only sprinklers being present excluding fire service costs.

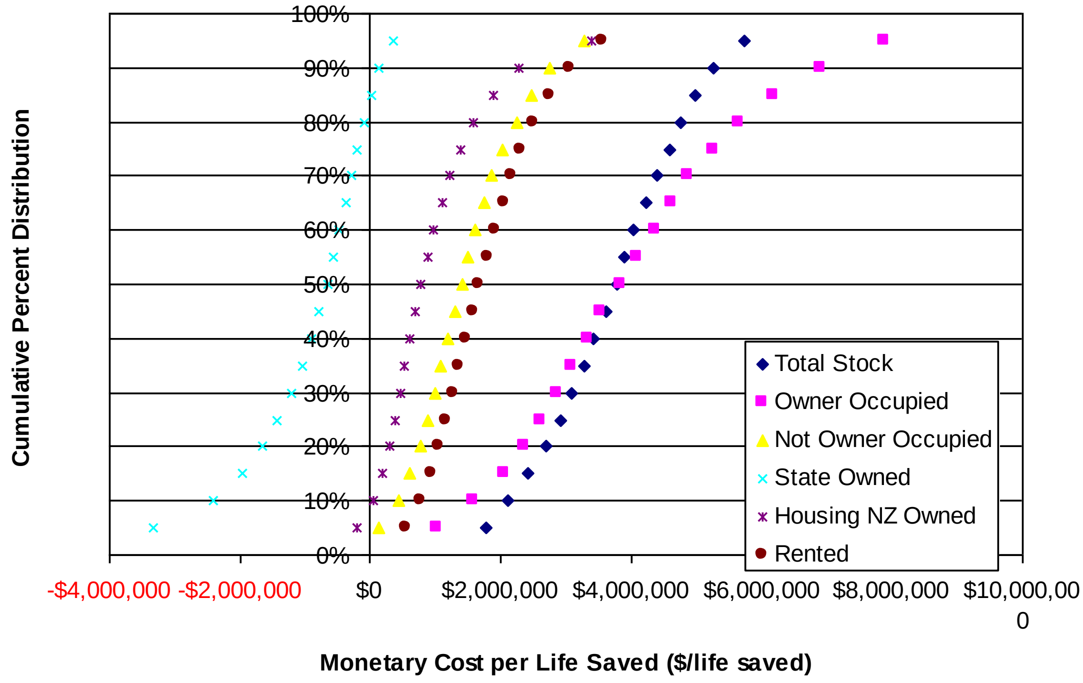


Figure 61: Cumulative percent distribution for the monetary cost per life saved for the total residential building stock when considering only sprinklers being present excluding indirect injury costs.

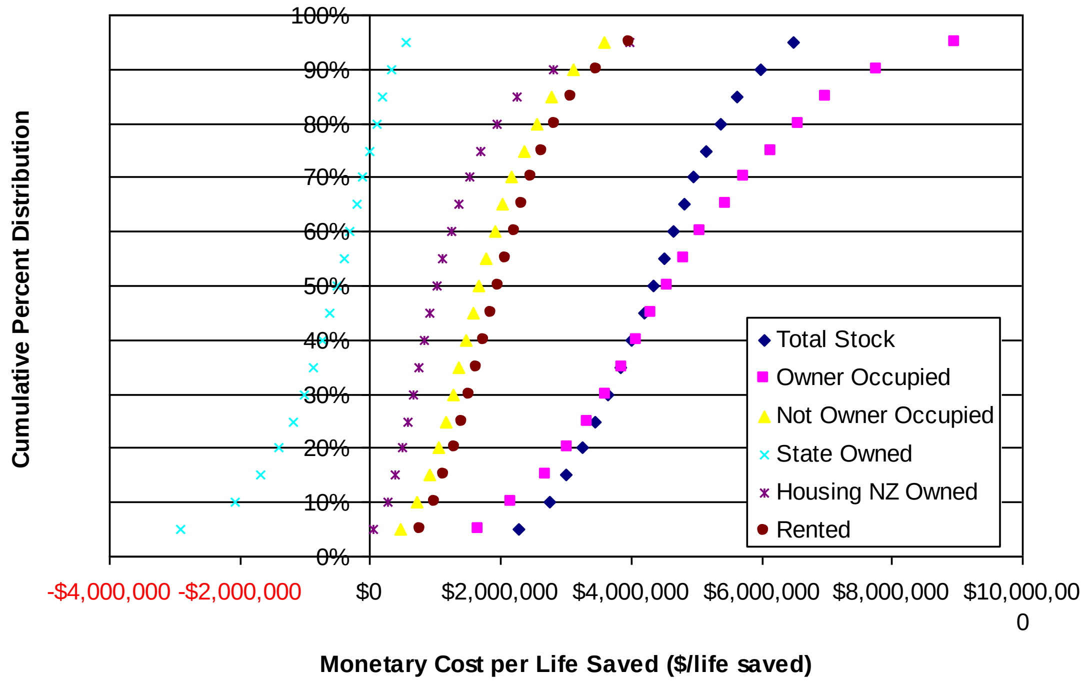


Figure 62: Cumulative percent distribution for the monetary cost per life saved for the total residential building stock when considering only sprinklers being present excluding reductions in insurance premiums.

Table 58: Summary of the minimum, mean, maximum and standard deviation results for the monetary cost per life saved for the various cases considered for only sprinklers being present.

Base Case						
Residential Building Stock	**Total Stock**	**Owner Occupied**	**Not Owner Occupied**	**State Owned**	**Housing NZ Owned**	**Rented**
Minimum	-$190,000	-$930,000	-$1,200,000	-$10,000,000	-$3,600,000	-$440,000
Mean	$3,700,000	$4,100,000	$4,100,000	-$970,000	$1,100,000	$1,800,000
Maximum	$7,200,000	$17,000,000	$16,000,000	$2,400,000	$32,000,000	$7,500,000
Standard Deviation	$1,200,000	$2,100,000	$2,100,000	$1,300,000	$1,600,000	$990,000
Excluding Fire Service Costs						
Residential Building Stock	**Total Stock**	**Owner Occupied**	**Not Owner Occupied**	**State Owned**	**Housing NZ Owned**	**Rented**
Minimum	$60,000	-$980,000	-$970,000	-$9,400,000	-$14,000,000	-$720,000
Mean	$3,700,000	$4,100,000	$1,500,000	-$950,000	$1,100,000	$1,800,000
Maximum	$7,800,000	$13,000,000	$7,100,000	$1,800,000	$26,000,000	$8,100,000
Standard Deviation	$1,300,000	$2,000,000	$920,000	$1,200,000	$1,500,000	$990,000
Excluding Indirect Injury costs						
Residential Building Stock	**Total Stock**	**Owner Occupied**	**Not Owner Occupied**	**State Owned**	**Housing NZ Owned**	**Rented**
Minimum	-$2,900	-$1,900,000	-$1,800,000	-$16,000,000	-$3,500,000	-$520,000
Mean	$3,700,000	$4,100,000	$1,500,000	-$980,000	$1,100,000	$1,800,000
Maximum	$7,700,000	$13,000,000	$7,000,000	$2,300,000	$47,000,000	$7,400,000
Standard Deviation	$1,200,000	$2,100,000	$970,000	$1,300,000	$1,700,000	$960,000
Excluding Reductions in Insurance Premiums						
Residential Building Stock	**Total Stock**	**Owner Occupied**	**Not Owner Occupied**	**State Owned**	**Housing NZ Owned**	**Rented**
Minimum	$69,000	-$130,000	-$550,000	-$13,000,000	-$3,200,000	-$210,000
Mean	$4,300,000	$4,900,000	$1,800,000	-$760,000	$1,400,000	$2,100,000
Maximum	$9,000,000	$16,000,000	$7,300,000	$2,600,000	$35,000,000	$7,800,000
Standard Deviation	$1,300,000	$2,300,000	$1,000,000	$1,200,000	$1,700,000	$1,000,000

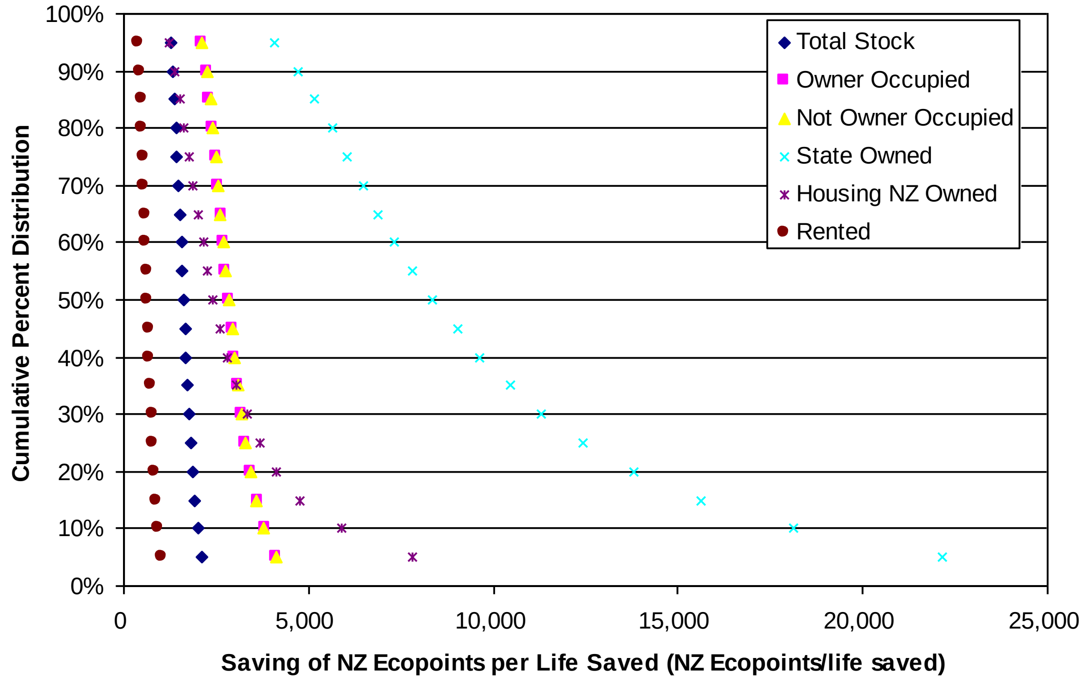


Figure 63: Cumulative percent distribution for the NZ Ecopoint savings per life saved for the total residential building stock when considering only sprinklers being present.

Table 59: Summary of the minimum, mean, maximum and standard deviation results for the NZ Ecopoint cost per life saved for the various cases considered for only sprinklers being present. *

Residential Building Stock	Total Stock	Owner Occupied	Not Owner Occupied	State Owned	Housing NZ Owned	Rented
Minimum	-2,800	-5,700	-5,700	-52,000	-220,000	-1,400
Mean	-1,600	-3,000	-3,000	-10,000	-3,400	-670
Maximum	-1,100	-1,600	-1,700	-2,700	-780	-130
Standard Deviation	270	630	640	5,900	4,700	200

Note: * The results relating to the base case are presented here, since the cases considering excluding various monetary benefits does not affect the NZ Ecopoint results.

8.3.1 Summary of the Net Present Value of the Costs & Benefits Assessed

A summary of the base Net Present Values (NPV) of the costs and benefits considered for the inclusion of home sprinkler systems in new buildings and retrofitted for existing building stock is included in **Error! Reference source not found.** for each of the cases considered.

8.3.2 Importance Analysis

The base case of both sprinkler systems and smoke alarms are considered for this importance analysis. Each of the categories of residential building stock occupier are considered here.

Critical variables were indentified by determining importance values for the monetary cost per life saved and the NZ Ecopoint cost per life saved (between 0 and 1) based on the rank order correlation of each input, as presented in Table 60 and Table 61 for the monetary related costs and in Table 62 and Table 63 for the NZ Ecopoint costs. A full summary of these tables is included in Appendix **Error! Reference source not found.**. For comparison the regression sensitivity for each of the output parameters were also calculated, as shown in Figure 64 for the monetary cost per life saved and in Figure 65 for the NZ Ecopoint cost per life saved. The examples of the results used here are for the case considering the total residential building stock when sprinklers and smoke alarms are present.

The common input parameters with relatively high importance values for the monetary cost per life saved for the categories of residential building stock considered are:

- Cost of sprinkler system design and installation,
- Number of deaths per 1000 fires,
- Monetary reduction in the cost of property loss for a sprinklered fire,
- Smoke alarm effectiveness,
- Number of house structure fires per year,
- Rate of retrofit of sprinkler systems into existing properties,
- Sprinkler effectiveness,
- Monetary reduction in insurance premiums,
- Discount rate,
- Inflation rate, and
- Proportion of fire incidents occurring in rooms with cover required by NZS 4517.

The common input parameters with relatively high importance values for the NZ Ecopoint cost per life saved for the categories of residential building stock considered are:

- Number of deaths per 1000 fires,
- Smoke alarm effectiveness,
- Proportion of fire incidents occurring in rooms with cover required by NZS 4517,
- Increase of the number of households per year,
- Sprinkler effectiveness
- Percentage threshold for the total loss of a building,
- Proporiton of fire fatalities occurring where the room of fire origin is required to have coverage by NZS 4517,
- Number of house structure fires per year,
- Discount rate

Similarly, importance ranking results for the base case when only home sprinkler systems are considered are presented in Table 64, Table 65, Table 66 and Table 67. Further details of these tables are included in Appendix **Error! Reference source not found.**. For comparison the regression sensitivity for each of the output parameters were also calculated, as shown in Figure 66 for the monetary cost per life saved and in Figure 67 for the NZ Ecopoint cost per life saved.

Table 60: First ten importance ranking, based on correlation coefficients of the input parameters, for the monetary cost per life saved for total residential building stock, owner occupied and not owner occupied residential building stock for the base case with sprinklers & smoke alarms.

Total Residential Building Stock		Owner Occupied		Not Owner Occupied	
Input Variable Name	Importance Value	Input Variable Name	Importance Value	Input Variable Name	Importance Value
Sprinkler mat. & inst. - retrofit	0.815	Sprinkler mat. & inst. - retrofit	0.653	Sprinkler mat. & inst. - retrofit	0.521
Deaths per 1000 fires - no spr & no alarms	0.343	House structure fires per year	0.439	House structure fires per year	0.471
Property loss - $/unsprnk fire	0.238	Deaths per 1000 fires - no spr & no alarms	0.373	Property loss - $/unsprnk fire	0.433
Smoke alarm effectiveness	0.229	Property loss - $/unsprnk fire	0.262	Deaths per 1000 fires - no spr & no smoke	0.345
House structure fires per year	0.132	Smoke alarm effectiveness	0.146	Sprinkler mat. & inst. - new	0.275
Property loss per sprinklered fire - reduction	0.111	Insurance premiums - reduction	0.095	Smoke alarm effectiveness	0.101
Households - rate of retrofit of sprnk	0.083	Sprinkler effectiveness	0.063	No. households - inc. per year	0.097
Insurance premiums - reduction	0.078	Households - rate of retrofit of sprnk	0.048	Insurance premiums - reduction	0.075
Sprinkler effectiveness	0.077	Insurance premium - avg	0.044	Potable water - $/litre	0.051
Insurance premium - avg	0.066	Total loss threashold - %	0.042	Sprinkler effectiveness	0.049

Table 61: First ten importance ranking, based on correlation coefficients of the input parameters, for the monetary cost per life saved for state owned, Housing New Zealand owned and rented residential building stock for the base case with sprinklers and smoke alarms.

State Owned		Housing NZ Owned		Rented	
Input Variable Name	Importance Value	Input Variable Name	Importance Value	Input Variable Name	Importance Value
Property loss - $/unsprnk fire	0.804	Sprinkler mat. & inst. - retrofit	0.565	House structure fires per year	0.492
Sprinkler mat. & inst. - retrofit	0.361	Deaths per 1000 fires - no spr & no alarms	0.489	Sprinkler mat. & inst. - new	0.396
Deaths per 1000 fires - no spr & no alarms	0.316	Property loss - $/unsprnk fire	0.418	Property loss - $/unsprnk fire	0.385
Discount rate	0.110	House structure fires per year	0.321	Sprinkler mat. & inst. - retrofit	0.380
Property loss per sprinklered fire - reduction	0.095	Insurance premiums - reduction	0.090	Deaths per 1000 fires - no spr & no alarms	0.338
Insurance premium - avg	0.077	Smoke alarm effectiveness	0.089	No. households - inc. per year	0.150
Insurance premiums - reduction	0.066	No. households - inc. per year	0.070	Smoke alarm effectiveness	0.114
Inflation rate	0.054	Discount rate	0.062	Fatalites covered by NZS4517 - %	0.078
Fire incidents covered by NZS4517 - %	0.046	Insurance premium - avg	0.061	Insurance premium - avg	0.077
Fire injury - direct costs	0.035	Property loss per sprinklered fire - reduction	0.047	Insurance premiums - reduction	0.073

Table 62: First ten importance ranking, based on correlation coefficients of the input parameters, for the NZ Ecopoint cost per life saved for total residential building stock, owner occupied and not owner occupied residential building stock for the base case with sprinklers and smoke alarms.

Total Residential Building Stock		Owner Occupied		Not Owner Occupied	
Input Variable Name	Importance Value	Input Variable Name	Importance Value	Input Variable Name	Importance Value
Deaths per 1000 fires - no spr & no alarms	0.727	Deaths per 1000 fires - no spr & no alarms	0.842	Deaths per 1000 fires - no spr & no alarms	0.789
Smoke alarm effectiveness	0.384	Smoke alarm effectiveness	0.340	No. households - inc. per year	0.396
Fire incidents covered by NZS4517 - %	0.255	No. households - inc. per year	0.244	Smoke alarm effectiveness	0.273
No. households - inc. per year	0.225	Fire incidents covered by NZS4517 - %	0.228	Fire incidents covered by NZS4517 - %	0.159
Sprinkler effectiveness	0.166	House structure fires per year	0.128	House structure fires per year	0.141
Total loss threashold - %	0.104	Sprinkler effectiveness	0.088	Sprinkler effectiveness	0.134
Fatalites covered by a NZS4517 system - %	0.071	Total loss threashold - %	0.082	Total loss threashold - %	0.108
House structure fires per year	0.065	Fatalites covered by a NZS4517 system - %	0.069	Insurance premium - avg	0.052
Flame damage - limit for sprnk	0.064	Property loss - $/unsprnk fire	0.050	Fire injury - direct costs	0.048
Fire injury - indirect costs	0.052	Flame damage - limit for sprnk	0.048	Fatalites covered by NZS4517 - %	0.046

Table 63: First ten importance ranking, based on correlation coefficients of the input parameters, for the NZ Ecopoint cost per life saved for state owned, Housing New Zealand owned and rented residential building stock for the base case with sprinklers and smoke alarms.

State Owned		Housing NZ Owned		Rented	
Input Variable Name	Importance Value	Input Variable Name	Importance Value	Input Variable Name	Importance Value
Deaths per 1000 fires - no spr & no alarms	0.960	Deaths per 1000 fires - no spr & no alarms	0.926	Deaths per 1000 fires - no spr & no alarms	0.576
No. households - inc. per year	0.204	No. households - inc. per year	0.289	No. households - inc. per year	0.551
Smoke alarm effectiveness	0.168	Smoke alarm effectiveness	0.153	House structure fires per year	0.294
Fire incidents covered by NZS4517 - %	0.109	Fire incidents covered by NZS4517 - %	0.092	Smoke alarm effectiveness	0.228
Flame damage - limit for sprnk	0.054	Fatalites covered by NZS4517 - %	0.057	Fire incidents covered by NZS4517 - %	0.206
Fatalites covered by NZS4517 - %	0.036	Sprinkler effectiveness	0.054	Sprinkler effectiveness	0.150
Fire Service - costs/unsprnk fire	0.032	Total loss threashold - %	0.039	Fatalites covered by NZS4517 - %	0.075
Inflation rate	0.030	Property loss - $/unsprnk fire	0.032	Flame damage - limit for sprnk	0.073
Insurance premiums - reduction	0.025	Inflation rate	0.032	Fire injury - direct costs	0.067
Insurance premium - avg	0.024	Fire Service - costs/unsprnk fire	0.029	Total loss threashold - %	0.055

Table 64: First ten importance ranking, based on correlation coefficients of the input parameters, for the monetary cost per life saved for total residential building stock, owner occupied and not owner occupied residential building stock for the base case with only sprinklers.

Total Residential Building Stock		Owner Occupied		Not Owner Occupied	
Input Variable Name	**Importance Value**	**Input Variable Name**	**Importance Value**	**Input Variable Name**	**Importance Value**
Sprnk system – mat. & instal. - retrofit	0.821	Sprnk system – mat. & instal. - retrofit	0.682	Sprnk system – mat. & instal. - retrofit	0.675
Deaths per 1000 fires, no spr, no alarms	0.373	House structure fires/ year	0.479	House structure fires/ year	0.502
Property loss - $/unsprnk fire	0.213	Deaths per 1000 fires, no spr, no alarms	0.371	Deaths per 1000 fires, no spr, no alarms	0.334
Property loss - % red/ sprnk fire	0.164	Property loss - $/unsprnk fire	0.272	Property loss - $/unsprnk fire	0.280
Insurance premium - avg.	0.112	Insurance premiums - % red. for sprnks	0.108	Insurance premiums - % red. for sprnks	0.104
House structure fires/ year	0.101	Rate of retrofit of sprinklers in households	0.088	Insurance premium - avg.	0.081
Sprnk system – mat. & instal. - new	0.091	Insurance premium - avg.	0.070	Rate of retrofit of sprinklers in households	0.060
Potable water - $/litre	0.088	Sprinkler effectiveness	0.065	Sprinkler effectiveness	0.053
Insurance premiums - % red. for sprnks	0.086	Property loss - % red/ sprnk fire	0.063	Fatalites - % covered by NZS4517	0.052
Sprinkler effectiveness	0.062	Injuries - % covered by NZS4517	0.055	Threshold %structure dmg. for total loss	0.046

Table 65: First ten importance ranking, based on correlation coefficients of the input parameters, for the monetary cost per life saved for state owned, Housing New Zealand owned and rented residential building stock for the base case with only sprinklers.

Total Residential Building Stock		Owner Occupied		Not Owner Occupied	
Input Variable Name	**Importance Value**	**Input Variable Name**	**Importance Value**	**Input Variable Name**	**Importance Value**
Property loss - $/unsprnk fire	0.803	Sprnk system – mat. & instal. - retrofit	0.587	House structure fires/ year	0.528
Sprnk system – mat. & instal. - retrofit	0.370	Deaths per 1000 fires, no spr, no alarms	0.455	Sprnk system – mat. & instal. - retrofit	0.432
Deaths per 1000 fires, no spr, no alarms	0.337	Property loss - $/unsprnk fire	0.435	Sprnk system – mat. & instal. - new	0.404
Discount rate	0.144	House structure fires/ year	0.325	Deaths per 1000 fires, no spr, no alarms	0.359
Property loss - % red/ sprnk fire	0.119	Property loss - % red/ sprnk fire	0.081	Property loss - $/unsprnk fire	0.353
Inflation rate	0.066	Households - inc./ year	0.079	Households - inc./ year	0.175
Insurance premiums - % red. for sprnks	0.047	Discount rate	0.061	Rate of retrofit of sprinklers in households	0.109
Injuries per 1000 fires, no spr, no alarms	0.046	Insurance premium - avg.	0.059	Insurance premium - avg.	0.086
Sprinkler effectiveness	0.044	Injury costs - direct	0.056	Property loss - % red/ sprnk fire	0.067
Fire incidents - % covered by NZS4517	0.035	Inflation rate	0.042	Sprinkler effectiveness	0.066

Table 66: First ten importance ranking, based on correlation coefficients of the input parameters, for the NZ Ecopoint cost per life saved for total residential building stock, owner occupied and not owner occupied residential building stock for the base case with only sprinklers.

Total Residential Building Stock		Owner Occupied		Not Owner Occupied	
Input Variable Name	Importance Value	Input Variable Name	Importance Value	Input Variable Name	Importance Value
Deaths per 1000 fires, no spr, no alarms	0.818	Deaths per 1000 fires, no spr, no alarms	0.894	Deaths per 1000 fires, no spr, no alarms	0.893
Fire incidents - % covered by NZS4517	0.363	Fire incidents - % covered by NZS4517	0.248	Fire incidents - % covered by NZS4517	0.247
Households - inc./ year	0.304	Households - inc./ year	0.227	Households - inc./ year	0.221
Sprinkler effectiveness	0.185	House structure fires/ year	0.126	Limit of flame dmg for effective sprnk sys.	0.142
Limit of flame dmg for effective sprnk sys.	0.151	Limit of flame dmg for effective sprnk sys.	0.098	House structure fires/ year	0.114
Threshold %structure damage for total loss	0.148	Sprinkler effectiveness	0.097	Sprinkler effectiveness	0.102
Fatalites - % covered by NZS4517	0.112	Fatalites - % covered by NZS4517	0.083	Fatalites - % covered by NZS4517	0.095
Insurance premium - avg.	0.073	Threshold %structure damage for total loss	0.070	Threshold %structure dmg for total loss	0.065
House structure fires/ year	0.062	Injuries per 1000 fires, no spr, no alarms	0.047	Insurance premiums - % red. for sprnks	0.058
Injury costs - indirect	0.041	Sprnk system – mat. & instal. - retrofit	0.047	Insurance premium - avg.	0.054

Table 67: First ten importance ranking, based on correlation coefficients of the input parameters, for the NZ Ecopoint cost per life saved for state owned, Housing New Zealand owned and rented residential building stock for the base case with only sprinklers.

Total Residential Building Stock		Owner Occupied		Not Owner Occupied	
Input Variable Name	Importance Value	Input Variable Name	Importance Value	Input Variable Name	Importance Value
Deaths per 1000 fires, no spr, no alarms	0.971	Deaths per 1000 fires, no spr, no alarms	0.928	Households - inc./ year	0.608
Households - inc./ year	0.194	Households - inc./ year	0.313	Deaths per 1000 fires, no spr, no alarms	0.595
Fire incidents - % covered by NZS4517	0.084	Fire incidents - % covered by NZS4517	0.113	House structure fires/ year	0.352
Fatalites - % covered by NZS4517	0.051	Threshold %structure damage for total loss	0.042	Fire incidents - % covered by NZS4517	0.231
Sprinkler effectiveness	0.045	Sprinkler effectiveness	0.042	Sprinkler effectiveness	0.112
Injury costs - indirect	0.038	Fatalites - % covered by NZS4517	0.031	Threshold %structure dmg. for total loss	0.085
Limit of flame dmg for effective sprnk sys.	0.031	Insurance premium - avg.	0.026	Limit of flame dmg for effective sprnk sys.	0.056
Property loss - $/unsprnk fire	0.030	Rate of retrofit of sprinklers in households	0.024	Fatalites - % covered by NZS4517	0.054
Discount rate	0.026	Property loss - $/unsprnk fire	0.023	Rate of retrofit of sprinklers in households	0.044
Sprnk system – mat. & instal. - new	0.024	Injuries - % covered by NZS4517	0.017	Sprnk system – mat. & instal. - retrofit	0.039

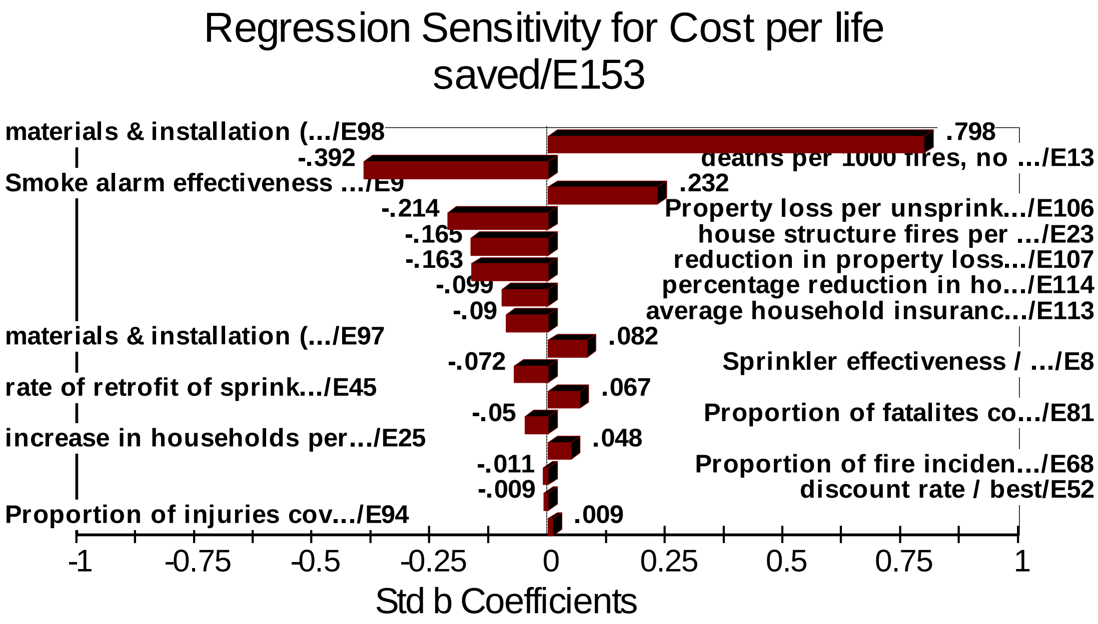


Figure 64: An example of the regression sensitivity results for the monetary cost per life saved for all residential building stock for the base case when sprinklers and smoke alarms are present.

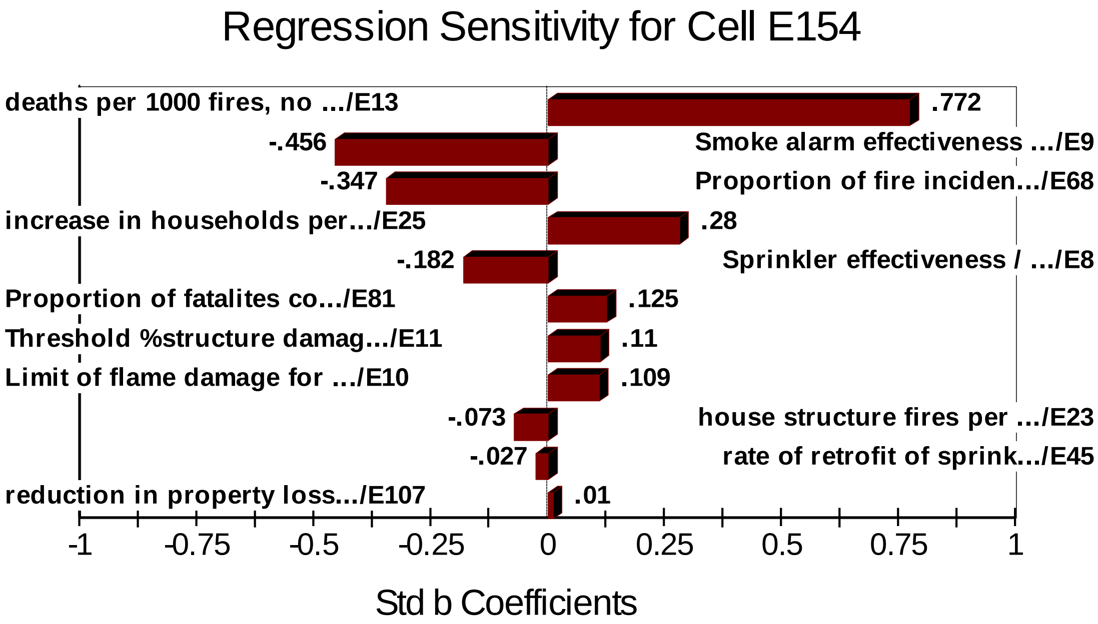


Figure 65: An example of the regression sensitivity results for the NZ Ecopoint cost per life saved for all residential building stock for the base case when sprinklers and smoke alarms are present.

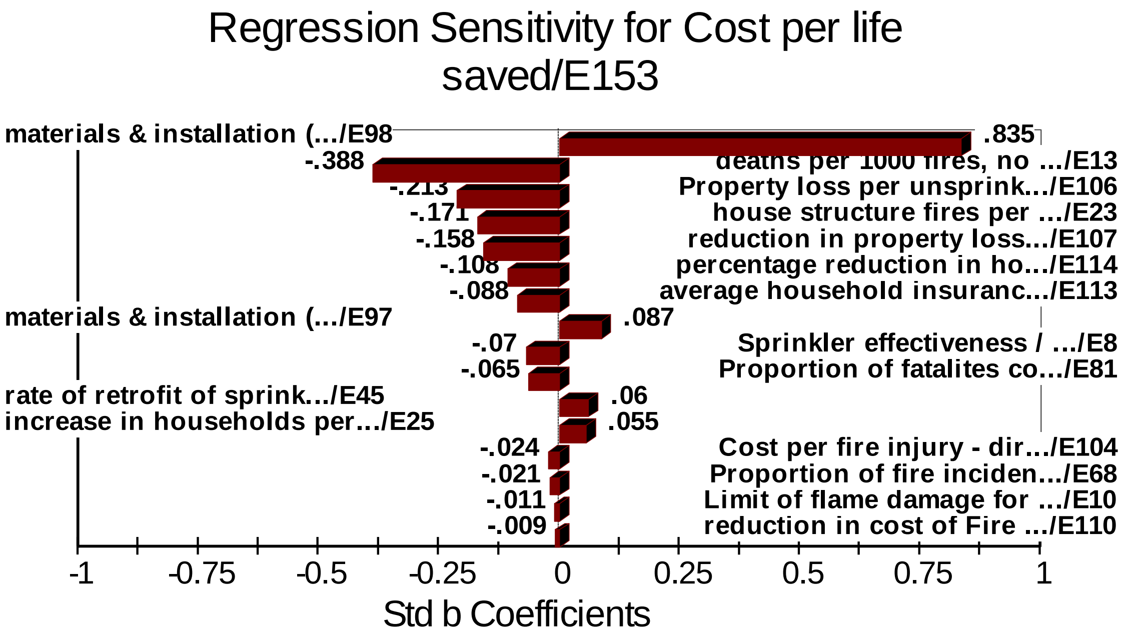


Figure 66: An example of the regression sensitivity results for the monetary cost per life saved for all residential building stock for the base case when sprinklers only present.

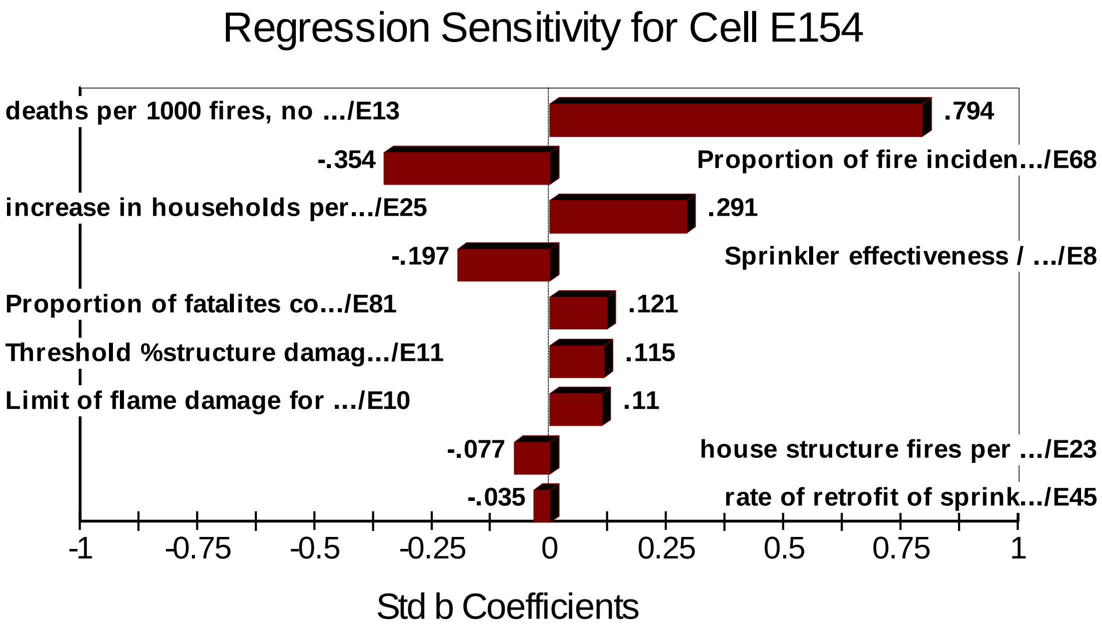


Figure 67: An example of the regression sensitivity results for the NZ Ecopoint cost per life saved for all residential building stock for the base case when sprinklers only are present.

8.3.3 Sensitivity Analysis

A sensitivity analysis was conducted for each of the scenarios described in Section 8.1, in terms of step-wise regression and correlation coefficients. Example results for the base case, for the monetary cost per life saved for the step-wise regression are shown in Figure 68 and for the correlation coefficient are shown in Figure 69. Similarly, example results for the NZ Ecopoint cost per life saved for the step-wise regression are shown in Figure 70 and for the correlation coefficient are shown in Figure 71.

Detailed model results are presented in **Error! Reference source not found.**.

In addition several input parameters were individually excluded to determine the influence of each of these parameters on the model results. These parameters were:

- presence of smoke alarms,
- fire service costs,
- insurance premium reductions, and
- indirect costs from civilian fire injuries.

The model results for these are summarised in Section 8.1 and details are included in **Error! Reference source not found.**.

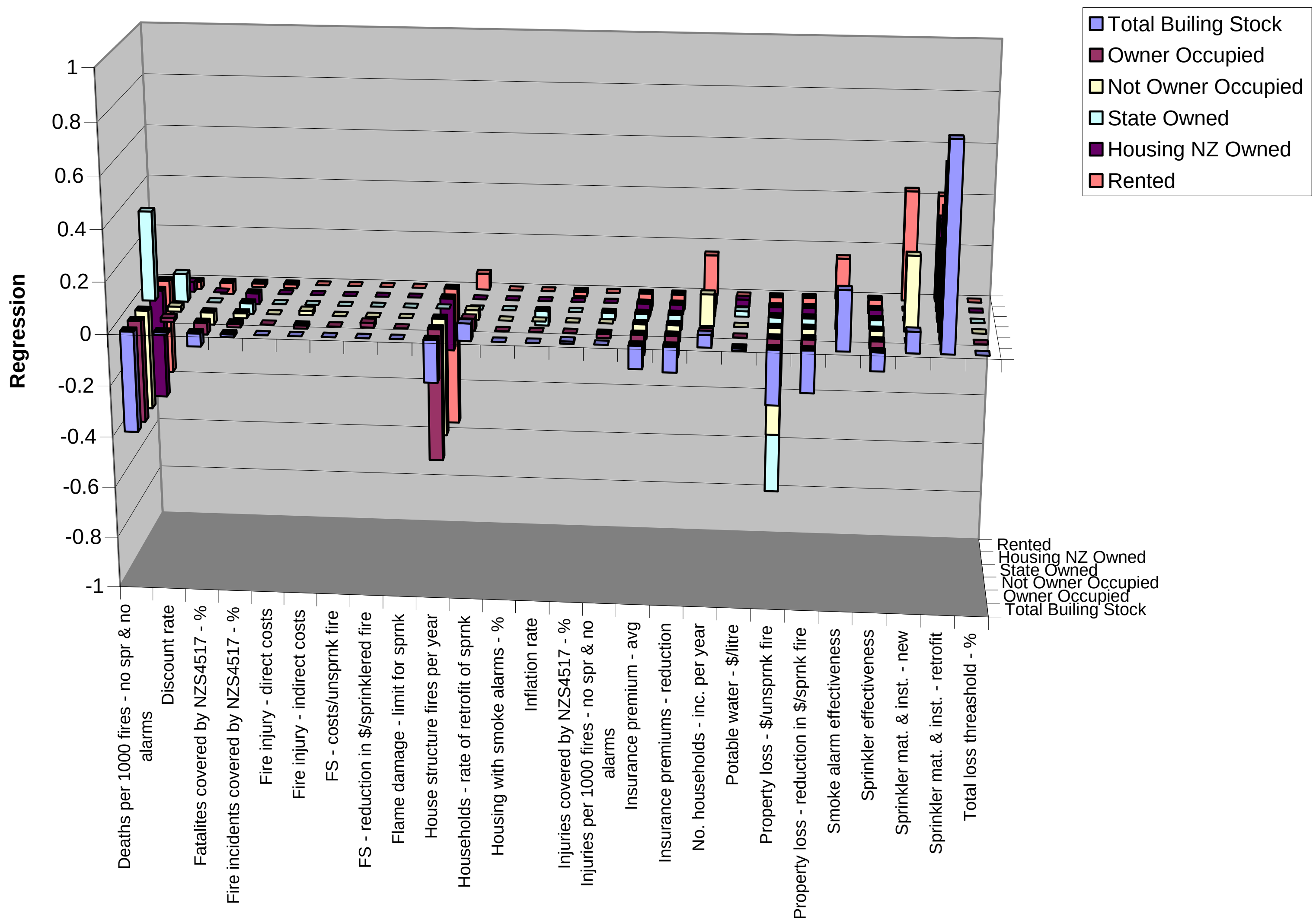


Figure 68: Step-wise regression results for the input variables for cost per life saved for the model considering sprinklers and smoke alarms present, for the base case with sprinklers and smoke alarms.

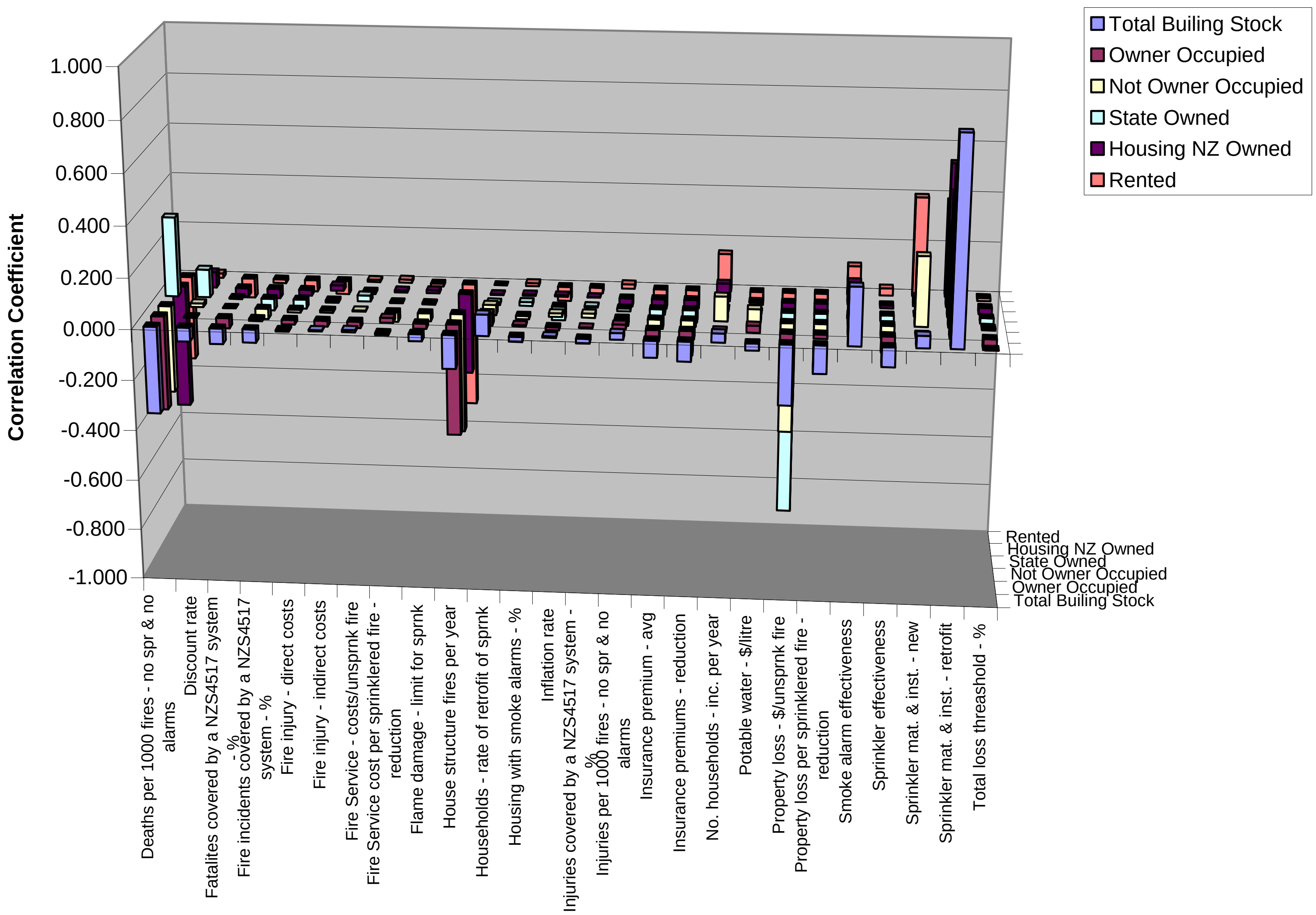


Figure 69: Correlation coefficient results for the input variables for cost per life saved for the model considering sprinklers and smoke alarms present, for the base case with sprinklers and smoke alarms.

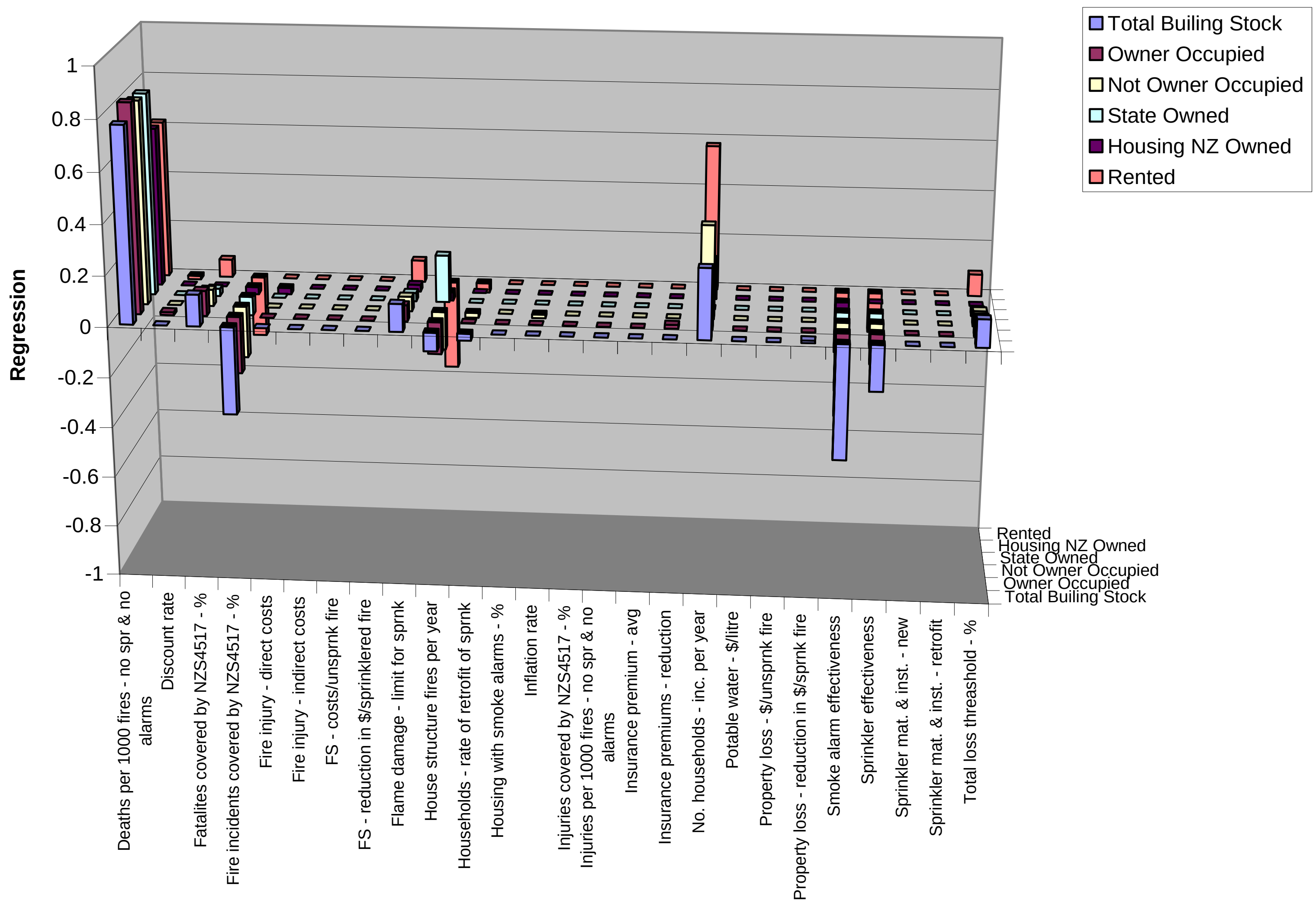


Figure 70: Step-wise regression results for the input variables for NZ Ecopoint cost per life saved for the model considering sprinklers and smoke alarms present, for the base case with sprinklers and smoke alarms.

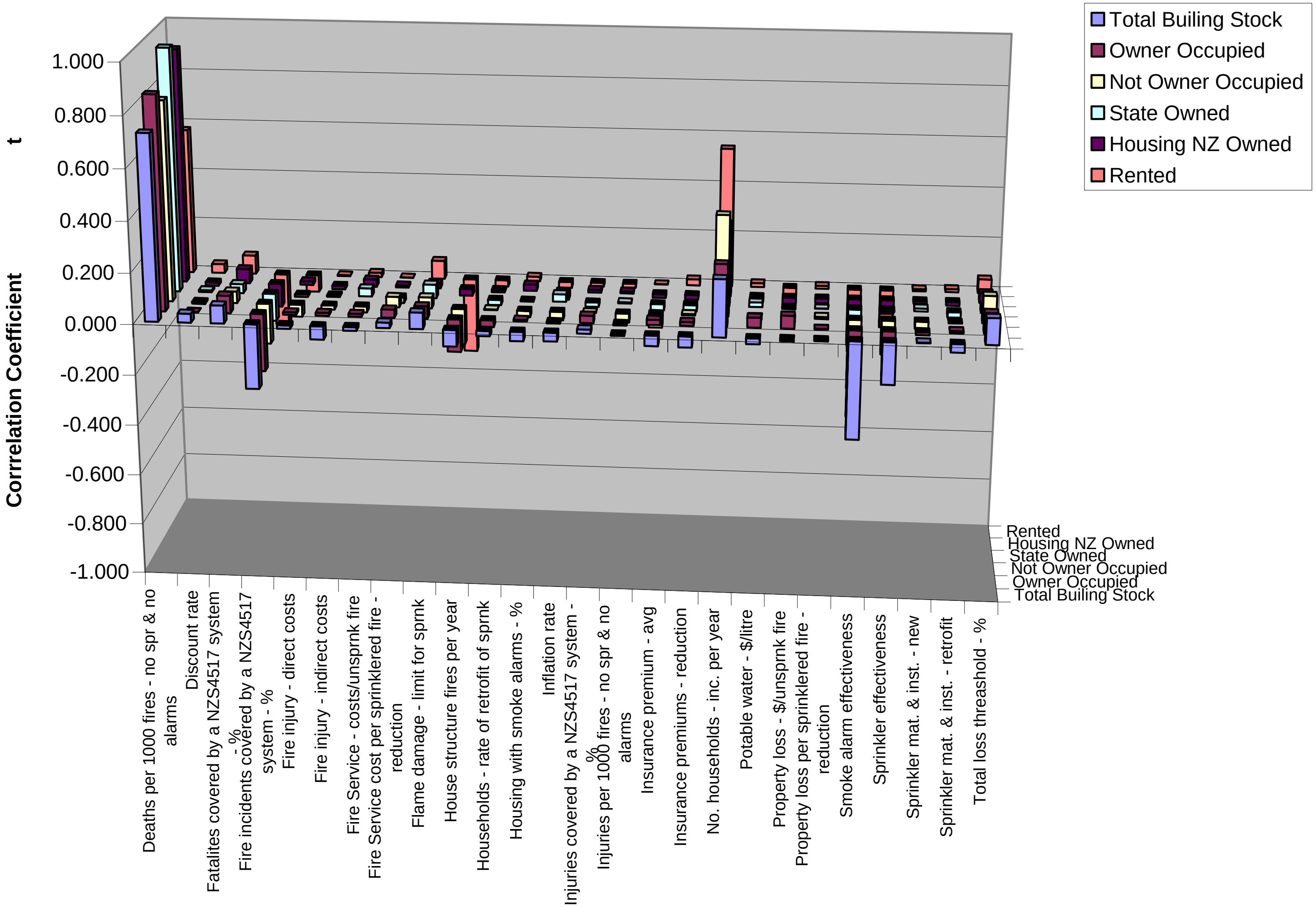


Figure 71: Correlation coefficient results for the input variables for NZ Ecopoint cost per life saved for the model considering sprinklers and smoke alarms present, for the base case with sprinklers and smoke alarms.

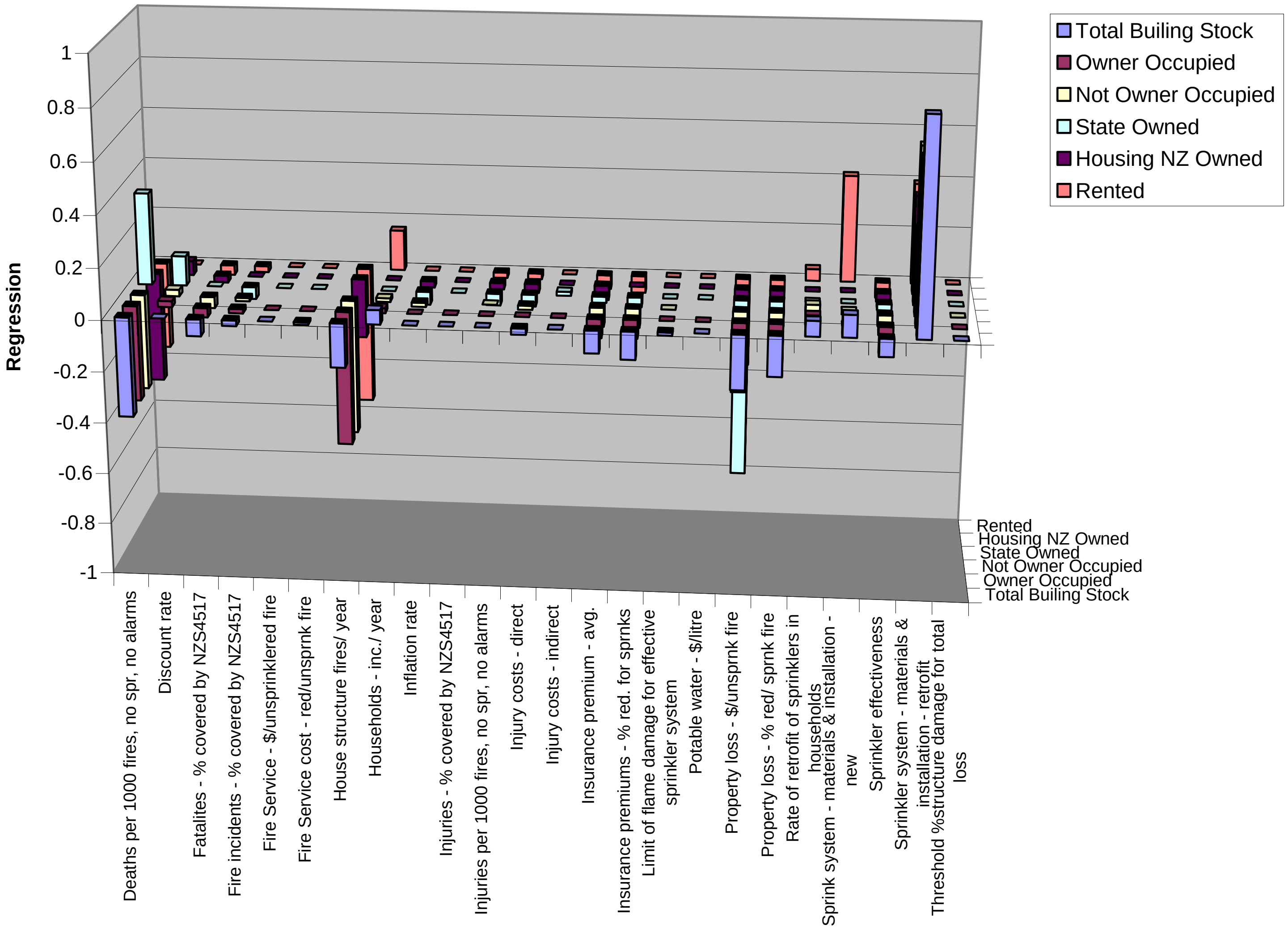


Figure 72: Step-wise regression results for the input variables for cost per life saved for the model considering sprinklers and smoke alarms present, for the base case with sprinklers only.

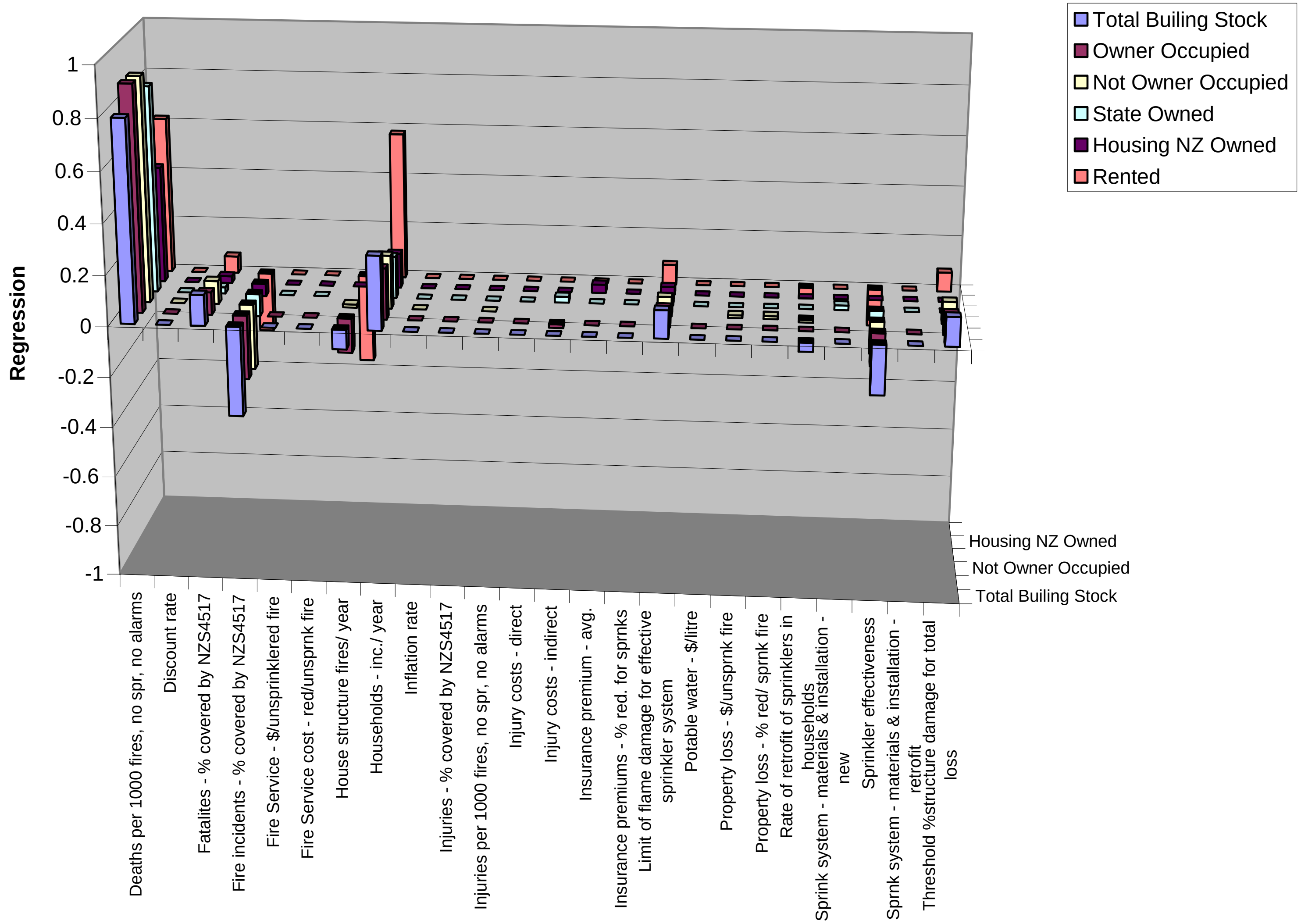


Figure 73: Correlation coefficient results for the input variables for cost per life saved for the model considering sprinklers and smoke alarms present, for the base case with sprinklers only.

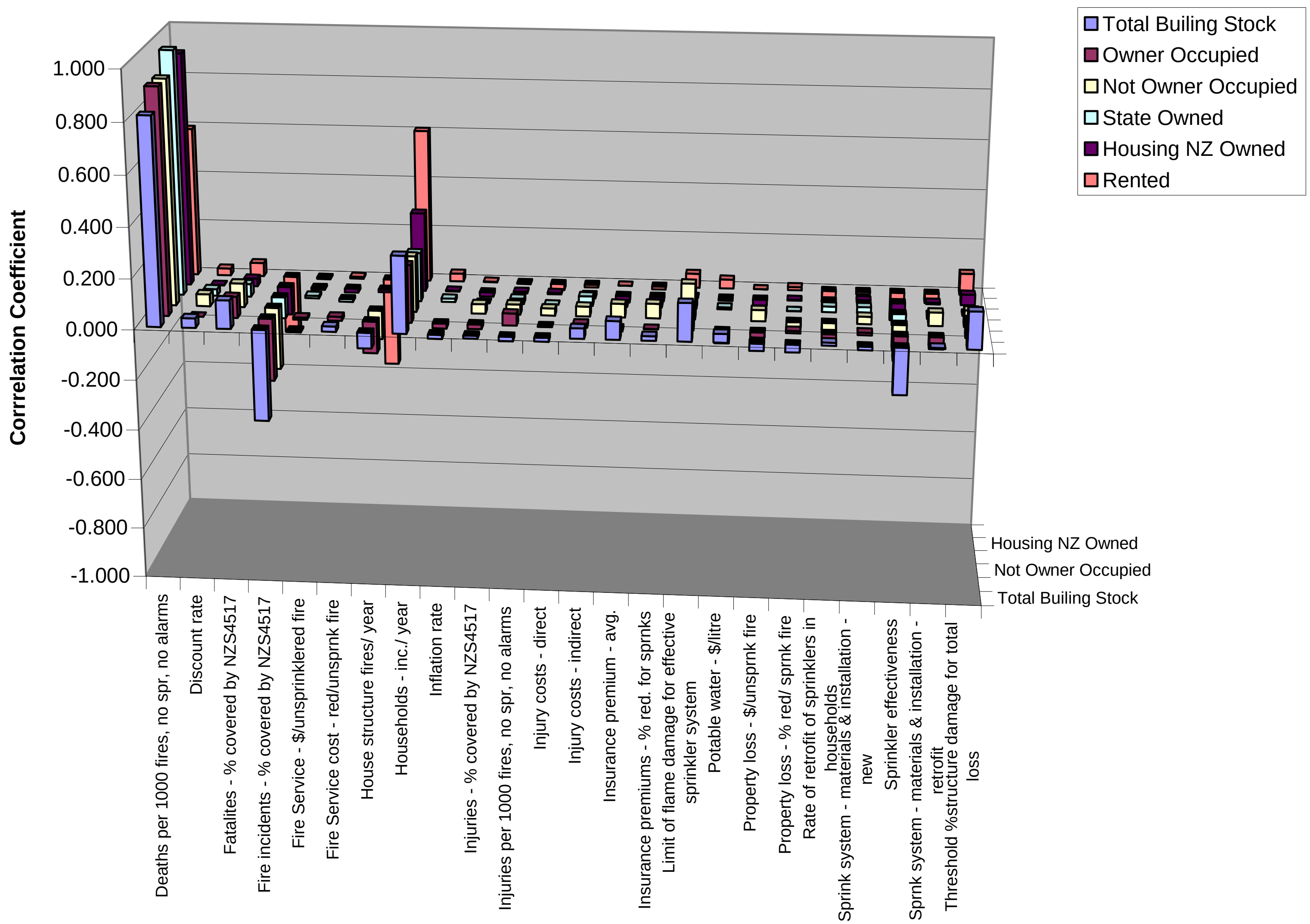


Figure 74: Step-wise regression results for the input variables for NZ Ecopoint cost per life saved for the model considering sprinklers and smoke alarms present, for the base case with sprinklers only.

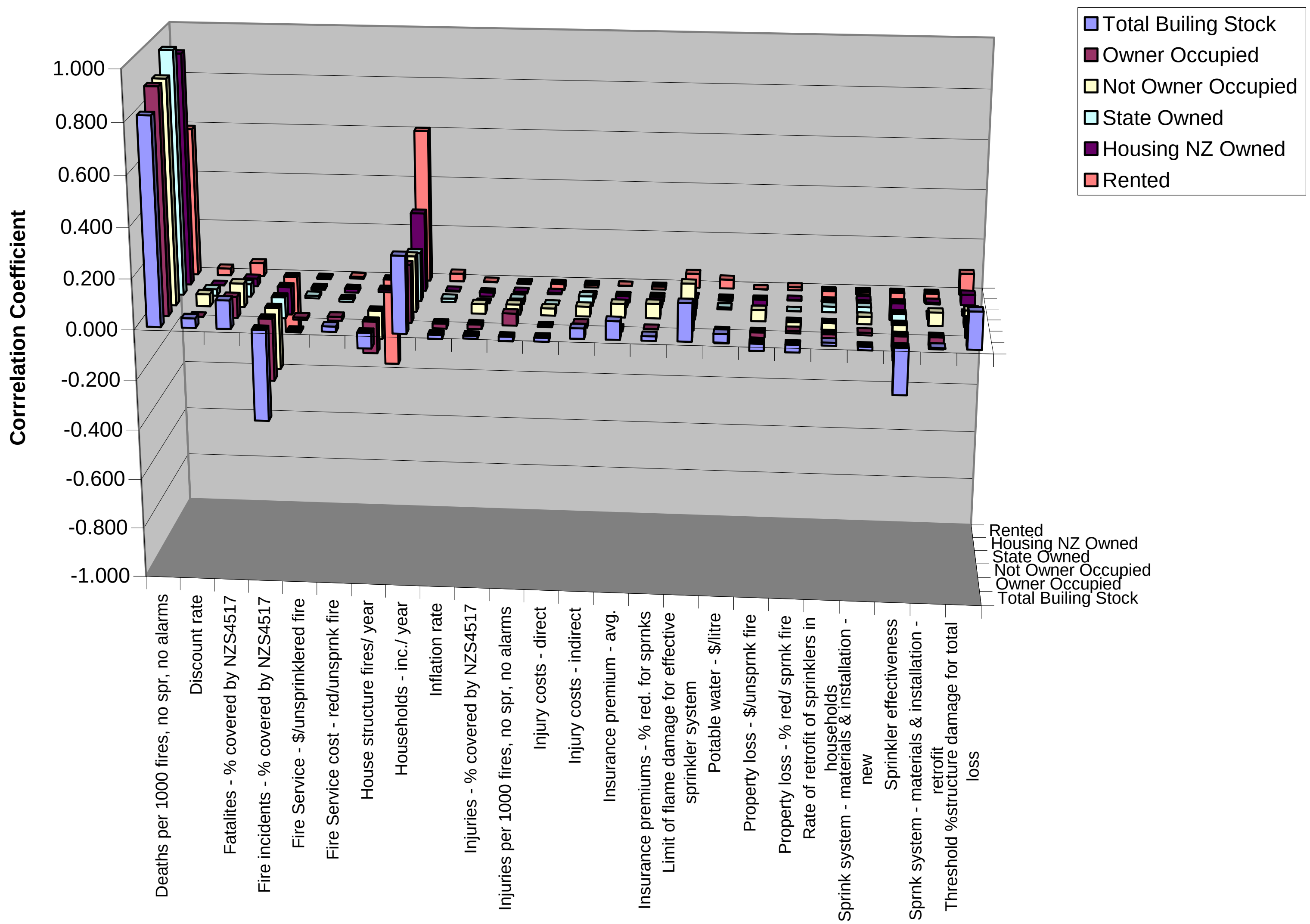


Figure 75: Correlation coefficient results for the input variables for NZ Ecopoint cost per life saved for the model considering sprinklers and smoke alarms present, for the base case with sprinklers only.

8.4 Discussion of Model Results

The results of the example model results are discussed in this section. The results related to environmental issues and monetary issues are initially discussed separately, before being combined.

8.4.1 Environmental Impact Module Results

The results for the number of NZ Ecopoints saved per life saved were consistent for the base case and each case excluding a selected monetary benefit for each home sprinkler system and smoke alarm combination considered (see **Error! Reference source not found.**). The minor differences between the base case and the cases excluding a particular monetary benefit can be attributed to the random selection of the seed for each set of iterations using Latin Hypercube sampling methods.

For all scenarios considered in this study, a gross savings of NZ Ecopoints was consistently calculated for the presence of home sprinkler systems. That is, a saving of NZ Ecopoints means a net benefit to the surrounds and environment. Specifically, the model results mean that the environmental impact of the reduced structure loss and subsequent replacement outweighs the environmental impact added by the materials and transport required for home sprinklers is less than the environmental impact associated with no home sprinkler systems being present. It should be noted that the environmental impact of direct fire effects and of the loss and replacement of household contents were not included in this model. The reduction of these additional environmental issues would be expected to further increase the environmental benefits associated with the inclusion of home sprinkler systems in New Zealand households. It shall be noted that the environmental impacts from fires (e.g. toxic fire water runoff, air pollution and soil contamination) have not been quantitatively assessed, but it is reasonable to assume that the inclusion of such environmental impacts in the model would add to the gross savings of the environment with the presence of domestic sprinkler systems.

Considering the scenarios where sprinklers and smoke alarms are present, the results relating to State owned residential properties indicate the most sustainablitity related benefits per life saved (as shown in Figure 58 and Table 57). Whereas the results for the NZ Ecopoints saved per life saved were the least for the categories of rented properties, non owner occupied properties, and the total residential building stock. These results are consistent with the significantly greater number of residential fire incidents (as shown in Figure 25) and civilian fire fatalities (as shown in Figure 28) reported per 100,000 properties for State owned properties than for the other categories considered in this study.

Similarly for the scenarios where sprinklers only are present, the results relating to State owned residential properties also indicate the most environmental impact related benefits per life saved (as shown in Figure 63 and Table 59). The results relating to the least number of NZ Ecopoints saved per life saved were related to the residential occupier categories of rented and total residential building stock. The number of NZ Ecopoints saved per life saved for the sprinklers only were generally less than the results for the combined sprinklers and smoke alarms case. This is expected because of the number of lives saved would be reduced with the removal of smoke alarms compared to the combination of sprinklers and smoke alarms.

For the scenarios and occupier categories considered, input parameters with high model sensitivity for the calculation of the NZ Ecopoint cost per life saved were consistently:

- Number of fatalities per 1000 fires,

- Proportion of fire fatalities occuring where the room of fire origin requires coverage by NZS 4517,
- Smoke alarm effectiveness,
- Sprinkler effectiveness
- Proportion of fire incidents occuring in rooms with cover required by NZS 4517,
- Percentage threshold for the total loss of a building,
- Number of house structure fires per year, and
- Increase of the number of households per year,

These input parameters relate to the calculation of the number of lives saved (the number of deaths per 1000 fires, the proportion of fatalities covered by a NZS 4517 system, the smoke alarm effectiveness and the sprinkler effectiveness) and the amount of structure damage sustained (the sprinkler effectiveness, proportion of fire incidents covered by NZS 4517, the threshold structure damage assumed for required total replacement, the number of fire incidents per year and the number of households). This is in agreement with the model calculations for the savings/cost of NZ Ecopoints.

The confidence of the values for each of these input parameters varies. For example, the parameters based on analysis of statistical records (such as the number of fatalities and number of fire incidents and indirectly to the effectiveness of systems in saving lives) rely on the accuracy of recording methods, an averaging of the effects of the standards of the building stock and changes in regulation, the assumption that records reflect an accurate state of the population and the assumption that historic trends can be used to estimate future predictions. Therefore, although the input parameter values of this study have been updated with the latest available statistical data sets, it should be noted that there are limitations of the application of this data and care should be used when applying the results of this model.

For the other input parameters there were a range of assumptions, which were summarised in Section 7. In brief, the values for system effectiveness are a combination of laboratory test results in controlled conditions and analysis of international statistical records. The number of fire incidents per year was assumed to be proportional to the number of households. The number of households for each category of residential occupier was assumed to follow the trend of the previous 2 csensuses. The assumptions for the proportion of fire incidents in rooms covered by a NZS 4517 system and the threshold value for a building to be considered a write-off due to fire damage were conservative assumptions.

Considering that 100 NZ Ecopoints is equivalent to the average environmental impact of a New Zealander per year, the mean model values for the case considering sprinklers and smoke alarms present equate to a saving of approximately:

- 28 years of an average individual’s environmental impact per life saved when considering the total residential building stock,
- 50 years of an average individual’s environmental impact per life saved when considering the owner occupied residential building stock,
- 21 years of an average individual’s environmental impact per life saved when considering the residential building stock not occupied by the owner,
- 170 years of an average individual’s environmental impact per life saved when considering the State owned residential building stock,
- 56 years of an average individual’s environmental impact per life saved when considering the Housing New Zealand owned residential building stock, and

- 11 years of an average individual's environmental impact per life saved when considering the rented residential building stock.

8.4.2 Monetary Results

A value of a statistical life was not estimated as part of this study. Instead a cost effectiveness analysis was performed to estimate the monetary cost per life saved. The resulting costs are net present value. The lives saved were not discounted, since saving a life today is the same as saving a life tomorrow and the discounting would manifest in the monetary value assigned at each time. Therefore the model results for the monetary cost per life saved can be directly compared to existing net present values for estimates of the value of a statistical life.

Considering the base case where home sprinkler systems and smoke alarms form the fire safety systems (Figure 54 and Table 56), the model results for State owned residential building stock show the least monetary cost per life saved compared to the other occupier categories considered. In fact the distribution of model results are mostly negative for the monetary cost per life saved, which means that there would be a monetary saving per life saved of an average $1.5 million. The next least costly expenditure per life saved is for Housing NZ owned building stock (at an average cost of $1.9 million/life saved), not owner occupied residential building stock (at an average cost of $2.7 million/life saved), and rented building stock (at an average cost of $3.1 million/life saved). The model results for the total residential building stock and owner occupied building stock were $6.3 million/life saved and $7.0 million/life saved, respectively.

8.4.3 Overall Cost Effectiveness Analysis Results

The overall cost effectiveness analysis results are a combination of the monetary cost per life saved and the measure of environmental impact per life saved (in this case the metric of NZ Ecopoints was used). That is, for the monetary cost of installing home sprinklers there are two types of benefits, lives saved and reduced impact on the environment.

The mean model results for the base case considering the impact of home sprinklers and smoke alarms are summarised in Table 68 and Figure 76 and the results when sprinklers only are considered are summarised in Table 69 and Figure 77.

When considering the mean model results for the monetary cost, environmental impact avoided and the number of lives saved, as presented in Table 68 and Table 69, the numbers for individual categories do not add up to combined categories (i.e., total stock or not owner occupied) since the sub-categories included in these are assumed to be proportional over the period of analysis. Whereas the model results for each individual category reflects the related statistical-based input parameter values (such as fatality and injury statistics and household number growth rates). In addition, the single value of the mean model output is not representational of the model output distributions. Therefore care must be applied when comparing category results directly.

The monetary costs and the environmental benefits per life saved are not proportional. This is expected, since the environmental impact 'costs' and 'benefits' are additional to the monetary costs and benefits. Similarly to the use of a monetary value to represent a life saved, it may be beneficial from a pure cost benefit analysis approach to estimate the monetary value of 100 NZ Ecopoints, which represents the average yearly impact of a New Zealander. Estimating a monetary value for either the value of a statistical life or the monetary value for 100 NZ Ecopoints is beyond the scope of this study. However the results of this study are such that a net present value for either of these estimates can be directly compared.

The results of the model clearly demonstrate that inclusion of home sprinklers will have a different monetary and environmental related impact depending on the sector of the residential building stock occupiers. The differences in model results for each of the sectors of the residential building occupiers relies on the statistical data sets available for each of these sectors of the total population. Analysing the monetary and environmental impact results for sectors of the total residential building stock, where home sprinklers could be suitable, allows targeted applications to be identified. For example, ranking the sectors considered in terms of greatest monetary benefits per life saved, for the model results for the base case considering sprinklers and smoke alarms are present, produces:

1. State owned building stock,
2. Housing NZ owned building stock,
3. Rented residential building stock, and
4. Owner occupied residential building stock.

Whereas ranking the categories in terms of greatest environmental impact benefits per life saved, for the model results for the base case considering sprinklers and smoke alarms are present, produces:

1. State owned building stock,
2. Housing NZ owned building stock,
3. Owner occupied residential building stock, and
4. Rented residential building stock.

Table 68: Mean model results attributed to home sprinkler systems for the base case when sprinklers and smoke alarms are present.

Residential Building Stock	Mean Monetary Cost per Life Saved ($million/ life saved)	Mean Environmental Benefits per Life Saved (100 NZ Ecopoints saved/ life saved)	Mean Total Number of Lives Saved over the 50 Year Analysis Period
Total Stock	$6.3	28	620
Owner Occupied	$7.0	50	200
Not Owner Occupied	$2.7	21	560
State Owned	-$1.5	170	13
Housing NZ Owned	$1.9	56	33
Rented	$3.1	11	800

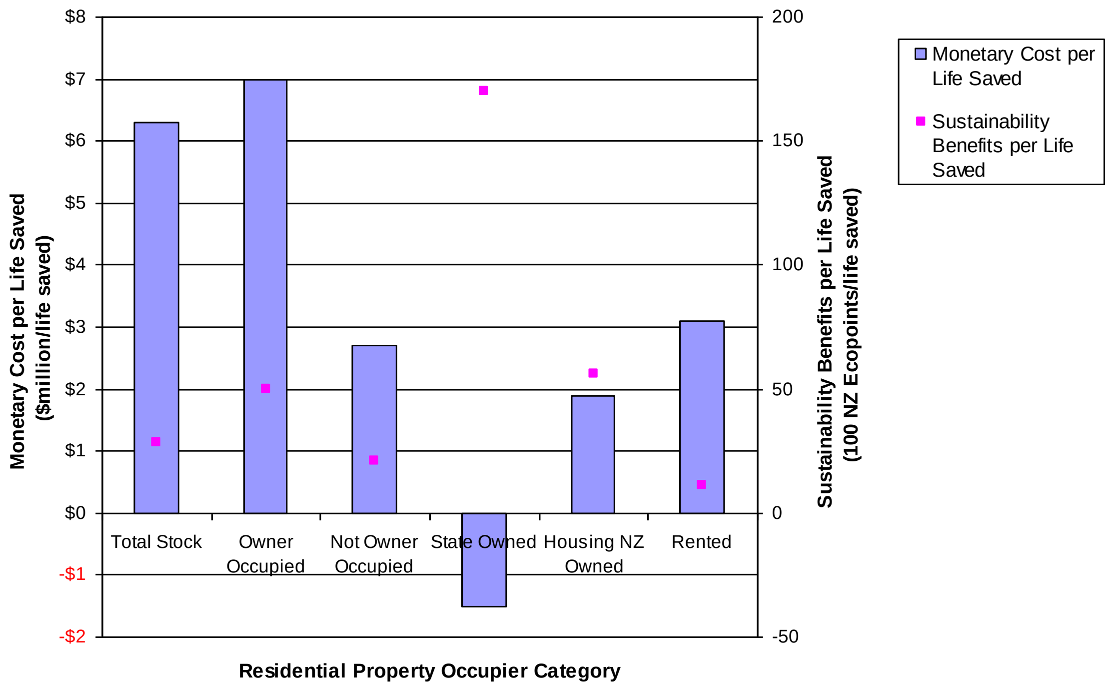


Figure 76: Summary of the mean values for monetary cost and sustainability aspects in terms of environmental benefits per life saved for the base case when home sprinklers and smoke alarms are present.

Table 69: Mean model results attributed to home sprinkler systems for the base case when sprinklers only are present.

Residential Building Stock	**Mean Monetary Cost per Life Saved ($million/life saved)**	**Mean Envorinmental Benefits per Life Saved (100 NZ Ecopoints saved/ life saved)**	**Mean Total Number of Lives Saved over the 50 Year Analysis Period**
Total Stock	$3.7	16	1000
Owner Occupied	$4.1	30	330
Not Owner Occupied	$4.1	29	930
State Owned	-$1.0	101	22
Housing NZ Owned	$1.1	34	55
Rented	$1.8	7	1300

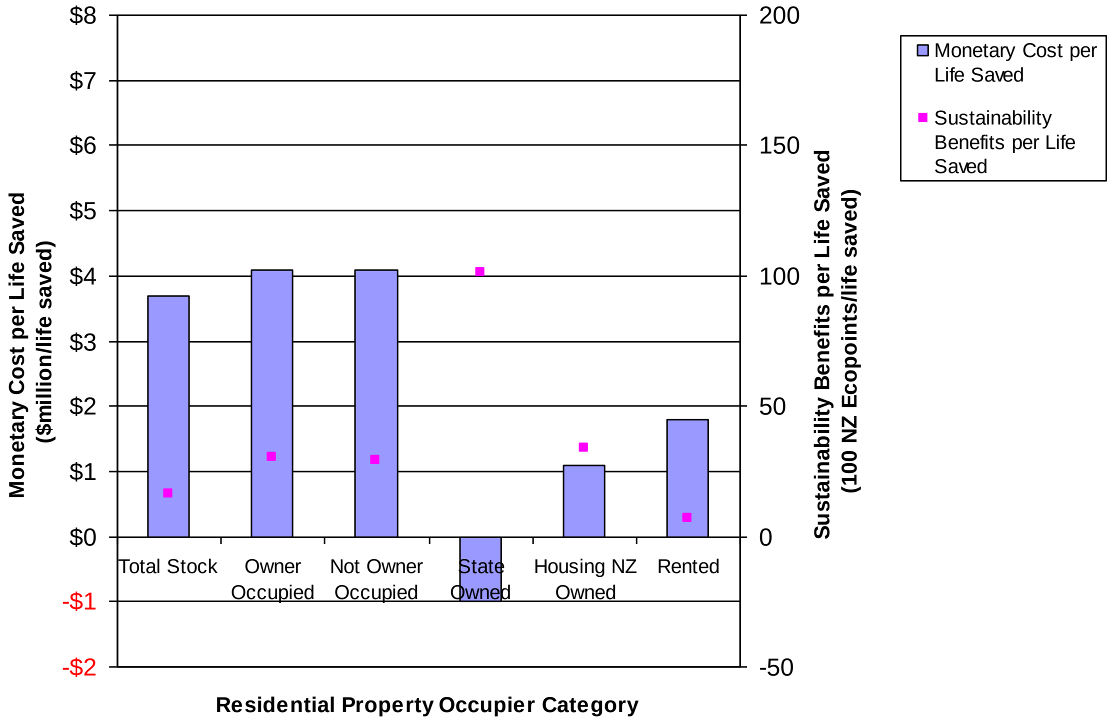


Figure 77: Summary of the mean values for monetary cost and sustainability aspects in terms of environmental benefits per life saved for the base case when home sprinklers only are present.

8.4.4 General Input Parameter Values and Model Sensitivity

Technically, all values based on statistics effectively incorporate the "effectiveness" of the system considered (e.g. the historical record of the number of fatalities per year where sprinkler and alarm systems were present incorporates a measure of the effectiveness of preventing fatalities in the field for the systems involved). However considering the potential for error within the collation and estimation methods for the statistical data sets in combination with the statistical relevance of the small data sets, the sprinkler effectiveness is applied to these values within the cost effectiveness analysis. Therefore providing a conservative result in terms of how effective a sprinkler system may be.

8.4.5 Model Limitations

The model limitations are related to the assumed values for the input parameters. As with all predictive models, in particular future-based input parameter values have the least confidence. Therefore care must be applied when interperating the model results for use. Input values should continue to be assessed and updated as more statiscial and economic data becomes available. Details of the model input value assumptions are included in Section 7.

All model assumptions were based upon conservative estimates. That is the model results for monetary cost per life saved is expected to be an over estimate for the influences considered and the results for environmental benefits per life saved is expected to be an underestimate.

The monetary and sustainability aspect related costs are not entirely independent. For example there are monetary charges based on the scarecity of resources (such as non-renewable fuel sources, etc). This proportion of the monetary charge would ideally be invested in developing new avenues or alternate sources to the scarce resource. However there is neither a specific process for accounting for the additional monetary charges nor for tracking the investment in development of future alternatives. It is assumed for this assessment that the overlap between the monetary and sustainability aspect related costs is currently minor.

The results of the model should be assessed primarily on the output distributions rather than the summarised results (such as mean, range and standard deviation), since the summarised results are calculated on the assumption of a normal distribution, which may not be the most appropriate description of the distribution. Therefore although the model output distributions are more complicated, they provide a more appropriate description of the results than the summarised results alone.

9. CONCLUSIONS

Conclusions relating to sustainability issues:

- Sustainability aspects associated with home sprinklers and structure fires were successfully incorporated into the cost effectiveness analysis for home sprinkler systems in terms of a module for environmental impact.
- The use of a Life Cycle Assessment approach, in accordance with ISO 14040, allowed a wide range of environmental impacts to be considered and for a single representative measurement to be used in conjunction with the monetary based cost effectiveness analysis of the impact of home sprinkler systems.
- This study represents the first use in New Zealand of Ecopoints for the quantitative metric for environmental impact, which is currently commonplace in the UK and elsewhere.
- The results for all scenarios indicated that a saving of NZ Ecopoints would be made for each life saved with the inclusion of home sprinklers in New Zealand residential properties. That is, for the monetary cost associated with each life saved, a net positive impact for the sutainabiltiy aspects, in terms of the environmental issues, considered here was also achieved.
- The model results for the impact of home sprinkler systems for the base case, considering sprinklers and smoke detectors present, indicate a range of mean environmental benefits per life saved of approximately 11 to 170 equivalent years of average environmental impact of a New Zealander (i.e., 1,100 to 17,000 NZ Ecopoints, Table 68 and Figure 76) depending on the category of residential building stock occupier.
- The results for environmental impact benefits per life saved were presented as distributions to account for input parameter uncertainty (e.g. for the base case, considering sprinklers and smoke alarms present, Figure 58 and Table 57).
- The approach to incorporating sustainability aspects into this model only considered the environmental issues for the cradle to gate impact for sprinkler systems and loss and replacement of flame damaged building stock. That is, the environmental impact related effects of fire and the loss and replacement of home contents was not included in the assessment. It is expected that the inclusion of these additional aspects would produce an even more positive contribution to the measure of environmental benefits.
- The use of NZ Ecopoints to provide a measure of a wide range of environmental impacts allows broader sustainability aspects to be incorporated into current cost effectiveness analyses, with the opportunity for direct comparison as monetary estimates are proposed in the future.

Conclusions relating to monetary issues:

- Considering categories of the residential building stock occupier as well as the total residential building stock for home sprinkler systems provided a wide range of monetary costs per life saved. This also indicated that targeting the use of home sprinklers for specific occupier groups would be beneficial.
- The model results for the base case, considering sprinklers and smoke detectors present, indicate a range of mean monetary benefits per life saved of approximately -$1.5 to $ 7.0 million (Table 68 and Figure 76) depending on the category of residential building stock occupier.

- The results for monetary costs per life saved were presented as distributions to account for input parameter uncertainty (e.g. for the base case, considering sprinklers and smoke alarms present, Figure 54 – Figure 58 and Table 56).
- The model results are presented in a form designed to allow direct comparison with net present value estimates of the value of a statistical life.

Conclusions relating to the overall home sprinkler system cost effectiveness analysis results:

- Incorporation of sustainability aspects into the cost effectiveness analysis for home sprinkler systems provides a broader insight into the overall costs and benefits, including aspects that currently have no monetary equivalent.
- Considering sectors of the initial target population for potential application of home sprinkler systems provided a more thorough understanding of the potential costs and benefits of the application of home sprinkler systems. Futhermore any category or sector for which fire statistics are available can be investigated.

9.1 Recommendations for Future Work

Areas of future work recommended include:

- Expansion of the environmental impact module to include the effects of fire and the loss and replacement of home contents.
- Estimation of a monetary value to be applied to NZ Ecopoints, similar to the approach of a Value of a Statistical Life estimated for a life saved.
- Expansion of the concept of the incorporation of the environmental impact module complimenting a cost-benefit analysis to include broader sustainability issues, which cover environmental, economic and social aspects.
- Potential costs associated with the regulation for the requirement for home sprinklers were included in the methodology of this model. However no parameter values were used in the evaluation of the model. Thus there is the potential for regulatory costs to be included in this assessment.
- Identification of other potential categories of residential properties for which home sprinklers may be of particular benefit. For example, residences in rural areas, because of the potential extra time delay in fire service (which may be solely volunteer based in some areas) arrival at the scene and potential water supply problems. In addition, a house fire in a rural or remote surrounds would be more likely to be adjacent to ecologically sensitive areas. Therefore the less water used in a sprinkler system the less soil and aquatic contamination in combination with a smaller fire in total and the environmental damage associated with that.

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