Fire Research Report

Residential Kitchen Local Fire Protection - Cost Effectiveness Analysis

BRANZ

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This report summarises an approach developed to evaluate the cost effectiveness of potential systems for use in suppression of local kitchen fires. A framework to experimentally quantify the effectiveness of such systems was also developed that includes a generic test method and a calculation methodology and the results of that investigation are incorporated into the cost effectiveness analysis presented here.

Distributed parameter values and results were considered, to provide insight into the influences. The influences of input parameter values were investigated in terms of the most important parameters within the proposed framework.

A single residential sprinkler head is used to demonstrate the proposed methodology for a cost effectiveness analysis for a limited fire challenge.

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STUDY REPORT

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Residential Kitchen Local Fire Protection - Cost Effectiveness Analysis

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Preface

This is the second of a series of two reports prepared during research into kitchen stove-top fires and a method of using cost effectiveness analyses to compare various solutions. The first report in this series is BRANZ Study Report 225, Residential Kitchen Local Fire Protection - Experiments.

Acknowledgments

This work was jointly funded by the New Zealand Fire Service Commission from the Contestable Research Fund, and BRANZ from the Building Research Levy.

Note

This report is intended for regulating authorities, policy advisers, researchers and fire engineers.

Residential Kitchen Local Fire Protection – Cost Effectiveness Analysis

BRANZ Study Report SR 226

A. P. Robbins

Reference

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Abstract

Residential kitchen fires are attributable to a large proportion of residential fires leading to deaths, injuries and damage, therefore a reduction in kitchen related fires would make a significant impact in our community.

This report summarises an approach developed to evaluate the cost effectiveness of potential systems for use in suppression of local kitchen fires. A framework to experimentally quantify the effectiveness of such systems was also developed that includes a generic test method and a calculation methodology and the results of that investigation are incorporated into the cost effectiveness analysis presented here.

Distributed parameter values and results were considered, to provide insight into the influences. The influences of input parameter values were investigated in terms of the most important parameters within the proposed framework.

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1. INTRODUCTION

Over the period 1995 - 2005 in New Zealand, kitchen fires accounted for approximately 14,000 incidents, 60 deaths and 1,200 injuries. Residential kitchen fires are attributable to a large proportion of residential fire deaths, injuries and damage, therefore a reduction in kitchen related fires would make a significant impact in our community. A rigorous, science-based method is needed to assess the performance of potential systems for use in suppression of local kitchen fires. A framework to quantify the impact of such systems is also needed. Development of a generic test method and quantitative performance criteria for determining the appropriateness of retrofit active residential kitchen local stove-top fire protection systems was conducted to provide a basis for future guidelines for appropriate design and assessment for local residential kitchen fire protection systems.

1.1 Motivation

Use of home sprinkler systems is rapidly gaining traction in New Zealand and is generally most suitable for inclusion in new houses rather than retrofit applications since these systems are more expensive to retrofit. Targeting the existing housing stock throughout New Zealand with quick-win fire protection strategies will be more likely to impact positively on reducing the fire incident rate in houses in the short to medium term. Home sprinkler systems, while offering a more complete protection strategy, can be seen as a medium to long term solution. A local fire protection system, targeting the stove-top, could be present in conjunction with a home sprinkler or residential sprinkler system to provided added targeted protection.

Over the period 1995-2005 in New Zealand, kitchen fires accounted for approximately 14,000 incidents, 60 deaths and 1200 injuries. As a percentage of the total for all fires in residential buildings this represents 41% of the total incidents, 25% of the total deaths and 44% of the total injuries (Robbins et al. 2008). These statistics are based on incidents reported to the New Zealand Fire Service, however there may be many more fires extinguished by occupants and not reported. Adopting a strategy that focuses on reducing the number of serious kitchen fires has the potential to lead to fewer fire deaths and injuries as well as the associated reductions in the amount of fire-damaged property.

There are many ways of approaching the reduction of cooking fire problems, including

- Community education,
- Improved detection,
- Thermostatic safety controls on cooking equipment and
- Suppression systems.

The research summarised here focuses on potential fire control or suppression systems.

The potential use of inexpensive localized fire protection systems in high fire risk areas (e.g. kitchens) for retrofit applications is a strategy currently being pursued by the United States Fire Administration (USFA) through their National Residential Fire Sprinkler Initiative (USFA 2007). Since 14% of all fatal residential fires in the US (1989-1998) are initiated in the kitchen, it is thought that having automatic suppression capability in the kitchens of manufactured homes would have the potential to provide a significant impact on reducing the number of deaths and injuries in those buildings. Contributing to this effort, the US National Institute of Standards and Technology

(NIST) are currently developing a test method to examine the performance of automatic fire suppression and control systems for kitchen stove-top residential applications (Madrzykowski Hamins and Mehta 2007). Their study is also aligned with the USFA National Residential Fire Sprinkler Initiative (USFA 2007).

There are many different approaches and therefore potential outcomes (in terms of the interrelated aspects of coverage, effectiveness and reliability, for example) for localised fire protection specifically for residential kitchen stove-top (or range) fires. A test method and performance criteria that can be used to assess different potential systems is needed to assess the appropriateness of a diverse stove-top of systems. This research is the initial development of a framework for a cost effectiveness module that includes results from a laboratory assessment of a specific design. This framework was developed to allow a more holistic comparison of potential different designs.

1.2 Objectives

The objectives for the cost effectiveness analysis section of this research, as summarised in this report, were:

- to develop a methodology for a cost effectiveness analysis to evaluate the impact of retrofit active residential kitchen local stove-top fire protection systems for the NZ situation, and
- to utilise experimental data and test method experience from the other part of the project focused on developing a generic test methodology and performance criteria for determining the appropriateness of retrofit active residential kitchen local stove-top fire protection systems.

1.3 Scope

This project focuses on reducing the problem of cooking fires using the approach of local suppression systems. Specifically, the cost effectiveness analysis aspect of this project was to develop a framework to assess the impact of potential local fire protection systems for stove-top kitchen fires.

An example system of a single residential sprinkler head was used for demonstration purposes for the cost effectiveness assessment framework presented here.

1.4 Approach

The approach taken to achieve the stated objectives was:

1. Carry out a literature review to learn about previous work that is relevant,
2. Analyse New Zealand fire incident data relating to kitchen stove-top fires in residential buildings and, if possible, identify any high risk area within various housing types,
3. Estimate system effectiveness (this is based on the experimental investigation, summarised in BRANZ Study Report 225),
4. Make an assessment of the potential benefits of an example system (reductions in fire deaths, injuries, property damage),
5. Estimate the cost of installation of the system,

6. Modify the previously developed cost effectiveness model for home sprinklers that addressed the uncertainty of the model inputs and results (Robbins, Wade et al., 2008) to assess and compare potential kitchen fire protection systems,
7. Perform a cost effectiveness analysis for an example system,
8. Perform a sensitivity analysis on the cost effectiveness framework to determine the importance of input parameters,
9. Develop guidelines for design/performance parameters of an example design, and
10. Report findings.

The results for this approach are summarised here.

2. LITERATURE REVIEW

It general, it has been recognised that the best situation is to fully sprinkler a residence in accordance with an appropriate standard, however local suppression units have the appeal of lower associated retrofit costs. (King 1998; Madrzykowski, Hamins and Mehta 2007)

2.1 Previous Research

Two general conditions have been the focus of investigations:

1. Identification of pre-ignition conditions and subsequent controlled shut off of the electricity or gas to the stove-top, and
2. Identification of fire conditions and subsequent activation of local suppression systems to extinguish the fire.

Investigations carried out in these two general areas are summarised here.

Stove-top and oven fires have been acknowledged as the leading cause of residential fires in the US (Johnsson 1995; CPSC 1998; Johnsson 1998; Madrzykowski, Hamins and Mehta 2007). In response to this the United States Consumer Product Safety Commission (CPSC) initiated a project investigating pre-ignition conditions on a stove top compared to normal cooking conditions in order to use the results to lessen the risk of cooking fires when incorporated with local suppression technologies (Johnsson 1995; CPSC 1998). The work for this project was carried out by the National Institute of Standards and Technology (NIST) and the CPSC. The overall objective of this study was to determine the feasibility of incorporating a device that would react to pre-ignition conditions into a stove-top to reduce the occurrence of unwanted stove-top fires.

The first two phases of this study investigated pre-ignition conditions associated with smoke particulates, hydrocarbon gases and temperatures. Over 50 tests were conducted using electric and gas stove-tops. Three different foods were placed in pans on burners set to high heat. Temperatures of the pan bottom, pan contents, stove-top and stove-top hood were recorded. Local plume velocity and laser-attenuation measurements were also recorded. Infrared spectrometer measurements were used to identify species produced above the food. Based on the test results, strong indicators of pre-ignition conditions were identified as temperatures, smoke particulates and hydrocarbon gases. Potential detection technologies for use in detecting pre-ignition conditions, based on the strong indicators identified from testing, to signal the shut-off of power or gas to the stove-top were also collated and reviewed. (Johnsson 1995)

The third phase consisted of testing scenarios for attended and unattended cooking fires. The variables that were considered included stove-top temperature settings, pan materials and location on the stove-top, air flow and thermal inertia. The potential of several detection devices were also examined. The set up used for testing was a mock up of a kitchen, similar to that used in the previous phases of the investigation except for the addition of a ceiling fan. Hydrocarbons, alcohols, moisture and smoke were measured in the room. Pan bottom and contents temperatures were also measured. (CPSC 1998)

A summary of the results of the CPSC and NIST investigations includes (Johnsson 1995; CPSC 1998; Johnsson 1998):

- Reasonable comparability was found between NIST and CPSC test results.

- Temperatures, smoke particulates and hydrocarbon gases were found to be strong indicators for impending ignition.
- Weak indicators for impending ignition were found to be the velocity above the burner and infrared imaging of the cooking area.
- Specific stove-tops, pans, foods, and ventilation were found to influence the pre-ignition characteristics. For example,
    - Ignition conditions were reached more quickly for foods cooked in a stainless steel pan compared to an aluminium pan.
    - Pre-ignition conditions for the same foods cooked on electric and gas stove-tops were similar.
    - Foods, except sugar, cooked on the electric stove-tops were found to reach ignition conditions more quickly than on gas stove-tops.
    - Soybean oil and bacon had similar temporal heating and ignition behaviours. Sugar showed different behaviour.
- A selection of potentially useful detection technologies were identified for further testing alone and in combinations, including:
    - Tin oxide sensors for hydrocarbon detection,
    - Narrow band infrared absorption for hydrocarbon detection,
    - Scattering or attenuation types of photoelectric devices for smoke particle detection, or
    - Thermocouples located at the burner, pan, above and below the stove-top surface or stove-top hood.
- No single sensor performed perfectly.
- The use of several sensors positioned at certain locations provided higher levels of differentiation than when used alone. Algebraically combining sets of sensor signals provided robust differentiation.
- False alarms may be eliminated by signal processing of two or more detection technologies. Selection of an appropriate threshold can appropriately trigger an alarm or no alarm.
- Some normal cooking practices (such as blackening of fish) can produce similar conditions to conditions approaching ignition.
- Existing control technologies were identified for the safe shutdown and restart of gas and electric stove-tops.
- Of the parameters and scenarios investigated, temperatures measured at the bottom of the pan provided the best indication of pre-ignition conditions.
- The gas sensors investigated were found to generally have low and variable responses until near ignition. Gas sensors were found to be influenced by moisture, previous cooking exposure, air flow and pan position. Modification would be needed for this specific application.
- The smoke detectors investigated responded inconsistently. Detection of alarm conditions were appropriate most of the time (95% for photoelectric and 81% for ionization), but there were a significant number of false alarms for the tests conducted (29% and 34%, respectively). Modification would be needed for this specific application.

- Stove-top hoods and ceiling fans substantially affected the gas sensor and smoke detector responses.
- Pan materials and contents influenced ignition.
- Electric and gas stove-tops were related to different ignition characteristics.
- Several potential control approaches were presented.
- Systems with shut off of electricity or gas to the stove-top on detection of pre-ignition conditions were insensitive to the stove-top type, stove-top hood status and pan material.

Recommendations from the investigations of this project included:

- Investigation of pre-ignition conditions where multiple burners and oven are in normal use.
- Determine whether gas sensors and smoke detectors can be modified for application in control systems for stove-top fire avoidance.
- Develop a prototype control system using thermocouples alone and in conjunction with gas sensors or smoke detectors to test for long term reliability of the control system.
- Investigation of the use of other sensors, e.g. for oven use or motion detectors, to cover a wider stove-top of types of cooking related fires.
- Investigation of alternative sensor technologies, e.g. electrochemical, fibreoptic, etc.
- More investigation of the use of detection based on multiple sensor signals.

NIST, USFA, US Department of Housing and Urban Development (HUD), and Partnership for Advancing Technology in Housing (PATH) co-funded a further investigation with the major project components of (Madrzykowski, Hamins and Mehta 2007):

- Kitchen fire hazard characterisation,
- Investigation of ‘passive’ and ‘active’ fire protection solutions and appropriate test protocols, and
- Limited full-scale evaluation.

In order to determine how effective a standardised test might be in evaluating the performance of a unit or system to suppress a localised kitchen fire, understanding the fire hazard characteristics was deemed fundamental. Kitchen fires were quantified in terms of engineering units, specifically heat release rate and heat flux. Several types of cooking oil were heated to auto-ignition and the results were compared to the heat release rate of heptane. The scenarios listed in UL 300A (2006) were also measured. Corn oil was chosen for the full-scale experiments. Toaster fires and coffeemaker fires were also initiated and measured. The coffeemaker was determined to produce a higher heat release rate with a longer burning duration. Therefore the coffeemaker was selected as the counter top appliance design hazard. (Madrzykowski, Hamins and Mehta 2007)

The ‘passive’ fire protection solutions included (Madrzykowski, Hamins and Mehta 2007):

- Spacing,

- Coverings,
- Choice of materials, and
- Coatings.

Of the solutions investigated, intumescent paint was suggested to be the best option, considering cone calorimeter results, the ease of retro fit and a limited number of full-scale kitchen tests. (Madrzykowski, Hamins and Mehta 2007)

Three types of active fire protection systems were tested (Madrzykowski, Hamins and Mehta 2007):

- A dry chemical system installed over the stove-top under the stove-top hood,
- A wet chemical system installed above the stove-top under the stove-top hood, and
- A single automatic fire sprinkler installed in the kitchen.

Full-scale kitchen experiments using a fire source based on a skillet fire were conducted utilising a vacant apartment building. These tests were to compare the effectiveness during a full-scale test to laboratory-based test results. The single low-flow residential sprinkler was tested in a pendant and sidewall configuration. Both were found to control the spread of the cooking fire despite shielding caused by the cabinetry. None of the potential solutions was deemed perfect. None of the solutions shut off the stove-top. Tested units (according to UL 300A) that shut off the stove-top were approximately 5 times the installed price. The sprinkler also requires an adequate water pressure and flow to be assured. In addition, further testing was recommended to investigate other fire sizes and orientations. (Madrzykowski, Hamins and Mehta 2007)

Further experimental investigation has been conducted in this area, where 40 tests have been performed at NIST. These results are not yet published however contact is being maintained with the primary investigator during the planning of the experiments to be performed in this current investigation. (Madrzykowski 2009)

Stove-top fires in family housing were indicated as a concern within the military services as well as across the US. Subsequently the US Marine Corps has funded several investigations into the use of stove top fire extinguishment systems in the context of use in family housing owned by the Corps (King 1998). That is, in these studies stove-top fires were assumed to start and then must be suppressed by a system.

King (1998) investigated the costs and benefits of continuing to installing stove-top hood fire extinguishing systems in US Marine Corps family housing. King recommended the discontinuation of the US Marine Corps policy of installing stove-top hood fire extinguishing systems in family housing. A summary of the reasons cited for this recommendation included (King 1998):

- The small amount of fire losses in US Marine Corps family housing. Although there were deficiencies identified in the recording process of used for the US Department of Defence fire loss database.
- High installation and maintenance costs of the stove-top hood fire extinguishing systems then used in the construction of the family housing.
- The lack of a national code mandating system requirements.
- There was also a lack of a standard for the testing of systems at the time.
- The results of the research indicated that residential sprinklers were sufficiently successful for the extinguishment and control of stove-top fires and provided a high level of protection. Furthermore installation of a residential sprinkler system

eliminated the need for stove-top hood fire extinguishing systems. Although it was noted that the sample size that the sprinkler data used in this study was based on was very small.

Further recommendations included (King 1998):

- Stove-top fires remain a concern in US Marine Corps family housing, therefore it was suggested that US Marine Corps fire departments expand their public fire education efforts on stove-top fires.
- Improvement of the recording processes used for the US Department of Defence fire loss database to ensure accurate data is available.
- Additional research to determine the performance of residential sprinklers during stove-top fires.

King's study is interesting, since the basis for the conclusions and recommendations was comparison of a residential sprinkler system alone to a residential sprinkler system and a stove-top fire extinguishing system. In a NZ context, a sprinkler system is not mandatory in houses (detached dwellings) and may not be required in buildings consisting of flats or apartments, depending on the details of the building.

NIST, CPSC and United States Fire Authority (USFA) combined resources to focus on reducing the problem of the large number of kitchen fires occurring in the US. A workshop was held with the objectives of identifying what is needed to reduce kitchen fire losses (i.e. prevention versus suppression), prioritise research needs, and identify what is needed to get effective retrofit systems into a significant number of homes. (Madrzykowski, Hamins and Mehta 2007)

The priorities of each area of discussion were voted on by each of the attendees of the workshop. In order of descending priority (from the most to the least numbers of votes), the important topics within each area of discussion were (Madrzykowski, Hamins and Mehta 2007):

- Needs for reducing kitchen fire losses, in terms of prevention:
    1. Detect and control pre-ignition
    2. Education
    3. Combination smoke alarms
    4. Insurance industry involvement
- Needs for reducing kitchen fire losses, in terms of suppression:
    1. Mass acceptance
    2. Control of fire
    3. Life safety
    4. Shut off of electricity or gas to stove-top
    5. Extinguishment
    6. System characteristics
    7. Property damage minimisation
- Research needs:
    1. Improved incident data
    2. Low flow/low volume solutions
    3. Performance of current technologies

4. Alternative technologies (e.g. misting, single nozzle)
5. Characterise hazard scenarios
6. Human behaviour
7. Test development (in addition to UL 300A)

- Needs for gaining mass acceptance of retrofit systems:
    1. Low cost
    2. Education
    3. Low maintenance
    4. Legislative rulings
    5. Insurance/tax credits
    6. Case study
    7. Verify and correlate data

The conclusions of the workshop were that the short-term priority was viewed as education. The long-term priority was viewed as the development of a low cost, low maintenance, low pressure, low volume, retrofit system. (Madrzykowski, Hamins and Mehta 2007)

The recommendations for on-going work in this area were listed as (Madrzykowski, Hamins and Mehta 2007):

- Analyse and improve the methods for collecting and collating incident data,
- Identify other research needs associated with the reduction of fire losses,
- Evaluate current performance standards, and
- Improve public education materials.

Public education has been identified as an important factor in reducing cooking related fires (Hall 1997; King 1998; FEMA 2004; Madrzykowski, Hamins and Mehta 2007). Hall (1997) recommended that public education should focus on topics including:

- Supervision of cooking,
- Using cooking equipment properly,
- Avoiding late night cooking, and
- Avoiding wearing loose-fitting clothing when cooking.

2.2 Determining Effectiveness

2.2.1 Test Methods

There is currently no standard that lists all types of residential stove-top fire suppression systems.

However Underwriters' Laboratory has published a document that outlines tests for residential stove-top top suppression systems, Subject UL 300A, *Outline of Investigation for Extinguishing System Units for Residential cooking Surfaces*. (*UL300A* 2006)

This outline provides test methods and performance requirements for stove-top top suppression systems.

The test apparatus consists of a stove-top and stove-top hood in isolation. Common kitchen materials that may contribute to a kitchen fire, such as cabinetry, counters or foods, are not included in the test.

The test method covers the parameters including: (*UL300A* 2006)

- Gas and electric stove-tops,
- Peanut and vegetable oil as representative foods,
- Various depths of each of the representative oil, and
- A stove-top of test cooking vessels: a cast iron skillet, stainless steel pan, stainless steel skillet, and steel pan.

Performance requirements of the extinguisher unit include (*UL300A* 2006):

- Complete extinguishment of flames in the test vessel,
- No observed re-ignition of the oil for 5 minutes after extinguishment,
- Temperature of the oil is reduced below the auto-ignition temperature after extinguishment,
- There is no splashing of the oil caused by the extinguisher unit (i.e. no drops of oil found around vessel), and
- Safe shutoff of the stove-top.

UL 300A (2006) also requires installation, operation and maintenance instructions for the unit.

2.3 Types of Local Suppression Methods

A selection of the types of fire suppression solutions is presented here to form a basis for the types of equipment setups to be tested. Therefore this information is used as background in the design of the experimental approach and apparatus. The indication or reference to commercial entities, products, materials or systems in this document does not form a recommendation, endorsement or implication of adequacy of the entities, products, materials or systems.

Some examples of prevention solutions are included in this section, as the sensors used may be elements of a suppression solution that includes the shut off of electricity or gas to the stove-top.

2.3.1 Summary of Example Types

2.3.1.1 Suppression Solutions

Stove-top fire suppression units that have been tested to Subject UL 300A (2006) are listed on the Underwriters' Laboratory web site (UL 2009). At the time this study was being conducted, only three units had been tested and listed according to UL 300A.

The listed units utilise either a stored-pressure type wet chemical automatic extinguisher unit or a stored pressure type dry chemical automatic extinguisher unit. (UL 2009)

2.3.1.2 Prevention Solutions

Sensors have been developed to monitor the state of a cooking vessel and be used to shut off the electricity or gas to a stove-top pre-ignition without interfering in normal cooking practices. The types of sensors include contact-sensors that are exposed and in direct contact with the bottom of the cooking vessel, and the use of a thermally isolated radiant element located directly under the cooking vessel. (*Energy International, Inc.* 2000)

2.4 Quantification of Suppression Effectiveness

Fire fighting suppression effectiveness has been investigated for water additives compared to using water alone (Madrzykowski 1998). The parameters considered for comparison were for both laboratory scale and large scale testing for fire suppression characteristics to compliment the standard tests for the potential health effects due to exposure of humans to the agent itself and the environmental effects of the run-off. The total parameters used to characterise the water additives were:

- For the base agent:
    - Environmental impact related properties including biodegradability, mammalian acute oral and acute dermal toxicity, primary eye and skin irritation, fish toxicity, etc.
    - Flammability properties including flash point, fire point, etc.
    - Material properties including vapour pressure, pH , density, miscibility, conductivity, stability,
    - Fire suppression related properties including wetting and foaming ability, expansion and drain time, etc.
    - Impacts other than those directly related to fire suppression including corrosion effects on materials in foam delivery systems.
- For fire and suppression related characteristics:
    - Smoke generation, as related to environmental impact and potential hazards to human health
    - Retention of the suppressant agent on the surfaces intended for protection,
    - Ignition inhibition
- Large scale:
    - Time to suppression
    - Time to re-ignition

3. SUMMARY OF FIRE INCIDENT STATISTICS

3.1 New Zealand

The proportions of residential fires, fatalities and injuries that originate in the kitchen and are associated with the stove-top or oven are summarised in Table 1. These summarised statistics are based on incident data from 2002 to 2008. Although a local fire suppression system that covers the stove-top may also have a level of suppression on other fires in the nearby area, for this investigation only stove-top fires are considered within the scope.

Table 1: Summary of New Zealand residential fire statistics relating to kitchen and stove-top or oven fires from 2002 to 2008 (based on fire incident data from the NZFS Station Management System).

Description	Fire Incidents	Fatalities	Moderate to Life Threatening Injuries
Number of Residential Fire Incidents	21,673	134	806
Number of Residential Fire Incidents that Originated in the Kitchen Area	9,035	36	413
Number of Kitchen Fires that were associated with Stove-top or Oven Fires	6,618	26	365
Number of Stove-top or Oven Kitchen Fires that were Unattended or People Involved were Impaired [a]	5,710	20	309

Notes:
[a] This included where the equipment was accidently switched on or accidently left on, and left unattended, or where the user was impaired due to alcohol, medication, illicit drugs or for other reasons.

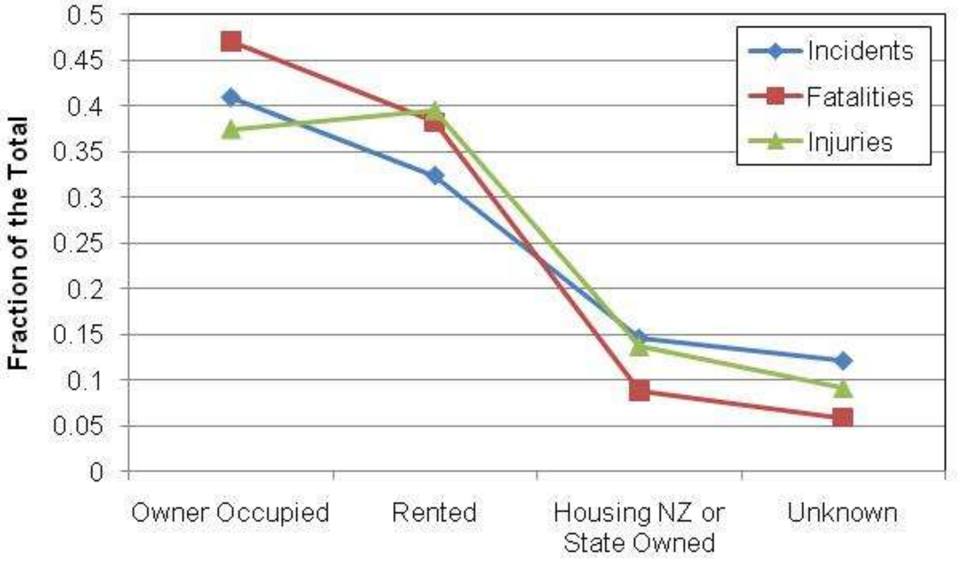

Figure 1: Fractions of the total incidents, fatalities and injuries for all residential kitchen stove-top fires for categories of occupier (based on 2002 to 2008 fire incident data from the NZFS Station Management System).

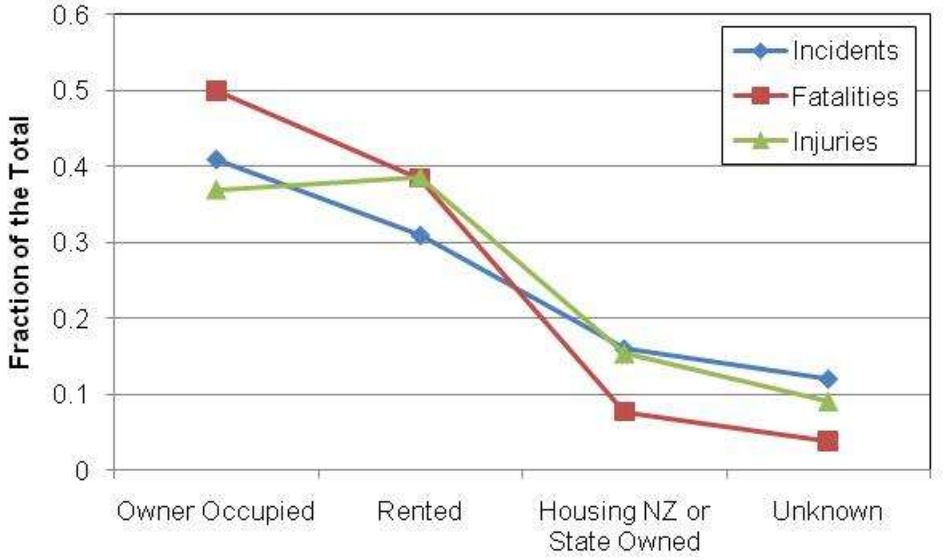

Figure 2: Fractions of the total incidents, fatalities and injuries for residential kitchen stove-top and oven fires for categories of occupier (based on 2002 to 2008 fire incident data from the NZFS Station Management System).

Figure 3: Fractions of the total incidents, fatalities and injuries for unattended or impaired residential kitchen stove-top and oven fires for categories of occupier (based on 2002 to 2008 fire incident data from the NZFS Station Management System).

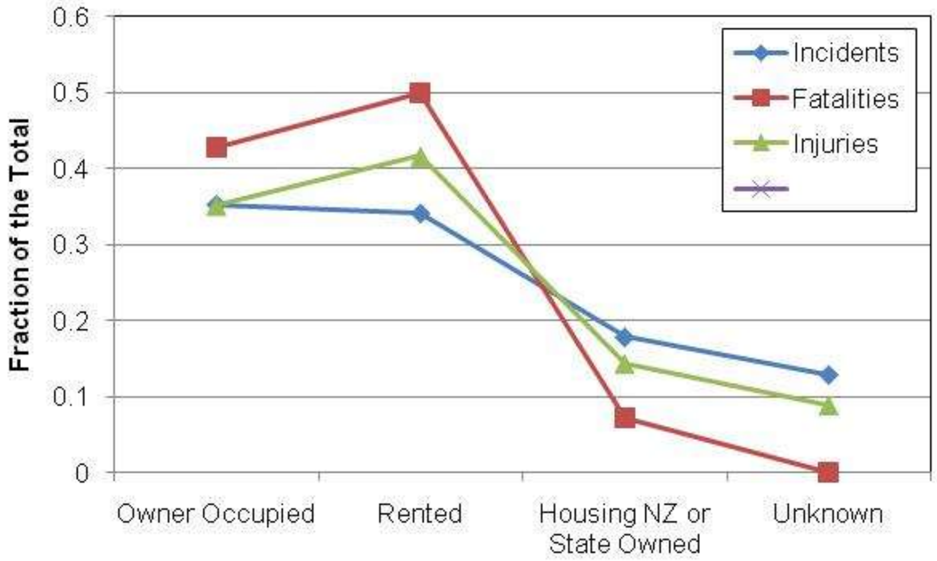

Figure 4: Fractions of the total incidents, fatalities and injuries for food, grease or cooking oil residential kitchen for categories of occupier (based on 2002 to 2008 fire incident data from the NZFS Station Management System).

3.2 United States

Cooking has been identified as the leading cause of home fires in the US (Hall 1997; USCPSC 1998; Hall 2006; Madrzykowski, Hamins and Mehta 2007)

United States residential fire statistics from 1990 to 1994 showed an average number of fires that started with a stove-top or oven were approximately 93,800 per year that were associated with an average of 250 fatalities and 4,700 injuries per year. Ignition of food, grease or cooking oils accounted for approximately 75% of these fires and unattended cooking fires accounted for approximately 65%. (Hall 1997)

The statistics from 2003 showed 118,700 cooking related fires, with 250 fatalities and 3,880 injuries. Of these fires approximately 66% involved the stove-top or stove top, and approximately 41% of the fires occurred while the victims were asleep. (Hall 2006; Nicholson 2006)

The fire statistics from 2002 indicated that the most common cause of kitchen fires is cooking, contributing 89% of the total number of kitchen fires. The next two most common causes are other heating, flames or sparks (~3%) and appliances and air conditioners (~2%). Approximately 28% of kitchen fires occurred under 'normal cooking practices' as no factor was attributed to the cause of ignition, indicating that normal practices are risky. Unattended equipment accounted for 19% of all kitchen fires and the misuse of a material or product accounted for 7%. The most common materials first ignited were oils, fats and grease (~37%) followed by food, starch and flour (~14%) and plastic (~10%). Analysis of the statistics according to the time of day showed a peak of kitchen fires between 6 p.m. and 7 p.m. Compared to other residential structure fires, kitchen fires were associated with less property loss and less fatalities but more injuries. (FEMA 2004)

Approximately 55% of the home cooking fire related injuries reported in 1993 to 2003 occurred when people tried to fight the fire themselves. Approximately 33% of the reported cooking fire related injuries were associated with an incident type indicating a confined cooking fire (where the fire was within a cooking vessel). Fire related injuries for home fires not caused by cooking approximately 11% of injuries caused by people trying to fight the fire themselves. Of the cooking fire fatalities, sleeping (41%) was the leading primary activity of the victim, followed by escaping (14%) and fire fighting attempts (11%). (Aherns et al 2007)

The leading factor in home cooking fires was found to be unattended cooking, with 37% of the cooking fires, 42% of cooking fire deaths and 44% of injuries. Cooking fires that occurred because combustible materials (e.g. loose clothing, food packaging, plastic bags, towels, curtains, etc.) were too close to the heat source was attributed to 13% of home cooking fires, 24% of home cooking fire fatalities and 12 % of injuries. This was the second leading factor in the reported home cooking fires. The third leading factor was equipment accidently turned on or not turned off. (Aherns et al 2007)

The survey results from one- and three-monthly recall periods of cooking equipment performed for the CPSC, indicated that most cooking fires are not reported, and approximately 5% of unreported cooking fires resulted in an injury or illness (headaches, dizziness, etc.). (Aherns et al 2007)

3.3 Types/Categories/Conditions

In summary, the most common type of stove-top fire was associated with the ignition of food, grease or cooking oils and the most costly was unattended cooking fires.

4. FIRE PROTECTION EFFECTIVENESS

For this study the fire protection effectiveness of a system was considered in terms of two aspects: item to item fire spread and flashover. Estimating effectiveness is discussed in detail in the first of these reports (Robbins 2010). The potential spread of fire is of concern in terms of the coverage area of a local fire protection system. Therefore this in incorporated into the estimate of the value for fire protection effectiveness for a specific system.

Considering, in general terms, the desired outcome of an effective local kitchen stove-top fire protection system, effectiveness may be estimated in terms of:

- reduction of amount of energy released in total,
- reduction of amount of energy released per unit of time,
- delay of critical temperatures, heat fluxes or defined conditions being reached, or
- a combination of these.

The amount of any reduction or delay of conditions that a local fire protection system might achieve is in relation to the original challenge scenario without fire protection. The comparison of the measured conditions with and without fire protection provides an indication of the level of protection the fire protection system provides over the completely unprotected scenario.

Potential critical or threshold values are also considered. In terms of item to item fire spread, autoignition temperatures of common materials was considered as well as incident heat flux. Autoignition temperature for wood products (such as firbreboard, hardboard or plywood) and polymer products that may be found in a residential home range from approximately 220 to 350°C (based on values summarised by Babrauskas (2003)). An indication of item to item fire spread was chosen as 200°C and 10 kW/m² for surrounding areas at a distance of 0, 0.4 and 1.1 m vertically from the centre of the heating element (based on considerations of where items might be located around or near to the stove, e.g. range hood, cabinets, etc.) and at distances of 0.2 and 0.4 m from the centre of the heating element (based on an estimate of the closest distance an item can be located without being directly on a stove top). An indication of flashover was chosen as 600°C at the ceiling for the partial corridor orientation.

The application to the cost effectiveness analysis of the experience and results from the experimental part of this research (as summarised in Robbins (2010)) is discussed in Section 7.1.

5. SUMMARY OF TESTING PROCEDURES

Details of the testing methodology and analysis used to estimate the fire protection effectiveness of a system is presented in the first report in this series, BRANZ Study Report 225 (Robbins, 2010). A summary of the recommended test methodology is included in this Section.

5.1 Recommended Test Methodology

There are infinite permutations for residential kitchen configurations. Therefore it is important to identify both the configurations that are expected to be successfully protected by a specific fire protection system as well as those that would be expected to cause problems with the effectiveness of the system. Therefore the key points that must be initially described are for each specific system to be tested are:

- Identify the specific design of the proposed fire protection system, including any parts that are intended to be interchangeable or optional,
- Identify the suppression system in terms of what it is designed to achieve and in what conditions/situations, and
- Identify limiting factors for the system in terms of kitchen configurations. (This list may be subsequently modified or added to based on an analysis of test results.)

The answers to these key points will define the scope of the testing program that is necessary to challenge the system and provide an estimate of the effectiveness of the system for the tested scenarios. Then the methodology described in Sections 3 and 6 of BRANZ Study Report 225 (Robbins, 2010) would provide a robust estimate of the effectiveness of a specific local fire protection system for residential stove-top fires and the limitations of scenarios and conditions of the system.

It is recommended that initially at least 3 repeated tests of at least 3 of the most likely (and most challenging for the specific potential local fire protection system) scenarios are tested to establish a measure of the repeatability and the associated confidence in the testing regime. Based on this information, the final number of tests and scenario descriptions that will be used to assess the appropriateness of the system would then be confirmed.

6. COST EFFECTIVENESS ANALYSIS

The cost effectiveness analysis methodology was based on the previous research developed for home sprinkler systems (Robbins, Wade et al. 2008). This was chosen to provide a comparison for the results of a local fire suppression system to that of a system covering a larger area of a residential house.

6.1 Cost Effectiveness Factors

A list of the general factors considered in the cost effectiveness analysis of local fire suppression systems for residential kitchen stove-top fires is presented in Table 2. For this investigation the monetary aspects were focused on. However it is recommended that a broader considerations be incorporated into future applications.

Table 2: Factors considered in the cost effectiveness analysis for local residential kitchen stove-top fire suppression systems for accidental fires.

Cost	**Considered in this Study**
Materials & Installation	✓
Annual inspection & maintenance	✓
Environmental impact & sustainability aspects of manufacture & installation of the local fire suppression system	✗
Environmental impact of activation of the local fire suppression system	✗
Accidental damage from non-emergency activation	✗
Accidental damage from non-emergency activation	✗
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.)	✗

6.2 Methodology

The local fire protection system cost effectiveness input parameters are listed with a brief description in Table 3 and Table 4. A list of the local fire protection system cost effectiveness output variables is presented in Table 5 and the calculation methods employed are presented in Table 6 and Table 7. The background and subsequent values used for these input parameters are discussed in detail in Section 7.

Table 3: List of local fire protection system cost effectiveness assessment input parameters.

Name	Symbol	Brief Description
Overall local kitchen fire protection system effectiveness	$\eta_{protected}$	A measure, based on statistics, for the local fire protection system to activate and control a fire according to the design of the system, assuming the fire is large enough to activate the local fire protection system.
Limit of flame damage for effective local kitchen fire protection system	$L_{protected}$	An assumed percentage of the total structure to which the effective kitchen local fire protection system would control the fire from spreading beyond.
Deaths per 1000 fires, no local automatic protection, with alarms	$D_{0,smoke}$	Current average number of civilian fatalities per 1000 residential kitchen/stove/oven fires where no local fire protection system is present but smoke alarms are present (i.e. approximately describes the current NZ situation and associated fire incident statistics).
Percentage reduction in deaths per 1000 fires	$p_{protected,fatalities}$	Estimate of the percentage of reduction in civilian fatalities for successful effective local kitchen fire protection, such that the number of civilian deaths can be estimated by: $D_{protected,smoke} = (1 - p_{protected,fatalities}) D_{0,smoke}$
Injuries per 1000 fires, no local automatic protection, with alarms	$I_{0,smoke}$	Current average number of civilian injuries per 1000 residential fires where no local kitchen fire protection system is present but smoke alarms are present (i.e. approximately describes the current NZ situation and associated fire incident statistics).
Percentage reduction in injuries per 1000 fires	$p_{protected,injuries}$	Estimate of the percentage of reduction in civilian fatalities for successful effective local kitchen fire protection, such that the number of civilian injuries can be estimated by: $I_{protected,smoke} = (1 - p_{protected,injuries}) I_{0,smoke}$
Initial number of residential kitchen/stove/oven structure fires per year	F_0	The current number of household fires per year, where households represent buildings where local kitchen fire protection 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 the local kitchen fire protection 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.

Table 4: Continued list of local fire protection system cost effectiveness assessment input parameters.

Name	Symbol	Brief Description
Initial number of households with the local fire protection system installed	$H_{0,protected}$	The current number of households with the local kitchen fire protection system installed. The number of local fire protected houses each year is both retrofitted and new local fire protection systems, $H_{t,protected} = r_{retrofit}(H_{t-1,all} - H_{t-1,protected}) + p_{new\_protected}(H_{t,all} - H_{t-1,all})$
Proportion of new households to have the local fire protection system installed	$p_{new,protected}$	The proportion of new households built with the local kitchen fire protection system installed.
Rate of retrofit of local fire protection in households	$r_{retrofit}$	An estimate of the average rate of retrofit of systems in households with no local fire protection system currently present.
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.
Local kitchen fire protection system life	Y_{sprink}	Number of years for the design life of the local kitchen fire protection system.
Materials & installation (new household)	$C_{0,newsprink}$	Average current cost of materials and installation of the local kitchen fire protection system during the construction of a new house.
Materials & installation (retrofit)	$C_{0,retrofitsprink}$	Average current cost of materials and installation of the local kitchen fire protection system for the retrofit of an existing house.
Design	$C_{0,deisgn}$	Average current cost for designing the local kitchen fire protection for a typical New Zealand household.
Annual Maintenance	$C_{i,maintenance}$	Average current cost of annual maintenance.
Initial regulatory costs	$C_{0,regulatory}$	Estimate of the initial regulatory costs required.
Yearly regulatory costs	$C_{i,annualregulatory}$	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 unprotected fire	$C_{0,propertyunprotected}$	Estimate of the current average cost of property loss per unprotected residential fire.
Reduction in property loss per protected fire	$p_{propertyprotection}$	Estimate of the average reduction in property loss where an effective local kitchen fire protection system is present.

Table 5: List of local fire protection system 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 local kitchen fire protection 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 local kitchen fire protection in houses.
Savings in injury costs per household per year	$S_{injury\$,avg,household}$	Estimation of the monetary savings per injury adverted by a local kitchen fire protection 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 local kitchen fire protection system per year per New Zealand household.
Total savings per household per year	$S_{total\$,avg,household}$	Estimation of the total monetary savings attributed to local kitchen fire protection 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 local kitchen fire protection 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 local kitchen fire protection 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 local kitchen fire protection systems per year per New Zealand household.
Cost per life saved	$C_{\$/life}$	Estimation of the total monetary costs per life saved attributable to local kitchen fire protection systems.

Table 6: List of local fire protection system cost effectiveness assessment calculation methods - savings.

Name	Calculation Method
Lives saved per year	$S_{life,avg} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(S_{life,t} \right)$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{H_{t,protection}}{H_{t,all}} p_{protected,fatalities} D_{0,smoke} \eta_{protection} \right)$
Lives saved per household per year	$S_{life,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{S_{life,t}}{H_{t,all}} \right)$
Savings in injury costs per household per year	$S_{injury\$,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{r_{discount} C_{0,injury} S_{injury,t}}{H_{t,all}} \right)$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{r_{discount} C_{t,injury} H_{t,protection}}{\left(H_{t,all} \right)^2} p_{protected,injuries} I_{0,smoke} \eta_{protection} \right)$
Savings in property loss per household per year	$S_{property\$,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{r_{discount} C_{property0} S_{t,property}}{H_{all,t}} \right)$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{r_{discount} C_{0,property} F_t p_{propertyprotected}}{\left(H_{t,all} \right)^2} \right)$
Total savings per household per year	$S_{total\$,avg,household} = S_{injury\$,avg,household} + S_{property\$,avg,household}$

Table 7: List of local fire protection system cost effectiveness assessment calculation methods - costs.

Name	Calculation Method
Design, installation and maintenance costs per household per year	$C_{design\&install\&maint,\$,avg,household} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{r_{discount} \left(\begin{array}{l} H_{new\_protected,t} \left(C_{t,design,new} + C_{t,installation,new} \right) \\ + H_{retrofit,t} \left(C_{t,design,retrofit} + C_{t,installation,retrofit} \right) + H_{protected,t-1} C_{t,maintenance} \end{array} \right)}{H_{all,t}} \right)$
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	$C_{\$/life} = \frac{C_{total,\$,avg,household} - S_{total,\$,avg,household}}{S_{life,avg,household}}$

6.3 Previously Identified Sensitive Variables

Previous cost benefit analyses that focused on sprinkler systems (Williams et al. 2004; Robbins, Wade et al. 2008) were found to be highly sensitive to future changes, which cannot be predicted with any level of confidence. Specifically the future related variables reported by Williams et al. (2004) included:

- 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 system costs,
- impact on the costs of providing public fire services, and
- interest rates and inflation.

The common input parameters with relatively high importance values for the monetary cost per life saved for the categories of residential building stock considered were found to be (Robbins, Wade et al. 2008):

- Cost of sprinkler system design and installation,
- Number of deaths per 1000 fires,
- Monetary reduction in the cost of property loss for a sprinklered house fire,
- Smoke alarm effectiveness,
- Number of house structure fires per year,
- Rate of retrofit of sprinkler system,
- Sprinkler effectiveness,
- Monetary reduction in insurance premiums,
- Discount rate,
- Inflation rate, and
- Proportion of fire incidents covered by the specific system of interest.

7. COST EFFECTIVENESS ANALYSIS VARIABLES

The background and subsequent choice of values used for the input variables, as described in Table 3 and Table 4, are discussed here.

For this investigation, an example potential local kitchen fire protection system was used to demonstrate the proposed cost effectiveness analysis methodology. The example system was a single residential sprinkler head positioned centrally in front of the stove-top, 1500 mm from the wall behind the stove-top in a ceiling located 1150 mm above the surface of the stove-top. This example system was also used in stove-top fire tests to estimate potential local kitchen fire protection system effectiveness using laboratory experiments (Robbins 2010). The specifics of this system are not detailed, as it is not the purpose of this investigation to recommend particular products or systems. The use of this example system is demonstration of concept purposes only.

7.1 Overall System Effectiveness

Overall system effectiveness consists of two components:

- Operational reliability of the components and system, and
- System fire protection effectiveness for successful system activation.

Reliability of the system is a measure of the certainty of operation when exposed to conditions that are expected to be sufficient to activate the system.

System effectiveness is a measure of the success expected when the system is activated.

Therefore, assuming that a fire is large enough to activate the system, the overall system effectiveness is calculated by:

Overall System Effectiveness = System Reliability x System Effectiveness

For established systems, the value for overall system effectiveness would be a combination of laboratory results, in terms of operational reliability within defined limits, and fire incident statistics, in terms of the fire control or suppression effectiveness in real fire scenarios. However for new systems, the only available data is based on laboratory test results for both operational reliability and fire protection effectiveness, until there is sufficient statistical data available from fire events.

7.1.1 Effectiveness of a Local Fire Protection System Based on Experiment Results

Establishing the reliability of each of the components of the system, and subsequently the system reliability, depends on defining the operational and environmental limits for the life of the system and testing the components and system for successful operation at the extremes (which may include cycling conditions) and repeating the testing until a statistically significant number of results have been collated for analysis.

7.1.2 Example of a System consisting of a Single Sprinkler Head

In general, when sprinkler suppression system effectiveness is typically considered, the system consists of multiple sprinkler heads and covers entire rooms or compartments and only specific allowable areas are not protected by the system. However this is not the case when considering the potential use of a single sprinkler head in terms of local fire protection within a residential kitchen area.

The example system utilises components that may form part of a residential or home sprinkler system. The operational reliabilities of these components is well established and therefore are used to estimate the value for the example local protection system using a single sprinkler head to provide coverage of the stove-top area and immediate surrounds. A summary of examples of operational reliability of residential sprinkler systems (with multiple heads) is included in Table 8. For the example of a single sprinkler head covering the stove-top, an operational reliability value of 86% (associated with a minimum of 80% and a maximum of 96%.

In order to estimate the fire protection effectiveness for the example single sprinkler head system, laboratory-based experimental results are used, since no relevant fire incident data is available. The particular attention needed to fully-define the use and limitations of each potential local fire protection system and therefore select appropriate fire scenarios to challenge the system for use in estimating the effectiveness of the system is described with the summary of the development of the test methodology and analysis, which is reported elsewhere (Robbins 2010).

In summary, the effectiveness is estimated based on the comparison of test results of the performance of the fire protection system compared to results for the free-burning challenge scenarios (i.e. the fire scenarios chosen to challenge the specific fire protection system) (Robbins 2010).

A local fire protection effectiveness of 1 was defined as maintaining the conditions that existed 5 s before ignition was observed. This implies that the situation of the fire being prevented is the most desired outcome (i.e. effectiveness = 1). In addition, if the fire protection has no effect on the scenario used to challenge it, then the effectiveness would have the value of zero. Furthermore, if the fire protection caused the conditions to worsen (implying that the fire protection is not appropriate for that particular scenario) then the effectiveness would have a negative value. Zero or negative effectiveness values indicate the use of a potential fire protection system in scenarios or conditions beyond its limitations. (Robbins 2010)

For the potential local fire protection system consisting of a single residential sprinkler head, the value for fire protection effectiveness was found to be approximately 70% (with a spread from 40% to 90%). However this value is only based on one type challenge scenario, and therefore this value is only applicable to that particular scenario. To provide a robust estimate of any specific design for a local fire protection system for residential stove-top fires, a more diverse program of testing would be used based on the methodology described in this demonstration of concept discussed in the full report (Robbins 2010).

In comparison, the fire protection effectiveness for the local system covering stove-top fires is less than the fire protection effectiveness for a system that is designed to fully cover a room or building (e.g. as compared to a residential sprinkler system of approximately 93 – 99%, as in Table 8), as expected.

Table 8: Examples of sprinkler system (e.g. residential or home 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 [g] (min =90% & max = 99%)					(Wade & Duncan, 2000)
BRANZ 2009 CBA estimate			95 (min = 90 & max = 99)			(Robbins, Wade et al. 2008)

Notes for Table 8:
[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.

7.2 Smoke Alarm Effectiveness

Smoke alarms are required by Warning Systems Compliance Document F7/AS1 (Amd 4 April, DBH, 2003). For this study it was assumed that the overall effectiveness of smoke alarms is adequately represented in the fire incident statistics for New Zealand, since the data set from 2002 to 2008 was used. Therefore smoke alarm effectiveness was not separately included in this study.

7.3 Limit of Flame Damage for Effective Local Fire Protection Operation

A maximum limit for flame damage of a residential structure was estimated, assuming effective operation of the local kitchen fire protection system. There is currently no published literature that specifically relates to such a limit or fire incident data for any new potential local fire protection system. Therefore for the single sprinkler head a conservative estimate was made of a mean damage limit of 2% of the floor area of a home, with a minimum of 1% and a maximum of 4%, which is a conservative estimate.

These estimates for each specific design for a local kitchen fire protection system would be different, depending on the specific action of the system. This may include the amount of 'cleanup' (e.g. of chemicals, etc. that need to be fully removed from the area) required after activation of the system as well as direct fire damage.

7.4 Fire Incidents Originating in Kitchen Areas

The type of fire incident scenario that was the focus of this study was unattended cooking fires that originated in the kitchen.

The percentage distributions of the room of fire origin for civilian fatalities, civilian injuries and residential fire incidents, based on incident statistics, are presented in Table 9 for a stove-top of countries. A comparison of the percentage distributions for civilian fatalities for various countries is shown in Figure 5. 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 6. A comparison of the percentage distributions for fire incidents for various countries is shown in Figure 7. The kitchen is consistently the most common room of fire origin for fire incidents and civilian (moderate and severe) injuries. The kitchen is consistently the third most common room of fire origin for civilian fire fatalities.

This study focuses on stove-top fires that occur in the kitchen. The values used for the current study were primarily based on the New Zealand statistics, from 2002 to 2008. The fraction of fire incidents and casualties for kitchen fires and unattended cooking fires for various types of residential occupiers are shown in Figure 8 and Figure 9, respectively.

Figure 5: Percentages of civilian fatalities for various countries over various periods. (Details are presented in Table 9.)

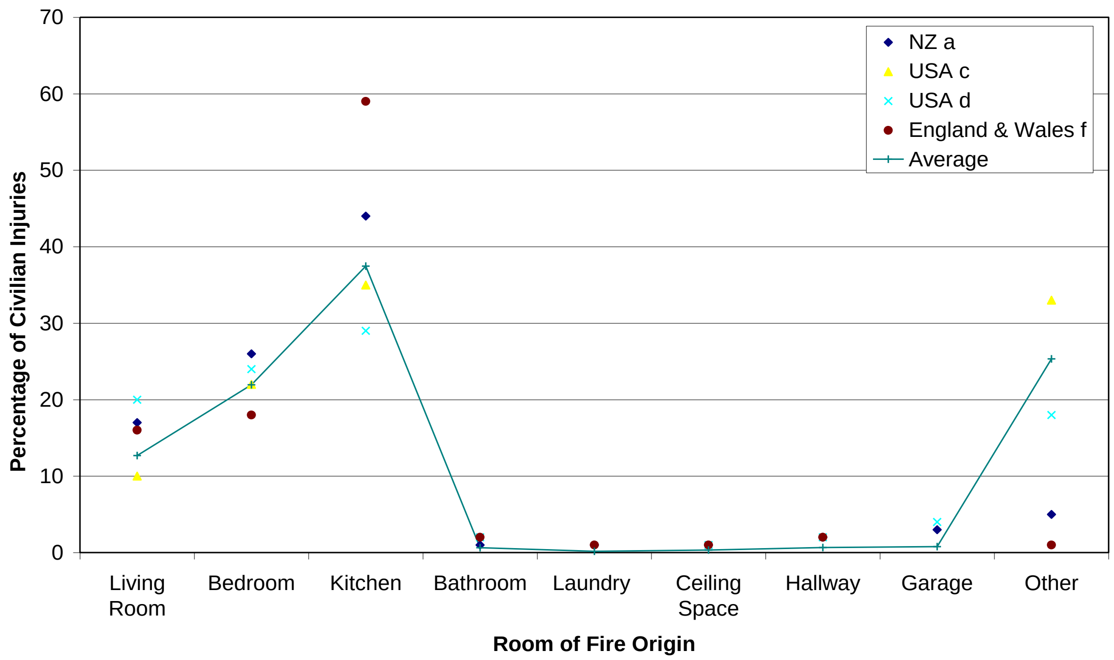

Figure 6: Percentages of civilian injuries for various countries over various periods. (Details are presented in Table 9.)

Table 9: Distribution of fire incidents, fatalities and injuries by room of fire origin for residential structure fire incidents (Extracted from Robbins, Wade et al. 2008).

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	12	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 of Robbins, Wade et al. (2008).
[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 (2010), Table A1.2(b). The statistics are from 1986 – 1990.
[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.

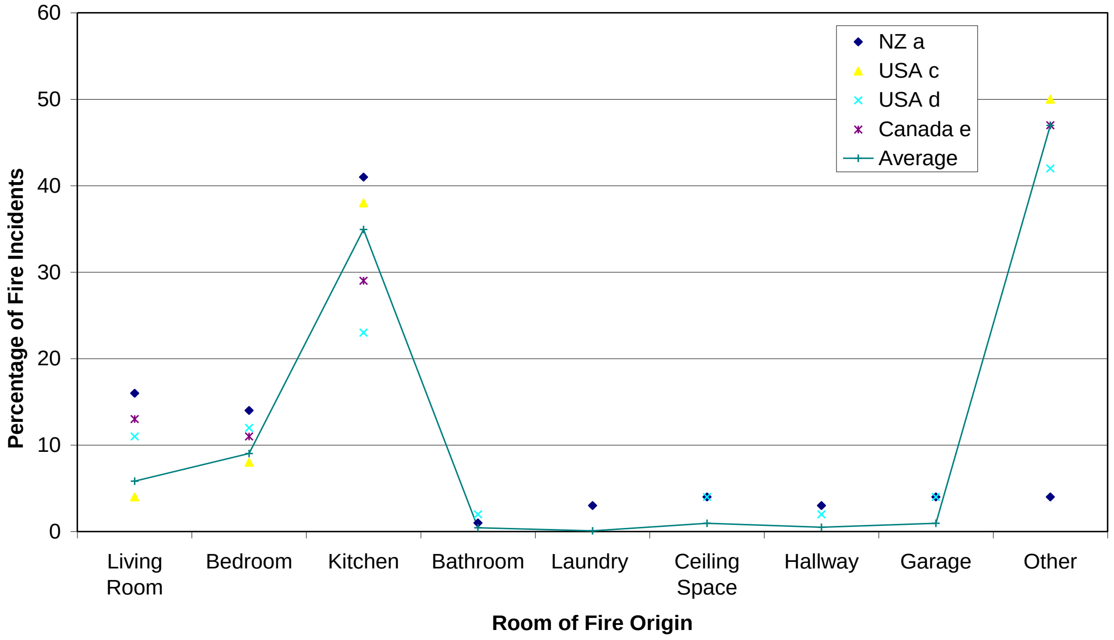

Figure 7: Percentages of residential structure fire incidents for various countries over various periods. (Details are presented in Table 9.)

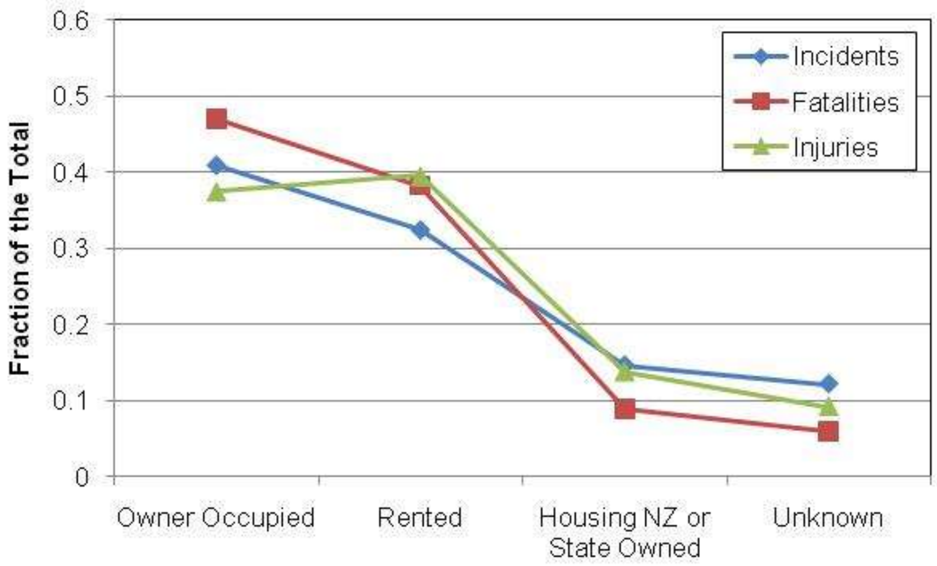

Figure 8: Fraction of the total fire incidents, civilian fatalities and moderate to severe injuries that occurred in fire incidents originating in the kitchen area for variation types of residential occupier. Adapted from New Zealand Station Management System incident data, 2002 – 2008, (Challands 2009).

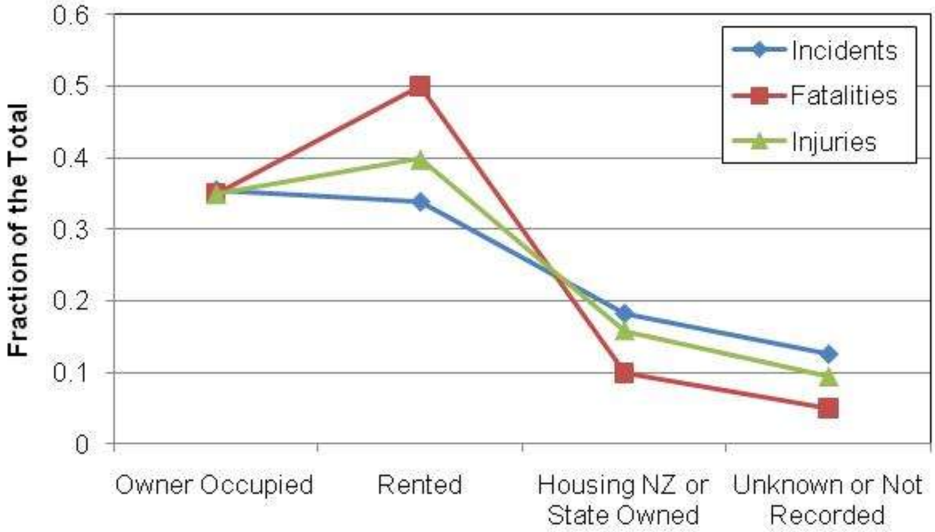

Figure 9: Fraction of the total fire incidents, civilian fatalities and moderate to severe injuries that occurred in unattended cooking fire incidents originating in the kitchen area for variation types of residential occupier. Adapted from New Zealand Station Management System incident data, 2002 – 2008, (Challands 2009).

7.4.1 Numbers of Fire Incidents

For the current study, estimates of yearly unattended kitchen cooking fire incidents were based on average New Zealand data for 2002 – 2008, as summarised in Figure 10 and Table 10.

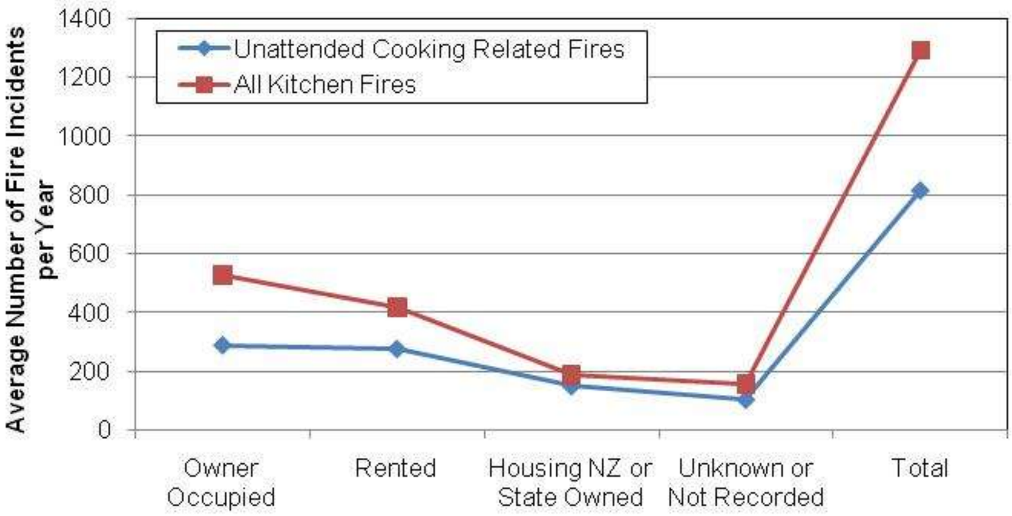

Figure 10: Average numbers of yearly fire incidents originating in the kitchen area and unattended cooking fires, based on New Zealand fire incident data from 2002 to 2008.

Table 10: Average numbers of yearly fire incidents originating in the kitchen for unattended cooking fires, based on New Zealand fire incident data from 2002 to 2008.

Type of Residential Occupier	Average Yearly Number of Unattended Cooking Related Fires (minimum, maximum)
Owner Occupied	289 (250, 300)
Rented	276 (240, 300)
Housing NZ or State Owned	149 (120, 170)
Unknown or Not Recorded	103 (80, 130)
Total	816 (730, 900)

7.4.2 Casualties per Fire Incident

Similarly, estimates of the number of casualties per 1000 fire incidents used for this study were based on average New Zealand data for 2002 – 2008, as summarised in Table 11.

Table 11: Average numbers of civilian casualties per 1000 fire incidents originating in the kitchen for unattended cooking fires, based on New Zealand fire incident data from 2002 to 2008.

Type of Residential Occupier	Average No. Fatalities per 1000 Fire Incidents (minimum, maximum)	Average No. Moderate to Severe Injuries per 1000 Fire Incidents (minimum, maximum)
Owner Occupied	3.5 (2.8, 3.9)	53 (45, 59)
Rented	5.2 (4.0, 6.1)	64 (58, 72)
Housing NZ or State Owned	1.9 (1.6, 2.6)	47 (41, 52)
Unknown or Not Recorded	1.4 (0.8, 2.0)	40 (27, 55)
Total	3.5 (2.7, 4.5)	54 (48, 61)

7.5 Expected Number of Lives Saved

Since there is no fire incident data related to the specific local kitchen fire protection system consisting of a single sprinkler head, the potential reduction in civilian fatalities for other types of fire protection are considered.

For example considering the impact of smoke alarms in New Zealand, 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 constituted a reduction in fatalities of approximately 60%.

Considering other examples, 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.

A summary of the published values for estimates for the percentage of adverted fatalities for smoke alarms and sprinkler systems are presented in Table 12.

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, 2000)

Considering the focus of unattended cooking fires of this study, it is expected that a smaller proportion of victims will be intimate with the fire than for the total stove-top of residential fires that are included in the summary presented in Table 12. The majority of casualties for unattended cooking fires is assumed to be remote from the ignition of the fire. Therefore an estimate of a 75% reduction in fatalities where a local stove-top fire protection system is present compare to smoke alarms only being present is used for this study.

7.6 Expected Number of Injuries

Similarly to the estimates for the reduction in civilian fire fatalities, there is no fire incident data related to the specific local kitchen fire protection system consisting of a single sprinkler head for the reduction in moderate to severe civilian injuries, therefore the potential reduction in civilian injuries for other types of fire protection are considered.

A summary of published values for reductions in civilian injuries where combinations of smoke alarms and sprinklers are present is presented in Table 13.

Considering the focus of unattended cooking fires of this study, it is expected that a smaller proportion of victims will be intimate with the fire than for the total stove-top of residential fires that are included in the summary presented in Table 13. The majority of moderate to severe injuries for unattended cooking fires is assumed to be remote from the ignition of the fire, therefore an estimate of a 30% reduction in moderate to severe civilian injuries where a local stove-top fire protection system is present compare to smoke alarms only being present is used for this study.

Table 12: 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				Reference
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 fatalities/ 1000 fires)	(Ruegg & Fuller, 1984) [b]
-	-	50%	-	(Rahmanian, 1995)
-	-	80 – 90%	-	(Ford, 1997)
-	-	55 – 85%	-	(Fraser-Mitchell, 2004; Williams et al., 2004) [c]
-	-	74%	-	(Rohr, 2000) [d]
-	53%	70 – 80%	83%	(DCLG, 2007) [e]
-	-	77%	-	(Hall, 2007) [f]
-	-	57%	-	(Hall, 2007) [g]
9.8	-	40% (5.9 fatalities/ 1000 fires)	-	(Rohr, 2000) [h]
9.7	-	52% (4.7 fatalities/ 1000 fires)	-	(Rohr, 2000) [i]
6.0	53% (2.8 fatalities/ 1000 fires)	80% (1.2 fatalities/ 1000 fires)	83% (1.0 fatalities/ 1000 fires)	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 census 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.

Table 13: 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/ 1000 fires)	(Ruegg & Fuller, 1984) [b]
-		30 – 15%	-	(Beever & Britton, 1999) [c]
40	70% (12 injuries/ 1000 fires)	-	-	(Wade & Duncan, 2000) [d, e]
-	-	30±15%	-	(Fraser-Mitchell, 2004) [f]
-	70%	45 – 65%	45 – 85%	(DCLG, 2007) [g]
40	70% (12 injuries/ 1000 fires)	62% (15 injuries/ 1000 fires)	75% (10 injuries/ 1000 fires)	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 census values.

7.7 Numbers of New Zealand Housing Stock

The total number of dwellings was 1.4 million in 2006. The initial estimate of the number of residential used in this framework was 1.5 million. The initial number of houses used in the study for each category of property occupier is presented in Table 14.

In a previous study involving home sprinkler systems (Robbins, Wade et al. 2008), an average increase in the total NZ building stock of 0.5% per annum was assumed. This was also assumed for the current framework, as shown in Table 15. The average increase in building stock for each of the residential occupier categories considered in this study is presented in Table 15. These values are based on analysis of the New Zealand census data for the years 1991, 1996, 2001 and 2006. These numbers for the categories of building stock by occupier type include some multistorey buildings.

It should be noted that for each of the combined category of households (i.e., total residential 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 category 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 15).

Table 14: 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 census).

Type of Residential Occupancy	Numbers of Housing Stock	Fraction of the Housing Stock
Owner Occupied	782,000	0.52
Rented	244,000	0.16
Housing NZ or State Owned	80,800	0.05
All Residential Properties *	1,500,000	1

Note: * The balance of properties were listed as unknown.

Table 15: 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%
Rented property	4.4%	2.3%	6.9%
Housing NZ or State owned	-4.7%	-7.7%	-2.4%
All Residential Properties	0.5%	0.1%	1.0%

7.8 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 stove-top 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%.

7.9 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%.

7.10 Discounting of Lives

Lives 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.

7.11 Local Kitchen Fire Protection System Life

The local kitchen fire protection system life was conservatively assumed to be shorter than that of domestic plumbing. The life of a local fire protection system was assumed to be 10 years. Although in practice, for the example using a single sprinkler head, the system life may be expected to be similar to that expected for domestic plumbing (~50 years).

7.12 Analysis Period

The analysis period considered was the equivalent of the assumed value for the life of the local kitchen fire protection system.

7.13 Local Kitchen Fire Protection System Installation Costs

Basing the estimating of the installation costs of a local kitchen fire protection system on the framework developed for 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 complete aspects of system costs are:

- 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) However this is not taken into account within this framework, but could be incorporated at a later time.

The costs assumed for design and installation costs for this study are presented in Table 16. A significant proportion of the cost for the retrofit situation is the cost of removing and replacing the wall and ceiling plasterboard for access to the domestic plumbing and locating the pipe and single sprinkler head, which all depends on the specific kitchen design.

Table 16: Assumed design and installation costs for a single head sprinkler used as the example local kitchen fire protection system for this study.

	Average Cost	Minimum Cost	Maximum Cost
Retrofit	240	90	540
New Build	150	70	180

7.14 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 National Health System. 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 value of a statistical life (VOSL) related to New Zealand fire fatalities has been suggested to be approximately 56 - 66% of the New Zealand road VOSL (BERL 2007). The New Zealand road VOSL was estimated at approximately $4.1 million in 2009 prices (Ministry of Transport 2009).

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 study performed by Rahmanian (1995).

A value of $30,000 for the average cost of a fire injury was used in 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)

7.15 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. Irwin (1997) suggested 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 from the Insurance Council of New Zealand (Davis, 2000) 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)

Table 17: 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 2010 Monetary Equivalent ***	**Quoted Value**	**NZ 2010 Monetary Equivalent ***	**Quoted Value**	**NZ 2008 Monetary Equivalent ***	
$102k (2005)	$165k	$255k (2005)	$413k	$2,550k (2005)	$4,130k	(BERL 2005)
				US$2,700k (1998)	$10,000k	From a FAA funded report (Hoffer et al. 1998; Porter, 2002)
				US$400k – 4,000k (1981)	$7,800k – $78,000k	(Fischhoff et al., 1981; Porter, 2002)
		£58.3k ±6.7% (2002)	$3,000k ±6.7%	£1,243k ±5% (2002)	$6,400k ±5%	(Fraser-Mitchell, 2004)
$135k (2008)	$165k	$365k (2008)	$413k	Framework results were compared to number of lives saved		(Robbins, Wade et al. 2008)
	$165k		$413k	Framework results are compared to number of lives saved		Estimates assumed for current framework.

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 discussed in Sections 7.8 and 7.9, and Appendix A of Robbins, Wade et al. (2008).

Table 18: Summary of direct costs associated with fire-related injuries.

Direct cost per injury		Source
Quoted Value	**NZ 2008 Monetary Equivalent ***	
NZ$13,000 (2005)	$21,000	Based on hospital & ACC costs (BERL 2005)
A$21,100 (1999)	$68,000	Including pain and suffering (Beever and Britton 1999)
US$20,000 (1984)	$290,000	(Ruegg and Fuller, 1984; Rahmanian, 1995)
NZ$30,000 (2000)	$79,000	(Duncan et al 2000)
$17.4k – 64.8k (avg. $30k) (2008)	$21k – 79k (avg. $36k)	(Robbins, Wade et al 2008)
	$21k – 79k (avg. $36k)	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 discussed in Sections 7.8 and 7.9, and Appendix A of Robbins, Wade et al. (2008).

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 20.

Table 19: 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 2010 Monetary Equivalent**	
US$1,700				(Ford, 1997).[a]
US$2,200	95%	US$45,000 (2001)	$129k	(Jelenewicz, 2005) [b]
US$3,700	88%	US$32,000 (2003)	$75k	(Jelenewicz, 2005) [c]
US$5,400	50%	US$10,900	$17k	(Aherns 2007) [e]
		NZ$18,000-$20,000	$29k – 32k	(BERL 2005) [f]
	50±15%			(Fraser-Mitchell, 2004) [g]
US$5,400	42%	US$9,400	$22k	(Rohr, 2000) [h]
US$10,300	24%	US$13,500	$32k	(Rohr, 2000) [i]
	50 – 66%			(Rohr & Hall, 2005) [j]
US$7,800	19%	US$9,600	$23k	(Rohr, 2000) [k]
US$4,400	49%	US$7,800	$18k	(Rohr, 2000) [m]
US$11,000	17%	US$13,200	$31k	(Rohr, 2000) [n]
US$6,000	45%	US$10,800	$25k	(Rohr, 2000) [o]
US$14,700	42%	US$25,100	$40k	(Hall, 2007) [p]
US25,900	40%	US$15,600	$25k	(Hall, 2007) [q]

NZ$3,600	79%	NZ$17,200	$45k	Initial BRANZ 2000 study estimate (Duncan et al., 2000)
	20% – 95% (avg. 50%)		$18k – 120k (avg. $36k)	(Robbins, Wade et al., 2008)
	20% – 95% (avg. 50%)		$18k – 120k (avg. $36k)	Estimates used for this framework.

Notes for Table 19:

[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.

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

The increase in fire protection from smoke alarms only to a local kitchen fire protection system with smoke alarms was considered.

Four residential property occupier categories were considered:

1. Total population,
2. Owner occupied properties,
3. Rented properties, and
4. Housing New Zealand and state or council owned properties.

The results for the example system, consisting of a single residential sprinkler head, are presented below.

8.2 Calculation Description

Triangular distributions were assumed for the input parameter values, based on average, minimum and maximum values. The software package, @Risk, was used to calculate the distributed outputs. This was the same approach as utilised in previous cost effectiveness analyses (Robbins, Wade et al., 2008; Robbins, Page and Jaques, 2010). A random seed was used to initialise each run and 10,000 iterations were performed, using Latin-Hypercube sampling.

8.3 Summary of the Input Parameter Values

A summary of the input parameter values that are common for the scenarios discussed in Section 8.1 for the cost effectiveness analysis is presented in Table 20. A summary for the differences between property occupier types is presented in Table 21. Discussion of the background and selected values for each of the input parameters was presented in Section 7. An example of the user MS Excel user interface is included in Appendix A.

Table 20: Summary of the input parameter values for the cost effectiveness analysis for all scenarios considered.

Input Description	Minimum Value	Average	Maximum Value
System reliability	0.80	0.86	0.96
System effectiveness	0.40	0.70	0.90
Limit of flame damage for effective sprinkler system	1%	2%	4%
Reduction in deaths with local fire protection system present		75%	
Reduction in injuries with local fire protection system present		30%	
Initial number of households with local kitchen fire protection installed		0	
Proportion of new households with local kitchen fire protection installed		100%	
Rate of retrofit of local kitchen fire protection installed in households	7%	10%	15%
Cost of system materials & installation for retrofit of an existing household	$90	$240	$540
Cost of system materials & installation for a new household	$70	$150	$180
Annual maintenance of the local kitchen fire protection system		$0	
Initial regulatory costs		$0	
Yearly regulatory costs		$0	
Fatality cost per fire	$2,300,000	$2,700,000	$2,700,000
Injury (moderate to severe) cost per fire - direct	$21,000	$36,000	$79,000
Injury (moderate to severe) cost per fire - indirect	$165,000	$200,000	$413,000
Property loss per unprotected fire	$18,000	$36,000	$120,000
Reduction in property loss per fire due to a local kitchen fire protection system	20%	50%	95%

Table 21: Summary of the input parameter values for the cost effectiveness analysis for categories of residential occupier considered.

Input Description	Minimum Value	Average	Maximum Value
Civilian fatalities per 1000 kitchen fires, smoke alarms only	-	-	-
- All Residential	2.7	3.5	4.5
- Owner occupier	2.8	3.5	3.9
- Rented	4.0	5.2	6.1
- Housing NZ or State owned	1.6	1.9	2.6
Civilian injuries per 1000 kitchen fires, smoke alarms only	-	-	-
- All Residential	48	54	61
- Owner occupier	45	53	59
- Rented	58	64	72
- Housing NZ or State owned	51	47	52
Number of structure fires per year originating in the kitchen as unattended cooking fires	-	-	-
- All Residential	730	816	900
- Owner occupier	250	289	300
- Rented	240	276	300
- Housing NZ or State owned	120	149	170
Current number of households	-	-	-
- All Residential		1,500,000	
- Owner occupier		782,000	
- Rented		244,000	
- Housing NZ or State owned		80,80	
Increase/Decrease in numbers of households per year	-	-	-
- All Residential	0.1%	0.5%	1.0%
- Owner occupier	-0.9%	-0.3%	0.1%
- Rented	2.3%	4.4%	6.9%
- Housing NZ or State owned	-7.7%	-4.7%	-2.4%

8.4 Summary of Results

A summary of the model results are presented in this section. Detailed model results are presented in Appendix B.

The estimated number of lives saved per year attributable to the example local kitchen fire protection system for each of the types of residential occupier is shown in Figure 11. The estimated net present value (NPV) cost per household per year attributable to the example local kitchen fire protection system for each of the types of residential occupier is shown in Figure 12. The estimated NPV cost per life saved per year attributable to the example local kitchen fire protection system for each of the type of residential occupier is shown in Figure 13. The estimated NPV cost per unattended stove-top fire attributable to the example local kitchen fire protection system for each of the type of residential occupier is shown in Figure 14.

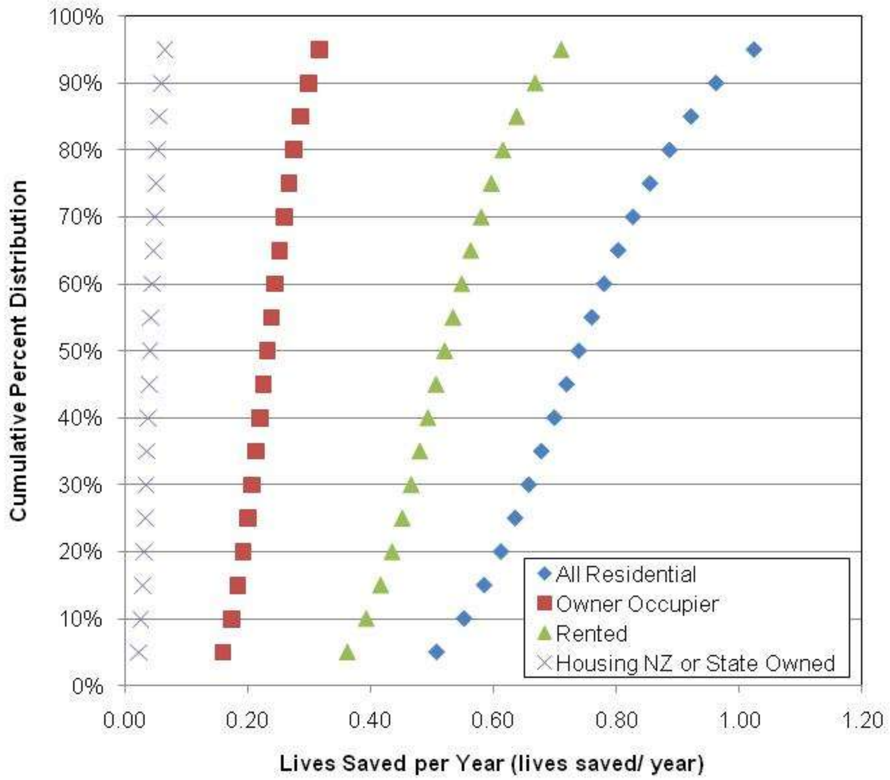

Figure 11: Summary of the number of lives saved per year for each type of residential occupier with the introduction of the example local kitchen fire suppression system used to demonstrate the proposed framework.

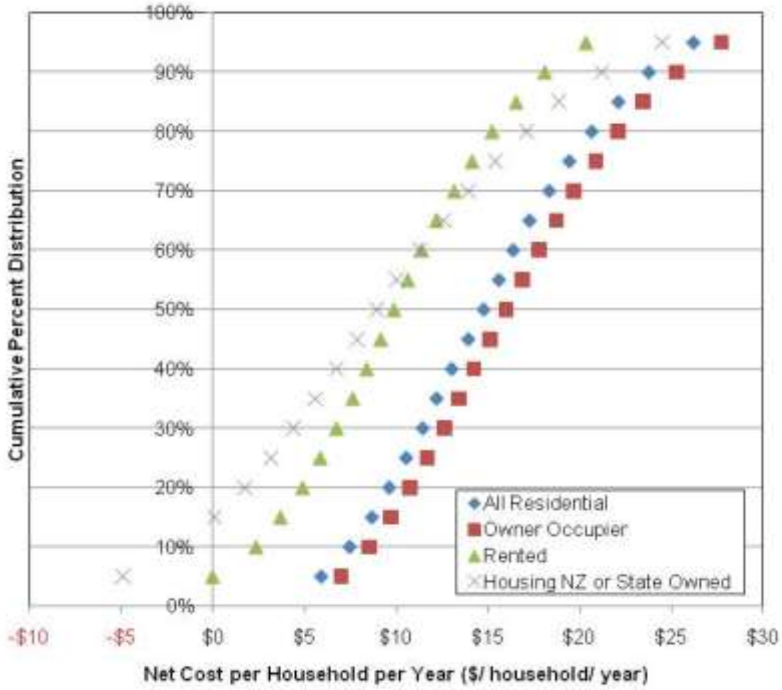

Figure 12: Summary of the NPV cost per household per year for each type of residential occupier with the introduction of the example local kitchen fire suppression system used to demonstrate the proposed framework.

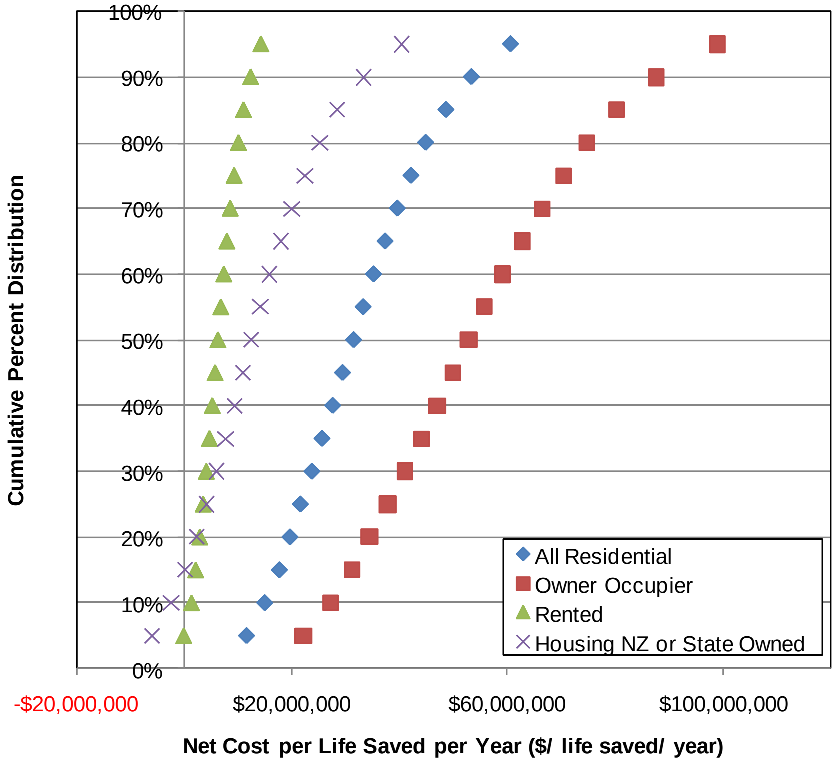

Figure 13: Summary of the NPV cost per life saved per year for each type of residential occupier with the introduction of the example local kitchen fire suppression system used to demonstrate the proposed framework.

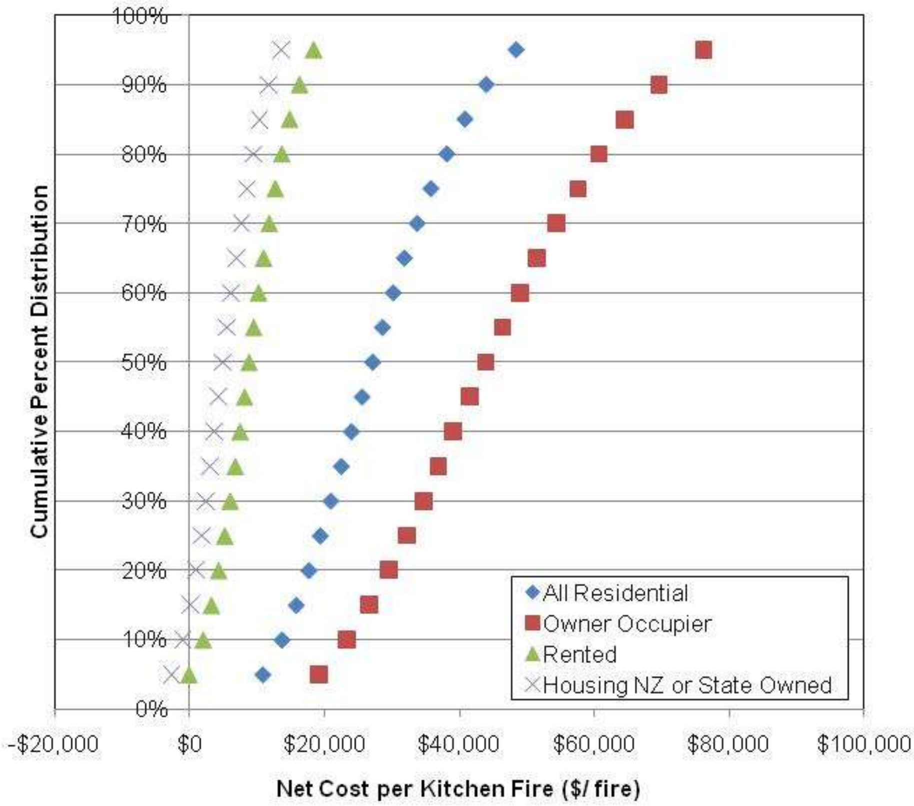

Figure 14: Summary of the NPV cost per unattended stove-top fire for each type of residential occupier with the introduction of the example local kitchen fire suppression system used to demonstrate the proposed framework.

8.4.1 Sensitivity Analysis

The example case of the introduction of a single residential sprinkler head as a local kitchen fire protection system is summarised in this sensitivity analysis. Each of the categories of residential occupier are considered here.

Critical input parameters were determined using linear regression analysis for the NPV monetary cost per household, per life saved and per unattended stove-top fire. Details of the sensitivity analysis for each of the occupier types is included in Appendix B.

The common input parameters with relatively high sensitivity, based on a step-wise regression analysis, for the monetary cost per household, cost per life saved and cost per fire for the categories of occupier considered were consistently found to be:

- Cost of the system design and installation for retrofit situations,
- Property loss per unprotected fire,
- Rate of retrofit of the system to the existing households,
- Reduction in monetary property loss per kitchen fire with a kitchen fire suppression system,
- System fire protection effectiveness,
- Number of deaths per 1,000 unattended stove-top kitchen fires,
- Discount rate,
- Number of unattended stove-top structure fires per year,
- System reliability,
- Inflation rate, and
- Cost of the system design and installation for newly built households

These results are similar to the most influential parameters for the cost effectiveness analysis for home sprinkler systems (Robbins, Wade et al., 2008) that this framework was initially based on.

8.4.2 Establishing Cost-Effectiveness Break-Even Points

For a specific local fire protection system design with an associated operational reliability and fire protection effectiveness, a break-even point can be found for the materials and installation cost of the system, with all other input parameters assumed to be the same.

Firstly, considering the example system consisting of a single residential sprinkler head, as discussed in this study, the break-even point for the NVP cost per household per year varies with the occupier category. For example, the break-even point for this example system for all residential occupancies is a materials and installation retrofit cost of approximately $55 per system, $35 for owner occupier households, $125 for rental properties, and $125 for Housing NZ or state owned properties (Table 22). Therefore different systems (and therefore costs) maybe more cost effective for a different cross-section of the residential market. That is, solutions targeted to the type of occupier may be more appropriate than applying one system to every type of household within New Zealand.

Other values for operational reliability and fire protection effectiveness were also considered in terms of estimating a break-even point for the NPV cost per household per year. For example, a value of 1 for fire protection effectiveness, as discussed in Section 7.1.2 and BRANZ Study Report 225 (Robbins, 2010), indicates a system that prevents ignition. Assuming material and installation costs for a new-build are ~50% of a retrofit situation and the maximum and minimum costs are approximately twice and half the average cost respectively, in order to be approximately proportional to the values for the example system discussed in this report. Results for a stove-top of operational reliabilities and fire protection effectiveness values are summarised in Table 22.

It should be reinforced that this approach is only indicative to gain a feel for the numbers involved, since a different system would not only have different values for operational reliability and fire protection effectiveness but also the other framework input parameter values (e.g. reduction in property loss per fire, limit of flame damage for an effective system, reduction in civilian casualties, etc.) that will also have an impact on the break-even point for the NVP cost per household per year.

Table 22: Summary of average break-even values for the materials and installation cost of a potential local fire protection system for various values of reliability and effectiveness. *

Description	Operational Reliability	Fire Protection Effectiveness	Average Materials & Installation Cost (Retrofit) (min = -50%, max = +100%)			
			All Residential Occupancies	Owner Occupier	Rental Property	Housing NZ or State Owned Property
Study Example [a]	0.86 (min=0.8, max=0.96)	0.7 (min=0.4, max = 0.9)	$55	$35	$125	$125
Ignition Prevention System [b]	0.86 (min=0.8, max=0.96)	1	$75	$50	$185	$180

Notes:

* Values in this table are only for providing a general influence of the effectiveness value on the break-even values for materials and installation costs. A detailed assessment for each specific system is needed to provide the associated break-even values.

[a] Example system consisting of a single residential sprinkler head.

[b] A potential system with the same operational reliability as the example system considered in this study, but for a fire protection effectiveness of 1 (i.e. a system that prevents ignition).

9. SUMMARY & CONCLUSIONS

A summary of the highlights and conclusions from this investigation includes:

- A framework for assessing the cost effectiveness of potential local fire protection systems has been successfully developed.
- The cost effectiveness framework was demonstrated for an example local fire protection system consisting of a single residential sprinkler head.
  - This type of system is a low cost solution.
  - This is an example solution as a demonstration of concept and the cost effectiveness assessment framework presented here, in combination with the test method and analysis proposed for estimating effectiveness of a system in BRANZ Study Report 225 (Robbins 2010), could be applied to any other system for local fire protection and therefore other systems may be more appropriate for targeted situations.
- An estimate of the fire protection effectiveness was used within the proposed framework, based on the experimental investigation summarised in BRANZ Study Report 225 (Robbins, 2010).
- The type of residential occupier (i.e. owner occupier, rental properties and Housing NZ or state owned properties) was found to have an influence on the result of the cost effectiveness assessment, similar to the previous investigation on the impact of home sprinkler systems in New Zealand (Robbins, Wade et al. 2008).
  - Housing NZ or state owned and rental properties were found to consistently have the most benefit for a given local fire protection system that focuses on unattended stove-top fires.
  - Because of the influence of the type of household occupier on the results of the cost effectiveness, it is recommended that specific local fire protection systems be targeted to different types of households.
- The cost effectiveness assessment framework can be used to target break-even points or other sweet-spots in terms of system effectiveness versus material and installation costs, or any other input parameters. This may be useful in the development of other systems targeted for specific types of households or other scenarios.
- Sensitivity analyses were performed for the combinations of input parameters considered within this investigation. Consistently, the most influential parameters were found to be:
  - Type of household occupier,
  - Cost of the system design and installation for retrofit situations,
  - Property loss per unprotected fire,
  - Rate of retrofit of the system to the existing households,
  - Reduction in monetary property loss per kitchen fire with a kitchen fire suppression system,
  - System fire protection effectiveness,

  - Number of deaths per 1,000 unattended stove-top kitchen fires,
  - Discount rate,
  - Number of unattended stove-top structure fires per year,
  - System reliability,
  - Inflation rate, and
  - Cost of the system design and installation for newly built households.
- Considering fire protection effectiveness and system material and installation costs within this proposed framework, a fire prevention system for stove-top fires may be a competitive alternative to a fire protection system, such as the single residential sprinkler head used as an example within this investigation.

9.1 Recommendations for Future Research

Recommended areas for consideration in future research involving residential kitchen stove-top fires, local fire protection methods or estimation of fire protection effectiveness include:

- Consideration of ignition prevention systems.
- Develop different local fire protection/prevention systems based on the type of household to provide intelligently targeted solutions.

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APPENDIX A SUMMARY OF COST EFFECTIVENESS ANALYSIS INPUT

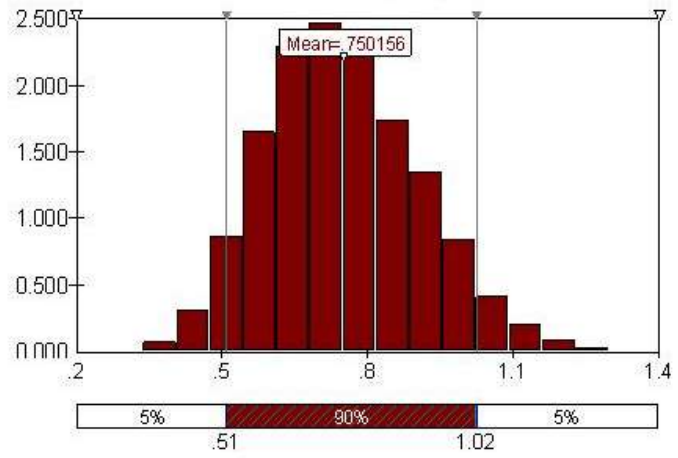
Table 23 shows an example of the input for the cost effectiveness analysis framework, using the all residential occupancy data set. The blue coloured cells require user input. The cells listed as 'calculated' are calculated based on the user input values.

Table 23: An example of the input table of values for the cost effectiveness analysis framework, using all residential occupancy values

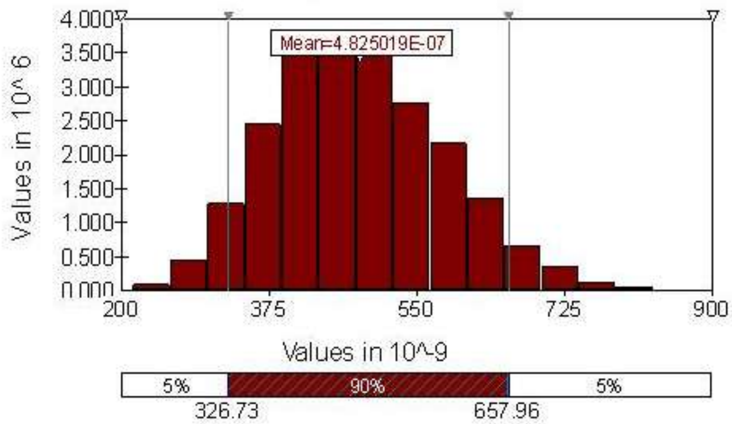
Inputs	Minimum Value	Best Value	Maximum Value
System reliability	0.8	0.86	0.96
System effectiveness	0.4	0.7	0.9
Overall system effectiveness		calculated	
Limit of flame damage for effective kitchen fire protection system	1%	2%	4%
Deaths per 1000 kitchen fires, smoke alarms only	2.7	3.5	4.5
% reduction in fatalities		75%	
Deaths per 1000 kitchen fires, with kitchen fire protection system		calculated	
Injuries per 1000 kitchen fires, smoke alarms only	48	54	61
% reduction in injuries		30%	
Injuries per 1000 kitchen fires, with kitchen fire protection system		calculated	
Structure fires per year originating in kitchen	730	816	900
Current number of households		1500000	
Increase in households per year	0.1%	0.5%	1.0%
Initial number of households with kitchen fire protection installed		0	
Proportion of new households with kitchen fire protection installed		100%	
Rate of retrofit of local kitchen fire protection systems in households	7.0%	10%	15.0%
Discount rate	7%	8%	9%
Inflation rate	2.0%	2.1%	3.0%
Analysis period		10 years	
Kitchen fire suppression system life		10 years	
Sprinkler Costs			
Materials & installation (new household)	$70	$150	$180
Materials & installation (retrofit)	$90	$240	$540
Annual maintenance		$0	
Initial regulatory costs		$0	
Yearly regulatory costs		$0	
Fire Damage Costs			
Cost per fire fatality	$2,300,000	$2,700,000	$2,700,000
Cost per fire injury - direct	$21,000	$36,000	$79,000
Cost per fire injury - indirect	$165,000	$200,000	$413,000
Property loss per unprotected fire	$18,000	$36,000	$120,000
Reduction in property loss per kitchen fire with a kitchen fire protection system	20%	50%	95%

APPENDIX B COST EFFECTIVENESS MODEL RESULTS

B.1 All Residential Households



(a)



(b)

Figure 15: Distributions for (a) lives saved per year and (b) lives saved per household per year for all residential occupancies.

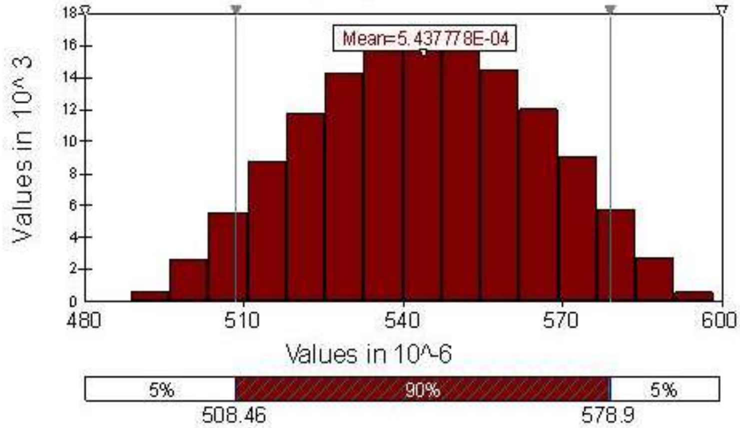
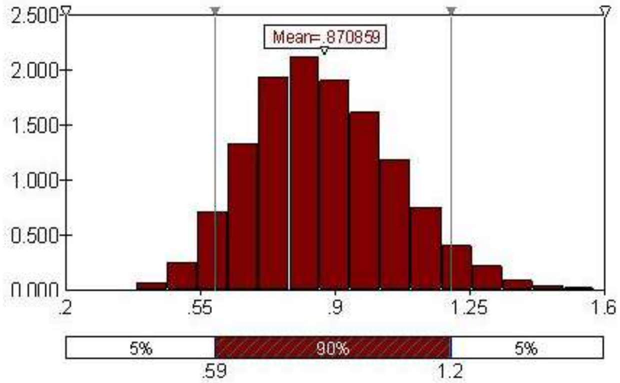
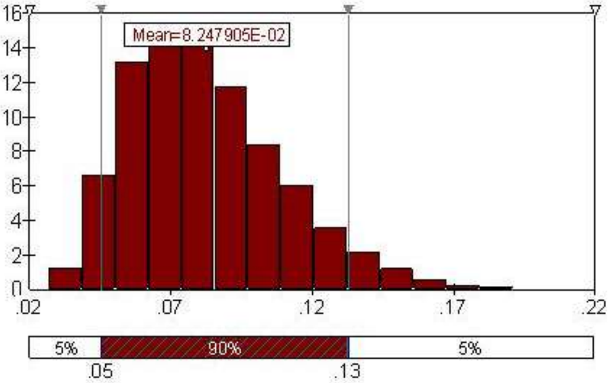


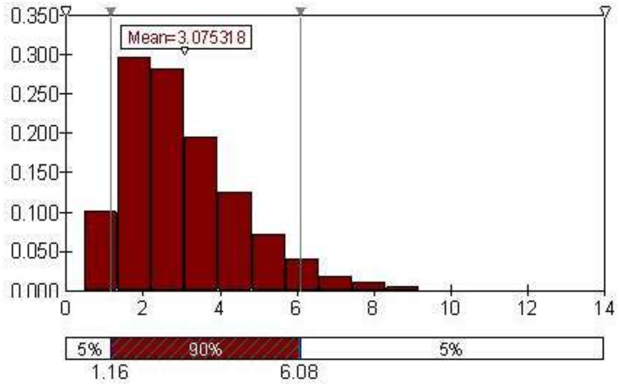
Figure 16: Distribution for numbers of kitchen fires per household per year for all residential occupancies.



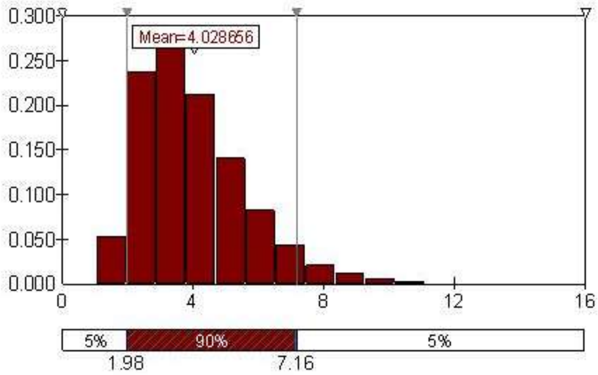
(a)



(b)



(c)



(d)

Figure 17: Distributions for monetary savings for (a) adverted fatality costs per household per year, (b) adverted injury costs per household per year, (c) adverted property damage costs, and (d) total savings per household per year for Housing NZ or State owned occupancies.

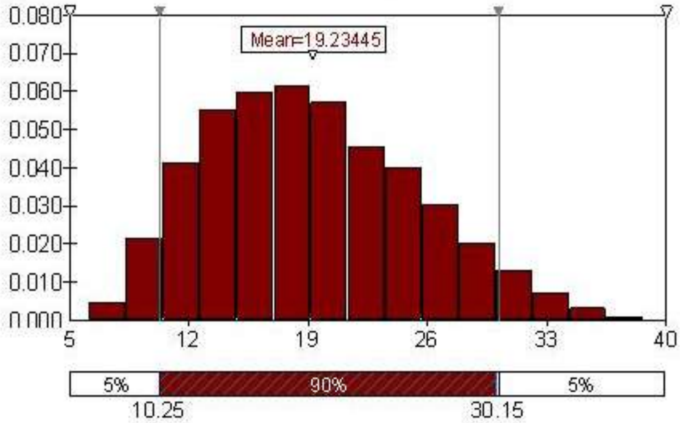
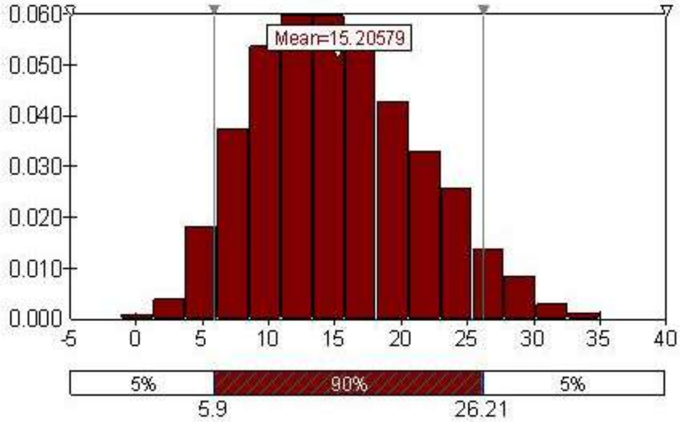
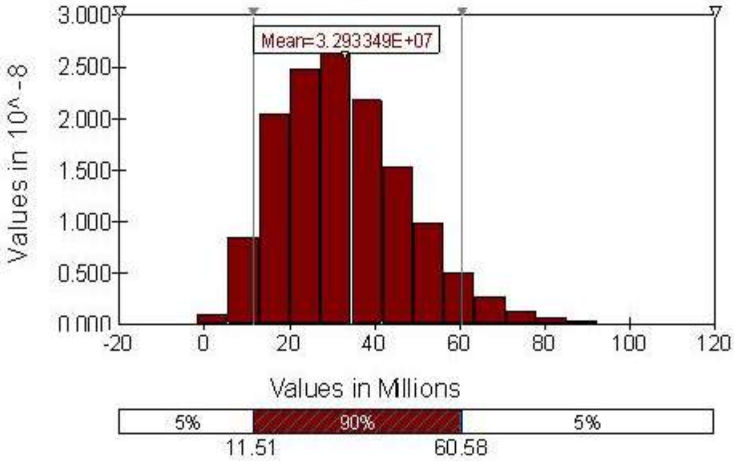


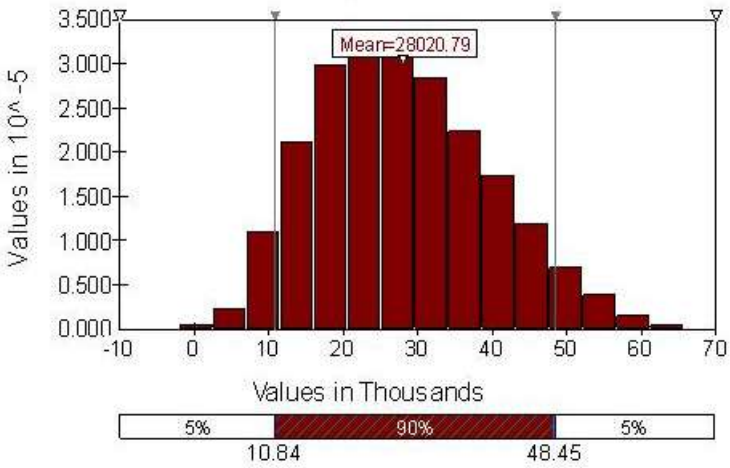
Figure 18: Distribution of total monetary costs per household per year for all residential occupancies.



(a)



(b)



(c)

Figure 19: Distributions of NPV cost (a) per household per year, (b) per life saved, and (c) per fire for all residential occupancies.

B.1.1 Influence of Parameter Values

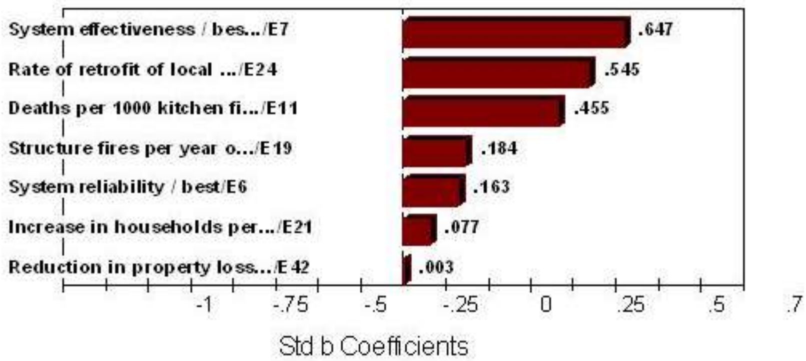


Figure 20: Step-wise regression results for the sensitivity of the number of lives saved per year for all residential occupancies.

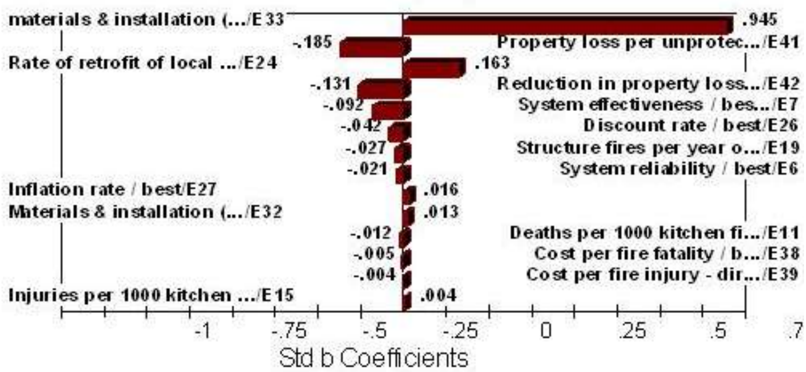


Figure 21: Step-wise regression results for the sensitivity of the number of lives saved per year for all residential occupancies.

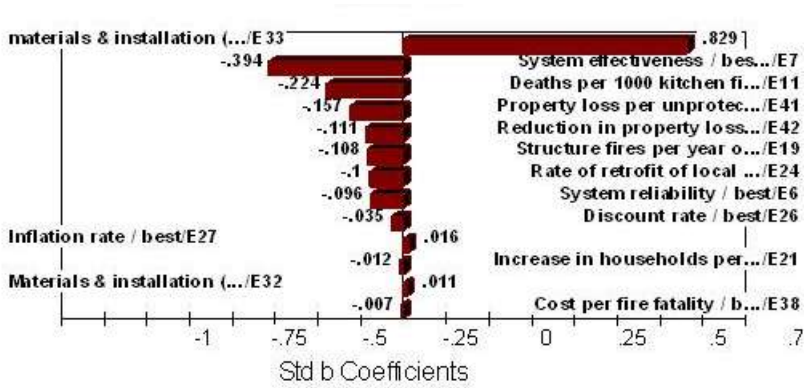


Figure 22: Step-wise regression results for the sensitivity of the NPV cost per life saved for all residential occupancies.

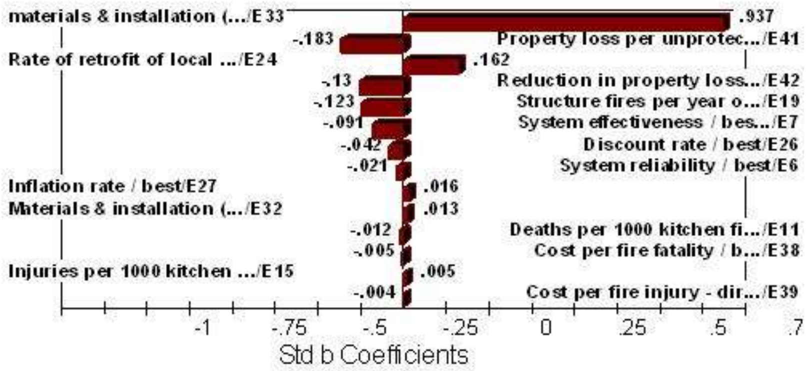
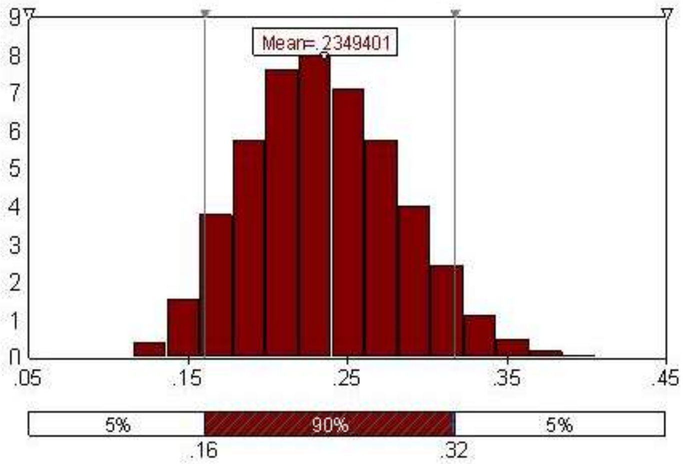
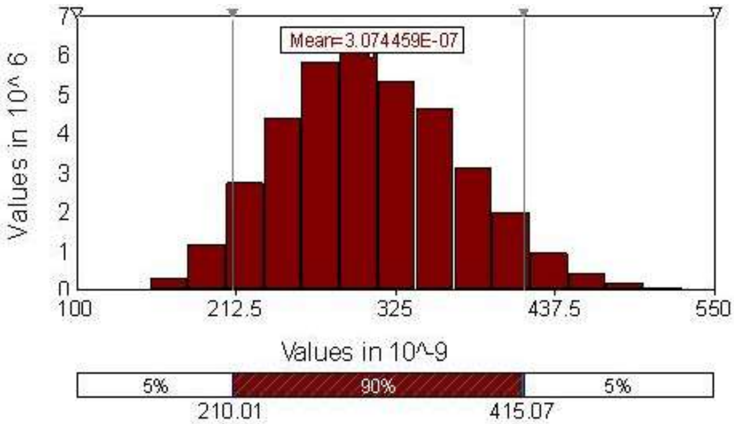


Figure 23: Step-wise regression results for the sensitivity of NPV cost per fire for all residential occupancies.

B.2 Owner Occupier



(a)



(b)

Figure 24: Distributions for (a) lives saved per year and (b) lives saved per household per year for owner occupier occupancies.

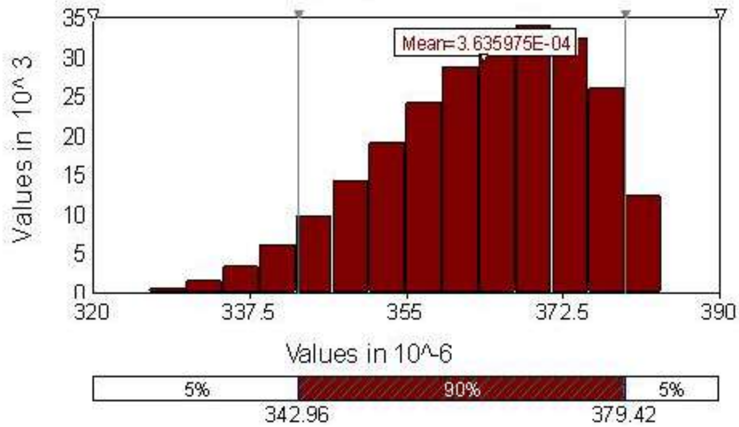
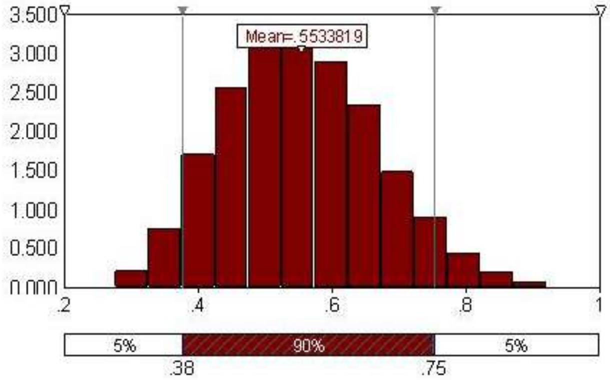
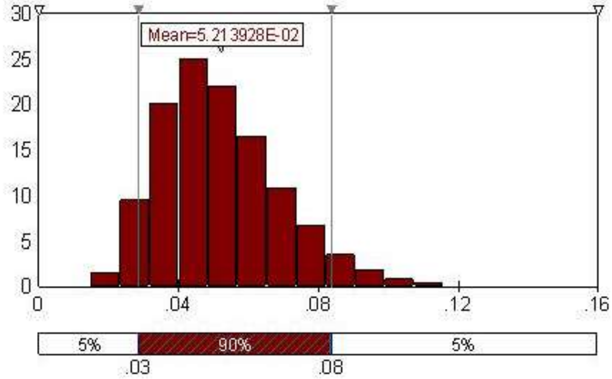


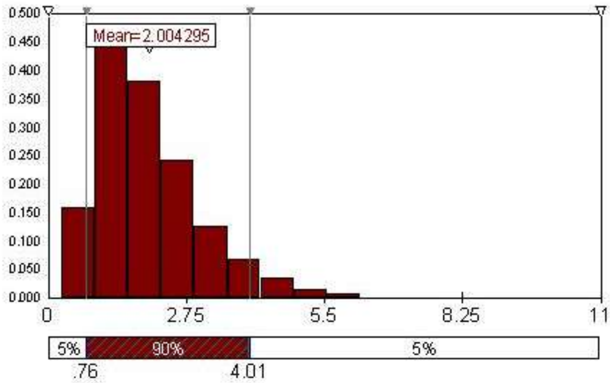
Figure 25: Distribution for numbers of kitchen fires per household per year for owner occupier occupancies.



(a)



(b)



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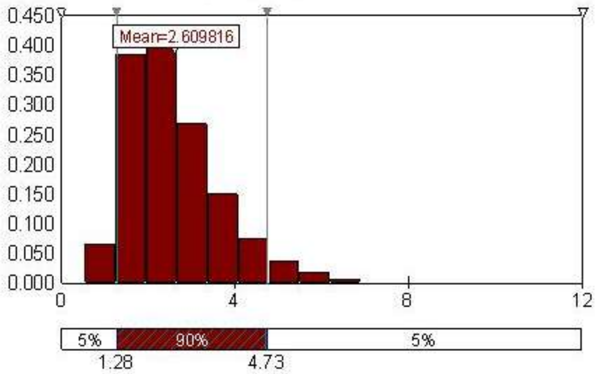


(d)

Figure 26: Distributions for monetary savings for (a) adverted fatality costs per household per year, (b) adverted injury costs per household per year, (c) adverted property damage costs, and (d) total savings per household per year for Housing NZ or State owned occupancies.

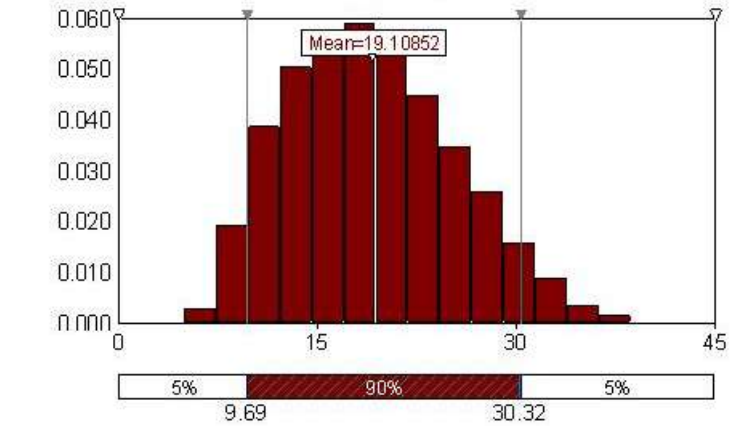
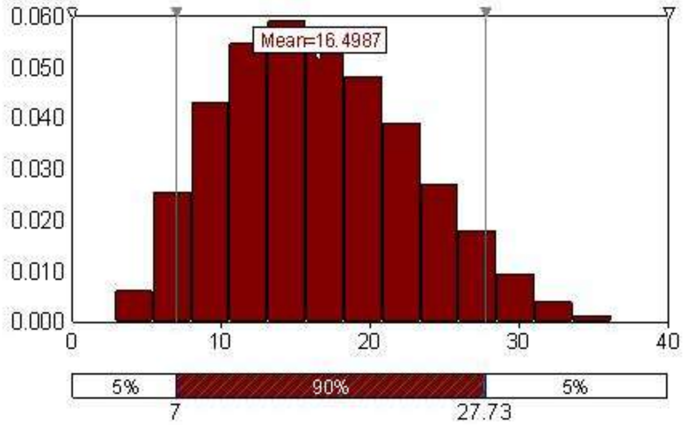
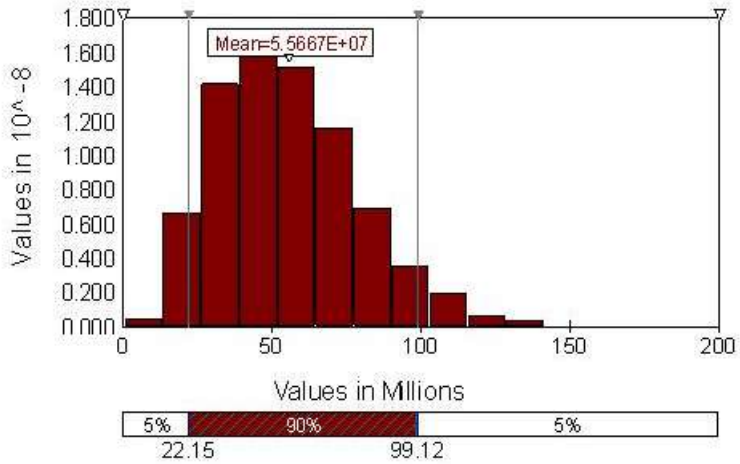


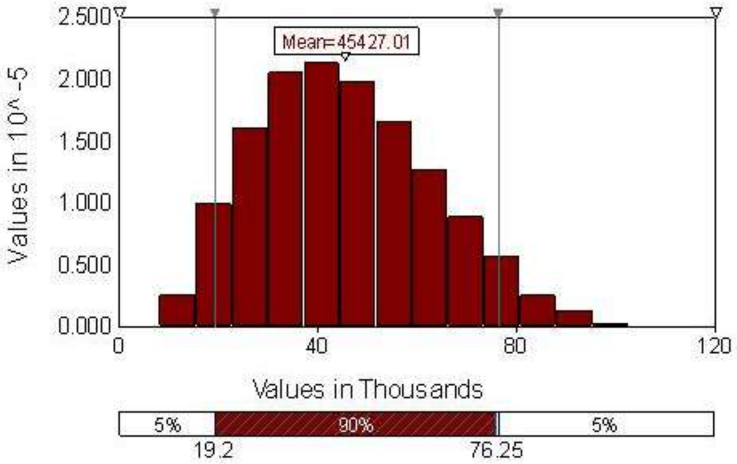
Figure 27: Distribution of total monetary costs per household per year for owner occupier occupancies.



(a)



(b)



(c)

Figure 28: Distributions of NPV cost (a) per household per year, (b) per life saved, and (c) per fire for owner occupier occupancies.

B.2.1 Influence of Parameter Values

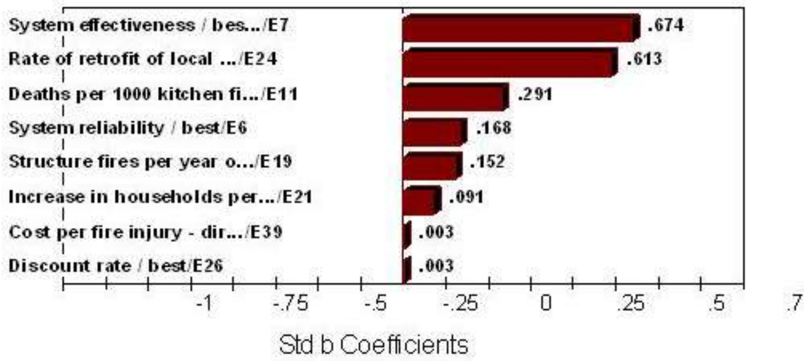


Figure 29: Step-wise regression results for the sensitivity of the number of lives saved per year for owner occupier occupancies.

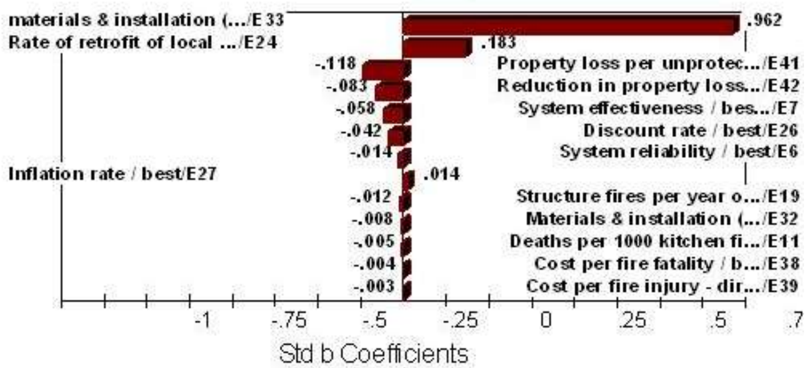


Figure 30: Step-wise regression results for the sensitivity of the number of lives saved per year for owner occupier occupancies.

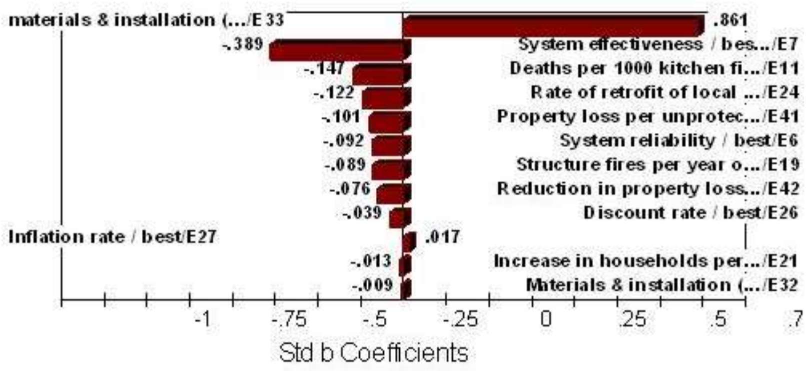


Figure 31: Step-wise regression results for the sensitivity of the NPV cost per life saved for owner occupier occupancies.

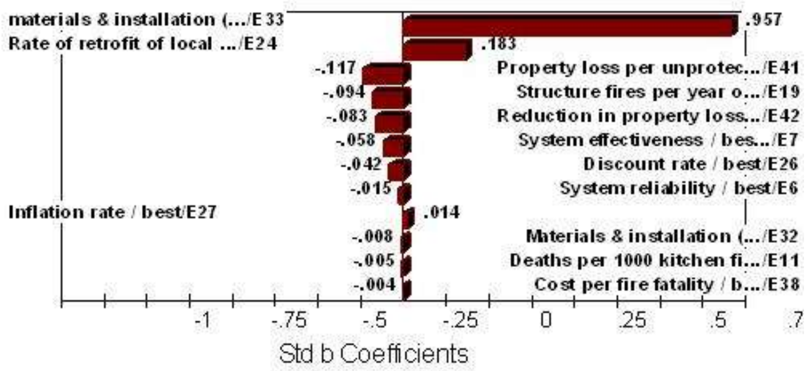
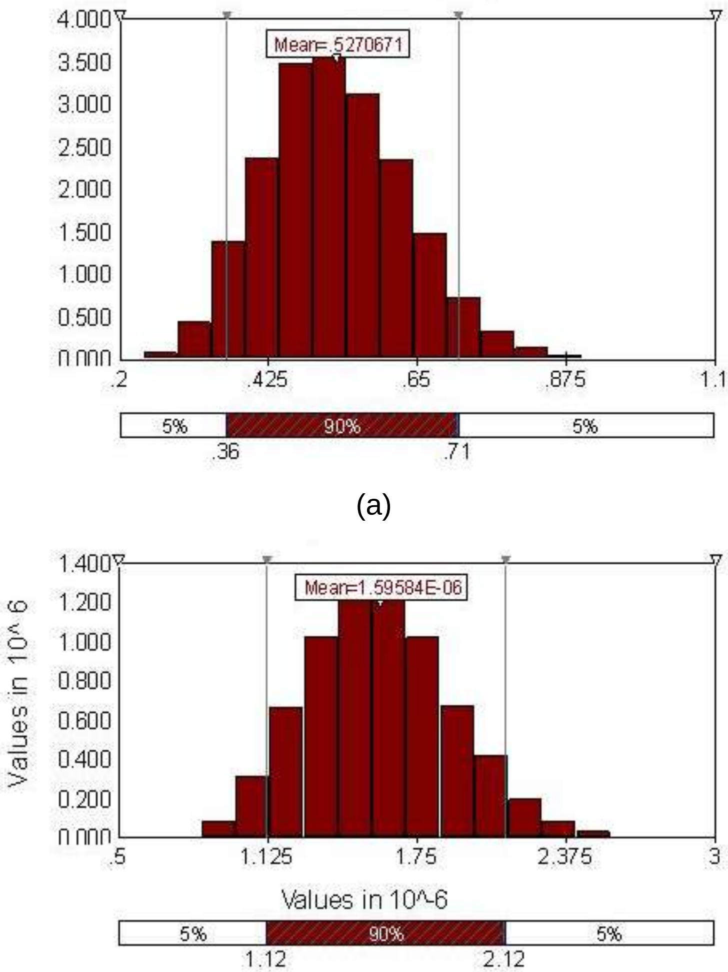


Figure 32: Step-wise regression results for the sensitivity of NPV cost per fire for owner occupier occupancies.

B.3 Rental Occupiers



(a)

(b)

Figure 33: Distributions for (a) lives saved per year and (b) lives saved per household per year for rental occupancies.

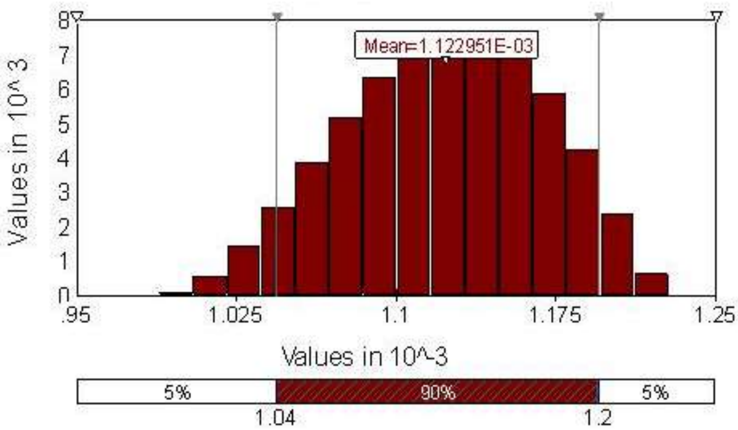
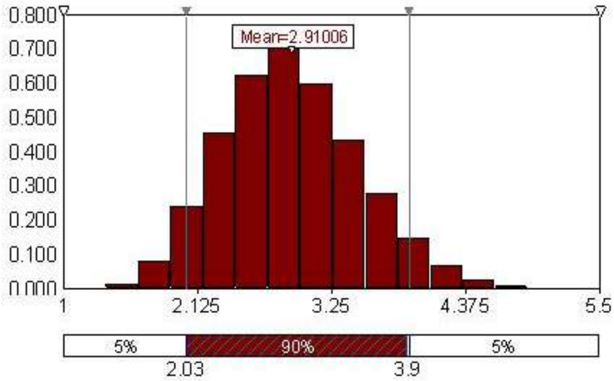
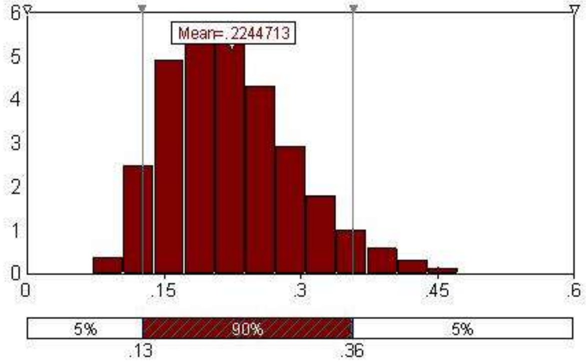


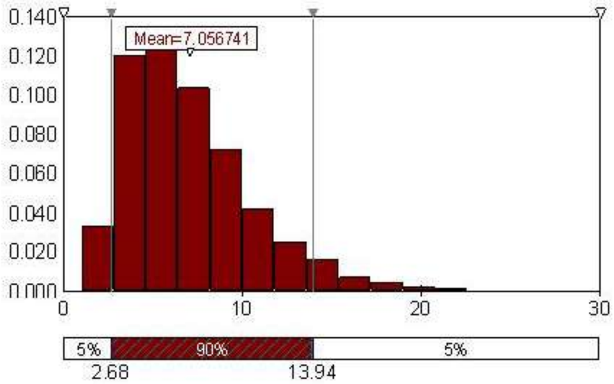
Figure 34: Distribution for numbers of kitchen fires per household per year for rental occupancies.



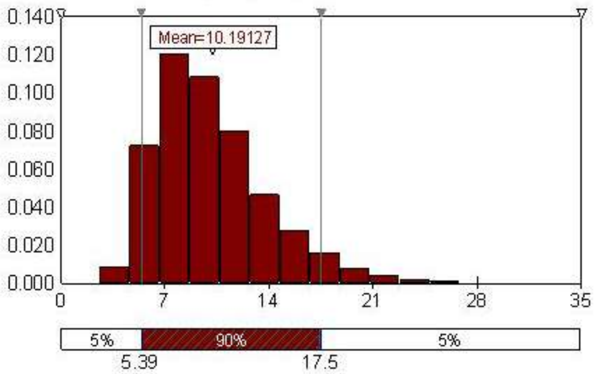
(a)



(b)



(c)



(d)

Figure 35: Distributions for monetary savings for (a) adverted fatality costs per household per year, (b) adverted injury costs per household per year, (c) adverted property damage costs, and (d) total savings per household per year for Housing NZ or State owned occupancies.

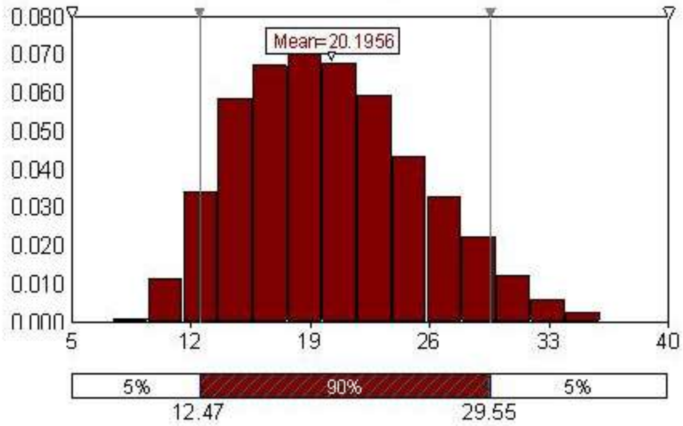
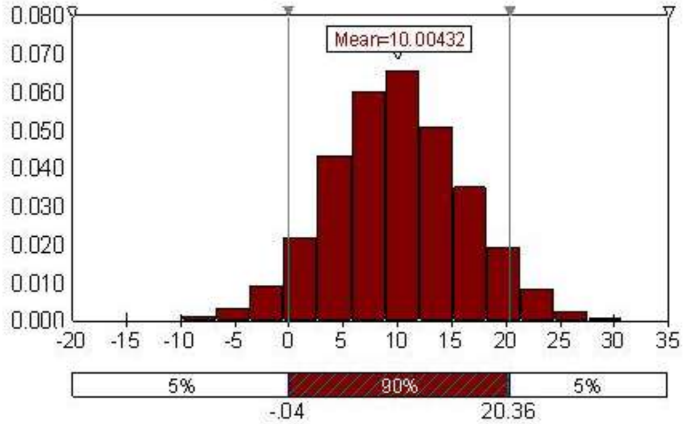
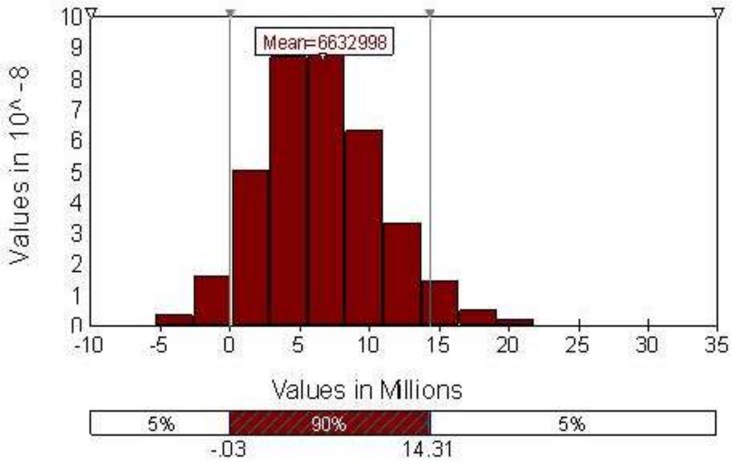


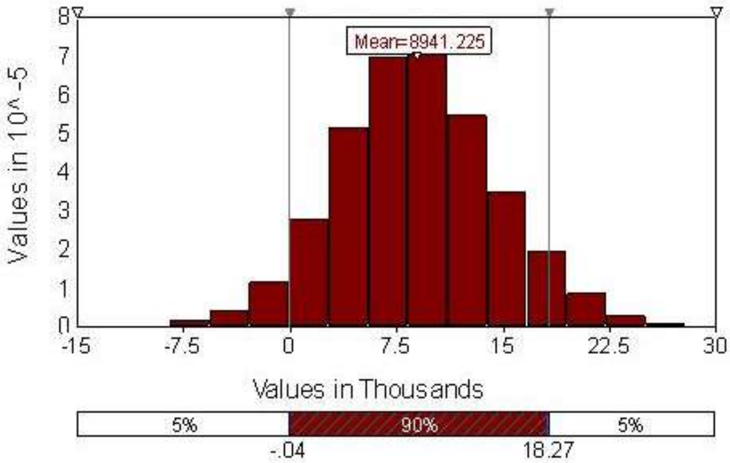
Figure 36: Distribution of total monetary costs per household per year for rental occupancies.



(a)



(b)



(c)

Figure 37: Distributions of NPV cost (a) per household per year, (b) per life saved, and (c) per fire for rental occupancies.

B.3.1 Influence of Parameter Values

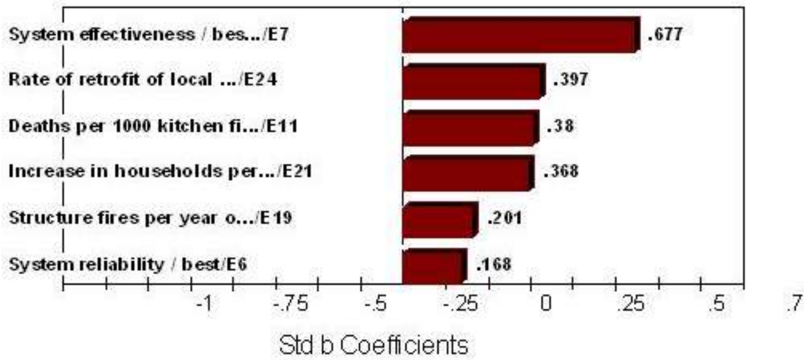


Figure 38: Step-wise regression results for the sensitivity of the number of lives saved per year for rental occupancies.

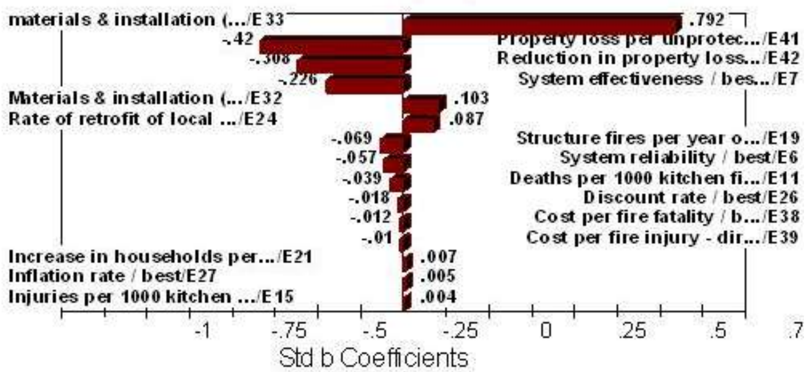


Figure 39: Step-wise regression results for the sensitivity of the number of lives saved per year for rental occupancies.

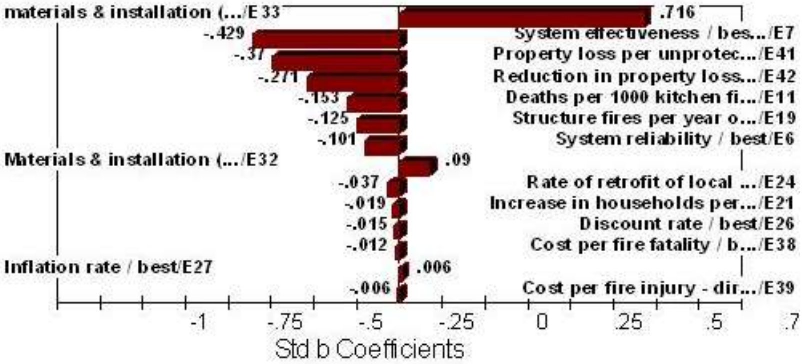


Figure 40: Step-wise regression results for the sensitivity of the NPV cost per life saved for rental occupancies.

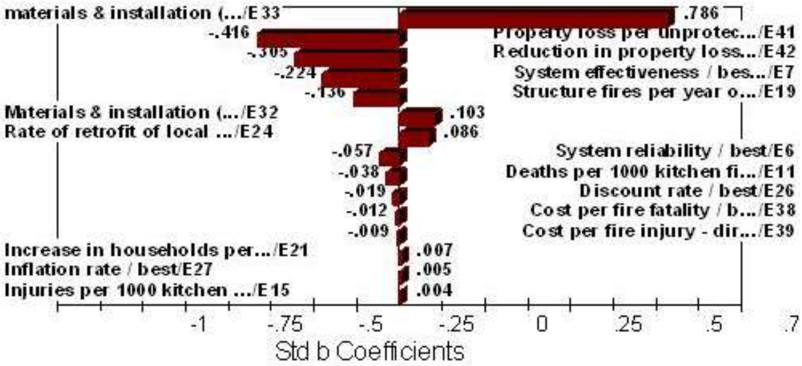
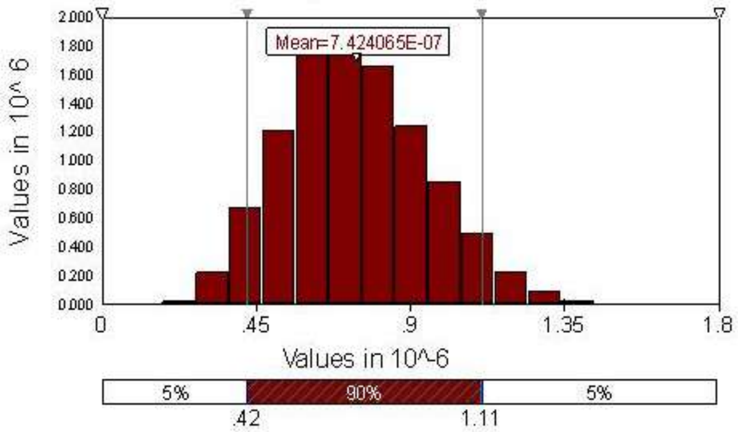
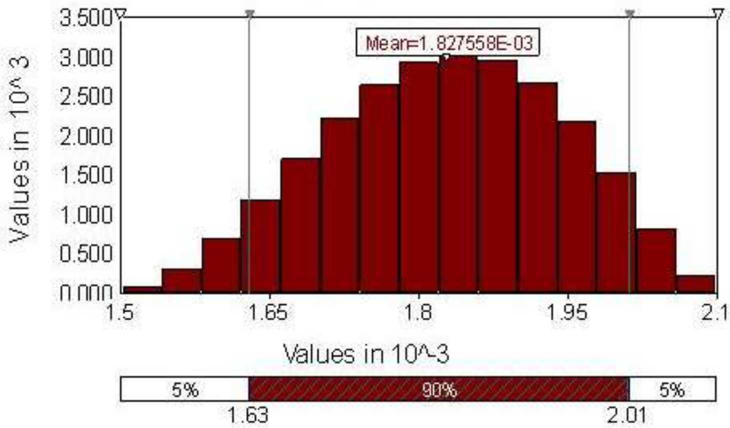


Figure 41: Step-wise regression results for the sensitivity of NPV cost per fire for rental occupancies.

B.4 Households where Property is Housing NZ or State Owned



(a)



(b)

Figure 42: Distributions for (a) lives saved per year and (b) lives saved per household per year for Housing NZ or State owned occupancies.

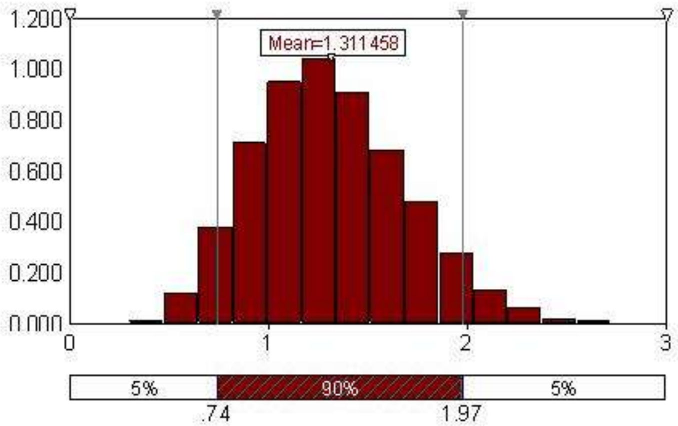


Figure 43: Distribution for numbers of kitchen fires per household per year for Housing NZ or State owned occupancies.

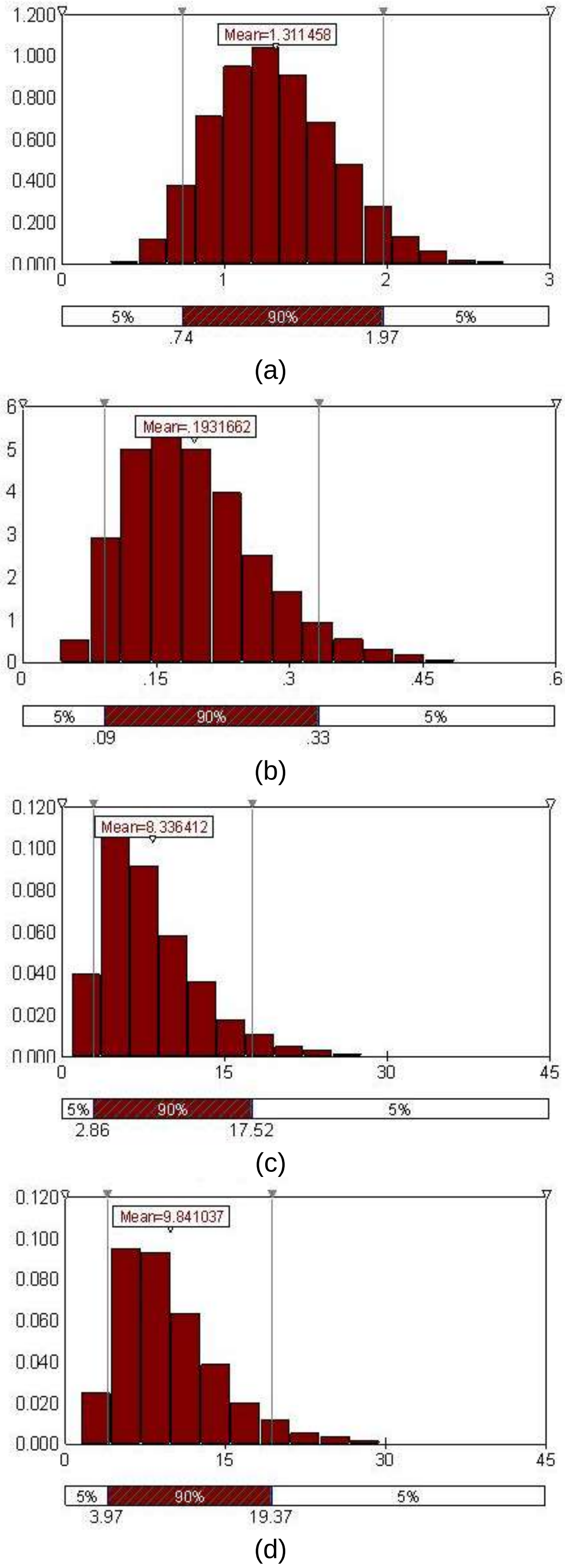


Figure 44: Distributions for monetary savings for (a) adverted fatality costs per household per year, (b) adverted injury costs per household per year, (c) adverted property damage costs, and (d) total savings per household per year for Housing NZ or State owned occupancies.

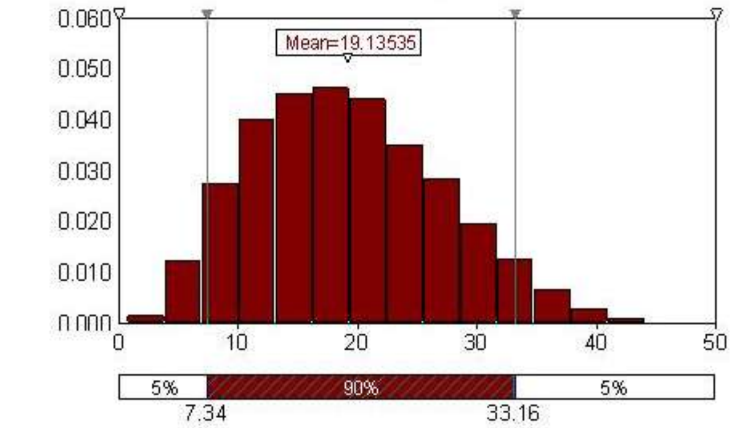
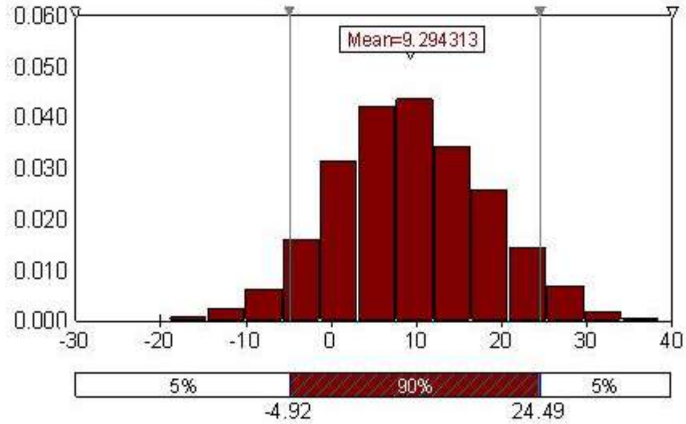
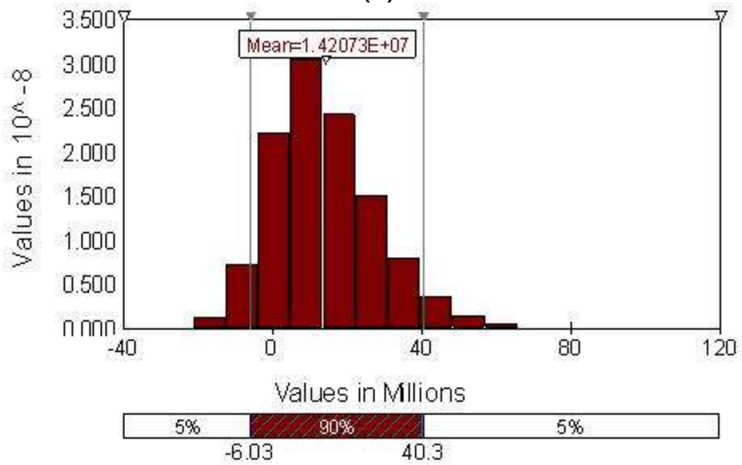


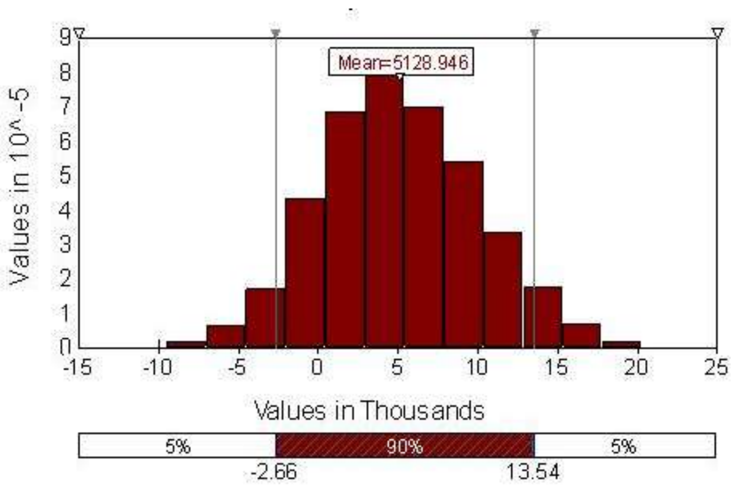
Figure 45: Distribution of total monetary costs per household per year for Housing NZ or State owned occupancies.



(a)



(b)



(c)

Figure 46: Distributions of NPV cost (a) per household per year, (b) per life saved, and (c) per fire for Housing NZ or State owned occupancies.

B.4.1 Influence of Parameter Values

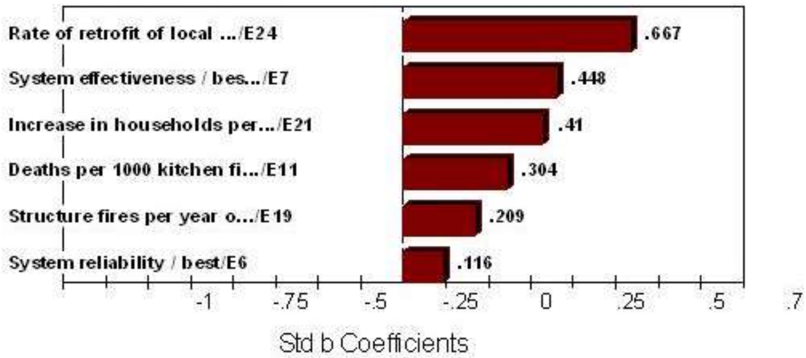


Figure 47: Step-wise regression results for the sensitivity of the number of lives saved per year for Housing NZ or State owned occupancies.

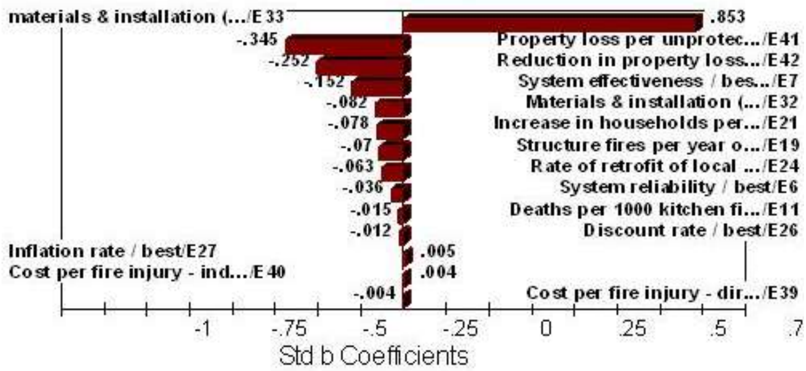


Figure 48: Step-wise regression results for the sensitivity of the number of lives saved per year for Housing NZ or State owned occupancies.

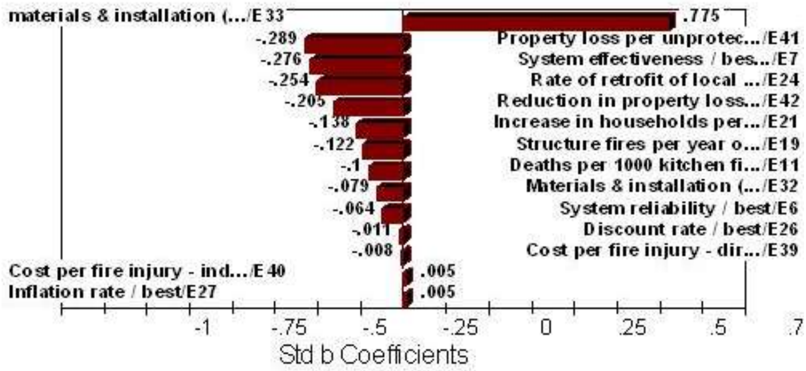


Figure 49: Step-wise regression results for the sensitivity of the NPV cost per life saved for Housing NZ or State owned occupancies.

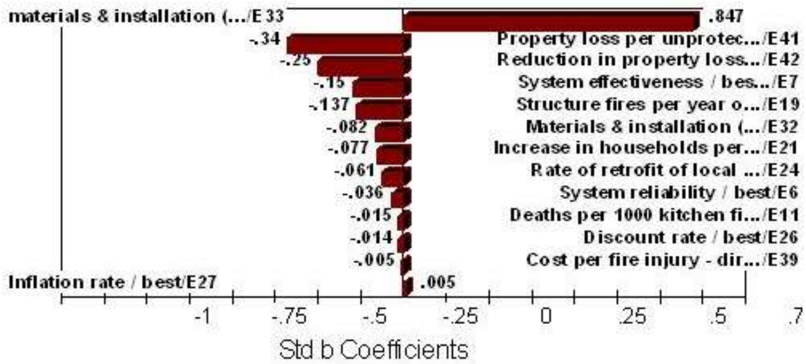


Figure 50: Step-wise regression results for the sensitivity of NPV cost per fire for Housing NZ or State owned occupancies.