STUDY REPORT

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House Fire GHG Emissions Estimation Tool

– A Preliminary Framework

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The work reported here was funded by the New Zealand Fire Service Commission through the New Zealand Fire Service Contestable Research Fund and performed under sub-contract to SCION.

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Preface

This report forms part of a larger research project conducted for the New Zealand Fire Service Commission into the green house gas emissions associated with house fires (conducted by BRANZ) and vegetation fires (conducted by SCION). The house fire portion of the project was performed by BRANZ under sub-contract to SCION. This report is a summary for only the house fire aspect of this project.

Acknowledgments

This work was funded by the New Zealand Fire Service Commission through the New Zealand Fire Service Contestable Research Fund and was performed in collaboration with and under sub-contract to SCION.

Note

This report is intended for the New Zealand Fire Service, policy makers and researchers.

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Reference

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Abstract

This report provides a summary of the description of a tool developed to provide an estimate of the GHG emissions impact of house fires. The GHG emissions considered in this study are only associated with the gaseous yield of CO_2 during a house fire where estimated house structure and contents are based on an exemplar house. The metric used for reporting the results of the House Fire GHG Emissions estimation tool is CO_2 Equivalent.

The framework developed for this estimation tool is designed to be easily expanded to incorporate future work and development, as more information and data becomes available.
A summary of the results of a selection of scenarios are presented as a demonstration of concept.

Executive Summary

The house fire GHG emissions estimation tool presented here is intended to provide comparative results to investigate the potential impact of different strategies or scenarios, e.g. the current situation versus the situation if no Fire Service intervention was available (or the average response time was increased or decreased), versus mandatory home sprinklers systems throughout the nation, and so on.

A house fire GHG emissions tool was successfully developed and results for example scenarios are presented as demonstration of the concept. The metric used for the output of the tool is GHG emissions in metric tonnes of CO_2 Equivalent, which is consistent with the vegetation fires part of this report and other GHG emission studies.

The house fire GHG emissions framework described here intentionally does not incorporate the elements covered in the previous home sprinkler cost effectiveness analysis incorporating sustainability impacts (Robbins, Wade et al. 2008), therefore the results from both of these frameworks can be used in combination since no component is counted twice.

The house fire GHG emissions tool is based on a range of input parameters including fire incident statistics, estimated materials and quantities involved in the structure and contents of an exemplar house, and effectiveness of different suppression methods.

An exemplar house was used as an estimate of the most common construction combinations and contents items for houses in New Zealand. Because of the lack of data, species yields were based upon data and information for well-ventilated fires. This was limited to average carbon dioxide (CO_2) yields. To account for the diversity in the NZ housing stock construction and contents and the flame damage for any individual fire event, the context of the national scope was used with an analysis period of 50 years. Results are expressed in terms of per year of this analysis period.

A selection of scenarios was considered so as to provide results to investigate the comparisons between the scenarios using the house fire GHG emissions framework developed here. The scenarios considered were:

1. Total fire loss of an exemplar house structure,
2. Total fire loss of an exemplar house contents,
3. House fires with fire suppression remaining the same as reflected in current fire incident statistics,
4. House fires where home sprinkler systems (according to NZS4817) are present with NZFS intervention using water (if needed in the cases where the home sprinkler system are not effective), and
5. House fires with the equivalent percentage of house area lost to fire increased to 50%.

For the estimations and assumptions used in this framework, the complete fire loss of the exemplar house structure was estimated to account for approximately 82 – 86% of the CO_2 released during a fire, with house contents contributing the balance.

This framework can be used to estimate the impact of changes in fire suppression strategies. For example, comparison of the current fire suppression strategies reflected in recent fire incident strategies (Scenario 3) and implementing a home sprinkler system strategy to protect the NZ housing stock within a 10 year period (Scenario 4) was estimated to provide a 60 – 70% mean reduction of CO_2 Equivalent GHG emissions being released during house fires (over the period of analysis) by the introduction of home sprinkler systems. Conversely, a reduction in house fire suppression strategies such that the equivalent percentage of floorarea loss per fire increased from 29% (Scenario 3) to 50% (Scenario 5) was associated with an approximately 90% mean increase in CO_2 Equivalent.

The most influential input parameters were found to be parameters related to the estimated number of fires per year and types of material or item that contributed the most CO_2 on average. Sensitivity to these parameters was as expected. For Scenario 4, where home sprinkler systems were introduced to the housing stock, the effectiveness of the system and the maximum limit of flame damage achieved by the system were also influential input parameters.

In summary the framework developed during this study and described in this report is a useful tool for estimating GHG emissions for house fires for NZ and the potential impact of changes in fire suppression strategies.

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Abbreviations

CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
GHG	Green House Gas
GWP	Global Warming Potential
N_2O	Nitrous Oxide
NZ	New Zealand
NZS	Standards New Zealand
PVC	polyvinyl chloride
SFPE	Society of Fire Protection Engineers
t	metric tonne

Standard International units are used throughout unless otherwise indicated.

Nomenclature

$A_{\% lost}$	Floorarea of house lost to fire
$E_{exe\_struct,i}$	GHG emissions from total loss of the structure of an exemplar house
E_{exe_cont}	GHG emissions from total loss of the contents of an exemplar house
$E_{house,total}$	GHG emissions released by house fires
F_0	Initial number of house structure fires per year
$gas_{\max}$	Maximum number of gas species
G_{gas}	Global Warming Potential of Species
$H_{0,all}$	Current number of households
$H_{0,sprink}$	Initial number of sprinklered households
$j_{\max}$	Maximum number of materials considered
$k_{\max}$	Maximum number of items considered
L_{sprink}	Limit of flame damage for effective sprinkler system
$m_{i,j}$	Mass of house structural component
m_k	Mass of house contents item
n_k	Number of house contents item
$p_{A\% lost,fires}$	Proportion of fires with specific proportion of floorarea burnt
$p_{A\% lost,x}$	Proportion of material burnt
$p_{fire,NZS4517}$	Proportion of fire incidents covered by an NZS4517 system
$p_{fire,ROO}$	Room of fire origin – distribution of fire incident
$p_{new,sprink}$	Proportion of new households sprinklered
$r_{discount}$	Discount rate
r_{house}	Increase in households per year
$r_{inflation}$	Inflation rate
$r_{retrofit}$	Rate of retrofit of sprinkler in households
S_{sprink}	GHG emissions saved from being released by house fires where home sprinkler systems are effective
$Y_{analysis}$	Analysis period
$Y_{gas,x}$	Species yield
Y_{sprink}	Sprinkler system life
η_{sprink}	Sprinkler effectiveness

1. INTRODUCTION

This report is a description of a tool developed to provide an estimate of the GHG emissions impact of house fires. A summary of the results of a selection of scenarios are also presented.

1.1 Research Objectives

The overall objective of the research project is to develop a methodology to quantitatively incorporate green house gas emissions into a cost effectiveness analysis.

Two cases were selected to demonstrate these concepts. These two cases are vegetation fires and house fires.

The specific objectives of the research project were to:

1. Develop a methodology for the calculation of GHG emissions from vegetation and house fires, and the impact that the New Zealand Fire Service's actions have on the emissions from these fires.
2. Create an Excel-based tool that the New Zealand Fire Service can use to estimate the GHG emissions from vegetation and house fires, and the impact that their actions had on the GHG emissions.
3. Provide a transparent and useful way of calculating ongoing GHG emissions from fires, and the impact that the NZFS has on these emissions.
4. Enable NZFS to assess the most efficient use of resources, through comparison of emissions from fires, with and without suppression action.
5. Provide a tool with which NZFS can use to estimate and report on GHG emissions from fire incidents.

1.2 Research Scope

Since the area of estimating the impact of green house gases associated with vegetation fires and house fires has been acknowledged as a new area of research from the outset, it is expected that there will be a limited amount of quantative information in some areas. The focus of this study is to develop and demonstrate a methodology to incorporate the impact of green house gases into a cost effectiveness analysis when considering two selected cases of fires: vegetation fires and house fires.

Data and information for estimating parameter values will be collected where possible, gap analysis (to assess the impact of information gaps) conducted and recommendations for future work to improve the confidence in estimated values.

1.3 General Research Approach

This research project was divided into two sections: vegetation fires and house fires.

In summary, the approach taken to achieve these objectives for the impact of green house gas emissions was:

- Review available literature

- Develop a methodology
- Collate data for each of the demonstration cases
- Use the methodology and analyse the results
- Summarise and report the results of the research

2. LITERATURE REVIEW

2.1 General

At the time this research was carried out, there was no published literature quantifying the impact of green house gas emissions from house fires. Furthermore there was limited published literature concerning green house gas emissions associated with house fires. Therefore residential fire related information that is useful in estimating the parameter values that effect green house gas emissions has been collated here and the information gaps discussed.

Since the impact of green house gas emissions associated with a house fire has not been previously quantified, the most influential parameters have not yet been identified. Therefore care is applied when making assumptions about what information is required and where information and data are not currently available.

2.2 Fire Statistics

The information available from house fire statistics does not relate directly to green house gas emissions, therefore the assumptions associated with the use of this information in the developed methodology must be clearly documented. This will be done in the next stage of this project as the methodology is developed.

Statistical fire information that is available and may be of use includes:

- numbers of house fires,
- approximate percentage of flame damage to the structure (however the method of recording this is crude, and therefore this information needs to be used with caution),
- numbers of fire events where various fire suppression methods were utilised, and
- the most common rooms of fire origin.

The statistics used in the methodology are presented in the following sections discussing the relevant input parameter values.

2.3 House Structure and Contents

Typically when considering house fire design the impact of the materials is considered in terms of life safety or structural stability. Therefore the material parameters influencing life safety and structure stability have the most information, since these have been the focus of previous work. The limits of the applicability of the typical parameters suggested for design fires to the issue of estimating the impact of green house gas emissions is not yet clear.

For example, an average Fire Load of approximately 500 kJ/m² (based on data collected in Switzerland) (Fire Engineering Design Guide 2008) is suggested to describe the typical contents of a home. An average value for soot yield and a selection of life safety related gas species (such as CO_2, CO, HCN) may also be estimated. However the parameters that strongly effect the emission of green house gases might be the types and amounts of materials involved and the temperatures reached during the fire. CO_2 yields might be estimated per unit mass of the averaged assumed representative fuel, but CH4 and NOx are of little interest when designing for life safety or structural stability.

Information on the types and amounts of materials typically available for burning in the structure and the contents of a house are needed to then estimate the impact. In the future CO_2, CH_4 and NOx yields may be available for materials burning in incineration conditions, and this information would be useful to contribute to other sources of these yield values.

As an aside, it is important to note that the average values are generally single point values, with no associated distribution.

2.3.1 Typical House Contents

Little is published on the numbers of items and amounts of materials in a typical New Zealand home. However a Canadian survey of living room furniture was conducted specifically for use in the estimation of residential design fires (Bwalya 2004; Bwalya et al. 2004). A summary of the average number of each furniture item in a living room is presented in Table 1. The living room and basement were the focus of the survey based on the high numbers of fires starting in these two locations reported in the Canadian statistics. Estimates of the materials and masses composing each of the typical types of furniture were based on information collected from local furniture suppliers.

In fire related assessments, the materials used in typical NZ furniture have been compared to typical construction elsewhere (Enright et al. 2001; Chen 2001; Wade et al. 2003). New Zealand has had fewer restrictions on fire safety features (such as ignitability of fabrics and fire retardant treatments of foams, etc.) of upholstered furniture than other countries. The differences in fire safety features may be associated with lower fire loads, higher required ignition temperatures and differences in the species emitted when a fire does occur. Therefore care must be used when adopting estimates of furniture material composition from other countries.

Some parameters to consider that may influence the amount or types of materials present in a house may include:

- Occupier type (e.g. owner occupier versus tenant, etc.)
- Number of occupants (e.g. is a higher number of occupants associated with a larger amount of contents, etc.)
- Age of occupants (e.g. are older or younger occupants associated with a larger amount of contents or larger amounts of particularly types of contents, etc.)

Alternative ways of possibly collecting information in order to estimate needed parameters may include:

- a home occupier survey to count numbers of furniture items in NZ homes (similar to the Canadian lounge room study by Bwalya 2004)
- a smaller targeted survey of the amounts of materials associated with each of the typical furniture items, to provide a distribution for the estimate the typical use within a residence (this would include dimensions and materials and masses for furniture items, amounts of materials on bookshelves, amounts of clothing, etc.)
- collating information from NZ furniture manufacturers and importers on the numbers of items sold per year and distributions for the typical types and amounts of materials contained in the ranges of furniture in each category (e.g. similar to the numbers of furniture items summarised for the United

Kingdom in National Statistics 2007 and the strategy used in the study by Bwalya 2004)

As this study focuses on the demonstration of the methodology, detailed surveys to determine the contents of typical contents of a NZ house is beyond the scope of this study. Therefore a considered approach based on available information will be used in this investigation.

Table 1: Average numbers of items in a living room per household. (Adapted from Bwalya 2004.)

Item of Furniture	Number of items per household
Small Table (e.g. side table, phone stand, etc)	1.45
Upholstered chair (e.g. recliner, covered chair, etc)	1.1
TV	1.0
Sofa	0.92
Entertainment unit	0.78
Coffee table	0.77
Bookcase	0.77
Loveseat	0.55
Magazine rack	0.33
Ottoman	0.20
Desk	0.17
Computer	0.16
Futon	0.13

2.4 Fire Suppression

Reported house fire suppression in NZ currently is typically performed by the Fire Service by applying water. Alternatives include home sprinkler systems and Fire Service intervention where foam additives are used. However recorded fire events in homes with sprinkler systems and the use of foam additives during suppression activities are not statistically significant in NZ. Therefore to include the effect of alternatives to Fire Service intervention using water-only suppression, the suppression effectiveness needs to be incorporated into house fire GHG emissions framework when such values become available.

The effectiveness of home sprinkler systems in a NZ context has been considered previously (Duncan et al. 2000; Robbins et al. 2008) and the values for suppression effectiveness used in these previous studies have been based on laboratory test results. The suppression effectiveness of water foam additives have also been tested in laboratory settings (Madrzykowski 1998). The emissions from the added foams, as these come into contact with flames and hot and burning materials, must also be included in considerations.

2.5 Conclusions

No published literature quantifying the impact of green house gas emissions from house fires currently exists. There is limited published literature concerning green house gas emissions associated with house fires. Information that is useful in estimating the parameter values that effect green house gas emissions has been collated here. There are many gaps in the available information. Some strategies for dealing with this lack of information have been outlined here. However this lack of available data is not seen to halt the development of a methodology to quantitatively assess the impact of green house emissions from fires and the demonstration example of house fires.

Since the impact of green house gas emissions associated with a house fire has not been previously quantitatively studied, the most influential parameters have not yet been identified. Therefore care has been applied during this research when making assumptions about what information is required and where information and data are not currently available.

3. APPROACH

3.1 General

The methodology for developing a house fire GHG emissions calculation tool is described in this section. The tool uses the metric tonnes of CO_2 Equivalent for GHG emissions, to provide consistency with the vegetation fires part of this research project and other GHG emission studies.

The variables used in the tool include:

- Numbers of house fire incidents per year,
- Areas of flame damage (or conversely areas saved),
- Exemplar houses for common construction combinations and contents, identifying materials and quantities per unit of floorarea,
- Distributions of house floorarea, and
- Material GHG potential yields.

A full list of the framework input parameters are presented in Table 3 and the assumptions for the estimated values are discussed in Section 1.

The GHG emissions that were considered within this framework are only associated with those emitted during a house fire by the burning structure materials and contents items. GHG emissions associated with suppression activities or replacement of structure or contents was not included in this framework, since these aspects have been considered in previous studies (e.g. Robbins, Wade et al. (2008) or PriceWaterhouseCoopers (2008)) that may be used in conjunction with the results from this tool without the overlap of specific content.

To reduce the impact of specific assumptions, the framework is designed utilising an analysis period that can be specified by the user. This analysis period starts with the current year and then estimates the impact forward, for future years, up to the analysis period specified by the user. The results are then reported in terms of CO_2 Equivalent per year.

It was expected that not all values for the input parameters would be available during the timeframe of this study. However the framework was intentionally developed to be inclusive. Therefore updated values can be added to the framework as they become available.

A few scenarios for different potential suppression methods were investigated and compared to provide comparison of the results based on the available data for tool input parameters. These are summarised in Section 3.3.1 and the results are presented in Section 5.

A sensitivity analysis was also performed to identify important parameters and assess the influence of estimated parameter values and distributions. The analysis is discussed in Section 3.3.2 and the results are presented in Section 5 following the results of the relevant Scenario.

3.2 Emissions Calculations & Metrics

To be in alignment with the vegetation fire part of this project as well as previous studies, such as the Price Waterhouse Coopers study that calculated the total GHG emissions for the New Zealand Fire Service (PriceWaterhouseCoopers, 2008), the estimates for GHG emissions from house fires will also utilise the metric of CO_2 Equivalent. This will allow indicative comparisons with the results from other studies; however it is cautioned that the numerical values will not be comparable because of the assumptions needed to be made for the input parameter values, as discussed in the following section.

CO_2 Equivalent is the estimate of the quantity that describes the amount of carbon dioxide that would have the same the Global Warming Potential (GWP), when measured over a timescale of 100 years, for a mix of greenhouse gases. The metric used to describe this potential of a particular gas combines a measure of how strongly it absorbs infrared radiation, and how long it stays in the atmosphere. Therefore the GWP of a particular gas of interest describes the mass of carbon dioxide that would provide the equivalent Global Warming effect over a specified period of time as one kilogram of the particular gas of interest. A 100-year time horizon is commonly used internationally for calculating CO_2 Equivalent. Table 2 presents the Global Warming Potential of a selection of gases.

Table 2: Examples of Global Warming Potential of selected gases.

Gas	Carbon Dioxide (CO_2)	Methane (CH_4)	Nitrous Oxide (N_2O)
Global Warming Potential	1	21	310

GHG emissions from the production, transport, etc. (cradle to gate) of the materials involved with the replacement 'cost' of materials as installed in the house construction and contents are not included in this framework. These aspects have been included in the previous study for a home sprinkler system cost effectiveness analysis incorporating sustainability issues (Robbins, Wade et al. 2008). The framework developed here is intentionally designed not to incorporate aspects of this previous framework, thus the results from both of these studies can be combined without counting any contribution twice.

3.2.1 GHG Emission Potential of the Materials Involved

In terms of material-related GHG emissions of house fires, it was initially assumed likely that CO_2, CH_4 and NOx yields would be available for materials burning in incineration conditions; however these values were unavailable within the timeframe required for this project. If these values become available in the future, some assumptions will have to be made in the use of incineration figures for a lower temperature house fire event.

Therefore it was expected that yields for CO_2, CH_4 and NOx would not be available for all types of materials included in this demonstration of concept. Subsequently the framework developed and described here has the capacity to include these additional yields as more appropriate values become available.

Values for CO_2 yields were estimated from limited experimental results and handbook values, where available. With this limitation the GHG emissions estimates are limited to CO_2 yields for the majority of materials that will are included in this demonstration of concept. A summary of the species yield values used in this study are presented in Sections 4.9.1 and 4.10.1.

3.3 Emissions Calculation Tool

The tool developed to calculate CO_2 equivalency was implemented using Microsoft® Excel and Palisade Corp. @RISK. MS Excel was chosen because of the common usage of this product and therefore provides future proofing of the tool for revisions as more data becomes available. The @RISK software (a commercial MS Excel add-in) was chosen because it offers one approach to input parameters as distributions instead of single values. This software also facilitates a systematic way of performing a sensitivity analysis.

The output of the tool is an estimate of GHG emissions in metric tonnes of CO_2 Equivalent.

The results were presented in terms of CO_2 Equivalent per year, per NZ household, and per fire for comparison.

GHG emissions were only considered in terms of gaseous species release. That is, the total amount of carbon was not used in the calculations, only the estimated yield of CO_2.

3.3.1 Scenarios

Scenarios were selected for consideration to provide a comparison for the results of the estimated GHG emissions using the framework described here. Because of the assumptions involved in the estimation of the parameters influencing GHG emissions made in this study, it is recommended that the results from this model be used to compare different scenarios instead of direct comparison with numerical results from other models.

The scenarios that were considered are:

1. Total fire loss of an exemplar house structure,
2. Total fire loss of an exemplar house contents,
3. House fires with fire suppression remaining the same as reflected in current fire incident statistics,
4. Home fires where home sprinkler systems (according to NZS4517) are present with NZFS intervention using water (if needed),
    - This scenario assumes the mandatory installation of home sprinklers in every new house built and a rate of retrofit such that the current building stock has NZS4517 system in 10 years.
5. An increase in house fire losses to an equivalent percentage of floorarea loss per fire of 50%.

Scenarios 1 and 2 provide baselines for the maximum GHG emissions per house fire.

3.3.2 Sensitivity Analysis

A sensitivity analysis was performed to identify the most influential parameters and the impact of distributions of the input parameters. The results of this analysis are presented in Section 5 for each Scenario.

3.4 Methodology

Since the type and amount of materials involved in the construction and contents of a New Zealand house vary so much throughout the current housing stock, the approach was taken to consider the impact as a nation over a specified number of years. This approach evens out the assumptions of the specific types and amounts of materials involved in each specific house fire to provide an indication of the magnitude of the overall impact.

The house fire GHG emissions framework input parameters are listed with a brief description in Table 3. A list of the house fire GHG emissions framework output variables is presented in Table 5 and the calculation methods employed are presented in Table 6.

Where input distributions were estimated, a Program Evaluation and Review Technique (PERT) distribution (identifying the best, maximum and minimum values to form a triangular distribution) was used, unless a more appropriate (such as a normal or uniform) distribution was identified.

The framework was run for 10,000 iterations, using Latin Hypercube sampling with a random seed generator.

3.4.1 House Fire GHG Emissions Framework Input Parameters

The house fire GHG emissions framework input parameters are listed with a brief description in Table 3. The framework input parameters associated with the potential impact of home sprinkler systems (as considered in Scenario 4) are listed with a brief description in Table 4.

Table 3: List of house fire GHG emissions framework input parameters.

Name	Symbol	Brief Description
Initial number of house structure fires per year	F_0	The current number of house fires per year. The number of house fires each year is assumed to be proportional to the number of houses, $F_t = \frac{H_{t,all}}{H_{0,all}} F_0$
Floorarea of house lost to fire	$A_{\%\,lost}$	The percentage of floorarea lost to fire of the exemplar house.
Current number of households	$H_{0,all}$	The current number of houses. The number of houses is assumed to increase at a uniform rate, $H_t = H_{0,all} tr_{house}$
Increase in households per year	r_{house}	An estimate of the average percentage increase of the number of house per year over the chosen analysis period.
Discount rate	$r_{discount}$	Estimated discount rate. Similar as typically used for money. A value is not included in this study, but this parameter is included in the framework, so that if at a effective value is recommended for the use of CO_2 Equivalent then it can be utilised within this framework.
Inflation rate	$r_{inflation}$	Estimated inflation rate. Similar as typically used for money. A value is not included in this study, but this parameter is included in the framework, so that if at an effective value is recommended for the use of CO_2 Equivalent then it can be utilised within this framework.
Analysis period	$Y_{analysis}$	Number of years considered for this analysis.
Global Warming Potential of Species	G_{gas}	The Global Warming Potential of the gas (gas), as listed in Table 2.
Species yield	$Y_{gas,x}$	Mass yield of a gas species (gas , e.g. CO_2, etc.) per unit of mass of fuel for each material or item (x).
Mass of house structural component	$m_{i,j}$	Estimated mass of each structural component (j) for each combination (i) of foundation, wall and roof cladding exemplar house. The structural components are listed in Table 12 and Table 13.
Number of house contents item	n_k	Estimated number of each item of house contents (k) in the exemplar house. The estimated numbers of items of house contents are listed in Table 15.
Mass of house contents item	m_k	Estimated mass of each contents item (k) for the exemplar house. The items of house contents and the associated estimated mass distribution are listed in Table 26.
Proportion of material burnt	$p_{A\%\,lost,x}$	Estimated proportion of each material, proxy material, item or proxy item (x) burnt for a particular amount of house floorarea burnt ($A_{\%,\,lost}$).
Proportion of fires with specific proportion of floorarea burnt	$p_{A\%\,lost,\,fires}$	Estimated proportion of fires with a particular amount of house floor area burnt ($A_{\%,\,lost}$).
Maximum number of gas species	$gas_{\max}$	The maximum number for the counter used for the gas species (gas).
Maximum number of materials considered	$j_{\max}$	The maximum number for the counter used for the materials, proxy materials, items or proxy items for structural components (j).
Maximum number of items considered	$k_{\max}$	The maximum number for the counter used for the materials, proxy materials, items or proxy items for structural components (k).

Table 4: List of house fire GHG emissions framework input parameters associated with the scenario considering the potential impact of home sprinkler systems (Scenario 4).

Name	Symbol	Brief Description
Sprinkler effectiveness	η_{sprink}	A measure, based on statistics, for a sprinkler system to activate and control a fire according to the design of the system, assuming the fire is large enough to activate the sprinkler system.
Limit of flame damage for effective sprinkler system	L_{sprink}	An assumed percentage of the total structure to which an effective sprinkler system would control the fire from spreading beyond.
Initial number of sprinklered households	$H_{0,sprink}$	The current number of NZS4517 sprinklered households. The number of sprinklered houses each year is both retrofitted and new sprinkler systems, $H_{t,sprink} = r_{retrofit}\left(H_{t-1,all} - H_{t-1,sprink}\right) + p_{new\_sprink}\left(H_{t,all} - H_{t-1,all}\right)$
Proportion of new households sprinklered	$p_{new,sprink}$	The proportion of new households built with a NZS4517 fire sprinkler system.
Rate of retrofit of sprinkler in households	$r_{retrofit}$	An estimate of the average rate of retrofit of systems in households with no fire sprinkler system currently present.
Sprinkler system life	Y_{sprink}	Number of years for the design life of the sprinkler system.
Discount rate	$r_{discount}$	Estimated discount rate
Room of fire origin – distribution of fire incident	$p_{fire,ROO}$	Proportions of fire incidents according to statistics for room of fire origin.
Proportion of fire incidents covered by an NZS4517 system	$p_{fire,NZS\ 4517}$	A proportion of the total incidents, to take into account that a NZS4517 system does not necessarily cover every room.

3.4.2 House Fire GHG Emissions Framework Output Variables

A list of the house fire GHG emissions framework output variables is presented in Table 5.

Table 5: List of house fire GHG emissions framework output variables.

Name	Symbol	Brief Description
GHG emissions from total loss of the structure of an exemplar house	$E_{exe\_struct,i}$	CO_2 Equivalent release for the total loss of the structure of the exemplar house for each combination (i) of foundation, wall and roof cladding.
GHG emissions from total loss of the contents of an exemplar house	E_{exe_cont}	CO_2 Equivalent release for the total loss of the contents of the exemplar house.
GHG emissions released by house fires	$E_{house,total}$	CO_2 Equivalent release due to house fires. The results are presented in terms of three units: 1. Equivalent CO_2 per household per year 2. Equivalent CO_2 per fire per year 3. Equivalent CO_2 per year
GHG emissions saved from being released by house fires where home sprinkler systems are effective	S_{sprink}	CO_2 Equivalent saved from being released due to house fires by an effective home sprinkler system. The results are presented in terms of three units: 1. CO_2 Equivalent per household per year 2. CO_2 Equivalent per fire per year 3. CO_2 Equivalent per year

3.4.3 House Fire GHG Emissions Framework Equations

The house fire GHG emissions framework calculation methods employed are presented in Table 6.

Table 6: List of house fire GHG emissions framework calculation methods.

Name	Calculation Method
GHG emissions from total loss of the structure of an exemplar house	$E_{exe\_struct,i} = \sum_{j=1}^{j_{max}} \sum_{gas=1}^{gas_{max}} \left(m_{i,j} p_{100\%,j} Y_{gas,j} G_{gas} \right)$ [kg $_{CO2}$]
GHG emissions from total loss of the contents of an exemplar house	$E_{exe\_cont} = \sum_{k=1}^{k_{max}} \sum_{gas=1}^{gas_{max}} \left(n_k m_k p_{100\%,k} Y_{gas,k} G_{gas} \right)$ [kg $_{CO2}$]
GHG emissions released by house fires	$E_{house,total} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{1}{H_{all,t}} \left(\frac{F_t \sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j} p_{A\%lost,j} p_{A\%lost,fires} Y_{gas,j} G_{gas} \right) \right)}{H_{all,t}} + F_t \sum_{k=1}^{k_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k p_{100\%lost,k} A_{\%lost} p_{A\%lost,fires} Y_{gas,k} G_{gas} \right) \right) \right)$ [kg $_{CO2}$ /household /year] $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\left(\frac{\sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j} p_{A\%lost,j} p_{A\%lost,fires} Y_{gas,j} G_{gas} \right) \right)}{H_{all,t}} + \sum_{k=1}^{k_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k p_{100\%lost,k} A_{\%lost} p_{A\%lost,fires} Y_{gas,k} G_{gas} \right) \right) \right)$ [kg $_{CO2}$ /fire/year] $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\left(\frac{F_t \sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j} p_{A\%lost,j} p_{A\%lost,fires} Y_{gas,j} G_{gas} \right) \right)}{H_{all,t}} + F_t \sum_{k=1}^{k_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k p_{100\%lost,k} A_{\%lost} p_{A\%lost,fires} Y_{gas,k} G_{gas} \right) \right) \right)$ [kg $_{CO2}$ /year]

GHG emissions saved from being released by house fires where home sprinkler systems are effective	$S_{sprink,total} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{1}{H_{all,t}} \left(\frac{F_t \sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j}\, p_{A\%lost,j}\, p_{A\%lost,fire} \left(\eta_{sprink} + p_{fire,NZS4517} - 1\right) Y_{gas,j} G_{gas} \right) \right)}{H_{all,t}} + F_t \sum_{k=1}^{k_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k\, p_{100\%,k}\, A_{\%lost,fires}\, p_{A\%lost,fires} \left(\eta_{sprink} + p_{fire,NZS4515} - 1\right) Y_{gas,k} G_{gas} \right) \right) \right) \quad [kg_{CO2}/household/year]$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\left(\frac{\sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j}\, p_{A\%lost,j}\, p_{A\%lost,fire} \left(\eta_{sprink} + p_{fire,NZS4517} - 1\right) Y_{gas,j} G_{gas} \right) \right)}{H_{all,t}} + \sum_{k=1}^{k_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k\, p_{100\%,k}\, A_{\%lost,fires}\, p_{A\%lost,fires} \left(\eta_{sprink} + p_{fire,NZS4515} - 1\right) Y_{gas,k} G_{gas} \right) \right) \right) \quad [kg_{CO2}/fire/year]$ $S_{sprink,total} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\left(\frac{F_t \sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j}\, p_{A\%lost,j}\, p_{A\%lost,fire} \left(\eta_{sprink} + p_{fire,NZS4517} - 1\right) Y_{gas,j} G_{gas} \right) \right)}{H_{all,t}} + F_t \sum_{k=1}^{k_{max}} \sum_{gas=1}^{gas_{max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k\, p_{100\%,k}\, A_{\%lost,fires}\, p_{A\%lost,fires} \left(\eta_{sprink} + p_{fire,NZS4515} - 1\right) Y_{gas,k} G_{gas} \right) \right) \right) \quad [kg_{CO2}/year]$

4. HOUSE FIRE GHG EMISSION FRAMEWORK INPUT PARAMETERS

The background and subsequent choice of values used for the input parameters of the framework to estimate GHG emissions from house fires, as described in Table 3, are discussed here. The input parameter values involve the amount of materials burned which will be estimated from the number of fire incidents, the amount of flame damage, proportions of types of construction and the materials used in the current New Zealand building stock.

4.1 Number of House Fires per Year

The numbers of house fires with structure damage in New Zealand based on the past fire incident statistics, as made available by the New Zealand Fire Service via the Fire Incident Reporting System (Challands 2009), are summarised in Figure 1.

The number of house fires per year used as a model input parameter value is conservatively based on the statistics for incidents with structure damage (i.e. incidents without structure damage are not included in this estimate) and 1997 to 2008 data is used. This approach is assumed to be conservative because fire incidents without structure damage would involve the burning of home contents. Therefore the contribution of CO_2 Equivalent of these incidents is not included, subsequently underestimating the amount of CO_2 Equivalent released by NZ house fires.

The estimate of the number of fires for the first year considered was a best value of 1600 fires per year, maximum value of 1800 fires per year and minimum value of 1400 fires per year.

The number of fires per year for subsequent years was assumed to be proportional to the total number of houses that year. This assumes the fire initiating propensity of the occupants, contents and structure remain the same throughout the analysis period considered.

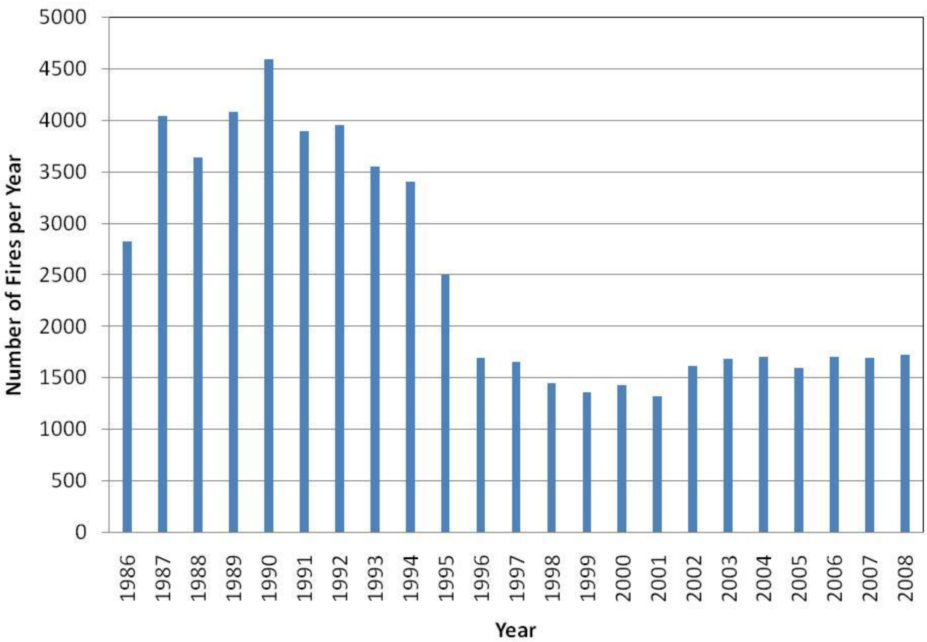


Figure 1: Number of house fire incidents with structure damage reported to the NZFS per year (1986 – 2009)

4.2 Analysis Period

The analysis period considered for this study was 50 years.

4.3 Discount Rate & Inflation Rate

Calculation of GHG emissions as estimated using the metric of CO_2 Equivalent incorporate discount rates and inflation rates. These rates were included to allow the value (or impact) of CO_2 Equivalent release, or averted release, at an earlier period in time to be of more value (or impact) compare to this happening at a later time, similar to the handling of financial models.

The values for these rates were set to zero for the purposes of this study because of the lack of data on the perceived value over time of CO_2 Equivalent release or averted release. When estimates become available for a discount rate and inflation rate (or real discount rate) of CO_2 Equivalent, the values can be entered into the current tool.

4.4 Floorarea Lost to Fire

The extent of damage per house fires is based on statistics for the estimates for the floorarea of flame damage (or the percentage of the structure saved) that are also available. An example of the summarised statistical results in Table 8 and for the period of 2005/2006 to 2007/2008 is presented in Table 9 (Challands 2009). These results are for all residential fire incidents.

These statistical values were used within the framework of the house fire GHG emissions only as an indication of the general trend in the overall statistics per year, since the uncertainty associated with the values is not quantified. (Challands 2009)

If a proportion of house contents were estimated for the extent of damage associated with the fire incidents with no structure damage, then this could be added to the framework.

The input parameter values used in the framework are those shown in Table 8. These proportions were assumed to be constant over the analysis period considered.

4.4.1 Equivalent Proportion of House Floorarea Lost to Fire

An equivalent percentage of house floorarea lost to fire can be calculated from the percentage of floorarea lost and the proportion of total fires that had the category of percentage floorarea lost. This provides an equivalent percentage of house floorarea lost to fire per fire.

Using the statistical data presented in Table 8, an example of the equivalent percentage of house floorarea lost to fire per fire is shown in Table 7. Based on the statistics for fire incidents with structure damage from the 2002 to 2006 corporate years, the equivalent percentage of house floorarea lost to fire is 29% of the housing stock that had fire events.

This approach provides one means of comparing current house fire suppression strategies (as reflected in fire incident statistics) to either general improvements in suppression strategies or reductions in suppression activities.

Table 7: Summary of the numbers of fire incidents associated with estimated areas of household property lost. Values based on statistics presented in Table 8

Average Percentage Household Area Lost	Total Number of Fire Incidents	Percentage of The Total Number of Fires	Cumulative Area Lost
100%	921	13%	13%
85%	132	1.9%	2%
75%	98	1.4%	1%
65%	169	2.4%	2%
55%	338	4.9%	3%
45%	173	2.5%	1%
35%	276	4.0%	1%
25%	410	6.0%	1%
15%	699	10%	2%
5%	3625	53%	3%
Total fires	**12962**	**100%**	**29%**

4.5 Types of Equipment Involved in Suppression

The equipment involved in suppression of the fires are also recorded in the statistics, as indicated in the example summary presented in Table 9. This summary indicates that the majority of the incidents reported here involved suppression using fire appliances, hose reels or monitors. The use of foams and sprinkler systems in these residential incidents is negligible.

Therefore it is assumed that framework input parameter values based on the current fire incident statistics provides a reasonable estimate of residential fire suppression for incidents without the use of foams or sprinkler systems (i.e. fire personnel using building facilities, portable equipment, or fire appliances, hose reels or monitors). Therefore the available fire incident statistics form the basis of the input values for Scenario 3 (Section 3.3.1). Scenario 4 is the estimate of the amount of CO_2 that would be saved due to the mandatory introduction of home sprinkler systems. The details of the framework assumptions related to home sprinkler system is discussed in Section 4.11. Similarly, as information becomes available on the use of foams in house fires, this information can be incorporated into the framework as an additional scenario for comparison.

Table 8: Summary of the numbers of fire incidents associated with estimated areas of household property lost

Average Percentage Household Area Lost	Range of Property Saved	Numbers of Fire Incidents						Percentage of The Total Number of Fires
		2002/03	2003/04	2004/05	2005/06	2006/07	Total	
100%	0-10%	179	220	193	154	175	921	7%
85%	11-20%	29	22	27	32	22	132	1%
75%	21-30%	18	16	20	25	19	98	1%
65%	31-40%	43	30	28	29	39	169	1%
55%	41-50%	60	76	59	62	81	338	3%
45%	51-60%	38	41	27	37	30	173	1%
35%	61-70%	54	55	60	61	46	276	2%
25%	70-80%	83	95	82	78	72	410	3%
15%	81-90%	132	134	143	135	155	699	5%
5%	91-100%	685	732	725	721	762	3625	28%
0%	No structural damage	1415	1283	1231	1087	1105	6121	47%
	Total fires	2736	2704	2595	2421	2506	12962	100

Table 9: Example of the statistical results available for the percentage of property saved and the equipment used in suppression activities for residential fire incidents (05/06 – 07/08) (Challands 2009)

Description of Category of Suppression	Equipment Used	Percentage of Property Saved										Total No. Fires
		0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%	
Contained by Occupant or Passer-By		19	1	2	2	8	2	4	17	42	1,138	1,236
Controlled by an In-Built Extinguishing System.	Sprinkler system	0	0	0	0	0	0	0	0	0	11	11
Fire Personnel Using Building Facility	Garden hose	2	1	0	0	1	0	1	3	6	89	103
	Extinguisher portable	0	0	0	0	0	0	0	0	0	3	3
	Hose reel fixed	0	0	0	0	0	0	0	0	1	18	19
	Power source isolated	0	0	0	0	0	0	0	0	0	96	96
	Fuel supply isolated	0	0	0	0	0	0	0	1	0	18	19
	Removal from building	0	0	0	0	0	0	0	1	0	56	57
	Bucket pump or buckets of water	1	0	0	0	0	0	1	1	1	76	80
	Fixed installations for Fire Service use	0	0	0	0	0	0	0	0	0	2	2
	Fire personnel using building facility - not classified above	0	0	0	0	0	0	0	0	0	21	21
Fire Appliance PorTable Extinguishers and Pumps.	CO_2 extinguisher	4	0	0	0	0	0	2	1	5	298	310
	Dry powder extinguisher	1	0	0	0	0	0	2	0	1	74	78
	Using portable water pump	9	1	0	1	2	0	1	0	0	18	32
Fire Appliance Hose Reels, Deliveries, Monitors.	Hose reel, high pressure delivery	254	45	37	63	147	92	118	190	376	1,598	2,920
	Low pressure delivery	164	36	20	25	59	17	29	33	46	92	521
Foam	Foam	7	0	2	1	5	3	2	3	4	11	38
No fire control needed	No fire control needed	73	8	8	13	25	5	14	22	53	3,274	3,495
	All Equipment Used	**534**	**92**	**69**	**105**	**247**	**119**	**174**	**272**	**535**	**6,893**	**9,041**

4.6 Numbers of New Zealand Housing Stock

The number of detached dwellings in 2006 by the decade in which they were built is shown in Figure 2. The total number of detached dwellings was 1.34 million in 2006.

In a previous study involving home sprinkler system (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.

The initial number of houses used in the framework was 1.4 million.

In the cost effectiveness study for home sprinkler systems in NZ a range of occupier categories was considered (e.g. owner occupier, rentals, state owned, etc.). This was not included in this current study, however the framework was developed to enable this at a future time if it is identified as of interest.

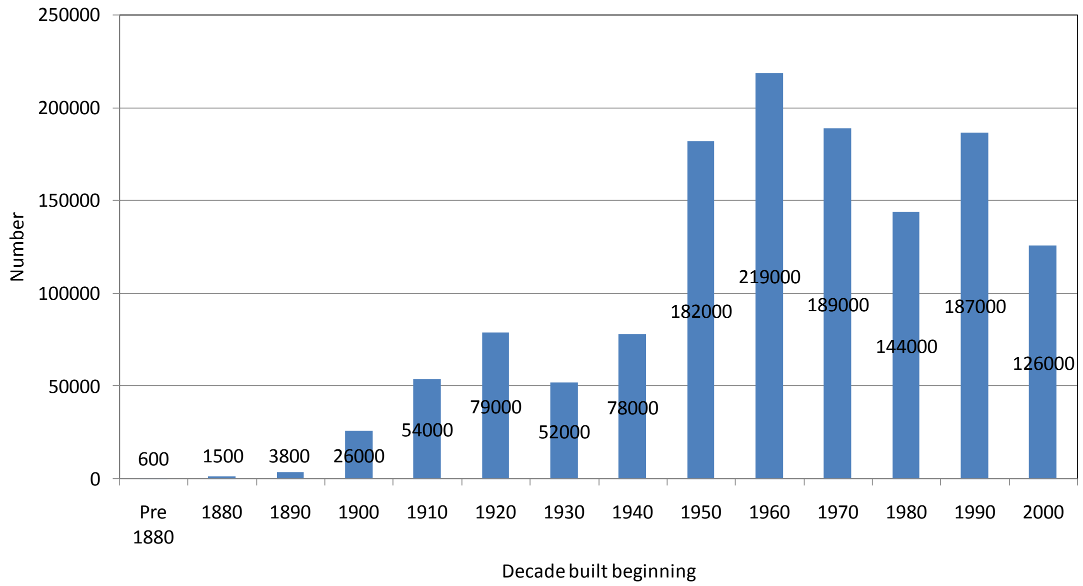


Figure 2: Number of detached residential dwellings in New Zealand by decade in which built as at 2006 (QVNZ, Census 2006, BRANZ)

4.7 Floorareas of New Zealand Housing Stock

A summary of the average floorarea according to the decade of construction for detached dwellings in 2006 is shown in Figure 3. The category denoted as mixed indicates cases where the original building had undergone renovations or extensions at a later date. The floorarea of the exemplar house used for the frame work was 195 m^2. The exemplar house is described in more detail in the following sections.

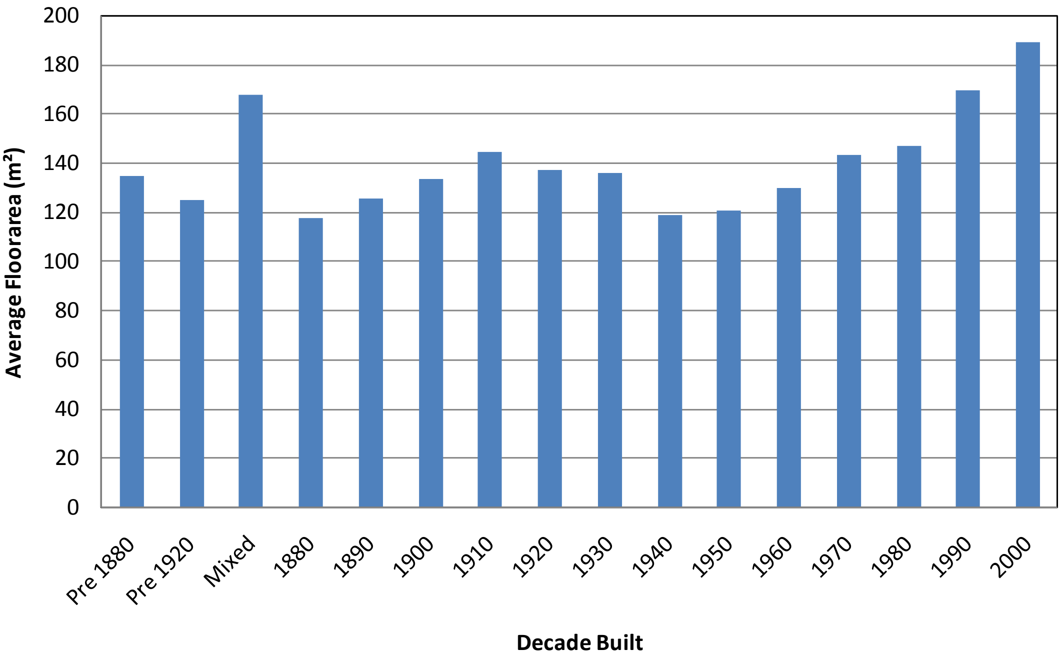


Figure 3: Average floorarea by decade in which built as at 2006 (QVNZ, Building Consents)

4.8 Construction Types of New Zealand Housing Stock

Examples of the information available on the types of wall claddings (Figure 4), flooring (Figure 5), roof claddings (Figure 6) and combinations of wall and roof claddings (Figure 7) by the year the structure was built are included to demonstrate that there are common construction components throughout the building stock. The source for this data was the BRANZ House Condition Survey (HCS) (Clark et al, 2005). This lends to the usage of an exemplar house for a select range of combinations of wall cladding, roof cladding and foundations. This is utilized in the following section for types and amounts of materials.

When considering future housing construction, the estimate for this framework is based on the most recent newly build housing, e.g. roof and wall cladding combinations for houses built in 2008, as presented in Table 10. From this information the top four combinations of roof cladding and wall claddings were estimated to represent approximately 55% of recently build houses.

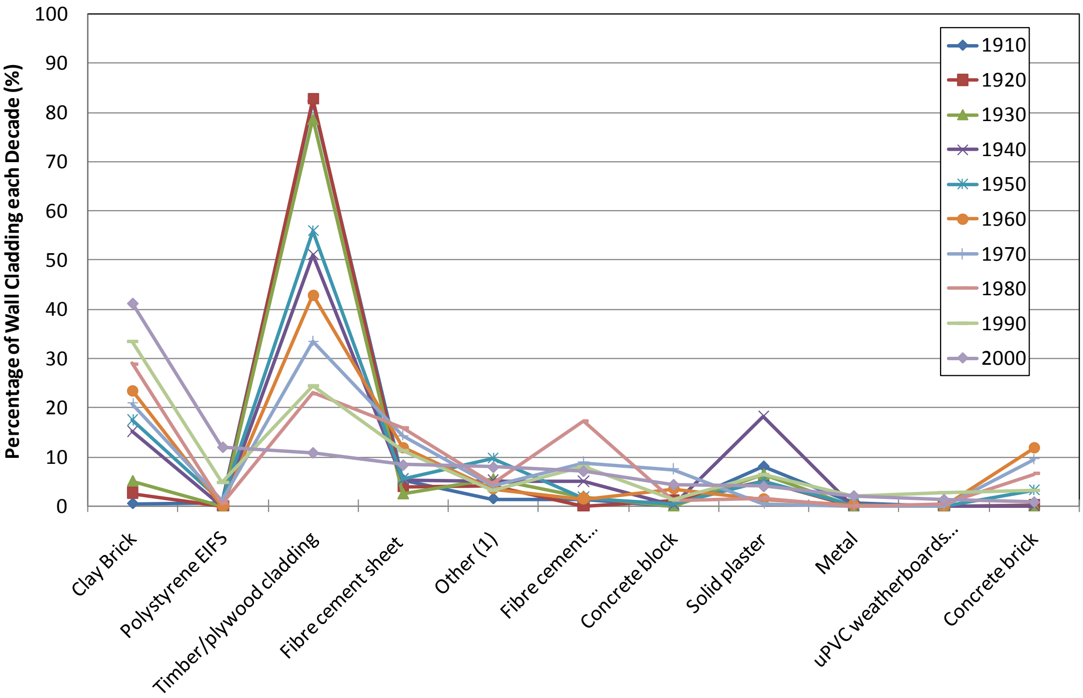


Figure 4: Percentages of each type of wall cladding used each decade (BRANZ HCS Survey)

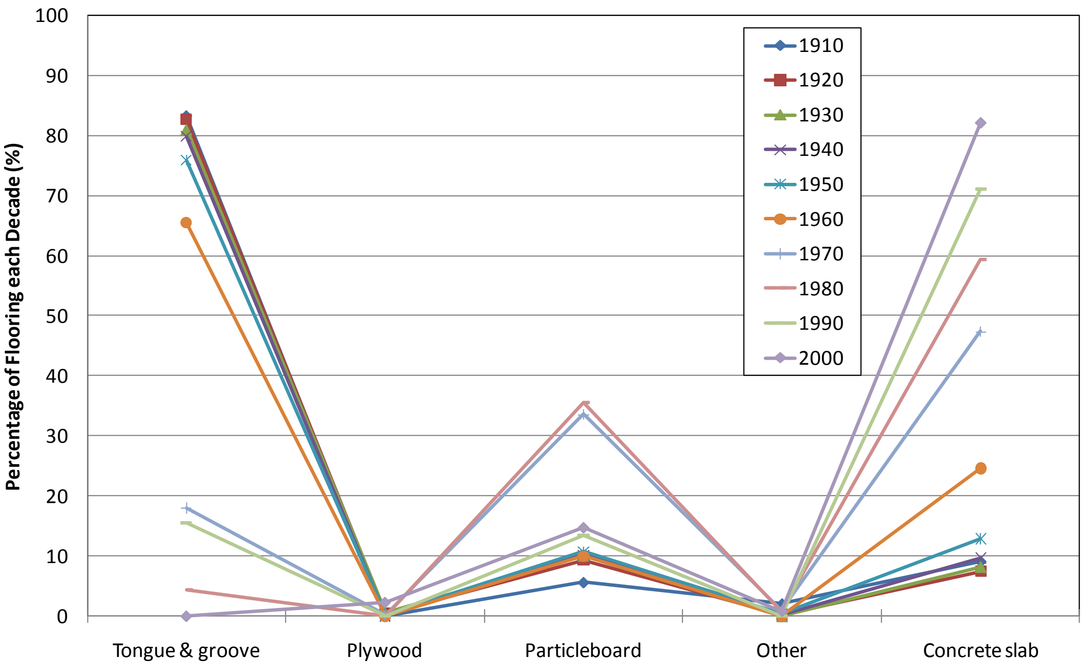


Figure 5: Percentages of each type of flooring used each decade (BRANZ HCS Survey)

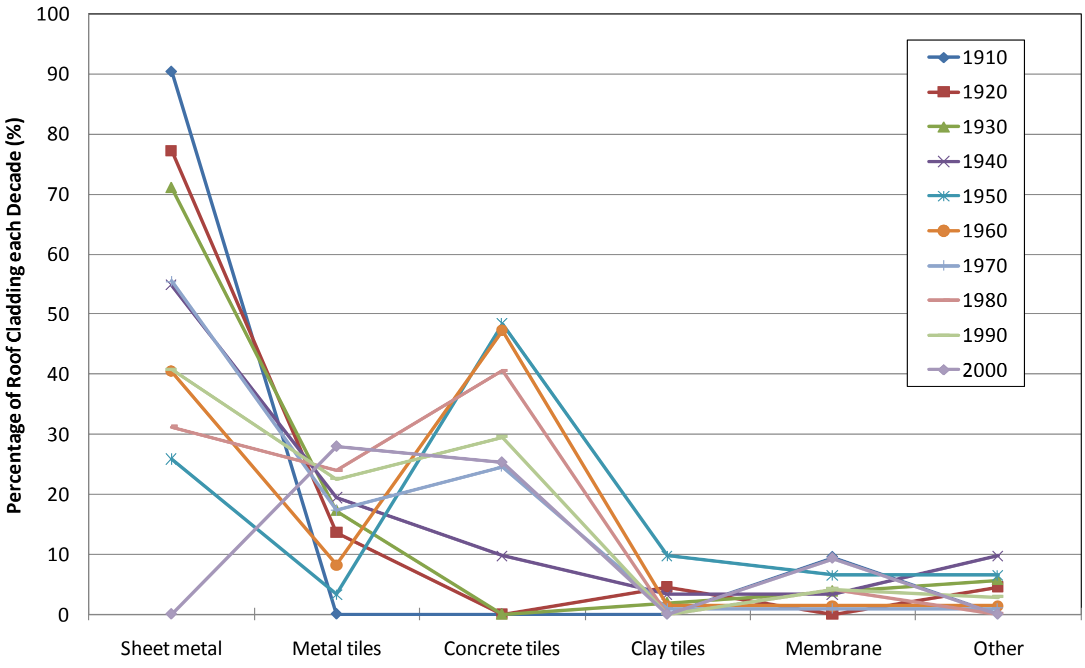


Figure 6: Percentages of each type of roof cladding used each decade (BRANZ HCS Survey)

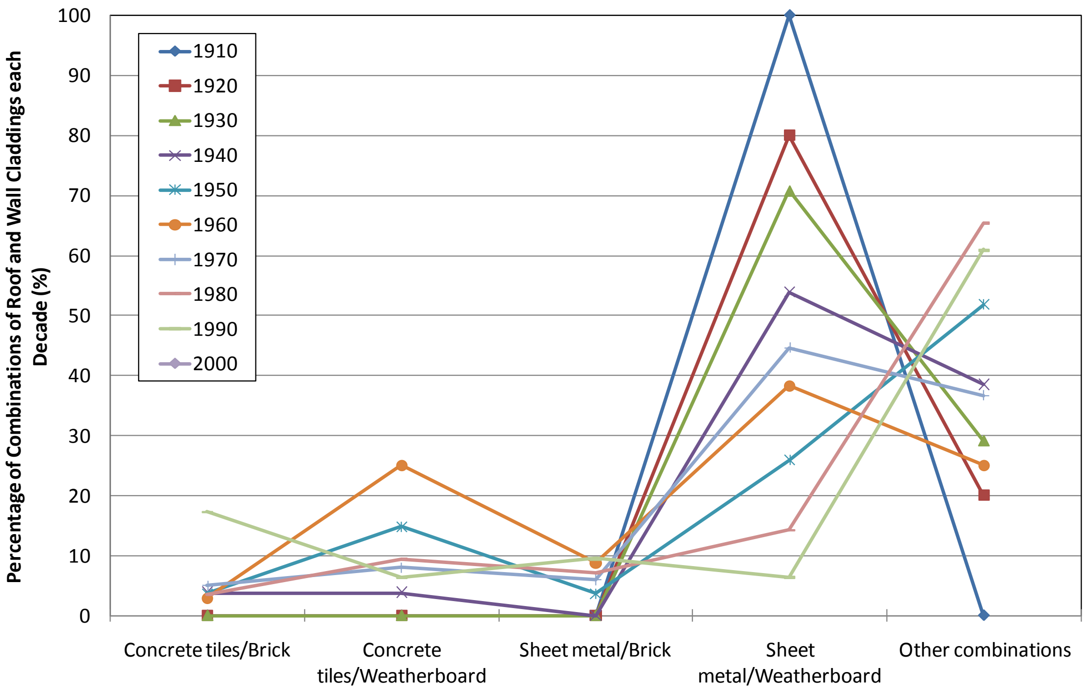


Figure 7: Percentages of selected combinations of roof and wall claddings used each decade (Page 2005)

Table 10: Roof and wall cladding combinations for houses built in 2008, based on survey results described in Page (2005).

Roof/Wall Cladding Combinations	Number	Percentage (%)
Sheet metal/brick	177	15.1
Concrete tile/brick	171	14.5
Metal tile/brick	158	13.4
Sheet metal/fibre cement weatherboard	136	11.6
Sheet metal/timber weatherboard	41	3.5
Sheet metal/EIFS	28	2.4
Metal tile/EIFS	18	1.5
Sheet metal/concrete block & panel	15	1.3
Concrete tile/EIFS	7	0.6
Concrete tile/Concrete block & panel	6	0.5
Metal tile/fibre cement weatherboard	6	0.5
Concrete tile/timber weatherboard	5	0.4
Concrete tile/fibre cement weatherboard	3	0.3
Metal tile/timber weatherboard	3	0.3
Metal tile/Concrete block & panel	3	0.3
Other combinations	399	33.9

4.9 Material Quantities of New Zealand Housing Stock

An exemplar house of 195 m² with six combinations of potential foundation, wall cladding and roof cladding combinations (as summarised in Table 11) was used as the basis for materials and quantities involved in the structure of a house that is representative of the New Zealand housing stock. The six combinations correspond to the most common combinations in the current building stock (Figure 4 to Figure 7 and Table 10), as discussed in the previous section.

The materials utilised in each of the combinations of foundation, wall and roof cladding are listed in Table 12. The common materials involved in each of the combinations considered are summarised in Table 13.

The masses of the materials used for each of the combinations considered are presented in Table 23 and Table 24.

Table 11: Combinations of foundation, wall cladding and roof cladding types considered for the exemplar house

Combination	A	B	C	D	E	F
Foundation	Slab	Slab	Slab	Timber	Slab	Timber
Wall Cladding	FC plank	Brick	Brick	FC plank	Timber weatherboard	Timber weatherboard
Roof Cladding	Sheet steel	Concrete tile	Sheet steel	Sheet steel	Sheet steel	Sheet steel

Table 12: Summary list of structural materials that were involved in foundations, external wall cladding or roofing for the exemplar house

House Component	Material Involved
Foundation	Sand blinding
	Re-steel
	Concrete blocks
	Concrete readymix
	Steel bolts/plates/straps
	PVC
	Fibre cement baseboard & soffits
	Timber piles H5
	Sawn timber H3.2 (deck)
	Framing timber H1.2
	Framing timber UT
	Deck planks H3.2
	Exterior H3.1 finish/battens
	Particle Board sheets
	Polythene DPC
	Foil insulation (floors)
External Wall Cladding	Fibre cement plank
	Brick
	Timber weatherboard
Roofing	Sheet Steel
	Concrete tile

Table 13: Summary list of structural materials involved in the internal lining and components and landscaping, etc. common to all of the six combinations of foundation, wall cladding and roof cladding for the exemplar house

House Component	Material Involved
Landscaping, etc.	Retain wall/fence timber H4
	Half round retain wall H4
	Sawn timber H3.2 (fences etc)
Internal linings	Interior UT mould, jamb, liner
	Fibre cement baseboard & soffits
	Building paper
	Windows glass
	Windows aluminium
	Insulation Fibreglass
	Plasterboard
	Wet wall lining(coated HB)
	Paint
	Wallpaper
	Carpet (pile & backing)
	Vinyl
	Nails
Other internal components	Doors

4.9.1 Structure Materials Species Yield Values

A summary of the values used for the distributions estimated for the CO_2 yield for each material involved in the structure of the exemplar house is presented in Table 14.

Table 14: Summary of the carbon dioxide yield for structure materials.

Structure Component	Material	Assumed to be Combustible	CO_2 Yield Distribution		
			Minimum Value	Best Value	Maximum Value
Foundation	Hardfill	n		-	
	Sand blinding	n		-	
	Re-steel	n		-	
	Concrete blocks	n		-	
	Concrete readymix	n		-	
	Steel bolts/plates/straps	n		-	
	PVC	y	0.3	0.46 [b]	1.1
	Fibre cement baseboard & soffits	y	1.2	1.4 [c]	1.6
	Timber piles H5	y	1.2	1.3 [a]	1.8
	Sawn timber H3.2 (deck)	y	1.2	1.3 [a]	1.8
	Framing timber H1.2	y	1.2	1.3 [a]	1.8
	Framing timber UT	y	1.2	1.3 [a]	1.8
	Deck planks H3.2	y	1.2	1.3 [a]	1.8
	Exterior H3.1 finish/battens	y	1.2	1.3 [a]	1.8
	Particle Board sheets	y	1.1	1.2 [d]	1.3
	Polythene Damp Proof Course	y	0.59 [e]		1.71
	Foil insulation (floors)	n		-	
Wall Cladding	Fibre cement Plank	n		1.4 [f]	
	Brick	n		-	
	Timber Weatherboard	n	1.2	1.3 [a]	1.8
Roofing	Sheet Steel	n		-	
	Concrete tile	n		-	
Common Materials	Paint	y	0.35	0.4 [g]	0.45
	Retain wall/fence timber H4	y	1.2	1.3 [a]	1.8
	Half round retain wall H4	y	1.2	1.3 [a]	1.8
	Sawn timber H3.2 (fences etc)	y	1.2	1.3 [a]	1.8
	Interior UT mould, jamb, liner	y	1.1 [h]		1.6
	Fibre cement baseboard & soffits	n		1.4 [f]	
	Building paper	n	1.2 [i]		1.3
	Windows glass	n		-	
	Windows aluminium	n		-	
	Insulation Fibreglass	n		-	
	Plasterboard	y	0.25	0.3 [j]	0.35
	Wet wall lining (coated Hardboard)	y		1.4 [f]	
	Doors	y	1.2 [i]		1.3
	Wallpaper	y	1.2 [i]		1.3
	Carpet pile	y	0.8 [k]		3.4
	Carpet backing	y	0.8 [k]		3.4
	Vinyl	y	0.59 [e,m]		1.71
	Nails	n		-	
	Electrical wiring	y	1.29 [n]		2.08

For Table notes see next page.

Notes (Table 14):
[a] Assumed to be an average of wood (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg from Table 3-4.14 from SFPE Handbook (2008)) for the best value and the range of values (1.2 – 1.8 kg/kg) based on real-scale in exhaust stack values (Gann et al. 2003).
[b] The best value (0.46 kg/kg) based on values published in Table 3-4.14 (SFPE 2008), and the range (0.3 – 1.1 kg/kg) from real-scale in exhaust stack measurements (Babrauskas et al. 1988).
[c] Assumed as the value for fiberboard listed in Table 3-4.14 of the SFPE Handbook (2008), then assuming ±10%.
[d] Taken as the value for particle board (1.2 kg/kg) listed in Table 3-4.14 of the SFPE Handbook (2008), then assuming ±10%.
[e] Assumed to be a uniform distribution based on the values listed in of Table 3-4.14 of the SFPE Handbook (2008) for polythene (25% chlorine 1.71 kg/kg, 36% chlorine 0.83 kg/kg, 48% chlorine 0.59 kg/kg)
[f] Assumed as the value for fiberboard listed in Table 3-4.14 of the SFPE Handbook (2008).
[g] Assumed to be similar to plastic on gypsumboard (0.4 kg/kg, (SFPE 2008)), then assuming ±10%.
[h] Uniform distribution assumed with values based on the values listed in the SFPE Handbook (2008) for rigid polyurethane building product (1.1 kg/kg) and polyurethane rigid foams (1.1 –1.6 kg/kg).
[i] Assumed to be a uniform distribution, with the values based on a combination of SFPE Handbook (2008) values for wood (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg), wood panel (1.2 kg/kg), and particle board (1.2 kg/kg).
[j] Assumed to be gypsumboard (0.3 kg/kg, (SFPE 2008)), assuming ±10%.
[k] A uniform distribution was assumed based on values from cone calorimeter data for non-fire retardant filament olefin carpet (3.36 kg/kg, 3.13 kg/kg, 2.6 kg/kg, (Grosshandler et al. 2005)), and wool (estimated to be approximately 0.8 kg/kg). The carpet value was also used for the carpet backing.
[m] Vinyl was assumed to have a similar value to polythene [e].
[n] A uniform distribution was assumed, with values based on polyethylene (1.29 – 2.08 kg/kg, (SFPE 2008)).

4.10 Material Quantities of New Zealand House Contents

There are no controls on the contents of a residence. Therefore an exemplar for residential contents was assembled from what data was available at the time of this study. Initially the materials involved in home contents for an exemplar house was approached in terms of individual component materials (e.g. cellulosic materials, cork, cotton, nylon, polyester, polyurethane, timber - pine, wool, etc.), similar to the approach used in listing the materials involved in the structural components of the exemplar house. However the data available for the amount of furniture sold in New Zealand is not useful since it is either reported in terms of total dollar amounts, such as statistics associated with the Statistics New Zealand Retail Trade Survey (SNZ 2009), Furniture Association of NZ (Dunnett 2009), Nielsen Media Research National Readership Survey (NMR 2009).

Implementation and execution of a survey of the contents of New Zealand residential spaces was beyond the initial scope of this project.

Therefore the data for the numbers (as summarised in Table 15), masses (as summarised in Table 26) and materials for this study is estimated to allow demonstration of concept of the methodology. The values used have been estimated based on results from the living room survey for Canadian homes (Bwalya 2004; Bwalya, Sultan and Benichou 2004), reported details of items of home contents used in fire experiments (e.g. Babrauskas (1980), Hietaniemi et al. (2001)), a limited survey of local New Zealand residential spaces and small samples of available local manufacturer's and supplier's information. Since the majority of fire incidents originate in kitchens, bedrooms or living rooms (as indicated in the statistics summarised in Table 17), the focus of exemplar home contents was based around these rooms. It is emphasised here that the values used are loosely indicative and have been estimated for the use within the house fire GHG emissions framework for demonstration of concept. As data becomes available, these numbers are to be updated.

The sensitivity analysis investigated the influence of the estimated parameter values and distributions associated with mass and CO_2 yield.

Table 15: Average numbers of items in the most common rooms of fire origin per household

Item Description	Estimates of the Average Number of Items in Each Room		
	Living Room	Bedroom [d]	Kitchen
Small Table (e.g. side table, phone stand, bedside table, etc)	1.45 [a]	0.6 [b]	
Upholstered chair (e.g. recliner, covered chair, etc)	1.1 [a]	0.2 [b]	
Television	1 [a]	0.75 [b]	
Sofa	0.92 [a]		
Entertainment unit	0.78 [a]		
Coffee table	0.77 [a]		
Bookcase	0.77 [a]	0.4 [b]	
Loveseat	0.55 [a]		
Magazine rack	0.33 [a]		
Ottoman	0.2 [a]		
Desk	0.17 [a]	0.7 [b]	
Computer	0.16 [a]	0.6 [b]	
Futon	0.13 [a]	0.1 [b]	
King, Queen or Double bed		0.5 [b]	
Single bed		0.6 [b]	
Drawers		1 [b]	
Built-in wardrobe		0.7 [b]	
Stand-alone wardrobe		0.3 [b]	
Clothes		1 [c]	
Manchester		1 [c]	
Toys		1 [c]	
Books/Magazines		1 [c]	
Fridge (separate or combined refrigerator-freezer, mini-bar, etc.)			1.5 [b]
Dishwasher			1 [b]
Microwave			1 [b]
Gas Stove			0.3 [b]
Electric Stove			0.7 [b]
Rangehood			0.8 [b]
Cabinet - wood finish			8 [b]
Cabinet - laminate finish			8 [b]
Table		0.5 [b]	1 [b]
Chairs		0.5 [b]	6 [b]
Washing machine			1 [b]
Dryer			1 [b]
Electrical cable (extension cords, multiboxes)	2 [b]	1 [b]	

Notes:

[a] Estimate based on a small sample of New Zealand households and the Canadian study by Bwalya (2004).

[b] Estimate based on a small sample of New Zealand households.

[c] These items are estimated to be 1 unit per bedroom.

[d] The number of items listed here estimated is per bedroom. The average number of bedrooms per house was estimated as 3.4.

4.10.1 House Contents Species Yield Values

A summary of the values used for the distributions estimated for the CO_2 yield and estimated proportion of combustible mass for each item involved in the contents of the exemplar house is presented in Table 16.

Table 16: Summary of the carbon dioxide yield for home contents items.

Item Description	Estimated Proportion of Mass of Combustibles	Average Carbon Dioxide Yield (kg/kg)			
		Minimum Value	Best/ Average Value	Maximum Value	Sample Standard Deviation
Small table	1 [a]	0.8 [d]		1.33	
Upholstered chair	0.8 [b]		1.6 [e]		0.35
TV	0.9 [a]		1.8 [g]		0.4
Sofa	0.8 [b]		1.6 [f]		0.35
Entertainment unit	0.9 [a]		2.5 [k]		0.2
Coffee table	1 [a]	1.27 [m]		1.33	
Bookcase	1 [a]		0.29 [n]		0.14
Loveseat	0.8 [b]		1.6 [e]		0.35
Magazine rack	1 [a]		0.29 [p]		0.14
Ottoman	0.8 [b]		1.6 [e]		0.35
Desk	1 [a]	0.8 [d]		1.33	
Computer	0.9 [a]		2.5 [k]		0.2
Futon	0.8 [b]		1.6 [e]		0.35
King, Queen or Double bed	0.8 [b]		1.6 [e]		0.35
Single bed	0.8 [c]		1.6 [e]		0.35
Drawers	1 [a]	0.8 [d]		1.33	
Stand-alone wardrobe	0.8 [a]	0.8 [d]		1.33	
Clothes	1 [a]	1.5 [q]		2.2	
Manchester	1 [a]	1.5 [r]		1.6	
Toys	1 [a]	1.5 [r]		2.2	
Books/Magazines	1 [a]	1.27 [s]		1.33	
Fridge	0.5 [a]		2.22 [j]		0.07
Dishwasher	0.5 [a]		1.62 [i]		0.02
Microwave	0.3 [a]		2.5 [k]		0.2
Gas Stove	0.2 [a]		2.5 [k]		0.2
Electric Stove	0.2 [a]		2.5 [k]		0.2
Rangehood	0.3 [a]		2.5 [k]		0.2
Cabinet - wood finish	1 [a]	1.27 [s]		1.33	
Cabinet - laminate finish	1 [a]	0.8 [t]		1.2	
Table	1 [a]	0.8 [d]		1.33	
Chairs	1 [a]	1.2 [u]		1.9	
Washing machine	0.3 [a]		2.43 [h]		0.34
Dryer	0.3 [a]		2.5 [k]		0.2
Electrical cable	0.8 [a]		0.12 [v]		0.05

For Table notes see next page.

Notes (Table 16):

[a] No published data available, therefore values were estimated.

[b] Values assumed to be similar to bed values, therefore used bed values from experiments by Babrauskas (1980).

[c] Single mattress values were based on the values published for experiments performed by Babrauskas (1980).

[d] Assumed to be a uniform distribution based on values listed in Table 3-4.14 (SFEP 2008) for melamine-faced particle board (0.8 kg/kg), wood panel (1.2 kg/kg), and wood (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg).

[e] Assuming a sofa as a proxy furniture item.

[f] A normal distribution was assumed based on published sofa values: pre-flashover 0.8 kg/kg ±0.17 and post-flashover 0.57 kg/kg ±0.12 (Gann et al. 2003); and upholstered cushions values in a steel frame: pre-flashover 1.59 kg/kg ±25% and post-flashover 1.13 kg/kg ±25% (Gann et al. 2007).

[g] Assumed to be a normal distribution based on the average and standard deviations of free-burning televisions: television sets (average 2.560 kg/kg, standard deviation 0.110kg/kg) (Hietaniemi et al. 2001), and for non-fire retardant specimens (1.39 kg/kg) and fire retardant specimens (0.74 kg/kg) (Babrauskas et al. 1988).

[h] Assumed to be a normal distribution based on the average and standard deviations of free-burning washing machines: 2.43 kg/kg, 0.34 kg/kg (Hietaniemi et al. 2001).

[i] Assumed to be a normal distribution based on the average and standard deviations of dishwashers burning in a cupboard: 1.62 kg/kg, 0.02 kg/kg (Hietaniemi et al. 2001).

[j] Assumed to be a normal distribution based on the average and standard deviations of free-burning refigerator-freezers: 2.22 kg/kg, 0.07 kg/kg (Hietaniemi et al. 2001).

[k] Assumed to be similar to the average and standard deviation of free-burning appliances (television sets [g]: 2.56 kg/kg, 0.11 kg/kg; washing machines [h]: 2.43 kg/kg, 0.34 kg/kg; dishwashers: 2.81 kg/kg, 0.27 kg/kg (Hietaniemi et al. 2001); refrigerator-freezers [j]: 2.22 kg/kg, 0.07 kg/kg)

[m] Assumed to be a uniform distribution, with values based on those listed in Table 3-4.14 (SFPE 2008) for (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg), and real-scale wood crib values measured in the exhaust stage (1.2 – 1.8 kg/kg) (Babrauskas et al. 1988).

[n] Assumed to be a normal distribution, with values based on average and standard deviation values from experimental measurements for a particle board bookcase: pre-flashover 0.29 kg/kg ±0.4, post-flashover 1.10 kg/kg ±0.80 (Gann et al. 2003), wood: red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg from Table 3-4.14 of (SFPE 2008), and room-scale fire tests of particle board with laminated PVC: pre-flashover 0.5+/-50%, post-flashover 0.12+/-45% (Gann et al. 2007).

[p] Assuming similar values to a bookcase (see note n).

[q] Assuming a uniform distribution, with values based on Nylon (2.06 kg/kg), Polyester (polyester-1: 1.65 kg/kg and polyester-2: 1.56 kg/kg) from Table 3-4.14 in SFPE Handbook (2008).

[r] Values were assumed to be similar to clothes.

[s] Assumed to be a uniform distribution, with values assumed to be similar to wood (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg) (Table 3-4.14 of SFPE 2008)

[t] Assumed to be a uniform distribution, with values based on melamine-faced particle board (0.8 kg/kg) and wood panel (1.2 kg/kg) from Table 3-4.14 of SFPE Handbook (2008).

[u] Assuming a uniform distribution, with values based on furniture calorimeter data (1.89 kg/kg) and cone calorimeter data (1.62 kg/kg) for mock chairs with a small nylon fabric covered polyurethane foam cushion (Babrauskas et al. 1988), and wood (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg) from Table 3-4.14 of SFPE Handbook (2008).

[v] Assuming a normal distribution, with values based on cable experiments with measurements reported for pre-flashover (0.057 kg/kg ±0.024), post-flashover (0.65 kg/kg ±0.10) (Gann et al. 2003), and pre-flashover(0.12 kg/kg ±45%) and post-flashover (1.38 kg/kg ±15%) (Gann et al. 2007).

4.11 Home Sprinkler Systems

Home sprinkler systems were considered in a New Zealand context in previous studies by Wade and Duncan (2000) and Robbins, Wade, et al. (2008). Therefore information available from these studies was used where appropriate. The following is a summary of the assumptions and input parameter values used in the framework for CO_2 Equivalent estimates within the context of Scenario 4 (Section 3.3.1).

4.11.1 Sprinkler Effectiveness

A summary of the information available on sprinkler system effectiveness is presented in Table 27. For this study an estimate of the overall effectiveness was used, combining suppression effectiveness when a system activates and the operational reliability of the system. The following is a summary of relevant published literature on sprinkler system effectiveness and reliability.

The estimate of the overall effectiveness of a home sprinkler was a best value of 95% with a maximum value of 99% and a minimum value of 90%, in alignment with the previous study by Robbins, Wade et al. (2008).

4.11.2 Limit of Flame Damage for Effective Sprinkler Operation

A maximum limit for flame damage of a residential structure was estimated, assuming effective operation of a home sprinkler system. There is currently no published literature that specifically relates to such a limit, therefore a conservative estimate was made of a mean damage limit of 5% of a structure, with a minimum of 2% and a maximum of 7%. These estimates are expected to be conservative, i.e. greater than would be expected for an effective home sprinkler system, and are in alignment with values used in a previous study related to home sprinkler systems (Robbins, Wade et al. 2008).

4.11.3 Distribution of Rooms of Fire Origin

The percentage distributions of the room of fire origin for residential fire incidents based on recorded statistics are presented in Table 17 for a range of countries. A comparison of the percentage distributions for fire incidents for various countries is shown in Figure 8. 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 summary of the values assumed for the current framework is presented in Table 17. These values were primarily based on the New Zealand statistics.

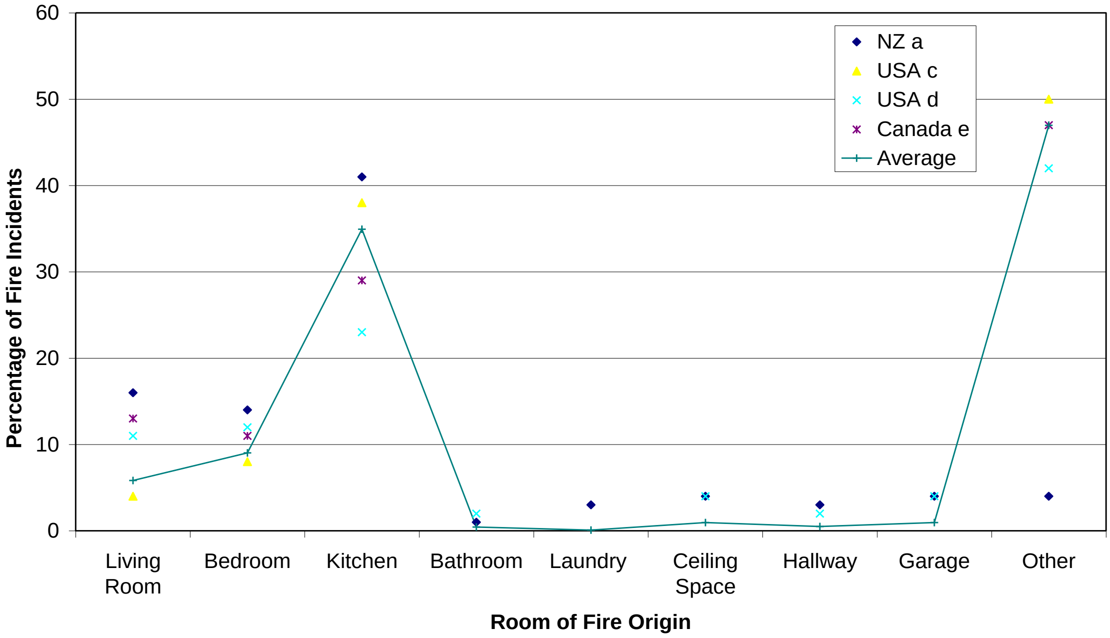


Figure 8: Percentages of residential structure fire incidents for various countries over various periods. (Extracted from Robbins, Wade et al. (2008). Details are presented in Table 17.)

Table 17: Summary of the distribution of fire incidents by room of fire origin used in the current framework

Room of Fire Origin	Percentage of Fire Incidents
Living Room	16
Bedroom	14
Kitchen	41
Bathroom	1
Laundry	3
Ceiling Space	4
Hallway	3
Garage	4
Other	14

4.11.3.1 Proportion of Structure Covered by NZS 4517

Since NZS 4517 does not require full coverage of all areas of a structure for which it is designed, a conservative approach was taken by including a coverage parameter. That is the coverage parameter for averting potential fire incidents is related to the proportion of the rooms covered by NZS 4517. For example, bathrooms and ceiling spaces do not have mandatory sprinkler coverage according to NZS 4517. Therefore when considering the coverage of home sprinklers, these spaces are excluded. As a conservative approach the 'other' category, as shown in Table 17, was also not included in the coverage of a NZS 4517 system.

The estimated values of coverage of a NZS 4517 system used for room of fire origin for fire incidents was 81% ± 5%.

4.11.4 Sprinkler System Life

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

5. RESULTS

The scenarios that were considered are:

1. Total fire loss of an exemplar house structure
2. Total fire loss of an exemplar house contents
3. House fires with fire suppression remaining the same as reflected in current fire incident statistics,
4. House fires where home sprinkler systems (according to NZS4817) are present with NZFS intervention using water (if needed), and
5. An increase of equivalent percentage of floorarea loss per fire to 50%.

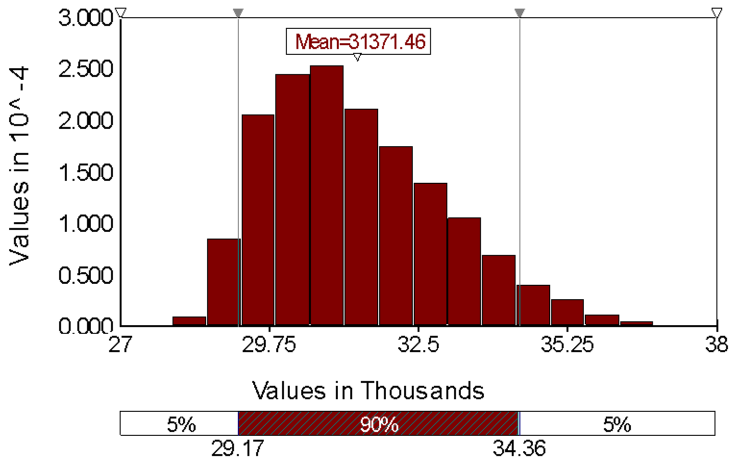
The results for each of these Scenarios are presented in the following Sections.

5.1 Scenario 1: Total fire loss of an exemplar house structure

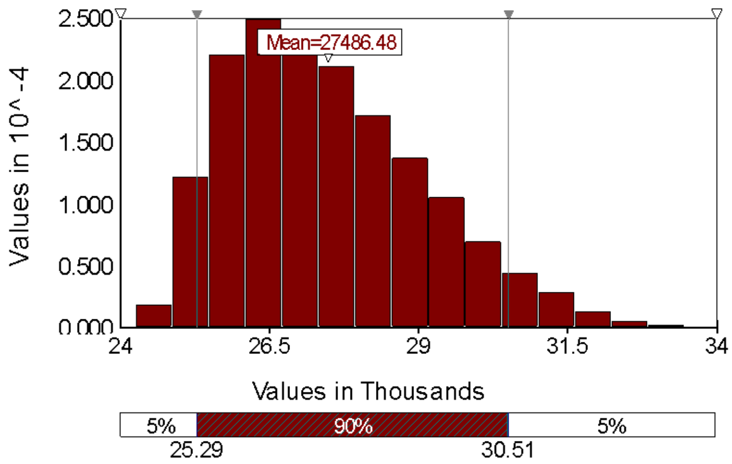
The results for Scenario 1 are summarised in Table 18 and Figure 9.

Table 18: Summary of the results for Scenario 1.

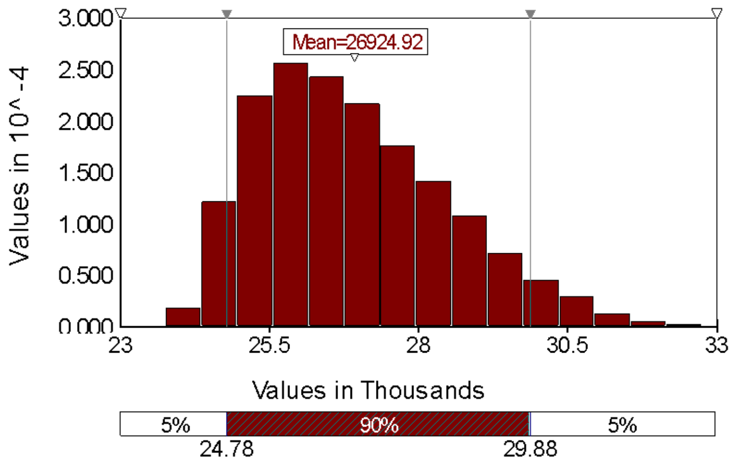
	Total CO_2 Equivalent Released by the Total Fire Loss of each Combination of 195 m^2 Exemplar House (kg CO_2)					
	A	B	C	D	E	F
Minimum	28,000	24,000	24,000	34,000	27,000	33,000
Maximum	37,000	33,000	33,000	46,000	38,000	46,000
Mean	31,000	27,000	27,000	38,000	31,000	37,000
Standard Deviation	1,600	1,600	1,600	2,000	1,900	2,300



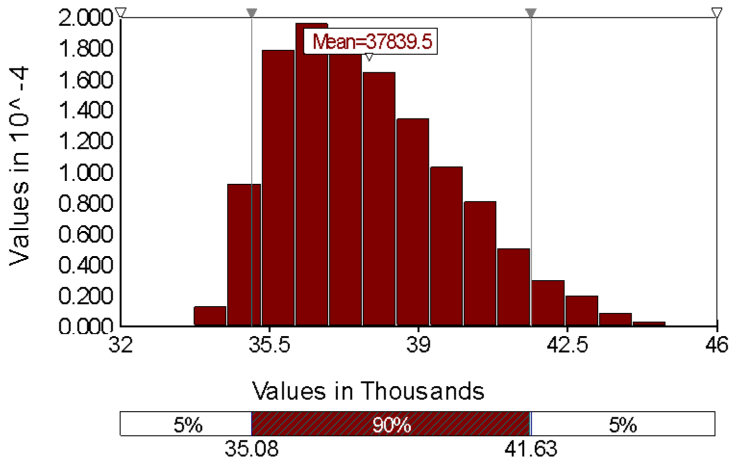
(a)


Values in 10^-4
2.500
2.000
1.500
1.000
0.500
0.000
24
26.5
29
31.5
34
Mean=27486.48
Values in Thousands
5%
90%
5%
25.29
30.51

(b)


Values in 10^-4
3.000
2.500
2.000
1.500
1.000
0.500
0.000
23
25.5
28
30.5
33
Mean=26924.92
Values in Thousands
5%
90%
5%
24.78
29.88

(c)


Values in 10^-4
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1.600
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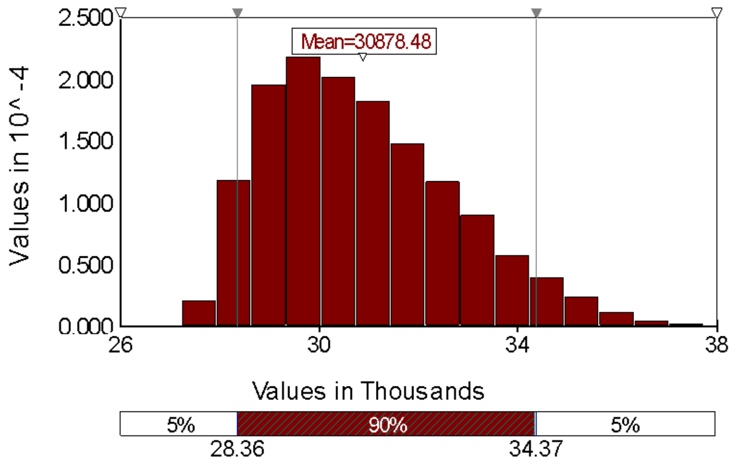
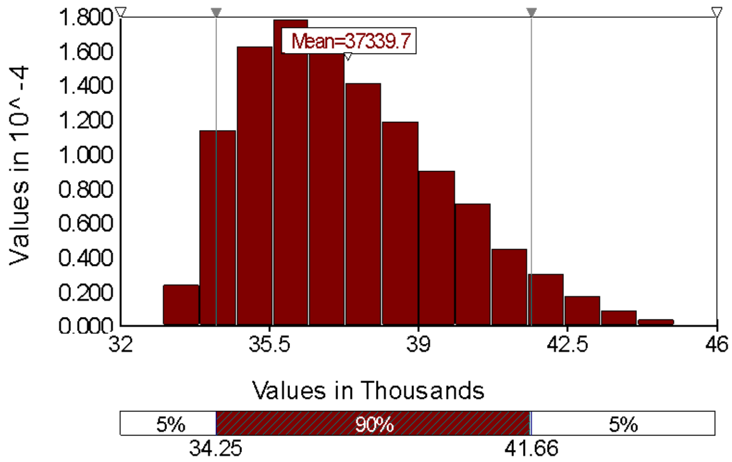
1.000
0.800
0.600
0.400
0.200
0.000
32
35.5
39
42.5
46
Mean=37839.5
Values in Thousands
5%
90%
5%
35.08
41.63

(d)



(e)

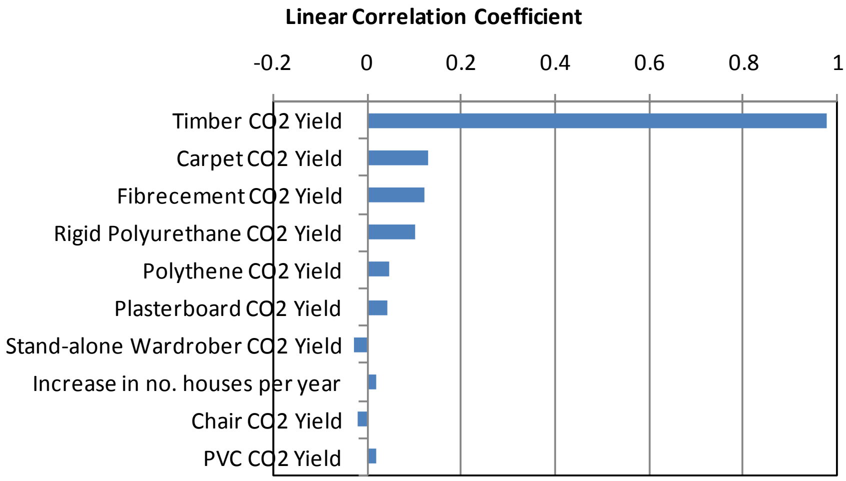


(f)

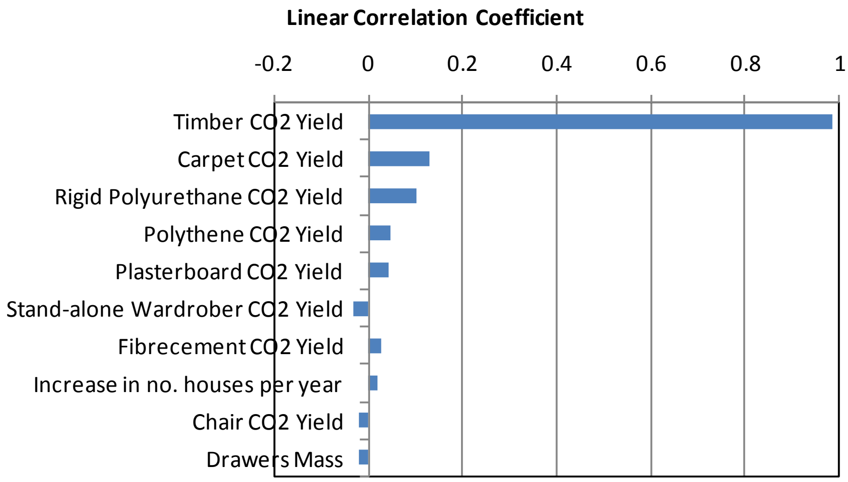
Figure 9: Summary of the results for Scenario 1 for each of the Exemplar house combinations considered: (a) Type A (b) Type B, (c) Type C, (d) Type D, (e) Type E and (f) Type F.

5.1.1 Sensitivity Analysis

The results for the Scenario 1 sensitivity analysis are summarised in Figure 10.


Linear Correlation Coefficient
-0.2
0
0.2
0.4
0.6
0.8
1
Timber CO2 Yield
Carpet CO2 Yield
Fibrecement CO2 Yield
Rigid Polyurethane CO2 Yield
Polythene CO2 Yield
Plasterboard CO2 Yield
Stand-alone Wardrober CO2 Yield
Increase in no. houses per year
Chair CO2 Yield
PVC CO2 Yield

(a)


Linear Correlation Coefficient
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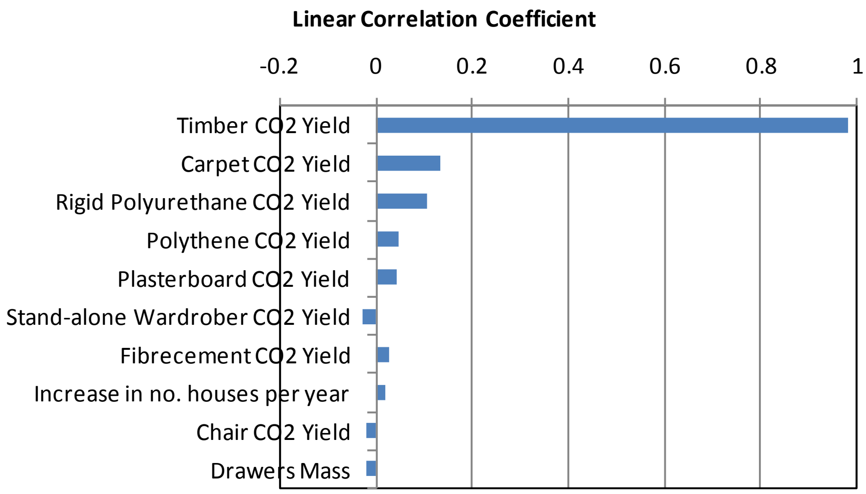
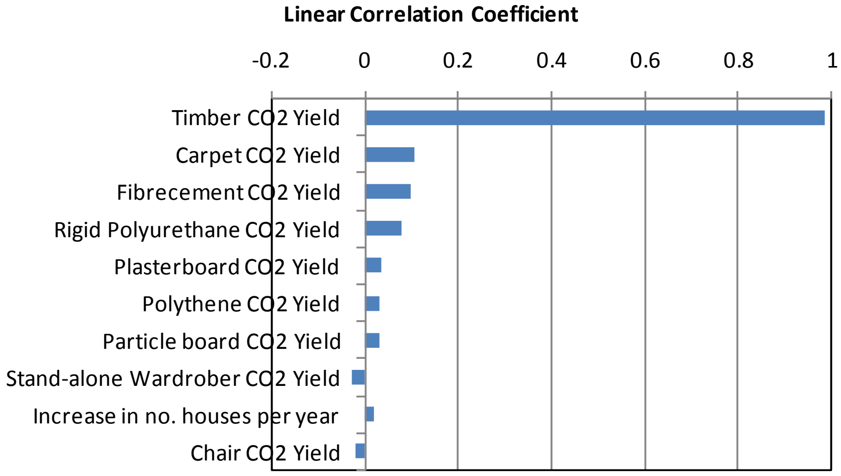
0
0.2
0.4
0.6
0.8
1
Timber CO2 Yield
Carpet CO2 Yield
Rigid Polyurethane CO2 Yield
Polythene CO2 Yield
Plasterboard CO2 Yield
Stand-alone Wardrober CO2 Yield
Fibrecement CO2 Yield
Increase in no. houses per year
Chair CO2 Yield
Drawers Mass

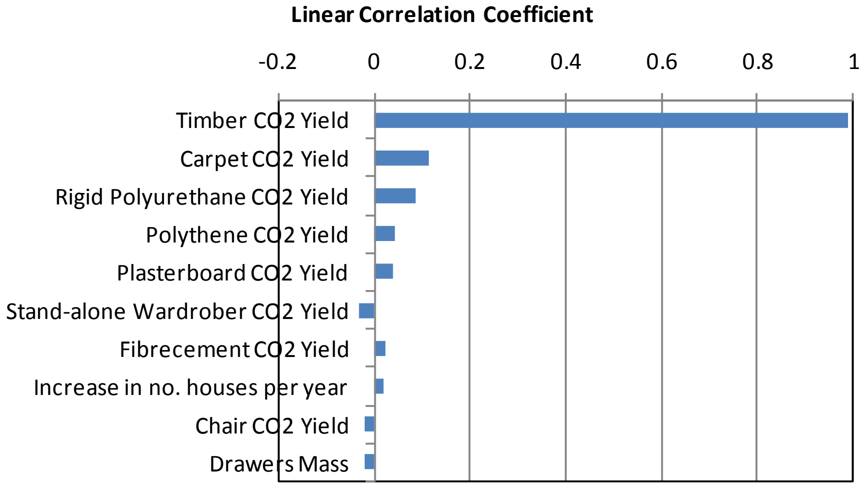
(b)


Linear Correlation Coefficient
-0.2
0
0.2
0.4
0.6
0.8
1
Timber CO2 Yield
Carpet CO2 Yield
Rigid Polyurethane CO2 Yield
Polythene CO2 Yield
Plasterboard CO2 Yield
Stand-alone Wardrober CO2 Yield
Fibrecement CO2 Yield
Increase in no. houses per year
Chair CO2 Yield
Drawers Mass

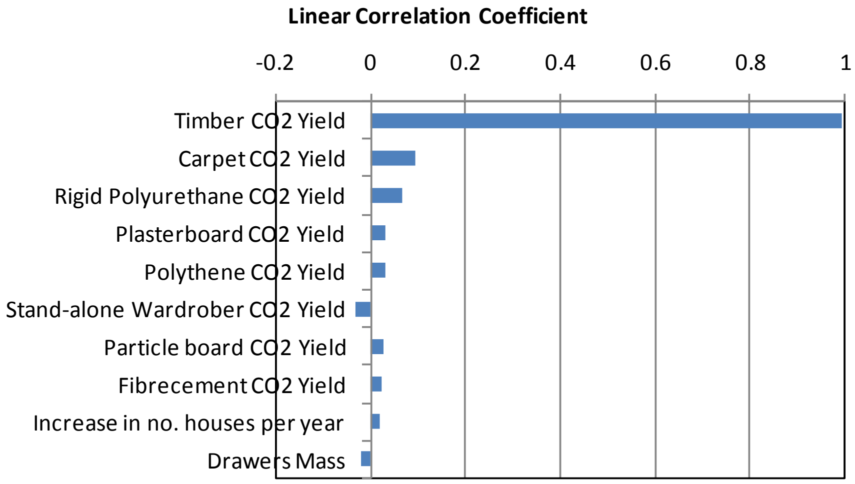
(c)



(d)



(e)



(f)

Figure 10: Summary of the top ten influential input parameters, based on fibre cement weatherboard correlation coefficients, for Scenario 1 for each of the Exemplar house combinations considered: (a) Type A (b) Type B, (c) Type C, (d) Type D, (e) Type E and (f) Type F.

5.2 Scenario 2: Total fire loss of an exemplar house contents

The results for Scenario 2 are summarised in Table 19 and Figure 11.

Table 19: Summary of the results for Scenario 2 for the CO_2 Equivalent released due to the total fire loss of the exemplar home contents.

	Total CO_2 Equivalent Released by the Total Fire Loss of the Contents of the 195 m² Exemplar House (kg CO_2)
Minimum	4,700
Maximum	7,500
Mean	6,000
Standard Deviation	400

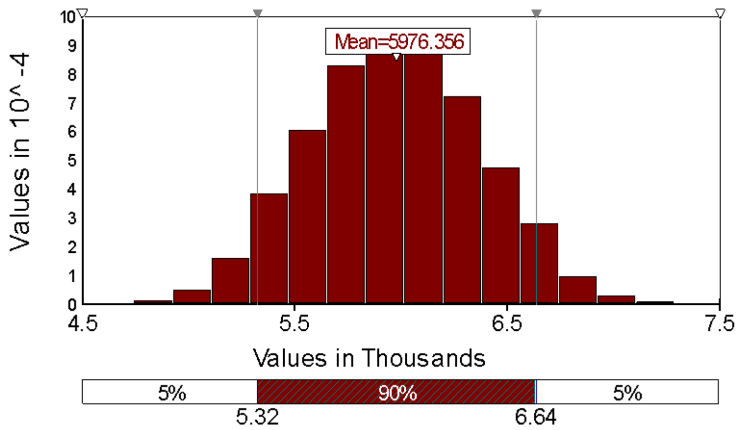


Figure 11: Summary of the results for Scenario 2 for the CO_2 Equivalent released due to the total fire loss of the exemplar home contents.

5.2.1 Sensitivity Analysis

The results for the Scenario 2 sensitivity analysis are summarised in Figure 12.

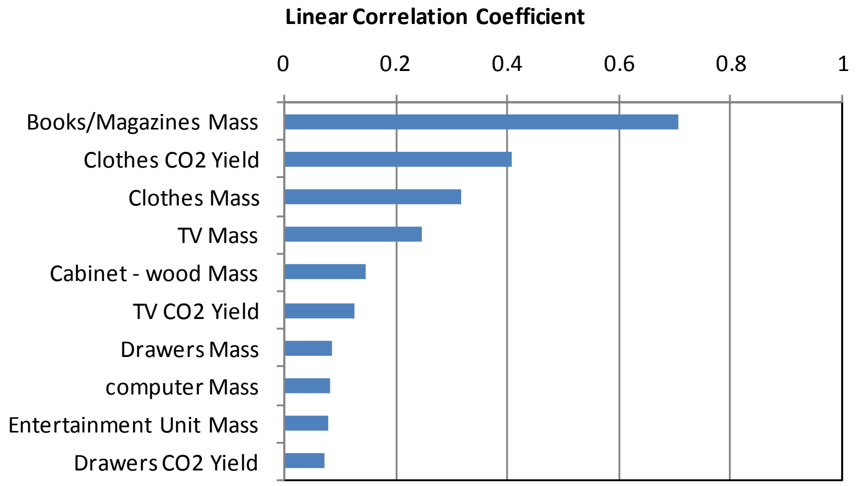


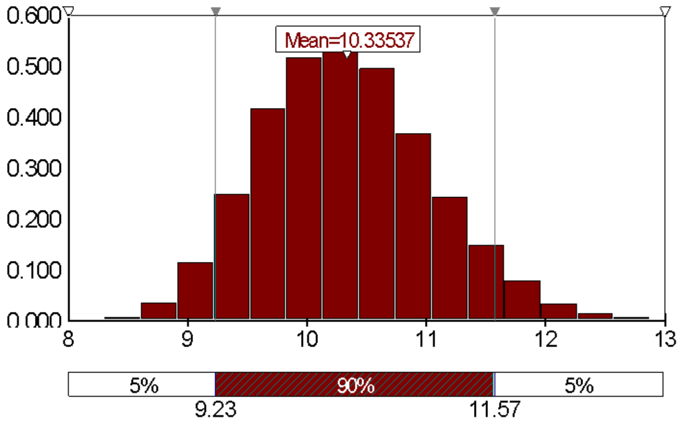
Figure 12: Summary of the top ten influential parameters for the CO_2 Equivalent released due to the total fire loss of the exemplar home contents, based on fibre cement weatherboard correlation coefficients.

5.3 Scenario 3: House fires with continuing current suppression strategies

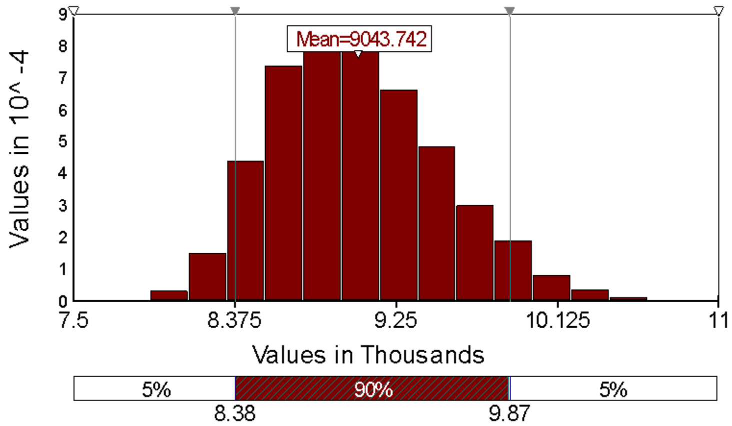
The results for Scenario 3 are summarised in Table 20 and Figure 13.

Table 20: Summary of the results for Scenario 3.

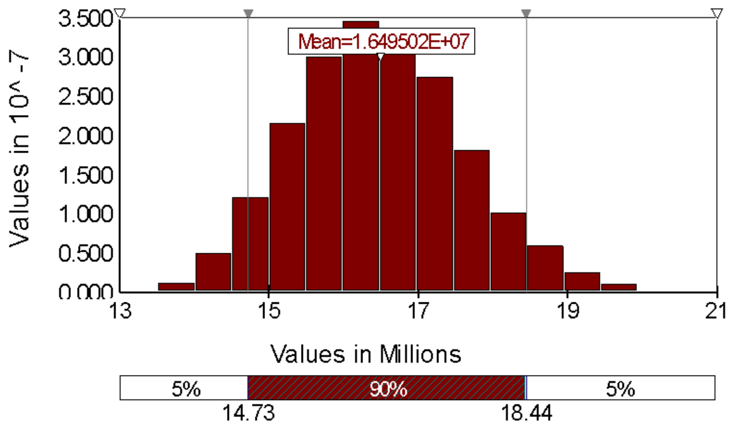
	Total CO_2 Equivalent Released by House Fires with fire suppression continuing as reflected in the current fire incident statistics		
	kg(CO_2)/ household/ year	kg(CO_2)/ fire/ year	t(CO_2)/ year
Minimum	8	7,700	14,000
Maximum	13	11,000	21,000
Mean	10	9,000	16,000
Standard Deviation	1	460	1,100



(a)



(b)

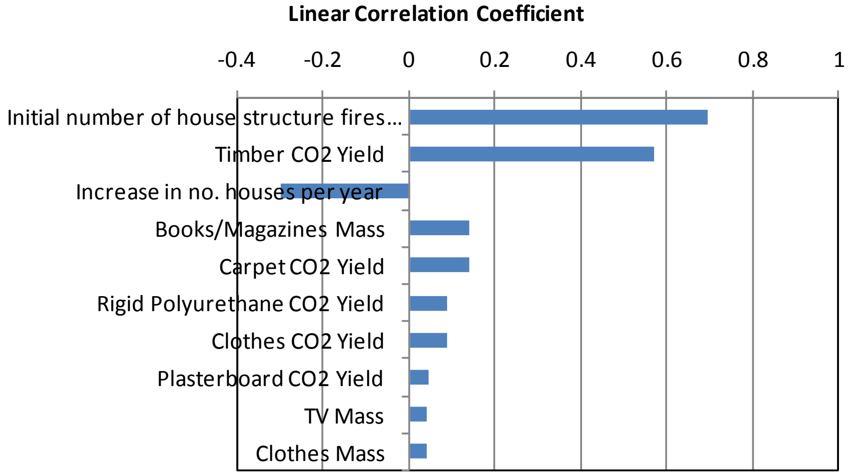


(c)

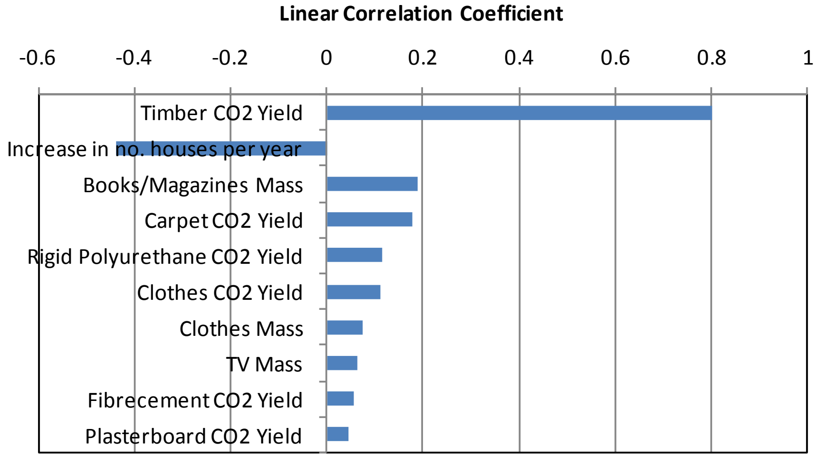
Figure 13: Summary of the results for Scenario 3 for the total CO_2 Equivalent released by NZ house fires with fire suppression continuing as reflected in the current fire incident statistics in (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

5.3.1 Sensitivity Analysis

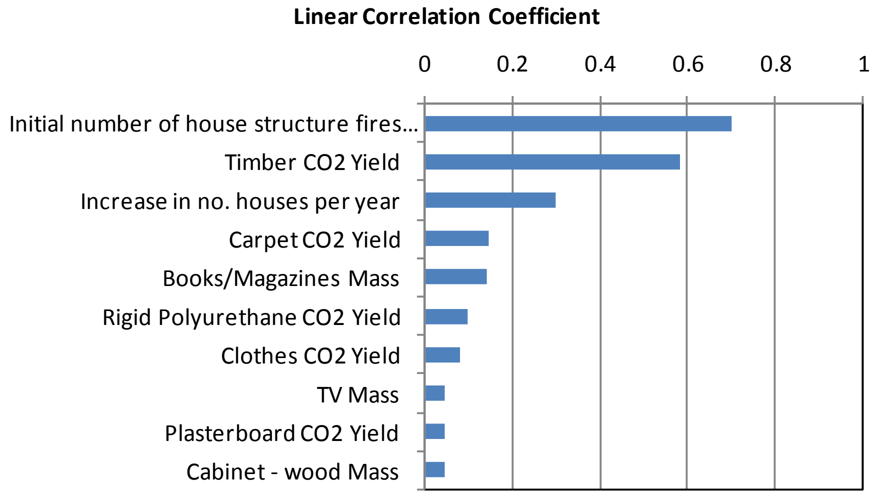
The results for the Scenario 3 sensitivity analysis are summarised in Figure 14.



(a)



(b)



(c)

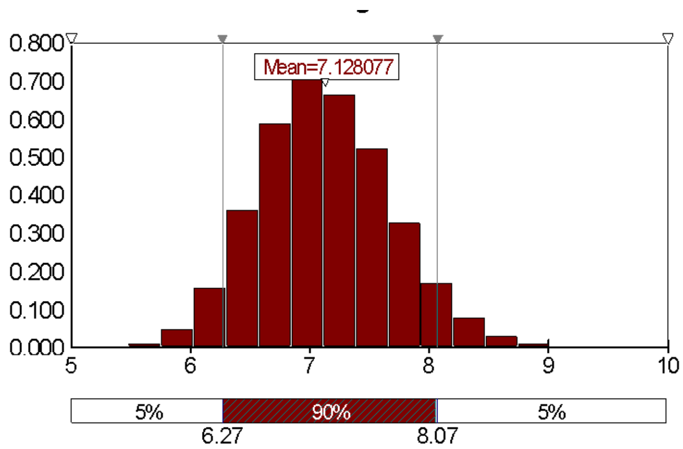
Figure 14: Summary of the top ten influential input parameters for the total CO_2 Equivalent released by NZ house fires with fire suppression continuing as reflected in the current fire incident statistics, based on fibre cement weatherboard correlation coefficients, for (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

5.4 Scenario 4: House fires where home sprinkler systems are present

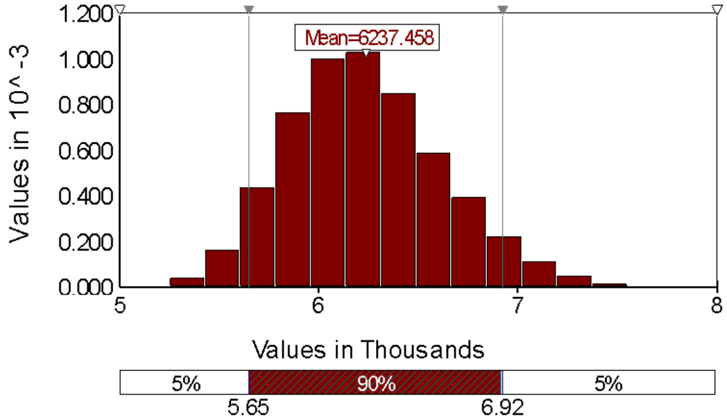
The results for Scenario 4 are summarised in Table 21 and Figure 15.

Table 21: Summary of the results for Scenario 4.

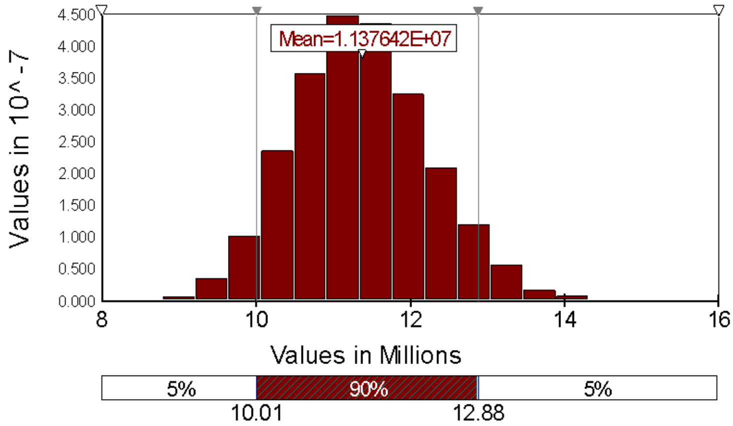
	Total CO_2 Equivalent Saved from being Released by House Fires with Home Sprinklers Present Compared to Scenario 3		
	kg(CO_2)/ household/ year	kg(CO_2)/ fire/ year	t(CO_2)/ year
Minimum	5	5,100	8,800
Maximum	10	7,700	15,000
Mean	7	6,200	11,000
Standard Deviation	0.5	390	880



(a)



(b)

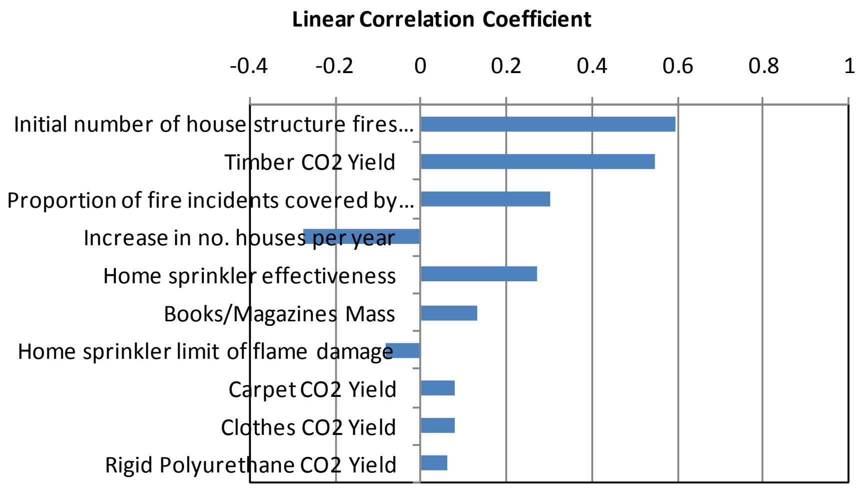


(c)

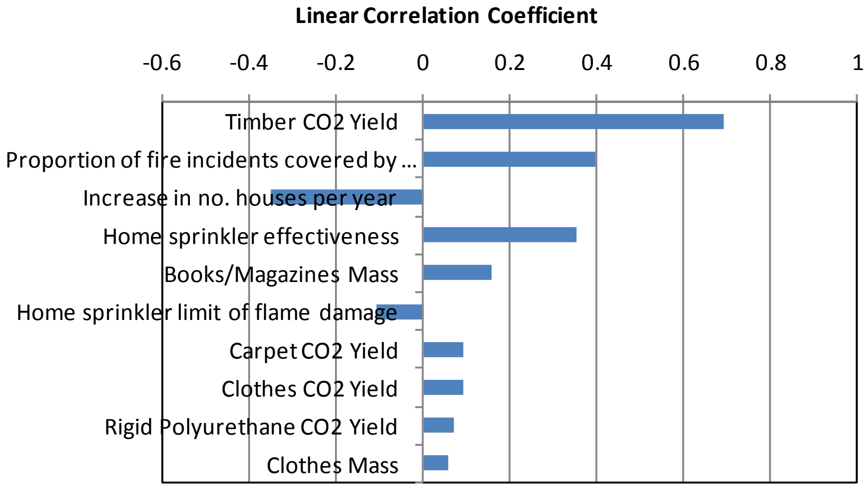
Figure 15: Summary of the results for Scenario 4 for the total CO_2 Equivalent saved from being released by NZ house fires with home sprinklers systems present in (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

5.4.1 Sensitivity Analysis

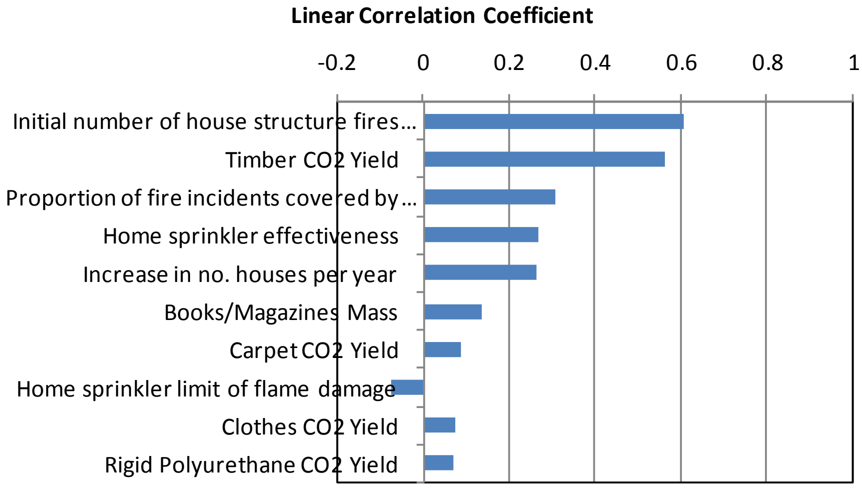
The results for the Scenario 4 sensitivity analysis are summarised in Figure 16.



(a)



(b)



(c)

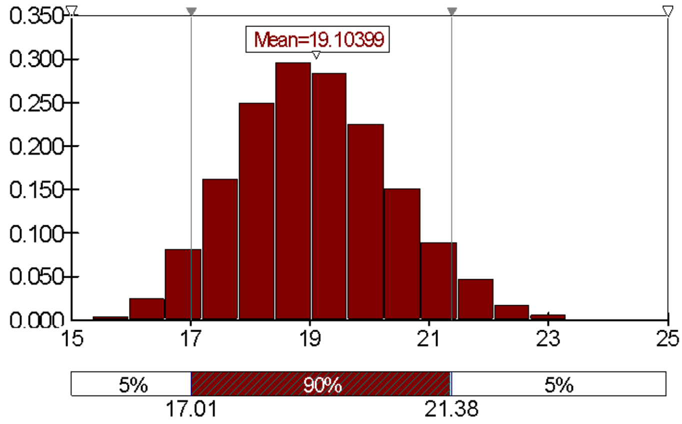
Figure 16: Summary of the top ten influential input parameters for the total CO_2 Equivalent saved from being released by NZ house fires by home sprinklers systems present, based on fibre cement weatherboard correlation coefficients, for (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

5.5 Scenario 5: Increased equivalent floorarea loss% per fire to 50%

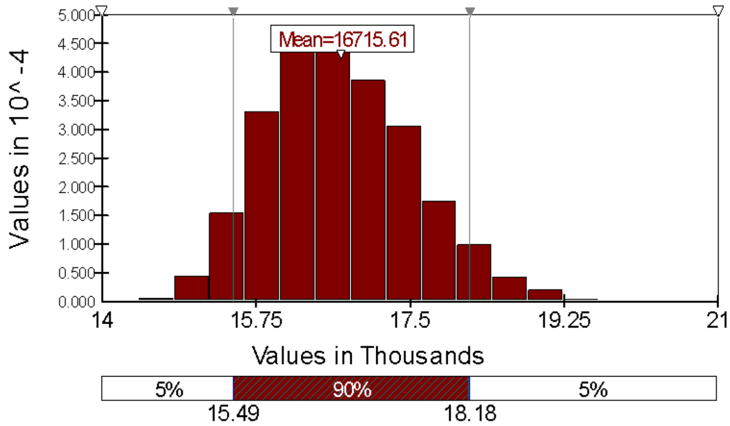
The results for Scenario 5 are summarised in Table 22 and Figure 17.

Table 22: Summary of the results for Scenario 5.

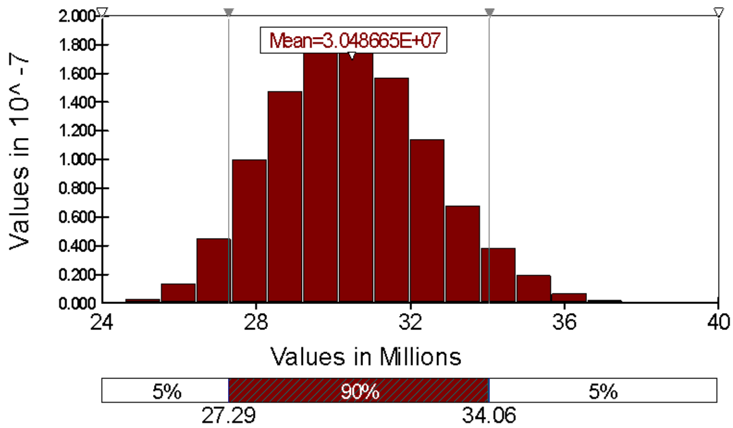
	Total CO_2 Equivalent Released by House Fires with the Equivalent Floorarea Loss Percentage Increased to 50%		
	kg(CO_2)/ household/ year	kg(CO_2)/ fire/ year	t(CO_2)/ year
Minimum	15	14,000	25,000
Maximum	25	20,000	38,000
Mean	19	17,000	30,000
Standard Deviation	1	800	2,000



(a)



(b)

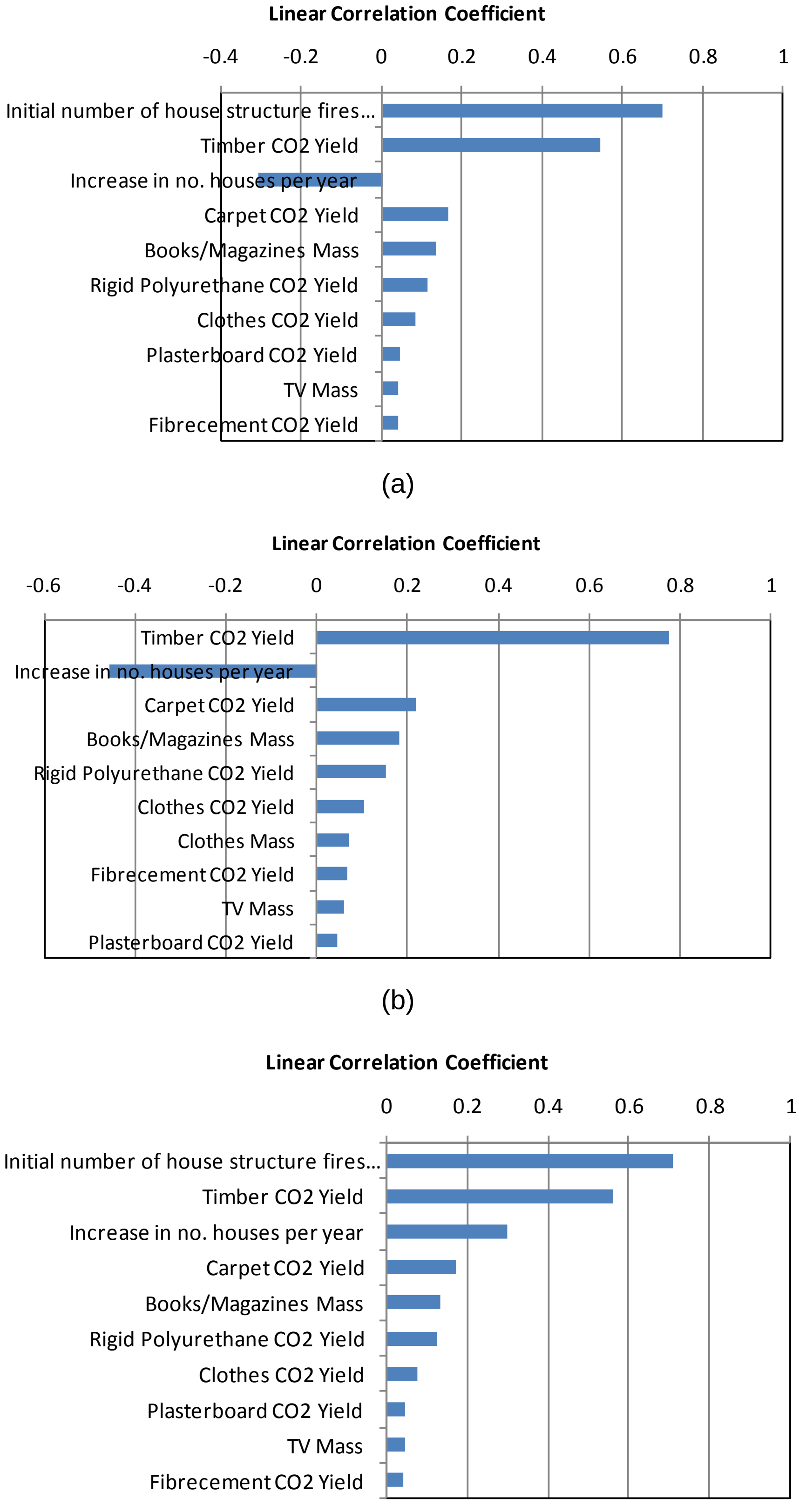


(c)

Figure 17: Summary of the results for Scenario 5 for total CO_2 Equivalent released by NZ house fires with the equivalent floorarea loss increased to 50% in (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

5.5.1 Sensitivity Analysis

The results for the Scenario 5 sensitivity analysis are summarised in Figure 18.



(c)

Figure 18: Summary of the top ten influential input parameters for the total CO_2 Equivalent released by NZ house fires with the equivalent floorarea loss increased to 50%, based on fibre cement weatherboard correlation coefficients, for (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

6. DISCUSSION OF RESULTS AND ANALYSIS

The mean values for the CO_2 Equivalent released from the complete fire loss of the structure of an exemplar house is approximately 27 to 38 t(CO_2), as shown in the results of Scenario 1 summarised in Section 5.1. The most influential input parameters for the estimates of CO_2 equivalency associated with the exemplar house structure were consistently associated with estimations of the amount of CO_2 yielded for timber, carpet, rigid polyurethane, fibreboard, plasterboard, polythene, doors, particle board and PVC. That is, the estimated values for CO_2 yield, extent of material burnt and mass for each of the components. These parameters were expected to have the most influence as they are the basis of the calculation for estimating CO_2 Equivalent. Timber was expected to be highly influential component, because of the large amounts of timber involved with each of the exemplar house combinations considered (Table 23, Table 25 and Table 14).

The mean values for the CO_2 Equivalent released from the complete fire loss of the contents of an exemplar house is approximately 6 t(CO_2), as shown in the results of Scenario 2 summarised in Section 5.2. This represents approximately 16 – 22% of the CO_2 Equivalent released from the complete fire loss of the structure of an exemplar house, for the assumptions used in this study. Therefore when exemplar structure and contents are combined, the structure contributes approximately 82 – 86% of the total CO_2 Equivalent released during an exemplar house fire. The most influential input parameters for the estimates of CO_2 Equivalent for the total loss of exemplar house contents were associated with books and magazines, clothes, television, cabinets, drawers and beds. Parameters associated with these items were expected to have a significant influence on results, since they are related to contents items of large collective mass and CO_2 yield.

Considering the house fires throughout New Zealand and the suppression strategies reflected in the fire incident statistics of the past five years continue for the next 50 years, the CO_2 Equivalent released to the atmosphere was estimated at a mean value of 10 kg(CO_2)/NZ household/year or 9,000 kg(CO_2)/house fire/year, which is a mean total of approximately 16,000,000 kg(CO_2)/year (as summarised for Scenario 3 in Section 5.3). The most influential parameters are associated with the number of structure fires (relating to the specific parameters of the initial number of house structure fires that is used to set the proportion of houses that have a structure fire each year, and the increase in the number of houses per year), and the CO_2 Equivalent associated with timber, carpet, books and magazines, rigid polyurethane and clothes.

Considering the house fires throughout New Zealand with the same proportion of houses have fire incidents based on the statistics of the past five years and the mandatory inclusion of home sprinkler systems in newly constructed houses and retrofit of existing houses (such that the entire building stock is retrofitted in 10 years), then from analysing the next 50 years the CO_2 Equivalent released to the atmosphere was estimated at a mean value of 3 kg(CO_2)/NZ household/year or 4,000 kg(CO_2)/house fire/year, which is a mean total of approximately 5,000,000 kg(CO_2)/year. This is a reduction in the CO_2 Equivalent released into the atmosphere compared to continuing the house fire suppression strategies currently reflected in the fire incident statistics (Scenario 3). The estimated mean amount of CO_2 Equivalent saved from being released into the atmosphere was approximately 7 kg(CO_2)/NZ household/year or 6,000 kg(CO_2)/house fire/year, which is a mean total of approximately 11,000,000 kg(CO_2)/year (as summarised for Scenario 4 in Section 5.4). Considering the mean values of estimated CO_2 Equivalent, for the scenario for the mandatory introduction of home sprinkler systems throughout New Zealand, approximately 60 – 70% of CO_2 Equivalent could be saved from being released during house fires compared to the current situation of house fire suppression represented by the last five years of New Zealand fire incident statistics for structure fires (i.e. predominantly by NZ Fire Service personnel with portable suppression or appliances, etc).

The most influential parameters in the results of Scenario 4 were the same as Scenario 3 in addition to the effectiveness of a home sprinkler system and the maximum percentage of floorarea that a home sprinkler system would limit flame damage to.

Considering the house fires throughout New Zealand assuming a effective decrease in the suppression strategies that are reflected in the fire incident statistics of the past five such that the equivalent floorarea lost to flame damage is increased to 50% per house fire and this continues for the next 50 years, the CO_2 Equivalent released to the atmosphere was estimated at a mean value of 19 kg(CO_2)/NZ household/year or 17,000 kg(CO_2)/house fire/year, which is a mean total of approximately 30,000,000 kg(CO_2)/year (as summarised for Scenario 5 in Section 5.5). This represents a mean increase of approximately 90% from Scenario 3 that assumes house fire suppression strategies remain similar to those reflected in the fire incident statistics of the last five years. The most influential parameters in the results of Scenario 5 were the same as Scenario 3.

7. SUMMARY & CONCLUSIONS

Summary and important conclusions of this study include:

- A House Fire GHG Emissions estimate tool was developed.
- The House Fire GHG Emissions estimate tool is based on input parameters for:
    - Numbers of house structure fires per year,
    - Current numbers of housing stock,
    - Rate of increase of housing stock numbers,
    - Percentages of house floorareas lost to fire,
    - Types and amounts of materials involved in house structures,
    - Numbers and masses of items included in house contents,
    - CO_2 yields for materials and items included in the framework,
    - Effectiveness of suppression strategies considered, and
    - Extent and rate of installation of these suppression strategies in houses.
- The results of the House Fire GHG Emissions estimate tool are reported in CO_2 Equivalent.
- The House Fire GHG Emissions estimate tool only considers the GHG emissions related to the fire loss of the house structure and contents.
    - Cradle-to-gate GHG emissions related to the replacement of house structure after a fire was included in a previous study by Robbins, Wade et al. (2007). The framework developed in this study was designed to be used in parallel with the previous study, with no double counting of impacts between studies.
- Construction of the NZ housing stock is diverse; therefore use of an exemplar house was used. Types and amounts of materials were estimated for exemplar houses representing the top six combinations of foundation, wall and roof claddings (Table 11). Similarly, numbers of items and masses of contents were estimated for an exemplar house.
- Because of the estimation of the housing stock using an exemplar house approach, the results are most relevant in terms of a national average.
    - The scenarios considered in this study for comparison use an analysis period of 50 years.
- Five scenarios were considered to demonstrate the concept of the potential usages for the estimation tool:
    - Scenario 1: Total fire loss of an exemplar house structure.
        - This scenario provided a baseline for the maximum GHG emissions per type of exemplar house structure.
        - The complete fire loss of the exemplar house structure releases approximately 27 to 38 t CO_2 Equivalent.
    - Scenario 2: Total fire loss of an exemplar house contents.
        - This scenario provided a baseline for the maximum GHG emissions for total house contents.

        - The complete fire loss of the exemplar house contents releases approximately 6 t CO_2 Equivalent.
        - Assuming a homogeneous fire loss of structure and contents based on floorarea, house contents are associated with approximately 14 – 18% of the GHG emissions in this study.
    - Scenario 3: House fires with fire suppression remaining the same as reflected in current fire incident statistics.
        - This scenario estimated the GHG emissions from house fires assuming the fire suppression strategies remain similar to current strategies for the next 50 years.
        - The CO_2 Equivalent released to the atmosphere was estimated at an approximate mean value of 10 kg(CO_2)/NZ household/year or 9 t(CO_2)/house fire/year, which is a mean total of approximately 16,000 t(CO_2)/year for the house fires across the nation.
    - Scenario 4: Home fires where home sprinkler systems (according to NZS4517) are present with NZFS intervention using water (if needed),
        - This scenario estimated the savings in GHG emissions results assuming the mandatory installation of home sprinklers in every new house built and a rate of retrofit such that the current building stock has NZS4517 protection within 10 years compared to the results of Scenario 3 (i.e. an estimate of the savings of GHG emissions).
        - Implementing a home sprinkler strategy to protect the NZ housing stock (according to the assumptions of Scenario 4) was estimated to save approximately a mean value of 7 kg(CO_2)/NZ household/year or 6 t(CO_2)/house fire/year, which is a mean total of approximately 11,000 t(CO_2)/year compared to current suppression strategies reflected in the recent fire incident statistics (as used in Scenario 3).
        - This indicates a 60-70% (based on mean values) reduction of CO_2 Equivalent GHG emissions could be saved from being released during house fires by the introduction of home sprinkler systems compared to the current suppression strategies represented by the recent NZ fire incident statistics.
    - Scenario 5: An increase in house fire losses to an equivalent percentage of floorarea loss per fire of 50%.
        - This scenario estimated the fire suppression strategies used over the next 50 years were decreased from the current strategies (producing an equivalent percentage of floorarea fire loss per fire of approximately 29% per house fire, based on statistics) to 50%. This would be the equivalent of less NZFS intervention. This equivalent percentage of floorarea loss per fire is a user input parameter.
        - The reduction in suppression strategies from those reflected in recent fire incident statistics (as used in Scenario 3, with an equivalent percentage of floorarea fire loss of 29% per house fire) to a strategy that produces an equivalent percentage of floorarea fire loss of 50% per house fire (Scenario 4) was estimated to increase the GHG emissions by 9 kg(CO_2)/NZ

household/year or 8 t(CO_2)/house fire/year, which is a mean total of approximately 14,000 t(CO_2)/year

- An increase in the loss of equivalent percentage of floorarea fire loss per house fire from 29% to 50% (representing a 72% increase in fire damage during house fires), was associated with a 90% increase in GHG emissions.
- The approach used in this Scenario may be used to explore the GHG emissions saving impact of the current NZFS house fire suppression strategies compared to generic conditions with less fire intervention (e.g. if the Fire Service didn't attend, etc.).
- Similarly, the approach of this Scenario could also be used to assess the impact of potential new strategies for house fire intervention in terms of the GHG emissions impact saved for an increase in effectiveness (i.e. a reduction in house floorarea fire loss).

- The most influential input parameters were found to be parameters related to the estimated number of fires per year (i.e. the initial number of structure fires per year, the initial number of housing stock and the rate of increase of housing stock) and types of material or item that contributed the most CO_2 (i.e. the mass or number of items per exemplar house for timber, carpeting, rigid polyurethane, books and magazines, clothes, etc). Sensitivity to these parameters is as expected, because of the assumption that house construction materials and contents were evenly distributed over the house floorarea (i.e. location of individual fire starts were not included in the approach). For Scenario 4, where home sprinkler systems were introduced to the housing stock, the effectiveness of the system and the maximum limit of flame damage achieved by the system were also influential input parameters.

7.1 Recommendations for Future Work

Recommended future work includes:

- Collection and collation of species yields associated with GHG emissions during material and item fire testing in addition to the current species yields associated with life safety.
- Development of a survey and database for estimates of residential contents, in terms of types of items, materials, masses and proportion of item mass of combustible material that would contribute to the fire load. If such details were available, then this would be useful for a range of studies including GHG emissions from house fires, as investigated here, as well as item-to-item fire spread and the impact of the change of amounts and types of home contents on the fire load and fire hazard, etc.
- As more detailed information becomes available and is collated, the framework developed here can be adapted to consider the GHG emissions impact of house fires based on proportions of fire events for different rooms of fire origin. This may be a useful contribution to other residential fire studies, enabling GHG emissions impacts to be incorporated into a broader study of impacts.
- The House Fire GHG Emissions tool can be used to assess the impact of a wider range of fire suppression strategies, where information on the effectiveness and potential GHG emissions associated with the strategy can be quantitatively estimated. Further research is required before other types of suppression strategies can be assessed using this framework.

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APPENDIX A ADDITIONAL INPUT VALUES USED IN FRAMEWORK

A.1 Home Construction Masses

Table 23: Material quantities for each combination of foundation, wall and roof claddings considered for the exemplar house.

Component of Construction	Material	Units	Material Quantities For the Exemplar Combinations Types					
			A	B	C	D	E	F
Foundation	**Hardfill**	m3	13.5	13.5	13.5	3.5	13.5	3.5
	Sand blinding	m2	168	168	168	35	168	35
	Re-steel	kg	789	789	789	229	789	229
	Concrete blocks	kg	1312	1312	1312	460	1312	460
	Concrete readymix	m3	33.8	35.6	35.6	21.7	33.8	21.7
	Steel bolts/plates/straps	kg	27.6	27.6	27.6	25.4	27.6	25.4
	PVC	kg	94.3	81.7	81.7	104.9	94.3	104.9
	Fibre cement baseboard & soffits	kg	392	392	392	509	392	509
	Timber piles H5	m3	0.0	0.0	0.0	0.53	0.0	0.53
	Sawn timber H3.2 (deck)	m3	0.0	0.0	0.0	1.11	0.0	1.11
	Framing timber H1.2	m3	7.4	7.4	7.4	10.7	7.4	10.7
	Framing timber UT	m3	11.0	11.6	11.0	11.0	11.0	11.0
	Deck planks H3.2	m3	0.00	0.00	0.00	1.11	0.00	1.11
	Exterior H3.1 finish/battens	m3	1.05	0.73	0.73	1.05	1.06	1.05
	Particle Board sheets	m3	1.00	1.00	1.00	3.07	1.00	3.07
	Polythene Damp Proof Course	m2	173	173	173	40	173	40
	Foil insulation (floors)	m2	0	0	0	106	0	106
Wall Cladding	**Fibre cement Plank**	kg	2940	0	0	2940	0	0
	Brick	kg	0	4120	4120	0	0	0
	Timber Weatherboard	kg	0	0	0	0	2646	2646
Roofing	**Sheet Steel**	kg	1048	0	1048	1048	1048	1048
	Concrete tile	kg	0	10350	0	0	0	0

Table 24: Material quantities of the common house components for each combination of foundation, wall and roof claddings considered for the exemplar house.

Material	Units	Material Quantities For the Exemplar Combinations Types					
		A	B	C	D	E	F
Paint	litres	119	83	83	116	119	116
Retain wall/fence timber H4	m3	0.95	0.95	0.95	0.95	0.95	0.95
Half round retain wall H4	m3	1.12	1.12	1.12	1.12	1.12	1.12
Sawn timber H3.2 (fences etc)	m3	0.59	0.59	0.59	0.59	0.59	0.59
Interior UT mould, jamb, liner	m3	1.79	1.79	1.79	1.79	1.79	1.79
Fibre cement baseboard & soffits	kg	392	392	392	392	392	392
Building paper	m2	355	355	355	355	355	355
Windows glass	kg	450	450	450	450	450	450
Windows aluminium	kg	144	144	144	144	144	144
Insulation fibreglass	kg	294	294	294	294	294	294
Plasterboard	kg	4518	4518	4518	4518	4518	4518
Wet wall lining (coated Hardboard)	kg	59	59	59	59	59	59
Doors	no	19	19	19	19	19	19
Wallpaper	m2	346	346	346	346	346	346
Carpet pile	m2	132	132	132	132	132	132
Carpet backing	m2	132	132	132	132	132	132
Vinyl	m2	15.0	15.0	15.0	15.0	15.0	15.0
Nails	kg	60.0	60.0	60.0	60.0	60.0	60.0

Table 25: Proportions of each structure material component lost to fire for a given proportion of house floorarea lost to fire

Structure Component	Material	Proportion of Component Material Lost to Fire for Proportion of House Floorarea Lost to Fire									
		10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Foundation & Frame	Hardfill	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sand blinding	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Re-steel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Concrete blocks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Concrete readymix	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Steel bolts/plates/straps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PVC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
	Fibre cement baseboard & soffits	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	0.0
	Timber piles H5	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Sawn timber H3.2 (deck)	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Framing timber H1.2	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Framing timber UT	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Deck planks H3.2	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Exterior H3.1 finish/battens	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Particle Board sheets	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Polythene Damp Proof Course	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Foil insulation (floors)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wall cladding	Fibre cement Plank	0.1	0.1	0.2	0.3	0.4	0.5	0.5	0.5	1.0	1.0
	Brick	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	Timber Weatherboard	0.1	0.1	0.2	0.3	0.4	0.5	0.5	0.5	1.0	1.0
Roofing	Sheet Steel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Concrete tile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Common Materials	Paint	0.2	0.3	0.5	0.6	0.8	1.0	1.0	1.0	1.0	1.0
	Retain wall/fence timber H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.0
	Half round retain wall H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.0
	Sawn timber H3.2 (fences etc)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.0
	Interior UT mould, jamb, liner	0.1	0.2	0.4	0.6	0.7	0.9	1.0	1.0	1.0	1.0
	Fibre cement baseboard & soffits	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.0	1.0	1.0
	Building paper	0.1	0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.0
	Windows glass	0.1	0.1	0.2	0.2	0.4	0.6	0.8	1.0	1.0	1.0
	Windows aluminium	0.1	0.1	0.2	0.2	0.4	0.6	0.8	1.0	1.0	1.0
	Insulation Fibreglass	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.0
	Plasterboard	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.0
	Wet wall lining (coated Hardboard)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.0
	Doors	0.1	0.1	0.2	0.2	0.4	0.6	0.8	1.0	1.0	1.0
	Wallpaper	0.2	0.3	0.5	0.6	0.8	1.0	1.0	1.0	1.0	1.0
	Carpet pile	0.2	0.3	0.5	0.6	0.8	1.0	1.0	1.0	1.0	1.0
	Carpet backing	0.2	0.3	0.5	0.6	0.8	1.0	1.0	1.0	1.0	1.0
	Vinyl	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.0

A.2 Home Contents Masses

Table 26: A summary of the estimated values for the mass for each item considered to be potentially present in a house.

Item Description	Items Included	Item Mass (kg) Low	Medium	High
Small Table	Side Table [a]	6	16	26
	Phone stand [a]	6	11	15
	Bedside Table [a]	14	22	27
	Sofa Table [a]	32	35	40
	Values used	**6**	**21**	**40**
Upholstered chair	**recliner/chair [a]**	**27**	**41**	**53**
Television	< 13" [a]	11	12	13
	14"-20" [a]	22	26	30
	21"-26" [a]	41	50	55
	27" [a]	41	50	55
	28"-36" [a]	53	67	80
	>37" [a]	72	95	128
	computer [a]	23	30	40
	28" [c]		32	
	25" [c]		24	
	28" [c]		31	
	Values used [k]	**11**	**29**	**128**
Sofa	**Three-seat sofa [a]**	**46**	**65**	**91**
Entertainment unit	**Entertainment unit, TV stand [a]**	**21**	**67**	**130**
Coffee table	**Coffee Table [a]**	**9**	**24**	**32**
Bookcase	**Bookcase [a]**	**10**	**30**	**48**
Loveseat	**Loveseat [a]**	**38**	**48**	**60**
Magazine rack	**Magazine table, rack [a]**	**6**	**11**	**15**
Ottoman	**Light chair, computer chair [a]**	**6**	**12**	**16**
Desk	Computer desk [a]	19	43	56
Computer	computer [a]	23	30	40
	laptop [r]	2	3	6
	Values used	**2**	**10**	**40**
Futon	**Futon [a]**	**44**	**51**	**57**
King, Queen or Double bed	Double bed, mattress and box-spring [a]	61	68	73
	2x Single bed values [g]	6	27	50
	Values used	**27**	**68**	**88**
Single bed	**Single bed (Ref 6) [e]**	**3**	**14**	**25**
Drawers	**Drawer chest [a]**	**31**	**53**	**80**
Stand-alone wardrobe	**Estimate**	**30**	**106**	**160**
Clothes [h]	**Estimate**	**226**	**283**	**340**
Manchester [f]	**Estimate**	**22**	**28**	**33**
Toys [i]	**Estimate**	**22**	**28**	**33**
Books/Magazines [j]	**Estimate**	**170**	**340**	**510**
Refrigerator -Freezer	Refrigerator-freezer [c(1)]		70	
	Refrigerator-freezer [c(2)]		67.2	
	Refrigerator-freezer [c(3)]		64	
	Refrigerator-freezer [c(4)]		71	
	Values used [m]	**54.34**	**68**	**81.51**

Dishwasher	Dishwasher [c(5)]		36	
	Dishwasher [c(6)]		48	
	Dishwasher [c(7)]		47	
	Dishwasher [c(8)]		44	
	Values used [m]	**34.8**	**44**	**52.2**
Microwave	**Estimate [n]**	**5.8**	**7.25**	**8.7**
Gas Stove	**Estimate [o]**	**44.4**	**55.5**	**66.6**
Electric Stove	**Estimate [o]**	**44.4**	**55.5**	**66.6**
Rangehood	**Estimate [p]**	**23.2**	**29**	**34.8**
Cabinet - wood finish	estimate based on 2/3 of drawers mass	20.46	34.98	52.8
	Cabinet [c(9)]		22.3	
	Cabinet [c (9)]		22.6	
	Values used	**20.46**	**26.62667**	**52.8**
Cabinet - laminate finish	Estimated as 1/3 of drawers mass	10.23	17.49	26.4
	Cabinet [c(9)]		22.3	
	Cabinet [c(9)]		22.6	
	Values used	**10.23**	**20.79667**	**26.4**
Table	Computer desk [a]	19	43	56
	Air hokey Table [a]	26	30	34
	Foosball Table [a]	26	30	34
	Pool Table [a,b]	113	115	118
	Values used	**19**	**34**	**56**
Chairs	**Light chair, computer chair [a]**	**6**	**12**	**16**
Washing machine	Washing machine [c(10)]		69	
	Washing machine [c(11)]		69.9	
	Washing machine [c(12)]		63.3	
	Values used [m]	**54**	**68**	**81**
Dryer	**Estimate [d]**	**54**	**67.5**	**81**
Electrical cable	**Estimate [q]**	**0.5**	**0.8**	**2.5**

Notes:

[a] Values from the Canadian study reported by Bwalya (2004) and Bwalya, Sultan and Benichou (2004).

[b] This value was not used in these calculations, and is included here only for information purposes.

[c] Values from the Finnish electrical appliance study by Hietaniemi et al. (2001). Descriptions of the items tested are:

1. Refigerator-freezer description: side walls and hatch made of steel, plastic bottom plate, no deck.
2. Refigerator-freezer description: side walls, all intermediate levels made of plastic.
3. Refigerator-freezer description: side walls, plate between fridge and freezer, and plate under motor made of steel, ceiling made of plastic.
4. Refigerator-freezer description: side walls and plate below the motor made of steel.
5. Dishwasher: side, rear wall, hatch and bottom plate made of steel, no deck, insulation assumed to be felt.
6. Dishwasher: side, rear wall, hatch and bottom plate made of steel, no deck, insulation assumed to be bitumen.
7. Dishwasher: side, rear wall, hatch and bottom plate made of steel, no deck, insulation assumed to be bitumen.
8. Dishwasher: side walls, hatch and base in the back made of steel, no rear wall or deck, bottom plate made of plastic.
9. Cabinet: cabinets tested around a dishwasher.
10. Washing machine: housing, deck, bottom plate and washing drum made of steel, basin made of plastic.
11. Washing machine: housing, deck, bottom plate and washing drum made of steel, basin made of plastic.

12. Washing machine: housing, deck and washing drum made of steel, washing basin and upper part of rear wall made of plastic, no bottom plate.

[d] Dryers were assumed to have a similar mass washing machines.

[e] Values from mattress combustion experiments reported by Babrauskas (1980).

[f] Values estimated from the masses of bedding used in testing by Babrauskas (1980) for single beds, assuming that larger sized beds have twice the mass of bedding and there is a spare set for every bed. This conservative estimate using the masses of bedding was used to attempt to account for other manchester typically found in a household, e.g. towels, etc.

[g] The mass estimate for the double, king and queen sized bed category was based on twice the mass of the single beds listed in the report by Babrauskas (1980).

[h] The mass of clothes per bedroom was estimated as three times the amount of manchester in the house.

[i] The mass of toys per bedroom were estimated to be similar to the mass of manchester per bedroom.

[j] The mass of books and magazines per bedroom were estimated to be 100 kg per bedroom ± 50%.

[k] The assumed mass distribution of a television were that the medium value was based on the masses of the computer and the newer television values available.

[m] The assumed mass distributions of the refrigerator-freezer, dishwasher and washing machine were taken as the average medium mass ±20% of the available values.

[n] The assumed mass distribution of a microwave was estimated as one sixth of a dishwasher.

[o] The assumed mass distributions of the gas or electric stove with oven were estimated as similar to washing machine and dishwasher estimates.

[p] The assumed mass distribution of a rangehood was estimated as two thirds of a dishwasher.

[q] The mass distribution was estimated based on products extension cords and multiboxes available at local stores.

[r] Estimate based on office laptops.

A.3 Background Information for Sprinkler Effectiveness

Table 27: A summary of sprinkler system effectiveness. Adapted from Robbins, Wade et al. (2008).

Sprinkler System Description & Building Type	Effectiveness when Operates (%)	Operational Reliability	Overall Effectiveness Reliability	Country	Years Statistics are Based on	Reference
Residential Sprinklers						
One- and two-family dwellings	94			US	1999 – 2002	(Aherns 2007)
Apartments	98			US	1999 – 2002	(Aherns 2007)
All sprinkler system types						
All building types	99.45			Australia & New Zealand	1886 – 1986	(Marryatt 1988) [a]
All building types	93			US	1999 – 2002	(Rohr & Hall 2005) [b]
All residential properties		84.6		US	1989 – 1998	(Hall 2003) [c]
All residential properties		86.3		US	1999	(Hall 2003) [c]
One- and two-family dwellings		80.0		US	1989 – 1998	(Hall 2003) [c]
One- and two-family dwellings		81.8		US	1999	(Hall 2003) [c]
Apartments		87.6		US	1989 – 1998	(Hall 2003) [c]
Apartments		89.2		US	1999	(Hall 2003) [c]
Wet pipe sprinkler systems						
All residential properties	98 [d]	96 [e]	94 [f]	US	2002 – 2004	(Hall 2007)
Home sprinkler System (NZS 4517)						
BRANZ 2000 CBA estimate	95 (min =90% & max = 99%)					(Wade & Duncan 2000)
BRANZ 2007 Cost Effectiveness estimate			95 (min = 90 & max = 99)			(Robbins et al. 2008)
Current CO_2 Equivalent Framework			95 (min = 90 & max = 99)			

Notes (Table 27):
[a] Not including systems that failed to operate.
[b] Based on NZFS Station Management System data.
[c] Excluding structure fires coded as being too small to activate sprinklers.
[d] Based on non-confined structure fires NZFS Station Management System data, where the sprinklers operated and the fire was reported as large enough to activate sprinklers, for 3,400 residential fires.
[e] Based on NZFS Station Management System 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.

APPENDIX B HOUSE GHG EMISSIONS TOOL OVERVIEW

The following tables (Table 28 – Table 37) show the input parameters that can be changed by a user (as indicated by the highlighted cells) and provide an example of input values used in the study results presented in this report. Parameter descriptions and selection of parameter values are discussed in Section 4. It is recommended that values present in cells that are not highlighted remain unchanged by the user, since these values are calculated from values entered in the highlighted cells in the tool and therefore inconsistencies may arise.

Table 28: Tool inputs associated with the base Scenario (Scenarios 1 – 3), presented using tool layout.

Framework Input Description	Input Parameter Value		
	min	best	max
Initial number of house structure fires per year	1400	1600 [a]	1800
Initial number of households		1400000	
increase in households per year	0.1%	0.5% [b]	1.0%
proportion of current building stock - type A		5.0%	
proportion of current building stock - type B		15.0%	
proportion of current building stock - type C		10.0%	
proportion of current building stock - type D		30.0%	
proportion of current building stock - type E		10.0%	
proportion of current building stock - type F		30.0%	
	Total	100.0%	
proportion of future building stock - type A		5.0%	
proportion of future building stock - type B		15.0%	
proportion of future building stock - type C		10.0%	
proportion of future building stock - type D		30.0%	
proportion of future building stock - type E		10.0%	
proportion of future building stock - type F		30.0%	
	Total	100.0%	
discount rate	0%	0% [c]	0%
inflation rate	0.0%	0.0% [d]	0.0%
analysis period (years)		50	
Equivalent proportion of houses with fires with structure damage (based on all other values entered, details in 'Area Saved Statistics')		29%	

Notes:

[a] PERT distribution function used: RiskPert(1400,1600,1800, RiskName(“Initial number of house structure fires per year”))

[b] PERT distribution function used: RiskPert(0.001,0.005,0.001,RiskName(“Increase in no. houses per year”, RiskTruncate(0,1))

[c] PERT distribution function used: RiskPert(0,0,0, RiskName(“Discount Rate”, RiskTruncate(0,1))

[d] PERT distribution function used: RiskPert(0.0,0.0,0.0, RiskName(“Inflation rate”, RiskTruncate(0,1))

Table 29: Additional tool inputs associated only with Scenario 4, presented using tool layout.

Framework Input Description	Input Parameter Value		
	min	best	max
Home sprinkler system extinguishment method effectiveness (assuming a fire that is large enough to activate the sprinkler system)	0.9	0.95 [e]	0.99
Limit of flame damage for extinguishment method (estimate of the upper percentage of floorarea of flame damage with a successful home sprinkler system)	2%	5% [f]	7%
Initial number of sprinklered households		1000	
Proportion of new households sprinklered		100%	
Rate of retrofit of sprinklers in households	7.0%	10% [g]	15%
Sprinkler system life (years)		50	
Room of fire origin - distribution of fire incidents			
living room		16.0%	
bedroom		14.0%	
kitchen		41.0%	
bathroom		1.0%	
laundry		3.0%	
ceiling space		4.0%	
hallway		3.0%	
garage		4.0%	
other		14.0%	
		100.0%	
Proportion of fire incidents covered by a NZS4517 system	$p_{fire,NZS4517} + 5\%$	$p_{fire,NZS4517}$ [h]	$p_{fire,NZS4517} + 5\%$

Notes:

[e] PERT distribution function used: RiskPert(0.9,0.95,0.99, RiskName("Home sprinkler effectiveness"),RiskTruncate(0,1))

[f] PERT distribution function used: RiskPert(0.02,0.05,0.07, RiskName("Home sprinkler limit of flame damage"),RiskTruncate(0,1))

[g] PERT distribution function used: RiskPert(0.07,0.01,0.15, RiskName("Rate of retrofit of sprinklers in households"),RiskTruncate(0,1))

[h] PERT distribution function used: RiskPert($p_{fire,NZS4517} - 5\%$,$p_{fire,NZS4517}$,$p_{fire,NZS4517} + 5\%$,RiskName("Proportion of fire incidents covered by a NZS4517 system"),RiskTruncate(0,1)) , where $p_{fire,NZS4517} = \sum_{ROO=NZS4517\ coverage} p_{fire,ROO}$ (Rooms covered by NZS4517 (2002) include at the minimum: living room , bedroom, kitchen, laundry, hallway, garage.)

Table 30: Tool inputs associated only with Scenario 5, presented using tool layout.

Framework Input Description	Input Parameter Value		
	min	best	max
Alternative equivalent proportion of floorarea of houses with fires with structure damage for comparison		50%	

Table 31: Tool inputs associated with the floorarea saved statistics, presented using tool layout.

Average Percentage Household Area Lost	Ranges of Floorarea Saved, as used in Statistics	Corporate Year					Total	Fraction of Total Fires with Structure Damage
		02/03	03/04	04/05	05/06	06/07		
100%	0-10%	179	220	193	154	175	921	0.13
85%	11-20%	29	22	27	32	22	132	0.02
75%	21-30%	18	16	20	25	19	98	0.01
65%	31-40%	43	30	28	29	39	169	0.02
55%	41-50%	60	76	59	62	81	338	0.05
45%	51-60%	38	41	27	37	30	173	0.03
35%	61-70%	54	55	60	61	46	276	0.04
25%	70-80%	83	95	82	78	72	410	0.06
15%	81-90%	132	134	143	135	155	699	0.10
5%	91-100%	685	732	725	721	762	3625	0.53
	Total fires	1321	1421	1364	1334	1401	6841	
	No structure damage *	1415	1283	1231	1087	1105	6121	

Notes: * The values for fire incidents with no structure damage were not used in the framework. They are only included here for comparison purposes.

Table 32: Tool inputs associated with material quantities for each combination of foundation, wall and roof claddings considered for the exemplar house, presented using layout similar to layout in tool. (Adapted from Table 23.)

Component of Construction	Material	Units	Material Quantities For the Exemplar Combinations Types					
			A	B	C	D	E	F
Foundation	Hardfill	m3	13.5	13.5	13.5	3.5	13.5	3.5
	Sand blinding	m2	168	168	168	35	168	35
	Re-steel	kg	789	789	789	229	789	229
	Concrete blocks	kg	1312	1312	1312	460	1312	460
	Concrete readymix	m3	33.8	35.6	35.6	21.7	33.8	21.7
	Steel bolts/plates/straps	kg	27.6	27.6	27.6	25.4	27.6	25.4
	PVC	kg	94.3	81.7	81.7	104.9	94.3	104.9
	Fibre cement baseboard & soffits	kg	392	392	392	509	392	509
	Timber piles H5	m3	0.0	0.0	0.0	0.53	0.0	0.53
	Sawn timber H3.2 (deck)	m3	0.0	0.0	0.0	1.11	0.0	1.11
	Framing timber H1.2	m3	7.4	7.4	7.4	10.7	7.4	10.7
	Framing timber UT	m3	11.0	11.6	11.0	11.0	11.0	11.0
	Deck planks H3.2	m3	0.00	0.00	0.00	1.11	0.00	1.11
	Exterior H3.1 finish/battens	m3	1.05	0.73	0.73	1.05	1.06	1.05
	Particle Board sheets	m3	1.00	1.00	1.00	3.07	1.00	3.07
	Polythene Damp Proof Course	m2	173	173	173	40	173	40
	Foil insulation (floors)	m2	0	0	0	106	0	106
Wall Cladding	Fibre cement Plank	kg	2940	0	0	2940	0	0
	Brick	kg	0	4120	4120	0	0	0
	Timber Weatherboard	kg	0	0	0	0	2646	2646
Roofing	Sheet Steel	kg	1048	0	1048	1048	1048	1048
	Concrete tile	kg	0	10350	0	0	0	0

Table 33: Tool inputs associated with the carbon dioxide yield for structure materials, using a layout similar to that used in the tool. (Adapted from Table 14.)

Structure Component	Material	Assumed to be Combustible	CO_2 Yield Distribution		
			Minimum Value	Best Value	Maximum Value
Foundation	Hardfill	n		-	
	Sand blinding	n		-	
	Re-steel	n		-	
	Concrete blocks	n		-	
	Concrete readymix	n		-	
	Steel bolts/plates/straps	n		-	
	PVC	y	0.3	0.46	1.1
	Fibre cement baseboard & soffits	y	1.2	1.4	1.6
	Timber piles H5	y	1.2	1.3	1.8
	Sawn timber H3.2 (deck)	y	1.2	1.3	1.8
	Framing timber H1.2	y	1.2	1.3	1.8
	Framing timber UT	y	1.2	1.3	1.8
	Deck planks H3.2	y	1.2	1.3	1.8
	Exterior H3.1 finish/battens	y	1.2	1.3	1.8
	Particle Board sheets	y	1.1	1.2	1.3
	Polythene Damp Proof Course	y	0.59		1.71
	Foil insulation (floors)	n		-	
Wall Cladding	Fibre cement Plank	n		1.4	
	Brick	n		-	
	Timber Weatherboard	n	1.2	1.3	1.8
Roofing	Sheet Steel	n		-	
	Concrete tile	n		-	
Common Materials	Paint	y	0.35	0.4	0.45
	Retain wall/fence timber H4	y	1.2	1.3	1.8
	Half round retain wall H4	y	1.2	1.3	1.8
	Sawn timber H3.2 (fences etc)	y	1.2	1.3	1.8
	Interior UT mould, jamb, liner	y	1.1		1.6
	Fibre cement baseboard & soffits	n		1.4	
	Building paper	n	1.2		1.3
	Windows glass	n		-	
	Windows aluminium	n		-	
	Insulation Fibreglass	n		-	
	Plasterboard	y	0.25	0.3	0.35
	Wet wall lining (coated Hardboard)	y		1.4	
	Doors	y	1.2		1.3
	Wallpaper	y	1.2		1.3
	Carpet pile	y	0.8		3.4
	Carpet backing	y	0.8		3.4
	Vinyl	y	0.59		1.71
	Nails	n		-	
	Electrical wiring	y	1.29		2.08

Table 34: Tool inputs associated with the proportions of each structure material component lost to fire for a given proportion of house floorarea lost to fire, presented using same layout as the tool. (Adapted from Table 25.)

Structure Component	Material	Proportion of Component Material Lost to Fire for Proportion of House Floorarea Lost to Fire									
		10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Foundation & Frame	Hardfill	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sand blinding	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Re-steel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Concrete blocks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Concrete readymix	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Steel bolts/plates/straps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PVC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
	Fibre cement baseboard & soffits	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	0.0
	Timber piles H5	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Sawn timber H3.2 (deck)	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Framing timber H1.2	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Framing timber UT	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Deck planks H3.2	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Exterior H3.1 finish/battens	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Particle Board sheets	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Polythene Damp Proof Course	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Foil insulation (floors)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wall cladding	Fibre cement Plank	0.1	0.1	0.2	0.3	0.4	0.5	0.5	0.5	1.0	1.0
	Brick	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	Timber Weatherboard	0.1	0.1	0.2	0.3	0.4	0.5	0.5	0.5	1.0	1.0
Roofing	Sheet Steel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Concrete tile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Common Materials	Paint	0.2	0.3	0.5	0.6	0.8	1.0	1.0	1.0	1.0	1.0
	Retain wall/fence timber H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.0
	Half round retain wall H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.0
	Sawn timber H3.2 (fences etc)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.0
	Interior UT mould, jamb, liner	0.1	0.2	0.4	0.6	0.7	0.9	1.0	1.0	1.0	1.0
	Fibre cement baseboard & soffits	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.0	1.0	1.0
	Building paper	0.1	0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.0
	Windows glass	0.1	0.1	0.2	0.2	0.4	0.6	0.8	1.0	1.0	1.0
	Windows aluminium	0.1	0.1	0.2	0.2	0.4	0.6	0.8	1.0	1.0	1.0
	Insulation Fibreglass	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.0
	Plasterboard	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.0
	Wet wall lining (coated Hardboard)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.0
	Doors	0.1	0.1	0.2	0.2	0.4	0.6	0.8	1.0	1.0	1.0
	Wallpaper	0.2	0.3	0.5	0.6	0.8	1.0	1.0	1.0	1.0	1.0
	Carpet pile	0.2	0.3	0.5	0.6	0.8	1.0	1.0	1.0	1.0	1.0

	Carpet backing	0.2	0.3	0.5	0.6	0.8	1.0	1.0	1.0	1.0	1.0
	Vinyl	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.0

Table 35: Tool inputs associated with the numbers of items in the most common rooms of fire origin per household, presented using a layout similar to that used in the tool. (Adapted from Table 15.)

Item Description	Estimates of the Average Number of Items in Each Room		
	Living Room	Bedroom	Kitchen
Small Table (e.g. side table, phone stand, bedside table, etc)	1.45	0.6	
Upholstered chair (e.g. recliner, covered chair, etc)	1.1	0.2	
Television	1	0.75	
Sofa	0.92		
Entertainment unit	0.78		
Coffee table	0.77		
Bookcase	0.77	0.4	
Loveseat	0.55		
Magazine rack	0.33		
Ottoman	0.2		
Desk	0.17	0.7	
Computer	0.16	0.6	
Futon	0.13	0.1	
King, Queen or Double bed		0.5	
Single bed		0.6	
Drawers		1	
Built-in wardrobe		0.7	
Stand-alone wardrobe		0.3	
Clothes		1	
Manchester		1	
Toys		1	
Books/Magazines		1	
Fridge (separate or combined refrigerator-freezer, mini-bar, etc.)			1.5
Dishwasher			1
Microwave			1
Gas Stove			0.3
Electric Stove			0.7
Rangehood			0.8
Cabinet - wood finish			8
Cabinet - laminate finish			8
Table		0.5	1
Chairs		0.5	6
Washing machine			1
Dryer			1
Electrical cable (extension cords, multiboxes)	2	1	
Number of Bedrooms per House		**3.4**	

Table 36: Tool inputs associated with the estimated values for the mass for each item, using a layout similar to that used in the tool. (Adapted from Table 26.)

Item Description	Items Included or Proxy Items Used	Item Mass (kg)		
		Low	Medium	High
Small Table	Values used based on a range of items	6	21	40
Upholstered chair	recliner/chair	27	41	53
Television	Values used based on a range of items	11	29	128
Sofa	Three-seat sofa	46	65	91
Entertainment unit	Entertainment unit, TV stand	21	67	130
Coffee table	Coffee Table	9	24	32
Bookcase	Bookcase	10	30	48
Loveseat	Loveseat	38	48	60
Magazine rack	Magazine table, rack	6	11	15
Ottoman	Light chair, computer chair	6	12	16
Desk	Computer desk	19	43	56
Computer	Values used based on a range of items	2	10	40
Futon	Futon	44	51	57
King, Queen or Double bed	Values used based on a range of items	27	68	88
Single bed	Single bed (Ref 6)	3	14	25
Drawers	Drawer chest	31	53	80
Stand-alone wardrobe	Estimate based on a range of items	30	106	160
Clothes [h]	Estimate based on a range of items	226	283	340
Manchester [f]	Estimate based on a range of items	22	28	33
Toys [i]	Estimate based on a range of items	22	28	33
Books/Magazines [j]	Estimate based on a range of items	170	340	510
Refrigerator -Freezer	Values used based on a range of items	54.3	68	81.5
Dishwasher	Values used based on a range of items	34.8	44	52.2
Microwave	Estimate based on a range of items	5.8	7.3	8.7
Gas Stove	Estimate based on a range of items	44.4	55.5	66.6
Electric Stove	Estimate based on a range of items	44.4	55.5	66.6
Rangehood	Estimate based on a range of items	23.2	29	34.8
Cabinet - wood finish	Values used based on a range of items	20.5	26.6	52.8
Cabinet - laminate finish	Values used based on a range of items	10.2	20.8	26.4
Table	Values used based on a range of items	19	34	56
Chairs	Light chair, computer chair	6	12	16
Washing machine	Values used	54	68	81
Dryer	Estimate based on a range of items	54	67.5	81
Electrical cable	Estimate based on a range of items	0.5	0.8	2.5

Table 37: Tool inputs associated with the carbon dioxide yield for home contents items, presented in a similar layout to that used in the tool. (Adapted from Table 16.)

Item Description	Estimated Proportion of Mass of Combustibles for 100% Burnt	Average Carbon Dioxide Yield (kg/kg)			
		Minimum Value	Best/ Average Value	Maximum Value	Sample Standard Deviation
Small table	1	0.8		1.33	
Upholstered chair	0.8		1.6		0.35
TV	0.9		1.8		0.4
Sofa	0.8		1.6		0.35
Entertainment unit	0.9		2.5		0.2
Coffee table	1	1.27		1.33	
Bookcase	1		0.29		0.14
Loveseat	0.8		1.6		0.35
Magazine rack	1		0.29		0.14
Ottoman	0.8		1.6		0.35
Desk	1	0.8		1.33	
Computer	0.9		2.5		0.2
Futon	0.8		1.6		0.35
King, Queen or Double bed	0.8		1.6		0.35
Single bed	0.8		1.6		0.35
Drawers	1	0.8		1.33	
Stand-alone wardrobe	0.8	0.8		1.33	
Clothes	1	1.5		2.2	
Manchester	1	1.5		1.6	
Toys	1	1.5		2.2	
Books/Magazines	1	1.27		1.33	
Fridge	0.5		2.22		0.07
Dishwasher	0.5		1.62		0.02
Microwave	0.3		2.5		0.2
Gas Stove	0.2		2.5		0.2
Electric Stove	0.2		2.5		0.2
Rangehood	0.3		2.5		0.2
Cabinet - wood finish	1	1.27		1.33	
Cabinet - laminate finish	1	0.8		1.2	
Table	1	0.8		1.33	
Chairs	1	1.2		1.9	
Washing machine	0.3		2.43		0.34
Dryer	0.3		2.5		0.2
Electrical cable	0.8		0.12		0.05