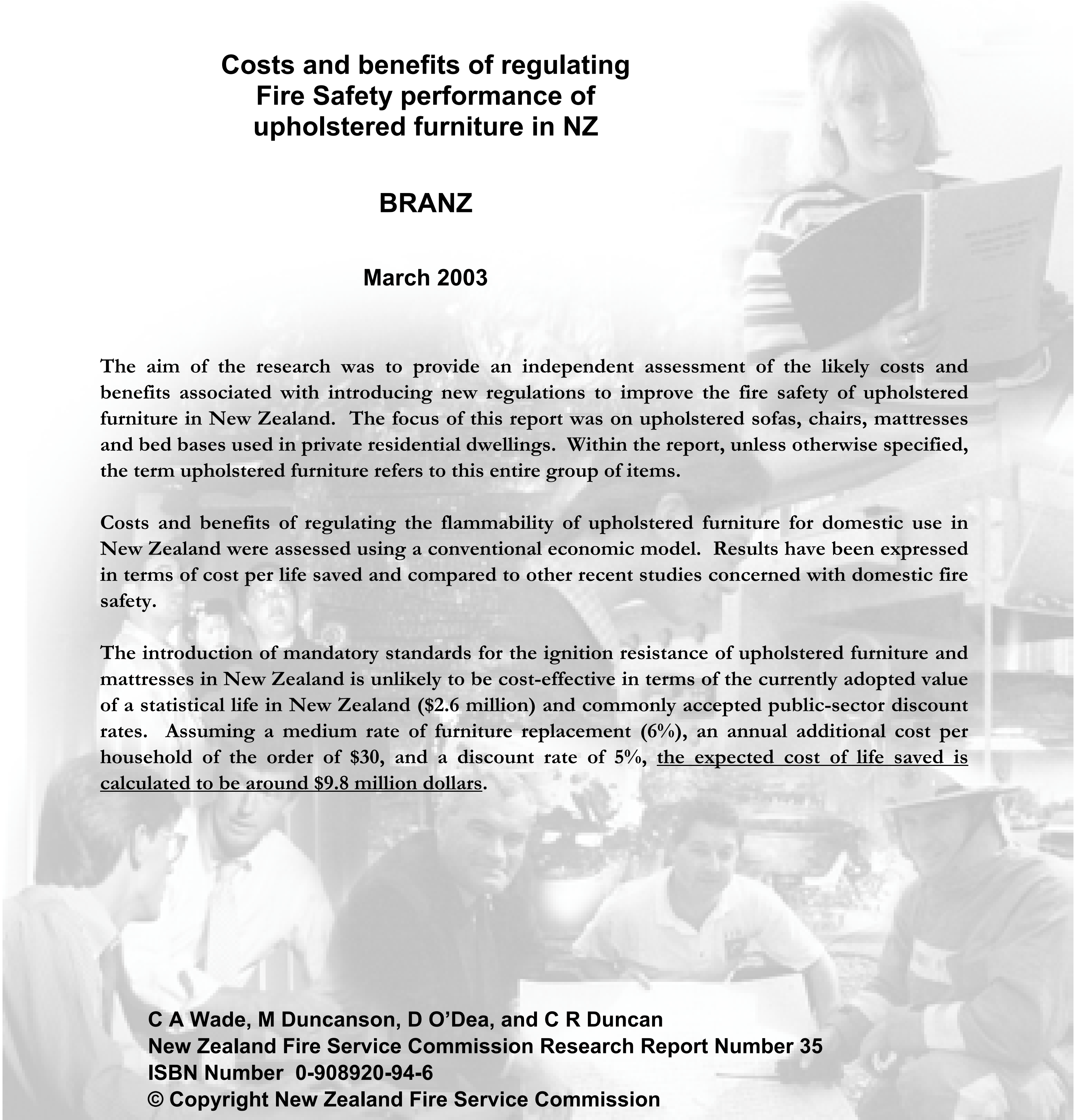
Fire Research
Report



Costs and benefits of regulating Fire Safety performance of upholstered furniture in NZ

BRANZ

March 2003

The aim of the research was to provide an independent assessment of the likely costs and benefits associated with introducing new regulations to improve the fire safety of upholstered furniture in New Zealand. The focus of this report was on upholstered sofas, chairs, mattresses and bed bases used in private residential dwellings. Within the report, unless otherwise specified, the term upholstered furniture refers to this entire group of items.

Costs and benefits of regulating the flammability of upholstered furniture for domestic use in New Zealand were assessed using a conventional economic model. Results have been expressed in terms of cost per life saved and compared to other recent studies concerned with domestic fire safety.

The introduction of mandatory standards for the ignition resistance of upholstered furniture and mattresses in New Zealand is unlikely to be cost-effective in terms of the currently adopted value of a statistical life in New Zealand ($2.6 million) and commonly accepted public-sector discount rates. Assuming a medium rate of furniture replacement (6%), an annual additional cost per household of the order of $30, and a discount rate of 5%, <u>the expected cost of life saved is calculated to be around $9.8 million dollars</u>.

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Costs and Benefits of Regulating Fire Safety Performance of Upholstered Furniture in New Zealand

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Abbreviations used in this report

£	Pounds sterling
AFIRS	Australian fire incident reporting system
ASTM	ASTM International (formerly American Society for Testing and Materials)
BERL	Business and Economic Research Limited (New Zealand)
BHFTI	Bureau of Home Furnishings and Thermal Insulation (United States of America)
BRANZ	Building Research Association of New Zealand Ltd
BSI	British Standards Institution
CBUF	Combustion behaviour of upholstered furniture (European research project)
CFAST	Consolidated Fire and Smoke Transport Model (United States of America)
CPSC	Consumer Products Safety Commission (United States of America)
DTI	Department of Trade and Industry (United Kingdom)
FED	Fractional Effective Dose (fraction of an incapacitating dose)
FIRS	Fire incident reporting system (New Zealand)
FR	Fire-retardant
HCN	Hydrogen cyanide
HRR	Heat release rate
HSS	Health Statistics Service (now New Zealand Health Information Service)
LTSA	Land Transport Safety Authority (New Zealand)
NFPA	National Fire Protection Association (United States of America)
NZHIS	New Zealand Health Information Service (formerly Health Statistics Service)
PBDE	Polybrominated diphenyl ethers
UFAC	Upholstered Furniture Action Council (United States of America)
UK	United Kingdom (England, Scotland, Wales and Northern Ireland)
US	United States (of America)
VoSL	Value of statistical life
WRONZ	Wool Research Organisation of New Zealand

1. EXECUTIVE SUMMARY

1.1. Introduction

The aim of the research was to provide an independent assessment of the likely costs and benefits associated with introducing new regulations to improve the fire safety of upholstered furniture in New Zealand. The focus of this report was on upholstered sofas, chairs, mattresses and bed bases used in private residential dwellings. Within the report, unless otherwise specified, the term upholstered furniture refers to this entire group of items.

Costs and benefits of regulating the flammability of upholstered furniture for domestic use in New Zealand were assessed using a conventional economic model. Results have been expressed in terms of cost per life saved and compared to other recent studies concerned with domestic fire safety.

1.2. Literature review

The key New Zealand research projects with a specific focus on human injury and upholstered furniture were conducted by Brereton (1992) and Wong (2001). More general investigations of domestic fire hazard and of fire-related mortality that include information about heat sources and items ignited are those by Irwin (1997), and Duncanson, Ormsby, Reid, Langley and Woodward (2001a, 2001b, 2001c). Findings of New Zealand research projects are listed in Table 3-1 on page 19.

Brereton and Laing found that upholstered furniture and bedding were implicated in 28% of burn-related deaths in New Zealand from 1977 to 1986, with bedding a particular hazard. Mortality rates in fires involving upholstered furniture were highest for those aged over 55 years and those who lived alone. Alcohol was involved in 14% of the fatalities involving upholstered furniture. Eleven per cent of hospital admissions involving burns from fire were the result of fire which started in a lounge or bedroom, and so could have involved upholstered furniture (Brereton, 1990).

Wong (2001) reviewed FIRS data and coroners' reports for fatal residential fire incidents between 1995 and 2000 in New Zealand. Upholstered furniture (including beds and mattresses) was involved in 45 fatalities or 35.4% of all residential fire deaths, and was likely to have been involved in a further 19% of fire related deaths.

In the United States, upholstered furniture, mattresses and bedding, curtains, blinds and drapes, and carpets and rugs were the first materials or items ignited in about 11% of all fires in single-family dwellings between 1982 and 1996. Those fires accounted for more than 35% of the fires deaths and 25% of fire injuries in those structures (Richardson, 2001).

Between 1979 and 1984 the Wool Research Organisation of New Zealand (WRONZ) highlighted the fire hazard of polyurethane foam upholstered furniture and bedding in New Zealand and recommended regulatory action. Similar testing methods were used in research at the University of Canterbury. The main objective of research at the University of Canterbury has been to predict the combustion behaviour of upholstered furniture through use of small-scale tests. Conclusions from the research have shown that it is possible to make some predictions on the basis of small-scale tests but the behaviour is also influenced by geometry and configuration of the furniture. The effect of fabric covers on the combustion behaviour of the furniture is also important. It is the combination of fabric and foam which has the most significant influence on the ignitability of the furniture.

An outcome of the European study of the Combustion Behaviour of Upholstered Furniture (CBUF, 1995) has been progress towards being able to predict the behaviour of upholstered furniture using mathematical models based on the combustion behaviour of small-scale samples. Model I is a method to predict the heat release rate (HRR) of a burning furniture item; Model II predicts the HRR time history. Model III of CBUF investigates the combustion behaviour of mattresses. Part of the Canterbury University research has focussed on comparing the combustion behaviour of New Zealand furniture samples to the findings of the CBUF research using European-sourced furniture, and in particular the applicability of CBUF Models I and II to New Zealand.

1.3. Regulations, codes and test standards

1.3.1. United Kingdom

The Furniture and Furnishings (Fire) (Safety) Regulations 1988 in the United Kingdom (HMSO, 1988) specify that fillings and coverings of all furniture must pass stringent flammability tests according to BS 5852 Parts 1, 2 or BS 7177/BS 6807. The requirements are generally met by use of chemical flame retardants in the foam (combustion modified foams) and in the back-coating for covering fabrics. In general the regulations require testing of foam/fabric composites and allow the option of a bench-scale test whereby fabrics are tested over standard padding, and paddings are tested beneath a standard fabric. If different construction is used for different parts of the furniture, e.g: seat, back, sides then separate tests are required.

A review of the impact of the Furniture and Furnishings (Fire) (Safety) Regulations 1988 in the United Kingdom commissioned by the Department of Trade and Industry (DTI) concluded:

> *Significant life-saving and injury reduction benefits have resulted from the introduction of the Furniture and Furnishings (Fire) (Safety) Regulations in 1988 in the UK. Corresponding benefits relate to reductions in the number of serious dwelling fires and in cost savings arising from reduced property loss and lives saved.* (Department of Trade and Industry (DTI), 2000 p23).

The report was written with the benefit of almost 10 years of fire statistics since the introduction of the regulations in 1988, and was essentially an economic analysis of the costs and benefits resulting those regulations.

The cumulative benefits attributed by the report to the regulations in the 10 years from 1988 to 1997 included:

- 710 lives saved which would have been lost in fires first ignited in upholstered furniture from 1988 to 1997. Possible saving of a further 150 lives in fires which did not start in upholstered furniture but which may have spread to include upholstered furniture.
- Prevention of 5774 non-fatal injuries which would have occurred in fires in upholstered furniture. Possible prevention of a further 11,226 non-fatal injuries which

did not start in upholstered furniture but which may have spread to include upholstered furniture.

- £53 million worth of property saved.
- Projected saving of at least 791 lives, prevention of 7250 non-fatal injuries and prevention of £112 million property damage from 1998 to 2031.
- The report concluded that the benefit to cost ratio of implementation of the regulations was 38:1 (that is £38 of benefit for every £1 spent) using cost savings estimates for property damage.
- The cost of the regulations to industry and to those who buy furniture was estimated to be between £15 and £20 per item.

1.3.2. United States

In the United States there are voluntary standards for cigarette ignition of upholstered furniture for both residential and institutional buildings. These standards were produced by the Upholstered Furniture Action Council (UFAC) and were agreed to by the US Consumer Products Safety Commission (CPSC) in 1981. For residential furniture they are basically cigarette ignition tests. UFAC procedures were published in NFPA 260 (1986) and ASTM E 1353 (1990).

California has its own regulations for cigarette and small-flame ignition resistance of fabrics and padding material. The relevant standards for residential furniture components are TB116 and TB117 (Bureau of Home Furnishings and Thermal Insulation (BHFTI), 1980, 2000a). These have been the minimum standards for any occupancy in California since 1975. TB116 is a voluntary standard requiring that either the furniture meet cigarette ignition criteria or be labelled if it does not. TB117 is a mandatory standard in California and requires flammability testing of the fabric and padding. TB117 does not require the use of fire-retardant covers or fabrics. There are also standards for institutional occupancies i.e. TB129 and TB133 (BHFTI, 1993; BHFTI, 1991).

Mattresses in the US are subject to mandatory federal flammability standards. Currently all mattresses manufactured in the United States are subject to CPSC Standard DOC FF4-72, a flammability standard established by the CPSC in 1972 to address cigarette ignition resistance (CPSC, 1998) for mattresses in residential buildings. In October 2001, the CPSC announced it also intended to develop a small-flame ignition resistance test for mattresses (CPSC, 2001).

Between 1994 and 1997 the CPSC developed a small-flame ignition test for upholstered furniture. However, because the new flammability test was expected to result in increased use of fire retardants and the speculation that these fire retardants would pose toxic hazards of their own, the CPSC was required to commission research on the toxicity of fire retardants, delaying any further action regarding the small-flame ignition test. The CPSC developed the test because after extensive laboratory testing it believed the TB117 test did not give results that correlated with full-scale furniture behaviour. It was concluded that the BS 5852 approach, using composite mock-up specimens (British Standards Institution (BSI), 1990), was better able to achieve this, so it developed a new test similar to BS 5852.

1.4. Regulatory actions and their effectiveness

Key factors to be considered in conducting an economic evaluation of flammability standards of upholstered furniture relate to the potential savings through reduced property damage, together with fewer deaths and injuries, and the costs to the industry, consumers and society as a whole of developing and implementing standards. International precedents suggest three principal levels of standard development:

- Mandatory labelling of upholstered furniture and mattresses, warning of the fire risk associated with upholstered furniture and indicating compliance or not with an appropriate standard.
- Mandatory standards for flammability in mattresses with voluntary standards for lounge furniture with labelling as above.
- Mandatory standards for flammability of all upholstered furniture products and mattresses.

The cost-benefit study in this report is based on introducing mandatory standards for ignition resistance of upholstered furniture and mattresses, similar to those currently used in United Kingdom and proposed for use in the USA. In each of these cases the regulatory change has been argued to be cost-effective, and thus it is of interest to assess whether this is also the case for New Zealand.

1.5. Cost-benefit analysis

Cost-benefit analysis measures the costs and benefits and provides the decision-maker with the results of these calculations in an appropriate form. If there is risk and uncertainty associated with the estimated costs and benefits, as is generally the case, the cost-benefit analyses can also include analyses measuring the sensitivity of the results to variations.

The major benefit from the proposal examined in this report are the lives saved as a result of fires not starting in upholstered furniture, or as a result of fires developing more slowly and allowing occupants time to escape.

The decision criterion used is, therefore, cost per life saved. The same criterion has been used in other recent studies (Wade and Duncan, 2000; Beever and Britton, 1999; DTI, 2001). If the net cost is significantly less than the ‘value of statistical life’ currently used in the New Zealand land transport sector, then the proposed new standard is worth introducing. To convince policymakers, this criterion will probably need to be met for discount rates of the order of 5% per annum and higher.

1.6. Conclusions and recommendations

The introduction of mandatory standards for the ignition resistance of upholstered furniture and mattresses in New Zealand is unlikely to be cost-effective in terms of the currently adopted value of a statistical life in New Zealand ($2.6 million) and commonly accepted public-sector discount rates. Assuming a medium rate of furniture replacement (6%), an annual additional cost per household of the order of $30, and a discount rate of 5%, **the expected cost per life saved is calculated to be around $9.8 million dollars.**

Some of the reasons for the lower apparent cost-effectiveness compared to the analysis of the cost-effectiveness of regulations introduced in the United Kingdom in 1988 include:

- The statistical value of human life for New Zealand as used in this study, and as used by the Land Transport Safety Authority (LTSA), is only about one-fourth of that adopted for recent cost-benefit studies in the United Kingdom and in the United States. In fact, if the statistical value of human life were taken as $10 million rather than $2.6 million, then as shown in Figure 8-2 on page 80, the regulation of furniture flammability might just be justifiable as providing a net benefit to New Zealand. However, this is before deducting gains in lives saved in any case from wider use of smoke alarms, and possible declines in the rate of smoking.
- The number of reported fire deaths per 1000 house fires appears to be significantly lower in New Zealand compared to the United Kingdom. One reason for this is likely to be the much lower population density in New Zealand, where most households live in detached dwellings, as compared with high-rise apartment complexes in the United Kingdom.
- The UK analysts assume a substantially greater reduction in fire deaths (70%) from the introduction of the new standards than we do (30%). However, even with an assumed 47% reduction in deaths, our calculated expected cost per life saved is $5.1 million dollars and our conclusions do not change.
- The estimated added cost to households buying furniture in New Zealand is substantially higher than that used in the DTI study for the United Kingdom. The UK analyses have the benefit of actual experience of the new standards. Also there are economies of scale possible in the British and European markets unattainable in Australasia. Even so, it is not easy to reconcile the cost assessments used in the UK studies with the expected costs provided by New Zealand manufacturers and distributors.
- Mandatory standards for upholstered furniture and mattresses in New Zealand would be cost effective if the additional average cost of fire-retardant treatment or other means to achieve the required level of performance was $10 or less per household per year, or about $150 on the cost of an average lounge suite purchase.
- To reduce uncertainties in the assumptions required for this cost-benefit study, more detailed data in routinely collected datasets, such as the Fire Incident Reporting System (FIRS), concerning the number of fire incidents, deaths and injuries and the extent that upholstered furniture and mattresses contributed to them as items first ignited *and as items principally responsible for development of the fire,* would be greatly beneficial; and
- Accurate estimates of production costs associated with compliance with standards are also needed. Within the scope and timeframe of the current project it was not possible to assess the extent to which estimates may have been underestimated in the United Kingdom or overestimated in New Zealand.

2. INTRODUCTION

This report is on a study jointly carried out by BRANZ Ltd and the University of Otago investigating the cost-benefit of introducing regulations to control flammability of upholstered furniture in New Zealand.

Upholstered furniture was involved in 35% or more of all residential fire deaths in New Zealand from 1995 to 2000, either as the item first ignited or more commonly as a contributor to the development of the fire. There are no mandatory fire performance standards applying to furniture sold in New Zealand and full-scale testing has confirmed the potential for rapid fire growth and generation of hazardous environments resulting from the burning of some types of furniture, particularly those incorporating polyurethane foams. Fire safety standards for furniture and furnishings were mandated in the United Kingdom in 1988 and a recent analysis of the effect of those regulations by the University of Surrey concluded significant numbers of lives saved and injuries reduced (Department of Trade and Industry, 2000).

The current study investigates the cost and benefits that are likely to result should regulations be introduced in New Zealand, using data derived from epidemiological and fire engineering research. The report is expected to provide independent and useful information to the New Zealand Fire Service, the upholstered furniture industry, and to the Ministry of Consumer Affairs, to assist in any future decision-making regarding the regulation of flammability of upholstered furniture.

2.1. Aim and objectives

The aim of the research was to provide an independent assessment of the likely costs and benefits associated with introducing new regulations to improve the fire safety of upholstered furniture in New Zealand and thus reduce fire deaths, injuries and property loss.

The focus of this report was on upholstered sofas, chairs and mattresses used in private residential dwellings. These are the items covered by the British legislation used to benchmark possible regulation in New Zealand.

Specific objectives of the project were:

- To benefit from what can already be learned from the experiences in the United Kingdom and the USA (California) where fire standards for furniture have been in place for some time.
- To estimate the likely costs of introducing mandatory standards for upholstered furniture in New Zealand.
- To estimate the costs of fires involving upholstered furniture in New Zealand.
- To assess the likely impact on fire damage and human injury of mandatory standards for upholstered furniture in New Zealand.
- To conduct a cost-benefit analysis for introducing mandatory standards for upholstered furniture in New Zealand.

2.2. Methods

The project used multiple methods to gather the information needed to undertake a cost-benefit analysis for introducing mandatory standards for upholstered furniture in New Zealand.

2.2.1. Literature review

A literature review used medical, textile and fire-related literature databases and internet search engines to get information about upholstered furniture and fire in private dwellings, including the use of fire-retardant foams to reduce flammability of such furniture. Recent New Zealand research at the University of Canterbury was summarised and results and outcomes from the European CBUF projects were reviewed, together with the relevance of the test methods proposed for the fire hazard assessment of upholstered furniture.

2.2.2. Regulations, codes and test standards review

Existing and proposed regulatory frameworks and test standards were identified and obtained from the USA, UK, and other relevant and accessible jurisdictions.

2.2.3. Key informant interviews

Semi-structured telephone interviews were held with key informants from the furniture industry in New Zealand to ascertain their views concerning the feasibility of upholstered furniture flammability standards inAotearoa New Zealand.

2.2.4. Computer simulation

Computer simulation techniques were used to demonstrate the potential hazard from different types of upholstered furniture in a typical house and to quantify the effects of hazard mitigating measures, such as the use of combustion-modified foam, domestic sprinklers, and smoke alarms, to highlight the probable direct effects of different fire-protection strategies.

2.2.5. Collation and analysis of existing data

New Zealand data and international fire incident statistics were reviewed and analysed.

2.2.6. Cost–benefit analysis

Data derived from the various methods were entered into a cost-benefit model based on that recommended by Drummond et al (1997), including a sensitivity analysis to account for areas of uncertainty and comparison of cost effectiveness outcomes with published data on other residential fire protection measures, such as domestic fire sprinklers and smoke alarms.

3. LITERATURE REVIEW

A literature review used medical, textile and fire-related literature databases and internet search engines to obtain information about upholstered furniture and fire in private dwellings. Abstracts and executive summaries of identified articles and reports were reviewed to identify and obtain copies of articles relevant to the cost-benefit analysis of mandatory flammability standards for upholstered furniture. Reference lists of study documents were also searched for relevant reports and papers. Where possible, originals were obtained. However, some references, which were not readily available, have been cited as secondary sources. Collectively, these data sources provided information about the relationship between upholstered furniture and fire incidents resulting in human injury and property damage, combustion behaviour of upholstered furniture, and about economic evaluation of fire safety interventions.

3.1. Upholstered furniture and fire-related injury

3.1.1. New Zealand

The key New Zealand research projects with a specific focus on human injury and upholstered furniture were conducted by Brereton (1990) and Wong (2001). Brereton's thesis was later published in peer-reviewed literature (Brereton and Laing, 1992). More general investigations of domestic fire hazard and of fire-related mortality which include information about heat sources and items ignited are those by Irwin (1997), and Duncanson, Ormsby, Reid, Langley and Woodward (2001a, 2001b, 2001c). Findings of New Zealand research projects are listed in Table 3-1 on page 19.

Brereton and Laing (1992) reviewed burn-related deaths (1977 to 1986) and hospitalisations (1986) to estimate the role of upholstered furniture in fire-related injury. Information regarding heat source and items ignited had not been collected systematically in the datasets analysed in the Brereton and Laing study, and they therefore caution that their results are likely to underestimate deaths and injury from fire involving upholstered furniture. Upholstered furniture and bedding were implicated in 28% (103) of the 364 burn-related deaths in New Zealand from 1977 to 1986. Bedding was a particular hazard, with bedding and mattresses being the first item ignited in 25% of all fatal bedroom fires. Furniture was the first item ignited in 7% of fires starting in a lounge. Mortality rates in fires involving upholstered furniture were highest for those aged over 55 years and those who lived alone. Alcohol was involved in 14% of the fatalities involving upholstered furniture.

It was not possible to determine the proportion of hospitalisations resulting from textile-related fires, as this information was not recorded systematically for each hospital admission. In 1986 there were 289 hospital admissions involving burns from fire. Thirty-one (11%) of these admissions were the result of fire which started in a lounge or bedroom, and so could have involved upholstered furniture (Brereton, 1990).

The cumulative mortality rate for fire incidents involving bedding and upholstered furniture from 1977 to 1986 was 1.14 per 100,000 population. The hospitalisation rate for burn-related injuries in 1986 was 9 per 100,000 population; no separate hospitalisation rate was calculated for fire incidents involving bedding and upholstered furniture (Brereton and Laing, 1992).

Wong (2001) reviewed Fire Incident Reporting System (FIRS) data and coroners' reports for fatal residential fire incidents from 1995 to 2000. The FIRS database recorded a total of 127 fatalities resulting from 105 fire incidents on residential property during this five-year period. Wong (2001) found that upholstered furniture was involved in 45 fatalities or 35.4% of all residential fire fatalities. The upholstered furniture was not usually the object first ignited, rather, upholstered furniture was ignited by other small-flame or large-flame ignition sources in the same room.

The degree of involvement of upholstered furniture in each fatal residential fire incident was coded to one of five categories.

1. Deaths were considered the result of incidents which *involved* upholstered furniture if the object ignited was coded as an item of upholstered furniture made of synthetic (open cell) foam, or the material generating most flame or smoke was coded as synthetic (open cell) foam. Cases where the coroners' files or fire investigation reports indicated that items of upholstered furniture were present in the rooms where the fire originated or spread were also included in this category.

2. Deaths were considered the result of incidents *likely to have involved upholstered furniture* in incidents where the fire originated from and spread to rooms and spaces that would typically be furnished with upholstered furniture. Although no mention was made of upholstered furniture in reports, the details of the fire and its spread mean it is likely that upholstered furniture contributed to the fatality.

3. Involvement of upholstered furniture was considered *unlikely* in fatal incidents where the fire originated from and spread to rooms and spaces that would typically be furnished with upholstered furniture, but no mention is made of upholstered furniture in reports and the details of the fire and its spread do not seem to indicate that upholstered furniture contributed to the fatality.

4. Upholstered furniture was considered *not involved* if the fire originated from and spread to rooms or spaces that do not typically contain upholstered furniture, no mention was made of upholstered furniture in reports, and the details of the fire and its spread make it unlikely that upholstered furniture contributed to the fatality.

5. There were also some incidents where codes indicated that heat source, object ignited, type of material and supposed cause are all *unknown*.

Using these criteria, Wong found that upholstered furniture was involved in 35% of fatal fire incidents and was likely to have been involved in a further 19% of fatal fire incidents between 1 July 1995 and 30 June 2000. Upholstered furniture was considered not to be involved in 32% of fatal fire incidents and unlikely to have been involved in 10% of fatal fire incidents in the same time-frame, with 4% of fatal fire incidents in the unknown category. Most (83%) of the fatal fire incidents involving upholstered furniture resulted in a single fatality, 8% resulted in two fatalities, and 8% in three or more fatalities.

Chairs and sofas alone were involved in 56% of the fatal fire incidents investigated by Wong; beds were involved in 20% of incidents and both upholstered lounge furniture and beds in the remaining 24% of incidents. The item of upholstered furniture was the first item ignited in only 16% of the incidents studied by Wong (2001). In most (84%) of the fatal residential fires involving upholstered furniture, flame spread to the furniture item by small- or large-flame ignition, after primary ignition of other combustibles. Where upholstered furniture was the first item ignited, the most common heat source was smoking materials.

Wong (2001) found that the majority (78%) of private dwellings where a fatal fire involving upholstered furniture occurred did not have a functioning smoke alarm. In five (11%) of such incidents an alarm activated but did not prevent fatal injury because the deceased was intimate with the fire (although the alarm allowed other occupants to evacuate safely) or the deceased was not aware of how to respond to the alarm. In 7% of the fatal incidents involving upholstered furniture, the homes had non-functioning alarms and in 4% of dwellings the alarm status was unknown.

Fire incidents involving upholstered furniture typically resulted in a single fatality, even though there was usually more than one person present in the home when the fire started. The most common cause of death for occupants not in the room of fire origin was smoke inhalation, while for occupants within the room of fire origin, it was severe burns or exposure to heat and smoke from the fire.

In summary the main findings from the Wong (2001) study concerning residential fire incidents involving upholstered furniture were that:

- They typically resulted in a single death;
- Usually more than one person was present in the residential structure when the fire started;
- Young children, the elderly and those under the influence of drugs or alcohol were particularly susceptible;
- Occupants were usually asleep when the fire started;
- The most common cause of death for occupants not in the room of fire origin was smoke inhalation;
- The most common cause of death for occupants within the room of fire origin was severe burns or exposure to heat and smoke from the fire;
- Smoke detectors were not present or defective in most incidents; and
- Upholstered furniture was usually not the object first ignited, but contributed to spread of the fire through either small-flame or large-flame secondary ignition.

Irwin (1997) analysed FIRS data from 1986 to 1994 inclusive to investigate domestic fire hazard in New Zealand. In this time period FIRS recorded 42,009 domestic fire incidents resulting in 292 civilian deaths (7 per 1000 fires) and 1701 non-fatal injuries (40.5 per 1000 fires). Fires resulting in civilian death or injury started predominantly in the bedroom, lounge and dining room, and kitchen. Mattresses, bedding and upholstered furniture were items first ignited in 29% of fatal domestic fire incidents and 26% of non-fatal injury incidents.

Review of collated FIRS and Health Service mortality data from 1991 to 1997 inclusive (Duncanson et al., 2002) showed that bedding was the item first ignited in 17% of 155 fatal domestic fire incidents, other combustibles in bedrooms in a further 14%, lounge furniture in 6%, and other combustibles in the lounge in a further 6% of such incidents. It was assumed that ignition of bedding led to involvement of mattresses in the fatal fire incidents. Thus upholstered furniture was directly involved in 23% of incidents and possibly involved in a further 20%.

Table 3-1. Summary of New Zealand research findings related to upholstered furniture and injury

Author (Publication date)	Years studied	Data sources	Outcome measure (n)	Findings	Comments
Brereton & Laing (1992)	1977-1986	HSS* Coroners' files	Burn-related deaths (364)	28% involved bedding or upholstered furniture as item first ignited	Alcohol involved in 14% of upholstered furniture fatalities.
Brereton & Laing (1992)	1986	HSS	Hospital admissions for burns from fire (289)	11% from fire started in bedroom or lounge	Data inadequate for further analysis
Wong (2001)	1995-2000	FIRS † Coroners' files	Residential fire fatalities (127)	35% involved bedding or upholstered furniture; 19% likely to involve such items	Upholstered furniture as item first ignited OR subsequently ignited and contributing to fire spread.
Irwin (1997)	1986-1994	FIRS	Civilian fatalities (292)	29% bedding or upholstered furniture item first ignited	
Irwin (1997)	1986-1994	FIRS	Civilian non-fatal injuries (1701)	26% bedding or upholstered furniture item first ignited	
Duncanson, Ormsby, Reid et al (2002)	1991-1997	NZHIS ‡ FIRS Coroners' files	Fatal domestic fire incidents (155)	23% bedding or upholstered furniture item first ignited; 20% possibly involved upholstered furniture	
Duncanson et al (2002)	1996-2000	NZHIS FIRS	Hospital admissions for burns from fire and flame in domestic location (289)	9% involved bedding, upholstered furniture or combustibles in bedroom or lounge.	Analysis based on limited data subset because of frequent missing information.

* Health Statistics Service

† Fire Incident Reporting System (New Zealand Fire Service)

‡ New Zealand Health Information Service

3.1.2. United States

Ignition of furnishings (including bedclothes, mattresses and lounge furniture) featured in the top three fire death scenarios in the USA in the early 1970s (Clarke III and Ottoson, 1983). These three scenarios accounted for 36% of all fire deaths. The approach of Clarke and Ottoson (1976) is interesting because of the focus on a chain of events, rather than simply the item ignited. The three most common scenarios occurred in a residential location and involved ignition of furnishings by smoking materials (27% of US fire deaths), open flame (5% of US fire deaths) or cooking and heating equipment (4% of US fire deaths). Motor vehicle fires and clothing ignitions shared the third-most common scenario position.

In the United States, upholstered furniture, mattresses and bedding, curtains, blinds and drapes, and carpets and rugs were the first materials or items ignited in about 11% of all fires in single-family dwellings between 1982 and 1996. Those fires accounted for more than 35% of the fire deaths and 25% of fire injuries in those structures (Richardson, 2001). Using a narrower definition more relevant to the current investigation, Richardson (2001) notes that between 1993 and 1997 the National Fire Protection Association in the US estimated that upholstered and non-upholstered furniture pieces were the first items ignited in 4% of all fires; 20% of fire deaths (4.3 deaths per 100 fires); 10.3% of fire injuries (11.6 injuries per 100 fires); with an average loss per fire of US$17,400. Mattresses and bedding were items first ignited in 6.2% of all fires; 15.3% of fire deaths (2.1 deaths per 100 fires); 14.5% of fire injuries (10.6 injuries per 100 fires); with an average loss per fire of US$12,900. In this time period, there were a total of 423,700 home fires resulting in 3616 deaths and 19,149 injuries.

In California, where mandatory standards for home furnishings have been in place since 1975, the incidence of fire death, injury and property loss have fallen faster than in the USA as a whole:

> *Fire statistics reveal that, since 1975, the incidence of fire death, injury and property loss due to fires involving upholstered furniture has dropped at a higher per capita rate in California than in the United States as a whole. While use of smoke detectors and sprinklers, a declining number of smokers, and increased consumer education about fires are important factors in avoiding fire losses, California's furniture flammability standard is the primary factor in the significantly reduced rate of fires involving home furnishings. This standard makes the average piece of furniture less likely to ignite rapidly, and, if ignited, less likely to burn quickly or to sustain burning. The logic is simple: an occupant is less likely to become a victim if we can provide more time to react and escape. The Bureau also enforces the Federal standard for the smolder resistance of mattresses, futons, and mattress pads.*

(Bureau of Home Furnishings and Thermal Insulation, 2000b)

Between 1978 and 1995 there was a significant decline in the number of deaths in the USA where upholstered furniture was the first item ignited, as shown in Table 3-2.

Table 3-2. Number of dwelling fires and associated deaths, with percentage change, in fires where upholstered furniture was the first item ignited in 1995 compared with 1978, USA. Table taken from Wong (2001) page 78.

	1978		1995		Change	
	Fires	**Deaths**	**Fires**	**Deaths**	**Fires**	**Deaths**
Total residential fires	730,500	6,185	425,500	3695	-41.8%	-40.3%
Total upholstered furniture fires	43,000	1600	13,600	670	-68.4%	-58.1%
Upholstered furniture fires due to smoking materials	28,000	1300	6400	500	-77.1%	-61.5%
Upholstered furniture fires due to open flame	7900	200	3500	90	-55.7%	-55.0%
Upholstered furniture fires due to other causes	7100	100	3700	80	-47.9%	-20.0%

3.1.3. Australia

Wong (2001) included data from Dowling and Ramsay (1997) in her report. Table 3-3 is derived from Australian Fire Incident Reporting System (AFIRS) data; AFIRS is thought to capture 81-85% of all fire incidents in Australia. From 1989 to1993 there were 44,297 fires in structures with lounge and sleeping areas, where the extent of damage was also recorded. Apart from fires where the cause was unknown (such fires often involve extensive damage so that reconstruction of events is difficult), the highest rates of death and injury per 1000 fires were in incidents where the item first ignited was upholstered lounge furniture or bedroom furniture. Fires involving upholstered furniture were five times more likely to spread beyond room of origin compared with fires involving cooking materials. Spread beyond the room of origin is significant in that it is a marker of increased threat to survival of dwelling occupants. Fires involving upholstered furniture also resulted in proportionately more fatalities than fires involving mattresses and bedding materials, or other items first ignited (Dowling and Ramsay, 1997 cited by Wong, 2001).

Table 3-3. Number and percentage of fires in Australian dwellings with lounge and sleeping areas by item first ignited, with number and rate per 1000 fires of occupant deaths and non-fatal injuries. Table taken fromWong (2001).

	Fires	**Deaths**		**Non-fatal injuries**	
Item first ignited	**Number* (%)**	**Number**	**Rate per 1000 fires**	**Number**	**Rate per 1000 fires**
Upholstered furniture	994 (2)	17	17	107	108
Mattress or bedding	2543 (6)	34	13	356	140
Cooking materials	7185 (16)	12	2	459	64
Other materials	27,873 (63)	86	3	1220	44
Unknown	5702 (13)	102	18	540	95
Total	**44,297 (100)**	**251**	**6**	**2682**	**61**

* Table excludes incidents where extent of dwelling damage was not known

3.1.4. United Kingdom

The Department of Transport, Local Government and Regions (DTLR) in the UK reports that from 1990 to 2000 there was a general reduction in damage caused by fires, and that when fires did occur they spread less rapidly. DTLR cautions that some of the statistical patterns observed could have resulted from changes in recording methods after the introduction of a new fire report form in 1994 (DTLR 2002, p 36).

The British Crime Survey in 2000 showed that 3% of households in England and Wales experienced a fire in 1999 (Aust, 2001). This was down from 3.4% in 1995 and 3.9% in 1993, although tests of statistical significance were not reported. The question in the survey was designed to capture as many experiences of fire as possible, including minor fires, and is thus a useful adjunct to fire service data in that it provides a fuller measure of the number of domestic fires in England and Wales. Most of the affected households reported only one fire in the previous 12 months; however 11% of affected households reported more than one incident, with a few reporting five or more incidents. The survey estimated that 13% of fires in private dwellings in England and Wales were attended by the fire brigade, and that 11% of all fires resulted in injury.

Despite an overall increase in the number of dwelling fires between 1988 and 1993, there was a gradual decrease in the percentage of dwelling fires involving upholstered furniture, as shown in Table 3-4, and further a decrease in the number of fires and fire fatalities/casualties attributed to upholstered furniture.

Table 3-4. Upholstered furniture (UF) related fire incidents and casualties in the United Kingdom between 1988 and 1993. Table taken from Wong (2001)

Year	No. of Fires	% of dwelling fires	No. of deaths	Deaths (per 1000 UF fires)	Non-fatal casualties	Non-fatal casualties (per 1000 UF fires)
1988	4818	7.5	247	51	1896	394
1989	4482	6.9	201	45	1707	381
1990	4327	6.9	180	42	1759	407
1991	4311	6.7	147	34	1803	418
1992	4048	6.3	166	41	1660	410
1993	3746	5.7	146	39	1618	432

3.1.5. Canada

From 1988 to 1997 both the incidence and impact of residential fires declined. The annual rate of fire incidence fell from 125 to 71 per 100,000 population with corresponding falls in the fire-related mortality rates (1.6 to 1.0 per 100,000 population) and injuries (9.8 to 6.9 per 100,000 population) (Richardson, 2001). In 1999 there were 22,150 residential property fires in Canada, resulting in 284 deaths and C$517 million property loss (Human Resources Development Canada, 2000).

3.2. Combustion behaviour of upholstered furniture – key European research

3.2.1. Fire safety of upholstered furniture (CBUF) - Introduction

The objective of the CBUF study (Sundstrom, 1995) was to support a draft EU furniture directive which said –

> *"The atmosphere in the room in which the upholstered furniture or related article are on fire should despite the production of heat and smoke … remain for a reasonable period of time after ignition such that it does not endanger the lives or physical well being of exposed persons. This will be achieved by controlling the rates of heat release, and smoke and toxic gas production. This would allow time for the escape by alert and able-bodied persons."*

The CBUF research programme was set up to develop methods for measuring the burning behaviour of upholstered furniture as needed for the implementation of possible EU or national legislation or for European standardisation (Sundstrom, 1995).

An outcome from the European study of the Combustion Behaviour of Upholstered Furniture (CBUF), and an aim of Canterbury University research (discussed later), has been to predict the behaviour of upholstered furniture using mathematical models based on the combustion behaviour of small-scale samples. Model I is a method to predict the heat release rate (HRR) of a burning furniture item; Model II predicts the heat release rate time history. Model III of CBUF investigates the combustion behaviour of mattresses.

3.2.2. Projects

The CBUF research was split into five projects:

- Room scenario
- Furniture calorimeter
- Cone calorimeter (composites)
- Cone calorimeter (components)
- Furniture design

When combined, the projects aimed to predict the fire conditions caused by combustion of upholstered furniture in a room based on the results of small-scale tests.

1. Room scenario

The objective of this part of the study was to undertake a hazard analysis of the fire conditions in rooms where a single item of upholstered furniture is on fire (Sundstrom, 1995). The conditions in the ISO 9705 (1993) standard room were studied using the parameters of heat release rate, smoke and toxic gas production. Tenability limits, and the time to reach these limits were also studied.

Seventy-one room tests were carried out. These tests included a single item of furniture burning in the standard ISO 9705 room, another larger room, and variations in ventilation within these rooms. The hazard analysis was then based on data obtainable from the Furniture Calorimeter and comparing it to the actual findings from tests within a room in order to predict the time to untenable conditions. The hazard analysis of the furniture combustion behaviour was performed under controlled conditions (Sundstrom, 1995):

- The furniture burns alone in a room without interacting with any other combustibles.
- Tenability conditions are considered for the room of fire origin only.

From investigation of the burning behaviour of full-scale furniture and comparison with results from computer modelling, the CBUF study concluded the following (Sundstrom, 1995):

- Results from full-scale testing show that upholstered furniture dominates the fire development in the early stages. This was attributed to the large energy content stored in the furniture and relatively fast fire growth rate. The CBUF study concluded that as upholstered furniture is so dominant in reducing the tenability in the early stages of the fire it is sufficient to model combustion of the upholstered furniture alone, disregarding the interaction with other items in the room.
- The furniture calorimeter can be used to measure the relevant fire parameters with the room environment then being predicted by results from available room fire computer models.
- Two cases of combustion behaviour of upholstered furniture were distinguished: (1) furniture that will not burn to a degree that creates a hazard; and (2) furniture which after some time, will produce untenable conditions.
- It is concluded from the CBUF experiments that the tenability in a moderately-sized room scenario can be expressed by one parameter only; the height of the smoke interface. Considering the room as two-zone, hot upper layer and cooler lower layer, from the experiments the lower zone was shown within wide limits to be tenable in terms of temperature, heat flux, smoke density and toxic gases. The descent of the upper layer is therefore critical in determining the tenability in the room. Relevant room scenarios and acceptable heights must be determined by the user of CBUF results.
- CFAST calculations and comparison with experimental data gave relationships between the height of the smoke/gas layer and the heat release rate. Therefore fire modelling can be used to predict the HRR, hence the height of the smoke/gas layer, and estimate the tenability in the room.
- In a small closed room with no ventilation, tenability limits may be reached at very small fire sizes. French work (Sainrat et al, 1995) shows that only about 17 g of pyrolysed material per m^3 of room volume is sufficient to cause untenability, regardless of the type of furniture. Reduction of the hazard in this scenario can be based on ignition control and a mass loss criterion in addition to requirements of burning behaviour.

2. Furniture calorimeter

The furniture calorimeter determines the heat release rate from the furniture item by measuring the amount of oxygen consumed during combustion. The results from the hazard analysis of the room scenario were strongly reliant on full-scale tests of items of upholstered furniture. In total, 154 furniture calorimeter tests were undertaken as part of the CBUF study.

The furniture calorimeter data was used with two room fire computer models (two-zone model and field model) and compared to the findings from the room scenario tests. The data was effectively used to validate the outcomes from the models.

Two models were considered:

- Two-zone model – this approximates the atmosphere in a room to be a hot upper, smoke-filled zone and a cool lower zone.
- Field model – this splits the room into small control volumes and uses the principles of fluid dynamics to simulate the effects of the fire.

The two-zone model CFAST and the field model JASMINE were used to investigate the interface position, upper-layer gas temperature and gas species in the smoke layer as caused by a furniture fire in a room. The experimentally-measured HRR time histories from the furniture calorimeter tests were used as the input to the fire model. Outputs from the computer models were then compared to the findings from full-scale room scenario tests to validate their accuracy. Further details can be found in the CBUF report (Sundstrom, 1995).

The two-zone model was found to be sufficient at predicting when hazardous conditions are reached in rooms of domestic size. The field model was also found to be adequate at predicting hazardous fire conditions, but its accuracy is greater than the two-zone model particularly for more complex scenarios.

3. Cone calorimeter (composites)

The objective of the cone calorimeter tests of composite samples of furniture was to:

- Obtain data on the composites used in the full-scale furniture tests, including heat release rates, mass loss rates, heats of combustion, production and yields of smoke, CO, CO_2, and other gases as a function of time.
- Develop a test protocol to ensure repeatable and reproducible data can be obtained from the cone calorimeter.
- Assess the impact of reduced oxygen concentration on the burning of the test samples to simulate the effect of oxygen depletion on the burning behaviour of full-scale furniture.

In total, 1098 cone calorimeter tests of composites were undertaken. The results of the tests were for use as input data in the mathematical fire models.

4. Cone calorimeter (components)

The objective of the cone calorimeter tests of components was to develop a model for predicting the heat release rate, carbon monoxide and smoke yields of furniture composites based on measurements of the individual components (Sundstrom, 1995). In total, 172 cone calorimeter component tests were undertaken. The measurements of the heat release rates for the components were taken and a computer programme developed to predict the HRR curve for the composites.

5. Furniture design

Investigation of both the small-scale and full-scale furniture samples shows that the choice of material and material combinations, as well as the design of the furniture, can influence the burning behaviour. The six factors identified as influencing the burning behaviour are:

1. **Fabrics** – furniture fabrics were classified as charring and melting.
2. **Fillings** – it had been shown that the peak HRR of a foam fire is more than linearly proportional to the mass of the upholstery. The research suggests that a reduction in the mass of the foam or use of fire-retardant foam would reduce the flammability of the furniture.
3. **Interliners** – are an intermediate layer between the fabric and the foam. They can be used to protect the foam, thus delaying the fire spread.
4. **Geometry** – the following geometry influences the fire spread: presence or absence of armrests, high or low back, gaps between major cushion areas, internal cavities, button tufting and the effect of innersprings (mattresses). Strategies suggested to improve fire behaviour are a reduction in combustible mass and panel-mounting rather than webbing to support chair cushioning.
5. **Frames** – strategies for improved fire behaviour based on modified furniture frames include: avoid producing frameless chair designs, avoid use of thermoplastic material frames, ensure the joints of wood frames are secure, and avoid use of corrugated metal joint plates in wood frames.
6. **Size** – the HRR is shown to be proportional to the mass of combustibles in the chair. Also, radiative effects influence the burning behaviour.

3.2.3. Models

Three furniture combustion behaviour prediction mathematical models were developed as a result of the CBUF research (Sundstrom, 1995):

- Model I is a simple correlation method using statistically correlated factors to predict the heat release rate (HRR) of a burning furniture item.
- Model II predicts the HRR time history and is based on an area convolution technique with empirical expressions of burning area over time determined for furniture types.
- Model III is based on novel extensions to thermal fire spread theory originally developed for wall surfaces and used here to predict the combustion behaviour of mattresses.

The models use the results from the small-scale cone calorimeter tests to predict the burning behaviour of the full-scale furniture. Details on the accuracy of the models can be found in the CBUF report (Sundstrom, 1995). They are generally considered to be reasonable but may be limited to the range of (European-sourced) furniture styles and materials used in the study. Variation between predicted and measured values can be due to errors from test procedures, variation in test samples and errors in the modelling.

3.2.4. Application to New Zealand

Figure 3-1 outlines the CBUF fire safety design procedure for upholstered furniture. The procedure uses a collection of test methods, modelling and correlation formulae to determine whether an item of upholstered furniture meets certain requirements of fire safety.

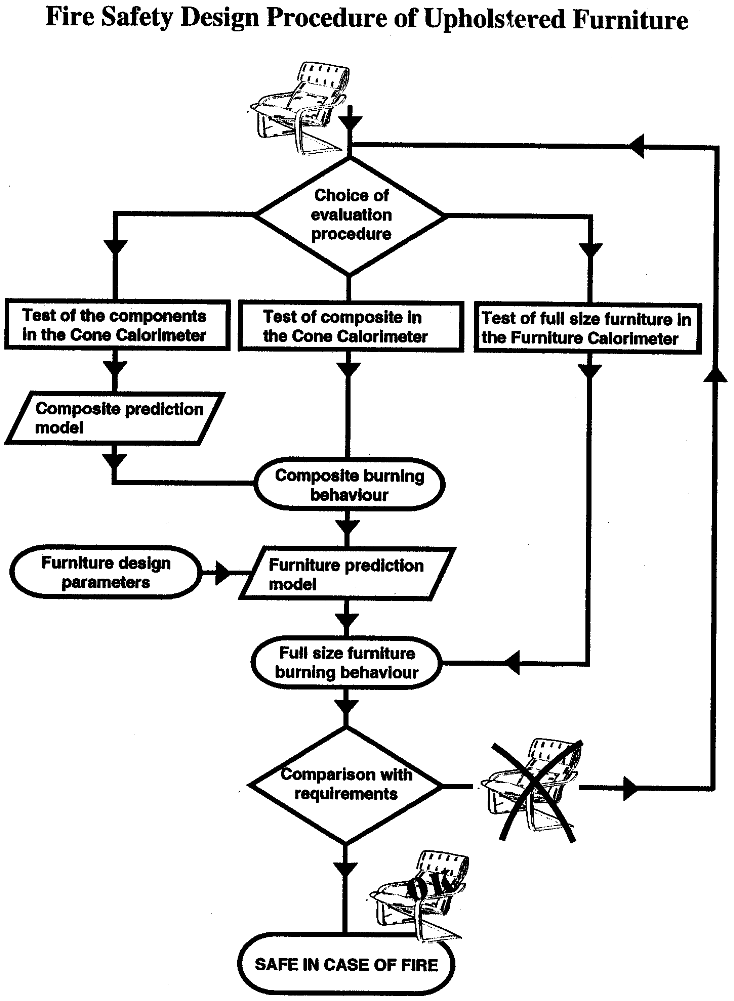


Figure 3-1. Procedure for fire safety design of upholstered furniture (reproduced from Sundstrom, 1995)

3.2.5. Relevance of test methods proposed

The results from the CBUF research could be applied to New Zealand upholstered furniture in the following ways:

- Use mathematical models to convert data from small-scale tests to that of full-scale furniture then use the full-scale results to predict the tenability levels in the room of fire origin. This has implications for the cost of testing for furniture manufacturers.
- The CBUF study concludes that as upholstered furniture is so dominant in reducing room tenability in the early stages of the fire it is therefore sufficient to

model combustion of the upholstered furniture alone, disregarding the interaction with other items in the room. This is significant with regard to developing an accurate fire scenario for use in computer models.

- In a small closed room with no ventilation, tenability limits may be reached at very small fire sizes. French work shows that only about 17 g/m^3 room volume of pyrolysed material is sufficient to cause untenability, regardless of type of furniture (Sainrat et al, 1995).
- The experiments incorporated some validation of field and zone computer fire models. The research concluded that field models are better at predicting fire environment in complex room scenarios but zone models are adequate at predicting the fire environment for simple domestic rooms.
- Further study of the accuracy of the prediction models using typical New Zealand upholstered furniture is necessary, such as that recently undertaken at the University of Canterbury (discussed later).

3.2.6. Summary and conclusions

- The CBUF research devised a method for scaling the combustion information from the furniture calorimeter to predicting its influence on the room fire environment.
- A second method for scaling up small-scale test calorific data to full-scale to predict the combustion behaviour of furniture in the room environment was also determined.
- The CBUF study provides information on the combustion behaviour of each of the components of the furniture and illustrates the influence that the covering fabric has on the ignition properties of the furniture.

3.3. Combustion behaviour of upholstered furniture – key New Zealand research

The following is a summary of the research published by the Wool Research Organisation of New Zealand (WRONZ) and the University of Canterbury (UoC) from 1979 to 2001.

3.3.1. Wool Research Organization of New Zealand

Ingham et al (1979, 1981, 1984) carried out various studies at WRONZ related to the flammability of polyurethane-upholstered furniture including full-scale house fire tests.

Ingham (1981a) determined that the influence of the foam type on chair ignitability was less than that of the fabric coverings, and recommended wool coverings for improved resistance to ignition. Ingham et al (1981b) then conducted two experimental house-fire tests, lighting an upholstered lounge suite with a match and resulting in full flashover of the room after only 3½ minutes. They reiterated the previous recommendation for implementing flammability controls on upholstered furniture in New Zealand.

Ingham and Edwards (1984) investigated the flammability of bedding materials and concluded that polyurethane foam mattresses are easily ignited and burn rapidly. They strongly recommended that wool underlay and wool bedding be used wherever possible as a means of reducing the fire danger. Ingham et al (1979) recommended that urgent consideration be given to implementing flammability controls on upholstered furniture in New Zealand, especially for furnishings in public buildings and in transportation. They also concluded that tests on fabrics alone are insufficient to assess the hazard and that a foam/fabric mock-up must be used. They highlighted the fire safety benefits of woollen upholstery fabric and bedding. However it is clear that these recommendations of some 20 years were not acted on.

3.3.2. University of Canterbury

The work previously reported by Wong (2001) found that combustion of upholstered furniture contributed to residential fire fatalities in the following ways:

- Production of toxic combustion products, i.e.: narcotic gases such as carbon monoxide and hydrogen cyanide.
- Rapid fire growth rate and flame spread, i.e.: unsafe tenability limits are reached before occupants are able to evacuate due to the combustion behaviour of the foam.
- Cigarette and small flame ignitability; i.e.: the configuration of the furniture and ease of ignitability assisting in the start and spread of the fire.

Denize (2000) evaluates the combustion severity of New Zealand upholstered furniture materials. An investigation of upholstered furniture identified the commonly used fabrics and foams in New Zealand furniture. The combustion behaviour of the combinations of fabric and foam were determined via bench-scale cone calorimeter testing. Samples of furniture were manufactured and burned in the furniture calorimeter with the results of the full-scale tests compared to the bench-scale tests via Model I of the CBUF report (Sundstrom, 1995). The aim was to predict full-scale furniture behaviour from bench-scale cone calorimeter tests. Denize (2000) undertook 63 bench-scale cone calorimeter and 10 full-scale furniture calorimeter experiments. Seven different polyurethane foams, including two fire-retardant types, were tested along with 100% polypropylene and 95% woollen fabric coverings. The experimental methods followed those developed by CBUF, the European Fire Research Programme, Combustion Behaviour of Upholstered Furniture (CBUF).

Both the small-scale cone calorimeter tests and the experiments on full-scale furniture show that the fabric covering the foam significantly influences their combustion behaviour. Denize (2000) compared the combustion behaviour of polypropylene fabric and wool and found the most significant difference was the ability of the wool to remain in place for longer than the polypropylene when exposed to intense heat. The wool fabric was shown to have the ability to act as a barrier and hinder ignition.

Denize (2000) also compared fire-retardant foam to standard foam and showed that combustion characteristics of the fire-retardant foam were significantly different to that of standard foams. The difference was shown by a prolonged time to ignition and longer times to reach peak heat release rates in both the small-scale and furniture tests, although Denize (2000) comments that the combination of foam and fabric has the most significant effect on the combustion characteristics. Excluding the fire-retardant foam, the other foams tested were unable to be ranked on a combustion severity basis as there appeared to be little difference in their HRR curves. Statistical significance was not reported. The foams studied are listed in Table 3-5.

Table 3-5. Foam types studied by Denize (2000)

Code	Density kg/m³	End Use Application
G	28	Domestic furniture
H	37	Domestic furniture (fire-retardant)
I	35	Domestic furniture, public seating
J	36	Public auditorium seating (fire-retardant)
L	36	Public auditorium and transport seating

Figure 3-2 and Figure 3-3 show the measured rate of heat release for upholstered chairs fabricated using five different types of polyurethane foam covered in either wool or polypropylene.

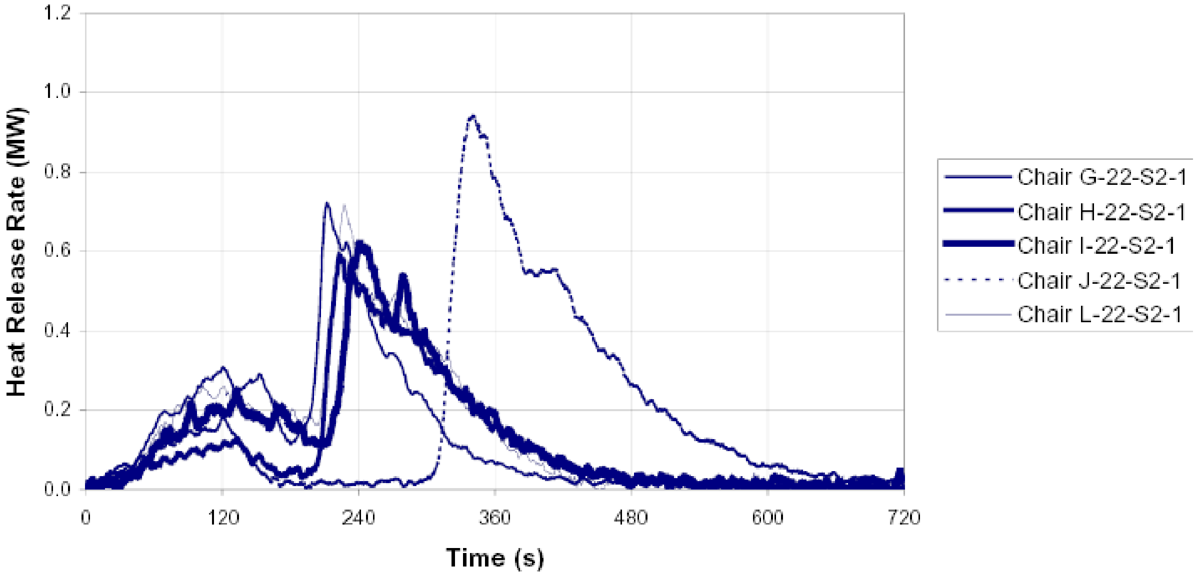


Figure 3-2 Heat release rate for wool-covered armchairs using five different types of foam. Chair H—22-S2-1 used domestic fire-retardant foam and chair J-22-S2-1 used fire-retardant foam for public auditorium seating. Remaining chairs used standard foam intended for domestic or public auditorium seating. Figure from Denize (2000).

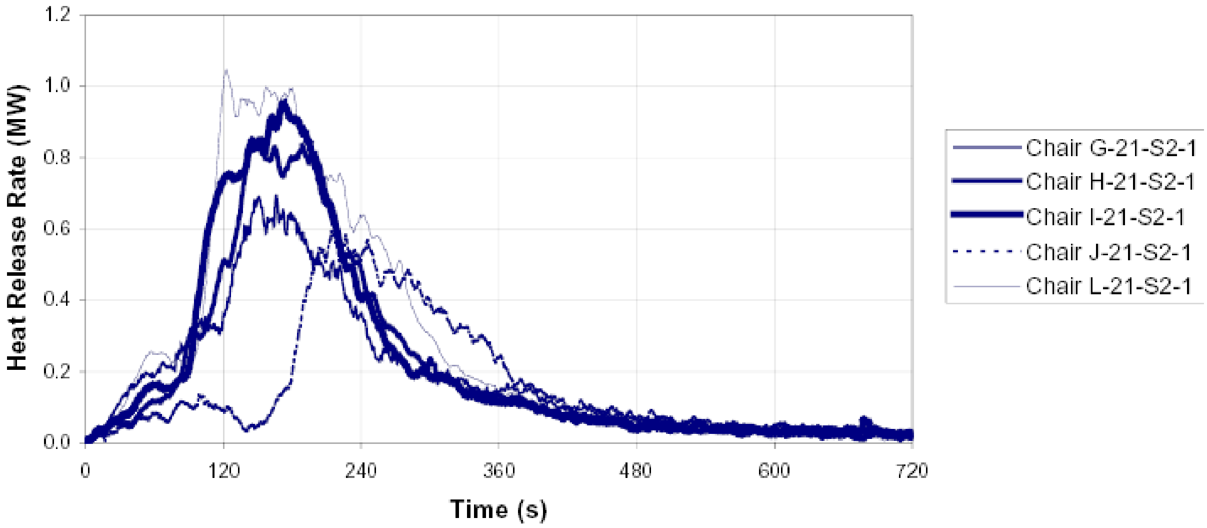


Figure 3-3. HRR for the polypropylene-covered armchairs using five different types of foam. Chair H—22-S2-1 used domestic fire-retardant foam and chair J-22-S2-1 used fire-retardant foam for public auditorium seating. Remaining chairs used standard foam intended for domestic or public auditorium seating. Figure from Denize (2000).

The beneficial effect of a fabric such as wool in delaying fire development can be seen. There is also little difference in the post-ignition heat release rate for the different types of foam with the exception of foam J, where fire development was delayed compared to the rest, although the peak heat release rate was similar.

Enright (1999) undertook research to better assess the hazard of furniture fires, especially with respect to the ability to predict the hazard. Hazard was assessed by quantifying the heat release rate of furniture items. The first part of this research was a review of fire calorimetric techniques which are the basis of heat release rate measurement. The second part of his research investigated CBUF Models I and II (see section 3.2.3) as applied to samples of typical New Zealand furniture.

Eight single-seat chairs and five two-seat sofas were tested using the cone calorimeter and the furniture calorimeter with the results compared to those of CBUF. The 13 furniture items consisted of combinations of polyurethane and polyether foam with varieties of fabric covering (polyester, nylon, polypropylene) and interliner.

Results and conclusions from the experiments showed (Enright, 1999):

- Pronounced fabric effect observed – fabric showed a tendency to either melt and peel or split and remain in place. The behaviour of the fabric had the effect of delaying the time to peak heat release of the foam.
- Comparison of combustion behaviour of New Zealand furniture to European – New Zealand furniture exhibited significantly higher peak HRR for relatively similar total heat.
- Model I: Goodness of the fit – CBUF Model I is not a good predictor of the behaviour of the New Zealand furniture tested.

- Model II: Goodness of the fit – Model II qualitatively is a better prediction tool than Model I. Model II is considered more useful than Model I as it characterises the HRR history rather than just a few properties.

Enright, Fleischmann and Vandervelde (2001) applied the CBUF Model II to New Zealand upholstered furniture items. CBUF Model II was not found to predict well the combustion behaviour of New Zealand upholstered furniture.

Coles (2001) undertook a series of cone calorimeter experiments to identify which combinations of fabric and foam pose the greatest fire hazard. The combustion behaviours of three foams combined with 14 fabrics were analysed. Coles (2001) identified that the composition of the fabric which covers the foam influences the burning characteristics of the system. Three types of fabric behaviour were identified:

- Melting – acrylic, polyester, polypropylene and olefin were identified as melting fabrics. Melting fabrics resulted in the highest total heat released and the fastest ignition times.
- Charring – cotton and nylon were identified as charring fabrics. Charring fabrics displayed the longest ignition times.
- Charring/melting – composite fabrics including polyester with viscose. Fabrics in this category had a tendency to smoulder.

General conclusions from the cone calorimeter tests include (Coles, 2001):

- The fabrics that pose the highest flammability are those that consist of polyester, polypropylene and olefin. These caused high peak HRR, high total heat released and faster time to peak HRR and untenable conditions due to their high heats of combustion.
- Standard polyurethane foams of densities 29 kg/m^3 and 38 kg/m^3 when coupled with the above fabrics were the most flammable.
- Fire-retardant foam produced large amounts of energy over longer periods when compared to standard polyurethane foam, but tended to smoulder after flaming extinction.

Chen (2001) investigated the ignitability of upholstered furniture, particularly looking at the time to ignition for various fabric coverings, using the ISO Ignitability Test (ISO5657). Fourteen fabrics, representative of those commonly used in New Zealand upholstered furniture, were chosen according to their composition and content for testing. The fabrics chosen were combinations of: polypropylene, polyester, acrylic, cotton, olefin, viscose, and nylon pile. Fire-retardant cotton was also chosen as one of the fabrics. Foam of density between 27 and 29 kg/m^3 was chosen as that was most commonly used for seat backs, seat cushions and arms in domestic and commercial furniture in New Zealand. The foam and fabric corresponded to that used by Denize (2000) in both small-scale and full-scale tests. The foam was cut into specimens of dimensions 167 mm square and thickness 50 mm then covered with a single layer of fabric.

A total of 750 samples were tested with each sample type exposed to a minimum of six levels of incident irradiance (40, 35, 30, 25, 20 and 15 kW/m^2). Results showed that the behaviour of the fabric can be described as either ‘charring’ or ‘melting’. The following table defines the characteristics of fabrics when subject to the ISO Ignitability Test.

Table 3-6. Ignition Behaviour of Fabrics (from Chen, 2001)

Fabric	Ignition Behaviour
100% Polypropylene	Melting
100% Polyester	Melting
100% Acrylic	Melting
100% Olefin	Melting
100% Nylon pile	Charring
100% Cotton (+ fire-retardant additive)	Charring
42% Polyester & 58% acrylic	Melting
51% Polyester & 49% cotton	Charring
50% Polyester & 50% olefin	Melting
51% Polyester & 49% viscose	Charring
60% Polypropylene & 40% polyester	Melting
31% Polyester, 21% acrylic & 48% cotton	Charring
43% Polyester, 41% acrylic & 16% olefin	Melting/Charring
39% Polyester, 40% cotton & 21% viscose	Charring

Fabric composites including Nylon pile and Cotton took longer to ignite than other fabrics. Nylon pile had the highest minimum heat flux (17 kW/m^2) and cotton had the lowest (6 kW/m^2). The 14 types of fabric/foam composites ignited at temperatures between 250°C and 300°C, calculated from the critical incident irradiance.

Results from this study included (Chen, 2001):

- Characterising the heating process leading up to ignition, fabrics can be divided into two categories – charring and melting.
- The thermally-thin theory is applicable for predicting the ignition time of the fabric/foam composites.
- The predicted ignition temperature for the composites of New Zealand upholstered furniture is: $T_{ig} = 280 \pm 40^{o}C$. Most ignition temperatures of the composites is predicted to be between 250°C and 300°C.
- The ignition time of foam/fabric composites can estimated from $t_{ig} = \frac{338}{(\dot{q}''_e - 7.8)}$

Firestone (1999) analysed the small to full-scale prediction of the combustion behaviour of a series of Nordtest furniture specimens. The Nordtest standard (Nordtest, 1991) specifies the dimensions and construction of the furniture. The research investigated the combustion results of 141 full-scale furniture specimens and 55 small-scale cone calorimeter tests (33 conducted at CSIRO, Melbourne and 22 at Canterbury University).

The Nordtest upholstered furniture specimens ranged from one- to three-seaters and used two different types of foam and fabric. The foams and fabrics represent those typically found on the market. The foams used were high-resilience polyurethane (32 kg/m^3) and standard polyurethane (23 kg/m^3). The fabrics were either 100% polypropylene (0.35 kg/m^2) or 100% cotton/linen blend (0.30 kg/m^2).

From analysis of both full-scale and small-scale tests, Firestone (1999) concludes:

- Fabric and foam interaction was important, with the fabric displaying quite dominant effects in influencing the peak HRR.
- Cotton/linen fabric protected the underlying foam longer than polypropylene. This had the effect of delaying ignition, reducing the peak HRR and increasing the time to reach peak heat release rate.

In summary the main objective of the University of Canterbury research work has been to predict the combustion behaviour of upholstered furniture through use of small-scale tests. Conclusions from the research have shown that it is possible to make some predictions on the basis of small-scale tests but the behaviour is also influenced by geometry and configuration of the furniture. Of particular importance is the effect of fabric on the combustion behaviour of the furniture. Findings from the research show that it is the combination of fabric and foam which has the most significant influence on the ignitability of the furniture.

There has been no research on leather covers in New Zealand, however leather is generally considered relatively fire-safe.

4. REGULATIONS, CODES AND TEST STANDARDS

4.1. Regulation as injury-prevention strategy

The role of regulation and legislation in improving safety has been affirmed by injury prevention specialists (Farquhar, 1998; Haddon & Baker, 1981; Pless, 1998). The editor of *Injury Prevention* stated in 1998:

> *Personally, I remain convinced that in most instances mandatory regulations, strictly enforced, with appropriate penalties, are, in the long run, the best way to ensure product safety.*
>
> (Pless, 1998) p 246

The right to safety is one of the consumer rights which underpin the United Nations Consumer Protection Guidelines. Proponents argue that a free market will “find the most efficient level of safety, balancing marginal costs and benefits … and in many ways the market mechanism may be more efficient than many safety advocates wish to admit” (Farquhar, 1998; p 253). However Farquhar goes on to outline situations where market failure justifies regulatory action to protect the right of the consumer to safety. In relation to injury control, market failure is indicated by high costs borne by the third parties. (In New Zealand the principal third party is the taxpayer, through health care, ACC and Income Support costs). Other examples of market failure include a lack of appropriate information for consumers to make informed choices about the relative safety of different products, and the reality of human failure whereby even with appropriate information, consumers may act irrationally or incompetently through an inability to process the information, or through other factors which influence choice.

Regulation of children’s nightwear flammability is a classic example of the impact of regulation on injury patterns (Pless, 1998). In 1956 Colebrook (cited by Pless, 1998) showed that 80% of burn deaths among children in England were related to clothing ignitions.

Introduction of fabric flammability standards for children's sleepwear has been associated with dramatic reductions in childhood burn injuries in the United States and in New Zealand (McLoughlin, Clarke, Stahl, & Crawford, 1998; McLoughlin, Langley, & Laing, 1986).

Barriers to the introduction of injury control regulations, adapted from Farquhar (1998) include:

- Industry reluctance
- Minimising significance of the problem
- Claiming ineffectiveness of proposed law
- Predictions of impossible cost
- Denial of constitutional rights
- Undue burden on personal freedom
- Proposed change not feasible or enforceable
- Not popular with most citizens
- Undue emphasis on personal responsibility.

While there is a need for a careful balance between protecting the safety of consumers and minimising the compliance costs of bureaucratic requirements, overall, the experience of injury prevention practitioners has been that voluntary measures tend to result in little or varied enforcement, and little compliance by manufacturers (Ashby and Routley, 1998).

The remainder of this section describes the regulations and related standards and test methods from selected countries. A summary of the test methods and their components is found in Table 4-2 on page 46.

4.2. United Kingdom

4.2.1. Upholstered furniture regulation in the United Kingdom

Upholstered Furniture (Fire) (Safety) regulations (HMSO, 1988) were introduced following a series of fatal home fires involving furniture. The regulations specify that fillings and coverings of all furniture should pass flammability tests according to BS5852 Parts 1, 2 or BS7177/BS6807. The requirements are generally able to be met by use of chemical flame retardants in the foam (combustion modified foams) and in the back-coating for covering fabrics. In general, the regulations required testing of foam/fabric composites and allowing the option of a bench-scale test whereby fabrics are tested over standard padding, and paddings are tested beneath a standard fabric. If different construction is used for different parts of the furniture e.g: seat, back, sides, then separate tests are required.

A review of the impact of the Furniture and Furnishings (Fire) (Safety) Regulations 1988 in the United Kingdom, commissioned by the Department of Trade and Industry (DTI, 2000), concluded:

> *Significant life-saving and injury reduction benefits have resulted from the introduction of the Furniture and Furnishings (Fire) (Safety) Regulations in 1988 in the UK. Corresponding benefits relate to reductions in the number of serious dwelling fires and in cost savings arising from reduced property loss and lives saved.* (DTI, 2000, p 23).

The report was written with the benefit of almost 10 years of fire statistics, since the introduction of the regulations, and was essentially an economic analysis of the costs and benefits resulting from the introduction of the regulations in 1988.

The cumulative benefits attributed to the regulations by the report in the 10 years from 1988 to 1997 included:

- 710 lives saved which would have been lost in fires first ignited in upholstered furniture from 1988 to 1997. Possible saving of a further 150 lives in fires which did not start in upholstered furniture but which may have spread to include upholstered furniture.
- 5774 non-fatal injuries prevented which would have occurred in fires first ignited in upholstered furniture. Possible prevention of a further 11,226 non-fatal injuries which did not start in upholstered furniture but which may have spread to include upholstered furniture.
- £53 million worth of property damage saved.
- Projected saving of at least 791 lives, prevention of 7250 non-fatal injuries and prevention of £112 million worth of property damage from 1998 to 2031.
- The report concluded that the benefit-to-cost ratio of implementation of the regulations was 38:1 (that is £38 of benefit for every £1 spent) using cost savings estimates for property damage.
- The cost of the regulations to industry and to those who buy furniture was estimated to be between £15 and £20.

UK manufacturers estimate upholstered furniture lasts between 8 and 15 years, thus possible full benefits had not been realised when the DTI report was compiled.

The report also concludes that the extent of smoke-detector penetration into UK dwellings is only modest and had little effect on the post-1988 trends. It contrasts this with US trends where there has been a progressive decrease in fire deaths and injuries (per capita) since 1976 matched by a significant number of fires being detected by smoke alarms, not evident in corresponding UK data.

Prager (1989) criticised the regulations for being material-component oriented concerning ignitability only and claims risk-oriented large-scale testing was not taken into consideration. He believed the regulations were disappointing and ‘represent a political compromise that disregarded nearly all the existing knowledge of fire performance testing’.

4.2.2. Other factors affecting fire risk in the UK

The DTI report attributes the reduction in the incidence and impact of upholstered furniture fires entirely to the introduction of the regulations. Other factors that may affect reported rates of fire incidence and casualty rates include changes in the prevalence of domestic smoke alarm installation, changes in smoking prevalence, changed methods of household heating and cooking, and changes to the reporting system itself. In relation to the latter example, a new fire report form was introduced in the UK in 1994 and this may have resulted in changes in the way in which information about fire incidents was recorded (DTLR, 2002).

The DTI report concluded that the impact of smoke alarms on fire incidence in the UK had been small. This conclusion was based on the small proportion of fires detected by alarms (1-2% of all fires; 10-12% of dwelling fires). Failure to detect a fire was attributed to the high number of poorly-positioned or non-functioning alarms. This observation does not take account of incidents which were detected early enough to be extinguished by household occupants. In fact, if smoke alarms are truly effective, they will prevent many fire incidents from becoming large enough to need fire service intervention and therefore to be captured by the fire incident records. This is, of course, the major failing of fire incident statistics relating to fires detected by a smoke alarm. However, in theory, the smoke alarm successes should be reflected in a lower number of total fires reported. The conclusion that the impact of smoke alarms has been minimal also fails to take account of the fact that the presence of a functioning smoke alarm is a secondary prevention strategy – allowing occupants time to escape when a fire does occur. Lack of a smoke alarm is a known risk factor for death in a fire incident (Runyan, Bangdiwala, Linzer, Sacks, and Butts, 1992; Marshall et al., 1998). This injury prevention value of domestic smoke alarms was illustrated by the observation, within the DTI report, that the death rate for fires detected by alarms was four per 1000 fires, compared with nine per 1000 fires for fires not discovered by alarms (Department of Trade and Industry, 2000).

Smoke alarm ownership in the UK has increased from 25% in 1989 to more than 80% in 2000, as shown in Figure 4-1. Fires discovered by a smoke alarm are discovered more rapidly after ignition, are associated with lower casualty rates, and cause less damage as they are often confined to the item first ignited (DTLR, 2002). The campaign initiated by the British Home Office in 1988 to increase smoke alarm use has been cited as an example of effective action to change society's attitudes to fire safety (Driscoll et al., not dated). DiGuiseppi et al (2002) reviewed the incidence of fires and fire-related injuries after giving out free alarms in two inner-London boroughs with a total of 330,000 residents, of whom 51% lived in council or other social housing. They found that giving out free alarms in a deprived, multi-ethnic urban community did not reduce injuries related to fire, mostly because few alarms had been installed or were maintained. It is essential that any distribution programme includes installation and maintenance of domestic smoke alarms.

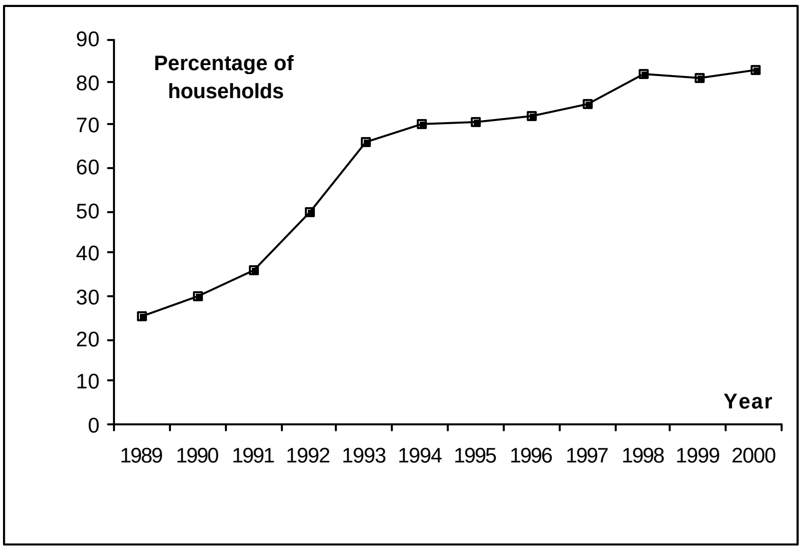


Figure 4-1. Percentage of households in the United Kingdom with smoke alarms installed 1989-2000. Data source: Department of Transport Local Government and Regions (2002) section 2.30.

In fires involving upholstered furniture the most common heat source is an abandoned cigarette. Fires characterised by a cigarette ignition of upholstered furniture have high injury and fatality rates, as they are typically smouldering fires with ignition many hours later, often while occupants are sleeping. Thus it might be expected that smoking prevalence and tobacco consumption might have an effect on fire incidence and impact.

Emsley at al (2002) reported that in 1988 the proportion of people smoking in the UK was around 30%, having declined from 40% in 1975. Since 1988 the proportion remained relatively constant compared with the pre-1988 period, fluctuating between 30 and 27%. They therefore concluded that changes in smoking prevalence were not a major influence on the post-1988 fire statistics. However this assumption is not supported by the observation that fires caused by smokers' materials have shown a long-term downward trend in the UK since 1990, with a 16% decline between 1999 and 2000 (Department of Transport Local Government and Regions, 2002).

Smoking rates and tobacco consumption have declined in the UK since 1970. In 1998 the total consumption of cigarettes had declined to 82940 million sticks compared with 128841 million sticks in 1970 (Corrao, Guindon, Sharma, & Shokoohi, 2000). Both a decrease in the proportion of the population who smoke, and a decrease in the annual weekly cigarette consumption of smokers contributed to this trend (Walker, Maher, Coulthard, Goddard, & Thomas, 2001).

Heating patterns in British homes also changed from the 1980s to 2000. The increasing proportion of homes with central heating over time, as shown in Figure 4-2, is likely to reduce the use of portable electric heaters which are a known risk for fire incidents. There is a socio-economic gradient associated with provision of central heating such that 96% of households where a member was in a professional socio-economic group had central heating, compared with 85% of households where the reference person was a unskilled manual labourer (Walker, Maher, Coulthard, Goddard, & Thomas, 2001).

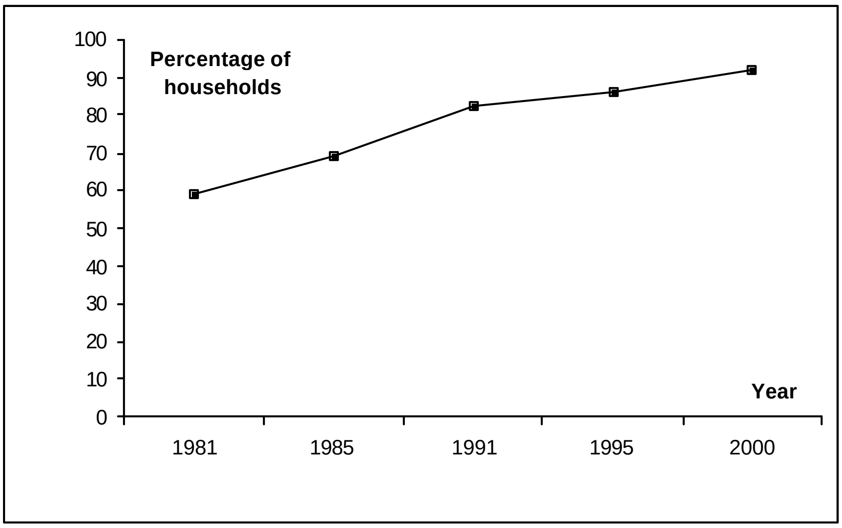


Figure 4-2. Percentage of households in Great Britain with central heating 1981-2000. Data source: Walker, Maher, Coulthard, Goddard, & Thomas (2001), Section 4.

4.2.3. British standard test methods

The Furniture and Furnishings (Fire) (Safety) Regulations 1988 (HMSO, 1988) as amended in 1989 and 1993 set levels of fire performance for domestic upholstered furniture, furnishings and other products containing upholstery based on:

BS 5852: Part 1 (BSI,1990)
BS 5852: Part 2 (BSI, 1990)
BS 6807 (in the case of composite non-foam fillings for mattresses and bed-bases, otherwise BS 5852 applies) (BSI, 1996)

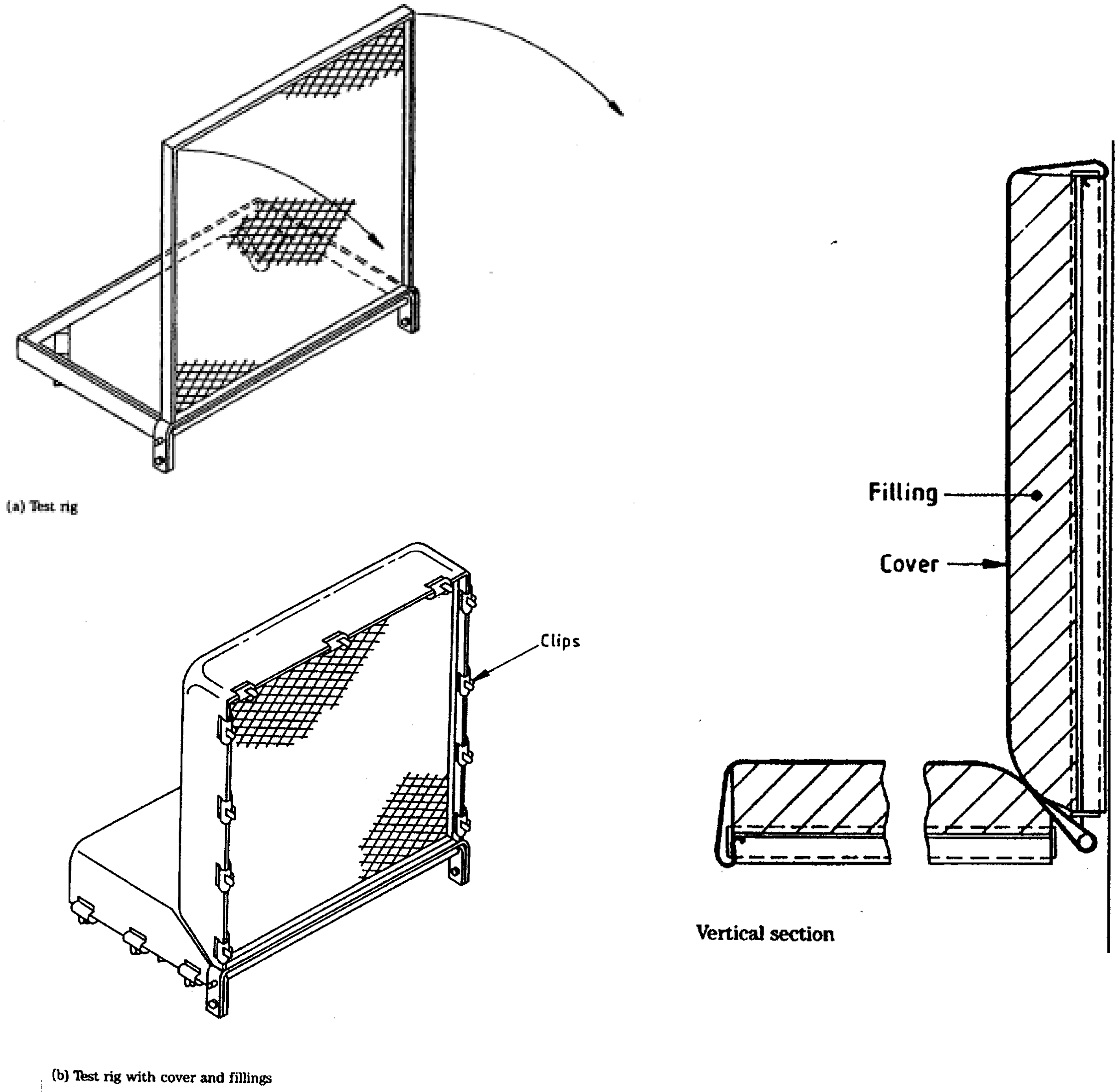
The tests are cigarette and small flame ignition resistance tests on material composites.

BS 5852:1990 (BSI, 1990) Methods of test for assessment of the ignitability of upholstered seating by smouldering and flaming ignition sources.

This standard describes a range of different tests and ignition sources. Section 2 describes a smouldering ignition source (0) – the same as specified in AS/NZS 3744.1:1998. Section 3 describes three gas-flame ignition sources (1, 2, 3) and four crib fire ignition sources (4, 5, 6, 7). The gas-flame ignition sources are the same as in AS/NZS 3744.2:1998 and AS/NZS 3744.3:1998. Section 4 describes methods of test for the ignitability of upholstery composites using all the above ignition sources except #1. The rig and assembly shown in Figure 4-3 is the same as AS/NZS 3744 and is a medium-scale mock-up comprising a simulated two-cushion (seat and back) on a steel frame. Section 5 describes methods of test for the ignitability of complete items of furniture. The ignition sources 0-7 may be used, in a variety of different locations. Ignition criteria are given for both progressive smouldering ignition and flaming ignition.

BS 5852 is a revision and development of the earlier standards above. It extends the range of ignition tests provided by BS EN 1021-1:1993 and BS EN 1021-2: 1993.

Note also that BS 7176 applies the tests described in BS 5852 to upholstered furniture in various hazard areas (non-domestic applications).


(a) Test rig

(b) Test rig with cover and fillings

Figure 4-3. BS 5852 Test rig assembly for testing ignitability of upholstered furniture by smouldering and flaming ignition sources (BSI, 1990)

4.3. United States

4.3.1. Upholstered furniture regulation in the USA

In the United States there are voluntary standards for cigarette ignition of upholstered furniture for both residential and institutional buildings. These standards were produced by the Upholstered Furniture Action Council (UFAC) and were agreed to by the US Consumer Products Safety Commission (CPSC) in 1981. For residential furniture they are basically cigarette ignition tests. UFAC procedures were published in NFPA 260 (1986) and ASTM E 1353 (1990).

Between 1994 and 1997 the CPSC developed a small flame ignition test. However, because the new flammability test was expected to result in increased use of fire retardants, and the speculation that these fire retardants would pose toxic hazards of their own, the CPSC was required to commission research on the toxicity of fire retardants delaying any further action regarding the small flame ignition test. The CPSC developed the test because following extensive laboratory testing it believed the TB 117 test did not give results that correlated with full-scale real furniture behaviour. It was concluded that the BS 5852 approach, using composite mock-up specimens, was better able to achieve this, so it developed a new test similar to BS 5852.

Since 1997, the CPSC continued to develop the small open flame standard and a briefing package, including draft standard and supporting documents and assessment of health risks associated with increased use of fire retardants, was released in October 2001 (CPSC, 2001).

California has its own regulations for cigarette and small flame ignition resistance of fabrics and padding material. The relevant standards for residential furniture components are TB 116 (BHFTI, 1980) and TB 117 (BHFTI, 2000a). These have been the minimum standards for any occupancy in California since 1975. TB 116 is a voluntary standard requiring that either the furniture meet cigarette ignition criteria or be labelled if it does not. TB 117 is a mandatory standard in California and requires flammability testing of the fabric and padding. TB 117 does not require the use of fire-retardant (FR) covers or fabrics. There are also standards for institutional occupancies i.e. TB 129 and TB133 (BHFTI, 1993; BHFTI, 1991).

The NFPA Life Safety Code (NFPA 101, 2000) requires, for unsprinklered residential occupancies, cigarette ignition resistance using NFPA 260 (NFPA, 1986).

The estimated annual cost to consumers of the small flame standard developed by CPSC is US$460-US$720 million (CPSC, 1997). CPSC also estimated an annual net benefit to consumers of about US$300 million, given the expected reduction in the small open flame and cigarette ignited fire losses.

Oliver (2001) carried out an economic analysis of the draft CPSC small open-flame test 1997 proposal and critiques the economic analysis carried out by the CPSC. He concluded that the CPSC overstated the benefits of the regulation and understated the costs. In particular the criticism included:

- The discount rate assumed (2.5%) was too low and did not reflect the consumers' opportunity costs.
- The FR backcoating required to pass the proposed test would not be durable enough to last the life of the piece of furniture.
- CPSC relies on fewer cigarette-ignited fires and by doing so the CPSC proposal would pass its own cost/benefit test even if the benefit from reducing small open-flame upholstery fires is zero.
- The cost of FR backcoating is underestimated (particularly for small runs).
- Increased use of FR chemicals means capital investment in pollution abatement equipment and higher disposal costs.

Some of these criticisms were subsequently refuted by the CPSC in the 2001 briefing package.

Unlike the upholstered furniture industry, mattresses are subject to mandatory federal flammability standards. These were established by the CPSC in 1972 for mattresses in residential occupancies. Currently all mattresses manufactured in the United States are subject to CPSC Standard DOC FF4-72 – a flammability standard for mattresses addressing cigarette ignition resistance (CPSC, 1996). In October 2001, the CPSC announced it also intended to develop a small flame ignition resistance test for mattresses (CPSC, 2001).

4.3.2. United States standard test methods

CPSC draft small flame ignition test – includes mock-up of seat/back area similar to BS 5852 (BSI, 1990).

NFPA 266 Standard method of test for fire characteristics of upholstered furniture exposed to flaming ignition source, 1998 edition. This method uses a full-scale furniture calorimeter to determine heat release, smoke density, weight loss, and generation of carbon monoxide of upholstered furniture or full-scale mock-up of furniture. The ignition source is a gas (propane) square-burner of stainless steel tubing with holes (12L/min) (NFPA, 1998).

NFPA 267 Standard method of test for fire characteristics of mattresses and bedding assemblies exposed to flaming ignition source, 1998 edition. This method uses an open calorimeter to determine heat release, smoke density, weight loss, and generation of carbon monoxide of mattresses and bedding assemblies. The ignition source is a gas (propane) T-burner (NFPA, 1998).

ASTM E1474-01 Standard test method for determining the heat release rate of upholstered furniture and mattress components or composites using a bench scale oxygen consumption calorimeter: used to determine the ignitability and heat release from the composites of contract, institutional, or high-risk occupancy upholstered furniture or mattresses using a bench scale oxygen consumption calorimeter (ASTM, 2001).

ASTM E1590-01 Standard test method for fire testing of mattresses: provides a means of determining the burning behaviour of mattresses used in public occupancies by measuring specific fire test responses when the test specimen, a mattress or mattress with foundation, is subjected to a specified flaming ignition source under well-ventilated conditions (ASTM, 2001).

TB 129 Flammability test procedure for mattresses for use in public buildings (BHFTI, 1993).

TB 133. This test uses a more substantial ignition source (about 18 kW) and one of the pass criteria is that the peak heat release rate of the burning item is no greater than 80 kW. Based on a series of full-scale room and furniture calorimeter tests carried out at the National Institute of Standards and Technology (NIST) it was concluded that there would be no possibility of reaching flashover in a room with this level of heat release, and also a low probability of igniting other items in the room (BHFTI, 1991).

TB 116 is a voluntary cigarette ignition test for residential upholstered furniture components (BHFTI, 1980).

TB 117 comprises a series of bench-scale tests on upholstered furniture components. Various procedures are specified depending on the padding materials used, e.g.: solid foams, shredded foam, expanded polystyrene beads, natural fibre filling materials and manmade fibre filling materials (BHFTI, 2000a).

The method developed by NIST for CPSC was first published as NFPA 261 in 1983 (NFPA, 1998) and as ASTM E 1352 in 1990 (revised 2002) (ASTM, 2002a).

4.3.3. Toxicity issues

The small open-flame ignition standard developed by CPSC was delayed due to concern regarding toxicity associated with increased use of fire-retardant chemicals anticipated should an open-flame ignition standard be adopted.

The CPSC concluded that a number of FR chemicals may be appropriate for use with upholstered furniture and are either not toxic or not bioavailable. Antimony trioxide, which is a candidate chemical for treating back coatings, though chronically toxic, would not expose consumers as a result of household use. CPSC felt insufficient data was available (in 1997) to evaluate the risks associated with all the candidate FR chemical treatments that might be used in upholstered furniture fabrics and therefore additional study was warranted.

Some product specifications introduced to reduce the specific hazard of an item may produce a more severe fire in terms of smoke toxicity (Hall & Harwood, 1995). Baron (2002) reported that polybrominated diphenyl ethers (PBDE) as flame retardants are accumulating and concentrating in the environment. These products are banned in Europe, however some of the detrimental effects are thought to arise from the degradation of foam from discarded furniture. The National Academy of Sciences in the USA was asked to study potential health risks of flame retardants, following an announcement by the Consumer Product Safety Commission that it was considering a flammability standard for all upholstered furniture in the USA (Walsh, 2000). The academy concluded that the eight flame retardants with potential application in upholstered furniture pose little or no health risk, though a further eight required further testing because there was insufficient data to rule out risk (see Table 4-1).

Table 4-1. Assessed safety of flame retardants with potential application in upholstered furniture. Information source: National Academy of Sciences 2000

Little or no risk to human health	Further research needed
Alumina trihydrate	Organic phosphonates and cyclic phosphate esters (dimethyl hydrogen phosphite)
Magnesium hydroxide	Tris monochloropropyl phosphates
Hexabromo-cydododecane	Tris (1,3 dichloropropyl-2) phosphates
Decabromodiphenyloxides	Antimony trioxide
Zinc borate	Antimony pentoxide and Sodium antimonates
Ammonium polyphosphates	Calcium and zinc molybdates
Phosphoric acid	Aromatic phosphate plasticizers (tricresyl phosphates)
Tetrakis hydroxymethyl phosphomium	Chlorinated paraffins

4.4. New Zealand and Australia

These standards are voluntary in New Zealand.

AS/NZS 3744.1:1998 Furniture – Assessment of the Ignitability of upholstered furniture. Part 1: Ignition source – Smouldering cigarette (SNZ, 1998a).

- Replaced NZS 8709.1:1984 (NZS, 1984).
  Equivalent to, and reproduced from ISO 8191-1:1987. (ISO, 1987) (BS EN 1021 is the EU adaptation of ISO 8191).
- Comprises a vertical and horizontal section of the upholstered assembly (cover, filling, interliner etc) held in a steel frame (see also Figure 4-3). The vertical piece measures 450 mm wide x 300 mm high, the horizontal piece measures 450 mm x 150 mm. Instances of progressive smouldering or flaming are noted.

AS/NZS 3744.2:1998 Furniture – Assessment of the Ignitability of upholstered furniture. Part 2: Ignition source – Match-flame equivalent (SNZ, 1998b).

- Replaced NZS 8709.1:1984. (NZS, 1984).
  Equivalent to, and reproduced from, ISO 8191-2:1988. (ISO, 1988)
- Same assembly as above except that the ignition source is a small gas flame to simulate a match flame ignition source.
- Method measures the ignitability of the overall composite of materials, i.e.: cover, interliner, infill material, etc as constructed on the test rig.

AS/NZS 3744.3:1998 Furniture – Assessment of the Ignitability of upholstered furniture. Part 3: Ignition sources – Nominal 160 mL/min gas flame and nominal 350 mL/min gas flame (SNZ, 1998c).

- Same assembly as above except that two further gas flame ignition sources are used, of a larger size compared to the match flame equivalent. 160 mL/min gas flame is allowed to burn for 40 seconds. 350 mL/min gas flame is allowed to burn for 70 seconds.
- This Standard sets out test methods to assess the ignitability of material combinations, such as covers and fillings used in upholstered seating, when subjected to gas flame ignition sources greater than the match-flame equivalent source in AS/NZS 3744.2. The gas flame ignition sources in this Standard are referred to as Source 2 and Source 3 and are identical to those in BS 5852 (BSI, 1990).

AS/NZS 4088.1:1996 Burning Behaviour of Upholstered Furniture. Part 1: Upholstery materials for domestic furniture - smouldering ignitability. (NZS, 1996). Method specifies a type of foam over which a fabric can be tested. The foam is a borderline pass foam and so only low flammability fabrics will pass this test.

- This Standard specifies testing and performance requirements for the ignitability of filling and covering materials used in upholstered furniture intended for use in domestic situations. Covering and filling materials are tested either individually or, if actual composites, together using a smouldering source. The requirements cover accidental application of a smouldering ignition source but not deliberate acts of vandalism.

4.5. Other

Nordtest NT FIRE 032 Upholstered furniture: Burning behaviour – Full-scale test Edition 2, approved 1991-05, 12 pages (Nordtest, 1991).

This is a standard test for full-size furniture items performed beneath a calorimeter hood. Wood crib ignition source (=crib 7 from BS5852 = 6/7 kW for 350 seconds). The specimens can be real, full-size, 3-seater sofas or full-size mock-up. Measurements include mass loss rate, heat release rate, production rates of CO CO2 and smoke. No criteria for pass/fail. Set by the end-user body.

Table 4-2. Furniture-flammability tests

Test	Cigarette Ignition	Flame Ignition	HRR	Smoke	Toxicity
ISO 8191 (Nordtest 039)	×	×			
BS 5852	×	×			
ASTM E 1352 (mock-ups)	×				
ASTM 1353 (components)	×				
NFPA 261 (mock-ups)	×				
NFPA 260 (components)	×				
California TB116, 117	×				
Upholstered Furniture Action Council	×				
Business and Institutional Furniture Manufacturers Association (BIFMA)	×	×			
Code of Federal Regulations Part 1632	×				
BS 6807 mattress test	×	×			
California TB133		×	×	×	×
California TB129 mattress test		×	×	×	×
California TB121 mattress test		×		×	×
ASTM E 1537		×		×	×
ASTM E 1590 mattress test		×		×	×
ASTM E 162 surface flammability test		×			
ASTM D 3675 surface flammability test		×			
ISO 5660			×	×	×
ASTM E 1474			×	×	×
ASTM 1354			×	×	×
NFPA 264-A			×	×	×
ASTM F 1550 M vandalised specimen				×	
ISO TR 5924				×	
ASTM E 662				×	
ASTM E 906			×	×	
ISO TR 9122					×
ISO TR 6543					×
ASTM 1678					×
AS/NZS 3744.1	×				
AS/NZS 3744.2		×			
AS/NZS 3744.3		×			
AS/NZS 3837			×	×	×
AS/NZS 4088.1	×				

5. COMPUTER SIMULATION OF SMOKE DEVELOPMENT IN A HOUSE

5.1. Objective

The purpose of this analysis was to demonstrate the likely rate of fire development and the associated hazard to people present within a simple single–storey house and the amount of time available for escape, depending on the type of upholstered chair first ignited (by an open flame source) and warning systems (e.g: smoke alarms) present. A comparison of the hazard is also made where the house is fitted with a domestic fire sprinkler system and with smoke alarms. It is intended that analysis of this type will help in the assessment of the 'effectiveness' of the different potential strategies for reducing fire deaths in New Zealand.

5.2. Upholstered furniture items

Two chairs were selected for the analysis and both had been the subject of previous research at the University of Canterbury (Denize, 2000) where measurements of rate of heat release for the chairs were made using a furniture calorimeter and used as input for this analysis. Both chairs were assembled from New Zealand-sourced materials.

- Chair L21 – was a single seater chair with non-fire-retardant polyurethane foam seats, sides and back, and with polypropylene fabric cover. This was intended to represent a typical chair with relatively poor fire performance behaviour.

- Chair J22 – was another chair of identical dimensions and geometry but with fire-retardant polyurethane foam and wool covering. This was intended to be representative of a chair likely to exhibit significantly better fire performance behaviour.

The heat release rate for each chair measured by Denize (2000) in a furniture calorimeter is shown in Figure 5-1. Each chair was ignited using a square ring LPG gas burner with a steady output of 30 kW. It was held 25 mm above the middle of the seat cushion. The burner was turned off after 2 minutes.

The rate of heat release is generally regarded as an excellent indicator of potential fire hazard, and is generally proportional to the quantity of gases/smoke generated by the burning item. The data is used as input to the computer simulation to predict the characteristics of the fire environment where the heat and smoke is transported within and between a series of interconnected rooms. Enclosure effects, whereby the burning rate of the chair is enhanced by radiant feedback from room surfaces and the hot gases, is not specifically allowed for.

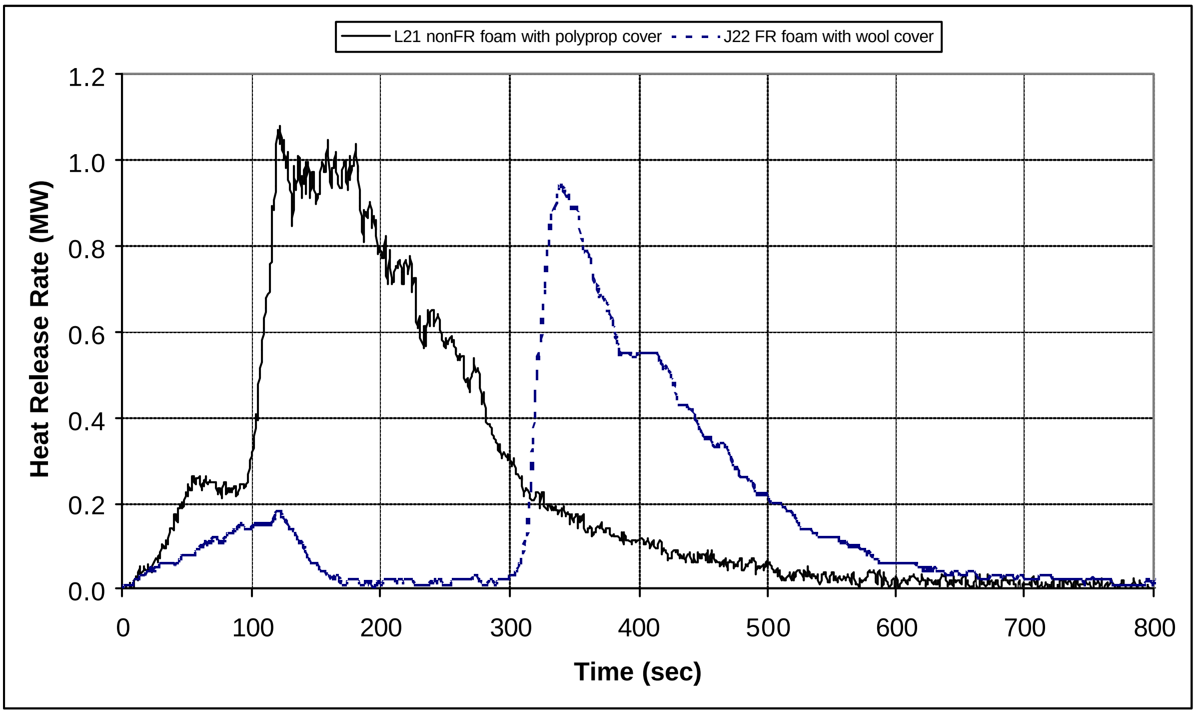


Figure 5-1. Heat release rate of single-seater chairs measured in a furniture calorimeter Chair L21 constructed of non-fire-retardant polyurethane foam seats, sides and back, and with polypropylene fabric cover and chair J22 constructed of fire-retardant polyurethane foam and wool covering. Figure from Denize (2000).

5.3. Building layout

The building selected for use in the simulations is a simple single-storey three bedroom house design (constructed at BRANZ and previously used for fire and other research). The house layout in plan is shown in Figure 5-2.

The building geometry for the simulation was represented by rectangular spaces of equivalent area to the actual rooms. The hallway was connected to a bedroom and to the lounge with open doors, and the kitchen was connected to the lounge also with an open door. A small amount of leakage to the exterior was included.

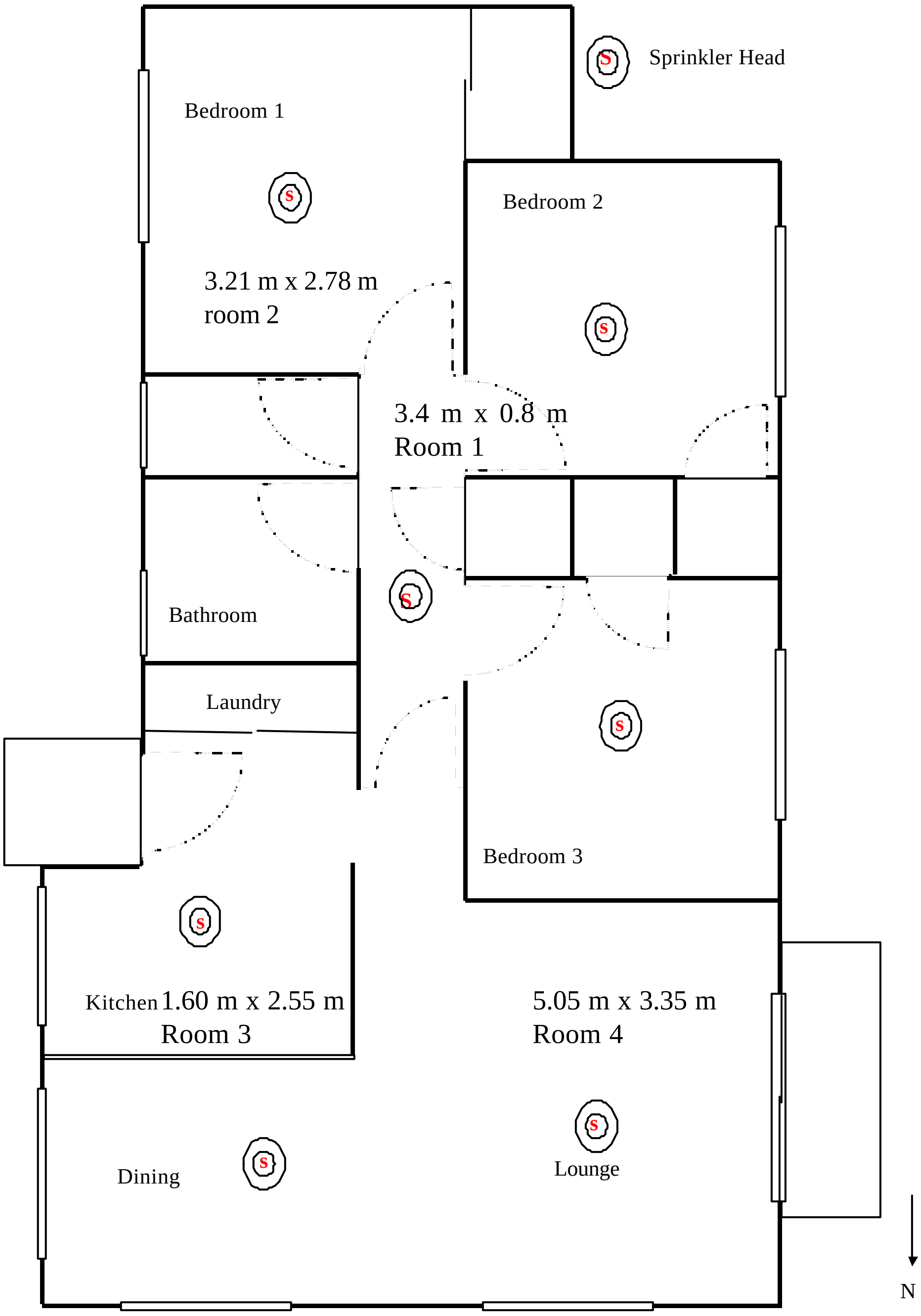


Figure 5-2. Plan view of simple house used in computer simulations

5.4. Fire scenario

The chair is located within the lounge room and ignited with a 30 kW flaming source (i.e. the same scenario from the University of Canterbury furniture calorimeter experiments). The chair is the only item burning; it is assumed that there is no fire spread to any other nearby combustible contents or construction. A person is assumed to be in the bedroom and thus escape via the hallway and kitchen would be necessary. The 30 kW flaming source is a severe ignition source, and thus this scenario is not representative of a cigarette or smoking material ignition scenario. The flaming source is particularly relevant given the observation by Wong (2001) of secondary rather than primary ignition in 84% of fatal fires involving upholstered furniture.

5.5. Fire model

A fire zone model (BRANZFIRE 2002.6) previously developed at the Building Research Association of New Zealand was used for the analysis (Wade, 2002). BRANZFIRE is a zone model used to calculate the time-dependent distribution of smoke, fire gases and heat throughout a group of connected rooms during a fire. In BRANZFIRE, each room is divided into two layers. The modelling equations used in BRANZFIRE take the mathematical form of an initial value problem for a system of ordinary differential equations (ODE). These equations are derived using the conservation of mass, the conservation of energy, the ideal gas law and relations for density and internal energy. These equations predict as functions of time quantities such as pressure, layer heights and temperatures, given the accumulation of mass and enthalpy in each of the two layers. The BRANZFIRE model then solves a set of ODE's to compute the environment in each compartment and a collection of algorithms to compute the mass and enthalpy source terms. The model incorporates the evolution of species, such as carbon monoxide, which are important to the safety of individuals subjected to a fire environment.

5.6. Assessment of hazardous conditions

The fire hazard is evaluated based on the quantitative predictions by the model for conditions in the hallway for:

- Visibility at a specified height. A height of 2 m above the floor is selected for this analysis and a limit of 2 m visibility. Visibility is generally dependent on the concentration of soot in smoke which is in turn dependent on the mass loss and soot yield of the fuel. It also depends on the luminosity of the vision ‘target’ (i.e: exit signage) through the smoke. It is commonly accepted that visibility limits tend to be reached before unacceptable levels of irritant gases (e.g. hydrogen chloride, acrolein), so this is assumed in this analysis.
- The cumulative effect of radiant heat incident on a target at a specified height (2 m) above the floor. The target is assumed to be a person in the hallway. The thermal radiation is due to the layer of hot gases accumulating beneath the ceiling emitting radiant heat to surfaces beneath. The higher the radiation received the shorter the time before pain or burns will occur on human skin.
- The cumulative dosage of ‘narcotic’ gases accumulating within the hallway at a specified height (2 m), and being inhaled by a person present. The main combustion product modelled here is ‘carbon monoxide’. Effects due to depletion of oxygen in the smoke layer and the effect of carbon dioxide on respiration rates are also allowed for in the analysis. The production of hydrogen cyanide (HCN), produced from burning polyurethane, has not been included.

The results of the simulation are analysed to determine the time at which the above threshold criteria are reached.

5.7. Residential sprinkler characteristics

For the case where a fire sprinkler is installed:

- Sprinkler located in lounge room

- Sprinkler suppression is simulated based on a water spray density (mm/min) = 5.0
- Actuation temperature (ºC) = 68.0
- Response time index $(m.s)^{½}$ = 50.0
- Sprinkler C-factor $(m.s)^{½}$ = 0.5
- Radial distance from the plume centreline (m) = 2.0
- Distance below ceiling (mm) = 25

The activation time of the sprinkler was determined by using the "NIST JET" option in BRANZFIRE. This uses a ceiling jet and sprinkler algorithm developed at NIST which includes the effect of a developing hot layer.

The smoke alarm activation times are based on optical density properties of the smoke gases.

5.8. Summary of simulation results

As shown in Figure 5-3, chair J22 showed delayed combustion and a lower peak heat release rate both with and without sprinklers. However the heat release rate began declining for both chairs within two minutes in the presence of sprinklers.

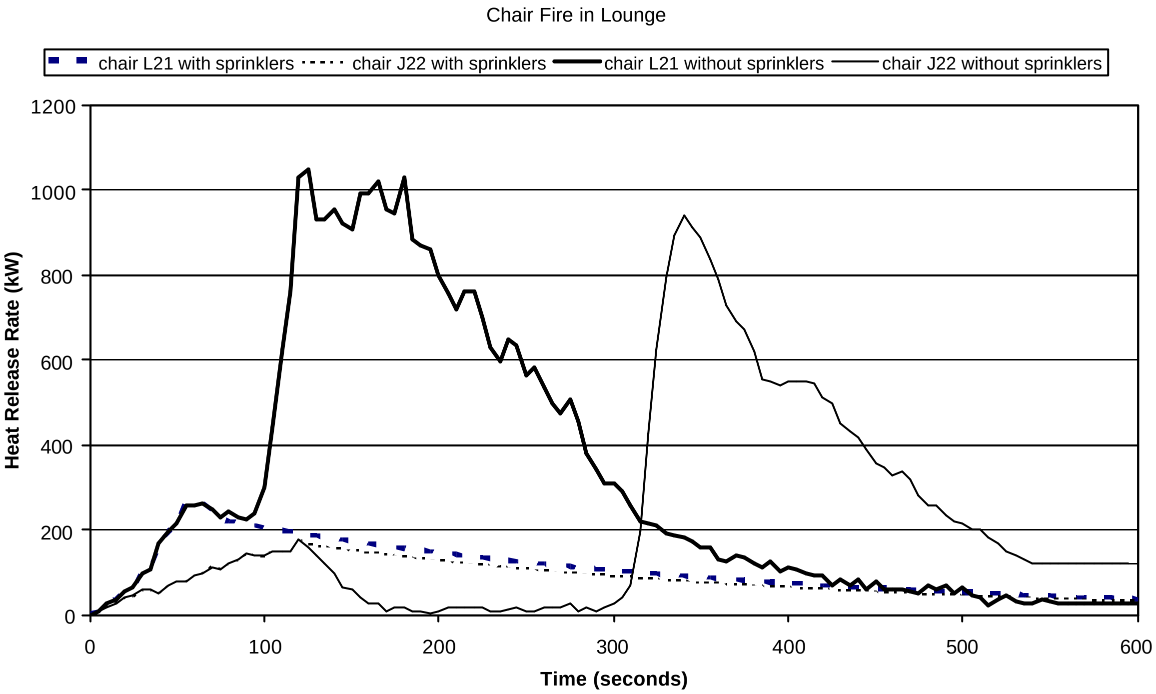


Figure 5-3. Simulated Heat Release Rate of single-seater chairs constructed of standard polyurethane foam with polypropylene cover (L21) and of fire-retardant polyurethane foam with wool cover (J22), by time.

The time for untenable conditions to be reached and estimated smoke alarms activation times are given in Table 5-1 to Table 5-4 and illustrated in Figure 5-3.

Table 5-1. Chair L21 (standard polyurethane foam with polypropylene cover), no sprinkler

	Time to untenable condition (sec)		
Tenability Criterion	Lounge 4	Hall 1	Bed 2
Visibility < 2 m @ 2 m above floor	35	50	80
FED inc (gases)	>600	>600	>600
FED inc (rad)	140	250	>600
Smoke alarm activation time	20	35	45

Table 5-2. Chair L21 (standard polyurethane foam with polypropylene cover), with sprinkler

	Time to untenable condition (sec)		
Tenability Criterion	Lounge 4	Hall 1	Bed 2
Visibility < 2 m @ 2 m above floor	35	50	80
FED inc (gases)	>600	>600	>600
FED inc (rad)	>600	>600	>600
Sprinkler activation time	73		
Smoke alarm activation time	20	35	45

Table 5-3. Chair J22 (fire-retardant polyurethane foam with wool cover), no sprinkler

	Time to untenable condition (sec)		
Tenability Criterion	Lounge 4	Hall 1	Bed 2
Visibility < 2 m @ 2 m above floor	25	55	90
FED inc (gases)	>600	>600	>600
FED inc (rad)	360	>600	>600
Smoke alarm activation time	13	29	47

Table 5-4. Chair J22 (fire-retardant polyurethane foam with wool cover), with sprinkler

	Time to untenable condition (sec)		
Tenability Criterion	Lounge 4	Hall 1	Bed 2
Visibility < 2 m @ 2 m above floor	25	55	90
FED inc (gases)	>600	>600	>600
FED inc (rad)	>600	>600	>600
Sprinkler activation time (sec)	124		
Smoke alarm activation time (sec)	13	29	47

Visibility and irritant gas effects – there was little difference in the time for the specified visibility criterion to be reached, for either chair with/without sprinklers. This is because the visibility criteria were exceeded at an early time, before the sprinklers would be expected to operate. The initial burning characteristics of each chair were also similar in this case, as the ignition source was an open-flame (gas burner). A cigarette ignition scenario may have produced different results. However, reduced visibility and presence of irritant gases are not in themselves likely to cause fatalities. They have the effect of slowing the ability of the occupants to escape, making them more likely to be exposed to lethal doses of narcotic gases or heat.

Incapacitating effects of narcotic gases – in none of the cases presented here did the concentration of narcotic gases reach a level likely to incapacitate occupants within a 10 minute period. In this analysis the key species considered is carbon monoxide, and the predicted concentrations were kept relatively low due to the fire not becoming ventilation limited because the combustion was assumed to be confined to the single seater chair, and did not spread to any other combustible items nearby. This may not have been the case had the chair been a larger item (with corresponding greater peak heat release rate) or if the fire had been assumed to spread to other items. The analysis also ignored the contribution of gaseous HCN likely to be produced by both polyurethane foam and wool materials, and which is also a narcotic gas.

Incapacitating effect of heat – when the sprinkler operated, the level of radiant heat from the hot gases was not sufficient to incapacitate occupants. In the absence of sprinklers, the burning L21 chair resulted in the thermal radiation criteria being exceeded after 140 seconds in the lounge, and 250 seconds in the hallway. However, longer times applied to the slower burning J22 chair where the critical times were 360 seconds for the lounge and >600 seconds for the hallway.

Conclusions

The use of a better-performing chair (e.g: using a fire-retardant foam with wool cover) ignited by a 30 kW open flame ignition source resulted in more time for escape, but would not necessarily stop hazardous conditions developing within the house. In contrast, a sprinkler system would most likely prevent the development of life-threatening conditions for this scenario.

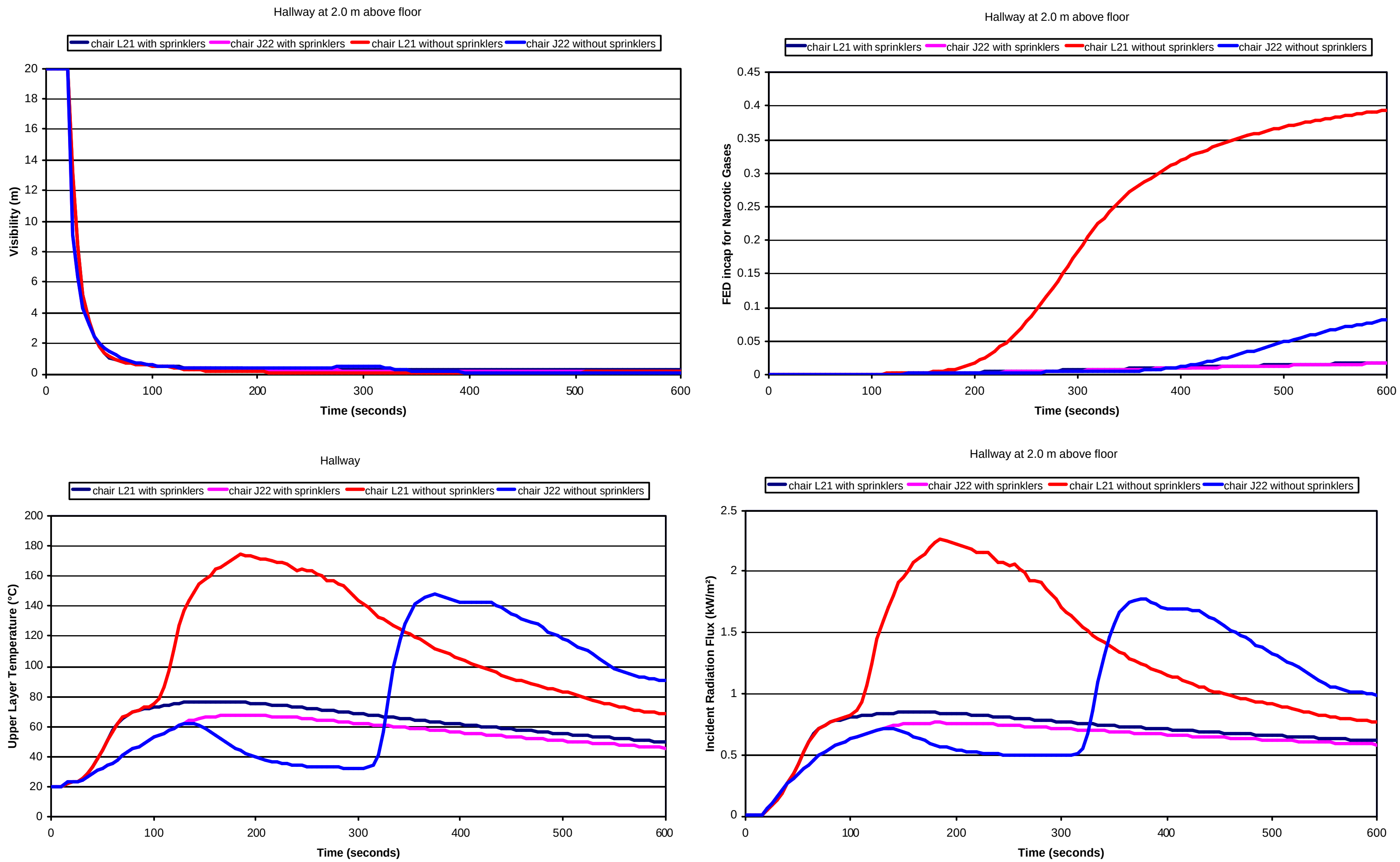


Figure 5-4. Simulated visibility, level of incapacitating noxious gases, temperature of upper air layer and incident radiation flux in hallway following ignition of single-seater chairs constructed of standard polyurethane foam with polypropylene cover (L21) and of fire-retardant polyurethane foam with wool cover (J22), by time.

6. FIRE INCIDENT STATISTICS

6.1. New Zealand

New Zealand studies included in the literature review used different data sources, used different criteria for identification of fire-related deaths, non-fatal injuries, and included different categories of fire incident location. For this reason FIRS data were obtained directly from the New Zealand Fire Service for analysis relevant to this project. Data were obtained for the corporate years 1991/1992 to 2001/2002. Residential structure fires were defined as a structure fire (i.e: structure fire with damage, structure fire with no damage, derelict building, chimney fire, or structure fire not classified) that occurred in residential property. The Fire Service definition of residential property is broad and includes boarding houses, hotels, motels and lodges in addition to houses, flats, and apartments. The data do not include fires on residential lawns, backyards, gardens, patios, private roads or driveways (all of these are classified as miscellaneous property fires). The Fire Service definition of residential property also excludes mobile property fires (in cars, campervans, caravans etc.) fires in health care and institutional property, such as hospitals, rest homes and prisons, and fires in educational property such as boarding schools.

The data obtained are likely, if anything, to be conservative in terms of numbers of fatal and non-fatal injuries per 1000 fires attended by the New Zealand Fire Service. Review of domestic[i] fire-related mortality 1991-1997 found that 19% of fire-related deaths identified from New Zealand Health Information Service data were not recorded in FIRS data (Duncanson, Reid, Langley & Woodward, 2001). The Fire Service acknowledge that there is uncertainty about non-fatal injury figures as "operational staff attending the incident are sometimes not in a position to accurately record the number of injuries, or the severity of injuries, to members of the public" (New Zealand Fire Service, 2002).

From July 1991 to June 2001 the New Zealand Fire Service attended 45,630 residential structure fires, an average of 4563 such fires per year. Residential structural fires began most commonly in the kitchen (28%), lounge (14%) or bedroom (12%). In the same time period FIRS recorded 219 civilian deaths and 2502 civilian injuries in structural residential fires, an average of 22 deaths and 250 non-fatal injuries per year. Of the non-fatal injuries, 107 (4%) were recorded as life threatening, 1574 (63%) as moderate and 815 (33%) as slight. Injury severity was unknown in six cases (< 1%). Mortality figures are lower than domestic fatality figures quoted in the literature review, because they exclude deaths in caravans, and deaths outdoors in residential property (e.g. deaths and injuries from fires occurring in lawns, backyards, gardens, patios and driveways). There had also been a decline in fire-related mortality rates from 1997 to 2001.

Figure 6-1 shows the calculated rates of residential structure fires using the 1991 census count of dwellings for 1991/92 to 1993/94; 1996 census data for 1994/95 to 1998/99; and 2001 census data for 1999/2000 to 2001/2002. The average decline over the period in house fire rates was 0.7% per annum (test for trend p<0.0001). The proportion of dwellings with at least

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[i] In this study the definition of a domestic environment differed from the fire service definition of residential structures by including outdoor fires and fires in stationary vehicles on private residential property, and excluding fires in commercial premises such as hotels, motels, and boarding houses (Duncanson, Reid, Langley & Woodward, 2001).

one domestic smoke alarm increased from 65% to 84% between 1998 and 2002 (Test for trend p<0.005).

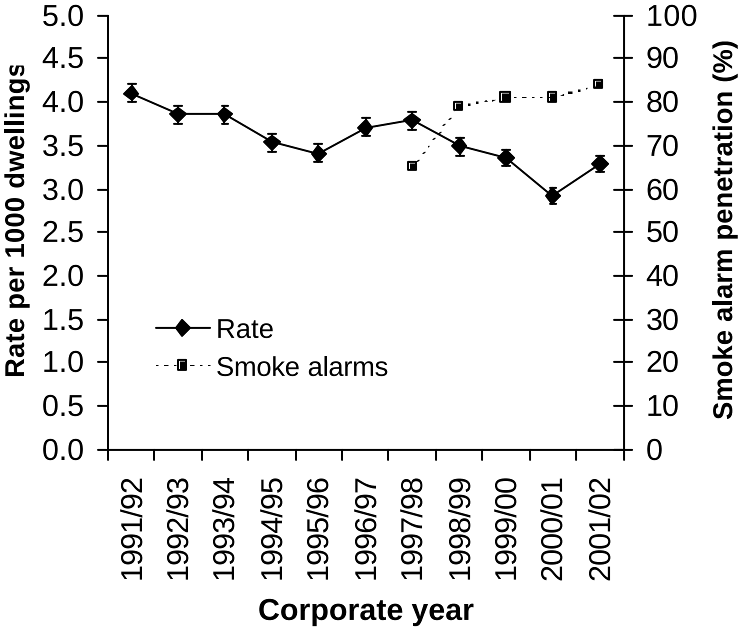

Figure 6-1. Residential structure fires per 1000 private dwellings July 1991 to June 2002 and percentage of households, with at least one domestic smoke alarm, 1998-2002. Error bars represent 95% confidence intervals. Data Sources: New Zealand Fire Service, Statistics New Zealand.

Recorded fatality and injury rates per 1000 fires by item first ignited are shown in Table 6-1. The item first ignited was unknown in approximately one-fifth (18%) of the residential structure fire incidents, and a similar proportion (21%) of fatal fire incidents. The highest incident fatality rates were observed for clothing ignitions. This is not surprising, given that in such incidents the casualty is intimate with the heat source and likely to sustain severe burns. Although upholstered furniture and bedding were the items first ignited in only 8% of all fires, they were items first ignited in 26% of all fatalities and 21% of non-fatal injuries. For fires where the item first ignited was bedding or upholstered furniture, there were 15 deaths and 140 non-fatal injuries per 1000 fires. The latter comprised four life-threatening, 92 moderate and 44 slight injuries per 1000 fires, as classified by the New Zealand Fire Service.

An even greater number of structural residential fires will have involved upholstered furniture as an accelerant contributing to fire spread. However existing data sources in New Zealand do not record this information.

Table 6-1. Object first ignited in residential structure fires, New Zealand, July 1991-June 2001 with number of fatalities and fatality rate per 1000 fires, and number of non-fatal injuries and non-fatal injury rate per 1000 fires. Data source: New Zealand Fire Service Fire Incident Reporting System.

Item first ignited	Residential structure fires n (%)	Fatalities n (%)	Rate *	Non-fatal injuries n (%)	Rate *
Clothing being worn	47 (<1)	5 (2)	106.4	12 (<1)	255.3
Bedding: mattress, pillow	755 (2)	12 (5)	15.9	86 (3)	113.9
Upholstered: chairs, sofas, beds, vehicle seats	977 (2)	15 (7)	15.4	148 (6)	151.5
Bedding: Blankets, sheets, duvet	1960 (4)	30 (14)	15.3	283 (11)	144.4
Hazardous substances and fuels	3906 (9)	22 (10)	5.6	216 (9)	55.3
Structure components	5861 (13)	30 (14)	5.1	225 (9)	38.4
Other furniture	1002 (2)	5 (2)	5.0	100 (4)	99.8
Soft goods (towels, tablecloths, curtains, etc)	2052 (4)	10 (5)	4.9	186 (7)	90.6
Cooking material, food (for human or animal)	8478 (19)	21 (10)	2.5	625 (25)	73.7
Other	12503 (27)	22 (10)	1.8	426 (17)	34.1
Unknown/ unable to classify	8089 (18)	47 (21)	5.8	195 (8)	24.1
Total/ Overall	**45630 (100)**	**219 (100)**	**4.8**	**2502 (100)**	**54.8**

* per 1000 residential structure fires

6.2. United Kingdom

Since 1997 the UK fire statistics have included detailed information about the item first ignited and the material mainly responsible for the development of the fire (Office of the Deputy Prime Minister ODPM, 2002). From 1997 to 2000 there were 285,948 dwelling fires which resulted in 1971 fatalities and 58,829 non-fatal injuries, as shown in **Error! Reference source not found.** and Table 6-3. The proportion of fires involving bedding or upholstered furniture is considerably lower than that reported in New Zealand. This may relate to the different patterns of heating in UK homes, as well as the more stringent furniture flammability regulations.

The inclusion of data concerning material mainly responsible for the development of the fire highlights the observation of Wong (2001) that upholstered furniture may be involved in residential fires where it is not the item first ignited. In the UK from 1997 to 2000 other foam furniture (i.e. not combustion modified), and beds or mattresses, were the material mainly responsible for the development of the fire in approximately twice as many fires, and fatal fires, as those where they were the item first ignited. The UK data lend support to our assumption that fires where bedding is the item first ignited are likely to involve mattresses as an agent of fire spread. From 1997 to 2000 there were 8200 fires where bedding was the item first ignited, and an additional 4609 dwelling fires where a bed or mattress was the material mainly responsible for the development of the fire.

It is notable that there were only 42 fires where the item first ignited was upholstered furniture containing combustion-modified foam, and that these fires resulted in only one fatal and 11 non-fatal injuries. Similarly, combustion-modified foam upholstery was the main contributor to fire spread in only 89 fires (0.5% of total dwelling fires), and these fires resulted in four fatalities and 32 non-fatal injuries. The data do not state how this item was assessed, and there is a possibility of classification bias. Nevertheless the data do support a greatly reduced likelihood of a fire starting if the household upholstered furniture is made with combustion modified foam.

Table 6-2. Material first ignited in dwelling fires in the United Kingdom with number and percentage of fire incidents, fire-related fatalities, and fire-related non-fatal injuries aggregate data 1997-2000. Data source: Office of the Deputy Prime Minister (UK).

Material first ignited	Fires (%) n=285948	Fatalities (%) n=1971	Fatalities per 1000 fires	Non-fatal injuries (%) n=58829	Non-fatal injuries per 1000 fires
Bedding	8200 (2.9)	206 (10.5)	25	3537 (6)	431
Bed or mattress	2679 (0.9)	21 (1.1)	8	832 (1.4)	311
Combustion modified foam upholstery	42 (0.01)	1 (0.1)	24	11 (<0.1)	262
Other foam upholstery	2136 (0.7)	61 (3.1)	29	720 (1.2)	337
Other upholstery – covers	8170 (2.9)	225 (11.4)	28	2944 (5)	360
Bedding and upholstered furniture	**21227 (7.4)**	**514 (26.1)**	**24**	**8044 (13.7)**	**379**

Table 6-3. Material mainly responsible for development of dwelling fires in the United Kingdom with number and percentage of fire incidents, fire-related fatalities, and fire-related non-fatal injuries aggregate data 1997-2000. Data source: Office of the Deputy Prime Minister (UK).

Material responsible for fire development	Fires (%) n=285948	Fatalities (%) n=1971	Fatalities per 1000 fires	Non-fatal injuries (%) n=58829	Non-fatal injuries per 1000 fires
Bedding	7228 (2.5)	152 (7.7)	21	2960 (5)	410
Bed or mattress	5581 (2)	82 (4.2)	15	1965 (3.3)	352
Combustion modified foam upholstery	89 (0.05)	4 (0.2)	45	32 (0.1)	360
Other foam upholstery	4780 (1.7)	153 (7.8)	32	1755 (3)	367
Other upholstery – covers	9106 (3.2)	231 (11.7)	25	3106 (5.3)	341
Bedding and upholstered furniture	**26784 (9.4)**	**622 (31.6)**	**23**	**9818 (16.7)**	**367**

Table 6-4. Percentage of reported fires with upholstered furniture as items first ignited, and rates of fire-related deaths and nonfatal injury per 1000 fires by country, with reference details.

Country	Year(s)	Item first ignited	Percentage of fires	Deaths per 1000 fires	Non-fatal injuries per 1000 fires	Reference
USA	1993-1997	Upholstered furniture	4.0	43	116	Richardson (2001)
		Mattress or bedding	6.2	21	106	
Australia	1989-1993	Upholstered furniture	2	17	108	Dowling & Ramsay (1997) cited by Wong (2001)
		Mattress or bedding	6	13	140	
United Kingdom	1988-1993	Bedding and upholstered furniture	6.7	42	406	Data cited by Wong (2001)
United Kingdom	1997-2000	Standard upholstered furniture	0.7	29	337	Office of the Deputy Prime Minister
		Mattress or bedding	3.8	21	403	
		Combustion modified foam furniture*	0.01	24	262	
New Zealand	1991-2001	Upholstered furniture	2	15	152	NZ Fire Service data
		Mattresses or bedding	6	15	136	

* There were 42 fires reported to involve combustion modified foam furniture with 1 death and 11 non-fatal injuries in the UK 1997-2000

7. REGULATORY ACTIONS AND THEIR EFFECTIVENESS

7.1. Options for regulating flammability of upholstered furniture

Fire incident statistics reports from the United Kingdom show a significantly higher proportion of fire fatalities in which upholstered furniture was the item first ignited compared with New Zealand. In New Zealand, a high proportion of objects first ignited are entered as undetermined. Reviews of fire scenarios involving upholstered furniture show the most common ignition source was abandoned smoking materials.

Key factors to be considered in conducting an economic evaluation of flammability standards of upholstered furniture relate to the potential savings through reduced property damages, together with fewer deaths and injuries, and the costs to the industry, consumers and society as a whole, of developing and implementing standards. International precedents suggest three levels of standard development:

- Mandatory labelling of upholstered furniture and mattresses warning of the fire risk associated with upholstered furniture and indicating compliance or not with standard.
- Mandatory standards for flammability in mattresses with voluntary standards for lounge furniture with labelling as above.
- Mandatory standards for flammability of all upholstered furniture products and mattresses.

Regulations for controlling the fire behaviour of upholstered furniture could take one of several forms:

Option 1
Mandatory labelling only - providing a performance rating (to specified test(s)) for the consumer, but with no mandatory requirement to limit the levels of performance achieved in the specified test(s). This relies on educating the consumer so they can make an informed choice when selecting furniture. However, those in the community who would benefit the most from ‘high performance’ furniture are usually those least able to afford it. Their purchasing decisions are more likely to be cost-driven.

Testing cost and complexity:	low
Added cost of furniture:	low
Effectiveness:	low

Option 2
Regulate the properties of both the foam and the covering (separately), as is done in the United Kingdom i.e: foams are tested with a ‘standard’ cover and covers are tested with a ‘standard’ foam. If existing AS/NZS 3744 (NZS 1998a, b, c) and 4088 tests (NZS, 1996) were to be used, standards development cost would be very low (negligible) but testing costs would be high because of the need to test foam/fabric composites. The Australian Wool Testing Authority (AWTA) estimate A$116 per test (Hamilton, 2002). Sample preparation costs by manufacturer are extra.

Testing cost and complexity: high
Added cost of furniture: medium
Effectiveness: high

Option 3
Regulate the fire behaviour of the composite article (end-use foam/fabric combination) using a bench scale flammability test (e.g: cone calorimeter). This has the disadvantage of the high number of possible foam/fabric combinations, making testing requirements more onerous. Requires more significant standards development to clarify the conditions of test, sample preparation and acceptance criteria. The test requires use of more sophisticated apparatus and hence is more expensive. BRANZ estimate NZ$1000 per test, but could be less depending on number of samples. The method provides the opportunity to regulate both the ignitability and post-ignition behaviour. Acceptance criteria would need to be developed, and be able to relate to full-scale behaviour.

Testing cost and complexity: high
Added cost of furniture: medium
Effectiveness: high

Option 4
Regulate only the properties of the foam. The advantage is that there are relatively few foam suppliers and manufacturers in New Zealand. Testing requirements would be greatly reduced compared to regulating flammability behaviour of the covers. It is uncertain how effective this would be where flammable or easily-ignited fabrics are used.

Testing cost and complexity: low-medium
Added cost of furniture: low-medium
Effectiveness: uncertain

Option 5
Full scale testing of furniture items in a room. Technically this is the most robust option but would be too expensive to be practical for a routine regulatory control.

Testing cost and complexity: high
Added cost of furniture: medium
Effectiveness: high

For each of these options the ‘effectiveness’ of the control would vary, affecting the cost-benefit outcome.

7.2. Options selected for cost-benefit analysis

The analysis that follows is based on introducing mandatory standards for ignition resistance of upholstered furniture and mattresses, similar to those currently used in United Kingdom and proposed for use in the USA. This is effectively Option 2, above. While other fire test methods, as discussed in this report, could be used which address heat release rate properties as well as ignition resistance, further work would need to be done to determine the most effective parameters to control and the appropriate acceptance criteria. It is anticipated that this type of deliberation would be carried out by the appropriate Standards Committee.

In the meantime, existing standards (i.e. AS/NZS 3744 Parts 1 to 3 and AS/NZS 4088 Part 1) are assumed for the purpose of carrying out the cost-benefit study.

7.3. Proposed effectiveness model

Ideally, a cost-benefit analysis needs to be able to account for the possibility of mandatory smoke alarms being required, independent of any upholstered furniture legislation. We have therefore developed an effectiveness model to cover four scenarios:

1. The current situation "status quo" i.e: voluntary standards for flammability of upholstered furniture and voluntary installation of smoke alarms. (Figure 7-2)
2. Introduction of a mandatory standard for upholstered furniture and continued voluntary use of smoke alarms. (Figure 7-3)
3. Introduction of a mandatory standard for upholstered furniture as well as mandatory installation of smoke alarms. (Figure 7-4)
4. Voluntary standard for upholstered furniture and mandated installation of smoke alarms in new dwellings. (Figure 7-5)

The figures (7-2 to 7-5) illustrate the four scenarios in the form of event trees, a diagram which describes the expected outcomes, and probability for each scenario.

The "effectiveness" of a protective measure is intended to take into account both the reliability and the efficacy of the feature. The assumptions for the model, the inputs and the basis for them are discussed in the next section of this report.

The expected outcomes (per annum) for each scenario once full effectiveness has been reached can be summarised as follows:

Table 7-1. Expected scenario outcomes at maximum effectiveness

Scenario	Expected No. deaths	Expected No. injuries	Expected property loss $	Expected NZFS costs $	Lives saved	Injuries prevented	Property saved $	NZFS costs averted $
1 Base case (status quo)	22	249	73.01 m	25.83 m	0	0	0	0
2 Furniture regulation	15	174	70.60 m	24.98 m	7	75	2.41 m	0.85 m
3 Smoke alarms regulation	13	152	53.84 m	25.83 m	9	97	19.17 m	0
4 Furniture + smoke	9	106	52.07 m	24.98 m	13	143	20.94 m	0.85 m

It was not within the scope of this study to also conduct a cost-benefit on the installation of smoke alarms however, we are interested in the marginal cost/benefit of regulating furniture if the installation of smoke alarms were to be mandated in new houses (i.e: scenario 3 would become the base case). However, in this situation, the new base case would also be implemented over time, and would not be fully effective immediately.

Table 7-2. Expected outcomes if smoke alarms installation were mandatory

Scenario	Expected No. deaths	Expected No. injuries	Expected $ loss	Expected $ NZFS costs	Lives saved	Injuries prevented	Property saved $	NZFS costs saved $
3 Smoke (new base case)	13	152	53.84 m	25.83 m	0	0	0	0
4 Furniture +smoke	9	106	52.07 m	24.98 m	4	46	1.77 m	0.85 m

7.4. Effectiveness model inputs

7.4.1. Numbers of fires in residential-type buildings

The number of fires attended by the New Zealand Fire Service each year in residential buildings averaged between July 1991 and June 2001 was 4563 (see Table 6-1).

7.4.2. Numbers of fires involving upholstered furniture and mattresses

USA data for home fires between 1991 and 1995 show that 3.4% were where upholstered furniture was the item first ignited and 6.5% where mattresses were the item first ignited, giving a total of about 10%. Krasny, Parker and Babrauskas (2001) also report a total of 9.7% for the period 1992 to 1996. One-third of these were due to upholstered furniture and two-thirds due to mattresses and bedding.

Before regulations were introduced in the United Kingdom in 1988, furniture was ignited in 7.5% of all house fires but resulted in 35% of all deaths in fire (DTI, 2001). In 1993 upholstered furniture was ignited in 5.7% of fire incidents in residential dwellings (cited by Wong, 2001).

Irwin (1997) analysed New Zealand FIRS data from 1986 to 1994 and found that:

Form of material ignited unknown	5937	(14.1%)
Furniture or utensil details unknown	174	(0.4%)
Upholstered sofa or chair	729	(1.7%)
Soft goods and wearing apparel details unknown	116	(0.3%)
Mattresses or pillows	840	(2.0%)
Other forms of material ignited	34,213	(81.4%)
Total	**42,009**	**(100%)**

And after excluding the unknowns:

Furniture or utensil details unknown	174	(0.5%)
Upholstered sofa or chair	729	(2.0%)
Soft goods and wearing apparel details unknown	116	(0.3%)
Mattresses or pillows	840	(2.3%)

Other forms of material ignited	34,213	(94.8%)
Total	**36,072**	**(100%)**

Irwin’s data summary suggests that upholstered furniture and mattresses are the form of the materials ignited in the range 4.3-5.1% of residential fire incidents. This is about half of the estimated figure based on USA data.

The recent data presented in **Error! Reference source not found.**, shows the proportion of fires where the object first ignited was: mattresses and pillows (2%), upholstered furniture (2%) and bedding (4%). A number of the fires where bedding was ignited would have subsequently involved the mattresses, thus it is likely that mattresses and upholstered furniture would be ‘involved’ in the range 4-8% of fires.

A conservative value to assume in this analysis is 5%, being consistent with the reported New Zealand data and conservative (lower) with respect to reported values based on USA and UK data.

7.4.3. Effect of smoke alarm presence on the risk of death

According to FEMA (1999) analysis of 1996 USA fire incident data, there were 11.6 deaths per 1000 fires where no smoke alarms were present and 5.0 deaths per 1000 fires where smoke alarms were present. Wade and Duncan (2001) reviewed this and other data relating to the effectiveness of smoke alarms and concluded that the overall benefit from installing a smoke alarm system would be in the range 42-67% reduction in the fire death rate depending upon the type of alarm system (ie, single/multiple alarms, battery/mains powered, single-station/interconnected).

In this study, the presence of a smoke alarm is assumed to reduce the observed fire death rate by 50%.

7.4.4. The effect of introducing an open-flame ignition standard

According to CPSC (2001) an open-flame ignition standard was estimated to reduce the number of upholstered furniture fires by 66%, the number of upholstered furniture related deaths by 88% and the value of property loss by 63%. These values have been used in the effectiveness model.

7.4.5. Fire incidents detected by a smoke alarm and attended by fire service

In the UK in 1997 the number of dwelling fires detected by a smoke alarm was reported to be 10% to 12% (DTI, 2000). The actual percentage will likely be higher due to fires that were detected and extinguished by occupants without Fire Service notification or involvement.

Recent analysis of USA data by Thomas (2002) for 1983 to 1995 fires in one and two family dwellings showed 476,646 fires where detectors were present (i.e: 37%) and 799,600 fires where detectors were not present (i.e: 63%).

We have assumed that 20% of currently reported fire incidents are for fires where a smoke alarm is present. This is lower than the expected number of alarms in the general housing stock since the fire risk is not uniform across the general housing stock; the fire risk is higher, and smoke alarm use is lower, in lower socio-economic areas.

In calculating the cost-benefit of smoke alarm use in conjunction with, or as an alternative to, a mandatory furniture flammability standard, it is assumed that the number of fire incidents as recorded by the New Zealand Fire Service would not change.

7.4.6. Fire death rate in residential fires

It is assumed that the fire death rate for fires involving upholstered furniture or mattresses and with no alarms present to be 37 deaths per 1000 fires, and 3.7 deaths per 1000 fires for fires not involving upholstered furniture or mattresses and with no alarms present.

The latter figure is slightly lower than the six deaths per 1000 fires used by Wade and Duncan (2000) since it excludes the higher-risk upholstered furniture fires. The former value (37) is determined by trial and error; with other inputs to the effectiveness model fixed, such that the predicted outcomes adequately reflect the existing fire death and injury historical record in New Zealand. However, it is of the same order as reported in the UK, where the fire death rate for upholstered furniture fire-related incidents from 1988 to 1993 decreased from 51 per 1000 fires to 39 per 1000 fires over the same period.

It is noted that the assumed fire death rate is significantly lower than indicated by corresponding USA data (approximately one-half) and United Kingdom data as illustrated in Figure 7-1. A more recent estimate of the New Zealand rate from New Zealand Fire Service data 1991 to 2002 is 4.8 deaths per 1000 fires.

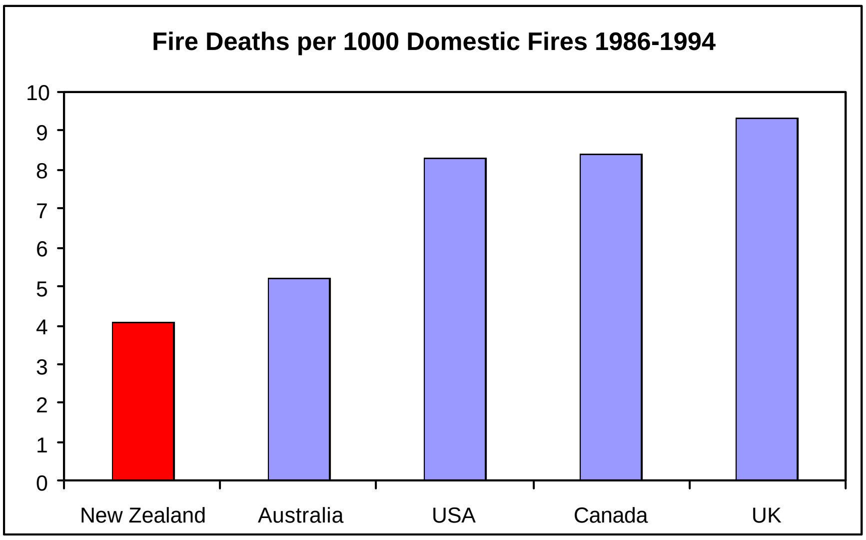

Figure 7-1. International comparison of fire death rates (Irwin, 1997)

7.4.7. Fire injury rate in residential fires

There were 2502 non-fatal injuries in dwelling fire incidents reported during the 10 year period from July 1991 to June 2001 by FIRS (i.e: an average of 250 injuries per year or 55 per 1000 fires based on 4563 fires per year). This compares to the average fire death rate of 4.8 per 1000 fires (i.e: ~11 times higher). An injury rate of 55 per 1000 dwelling fires appears comparable to Australian (48), Canadian (60) and US (45), data as summarised by Wade and Duncan (2000).

We have assumed that the rate of fire injuries will be in proportion to the number of deaths, and equal to 11.3 times the fire death rate.

7.4.8. Property losses in residential fires

Wade and Duncan (2000) estimated property losses in residential fires based on information from the Insurance Council and the presence or absence of smoke alarms in reported fire incidents. The estimated average property loss (house and contents) was $11,200 per fire where an alarm was present and $17,200 where there were no alarms. A weighted average value of $16,605 has been used in this analysis, taking account of the expected number of fire incidents with/without smoke alarms present.

These figures are comparable to US data for one and two family dwellings from Thomas (2002) where the average estimated dollar loss per fire is US$7,502 where alarms are not present and US$7,141 where alarms are present, except that the United States data indicates a relatively small reduction in the value of property loss (about 5%) when alarms are present.

7.4.9. Fire service attendance costs for residential fires

Business and Economic Research Limited (BERL, 2002) provided data of the cost of New Zealand Fire Service attendance at 7128 residential fires in year 2000. It estimated residential fires accounted for 23% of the resources delivered at a total cost of $40,353,000. This is an average cost of $5661 per residential fire ($5875 inflation adjusted). It is assumed that this amount can be saved for every reported fire prevented through regulation of upholstered furniture.

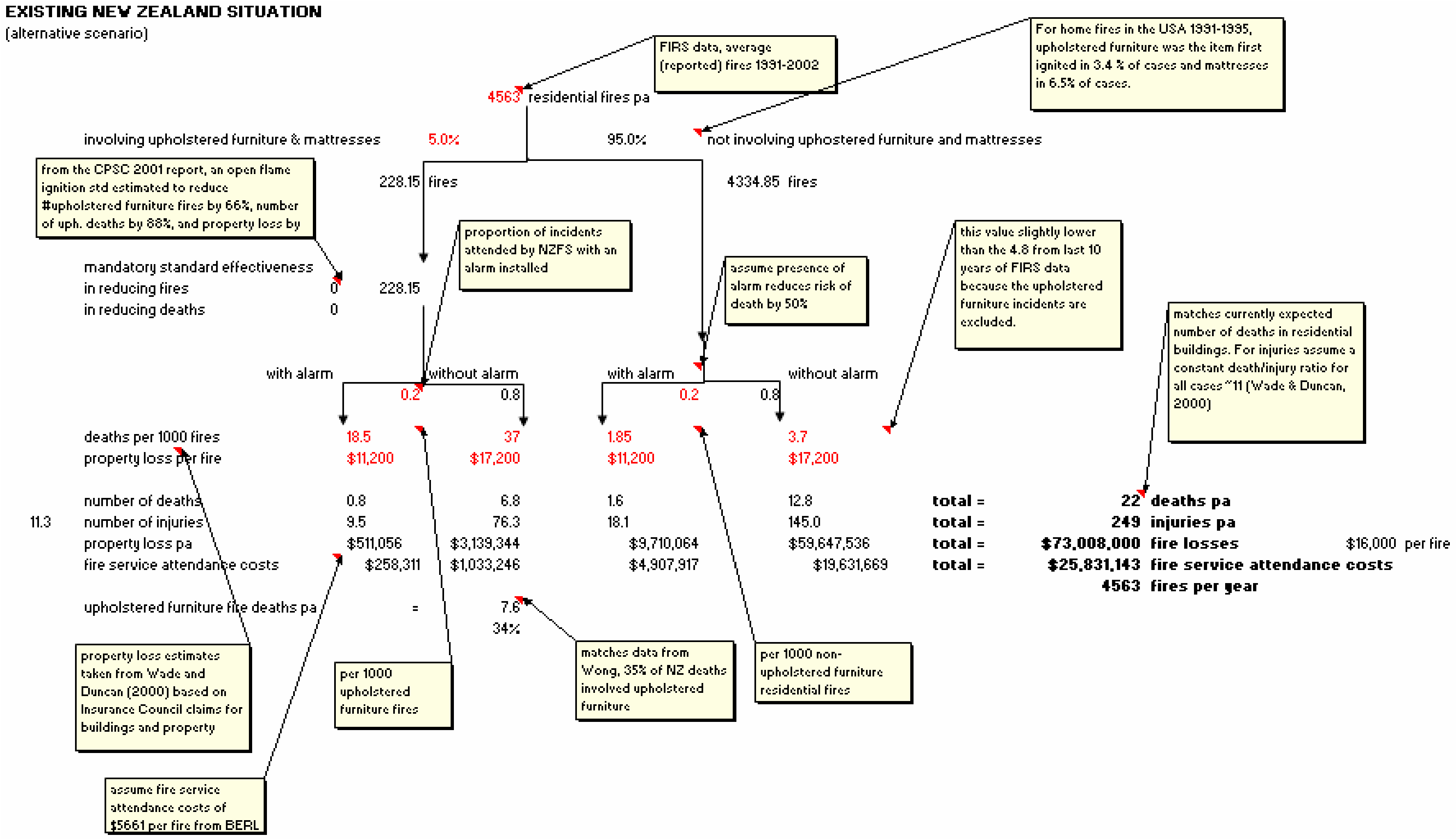

Figure 7-2. Existing New Zealand situation

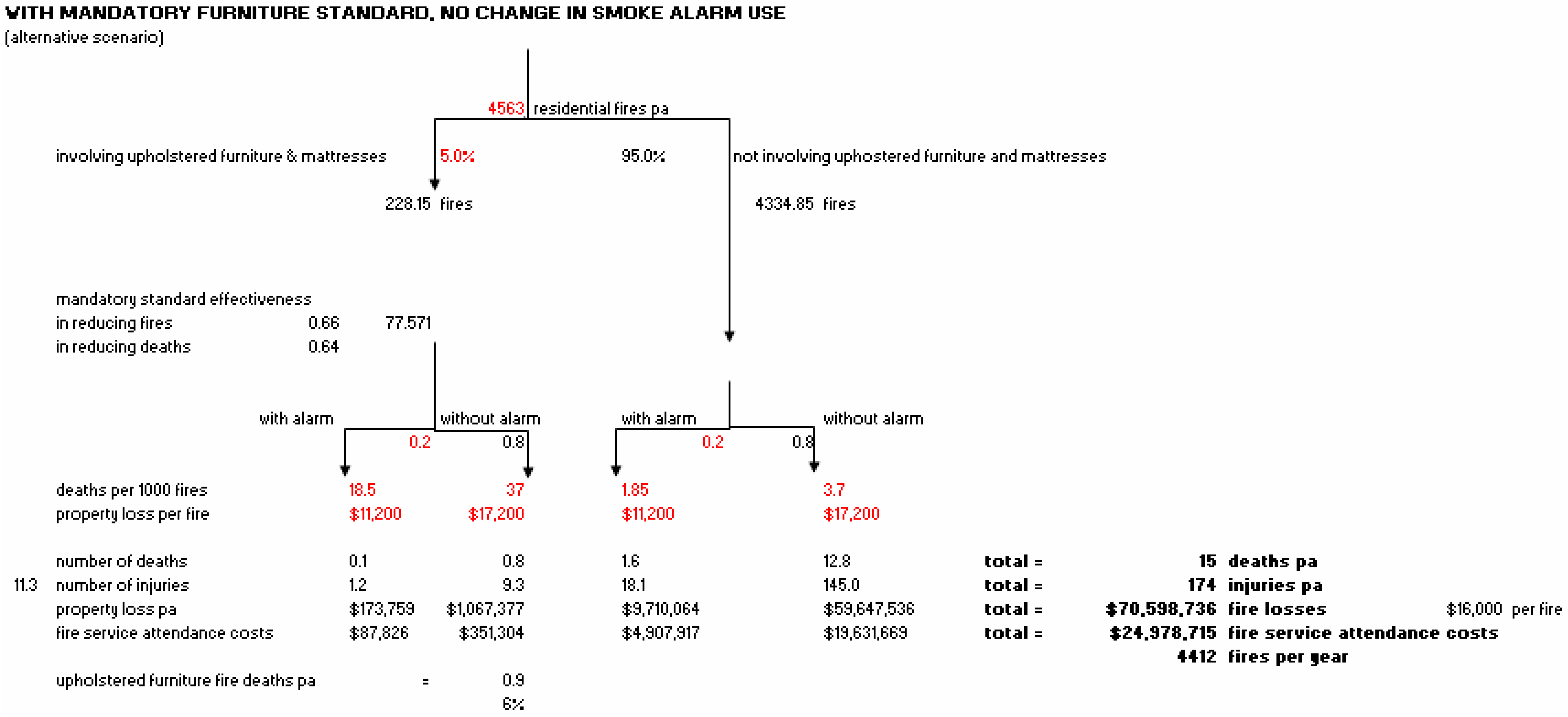

Figure 7-3. Mandatory upholstered furniture standard and no change to smoke alarm use

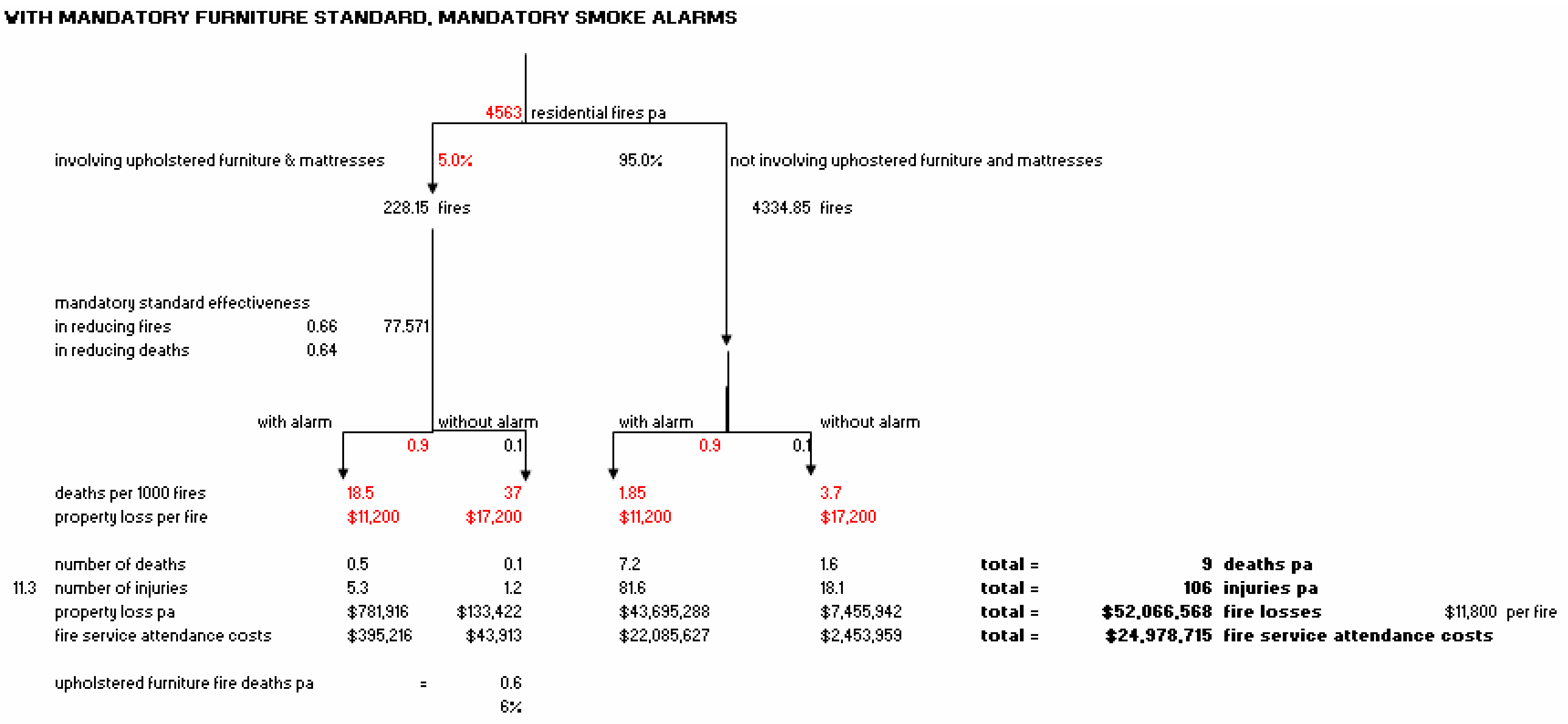

Figure 7-4. Mandatory furniture standard, mandatory installation of smoke alarms

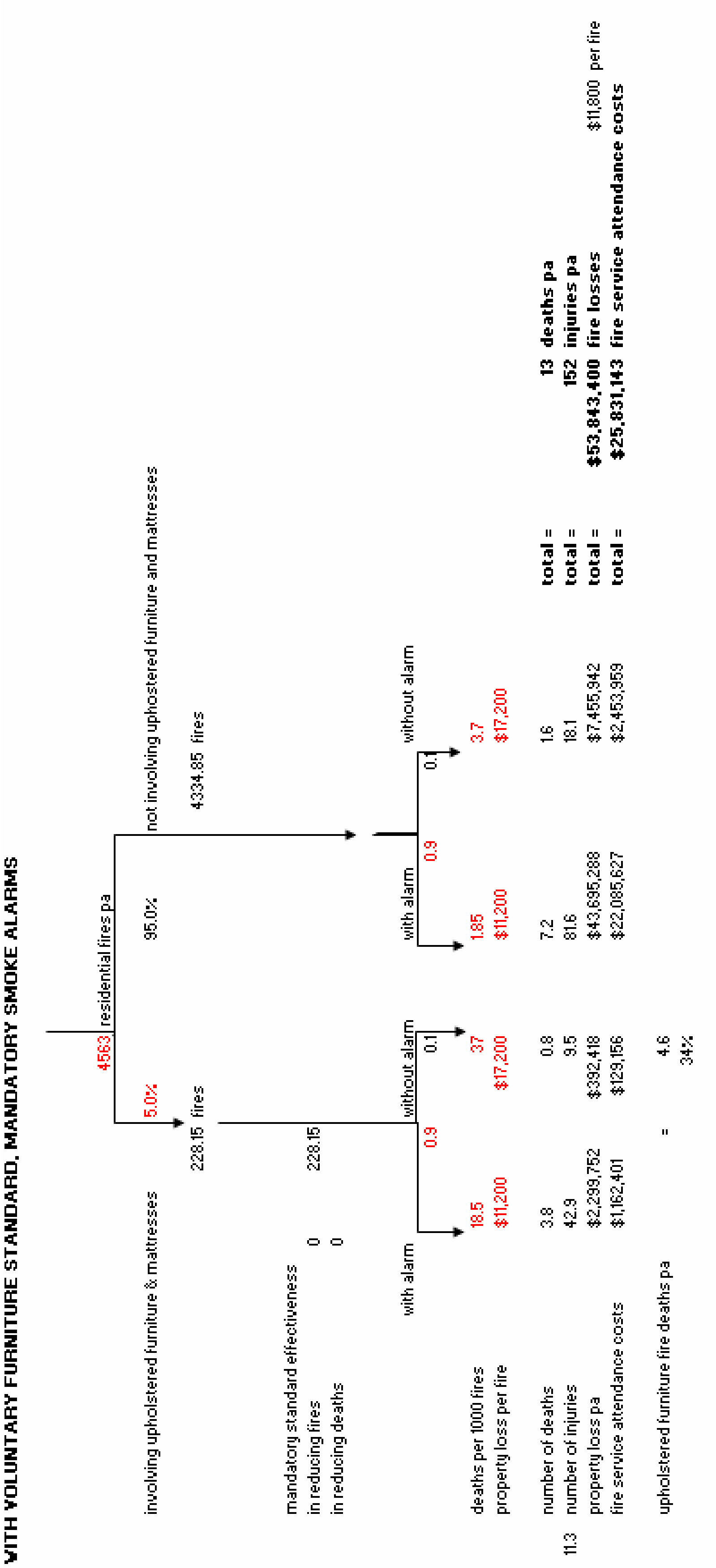

Figure 7-5. Voluntary upholstered furniture standard with mandatory installation of smoke alarms

8. COST-BENEFIT ANALYSIS

8.1. Cost-benefit and cost-effectiveness analysis

A proposed investment or intervention should go ahead only if expected benefits exceed expected costs, and do so by a margin greater than alternative interventions which achieve the same or similar benefits.

Cost-benefit analysis measures the costs and benefits and provides the decision-maker with the results of these calculations in an appropriate form. If there is risk and uncertainty associated with the estimated costs and benefits, as is generally the case, the cost-benefit analyses can also include analyses measuring the sensitivity of the results to variations.

To compare costs and benefits it is useful to have them measured in the same units. In general this is done in money terms, shown by dollars in constant prices. For health and safety interventions, however, the intended benefits are lives saved and injuries and illness averted. It is hard to put a dollar value on such benefits. Sometimes, therefore, 'cost-effectiveness' analyses are carried out in place of a full financial cost-benefit analysis. In these, dollar values are not placed on lives saved or other health outcomes. Instead, the results are presented in terms of 'dollar cost per specified outcome'. For example, dollar cost per life saved, or per life-year saved, or per 'quality-adjusted life-year' (QALY) saved, or per hospital admission prevented, or per fire prevented, etc. The decision-maker then has to decide whether the estimated cost per unit change in outcome is low enough to justify the proposal being given the go-ahead.

The major benefit from the proposal examined in this report is the lives saved as a result of fires prevented in upholstered furniture, or as a result of fires developing more slowly allowing occupants more time to escape.

The decision criterion used is, therefore, cost per life saved. The same criterion has been used in other recent studies (Wade and Duncan, Beever and Britton, DTI)

This still leaves the decision-maker with the problem of deciding when the cost per life saved is sufficiently low enough to justify the proposal going ahead. As a guide, the Land Transport Safety Authority (LTSA) has calculated a 'Value of Statistical Life' for New Zealand, based on surveys of how much people are 'willing to pay' for small reductions in risk of death and injury. The most up-to-date figures (June 2002) put the "Value of Statistical Life' (VoSL) as NZ$2.6 million. The VoSL is used to guide decisions on investment in highway construction and road-accident prevention measures. (More recent research by the LTSA suggests that a higher value, closer to NZ$4 million, would be appropriate, but this has not as yet been officially adopted.) The VoSL is a community average value – individual willingness to pay is affected by factors such as income, age, serious illness, and propensity to take risks. These are averaged out, however, in the overall measure.

On the basis of this result for the transport sector, and assuming it applies also to deaths caused by fire, a fire-prevention measure which costs less than NZ$2.6 million per life saved, in 2001/02 dollars, is certainly worth further consideration.

Alternatively, of course, each estimated life saved could be included in the calculations at the current dollar VoSL, and a standard cost-benefit analysis in monetary terms could be carried out. However, it has seemed preferable in this report to give the results in cost-effectiveness form – in dollars of net cost per life saved.

One reason for using ‘cost per life saved’ is that there is some evidence in the literature that people would be willing to pay more to avoid some forms of death, and decision-makers might wish to take account of this. Death caused by fire is possibly one form of death feared more than others. In general, though, deaths occurring in multi-fatality (‘dread’) incidents are feared more than smaller incidents, and people are willing to pay more for the prevention of such incidents. This is not really relevant for domestic fire deaths – but supports the view that there may be a greater willingness to pay for fire safety in certain occupancies (e.g. residential institutions or large hotels).

“The general public tends to be more concerned about fire scenarios that may kill, say, 100 people once every three years than they are about fire scenarios that kill one person at a time every week, year after year.” (Hall. 1997. p 11/85).

8.2. The problem and proposed solution

Unintentional house-fire deaths have averaged 22 per year in recent years (see section 6.1, page 55). About one-third of these involved upholstered furniture or bedding, which may have been involved in a further one-fifth of fatal incidents (Wong, 2001).

In addition, such fires cause non-fatal injuries – an estimated 11 ‘reported injuries’ per fatality on average (see section 6.1, page 55), and property damage. They also result in Fire Service costs.

The fire performance of furniture can be improved by making changes to the ‘infill’ material such as adding chemical/fire-retardant treatment; or by using more resistant linings for the fabric covers, or both.

8.2.1. The proposed solution

Introduce mandatory New Zealand standards requiring new furniture, manufactured locally or imported, to be made less flammable. Also perhaps applying similar standards to retail sales of second-hand furniture after some time lapse (DTI; 2000).

Note that there are options for any new standards – they could be couched in terms of infill, or fabric covers, or both, or in terms of overall outcome in reducing flammability, whether from an open flame or from a smouldering object (e.g: cigarette).

8.2.2. Benchmark against which alternative is being compared

The ‘comparator’ is the current situation without the proposed new standards. That is do nothing. Note, however, that the widespread use of smoke alarms and declines in the prevalence of smoking, are already causing a decline in domestic fires. The proposed new standards should be evaluated in terms of additional gains over and above these existing trends.

8.2.3. Measure of effectiveness

The measure used in this report is the net cost per life saved. If the net cost is significantly less, at appropriate discount rates, than the 'Value of statistical life' currently used in the New Zealand land transport sector, then the proposed new standard is worth introducing. To convince policymakers, this criterion will probably need to be met for discount rates in the order of 5% per annum and higher.

8.3. Expected costs and benefits

Expected costs and benefits are made up of –

a The resource costs of implementing the proposed new standards –

- Additional costs to consumers of furniture upgraded to meet the new standards
- Costs of the process of setting up the new standards
- Costs of enforcement of the new standards.

b The 'averted costs', that is resource costs which are now avoided because of the new standards, namely –

- Fire Service costs of fire attendance
- Property damage
- Cost of medical treatment.

'Averted costs' can be thought of as benefits, but for calculation purposes it is best to treat them as 'negative costs'.

c Benefits

- Deaths prevented, or life-years saved
- Quality-adjusted life-years gained, from there being fewer severe injuries through fire.

8.4. Costs – identification and valuation

8.4.1. Additional costs to consumers of furniture

There are overseas estimates available of these costs. DTI (2000) estimates an additional cost of £15 to £20 per item of furniture for fire-retardant treatment; for a total cost of £22 million to £30 million per year (implying manufacture of about 1.4 million 'items' per year – the New Zealand equivalent for a population roughly 1/15th the size is 90,000 to 100,000 items per year. The table on consumer purchases (Appendix A) suggests about 65,000 lounge suites are purchased annually). In New Zealand dollar terms, these UK numbers convert to roughly $45 to $60 per item of furniture, and $4.5 million to $6 million per year or $3.75 to $5.00 per household per year (an item being a single chair, or a multi-piece lounge suite.)

Beever and Britton (1999) estimate the cost of introducing legislation in Australia at A$20 to A$100 per household (page 96). They say this is an optimistic assumption based on significant progress on the cost-effective production of suitable materials. In New Zealand dollar terms this is roughly \$21 to \$105 per household. Or, for New Zealand as a whole (assuming about 1.2 million households), about \$25 million to \$126 million per year. The substantial difference between the United Kingdom and Australian numbers helps explain the difference in the conclusions from the two studies (see later).

CPSC (2001) estimates that there would be an US\$22-US\$34 per item increase in cost to consumers where fire-retardant treated fabric is used to comply with the standard, and US\$42-US\$56 where a fire-retardant barrier (interliner) is used. In New Zealand dollar terms this equates to between \$40 and \$112 per item.

To obtain New Zealand estimates we have sought information from a number of manufacturers and distributors of furniture and of materials for furniture manufacture. In general their estimates are in line with the estimates for Australia in Beever and Britton, rather than the lower UK or USA estimates. Some of the detail is given in Appendix A. In brief, we conclude that the expected increase in cost, assuming purchase of a substantial lounge suite every 15 years by an average household, is in the range of NZ\$20 to NZ\$40 per household per year. (None of these numbers are measured with great precision, of course, but they can be assumed to be, like other dollar values in this report, at approximately 2001/02 prices.)

The analysis assumes a ‘central’ value of an extra \$30 per household per year; and ‘low’ and ‘high’ values of \$20 and \$40, respectively, for sensitivity testing. This is on an assumed 15-year purchase cycle. For calculation purposes therefore, multiples of these values by 15 are entered at the expected time of purchase, so allowing changes in the turnover rate to be included in the cost-benefit model.

8.4.2. Furniture replacement rates

Existing furniture is only gradually replaced. The rate of replacement determines the extent of protection provided by the new standards after a given number of years. For calculation purposes, replacement curves like those in the DTI report (DTI, 2000), and USA reports (CPSC, 2001a), have been used. This is an exponential penetration growth model of the form:

$$P_n = (1 - e^{-kt}).100\%$$

Where k is the rate of penetration per year, and t is the number of years. In effect, this assumes that ‘pre-standard’ and ‘post-standard’ furniture will be replaced each year at the same rate. Initially the proportion of ‘old’ or ‘pre-standard’ furniture falls quite rapidly, but in later years the proportion drops only slowly

From the discussion in Appendix A, drawing on tabulations of household purchases from the Household Economic Survey, an annual replacement rate of 6% seems appropriate, and this has been taken as the ‘medium’ value. Low and high rates have been taken as 4% and 8%.

From Figure 8-1 it can be seen that the number of years for half the furniture stock to have converted to the new standard is about 9 years at an 8% replacement rate, 12 years at a 6% replacement rate, and 17 years at a 4% replacement rate.

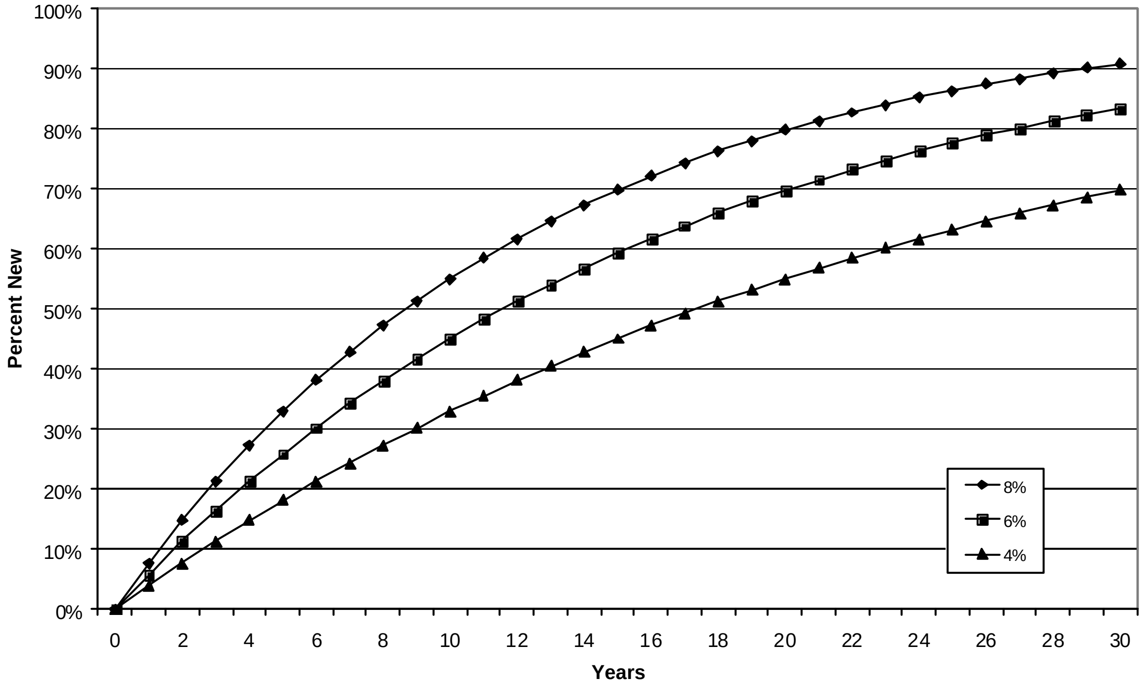

Figure 8-1. New furniture percentages over 30 years for different annual replacement rates

8.4.3. Regulatory costs

Regulatory costs have been assumed at an initial NZ$500,000 for the development and implementation of new standards, and NZ$50,000 per year for ongoing enforcement. The latter figure could be higher assuming regular ongoing testing of manufacturers' products, and imported furniture.

8.4.4. Other costs (averted)

New Zealand Fire Service costs per fire is taken as $5875. This is based on the cost of $5661 per residential fire which is calculable from an earlier research report to the Fire Services Commission (BERL, 2002. Table 7.2.2, page 30) for the year 1999/2000. This has been adjusted to 2001/02 dollar terms by scaling up by a factor of 3.78%. This was the increase in a labour costs index used by Transfund to adjust transport sector contracts.

Property damage per fire is based on the $16,000 used in Wade and Duncan (2000). Adjusting by the same factor as before to 2001/02 gives the number used in our calculations of $16,605.

8.4.5. Cost of fire injuries

During the 10 years between 1991/92 and 2000/01 there were, for upholstered furniture fires, 57 fatalities, 15 'life-threatening' injuries, 338 'moderate' injuries, and 164 'slight' injuries. That is, for each fatality there were 0.263 life-threatening injuries, and 8.807 moderate and slight injuries combined.

There are two main components to the cost of injuries. First there are the resource costs required for ambulance services, hospital treatment where required, and other treatment and rehabilitation and also lost productive contribution to the economy as a result of injury. Second, there are the ‘loss of quality of life’ losses, of which ‘pain and suffering’ is a component.

Beever and Britton (1999) used A$21,100 as the average cost per fire injury. Wade and Duncan (2000) reviewed the literature and recommended $30,000 per fire injury. The DTI (2000) study did not include injury costs in its analysis.

The CPSC (2001) states it used US$170,000 as an average injury cost, based on extensive research and that it reflects the pain and suffering components of many non-fatal fire injuries.

BERL (2002) in carrying out an economic assessment of industrial fires in New Zealand followed LTSA (2000) methodology and estimated average social costs of injuries by severity as follows. (In brief, the LTSA values lost quality of life for ‘serious’ injuries at 10% of the value of statistical life; and for ‘minor’ injuries at 0.4% of the VoSL. Serious and minor are equated here, in the NZFSC terminology, to ‘life-threatening’, and to all other injuries, respectively. In addition the estimates, based on LTSA work, include lost output and medical costs as well as ‘loss of life quality’):

• Non-life threatening injury	$10,800
• Life threatening injury	$258,200
• Fatality	$2,474,700

The fatality costs include $9700 medical costs on average.

Applying these to the numbers of injuries quoted above, and also adjusting for inflation over the two-year period 1999/00 to 2001/02, the average cost per injury including both resource costs and ‘quality of life’ costs is $19,766. This includes the medical costs associated with fatalities. (Note that the average BERL cost for injuries in industrial fire-related incidents is nearly $24,000 in 1999/00 dollars. This is higher than the number we have calculated here because of the higher proportion of life-threatening injuries in industrial fires: nine of 169 injuries in total.)

In this report we assume a cost of $20,000 per injury, including both resource costs and ‘lost quality of life’ costs.

8.5. Potential benefits

Deaths from domestic fires average 22 per year. The maximum possible benefit would therefore be the saving of these 22 lives per annum. However, this is clearly not achievable simply through making upholstered furniture more fire-resistant.

UK researchers seem, however, to postulate an eventual 70% reduction. This is in all domestic fire deaths, not just those starting in upholstered furniture.

Review of Wong (2001) suggests a smaller potential gain for NZ. Upholstered furniture was involved in 35.4% of all residential fire fatalities (page 50), and ‘likely’ involved in a further 18.9%, for a total of 54.3%.

The scenarios elsewhere in this report assume a potential reduction of 30% in the number of domestic deaths is achievable in the long-term as a result of making furniture less flammable. That is, about seven lives would eventually be saved each year. This is the ‘central’ estimate in our calculations. However, if some of the potential gain is achieved through wider and more effective use of smoke alarms, and reduced smoking rates, the gain from making furniture less flammable is reduced. That is, of the seven lives saved by mandatory furniture standards, three would be saved in any case by smoke alarms, so that the net gain from mandatory standards in addition to smoke alarms is approximately four lives per year, on current dwelling numbers (refer Table 7-2).

8.6. Adjustment for differential timing – discounting

Benefits and costs occurring at different time-points need to be brought to a common time-point; acknowledging that a sum of money at the present day has more value than the same amount at some future date. This is done by the standard process of discounting future costs and benefits back to their ‘present values’ of today.

Discount rates of 3, 5, 7, and 10% per annum have been applied to the data, as well as a zero discount rate (no discounting). The 10% is for comparison with standard public sector requirements in New Zealand; the lower rates of 3% to 7% for comparison with standard international practice. All rates are, of course, ‘real’; ie: applied to real costs and benefits.

The discount rate used in the economic analysis carried out in the USA by CPSC (2001) was 3%. That report also noted that a substantial body of research exists on the appropriate discount rate to use when considering future benefits of safety standards or other social policy actions. The preponderance of the literature suggested 1%-3%. CPSC also comment that though higher rates are generally used for discounting future benefits of capital projects, federal health and safety agencies generally use the lower range of rates for comparative analyses.

The time horizon used in the calculations was 30 years. It is inappropriate to use shorter periods, even at high discount rates.

8.7. Cost–benefit results

The calculated cost per life saved is tabulated and charted in Figure 8-2 for a range of discount rates and assumed rates of purchase of new furniture. These estimates are on the basis of an assumed extra $30 cost per household per year. It is also assumed there is no change to the current level of smoke alarm use.

Table 8-1. Calculated cost per life saved

Discount rate (%)	**Rate of furniture replacement per year**		
	4%	**6%**	**8%**
0	$6,762,374	$8,050,539	$9,408,134
2	$7,380,275	$8,697,469	$10,077,294
3	$7,724,521	$9,056,442	$10,447,516
5	$8,481,121	**$9,841,753**	$11,254,603
7	$9,321,685	$10,708,546	$12,140,977
10	$10,713,638	$12,132,077	$13,587,328

Assuming a medium rate of furniture replacement (6%) and a discount rate of 5%, the expected cost per life saved is calculated to be around $9.8 million dollars.

This ‘cost per life saved’ is clearly well above current estimates of the ‘value of statistical life’ of about $2.6 million, or even the proposed increased value of statistical life of $4 million.

The implication from these results for the ‘central’ parameter values is that there is not a sound economic case for introducing the proposed new standard for more fire-resistant furniture.

Even for a slower rate of furniture replacement of 4% per annum, and at lower discount rates, or zero discounting, the costs per life saved are substantially higher than the current value of statistical life benchmark.

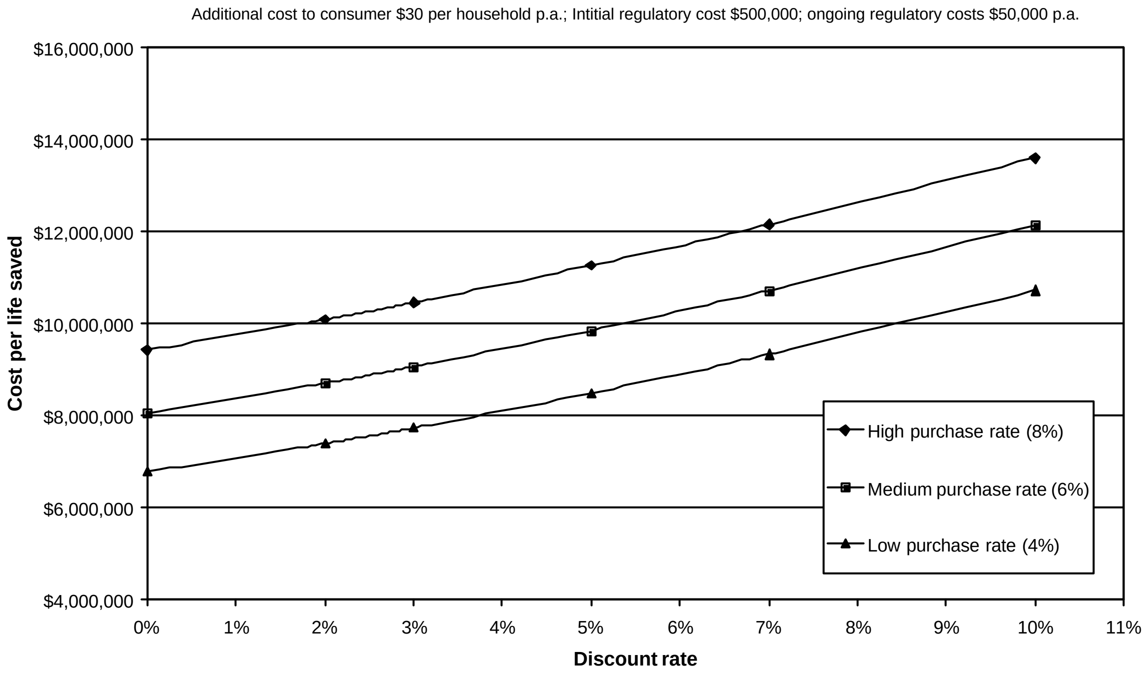

Figure 8-2. Cost per life saved due to introduction of mandatory standards for upholstered furniture and bedding

Allowing for a reduction in fires and deaths as a result of smoke-alarm usage

Suppose now that the installation of smoke alarms was mandated in new houses (as has been suggested) and this leads to a fall in domestic fires and fatalities. The potential gain from the proposed new furniture standard will be reduced. We would now estimate nine deaths per year, a saving of 13 lives, four of which are attributed to the furniture standard and the balance to the smoke alarms (refer Figure 7-4 and Figure 7-5). The results are shown in Figure 8-3. The costs per life saved are, of course, higher, and assuming a medium rate of furniture replacement (6%) and a discount rate of 5%, the expected cost per life saved is calculated to be $12.5 million dollars.

It is assumed that although smoke alarms are mandatory only in new houses, that added to the current level of smoke-alarm use, that the number of reported fires with alarms would increase from the existing 20% to 90%. This may be rather optimistic.

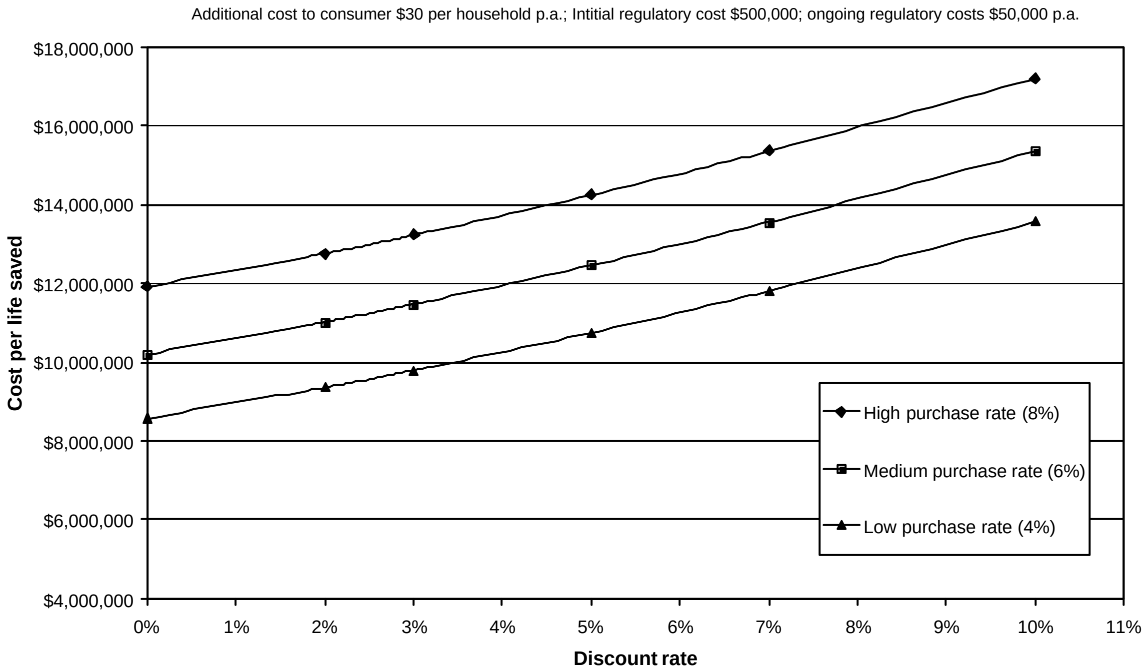

Figure 8-3. Predicted cost per life saved for introduction of furniture flammability regulations, dependent on furniture purchase rate and discount rate, and assuming mandatory smoke alarms in new dwellings

8.8. Sensitivity analyses

8.8.1. Regulatory costs

The results are relatively insensitive to the assumed value of the ongoing regulatory costs per year. Varying the initial cost in the range of $100,000 to $1,000,000 and annual cost $50,000 to $100,000 resulted in all cases in a less than 1% increase in the calculated cost per life saved. The charted results are to all appearances identical to Figure 8-2, so are not repeated here.

The reason for the lack of sensitivity to changes in regulatory costs is that overall costs are dominated by the extra costs to consumers of furniture meeting the proposed new standards.

8.8.2. Additional costs to the consumer

Figure 8-4 shows the variation in the cost per life saved with variations in these added costs to the consumer.

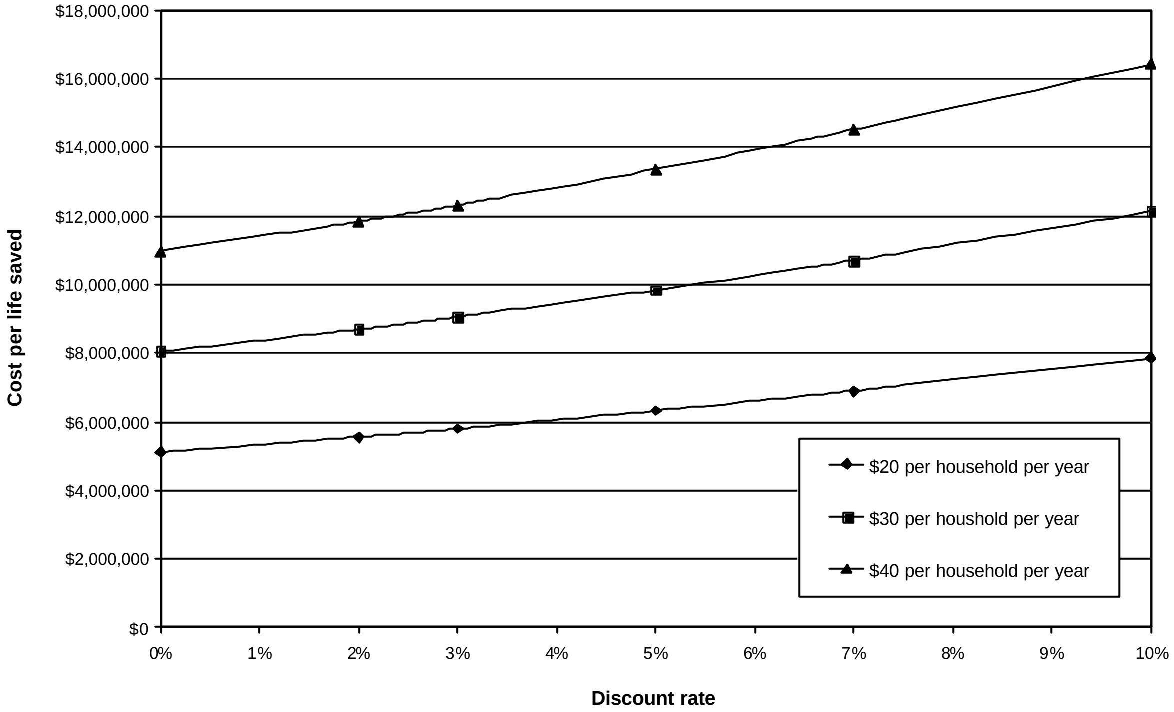

Figure 8-4. Sensitivity analysis on additional cost to the consumer

With respect to the added cost to the consumer, it is apparent that even for the ‘low’ cost of $20 per year per household, the cost per life saved is in excess, for all discount rates, of $4 million. This result holds for different penetration rates of furniture complying with the new standard.

8.8.3. Proportion of fires and fatalities involving upholstered furniture

In this study we have assumed that only 5% of residential fires ‘involve’ upholstered furniture or mattresses, as discussed in section 7.4, and that 34% of fatalities are in fires that ‘involve’ upholstered furniture or mattresses. This is based on Wong’s analysis (2000) of the percentage of fatalities where upholstered furniture was involved, which we have used as a lower bound. However, she also indicates that a further 19% of fatalities ‘are likely’ to have involved upholstered furniture, giving an upper bound estimate of 53%.

If the proportion of fires and fatalities involving upholstered furniture was 8% and 47% respectively, requiring corresponding lower estimates for the deaths per 1000 fires involving upholstered furniture as indicated in Figure 8-5 and Figure 8-6, then the expected number of deaths per annum due to the introduction of new standards would be 13, a reduction of nine (or 40%). The expected reduction in the number of reported residential fires per year would be 5.3%.

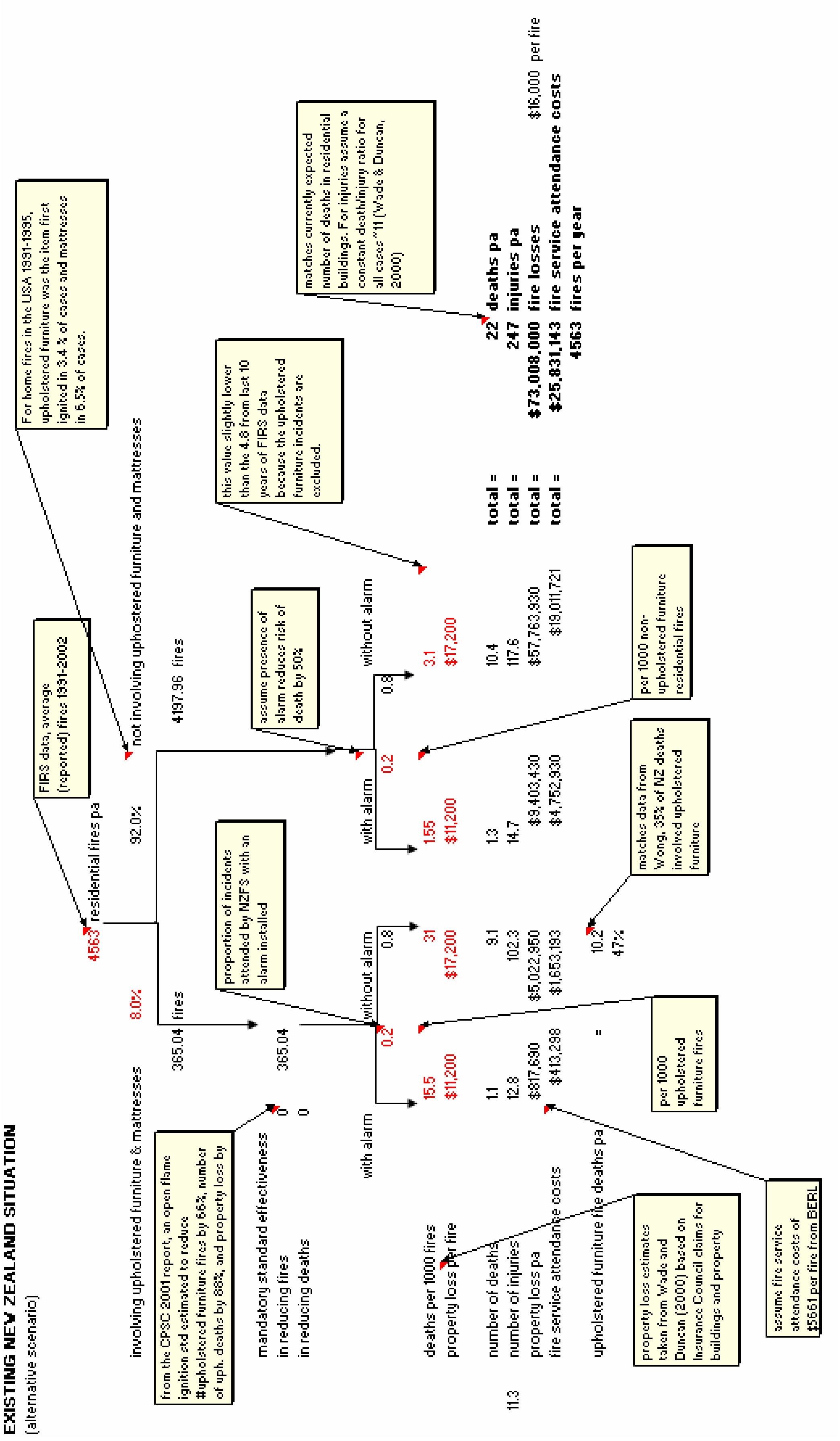

Figure 8-5. Effectiveness model for existing situation (alternative scenario)

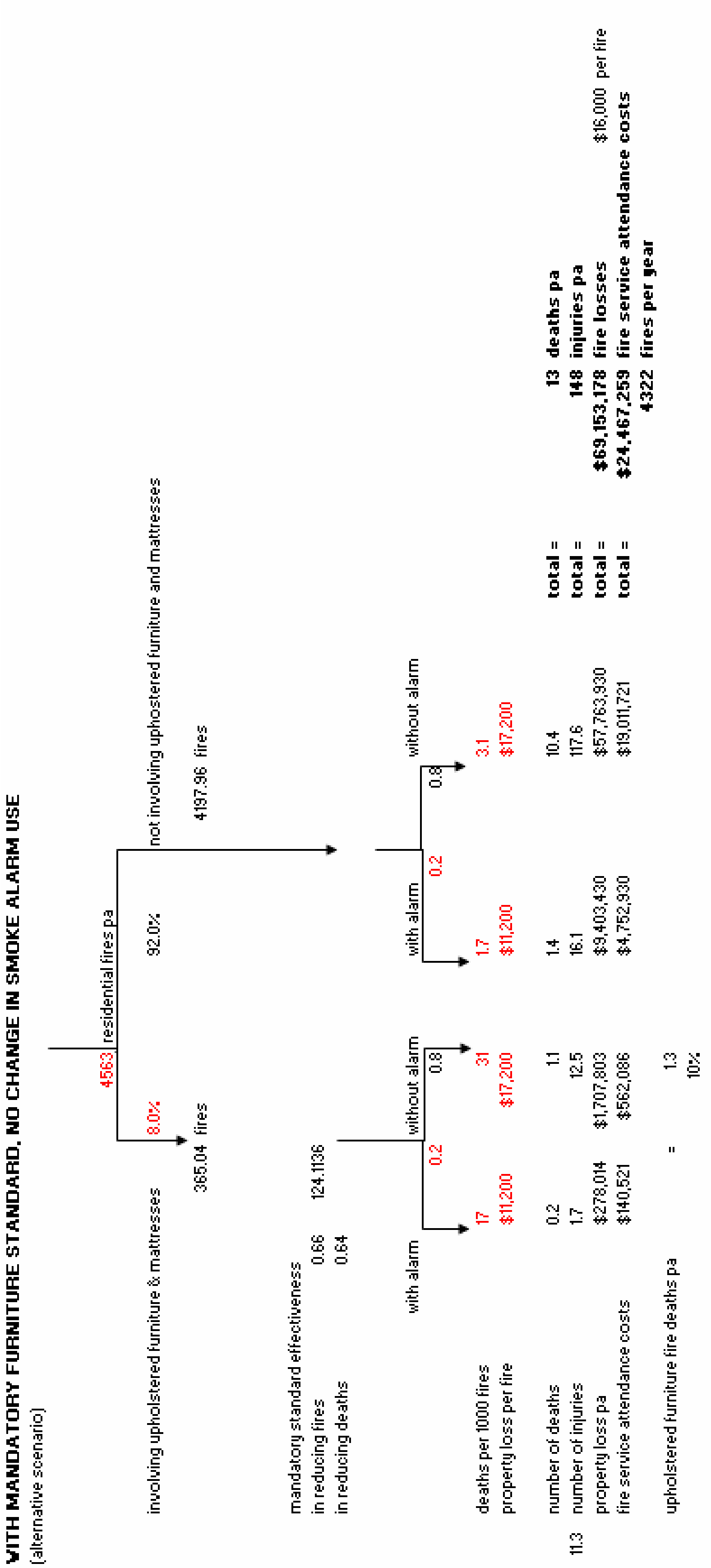

Figure 8-6. Effectiveness model for mandatory standards (alternative scenario)

The calculated cost per life saved for this alternative scenario is shown in Table 8-2, assuming the added consumer costs amount to $30 per household per year. Again, the results do not support mandatory introduction of new standards. This could change if the added cost to the consumer could be significantly reduced however, this is still before deducting gains in lives saved in any case from wider use of smoke alarms, and possible declines in the rate of smoking.

Table 8-2. Calculated cost per life saved (alternative scenario)

Discount rate (%)	**Rate of furniture replacement per year**		
	4%	**6%**	**8%**
0	$4,782,153	$5,748,277	$6,766,473
2	$5,245,579	$6,233,474	$7,268,343
3	$5,503,763	$6,502,703	$7,546,009
5	$6,071,213	**$7,091,687**	$8,151,325
7	$6,701,636	$7,741,781	$8,816,105
10	$7,745,600	$8,809,430	$9,900,869

8.9. Comparisons with results of others, and results for alternative fire protection measures

Wade and Duncan (2000) previously studied the cost-effectiveness of domestic fire sprinklers and smoke alarms in New Zealand dwellings. Beever and Britton (1999) also carried out a similar study previously for Australia. Table 8-3 compares the cost per life saved results for upholstered furniture with those obtained from these two studies for alternative forms of fire safety protection. A recently developed low-cost retrofitted sprinkler system for private dwellings has the potential to dramatically increase the cost effectiveness of home sprinklers.

Miller and Levy (2000) reviewed cost-outcome analyses in injury prevention and control in the US, using cost per quality adjusted life year saved (QALY) and benefit-to-cost ratios as the outcome measures. The interventions relevant to this study were smoke detector purchase installation and maintenance and reducing the ignition potential of cigarettes, which each had a cost per QALY of less than zero. The benefit-to-cost ratio of the smoke detectors was estimated at US$15 of benefit for every dollar spent; while for reducing the ignition potential of cigarettes Miller and Levy estimated US$505 of benefit for every dollar spent.

Table 8-3. Comparison of cost per live saved for alternative fire protection options

Fire protection measure	Expected deaths p.a.	$ cost per life saved	Reference
Home sprinklers (combined with domestic plumbing)	8.5	891,000*	Wade & Duncan (2000)
Smoke alarms, long-life battery operated, single-point x 4	12.7	2,400,000	Wade & Duncan (2000)
Smoke alarms, battery operated, single-point x 4 + home sprinklers	5.7	2,800,000*	Wade & Duncan (2000)
Smoke alarms, battery operated, single-point x 4	14.2	3,000,000	Wade & Duncan (2000)
Regulation of upholstered furniture and bedding (5% discount rate, 6% furniture replacement)	**15**	**9,842,000**	**this study**
NZS 4515:1995 sprinkler system	6.1	34,800,000*	Wade & Duncan (2000)
Upholstered furniture flammability legislation costing A$50 per household to introduce		A$10,000,000	Beever & Britton (1999)
Mattress flammability legislation		A$30,000,000	Beever & Britton (1999)

* assumed immediate effectiveness ie: gradual penetration into housing stock not considered and therefore no discounting of future benefits.

9. CONCLUSION

The introduction of mandatory standards for the ignition resistance of upholstered furniture and mattresses in New Zealand is unlikely to be cost-effective in terms of the currently adopted value of a statistical life in New Zealand ($2.6 million) and commonly accepted public-sector discount rates. Assuming a medium rate of furniture replacement (6%), an annual additional cost per household of the order of $30, and a discount rate of 5%, the expected cost per life saved is calculated to be around $9.8 million dollars.

The results are insensitive to the assumed value of the initial and ongoing regulatory costs.

Some of the reasons for the lower apparent cost-effectiveness compared to the analysis of the cost-effectiveness of regulations introduced in the United Kingdom in 1988 include:

- The statistical value of human life for New Zealand as used in this study (and as used by the LTSA) is only about one-fourth of that adopted for recent cost-benefit studies in the United Kingdom and in the United States. In fact if the statistical value of human life were taken as $10 million rather than $2.6 million, then as shown in Figure 8-2, the regulation of furniture flammability might just be justifiable as providing a net benefit to New Zealand. However, this is before deducting gains in lives saved in any case from wider use of smoke alarms, and possible declines in the rate of smoking.

- The number of reported fire deaths per 1000 house fires are significantly lower in New Zealand compared to the United Kingdom (refer Figure 7-1).

- The UK analysts assume a substantially greater reduction in fire deaths (70%) from the introduction of the new standards than is assumed in this report (30%). Also they attribute no credit to smoke alarms for the fall in fire deaths in the UK, although some of the data they report for the USA suggest, at least visually, that smoke alarms have had a significant impact there.

- The estimated added cost to households buying furniture in New Zealand is substantially higher than that used in the DTI study for the United Kingdom. The UK analyses have the benefit of actual experience of the new standards. Also, there are economies of scale possible in the British and European markets unattainable in Australasia. Even so, it is not easy to reconcile the numbers used in the UK studies with the information provided to us by New Zealand manufacturers and distributors.

To improve the cost-effectiveness of mandatory standards for upholstered furniture and mattresses in New Zealand, the additional average cost of fire-retardant treatment or other means to achieve the required level of performance must be reduced to about $10 or less per household per year, or about $150 on the cost of an average lounge suite purchase.

To reduce uncertainties in the assumptions required for this cost-benefit study, more detailed data on the number of fire incidents, deaths and injuries and the extent that upholstered furniture and mattresses contributed to them would be beneficial. More accurate costing of ‘fire-retardant’ upholstered furniture in New Zealand (as borne by the consumer) would also be helpful.

10.REFERENCES

Ashby, K., & Routley, V. (1998). Enforcing legislative and regulatory injury prevention strategies. *Hazard, 34*(March).

ASTM International (2002a). *Test methods for cigarette ignition resistance of mock-up furniture assemblies (ASTM E 1352).* West Conshohocken, PA: ASTM International.

ASTM International (1990). *Test methods for cigarette ignition resistance of components of upholstered furniture (ASTM E 1353).* West Conshohocken, PA: ASTM International.

ASTM *International* (2002b). *Standard fire test method for fire testing real scale furniture items (ASTM E 1537*). West Conshohocken, PA: ASTM International.

ASTM *International* (2001a). *Test method for determining the heat release rate of upholstered and mattress components or composites using a bench-scale oxygen calorimeter (ASTM E 1474).* West Conshohocken, PA: ASTM International.

ASTM International (*2001b*). *Test method for fire testing real scale mattresses (ASTM E 1590).* West Conshohocken, PA: ASTM International.

Aust, R. (2001). *Fires in the home: Findings from the 2000 British Crime Survey* (Bulletin 13/01). London: Department for Transport, Local Government and the Regions.

Babrauskas, V., Harris, R. H., Gann, R. G., Levin, B. C., Lee, B. T., Peacock, R. D., Paabo, M., Twilley, W., Yoklavich, M. F., & Clark, H. M. (1988). *Fire Hazard Comparison of Fire-Retarded and Non-Fire-Retarded Products* (Special Publication 749). Gaithersburg: National Bureau of Standards.

Barillo, D. J., Brigham, P. A., Kayden, D. A., Heck, R. T., & McManus, A. T. (2000). The fire-safe cigarette: A burn prevention tool. *Journal of Burn Care and Rehabilitation, 21*, 164-170.

Baron, E. (2002). Toxic troublemaker. *Canadian Geographic, 122*(3), 26.

Beever, P. and Britton, M. (1999). *Research into Cost-Effective Fire Safety Measures for Residential Buildings.* Melbourne, Australia: Centre for Environmental Safety and Risk Engineering.

Belles, D. W. (1992). Designing fire safe interiors. *NFPA Journal* (July/August), 33-38.

Botkin, J. R. (1988). The fire-safe cigarette. *Journal of the American Medical Association, 260*, 226-229.

Brereton, S. (1990). *Analysis of injury and death in New Zealand from ignition of textile covered furniture and its relevance to injury prevention strategies.* Unpublished master's thesis, Consumer and Applied Sciences. Dunedin NZ: University of Otago.

Brereton, S., and Laing, R. (1992). Analysis of injury and death from burning upholstered furniture. *New Zealand Medical Journal, 105*, 429-432.

British Standards Institution (1990). *Methods of test for assessment of the ignitability of upholstered seating by smouldering and flaming ignition sources (BS 5852:1990).* London: British Standards Institution.

British Standards Institution (1995). *Resistance to ignition of upholstered furniture for non-domestic seating by testing composites (BS 7176:1995).* London: British Standards Institution.

British Standards Institution (BSI) (1996). *Assessment of ignitability of mattresses, upholstered divans and upholstered bed bases with flaming types of primary and secondary sources of ignition. (BS 6807:1996).* London: British Standards Institution.

Bureau of Home Furnishings and Thermal Insulation (BHFTI) (1980). *Requirements, test procedures, and apparatus for testing the flame retardance of upholstered furniture.* (TB 116). North Highlands, CA: BHFTI.

Bureau of Home Furnishings and Thermal Insulation (BHFTI) (2000a). *Test Procedures, and Apparatus for Testing the Flame Retardancy of Resilient Filling Materials Used in Upholstered Furniture.* (TB 117). North Highlands, CA: BHFTI.

Bureau of Home Furnishings and Thermal Insulation (BHFTI) (2000b). *Mission statement.* Available: http://www.bhfti.ca.gov/aboutbhfti.htm .

Bureau of Home Furnishings and Thermal Insulation (BHFTI) (1993). *Flammability Test Procedure for Mattresses for Use in Public Occupancies.* (TB 129). North Highlands, CA: BHFTI.

Bureau of Home Furnishings and Thermal Insulation (BHFTI) (1991). *Flammability Test Procedure for Seating Furniture for Use in Public Occupancies.* (TB 133). North Highlands, CA: BHFTI.

Business and Economic Research Limited (BERL) (2002). *An Economic Assessment of Industrial Fires in New Zealand.* Research Report Number 28. New Zealand Fire Service Commission.

Chen, Flora (2001). *Radiant Ignition of New Zealand Upholstered Furniture Composites.* (Fire Engineering Research Report 01/2). Christchurch NZ: University of Canterbury.

Coles, Andrew (2001). *Flammability of Upholstered Furniture using the Cone Calorimeter,* (Fire Engineering Research Report 01/1), Christchurch NZ: University of Canterbury.

Clarke III, F. B., & Ottoson, J. (1983). Fire death scenarios and firesafety planning. In C. Rapkin (Ed.), *The Social and Economic Consequences of Residential Fires* (pp. 91-99): DC Heath & Company.

Consumer Product Safety Commission (CPSC) (1997). *Upholstered Furniture Flammability: Regulatory Options for Small Open Flame & Smoking Material Ignited Fires.* Bethesda, MD USA: CPSC.

Consumer Product Safety Commission (CPSC) (1998). *Federal Flammability Standard Part 1632 - Standard For The Flammability of Mattresses and Mattress Pads (FF 4-72, Amended).* Bethesda, MD USA: CPSC.

Consumer Product Safety Commission (CPSC) (2001a). *Briefing Package on Upholstered Furniture Flammability: Regulatory Options.* Bethesda, MD USA: CPSC.

Consumer Product Safety Commission (CPSC) (2001b). *News from CPSC.* Available from http://www.cpsc.gov/cpscpub/prerel/prhtml02/02001.html.

Corrao, M., Guindon, G., Sharma, N., & Shokoohi, D. (Eds.). (2000). *Tobacco control country profiles*. Atlanta, GA: American Cancer Society.

Denize, Hamish (2000). *The combustion behaviour of upholstered furniture materials in New Zealand.* (Fire Engineering Research Report 00/4). Christchurch NZ: University of Canterbury.

Department of Trade and Industry (DTI). (2000) *Effectiveness of the Furniture and Furnishings (Fire) (Safety) Regulations 1988.* London: DTI.

DiGuiseppi, C., Roberts, I., Wade, A., Sculpher, M., Edwards, P., Godward, C., Pan, H., & Slater, S. (2002). Incidence of fires and related injuries after giving out free smoke alarms: Cluster randomised controlled trial. *British Medical Journal*, 325, 995-997.

Driscoll, F., Harris, V., Levi, M., Mason, T., Meldrum, G., Peacock, L., & Young, S. (not dated). *Safe as houses: The report of the Community Fire Safety Task Force.* London: Home Office.

Drummond M.F., O'Brien B., Stoddart G. L., & Torrance G.W., (1997). Methods *for the Economic Evaluation of Health Care Programmes* (2nd edition), Oxford UK: Oxford Medical Publications.

Duncanson, M., Ormsby, C., Reid, P., Langley, J., & Woodward, A. (2001a). *Fire incidents resulting in deaths of New Zealand children aged under 15 years 1991-1997* (Research Report). Wellington: New Zealand Fire Service Commission.

Duncanson, M., Ormsby, C., Reid, P., Langley, J., & Woodward, A. (2001b). *Fire incidents resulting in deaths of New Zealanders aged 15-64 years 1991-1997* (Research Report). Wellington: New Zealand Fire Service Commission.

Duncanson, M., Ormsby, C., Reid, P., Langley, J., & Woodward, A. (2001c). *Fire incidents resulting in deaths of New Zealanders aged 65 and older 1991-1997.* (Research Report). Wellington: New Zealand Fire Service Commission.

Emsley, A.M., Lim, L., and Stevens, G.C. (2002). International fire statistics and the potential benefits of fire counter-measures. In: *Proceedings of Flame Retardants Conference 2002*. London: Interscience Communications Ltd.

Enright, Tony (1999). *Heat release and the combustion behaviour of upholstered furniture,* (Fire Engineering Research Report 99/17), Christchurch NZ: University of Canterbury.

Enright, P. A., Fleischmann, C. M. & Vandervelde, P (2001) CBUF Model II Applied to Exemplary New Zealand Furniture (NZ-CBUF), *Fire and Materials*, *25*, 105-115.

Farquhar, B. J. (1998). What makes regulation work? *Injury Prevention, 4,* 253-262.

Federal Emergency Management Agency. (1999). *Fire in the United States 1987-1996* (11th ed.). Washington: United States Fire Administration.

Firestone, James (1999). *An analysis of furniture heat release rates by the Nordtest* (Fire Engineering Research Report 99/7). Christchurch: University of Canterbury.

Haddon, W., & Baker, S. P. (1981). Injury control. In D. W. Clark & B. MacMahon (Eds.), *Preventive and Community Medicine* (2nd ed., pp. 109 -140). Boston: Little Brown & Company.

Hall, J. R. J. (1997). Fire risk analysis. In A. E. Cote & J. L. Linville & M.-K. Appy & R. P. Benedetti & R. M. Cote & M. H. Curtis & C. C. Grant & J. R. J. Hall & W. D. Moore & P. A. Powell & R. E. Solomon & G. O. Tokle & R. J. Vondrasek (Eds.), *Fire Protection Handbook* (18th ed., pp. 11/78-11/88). Quincy: National Fire Protection Association.

Hall, J R. (2001). Targeting upholstered furniture fires. *NFPA Journal* March/April, 57-60.

Hall, J. R., & Harwood, B. (1995). Smoke or burns: Which is deadlier? *NFPA Journal, 89*, 41-43.

Hamilton, R. 2002. Personal Communication. AWTA, Australia.

Her Majesty's Stationery Office (HMSO). (1988). *Consumer protection: The Furnishings and (Fire) (Safety) Regulations 1988, No. 1324, and The Furniture and (Fire) (Safety) (Amendment) Regulations 1989, No. 2358.* London: HMSO.

Human Resources Development Canada. (2000). *Fire losses in Canada Annual Report*. http://info.load-otea.hrdc-drhc.gc.ca/fire_prevention/fire_losses/annual.shtml

Ingham, P.E. Goddard, J.M. and Gruber, A.L. (1979). *The influence of fabric coverings on the flammability of polyurethane upholstered furniture*. Communication No. 66. Christchurch: Wool Research Organisation of New Zealand.

Ingham, P.E. Goddard, J.M. and Gruber, A.L. (1981a*). Part II, The flammability of polyurethane upholstered furniture: Tests with larger ignition sources and "improved" foams.* Communication No. 72. Christchurch: Wool Research Organisation of New Zealand.

Ingham, P.E. Goddard, J.M. and Gruber, A.L. (1981b). *Part III, House fire tests.* Communication No. 73. Christchurch: Wool Research Organisation of New Zealand.

Ingham, P.E. and Edwards, R.J. (1984). *The flammability of bedding materials.* Communication No. 88. Christchurch: Wool Research Organisation of New Zealand.

Irwin, K. (1997). *Domestic fire hazard in New Zealand* (Fire engineering research report 97/5). Christchurch: University of Canterbury.

International Organization for Standardization (ISO). (1987). *Furniture - Assessment of the ignitability of furniture Part 1 Ignition source smouldering cigarette. ISO 8191:1*, Geneva: ISO.

International Organization for Standardization (ISO). (1988). *Furniture - Assessment of the ignitability of Furniture Part 2 Ignition source match equivalent flame. ISO 8191:281*, Geneva: ISO.

International Organization for Standardization (ISO). (1993). *Fire tests – Reaction to fire – Rate of heat release from building products (cone method) ISO 5660*, Geneva: ISO.

Krasny, J.F, Parker, W.J. and Babrauskas, V. (2001). *Fire behaviour of upholstered furniture and mattresses.* New York: William Andrew Publishing.

Land Transport Safety Authority (Sept. 2000). *The social cost of road crashes and injuries: June 2000 Update.*

McLoughlin, E., Clarke, N., Stahl, K., & Crawford, J. D. (1998). One pediatric burn unit's experience with sleepwear related injuries. *Injury Prevention, 4,* 313-316.

McLoughlin, E., Langley, J. D., & Laing, R. M. (1986). Prevention of children's burns: Legislation and fabric flammability. *New Zealand Medical Journal, 99,* 804-807.

Marshall, S. W., Runyan, C. W., Bangdiwala, S. I., Linzer, M. A., Sacks, J. J., & Butts, J. D. (1998). Fatal residential fires: Who dies and who survives? *Journal of the American Medical Association, 279,* 1633-1637.

Miller, T and Guria, J. (1991). *The value of statistical life in New Zealand. Market research on road safety.* Wellington: Land Transport Division.

Miller, T., & Levy, D. (2000). Cost-outcome analysis in injury prevention and control: Eighty-four recent estimates for the United States. *Medical Care, 38*, 562-582.

National Bureau of Standards (NBS). (1979). Technical Note 1101. *Decision analysis of strategies for reducing upholstered furniture fire losses (Technical Note 1101). Gaithersburg, MD,* USA: Department of Commerce.

New Zealand Fire Service. (2002). *Emergency incident statistics: Edition for the 2000/2000 corporate* year. Wellington: New Zealand Fire Service.

National Fire Protection Association (NFPA). (2000). *Life safety code* (NFPA 101). Quincy, MA: NFPA.

National Fire Protection Association (NFPA). (1986). *Methods of tests and classification system for cigarette ignition resistance of components of upholstered furniture* (NFPA 260). Quincy, MA: NFPA.

National Fire Protection Association (NFPA). (1998). *Method of test for determining resistance of mock-up upholstered furniture material assemblies to ignition by smouldering cigarettes* (NFPA 261). Quincy, MA: NFPA.

National Fire Protection Association (NFPA). (1995). *Standard method of test of heat release rates of upholstered furniture components or composites and mattresses using an oxygen consumption calorimeter* (NFPA 264A). Quincy, MA: NFPA.

National Fire Protection Association (NFPA). (1998). *Standard method of test for fire characteristics of upholstered furniture exposed to flaming ignition source* (NFPA 266). Quincy, MA: NFPA.

National Fire Protection Association (NFPA). (1998) *Standard method of test for fire characteristics of mattresses and bedding assemblies exposed to flaming ignition source* (NFPA 267). Quincy, MA: NFPA.

Nordtest (1991). *Upholstered furniture: Burning behaviour - Full scale test Edition 2, Approved 1991-05* (NT FIRE 032). Spool, Finland: Author.

Office of the Deputy Prime Minister. (2002). *Fire statistics, Estimates United Kingdom, 2001*. London: Office of the Deputy Prime Minister.

Oliver, L.E. (2001). An *economic analysis of the draft small open-flame regulation of upholstered furniture.* Glassman-Oliver Economic Consultants.

Pless, I. B. (1998). Product safety: getting tough or being nice? [editorial]. *Injury Prevention, 4,* 245-246.

Prager, F.H. (1989). The United Kingdom upholstered furniture fire safety regulations 1988 – A challenge to fibres. *Journal of Fire Sciences, 7,* 291-309.

Richardson, L. R. (2001). What fire statistics tell us about our fire and building codes for housing and small buildings and fire risk for occupants of those structures. *Fire and Materials, 25*, 255-271.

Runyan, C. W., Bangdiwala, S. I., Linzer, M. A., Sacks, J. J., & Butts, J. (1992). Risk factors for fatal residential fires. *New England Journal of Medicine*, 327, 859-863

Sainrat, A., Hognon, B., Jouany, J.M. (1995). Research of critical levels in terms of people's health due to the fire effluents production from combustion of upholstered furniture. Ministère de l'Économie, des Finances et de l'Industrie (DGCCRF). France.

Standards New Zealand (SNZ). (1984). *Fire tests for furniture, Part 1: Methods of test for the ignitability by smokers' materials of upholstered composites for seating.* (NZS 8709). Wellington NZ: Standards New Zealand.

Standards New Zealand (SNZ). (1996). *Specification for burning behaviour of upholstered furniture, Part 1: Upholstered furniture, Part 1: Upholstered material for domestic furniture – smouldering ignitability* (AS/NZS 4088.1). Wellington NZ: Standards New Zealand.

Standards New Zealand. (SNZ). (1998a). Furniture – *Assessment of the ignitability of upholstered furniture. Part 1: Ignition source – Smouldering cigarette* (AS/NZS 3744.1). Wellington, NZ: Standards New Zealand.

Standards New Zealand (SNZ). (1998b). *Furniture* – Assessment *of the ignitability of upholstered furniture. Part 2: Ignition source – match-flame equivalent* (AS/NZS 3744.2). Wellington, NZ: Standards New Zealand.

Standards New Zealand (SNZ). (1998c). *Furniture – Assessment of the ignitability of upholstered furniture. Part 3: Ignition source – nominal 160 mL/min gas flame and nominal 350 mL/min gas flame* (AS/NZS 3744.3). Wellington, NZ: Standards New Zealand.

Sundström, Björn, ed. (1995). *CBUF – Fire safety of upholstered furniture – the final report on the CBUF research*, London: Interscience Communications Ltd.

Wade, C. A., & Duncan, C. R. (2000). *Cost-effective fire safety measures for residential buildings in New Zealand.* (Study Report 93). Judgeford: Building Research Association of New Zealand.

Walker, A., Maher, J., Coulthard, M., Goddard, E., & Thomas, M. (2001). *Living in Britain: Results from the 2000/1 general household survey*. London: The Stationery Office

Walsh, K. (2000). *Eight deemed safe for furniture*. *Chemical Week, 162,* 39.

Wong, C. R. (2001). *Contribution of upholstered furniture to residential fire fatalities in New Zealand.* (Fire Engineering Research Report 2001/9). Christchurch: University of Canterbury.

APPENDIX A: THE FURNITURE INDUSTRY

The Furniture Industry
Sales, production costs, and estimated costs of making upholstered furniture more fire-resistant

Data-sources:

i) Household Economic Survey (HES). This Statistics New Zealand survey, annual until recently, provides information on bought furniture by private households, including the proportion of households that have bought the main furniture types within the past year. A detailed tabulation has been purchased from Statistics New Zealand for the year 2000/01.

ii) Annual industry sales and imports of furniture. Compiled by Statistics New Zealand. (See for example quarterly releases on Manufacturing – Table 16 Furniture and Other Manufacturing). Also available from Business New Zealand, the organisation representing businesses and employers.

iii) Industry sources. A number of people involved in the manufacture and sale in New Zealand of upholstered furniture, and of materials used in the manufacture of furniture, have provided information on the likely costs involved in making furniture more fire-resistant.

A: Manufacturing

In the year ending March 2002; Furniture and Other Manufacturing[ii] –

Operating income	$1,840 million
Purchases and operating expenditure	$1,232 million
Salaries and Wages	$ 385 million

B: Retail purchases

The numbers on household spending in the following table are derived from the Household Economic Survey. Estimates are subject to sampling error, (95% confidence intervals for 'Furniture Items' sales being approximately ± 10%).

Expenditure on furniture items by private households

Excl. service costs. GST included.

[ii] Furniture manufacturing accounted for 66% of the 'furniture and other manufacturing' total in 1995/96. But 78% of sales to household final consumption.

March or June years	Aggregate annual expenditure. All private households $ million	Average annual expenditure per household $	Percentage of households reporting Expenditure during year. %	Average annual expenditure per reporting household $	Implicit number of private households
1996/97	571	$485	29.2	$1,661	1,177,000
1997/98	609	$521	29.5	$1,768	1,167,000
2000/01	783	$574	30.0	$1,912	1,365,000

Of course, not all of this expenditure is on upholstered furniture.

Additional detail at commodity level was obtained for 2000/01. The two most important items are 2301: Suites (lounge); and 2316: Bed components (mattresses, bases, etc.)

Item Number	Aggregate annual expenditure. All private households $ million	Average annual expenditure per household $	Percentage of households reporting Expenditure on item %	Average annual expenditure per reporting household $
2301 suites (lounge)	190	$141	4.8	$2,933
2316 bed components (mattresses, bases, etc.)	164	$120	8.7	$1,378

Other items have the following 'percentages reporting expenditure'. That is, the percentage of surveyed households reporting expenditure during the year on the designated item.

2304	Chairs (lounge), rocking chairs	1.0%
2307	Sofas, divans, couches	2.2%
2334	Second-hand lounge suites	1.5%
2302	Suites (bedroom), waterbed suites	1.0%

These could lift the proportions reporting expenditure on a reasonably substantial item of furniture in the 'lounge' and 'bedroom' areas, respectively, to perhaps 6% to 8% for lounge furniture, and around 10% for bedroom furniture. Of total spending in these two categories about 56% is on 'lounge' furniture and 44% on 'bedroom' furniture.

C: Breakdown of Retail Cost

Taking the $2933 and $1378 in the table above as the starting points, the component costs building up these retail prices are constructed as follows. (A small sample of four furniture retailers quoted us typical prices of $2,200, $2,500, $2,500, and $2,700 for a lounge suite, including GST.)

	2301 (Lounge suite)	2316 (Mattresses, bases)
Average retail purchase	$2,933	$1,378
Less GST	-$ 326	-$ 153
Store price less GST	$2,607	$1,225
Less wholesale/retail mark-up - assumed 39.4%[iii]	- $1,027	-$ 483
'Factory door'	$1,580	$ 742

Focusing on the lounge suite example, informants gave us the following approximate breakdown of factory costs for upholstered furniture. These will of course vary with quality and type of furniture, but the numbers below are claimed to be representative. Percentages are of 'factory door' costs.

	2302 (Lounge suite)	
Labour costs	22%	
Operating surplus, etc	8%	
Wood and products	6.4%	
Metal products	4%	
Textiles	18-22%	$ 316
Chemicals, plastics, rubber, etc.	18%	$ 284
Transport	5%	
Admin and fixed overheads	9.5%	
Selling expenses	5%	
Packaging, rebates and advertising	2.0% to 2.5%	

That is, textiles and chemicals, etc (mainly foam) make up nearly 40% of manufacturing cost.

[iii] An industry source reports a retail mark-up of 90%, including GST, as standard. Mark-ups on imported furniture are higher, between 120% and 130%. Another suggests 65%, excluding GST, which comes to 85.6% including GST. Using this 65%, the mark-up is 39.4% of store price, excluding GST (65/165).

We do not have information in such detail on mattresses, but are told that the foam content of an innersprung mattress is approximately 10% of the raw material cost. The main additional cost for mattresses would be in flame-resistant fabric. Extra costs in total could amount, it was claimed, to between \$50 and \$100.

D: Effect on costs, and retail prices, of using more fire-resistant materials

Unfortunately it has not been possible to get exact estimates of the extra costs which would be incurred in using more fire-resistant materials. Industry sources estimate that they would be substantial. The calculations are complex because of the different options available in terms of using foams of different density, and different fabric backings. The discussion below is based on information obtained from a half-dozen industry sources. We cannot vouch for the accuracy of the information, but those who supplied it were clearly doing so in good faith.

Foam:

One company estimated typical foam volumes to be about 0.75 m^3 for a lounge suite. They consider that using foam that can meet British furniture flammability standards would mean a 64-65% increase in foam costs. Current foam content costs of a lounge chair would vary from \$25 up to \$150, depending on complexity, and for a suite from \$100 to \$600. The manufacturing cost increase for a suite would then range from about \$65 to \$380.

Another source estimated that foam costs would increase 107%; and that as foam costs are 15% of total for a typical budget lounge suite, this would translate into an increase of just over 15% at the factory door. That is, \$237 on the numbers in the earlier table.

A third informant reported that a typical foam pack for a suite, of 0.4 (perhaps 0.5) m^3, on present specifications costs between \$160 and \$180.

A fourth informant considered that a chair would have a foam volume of 0.17 m^3, a sofa 0.41 m^3, and so a two-chair plus settee suite a total of 0.75 m^3. He pointed out that any cost increase in raw materials would have added to it ‘absorption costs’ that is manufacturers’ overheads of perhaps 70%, and then a retail mark-up of around 65% plus GST.

Summing up this fairly diverse information, the calculations for a ‘typical’ lounge suite, if there be such, might be as follows -

- Volume of 0.5 to 0.75 m^3 of foam
- Current cost of foam corresponding to these volumes: \$170 to \$255
- Cost increase to meet top British standard would range from 65% to 105%
- That is, \$ increases ranging from \$110 to \$165 and \$180 to \$270.

Fabric: One estimate is that ‘fire-proofed’ fabric would increase in cost by approximately \$2.50 per metre – or \$50-\$75 for a lounge suite. Another was “at least \$20”.

Overall: In total, this reasoning suggests that if both more fire-resistant fabrics and more fire resistant foams are required, the overall manufacturing cost increase for a ‘typical’ lounge suite would in general be in the range of between \$160 and \$350, centred around \$225.

To these should be added retail margins of 65%, excluding GST. This would mean an increase on a lounge suite (of retail value around $3000) ranging from $265 to $575, about a ‘central’ value of $370.

Assuming a purchase of this size only every 15 years, the approximate annual equivalent over all households ranges from $17.60 to $38.50, with a ‘middle’ value of $24.75.

There would also be some extra costs for other upholstered furniture, not part of a lounge suite, and for mattresses. Overall, it has seemed reasonable to assume an extra cost per household averaging $30 per year, ranging from $20 to $40 per year. The total annual cost, for 1.2 million households would then be $24 million through $36 million to $48 million. This is on a 15-year purchasing cycle. For a shorter purchasing cycle the annual equivalent cost would be higher, and lower for a longer cycle. Put another way, at each major purchase of a new lounge suite, the range assumed for the extra costs of meeting UK standards is $300/$450/$600.

Margins: These calculations assume a fixed retail margin (and also a constant mark-up at manufacturing level). In general, our informants think this is what would happen. Economic theory would suggest, however, that some of any cost increase would be pushed back on to manufacturers and retailers, rather than all passed on to consumers. If demand is relatively price-inelastic, however, the larger part of any cost increase could be passed on.