CHARACTERISING A DESIGN FIRE FOR A DELIBERATELY LIT FIRE SCENARIO

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Abstract

Deliberately lit fires make up over 15% of all fires in New Zealand buildings yet they are typically omitted from the design brief for fire engineering purposes. This report examines where deliberately lit fires should be included as part of the fire engineering design by examination of all deliberately lit fires recorded in the New Zealand Fire Incident Reporting System (NZ FIRS) between the years 1996 and 2006.

The main types of buildings identified where consideration of deliberately lit fires within the design would provide benefits are:

- Prisons
- Psychiatric institutions
- Schools
- Crowd activities
- Attached accommodation

The report also examined what is required to include deliberately lit fires as part of the design process. Based on an analysis of the fire incident statistics, the majority of deliberately lit fires are the result of unplanned activities and existing design fires will be adequate. Two critical fire scenarios were identified as exceeding these requirements, the ignition of multiple fires and the use of accelerants. Greater life safety benefits are obtained by considering accelerants.

In the case of multiple fires, each fire is likely to be within the capabilities of a fire engineered building however a number of such fires may overwhelm the fire protection features of a building. A number of issues for the fire engineer to consider are briefly discussed. In the case of accelerants, a number of experiments were completed to characterise the heat release rate and species production of a Molotov cocktail based on the fuel volume used. A second round of experiments extended this work by examining the scenario where a Molotov cocktail containing 1000 milliliters of petrol was deployed within a stairwell.

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Nomenclature

Symbol	Description	Units
a_n	Multiple fire factor	-
C_{vent}	Ventilation factor.	-
ΔH_c	Heat of combustion for petrol	MJ/kg
k	Wall factor	-
k_{sm}	Constant for the stair material	-
k_{loc}	Constant for the target location	-
$\dot{m}$	Mass loss rate of the fuel	kg/s
$\dot{m}_{Air}$	Mass flow rate of air in exhaust duct.	g/s
$\dot{m}_{CO}$	Mass flow rate of carbon monoxide	g/s
$\dot{m}_{CO2}$	Mass flow rate of carbon dioxide.	g/s
$\dot{m}_s$	Mass flow rate of the smoke plume for a single fire.	kg/s
$\dot{m}_{tot,n}$	Total mass flow rate of the smoke for ‘n’ fires	kg/s
n	Number of fires	-
M_{Air}	Molar mass of Air.	29 g/mol
M_{CO}	Molar mass of Carbon monoxide	28 g/mol
M_{CO2}	Molar mass of Carbon dioxide.	44 g/mol
$\dot{Q}$	Heat release rate of the fire	kW
$\dot{Q}_c$	Convective heat release rate of a single fire	kW
RSET	Required Safe Egress Time	min
t	Time after ignition	s
t_{det}	Detection time	min
t_{mov}	Movement time	min
t_{pk}	Time to peak heat release rate	s
t_{pre}	Pre-movement time	min
V	Volume of petrol used	mL
X_{CO}	Molar fraction of carbon monoxide in exhaust duct.	-

Nomenclature Cont.

Symbol	Description	Units
X_{CO2}	Molar fraction of carbon dioxide in exhaust duct.	-
y_{CO}	Yield of carbon monoxide	g/g fuel
$y_{CO,\infty}$	Yield of carbon monoxide under well ventilated conditions.	g/g fuel
Z	Height of rise from the fuel package to the bottom of the Smoke layer.	m
α	Correlation coefficients for the fuel package	-
β	Correlation coefficients for the fuel package	-
β_{inst}	Correction coefficient for instrument	-
ζ	Correlation coefficients for the fuel package	-
Φ	Equivalence ratio.	-

1.0 Introduction

All fires are started through one of three paths. They may be started through natural circumstances such as a lightning strike, accidental means including the failure of an electrical circuit or the buildup of static electricity or, they may be deliberately started by the conscious actions of an individual. Within a structure, natural fire causes are rare. In the 2004-05 year the New Zealand Fire Service coded only 1.5% of structure fires as 'Extreme conditions' with another 9.0% coded as 'Other supposed causes'[1] The majority of fires are considered accidental and this description covers causes such as 'Operating failure', 'Design, construction, installation faults' and 'Mechanical failure, malfunction' and the 'Carelessness' and 'Recklessness' categories. Collectively, accidental causes account for 73.7% of all structure fires. The remaining 15.6% of fires are categorized as deliberately lit. This is summarised below as Figure 1.1.

Over the years there has been a large body of work completed by the fire engineering community characterising a wide range of common fire scenarios, from the ignition of upholstered furniture to the ignition of electrical appliances such as computers. This work has been largely targeted towards accidental fire scenarios.

Over the last thirty years there has also been a significant amount of effort put into the development of strategies to combat arson, from education programs in schools[2] through to improvements in investigation techniques[3] and tools[4]. In the UK, the Arson Control Forum (ACF) was established in 2000[5] to coordinate a national response to arson, while, in the US a number of organizations such as the United States Fire Administration (USFA) and Office of Juvenile Justice and Delinquency Prevention (OJJDP) are involved in programs to combat arson. The fire engineering community has provided assistance through fire investigation training programs[6], however there appears to have been little work completed on addressing deliberately lit fires from a design perspective.

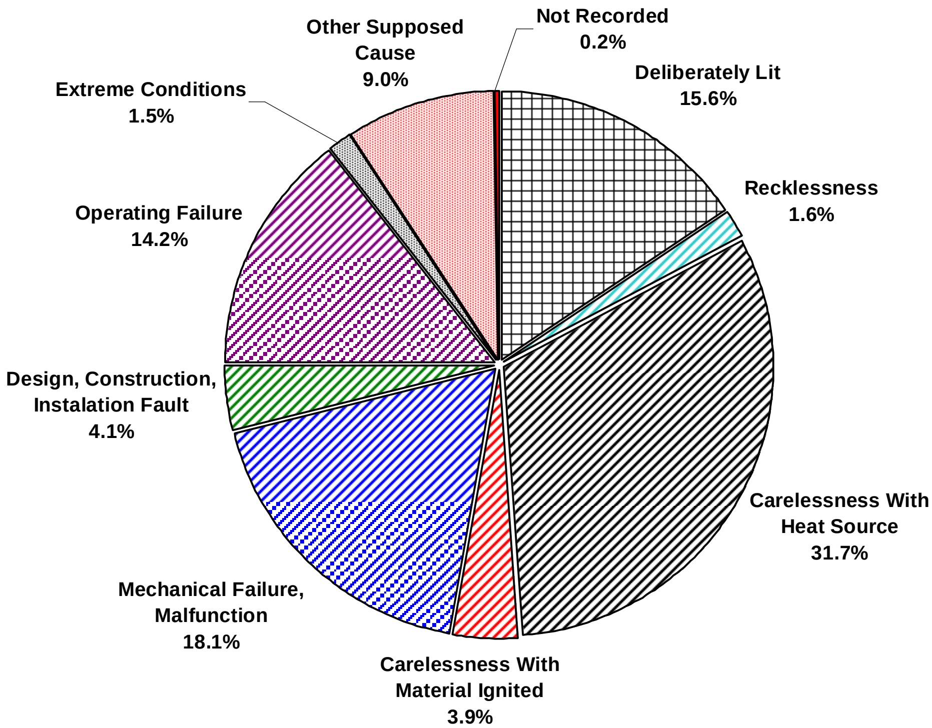

Figure 1.1: Cause of structure fires in New Zealand during the 2004-05 year. (Source: FIRS incident statistics).

1.1 Report Structure

This report is broken up into seven chapters, each covering a different part of the deliberately lit fire problem. Chapter one introduces a number of terms commonly used to describe fires that have been deliberately lit. It then proceeds to critique the current design philosophy and to define what will be considered as a reasonable deliberately lit fire case for the rest of this report. Finally it presents the justification for designing buildings around deliberately lit fires.

Chapter two investigates the methods used by authorities to predict deliberately lit fires and focus the resources of authorities to catch such individuals. A number of techniques are examined to determine their value to the fire engineer when constructing fire scenarios.

Chapter three covers an analysis of the New Zealand Fire Incident Reporting System (FIRS) database. It covers almost ten thousand fires that occurred in structures between 1996 and 2006. Structures are broken up corresponding to the principle building use as outlined in the Department of Building and Housings compliance document, C/AS1[7], to identify trends within each building category. Each category is examined to identify where designing for deliberately lit fires offers the greatest potential benefits.

Chapter four covers one of the two severe fire scenarios identified in chapter three, namely the ignition of multiple fires. The ignition of multiple fires creates a number of issues not covered under the current design fire philosophy and those issues that are significant to the fire engineer are discussed.

Chapters five and six address the other severe fire scenario, namely the use of accelerants to alter fire growth rates. Chapter five details the experimental procedure used to characterize a design fire for a Molotov cocktail based on the quantity of petrol used. Chapter six builds on this work by characterizing the impact that the surroundings have on the Molotov cocktail fire through the examination of the scenario where a Molotov cocktail is deployed within a stairwell.

Chapter seven brings all of the earlier work together to show what building types should consider including deliberately lit fires as part of the design process and what form such a fire should take before concluding with a number of recommendations.

1.2 Terminology

Before proceeding with further with this work, there are a number of terms used by the Fire Service and the Police when dealing with fires that have been deliberately lit that have similar meanings. To avoid confusion for the reader these terms need to have their definitions clarified.

Arson: DeHaan[8] defines arson as 'the willful and malicious burning of a person's property.' The term 'arson' is actually a legal term and in New Zealand, Section 267 of the Crimes Act[9] defines it as:

(1) Every one commits arson and is liable to imprisonment for a term not exceeding 14 years who-

a) intentionally or recklessly damages by fire or by means of any explosive any property if he or she knows or ought to know that danger to life is likely to ensue; or

b) intentionally or recklessly, and without claim of right damages by fire or by means of any explosive any immovable property, or any vehicle, ship or aircraft, in which that person has no interest; or

c) intentionally damages by fire or by means of any explosive any immovable property, or any vehicle, ship or aircraft, with intent to obtain any benefit, or to cause loss to any other person.

Deliberately Lit (Lawful): Used by the New Zealand Fire Service to describe a fire where the supposed cause is for some lawful or socially condoned purpose such as heating, cooking, rubbish disposal or agricultural purposes[10]**.**

Deliberately Lit (Unlawful): Used by the New Zealand Fire Service to describe a fire where the supposed cause of a fire is one where all possible accidental causes have been eliminated and one or more indicators as listed in sections 19.2 and 19.3 of NFPA 921:2004[11] have been observed. These fires may be reported as "incendiary". No judgement is required to be made as to whether or not the elements of the offence of arson or otherwise have been established[12].

Incendiary Fires: Defined by Cropp[12] as fires 'where physical evidence of legal decision indicated that the fire was deliberately lit.' In the USA the term has been replaced by 'Intentional Fires'[13]. This is another term used to describe unlawful deliberately lit fires.

Suspicious Fires: Defined by Cropp[12] as fires where circumstances indicate that the fire may have been deliberately set. The term differs from Incendiary Fires only by the level of proof required. If there is insufficient evidence to show that the fire has been deliberately set then the fire will be coded as suspicious rather than incendiary. The New Zealand Fire Service consider applying this term to describe a deliberately lit (unlawful) fire where one or more accidental causes cannot be eliminated and at least one incendiary fire indicators as defined in sections 19.2 and 19.3 of NFPA 921:2004 have been observed.

Unknown—used to indicate the supposed cause of a fire for which:
a) one or more accidental causes have been identified but not eliminated, and
b) no indications exist that the fire resulted from a deliberate act.
This does not exclude the possibility that the fire was intentionally set, but indicates that the investigator found no indications as such.

Structure Fire: The NFPA definition of a structure[14], used by fire departments when defining fire incidents, includes buildings but is not limited to them. It includes all man-made objects such as tunnels, storage vessels or covered walkways. For the purposes of this report, all non-building structures will be collectively grouped as 'other structures'.

As this report considers only those fires that are considered unlawful, the legality component of the term has been omitted. Within this report, all fires that are described as deliberately lit may be assumed to be unlawful.

1.3 Bounding The Problem

Deliberately lit fires may be viewed as a spectrum ranging from the ignition of materials located within the compartment through to the attacks on the World Trade Center where an aircraft containing approximately thirty tonnes of aviation kerosene was crashed into the building. This is illustrated graphically as Figure 1.2.

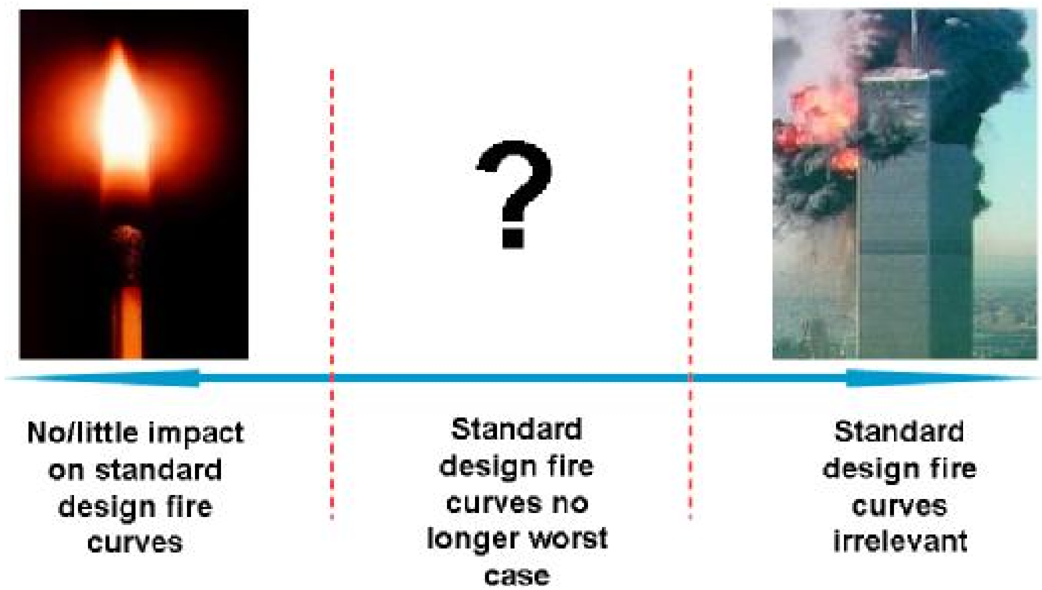

Figure 1.2: The deliberately lit fire spectrum indicating the impact on the design fire curve.

In the case of using a match to ignite materials present in the compartment, the fact that the fire has been deliberately lit has virtually no impact on the development of the resulting fire and standard design fire curves will remain adequate to test the resulting fire.

At the other end of the spectrum the use of a large quantity of aviation fuel represents an introduced fuel load. The growth rate of the resulting fire from such an event will be determined more by the introduced fuel load than the objects present in the building prior to the aircrafts impact. To design for these types of incident, special design fire curves are required as the design fires currently used by fire engineers are effectively irrelevant.

Between these two extremes lie incidents where the method used to start the fires does impact on the resulting fire growth however fire development is still largely determined by the objects present in the compartment. The use of accelerants is one example of this sort of incident.

As the severity of the fire increases the number of incidents drops off dramatically, this puts attacks such as that on the World Trade Center on a similar footing to the bombing of buildings, they are low-probability/high-consequence events[15]. Designing structures to survive the blast of a bomb or the burning of a number of tonnes of fuel represent significant challenges to the engineering community and impose significant costs onto the client. Clearly it is not practical to design all buildings against such rigorous standards so the use of bombs and explosive fires will not be considered.

Arson may also be used as a tool to commit murder. From a legal perspective the deliberate use of fire as a tool to kill an individual or group of people is considered murder rather than arson. This is discussed in more detail in the next chapter but such scenarios represent another rare situation in New Zealand and will not be specifically addressed in this report.

1.4 Current Fire Engineering Design Philosophy

The New Zealand Building Code comprises the first schedule of the New Zealand Building regulations[16] and requires that buildings be constructed to ensure the life safety of building occupants during a fire. To achieve these requirements, the current fire engineering design philosophy is to derive fire scenarios based on the structure's intended use. It is the use of the structures that determines the likely arrangement of the fuel load, thus enabling an assessment as to the credible fire size and growth rate for each scenario.

A number of different fire scenarios, covering fires in different locations throughout the structure should be examined to critically test the various components of the fire engineering design.

A particular fire scenario is typically selected based on:

- The historical incidence of fires in similar buildings.
- To stress a particular element of the design such as escape provisions or external fire spread.

If the fire scenarios selected are appropriately severe for the building use then a building that achieves the design objectives when tested against each scenario is deemed to be ‘safe’ and complies with the Building Code. This philosophy is adequate for accidental fires as the resulting fire development is governed by the principles of fire dynamics such as flame spread, energy transfer and ignition properties. It may not be adequate for deliberately lit fires as there is another parameter that is not considered, namely the actions of the individual lighting the fire.

1.5 Why Design For Deliberately Lit Fires?

There are four main reasons why deliberately lit fires should be considered as part of the design process. Firstly the design process should consider the most likely fire scenarios; if a common fire scenario is not included in the design process then the resulting design may have shortfalls against a reasonably likely fire threat. Secondly the design process should consider the risks that a given fire scenario poses to building occupants. A scenario that results in a serious fire should be given more significance than a scenario that results in a less severe fire. Finally, although arson is generally considered a property crime there are significant life safety risks that need to be considered.

Finally, there is also the issue of property protection, while not a requirement of the New Zealand Building Code, the loss of property may have significance far beyond its monetary value.

1.5.1 Cause of Fire

Deliberately lit fires represent a major contributor to fire losses, both in New Zealand[17] and around the world. The proportion of fires that are deliberately lit varies around the world; the 2004 United Kingdom fire statistics report a total of 16,100 deliberately lit fires in buildings other than dwellings[18]. This represents almost 43% of the total number of fires in these buildings. The 2003 United States statistics for structure fires gives a much lower proportion of 7%[13]. Part of the reason for this significant difference is the inclusion of dwellings in the US statistics; if they are included in the UK statistics then the proportion of fires that are deliberately lit drops to 29%. As stated earlier, the proportion of New Zealand structure fires that are deliberately lit is approximately half way between the UK and US data at 15.6%.

Many reports claim that arson is a growing problem; however in recent years the United Kingdom, United States and New Zealand have all experienced a decline in the number of deliberately lit fires in structures. There is anecdotal evidence indicating that much of Europe follows the United Kingom[19] so the downward trend may be more widespread than this. While the overall trend is downwards, deliberately lit fires still remain more likely than most other fire scenarios. In New Zealand, it the third most likely ignition scenario in structures after carelessness with a heat source and equipment malfunction.

1.5.2 Fire Severity

Deliberately lit fires tend to be more severe than accidental fires. UK data over the last fifty years indicates that the proportion of all fires that are deliberately lit has increased from less than one percent in the 1950's though to 25% in 1993[20]. Between 1966 and

1993, the cost of losses attributed to deliberately lit fires increased from approximately 6% through to almost 50% of the total cost of all fires. While these numbers are indicative only, they do suggest that deliberately lit fires are responsible for more damage than accidental fires.

Part of the reason for this is that intentional ignitions are more likely to spread beyond the compartment of origin. Data based on US fire statistics between 1994 and 1998, compiled by the NFPA and presented as Table 1.1 shows the probability that a fire will spread beyond the room of origin[21].

Major Cause of Fire	**Percent**
Exposure (to other hostile fire)	54.7
Incendiary or suspicious causes	47.9
Open flame, ember or torch	34.7
Child playing with fire	32.0
Natural causes	31.7
Electrical distribution equipment	27.9
Other heat source (e.g. candle)	23.6
Other equipment	23.1
Smoking	22.8
Heating equipment	21.5
Appliances or tools	13.3
Cooking equipment	6.9

Table 1.1: Probability that a fire spreads beyond compartment of origin for US fires between 1994 and 1998. (Reference 21).

The use of accelerants by perpetrators is likely to be a significant contributor to this. A significant proportion of deliberately lit fires are small and even self extinguish, however when accelerants are used the heat release rate of the fire increases faster resulting in an increased likelihood that the fire will not self extinguish. Accelerants may also be used to spread the fire quickly from one object to another.

1.5.3 Life Safety Considerations

The crime of arson is frequently viewed as a property crime. New Zealand statistics record it as a property crime[22], alongside willful damage as shown in Figure 1.3.

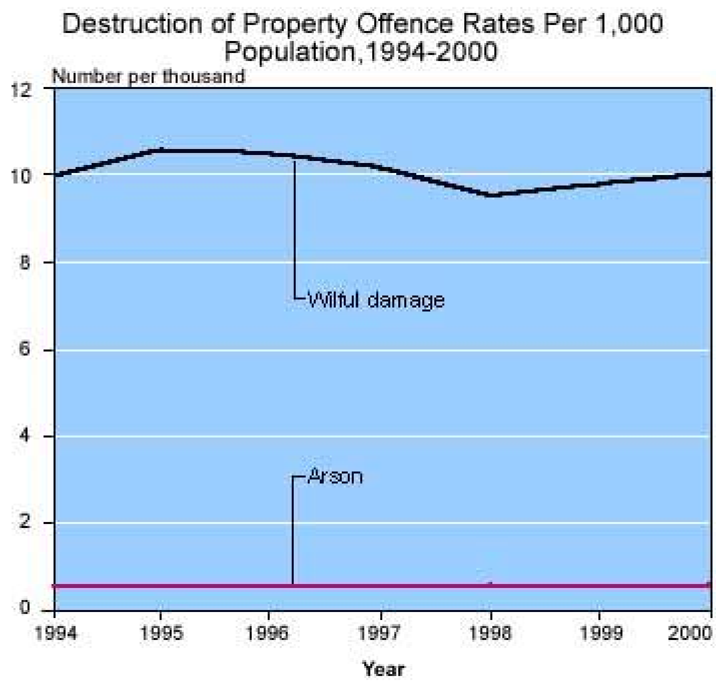

Figure 2.3: Arson offense rate graph taken from Statistics New Zealand website (Reference 22) illustrating the treatment of arson as a property crime.

While many deliberately lit fires do not pose a significant risk to life, considering the crime of arson as a property crime ignores the one quarter of incidents that do[23]. These incidents do represent a significant life safety risk that is currently not being addressed directly by authorities. In the United Kingdom, roughly one in six fire casualties occur in fires that are deliberately maliciously ignited[24]. In the United States, one in ten fire casualties is the result of a deliberately lit fire[25].

Based on these three points, a deliberately lit fire is a fire scenario that has more than a trivial chance of occurring, has a significant probability of spreading beyond the compartment of origin and may also endanger life. By not considering arson as a potential fire scenario, the requirements of the New Zealand Building Code are not being met.

2.0 Predicting Deliberately Lit Fires

No work on deliberately lit fires would be complete without a discussion as to why people light fires and the methods used to predict such behaviour. Individuals light fires for a large number of reasons ranging from the fire play activities of children through to the deliberate targeting of structures by extremists. The aim of this chapter is to examine the methods commonly used by organizations such as the Police and the Fire Service to combat the deliberate ignition of fires and to determine whether they have any value as tools for the fire engineer.

There are three main strategies that have been employed to predict the deliberately lit fire risk to an individual structure. Each of these will be discussed in turn along with an examination of their strengths, weaknesses and relevance to the fire engineer. The three strategies are:

- Focus on the individual setting the fires.
- Focus on the structure under consideration.
- Examination of past fire incidents.

While the strategies presented here have their origins in either the Fire Service or Police, understanding what drives someone to light a fire and the likely level of planning employed can assist in countering the efforts of these individuals.

2.1 Offender Focused Methods

There have been a large number of studies which have examined fire incidents and those offenders who get caught in an attempt to try and understand what drives them to commit arson. This work has been typically done either to identify groups or individuals who pose the greatest risk of fire setting behaviour, or to attempt to reduce the number of suspects when investigating a number of fires that may be related.

2.1.1 Motives to Commit Arson

There are a large number of reasons used by individuals to justify the lighting of fires. However these are commonly distilled down to a list of six commonly reported offender-based motives, based on a study of 1016 offenders, completed by the Prince George's County Fire Department (PGFD)[26]. The PGFD study determined that the most common motives are:

- Vandalism
- Excitement
- Revenge
- Crime concealment
- Profit
- Extremist beliefs.

Due to the complexities of human nature, these motives should not necessarily be considered in isolation. In many cases, there are elements of two or more motives involved. The ordering of this list is significant, reflecting the level of planning and therefore the overall risk to the structure. As one moves down this list the risk to the structure increases. The risk to building occupants does not follow this trend however.

Vandalism: Vandalism motivated fire setting is intended to cause damage to property. Offenders motivated by vandalism typically target education facilities and residential structures as well as vegetation and scrubland. The fires are generally not planned in any way with offenders typically starting the fires with materials present at the scene. The use of accelerants is not common. While the fires are not planned in advance, the offender lacks regard for the safety of others[8], so vandalism motivated fire setting does pose a risk to the safety of other people. The offender is typically a male, aged between 14 and 18 with average or below average intelligence[27].

Excitement: Some individuals light fires for the excitement it causes. They may derive excitement from the fire itself, the response by authorities or from the recognition of 'discovering' the fire. In rare cases, some individuals derive sexual gratification from the fire. People motivated by excitement are more likely to target construction sites or unoccupied structures as well as residential buildings. While the majority of fires still set using materials present at the scene there is a higher likelihood that the offender has prepared in some way so the use of accelerants or delayed triggering mechanisms is more common. The offenders are usually associated with the fire site in some way and are seeking to gain either attention or sympathy from others. Most fire setting by security guards and members of the Fire Service[28] falls into this category.

Revenge: People who light fires as an act of revenge are motivated to correct some real or imagined injustice. The perceived unjust event may have occurred recently, or it may have occurred years prior to the fire setting. This is an example of a targeted attack at a specific organization or individual so the most common targets for individuals motivated by revenge are residential structures (in the case of domestic disputes) or commercial premises (for corporate targets). Cases such as the Happy Land nightclub fire[29] show that offenders may also attack entertainment venues and other structures to strike at a target person. The use of accelerants by offenders is more common, with some offenders using considerably more accelerant than required.

Crime Concealment: Fires may be lit to conceal another crime, ranging from theft to murder. Obviously the target structure will depend on the crime that is being concealed so there is more diversity in the type of structure targeted. The degree of effort used to light the fire largely depends on the magnitude of the crime being concealed, in most cases the lighting of the fire is a spur of the moment decision and the use of accelerants is not likely. For more serious crimes such as murder, the use of accelerant is more common as an attempt to destroy forensic evidence.

Profit: People who commit arson for profit are intending to financially gain from the exercise, either directly from an insurance claim, or indirectly through the elimination of a competitor. There may also be non-financial benefits that may be realized from the destruction of property, such as the use of a fire to threaten an adverse witness in a court case. One of the most frequently encountered forms of profit motivation is the intention to defraud an insurance company as a method to recover from a financial loss or difficulty. There are a large number of potential reasons that may drive an individual to commit arson to achieve this goal[30] and, as insurance companies face significant difficulties in proving that a claim is fraudulent[31], it is seen as a low risk option. Because of this common motivator, both residential and business structures may be targeted by this type of arsonist. In the UK it is estimated that arson for fraud amounts to at least 10% of the total arson bill[32].

The use of hired "torches" is more common in cases that are profit motivated and the more skilled professional torches may take steps to render fire protection equipment such as sprinklers or detectors inoperative. Skilled individuals have an understanding of fire development and often have prior access to the site of the proposed fire to plan the strike. With the goal of destroying the target structure, the use of significant quantities of accelerants and multiple points of origin are more likely. As the motive is making money rather than targeting people, arsonists motivated by profit are more likely to time their attacks to when the structure is unoccupied.

Extremist Beliefs: Also called sensation arson, the use of fire as a weapon against people or organizations with differing beliefs has been around for hundreds of years. This is another form of targeted attack covering the whole spectrum of deliberately lit fires, ranging from the torching of churches and business such as research laboratories and abortion clinics, through to the attacks on the World Trade Center[33]. Political activists start fires for two reasons;

- To gain publicity for their cause.
- To destroy property of the people or establishment that they hate.

It is more likely that a group of people will be involved with this motive than any of the other common motives discussed, so these attacks are more likely to have a significant degree of planning including how to bypass fire protection and security systems. The presence of individuals in a structure is frequently not a concern[34], greater publicity is obtained when a number of people have been killed or injured so arson motivated by extreme beliefs can represent a significant life safety threat. Fortunately this is a much rarer motive than the other motives discussed.

The six motives identified by the PGFD are collectively known as the rational motives. There are two commonly reported groups which do not fit into these motives and these are referred to as irrational fire setting. The groups that fall into this behaviour are:

- Fire play by children.
- Fire setting by the mentally handicapped.

Fire play by Children: Many children have access to matches and lighters long before they develop the understanding of the dangers inherent in fire. While a significant number of fires lit by children are purely accidental, caused by experiments with fire that has got out of hand, a proportion of such fires are caused deliberately. The methods used are typically simple, such as the throwing of lit matches or the use of home made fireworks. Due to their limited mobility, the majority of fires lit by children under the age of ten are set at their home. Between the ages of 10 and 18, there is a shift in fire setting behaviour towards external targets such as schools, rubbish bins and scrubland and during this age period most authorities assume the individual is able to take some responsibility for their actions. Most children, under the age of 10 are assumed in law to be unable to form the intent to harm[13] however; fire play by children does pose a significant risk to life, being the sixth most common cause of civilian deaths in residential structures in the US[35].

Fire setting by the Mentally Handicapped: Fires lit by the mentally handicapped are often referred to as pyromania, however there are actually a number of mental afflictions that may manifest themselves as fire setting behaviour. From a fire engineering perspective, the fires are typically unplanned, started using only simple materials such as newspaper and matches. There is typically no connection between the arsonist and the structure so these individuals may target any structure. Frequently these incidents are seen as a cry for help.

The distribution of each of these motives is subject to debate among psychologists with published motivation statistics being quite variable. Early US data, based on a 1979 study for the Law Enforcement Assistance Administration[36], was indicative as it is based on responses of 16 major cities, only two of which used actual case data. The remainder gave impressions of the distribution. It was also not clear whether fire play by children was included as an option for this study, as the data contradicts the residential fatality statistics presented earlier. Subsequent analysis, completed by the Arson Prevention Bureau in 1993[37], gives a better examination of the motives and is presented as Figure 2.1. As vandalism has not been specifically included in these results, it is likely to be represented as 'no apparent motive'.

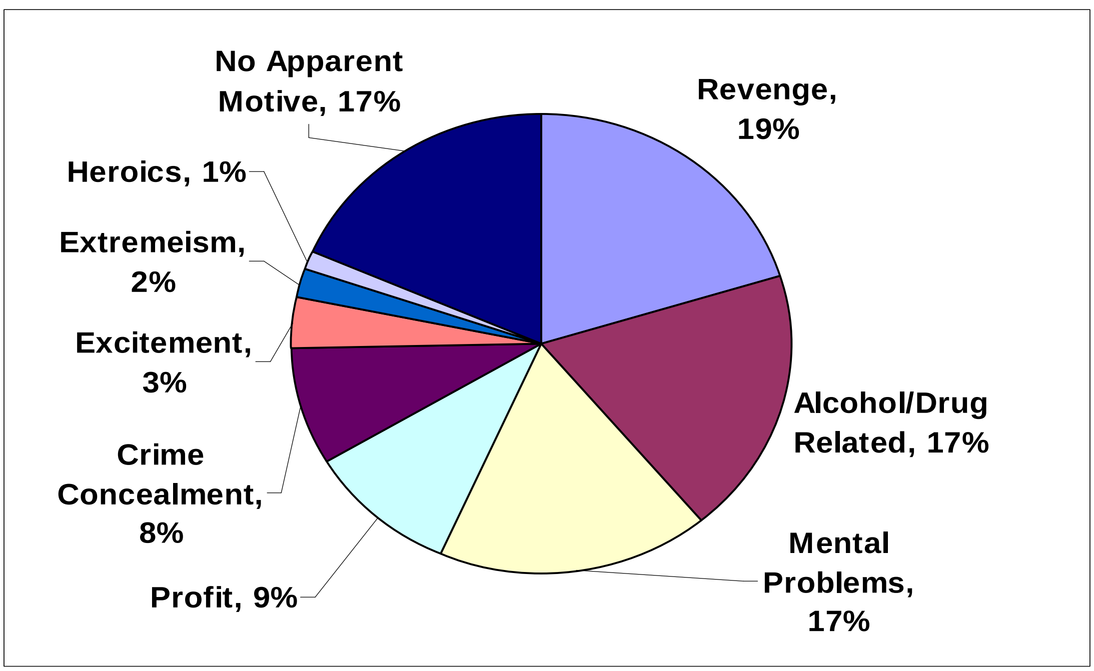

Figure 2.1: Breakdown of arson by motive based on the Arson Prevention Bureau study.

2.1.2 Murder/Suicide by Fire

Fire has been used as a tool to commit murder or suicide for many years. Some researchers claim that in between 10 and 20% of adult cases, the arson was committed as an attempt to commit suicide while in the case of juvenile arson, one quarter of incidents were an attempt at suicide[38]. Other researchers, looking at residential arson, quote much lower figures, of the order of 5%[39]. The actual ignition of oneself is considered unusual. There appears to be cultural differences in the use of fire as a tool to commit suicide, with Japanese fire death statistics dominated by incendiary suicide; which consistently accounts for one third of all fire fatalities[13].

As stated earlier, fire has been used as a tool to cover up a prior murder. It has also been used as a tool to commit murder directly. One trend identified in the US, which illustrates this point, is filicide by fire, the killing of children by their parents using a fire to do the actual killing[40].

The biggest issue for fire engineers is how to consider such events in the context of the design brief. It would be difficult to design a system that is capable of responding fast enough to prevent the death of an individual who has been doused with a flammable liquid and ignited without the system being prohibitively expensive. This issue is further complicated by the fact that distinguishing between murder and suicide by fire can be quite difficult without other supporting evidence[41]. It would be useful if such cases could be readily identified in fire statistics so their significance can be determined.

2.1.3 Spatial Profiling

Another arsonist focused method, used by the Police to help them catch offenders is a profiling technique known as circle theory, developed in 1993 by Canter and Larkin[42]. The basis of this technique is that to commit a crime and escape detection, a criminal requires a degree of knowledge about where the area surrounding the crime scene. As the seriousness of the crime increases, both the police response and the value of this knowledge also increase. Unless they have recently moved into an area, an individual's knowledge of an area will be greatest around their places of residence or work. Circle theory concludes that the majority of criminal activity is likely to occur within a short distance of either the offenders' place of residence or their work. Serious crimes such as murder and arson do follow this rule and the mean distance traveled by arsonists to commit a crime was 2.06 km[43]. Revenge motivated arsonists, who are targeting a specific individual or organization travel further to achieve their goals if required.

The basis of circle theory is to plot the incidents under consideration and find the center of the circle formed by the two most distant events. While the area covered by such a circle has the potential to be quite large, on average a few square kilometers, other profiling techniques may be used in conjunction to eliminate potential suspects.

2.1.4 Value of Offender Focused Methods to the Fire Engineer

The examination of motive has some value to the fire engineer as this provides an estimate of the level of planning and probable methods used by arsonists who may threaten a particular structure. This will allow the creation of a credible worst case deliberately lit fire scenario to test the fire protection systems. One criticism of these methods is that they are generally based on an analysis of those offenders who get caught. Consequently planned attacks and the activities of professional torches are likely to be under-represented in the statistics.

While circle theory has some use to enforcement agencies its value is limited to the fire engineer. Firstly the area of the circles is relatively large, comparable to the size of the central business district of many cities which would result in all buildings being designed around deliberately lit fires resulting in a substantial increase in the cost of fire protection. Secondly the fire engineer must consider the whole life of the building, likely to be of the order of fifty years or more and it is not possible to plot out the activities of an arsonist a number of years into the future. As many arsonists are juveniles this effectively requires the engineer to predict the fire setting activities of an individual before their birth.

2.2 Structure Focused Methods

The second option considered was to focus on the structure itself. Buildings such as schools face a significantly higher risk of being targeted by arsonists with a high proportion of fires in such structures being deliberately lit. Studies have identified a large number of variables which influence a structure's deliberately lit fire risk including security, economic and demographic factors[44].

2.2.1 Arson Predictive Tools

Over the years there have been a number of attempts to model the risk that a given structure faces from deliberately lit fires. Early attempts typically combined a number of factors to calculate some form of risk index. One of these studies, completed by the New York City Arson Strike Force calculated an index called the Arson Risk Prediction Index (ARPI)[45] in an attempt to identify arson prone buildings to prioritize the work of building inspectors. The variables covered by the study included:

- Building use (residential/non residential)
- Vacancy rate
- The length of the building frontage.
- Location of building (suburb)
- The number of quarters of tax arrears owed by building owners.
- Previous suspicious fire

Each of these variables were weighted and then summed to calculate the overall index. While the results were crude and of limited effectiveness they do illustrate the number of variables that impact on a buildings risk. One of the most significant variables is the location of the building as poorer suburbs face a much greater overall fire risk than wealthier neighborhoods. The poor generally have a higher proportion of family instability, lower levels of education and higher levels of substance abuse, all of which are factors linked to higher fire rates[46]. The rate of incendiarism is also higher in poor suburbs, in one Toledo study; the rate of incendiary or suspicious fires was 14.4 times higher in the low-income inner city suburbs than it was in the high-income neighbourhoods[47].

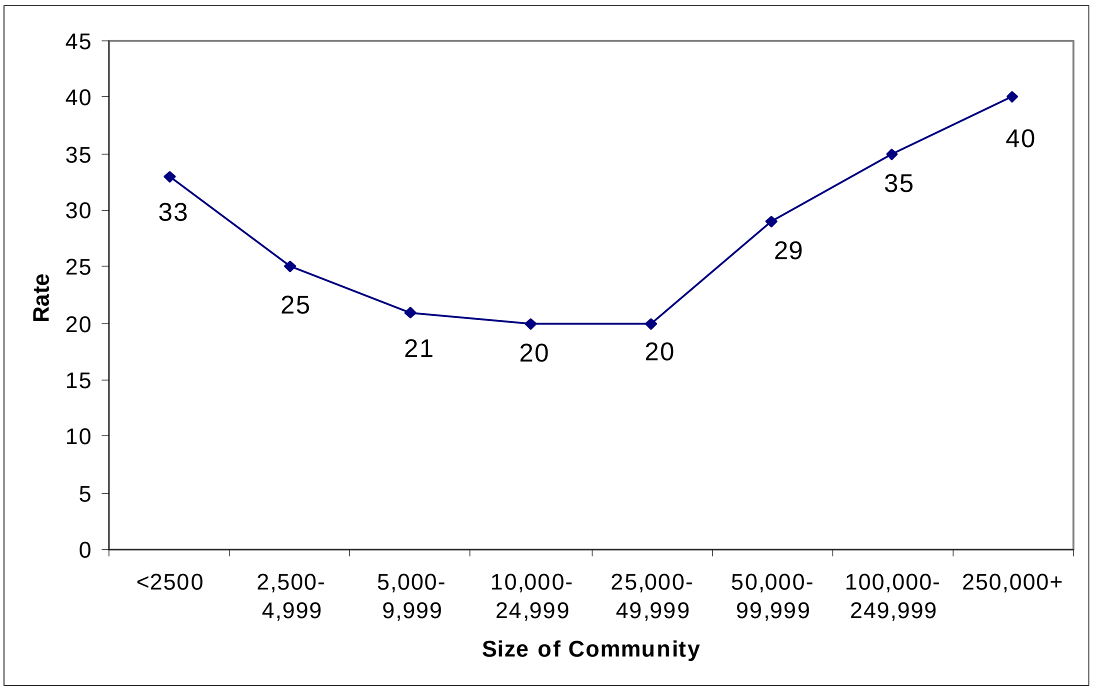

Figure 2.2: US incendiary and suspicious fire rate per 100,000 population by size of community [Ref 13].

NFPA studies have also identified that the community size also plays a role in the deliberately lit fire rate[13]. Both communities with large populations and those with small populations have a higher rate of deliberately lit fires per head of population than medium sized communities. This is illustrated as Figure 2.2. Published New Zealand data for the incendiary fire rate per head of population shows a similar trend, however the increased rate of fires in small communities is absent[12].

2.2.2 Value of Structure Focused Methods to the Fire Engineer

One major problem with structure focused models is that they are typically designed around the solution of a short term issue such as prioritizing work and consequently focus on the risks faced over the next year or so. Because of this their value to the fire engineer, who must consider longer time periods, is limited. Due to the number of variables involved and the divergent nature of the variables, these models contain information difficult to obtain by the fire engineering community. For example, it is unrealistic to expect that clients are willing to offer tax information to their fire engineer.

While not directly useful, structure focused prediction methods do offer an insight into the variables that impact on the deliberately lit fire rate. Two significant variables that can be used by the fire engineer to consider the deliberately lit fire risk are the community population and level of poverty in the neighborhood.

2.3 Analysis Of Past Fires

Finally, the examination of past deliberately lit fires can be used to obtain an estimate of the future risks faced to a structure. Fire statistics are available from most national fire bodies and these statistics may be used to identify the important risk factors relevant to each individual structure. If combined with building population information, this sort of analysis is able to identify what structures are more likely to be targeted by arsonists. Even without population information, there is a significant amount of information that can be obtained from such studies including identification of likely fire scenarios based on the building use.

2.3.1 Arson Maps

Past deliberately lit fire incidents may be plotted over a street map of a community to construct a risk profile for the various suburbs within a city. Such studies have been completed for some large cities in an attempt to focus arson prevention efforts[48]. This allows the risk for locations within a neighborhood to be calculated and, over a period of time, a geographical picture of that community's deliberately lit fire risk may be obtained. To remain relevant, these maps should remove old information as new data becomes available.

2.3.2 Value of Past Fire Analysis to the Fire Engineer

The use of past fire incidents to obtain estimates of a future fire risk is a common practice. It is based on the analysis of large amounts of data which is relatively easily obtainable to the fire engineering community however; the limitations of this practice do need to be considered.

Analysis of past fire incidents is effectively basing a judgment on a historical viewpoint. Data that is too old may no longer be relevant due to changes in technology or processes. This technique will almost certainly be slow to identify trends that stem from changes in the political or social climate.

How the original data was collected can influence the results obtained from subsequent analysis. For example changes in terminology or the grouping of incidents within the database can introduce false trends into the data. Nonetheless, analysis of past fires remains a valuable tool to the fire engineer and forms the basis of the next chapter.

3.0 Analysis of Fire Incident Statistics

The fire departments of many countries collect statistics on their activities[49] for reporting purposes and this data may be available to the fire engineer. The New Zealand Fire Service use the Fire Incident Reporting System (FIRS) and it is from this database that the New Zealand national fire statistics are compiled. The NZ FIRS database was upgraded in July 1995[50] with a number of coding options changed or removed so data prior to this time has not been included in the analysis.

3.1 Deliberately Lit Fires in New Zealand

In the 2004/2005 fire year (the Fire Service year runs from July the 1st through to June 30th the following year) the New Zealand Fire Service responded to 21859 fire incidents[1]. Of these incidents 6487 fires (or 29.7% of the total) involved structures. As discussed earlier, the majority of these incidents had an accidental cause however 1013 fires, or 15.6% of the total, were identified as being deliberately lit.

After a peak in the 2002/2003 year the number of deliberately lit structure fires has declined slightly, however the proportion of structure fires that were deliberately lit has remained roughly constant as shown in Figures 3.1 and 3.2.

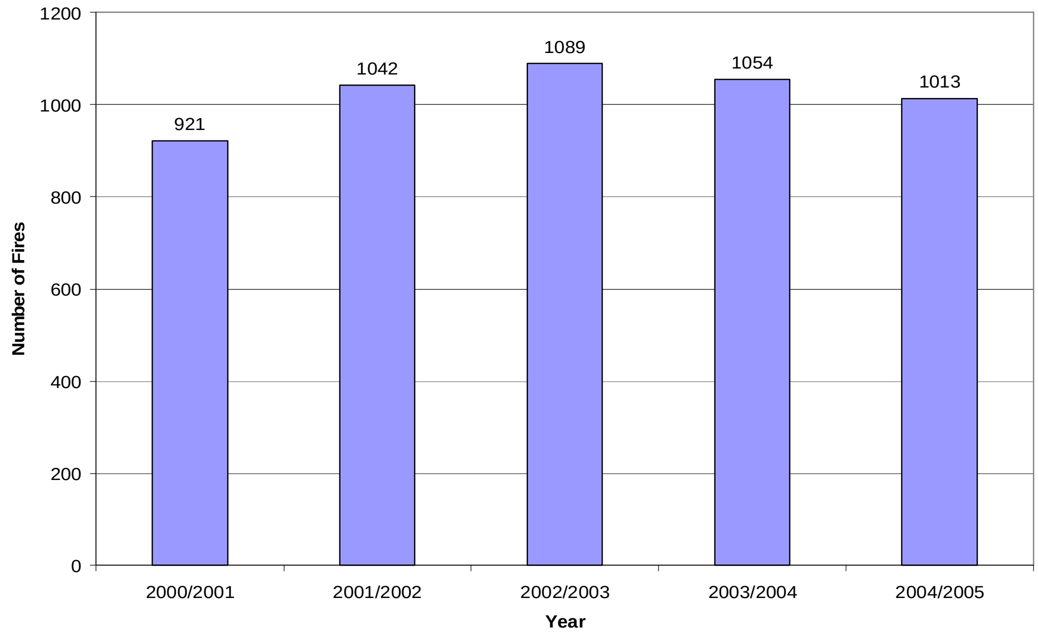

Figure 3.1: Number of deliberately lit structure fires occurring in New Zealand from July 2000 to June 2005. (FIRS statistics)

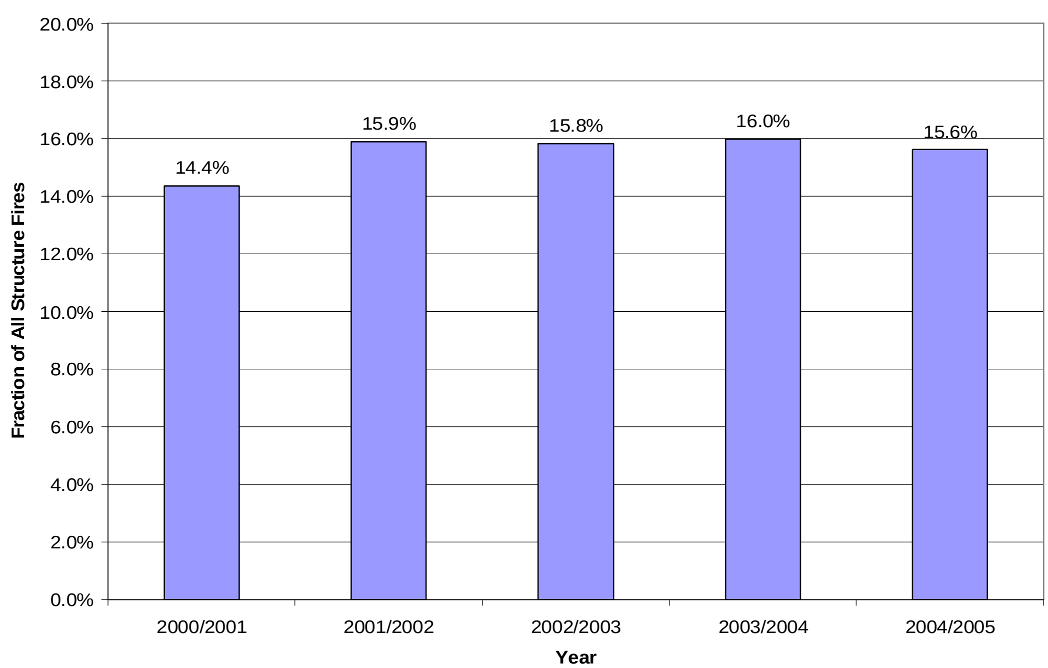

Figure 3.2: Proportion of New Zealand structure fires that were deliberately lit from July 2000 to June 2005 (FIRS statistics).

To investigate further, data from January 1st 1996 through to December 31st 2006 was taken from the New Zealand FIRS database to identify trends. The dataset was restricted to structure fires that had been coded as either unlawful or suspicious (supposed cause codes 111 and 114) to remove those fires that were the result of lawful activity such as heating and cooking. While some of those fires coded as 'legality not known' may in fact be deliberately lit, the small number of fires attributed to this category (1-2% of deliberately lit structure fires) is unlikely to have a significant effect on the results.

3.2 Analysis of The Overall Statistics

Between 1996 and 2006 there were a total of 9606 deliberately lit fires, an average of 873 fires per year. The annual deliberately lit fire rate peaked at 1003 incidents in 1997 and has since been trending downwards slightly as shown in Figure 3.3.

The average number of incidents in the five years between 2002 and 2006 was 847 per year compared with an average of 924 incidents per year between the years 1996 and 2000. This represents an 8.3% reduction in the annual deliberately lit fire rate. The dark line in Figure 3.3 (and in subsequent Figures) is a linear line of best fit to the data, obtained using Excel. The average number of incidents presented in the text represents a five year average, done to reduce the effect of anomalous years, and this has been used to calculate the change over the course of the study. Due to the differences in calculation the numbers occasionally do not exactly match the linear curve given in the figures.

Note that these numbers may differ slightly from those found in the annual fire incident statistics due to both the different year boundaries used and also small data changes due to error correction and outstanding reports being completed. When talking about average numbers of incidents the data will be rounded to the nearest whole number. This has been done as fractional incidents have no meaning in the physical world.

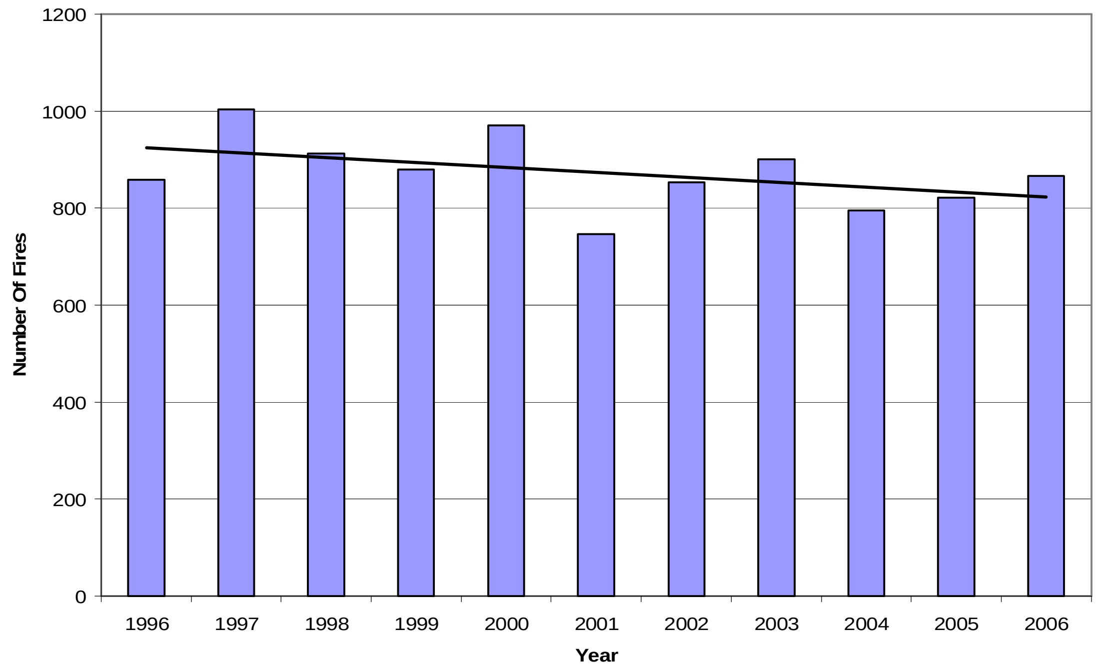

Figure 3.3: New Zealand overall annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

3.2.1 Time of Occurrence

Cropp[12] showed that peak time for deliberately lit fires differs from that of all fires both in the daily distribution and in the time of day. While the overall fire frequency is roughly evenly split between the seven days of the week, the daily fire frequency for deliberately lit fires is biased towards the weekend. The time of day where fires are most likely to occur, both in New Zealand and around the world has been established to occur at around 6 p.m. and falls away to a low point at around 4 a.m., then steadily increases throughout the day. For incendiary/ suspicious fires the peak occurs around midnight and the low point occurs from about 6 a.m. through to 1 p.m. Cropp's data covered the period from 1986 through to 1990.

Over the last ten years these trends have continued with 38.6% of all deliberately lit fires occurring on either a Saturday or Sunday. This is illustrated in Figure 3.4.

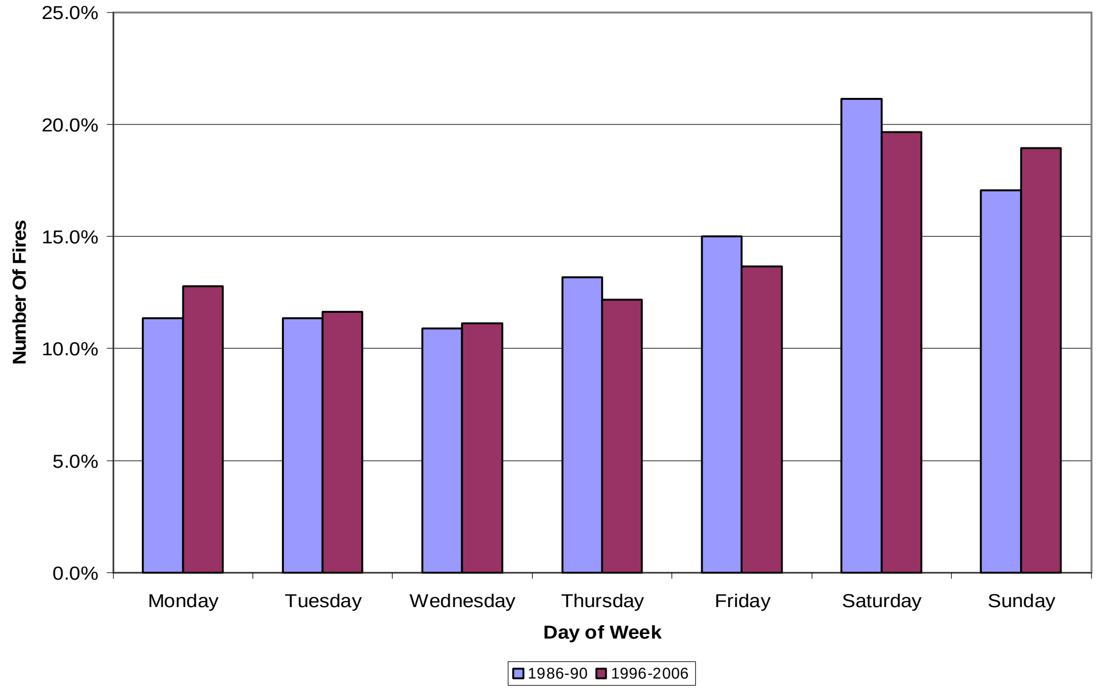

Figure 3.4: Comparison between the proportion of deliberately lit fires occurring each day of the week for the periods 1986-1990 (Ref 11) and 1996-2006 (FIRS statistics).

While still strongly biased towards the evening hours, the time of day of incidents appears to have had some flattening out. Cropp's data indicates that the number of incidents occurring at the peak time of midnight is approximately 300 fires and the number of incidents occurring at the minimum time of 8 a.m. is approximately 50 fires. This gives a ratio of maximum to minimum deliberately lit fire rates of approximately 6:1.

While the time of occurrence of the peak and minimum rate has not changed significantly the ratio of maximum to minimum deliberately lit fire rates has decreased significantly to 3.5:1. The time of day for deliberately lit fires from 1996 to 2006 has been plotted as Figure 3.5.

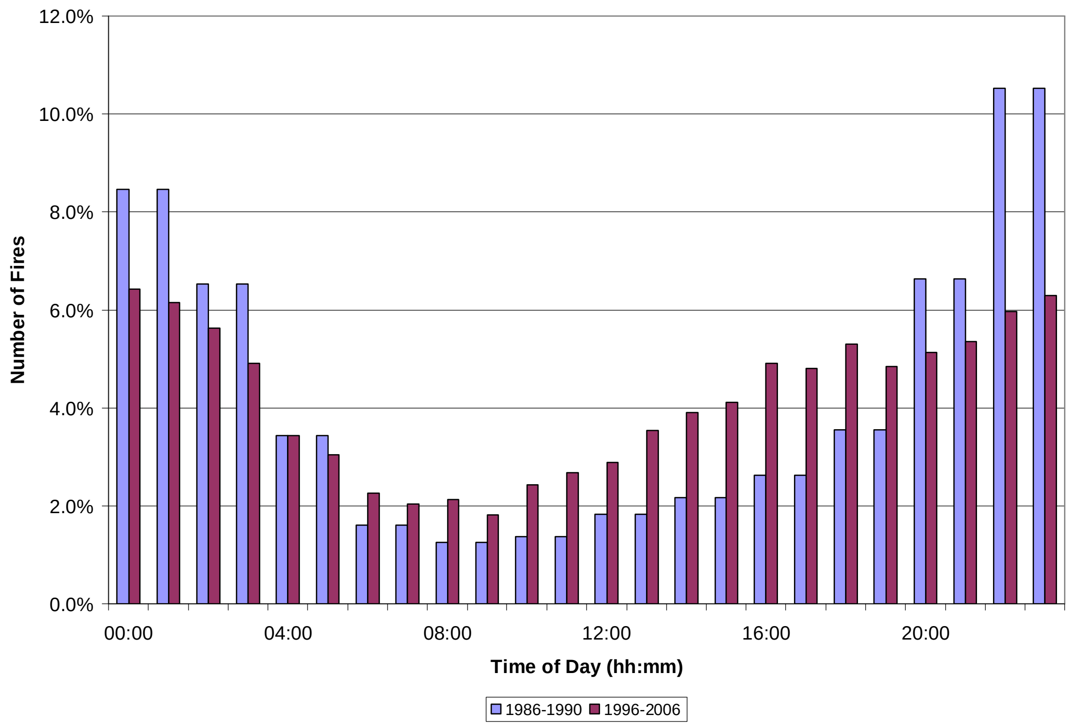

Figure 3.5: Comparison between the proportion of deliberately lit fires occurring each hour of the day for the periods 1986-1990 (Ref 11) and 1996-2006 (FIRS statistics).

If Figures 3.4 and 3.5 are combined to give the deliberately lit fire rate as a function of both time of day and day of the week, as illustrated in Figure 3.6, it shows that these two trends are generally additive. The daily trough in the deliberately lit fire rate during the morning occurs every day, however during the weekend, it does occur at a slightly later time. On Saturday and Sunday the minimum deliberately fire frequency occurs between 9 and 10 a.m. compared with between 6 to 8 a.m. during the weekdays.

The rate of deliberately lit fire ignition on a Sunday evening is generally similar to the weekdays as well suggesting that the increased rate of fires occurring on Sundays is likely to be influenced by activities such as the consumption of alcohol the previous night.

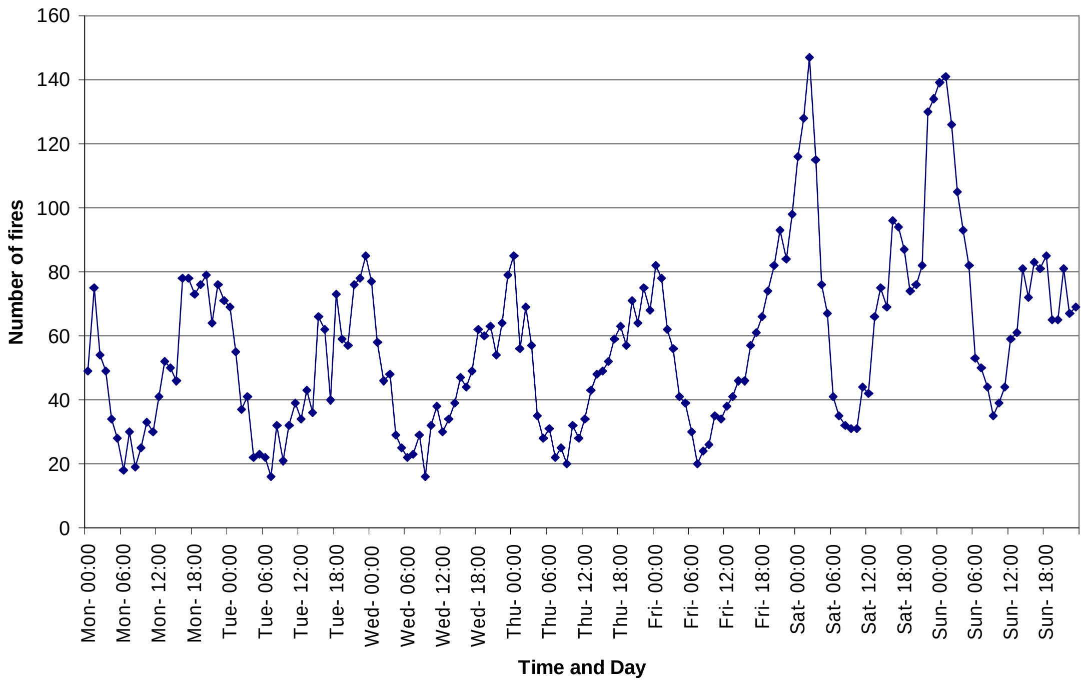

Figure 3.6: Overall deliberately lit fire rate by both hour and by day (FIRS statistics).

What this means for the fire engineer is that if deliberately lit fires are to be considered, to meet the life safety requirements of the Building Code, more significance should be placed when designing structures which are likely to be occupied during the evenings and the weekend. This includes accommodation buildings such as apartments, retail shopping where late night trading is done and buildings used for entertainment.

3.2.2 Compartment of Origin

When assessing likely fire scenarios the compartment of origin for a fire is of critical importance. Where a fire starts is one of a number of factors that determines whether a fire is a minor event or a significant event that poses significant risks to building occupants. For deliberately lit fires there is a diverse range of locations where fires may be started. The most common points of ignition are given as Table 3.1.

There are a large number of descriptions used in the FIRS database and, for a large number of these options, only a few fires are recorded. The FIRS database also contains a number of options that would be considered unusual as options that can be selected for most structure fires such as ‘Lawn, Park, Sports field’. These entries are intended to describe fires in such structures as portable toilets located at parks and sporting events. To reduce the size of Table 3.1 these have all been listed as ‘Other compartment of origin’.

Location Of Origin	**No. of Incidents**	**% of Total**
Garage, Carport, Vehicle storage, Storage Shed	1287	13.4%
Bedroom, Sleeping area, Cell: under 5 persons	1077	11.2%
Lounge, Common room, TV room, Sitting room, Music room	800	8.3%
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	791	8.2%
Wall surface (exterior)	762	7.9%
Kitchen, Cooking area	349	3.6%
Supply room/area, Tool room, Maintenance supply room	314	3.3%
Product storage, Tank, Bin, Agricultural storage, Hay barn, Hay stack	312	3.2%
Lobby, Entrance way	275	2.9%
Hallway, Passageway, Corridor, Walkway in mall	263	2.7%
Small assembly area: Classroom, Meeting room, Multi-purpose room	178	1.9%
Multiple areas of origin	174	1.8%
Wall assembly: Concealed wall space	135	1.4%
Vacant structural area	134	1.4%
Rubbish, Industrial waste, Waste container	117	1.2%
Storage and garage area - not classified above	103	1.1%
Crawl space, Basement	98	1.0%
Other compartment of origin	2437	25.4%
Total	**9606**	**100.0%**

Table 3.1: Most frequent location of fire origin for deliberately lit fires in New Zealand between 1996 and 2006 (FIRS statistics).

There are also a number of options used to describe the various situations where the data is incomplete. It is common practice in many fire reports to assign these incidents proportionally amongst the known entries. This practice has not been done for this analysis and all such entries have also been grouped in the 'Other compartment of origin'. This effectively means that the compartment of origin results presented should be considered as the lower boundary of the true situation.

The overall distribution is flat with the top three items accounting for 32.9% of all incidents and only five entries achieving more than 5% of the total. In most cases fires are lit in only a single compartment, however in a small number of cases (2.2% of the total including 'Outside area, multiple area - Not Classified above') fires are lit in multiple locations and this poses additional risks to occupants.

3.2.3 Object First Ignited

To assess likely growth rates for a deliberately lit fire scenario the likely item first ignited is another critical piece of information. The item first ignited determines the initial rate of growth of the fire and, depending on the location of this item, it may also influence the peak heat release rate. The rate of growth and the peak heat release rate are key parameters that determine the hazard to building occupants[51]. The most frequently encountered items that are ignited in deliberately lit fires are summarised as Table 3.2. Any object that accounted for less than 1.0% of the total was grouped into the 'Other object first ignited' entry.

There are a few issues to note from this list. Firstly the incidence of 'Unknown' is much higher than it is for compartment of origin. This is due to the fact that in a significant number of cases the level of damage at the seat of the fire makes positive identification of the object first ignited difficult or impossible. There is also the issue of Fire Service resources that can be devoted to investigation of deliberately lit fires. Many smaller towns and rural areas do not have the resources to fully investigate all fires. Because of these issues the 'Unknown' entries have been left in as a separate category.

Object First Ignited	No. of Incidents	% of Total
Rubbish, Garbage, Waste	1215	12.6%
Unknown	1038	10.8%
Newspaper, Magazine, Files	727	7.6%
Flammable liquid and gases (not aerosols or propellants)	524	5.5%
Multiple items	424	4.4%
Paper; excluding newspaper or rolled paper	390	4.1%
Upholstered Furniture e.g. Chairs, Sofas, Beds, Vehicle Seats	385	4.0%
Framing, Structural member, Interior walls and doors	383	4.0%
Exterior side wall covering surface, Cladding (including eaves)	341	3.5%
Box, Carton, Bag	293	3.1%
Rolled material, Rolled paper (not newspaper)	268	2.8%
Bedding e.g. Blankets, Sheets, Duvet	258	2.7%
Information not recorded	243	2.5%
Bedding e.g. Mattress, Pillow	235	2.4%
Clothing (Not being worn)	231	2.4%
Curtains, Blinds, Drapes	229	2.4%
Interior wall covering	229	2.4%
Floor coverings: Carpets, Mats, Rugs	197	2.1%
Books	157	1.6%
Agricultural: Hay, Straw (NOT food for human consumption)	141	1.5%
Exterior trim e.g. Doors, Porches, Decks	125	1.3%
Packing, Wrapping material	108	1.1%
Structure components - not classified above	97	1.0%
Other object first ignited	1368	14.2%
Total	**9606**	**100.0%**

Table 3.2: Items most frequently ignited in deliberately lit fires in New Zealand between 1996 and 2006 (FIRS statistics).

Secondly the proportion of cases where there are a number of fires lit within a compartment is greater than the incidence of lighting fires in multiple compartments. This is significant as multiple fires in a single compartment are able to interact and this may influence the time until flashover is reached.

Other than multiple fires and the use of accelerants the overwhelming majority of deliberately lit fires may be adequately addressed by the appropriate selection of the design fire. The most common items ignited are rubbish, paper or cardboard in various forms and furniture items. This suggests that most deliberate fires are opportunistic.

3.2.4 Casualty Rate From Deliberately Lit Fires

The New Zealand FIRS database records four levels of injury and these are not clearly defined in the FIRS manual. There also appears to be some differences in the way the terms are used by the Fire Service. For the sake of consistency the following definitions have been used:

- Fatality - The person died as a result of the injury received.
- Life-Threatening - The injury is serious enough to threaten the life of the victim. Such injuries require hospitalization and expert medical care to treat.
- Moderate - The injury is not life threatening but may require hospitalization or expert medical care to treat.
- Slight - The injury is not life threatening and does not require expert medical care to treat. These injuries are typically recorded for OSH purposes.

The 9606 fires deliberately lit structure fires makes up 13.3% of the 72539 structure fires attended by the Fire Service between 1996 and 2006. These deliberately lit fires resulted in 28 fatalities and another 157 moderate or life threatening injuries*. There was also another 127 slight injuries.

The 28 fatalities represent 10.6% of the overall death toll from structure fires and the 157 injuries represent 9.8% of the total structure injury rate. On the basis of these results it appears that deliberately lit fires are under-represented in the overall fire casualty rate, reinforcing the belief that the crime of arson is a crime against property.

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* This number differs slightly from the 154 injuries obtained from an earlier search of the FIRS database. These differences are due to error checking on the live database.

3.3 Analysis By Purpose Group

One limitation of the overall analysis is that the fire statistics are dominated by fires in private residences. One half of all of structure fires that occurred between 1996 and 2006 occurred in a 'Single House' and the proportion of deliberately lit fires that occurred in a 'Single House' is 35.4%. While useful for overall trends, any analysis of the overall statistics is likely to follow the trends for residential housing and trends in other types of structure may be missed. To get around this problem the analysis was repeated based on the purpose groups listed in the Compliance Document, C/AS1[7].

C/AS1 lists four broad categories and a number of individual purpose groups covering the range of activities that are done in structures. The four broad categories and their associated purpose groups have been included as Table 3.3.

Activity	**Purpose Groups**	**Examples**
Crowd Activities	CS/CL	Schools, churches, cinema
	CO	Open grandstands
	CM	Retail shopping
Sleeping Activities	SC	Hospitals, old aged care
	SD	Prisons
	SA	Temporary accommodation inc. Motels, hotels, boarding houses
	SR	Apartments and attached dwellings
	SH	Houses and separate dwellings
Working, Business & Storage Activities	WL	Offices, banks, manufacturing/ storage of non-combustible products
	WM/WH/WF	Manufacture/storage of combustible products
Intermittent Activities	IE	Exit ways
	IA	Car parks, toilets etc
	ID	Maintenance workshops

Table 3.3: Purpose group summary (from C/AS1).

To streamline the analysis purpose groups CS and CL have been combined into a single option. The reason for this is that these two groups differ only by the number of occupants permitted. If a cinema has a maximum occupancy of less than 100 individuals then it is considered a CS purpose group and if its maximum occupancy is greater than 100 individuals then it belongs to the CL purpose group. The Fire Service statistics do not indicate the occupancy limits of structures involved in fire so this distinction could not be completed with confidence.

A similar situation exists with the manufacturing/storage purpose groups. Selection of the appropriate purpose group is done on the basis of the type and quantity of material stored and the resulting fire growth rate. Again the Fire Service reports do not generally contain this information so all industrial manufacturing and storage incidents have been recorded as Manufacturing/Storage, irrespective of the material stored.

A large body of work has been written looking at deliberately lit fires in the education sector. They make up over 50% of the fires in CS/CL purpose groups. To separate them from the analysis an Education option, covering all education premises has been created.
Purpose group IE does not typically apply to a whole structure so no fires have been applied to this group.

There were a number of fires at locations such as vacant buildings or buildings under construction which do not clearly fit into any purpose group. These incidents have been collectively grouped as ‘Other’.

The full list of property uses as recorded by the Fire Service, the number of incidents that have occurred at each property and the purpose group that has been assigned to each is recorded as Appendix A. The breakdown of deliberately lit fires by purpose group is given as Figure 3.7. Due to the large proportion of deliberately lit fires occurring in detached accommodation, these fires have been excluded from Figure 3.7 to better illustrate the relative significance of the other property types.

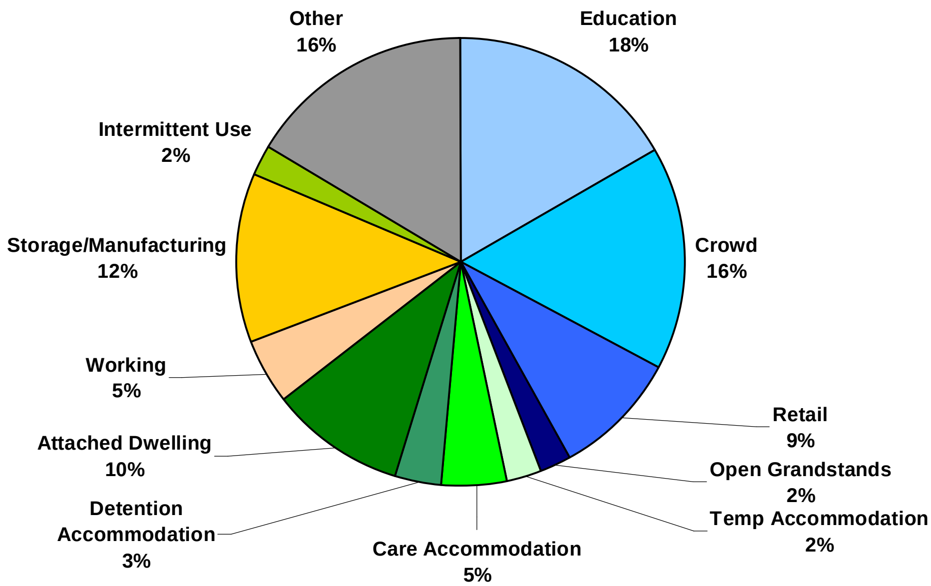

Figure 3.7: Breakdown of deliberately lit fires by property use (detached accommodation excluded) as defined by C/AS1.

It can be clearly seen that in addition to detached accommodation buildings, education and crowd activities are also common targets for deliberately lit fires. The 'other' fires building category is also significant however due to the diverse nature of this catch all building category specific recommendations are likely to be of limited effectiveness.

The proportion of deliberately lit fires in people's homes is slightly higher in the US, where 51% of such fires occur in people's homes[36]. As the definition of 'home' has not been specifically defined, it has been taken to be the sum of attached and detached accommodation.

3.4 Education Premises: Overall Trends

Education premises have been defined to cover all school buildings from primary though to tertiary providers such as universities, polytechnics and trade colleges. Between 1996 and 2006, education facilities in New Zealand experienced 983 deliberately lit fires, an average of 89 per year. The vast majority of these fires occur in primary and high schools, with only 10.5% of such fires occurring in outside these premises. Deliberately lit fires make up 47.8% of the total number of fires that occur at education premises so such fires pose a significant risk to property as well as their risk to life safety. Studies in the US[52] and UK[53] have provided similar estimates of the proportion of fires that are deliberately lit and the risks they pose.

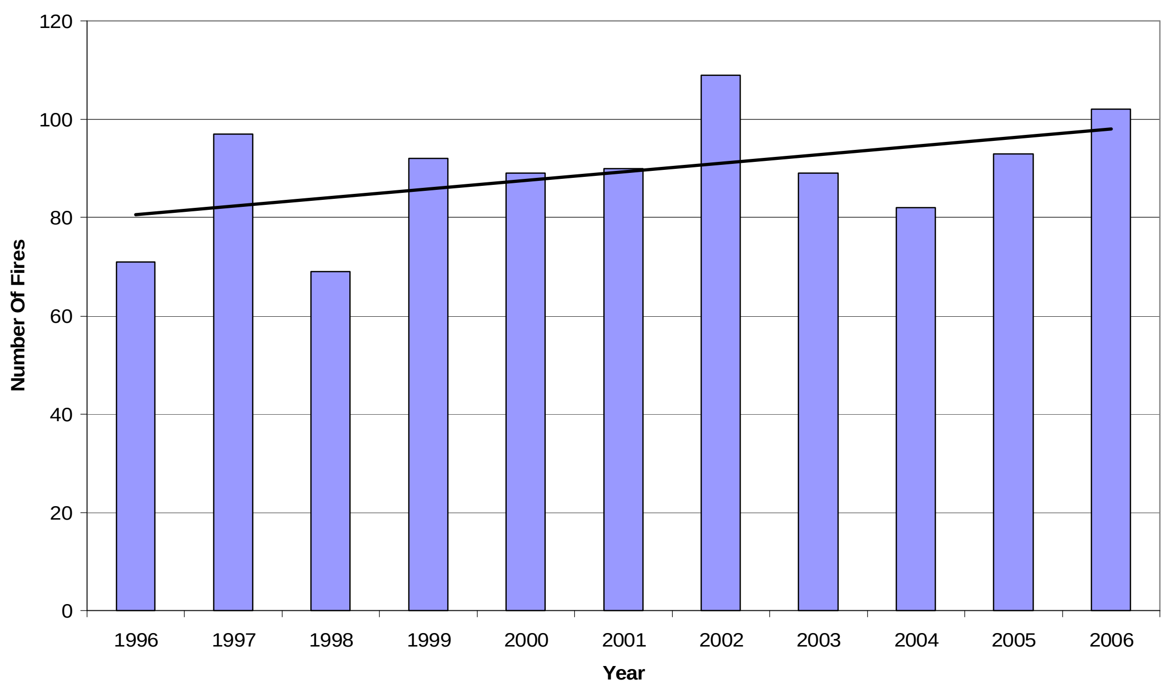

Figure 3.8: New Zealand education premises annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

Of greater concern is that the number of fires in such premises has increased from 83 to 95 incidents per year, an increase of 13.6% over the last eleven years. The trend over the period from 1996 to 2006 is illustrated as Figure 3.8. This is a continuation of a trend that goes back over the last twenty years however the rate of increase has slowed compared to the 75% increase in the number of incidents between 1986 and 1990[54].

3.4.1 Education Premises: Time of Occurrence

Deliberately lit fires in education premises show a similar distribution of their day of occurrence however the distribution of time of day shows a much flatter distribution, especially during the afternoon hours. While there is still a significant dip in the fire frequency during the morning hours the incidence of fires during the afternoon is a much closer to the evening rate. Unless these fires occur during school holiday periods, the life safety risk may be higher than what is normally assumed despite the fact that the majority of fires occur at schools where there is no residential population. One reason proposed to explain this result is that the majority of deliberate fires at schools are lit by juveniles[35]. The daily fire rate has been summarised as Figure 3.9 and the hourly fire rate as Figure 3.10.

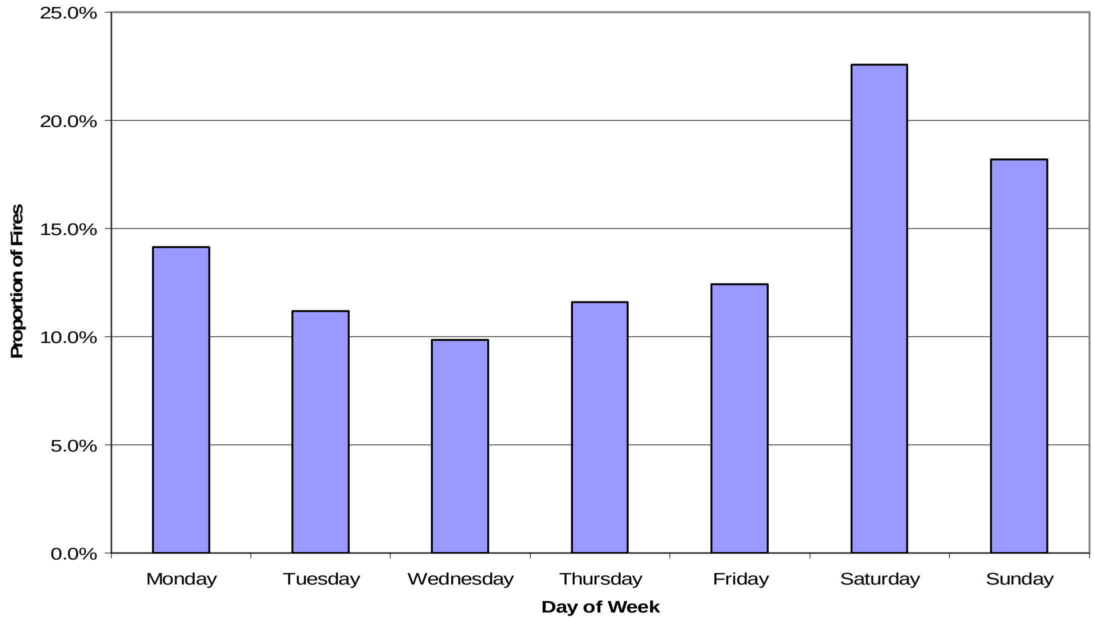

Figure 3.9: New Zealand education premises deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

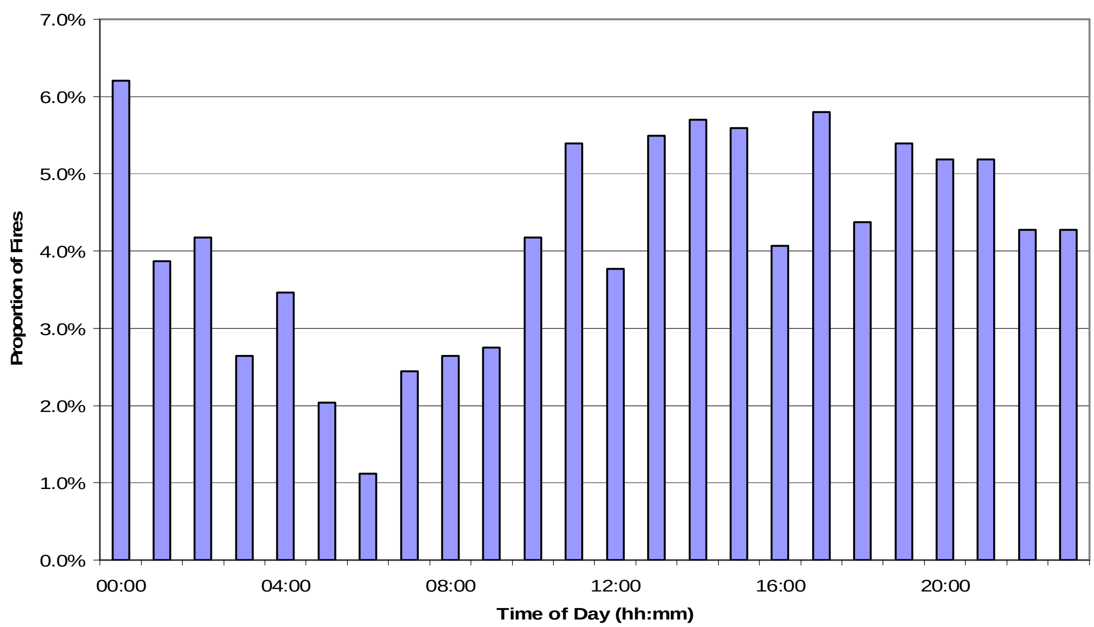

Figure 3.10: New Zealand education premises deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.4.2 Education Premises: Compartment of Origin

Fires were deliberately lit in a large range of locations as shown in Table 3.4. Deliberately lit fires appear to be lit where there is ready access, hence the high incidence of locations on the outside of the structure. These results are similar to what is found in intentional fires at education premises in the US[13], the major difference being fires are much more likely to be started in the toilets in US schools.

Overall, the distribution of location of origin is skewed with the top three items accounting for 40.3% of all incidents and seven entries achieving more than 5% of the total. The incidence of fires being lit in multiple compartments is low at 1.3%.

Most Common Location Of Origin	**No. of Incidents**	**% of Total**
Wall surface (exterior)	142	14.4%
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	137	13.9%
Small assembly area: Classroom, Meeting room, Multi-purpose room	118	12.0%
Patio, Court, Terrace, Gazebo	58	5.9%
Lobby, Entrance way	57	5.8%
Supply room/area, Tool room, Maintenance supply room	56	5.7%
Garage, Carport, Vehicle storage, Storage Shed	55	5.6%
Hallway, Passageway, Corridor, Walkway in mall	33	3.4%
Lounge, Common room, TV room, Sitting room, Music room	30	3.1%
Balcony, Porch, Veranda	26	2.6%
Wall Assembly: Concealed Wall Space	21	2.1%
Other Location of origin	250	25.4%
Total	**983**	**100.0%**

Table 3.4: Most frequent location of fire origin for deliberately lit fires in New Zealand education premises between 1996 and 2006 (FIRS statistics).

3.4.3 Education Premises: Object First Ignited

The most commonly ignited items in education premises are given as Table 3.5. There is little difference in the items found in Table 3.5 compared to the overall statistics presented in Table 3.2. All items in Table 3.5, with the possible exception of flammable liquids, are commonly found in a school environment suggesting that the individuals who light fires in education premises are typically not introducing unusual items. This may be due to the opportunistic nature of lighting fires and the increased risk of getting caught bringing an additional fuel package to the scene.

The incidence of igniting multiple fires is 3.7% and the total use of accelerants is 5.9%. This gives 9.6% of deliberately lit fires where an appropriately chosen design fire may be inadequate.

Most Common Object First Ignited	No. of Incidents	% of Total
Rubbish, Garbage, Waste	148	15.1%
Newspaper, Magazine, Files	76	7.7%
Unknown	66	6.7%
Paper; excluding newspaper or rolled paper	61	6.2%
Exterior side wall covering surface, Cladding (including eaves)	52	5.3%
Rolled material, Rolled paper (not newspaper)	52	5.3%
Flammable liquid and gases (not aerosols or propellants)	42	4.3%
Multiple items	36	3.7%
Curtains, Blinds, Drapes	35	3.6%
Box, Carton, Bag	29	3.0%
Basket, Barrel, Rubbish bin (NOT rubbish in bin)	27	2.7%
Exterior trim e.g. Doors, Porches, Decks	27	2.7%
Clothing (Not being worn)	25	2.5%
Framing, Structural member, Interior walls and doors	24	2.4%
Other Object first ignited	283	28.8%
Total	**983**	**100.0%**

Table 3.5: Items most frequently ignited in deliberately lit fires in New Zealand education premises between 1996 and 2006 (FIRS statistics).

3.4.4 Education Premises: Casualty Rate

The casualty rate in education premises is low with only two moderate and six slight injuries recorded between the years 1996 and 2006. These casualties resulted from eight separate incidents. In five of these incidents the fires were started in toilets; however there was no trend identified with the object first ignited. The most likely object ignited in incidents causing injury was some form of paper or rubbish.

Deliberately lit fires are slightly under-represented in injury statistics. 42.9% of all moderate or life threatening injuries in education premises have occurred in fires that were deliberately lit. Such fires account for 47.8% of all fires in this type of premises. No fatality occurred during the study period. The low casualty rate is due to the fact that 80% of deliberately lit fires occur outside normal school hours.

3.5 Crowd Premises: Overall Trends

Crowd premises have been defined to include all CS and CL purpose group activities other than education. This definition covers churches, community halls, cinemas, libraries, galleries, passenger terminals, drinking establishments, nightclubs and restaurants. For statistical purposes, the New Zealand Fire Service combines restaurants and taverns with supermarkets and delicatessens under the description 'Food and Beverage Sales' so there is some crossover between this building category and the retail category.

Between 1996 and 2006, crowd premises experienced 947 deliberately lit fires, or approximately 86 deliberately lit fires per year. Since 1996, the incidence of deliberately lit fires in crowd premises has decreased by 11.6% over this time dropping from 93 to 82 incidents per year as shown in Figure 3.11.

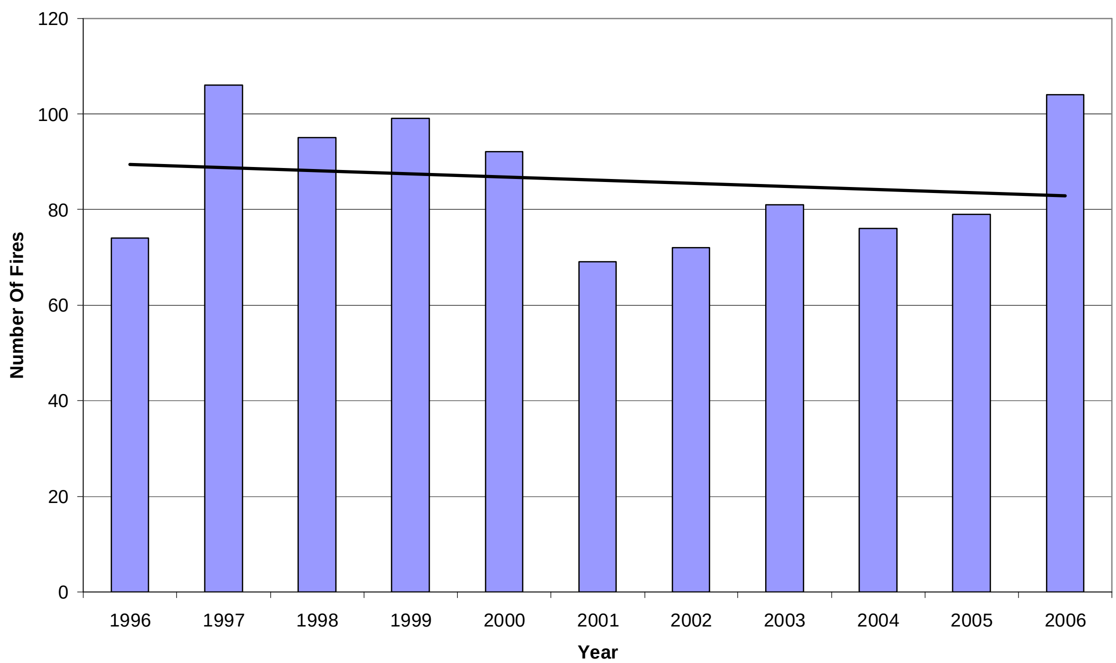

Figure 3.11: New Zealand crowd premises annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

While some structures in this category are more likely to experience a deliberately lit fire than others, on average 42.6% of the total number of fires that occurred in crowd premises were deliberately lit. As many of these structures have a greater occupancy during the evening and weekend this represents a risk to life safety. The incidence of deliberately lit fires in some of these structures in New Zealand differs to that found around the world. In New Zealand the proportion of fires in churches that is deliberately lit is 36.5% compared with approximately 66% in the UK[55]. Many of these structures have significant historical and community value in addition to their financial worth

3.5.1 Crowd Premises: Time of Occurrence

Like education premises and the overall statistics, crowd premises are approximately 50% more likely to experience a fire on a Saturday or Sunday compared to a weekday. The daily distribution of deliberately lit fires in crowd premises is illustrated as Figure 3.12.

When looking at the distribution by hour, two peaks are present. The first peak corresponds to the overall peak in deliberately lit fires, occurring at around midnight. The second peak occurs at roughly 4 p.m. and does not appear to have a clear cause. A plot of the probability that a fire will occur in a given hour is given as Figure 3.13. While not true for all crowd premises, deliberately lit fires do pose a significant risk to life safety as they are likely to occur during the time that these premises are occupied.

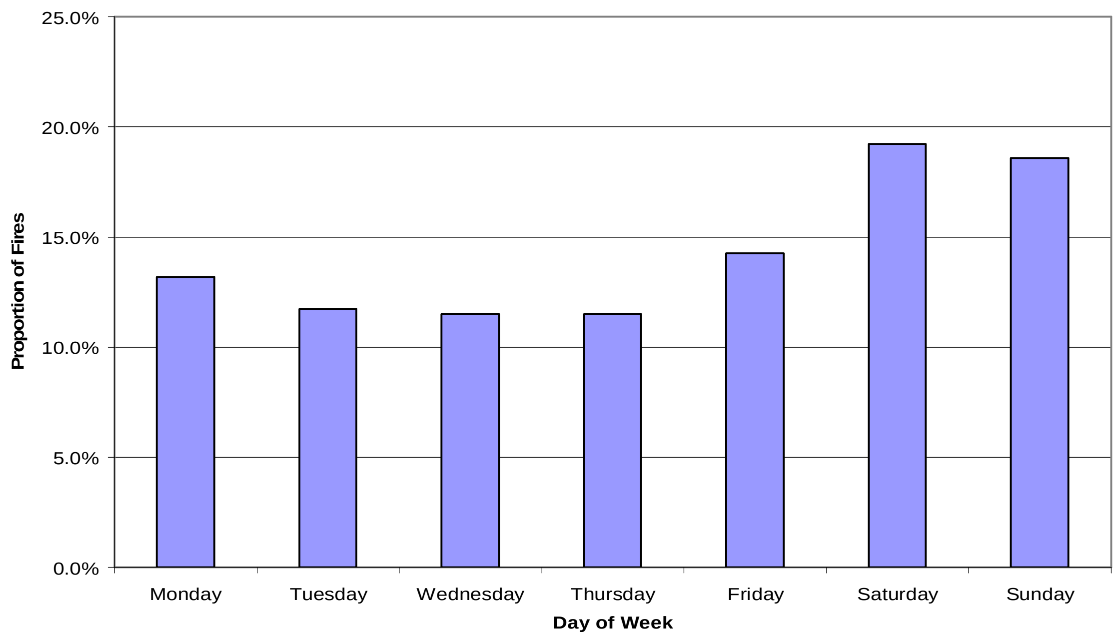

Figure 3.12: New Zealand crowd premises deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

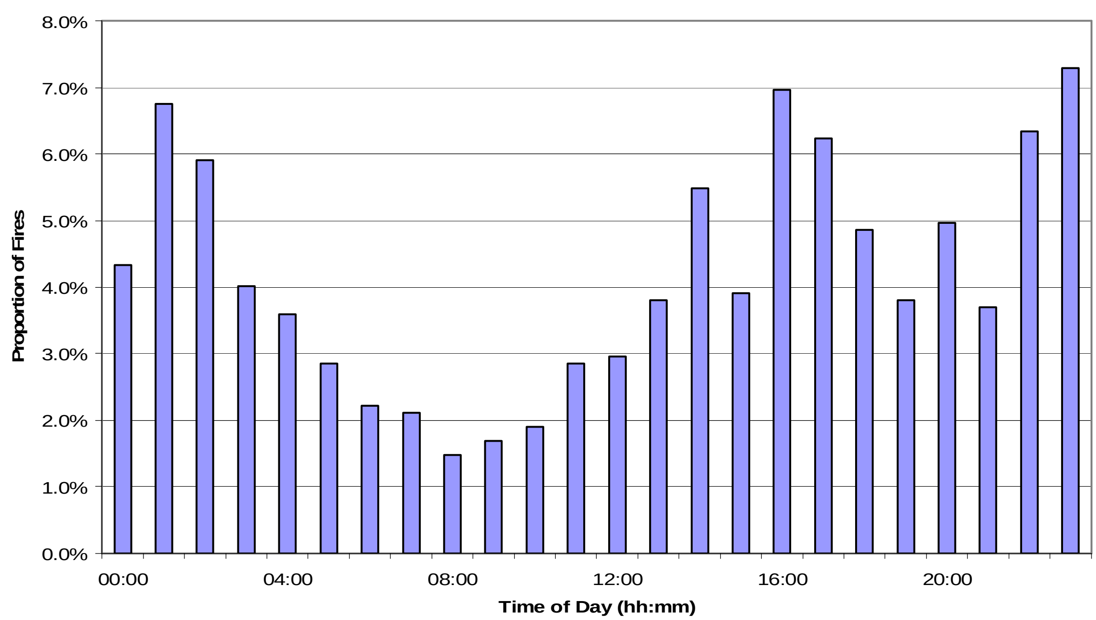

Figure 3.13: New Zealand crowd premises deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.5.2 Crowd Premises: Compartment of Origin

The most frequently encountered compartments of origin for crowd premises are presented as Table 3.6. Overall, the distribution of location of origin is skewed, with the top three items accounting for 40.5% of all incidents and only two entries achieving more than 5% of the total. The remainder of the data for compartment of origin shows a very flat distribution. Again there is a strong bias towards both the exterior of the structure and those compartments where there is ready access. This is consistent with the most common location of origin for intentional fires in the US[13]. The incidence of fires being lit in multiple compartments is low at 1.7%.

Most Common Location Of Origin	**No. of Incidents**	**% of Total**
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	230	24.3%
Wall surface (exterior)	108	11.4%
Supply room/area, Tool room, Maintenance supply room	45	4.8%
Garage, Carport, Vehicle storage, Storage Shed	43	4.5%
Lobby, Entrance way	36	3.8%
Lounge, Common room, TV room, Sitting room, Music room	32	3.4%
Small assembly area: Classroom, Meeting room, Multi-purpose room	28	3.0%
Large assembly area: Auditorium, Place of worship, Theatre, Arena, Lecture hall etc	26	2.7%
Kitchen, Cooking area	21	2.2%
Not Recorded	21	2.2%
Recreational: Swimming pool, Health club, Massage parlour, Sauna	20	2.1%
Hallway, Passageway, Corridor, Walkway in mall	19	2.0%
Other location of origin	318	33.6%
Total	**947**	**100.0%**

Table 3.6: Most frequent location of fire origin for deliberately lit fires in New Zealand crowd premises between 1996 and 2006 (FIRS statistics).

3.5.3 Crowd Premises: Object First Ignited

The most common items first ignited in crowd premises have been listed in Table 3.7. The item first ignited in crowd premises is virtually identical to the overall trend with nine of the first ten most commonly lit items appearing in both Table 3.7 and Table 3.2. The reasons for this are likely to be the same as those mentioned in education premises. Due to the increased likelihood of other people being present and the increased risk of discovery the use of transient fuel load appears to be very unlikely. With the exception of flammable liquids all of the items on this list could reasonably be expected to be present in a crowd premises.

The incidence of igniting multiple fires is 3.7% and the total use of accelerants is 5.3%. This gives 9.0% of deliberately lit fires where an appropriately chosen design fire may be inadequate.

Most Common Object First Ignited	**No. of Incidents**	**% of Total**
Rubbish, Garbage, Waste	132	13.9%
Unknown	96	10.1%
Newspaper, Magazine, Files	92	9.7%
Rolled material, Rolled paper (not newspaper)	75	7.9%
Paper; excluding newspaper or rolled paper	50	5.3%
Exterior side wall covering surface, Cladding (including eaves)	45	4.8%
Framing, Structural member, Interior walls and doors	36	3.8%
Multiple items	35	3.7%
Flammable liquid and gases (not aerosols or propellants)	32	3.4%
Box, Carton, Bag	28	3.0%
Exterior trim e.g. Doors, Porches, Decks	21	2.2%
Upholstered Furniture e.g. Chairs, Sofas, Beds, Vehicle Seats	20	2.1%
Other object first ignited	285	30.1%
Total	**947**	**100.0%**

Table 3.7: Items most frequently ignited in deliberately lit fires in New Zealand crowd premises between 1996 and 2006 (FIRS statistics).

3.5.4 Crowd Premises: Casualty Rate

Despite a high risk due to the expected occupancy at peak attack times there have only been five casualties in crowd occupancies between 1996 and 2006. There have been two life threatening injuries, one moderate injury and two slight injuries during this period. Part of the reason for this good result is crowd premises are likely to have an equal or greater level of fire protection compared to working occupancies. The most commonly encountered fire scenario resulting in an injury was the ignition of the cladding on the exterior surface of the structure, resulting in two injuries.

As already stated, deliberately lit fires comprise 42.6% of all fires in these premises. These fires accounted for 28.6% of the moderate and life threatening injuries in this sector which indicates that deliberately lit fires are under-represented in casualty statistics. The limited number of injuries in these premises means that this result should be treated with caution.

3.6 Retail Premises: Overall Trends

Retail premises cover all locations where goods and services are traded. It covers such things as shopping malls, service stations, hardware stores and supermarkets. Between 1996 and 2006, retail premises experienced 540 deliberately lit fires, or an average of 49 incidents per year. This corresponds to 14.7% of all fires experienced by this sector.
The incidence of deliberately lit fires in this sector is decreasing, dropping from 54 to 46 incidents per year, a decrease of 14.4%. This trend is illustrated as Figure 3.14.

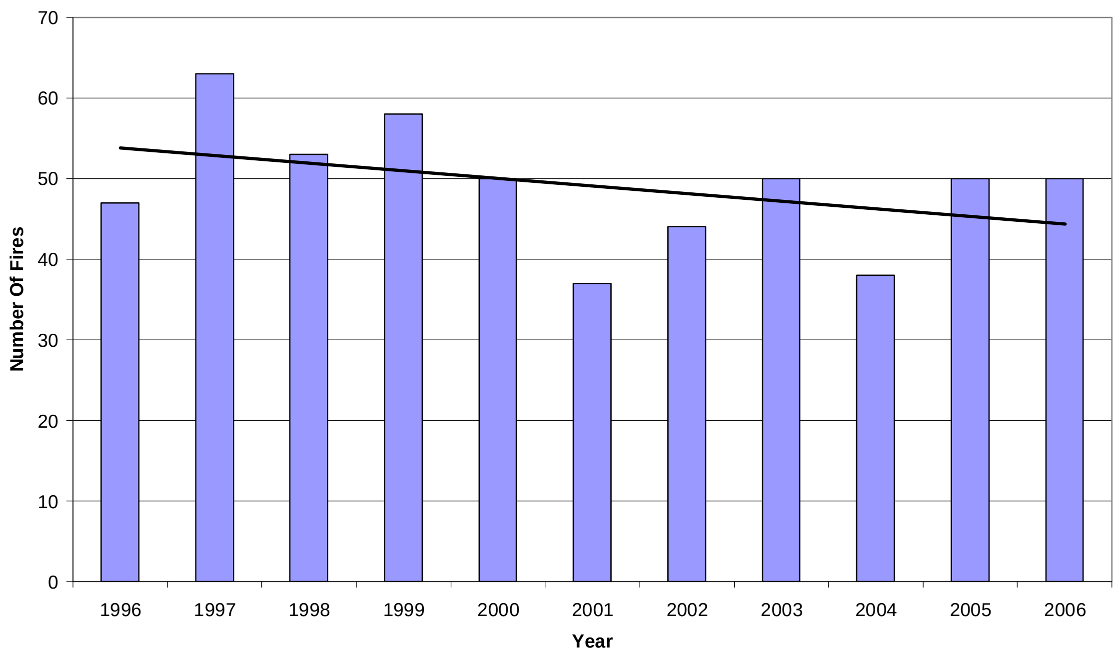

Figure 3.14: New Zealand retail premises annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

3.6.1 Retail Premises: Time of Occurrence

Retail premises show a greater bias towards deliberately lit fires during the weekend than other categories. 45.4% of all attacks occur on either a Saturday or Sunday. An attack is also significantly more likely to occur on a Sunday suggesting that this bias may be influenced by the increased likelihood that the retail store will be shut on Sundays, resulting in a lower risk of the offender being witnessed. The daily fire frequency is given as Figure 3.15.

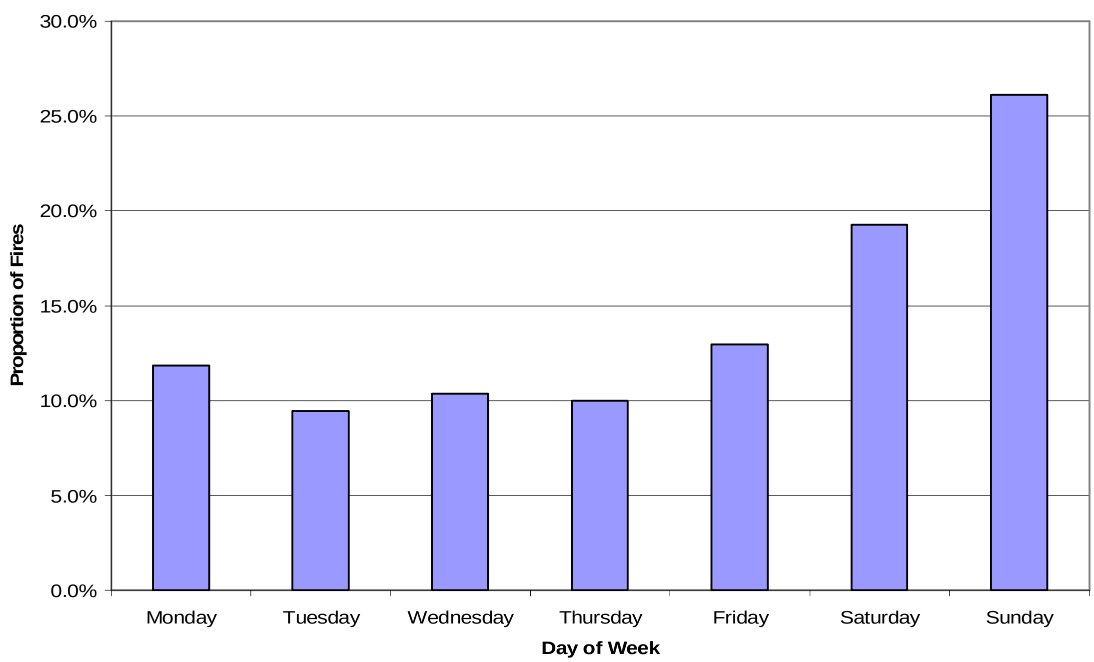

Figure 3.15: New Zealand retail premises deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

During the day the maximum deliberately lit fire rate occurs shortly after midnight, consistent with the overall trend. The minimum deliberately lit fire rate also occurs at a consistent time with the overall trend; however, the rate remains low for a much longer period resulting in almost 50% of deliberately lit fires in retail premises occurring between the hours of 9 p.m. and 3 a.m. This is illustrated as Figure 3.16.

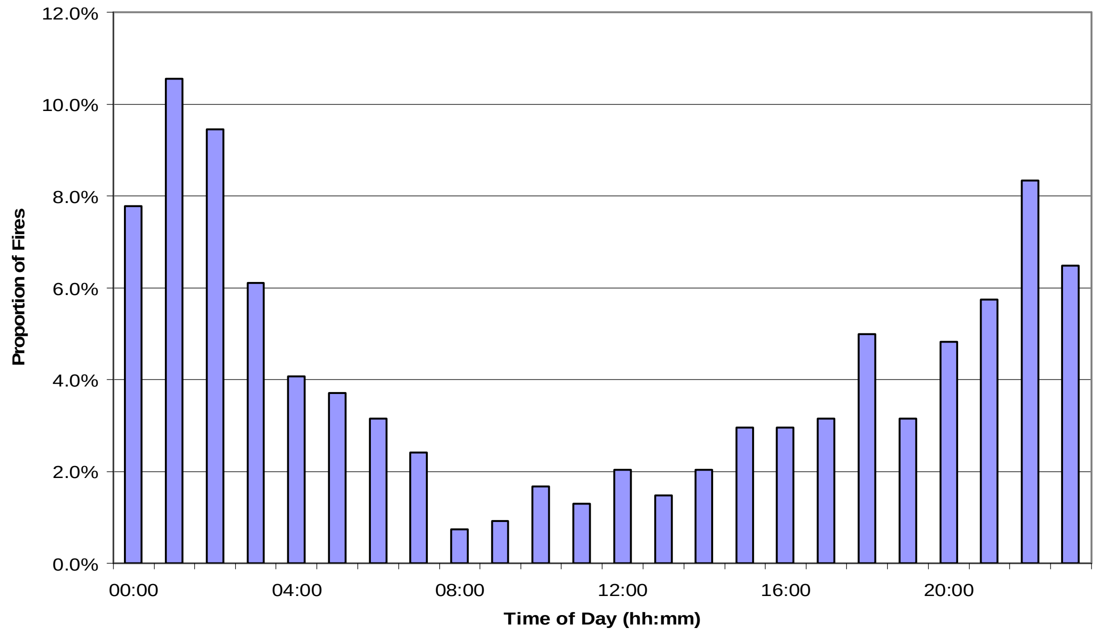

Figure 3.16: New Zealand retail premises deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.6.2 Retail Premises: Compartment of Origin

The compartment of origin for deliberately lit fires in retail premises is given as Table 3.8. The two most common compartments of origin in retail premises are identical to what is found in both crowd and education premises, indicating their significance as a potential fire scenario. US data combines retail and office fires[13]; however the locations of origin listed in Table 3.8 are also present in the US data.

Overall, the distribution of location of origin is flat, with the top three items accounting for 36.6% of all incidents and six entries achieving more than 5% of the total. The incidence of fires being lit in multiple compartments is low at 1.7%.

Most Common Location Of Origin	**No. of Incidents**	**% of Total**
Wall surface (exterior)	92	17.0%
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	58	10.7%
Showroom, Sales area	48	8.9%
Supply room/area, Tool room, Maintenance supply room	36	6.7%
Garage, Carport, Vehicle storage, Storage Shed	36	6.7%
Lobby, Entrance way	30	5.6%
Hallway, Passageway, Corridor, Walkway in mall	22	4.1%
Rubbish, Industrial waste, Waste container	19	3.5%
Patio, Court, Terrace, Gazebo	17	3.1%
Product storage, Tank, Bin, Agricultural storage, Hay barn, Hay stack	15	2.8%
Other location of origin	167	30.9%
Total	**540**	**100.0%**

Table 3.8: Most frequent location of fire origin for deliberately lit fires in New Zealand retail premises between 1996 and 2006 (FIRS statistics).

3.6.3 Retail Premises: Object First Ignited

The item first ignited in retail premises is similar to what is ignited in other property groups. A list of the most commonly used items is given as Table 3.9. All of the items on this list are likely to be present in the retail sector; the diverse nature of retail stock also makes the identification of introduced fuels more difficult than in other sectors. However the use of introduced fuels is considered unlikely.

The incidence of igniting multiple fires is 3.5% and the total use of accelerants is 6.1%. This gives 9.6% of deliberately lit fires where an appropriately chosen design fire may be inadequate.

Most Common Object First Ignited	**No. of Incidents**	**% of Total**
Rubbish, Garbage, Waste	123	22.8%
Box, Carton, Bag	48	8.9%
Newspaper, Magazine, Files	42	7.8%
Unknown	36	6.7%
Paper; excluding newspaper or rolled paper	30	5.6%
Flammable liquid and gases (not aerosols or propellants)	26	4.8%
Multiple items	19	3.5%
Exterior side wall covering surface, Cladding (including eaves)	16	3.0%
Rolled material, Rolled paper (not newspaper)	14	2.6%
Framing, Structural member, Interior walls and doors	12	2.2%
Upholstered Furniture e.g. Chairs, Sofas, Beds, Vehicle Seats	12	2.2%
Basket, Barrel, Rubbish bin (NOT rubbish in bin)	12	2.2%
Packing, Wrapping material	11	2.0%
Rubbish in bin inside a structure, Ashtray	11	2.0%
Clothing (Not being worn)	128	23.7%
Total	**540**	**100.0%**

Table 3.9: Items most frequently ignited in deliberately lit fires in New Zealand retail premises between 1996 and 2006 (FIRS statistics).

3.6.4 Retail Premises: Casualty Rate

Between 1996 and 2006, there was only a single casualty incident. A service station attendant was doused with a flammable liquid and set alight[56]. As the victim was intimate with the fire at the time of ignition, the buildings fire safety protection was unable to influence the outcome and the victim died at the scene.

Due to the small number of casualty incidents for deliberately lit fires, this should not be considered either representative or worst case for the retail premises as a whole. This fatality was the only fatality in the entire retail sector during the study period.

3.7 Open Grandstand Premises: Overall Trends

Open grandstand premises cover such structures as open air stadium, sports grounds and playgrounds. There have been a total of 123 fires in such structures between 1996 and 2006, giving an average rate of 11 fires per year. While the number of incidents is much less than other categories it should be remembered that there are considerably fewer buildings of this type in towns and cities. Deliberately lit fires comprise 32.2% of all fires in such structures.

As illustrated in Figure 3.17, there has been a significant increase in the number of incidents occurring at these premises, rising from eight to fifteen incidents per year, an increase of 92.1%. This trend is consistent with UK[57] experience which showed that these structures are vulnerable to attack due to their isolation and infrequent use.

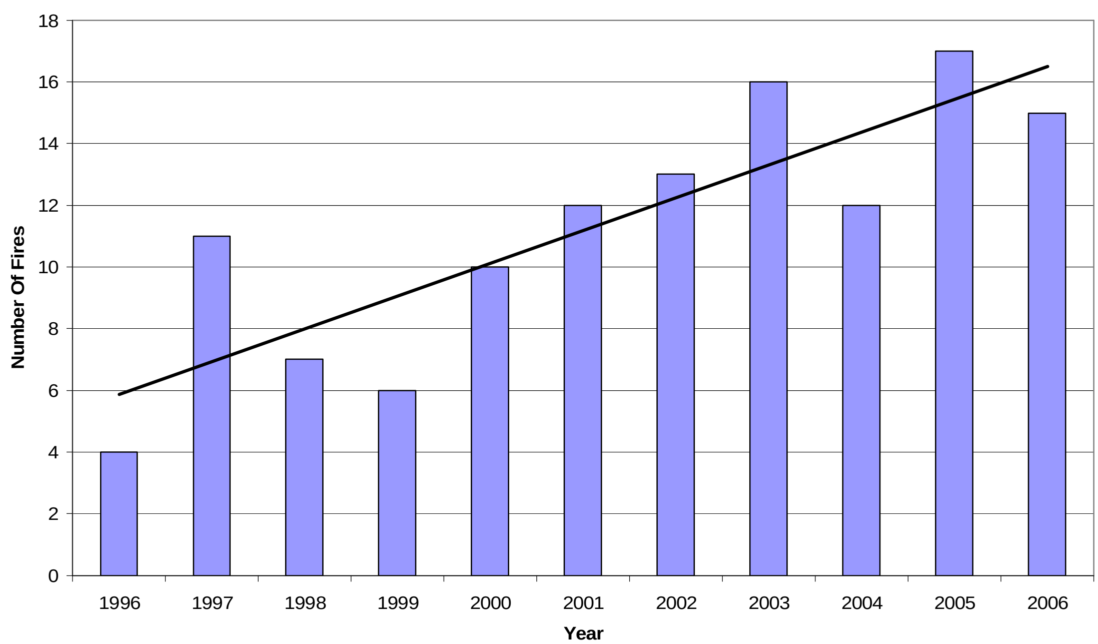

Figure 3.17: New Zealand open grandstand annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

3.7.1 Open Grandstand Premises: Time of Occurrence

The incidence of deliberately lit fires in open grandstands is strongly biased towards the weekend days as shown in Figure 3.18. This is consistent with the overall deliberately lit fire trend. When looking at the hourly distribution, in Figure 3.19, the maximum rate of deliberately lit fires occurs at a much earlier time, occurring during the middle of the afternoon at 4 p.m. This is considerably earlier than what is observed for other deliberately lit fires and suggests that the likely offender is a juvenile.

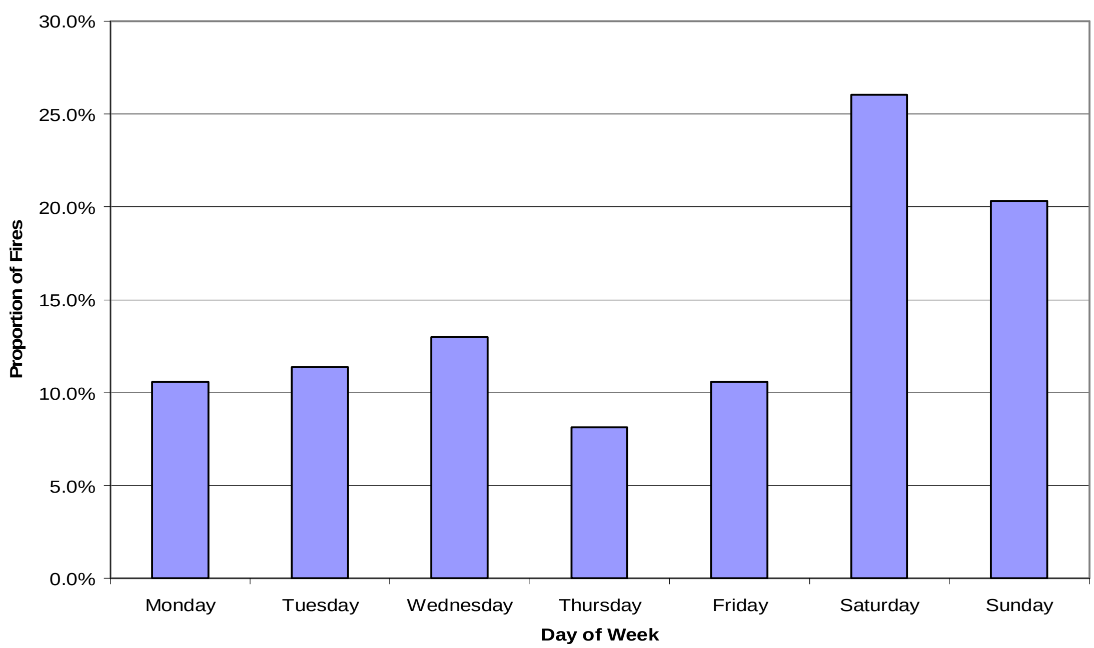

Figure 3.18: New Zealand open grandstand deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

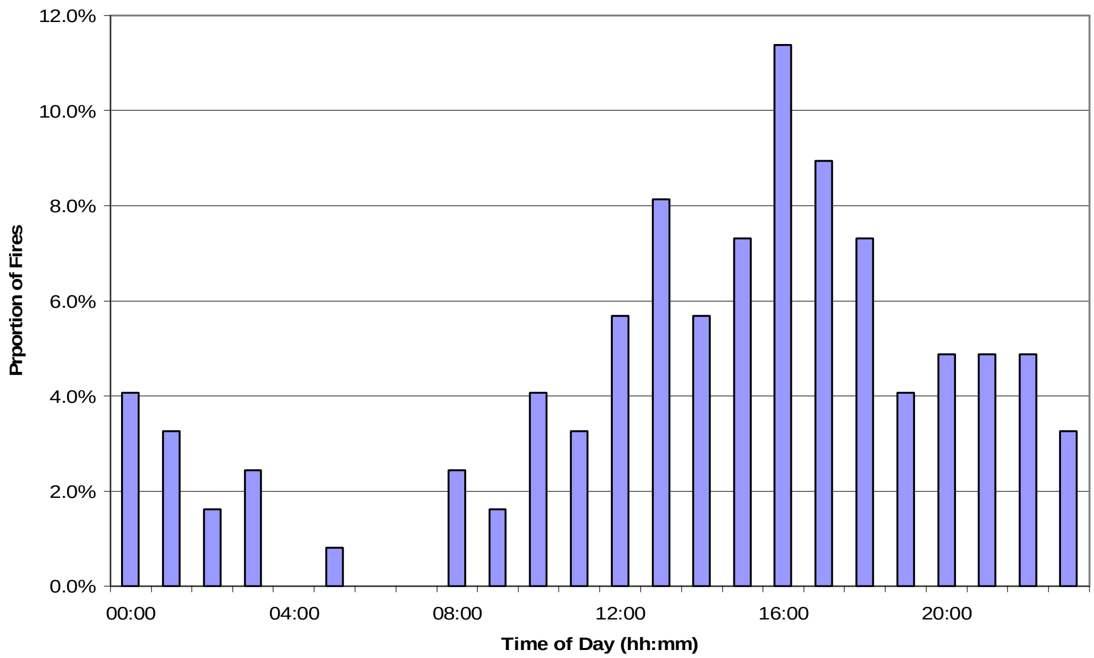

Figure 3.19: New Zealand open grandstand deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.7.2 Open Grandstand Premises: Compartment of Origin

Due to the different nature of these structures, compartment of origin options such as 'Lawn' have been included in the list of most common location of origins. The most common locations of origin are tabulated as Table 3.10. Fires are significantly more likely to be lit in toilet blocks than other locations suggesting perpetrators value locations that reduce the risk of observation. Overall, the distribution of location of origin is skewed, with the top three items accounting for 41.5% of all incidents and fire entries achieving more than 5% of the total. The incidence of fires being lit in multiple compartments is low at 1.6%.

Most Common Location Of Origin	**No. of Incidents**	**% of Total**
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	28	22.8%
Large assembly area: Auditorium, Place of worship, Theatre, Arena, Lecture hall, etc.	12	9.8%
Wall surface (exterior)	11	8.9%
Supply room/area, Tool room, Maintenance supply room	9	7.3%
Lawn , Park, Sports field	9	7.3%
Garage, Carport, Vehicle storage, Storage Shed	6	4.9%
Recreational: Swimming pool, Health club, Massage parlour, Sauna	6	4.9%
Wall assembly: Concealed wall space	5	4.1%
Small assembly area: Classroom, Meeting room, Multi-purpose room	4	3.3%
Unable to classify	3	2.4%
Open land, Scrub land, Farm land	3	2.4%
Ceiling and floor assembly	3	2.4%
Other location of origin	24	19.5%
Total	**123**	**100.0%**

Table 3.10: Most frequent location of fire origin for deliberately lit fires in New Zealand open grandstands between 1996 and 2006 (FIRS statistics).

3.7.3 Open Grandstand Premises: Object First Ignited

The list of objects most likely to be used to start a fire in a grandstand is given as Table 3.11. While the most likely items are similar to what is encountered in other purpose groups the presence of bedding at such locations may be considered as a transient fuel load. An appropriately selected design fire is expected to be able to cope with this scenario though.

The incidence of igniting multiple fires is 1.6% and the total use of accelerants is 7.3%. This gives 8.9% of deliberately lit fires where an appropriately chosen design fire may be inadequate.

Most Common Object First Ignited	No. of Incidents	% of Total
Rubbish, Garbage, Waste	19	15.4%
Newspaper, Magazine, Files	11	8.9%
Unknown	9	7.3%
Paper; excluding newspaper or rolled paper	8	6.5%
Rolled material, Rolled paper (not newspaper)	7	5.7%
Framing, Structural member, Interior walls and doors	7	5.7%
Structure components - not classified above	7	5.7%
NON-Upholstered Furniture e.g. Chairs, Sofas, Beds, Vehicle Seats	6	4.9%
Box, Carton, Bag	4	3.3%
Interior wall covering	4	3.3%
Bedding e.g. Mattress, Pillow	3	2.4%
Outdoor items - not classified above	3	2.4%
Paint, Resin, Varnish, Thinners (include residue)	3	2.4%
Other object first ignited.	32	26.0%
Total	**123**	**100.0%**

Table 3.11: Items most frequently ignited in deliberately lit fires in New Zealand open grandstands between 1996 and 2006 (FIRS statistics).

3.7.4 Open Grandstand Premises: Casualty Rate

Between 1996 and 2006, there has only been a single casualty at a grandstand premises. This was a slight injury as a result of a fire ignited by the use of fireworks on Guy Fawkes Night[58].

The low incidence of casualty incidents prevents further meaningful analysis. It represents 25% of the overall injury rate for this premises type.

3.8 Temporary Accommodation Premises: Overall Trends

Temporary accommodation covers all structures where the majority of occupants sleep in the building but they do not actually live there. It covers motels, hotels, dormitories of schools and universities, backpackers, timeshare accommodation and home stay accommodation.

Between 996 and 2006 there were 145 fires in temporary accommodation premises, an average of 13 fires per year. This represents 8.6% of the total number of fires involving these structures. The average number of fires per year dropped from 17 fires per year in the first half of the study to 11 fires per year in the later half, a decrease of 33.7%. The deliberately lit fire rate for temporary accommodation premises is given as Figure 3.20.

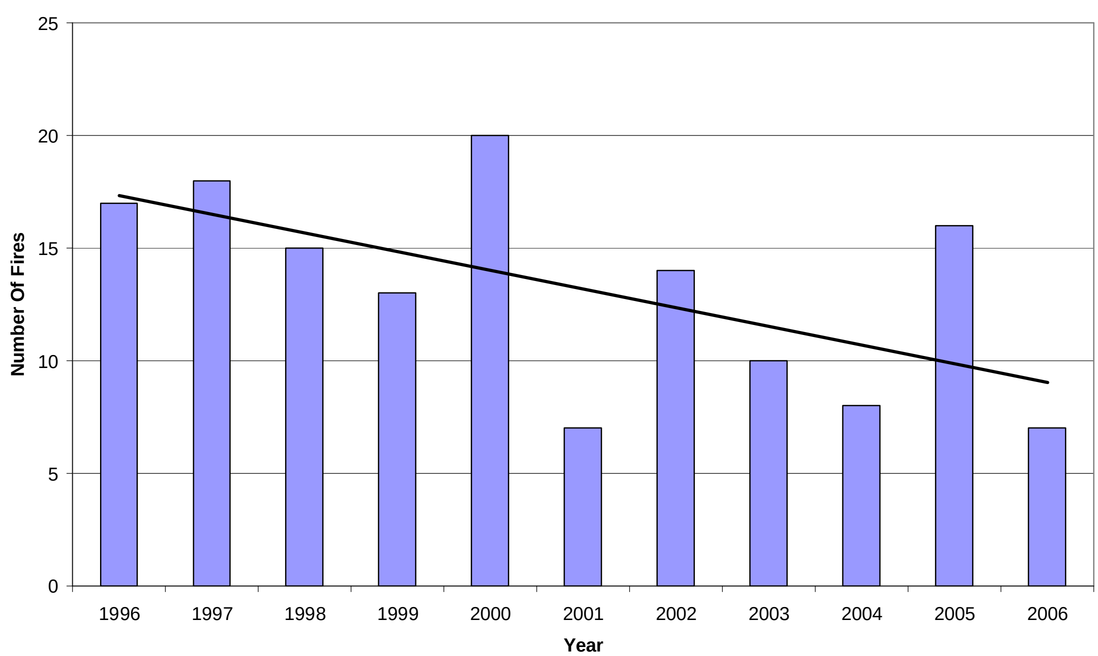

Figure 3.20: New Zealand temporary accommodation premises annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

3.8.1 Temporary Accommodation Premises: Time of Occurrence

Deliberately lit fires are more evenly distributed throughout the days of the week in temporary accommodation premises than in other premises. While the first half of the working week has a lower incidence of deliberately lit fires, the latter half of the working week has a rate that is virtually the same as the weekend. The daily distribution of incidents is given as Figure 3.21.

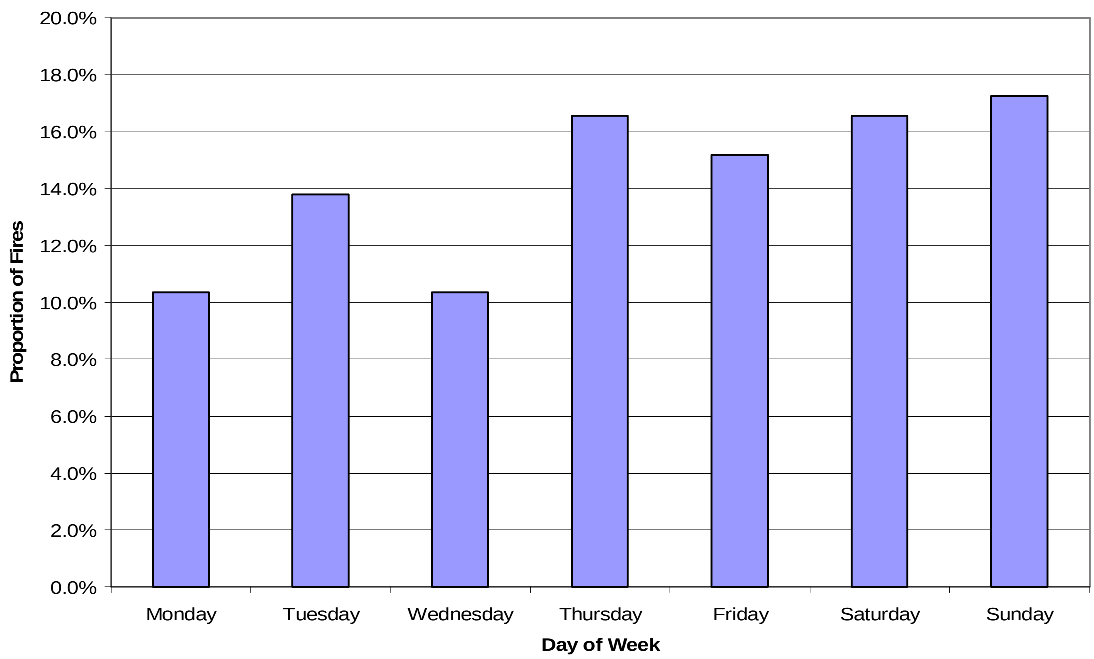

Figure 3.21: New Zealand temporary accommodation premises deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

On an hourly basis the general trend is the same as for other purpose groups with the maximum probability of an attack occurring during the night and the minimum probability occurring during the late morning. The hourly probability of a deliberately lit fire occurring is given as Figure 3.22. However, these premises are likely to have their greatest occupancy during their time of greatest risk - during the evenings and weekends.

Occupants may also be unfamiliar with the building further increasing the risk to life safety.

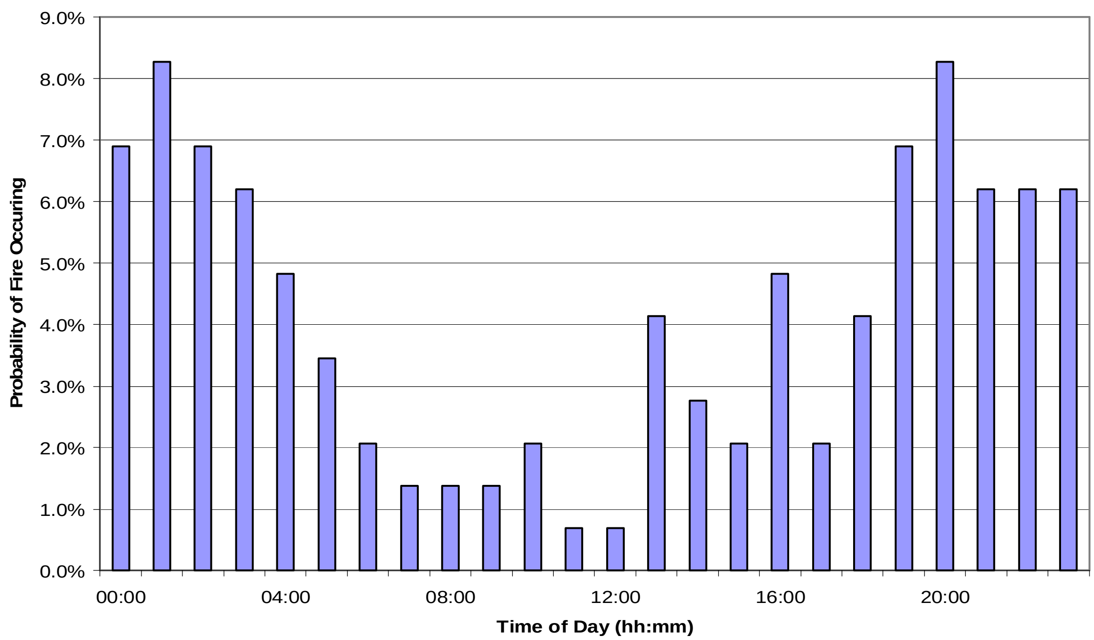

Figure 3.22: New Zealand temporary accommodation premises deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.8.2 Temporary Accommodation Premises: Compartment of Origin

The most common compartment of origin for deliberately lit fires in temporary accommodation structures is given as Table 3.12. The single most likely location for a deliberately lit fire is a bedroom, accounting for almost a third of all incidents. In most hotels and motels access to these compartments requires a key. This, combined with the time that deliberately lit fires are most likely to be started suggests that staff, a guest or someone with a guest is the most likely person to light a fire in these premises. This has implications for the security of the building as these individuals cannot reasonably be denied access.

Overall, the distribution of location of origin is highly skewed, with the top three items accounting for 50.3% of all incidents and six entries achieving more than 5% of the total. The incidence of fires being lit in multiple compartments is low at 0.7%.

Most Common Location Of Origin	**No. of Incidents**	**% of Total**
Bedroom, Sleeping area, Cell: under 5 persons	46	31.7%
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	15	10.3%
Garage, Carport, Vehicle storage, Storage Shed	12	8.3%
Lounge, Common room, TV room, Sitting room, Music room	11	7.6%
Hallway, Passageway, Corridor, Walkway in mall	9	6.2%
Kitchen, Cooking area	8	5.5%
Wall surface (exterior)	5	3.4%
Wardrobe, Cupboard, Walk in pantry	4	2.8%
Wall assembly: Concealed wall space	3	2.1%
Patio, Court, Terrace, Gazebo	3	2.1%
Other location of origin	29	20%
Total	**145**	**100.0%**

Table 3.12: Most frequent location of fire origin for deliberately lit fires in New Zealand temporary accommodation premises between 1996 and 2006 (FIRS statistics).

3.8.3 Temporary Accommodation Premises: Object First Ignited

The most commonly ignited objects for temporary accommodation are listed as Table 3.13 and this list has strong similarities to that of other types of premises. One difference that is readily apparent is the decreased significance of paper items and an increased incidence of bedding and cloth items. This is likely to be due to the presence of such items in a typical motel bedroom. With the exception of flammable liquids none of these items would be considered unusual in this type of building. The incidence of igniting multiple fires is 0.7% and the total use of accelerants is 4.8%. This gives 5.5% of deliberately lit fires where an appropriately chosen design fire may be inadequate.

Most Common Object First Ignited	**No. of Incidents**	**% of Total**
Newspaper, Magazine, Files	19	13.1%
Unknown	16	11.0%
Curtains, Blinds, Drapes	15	10.3%
Rubbish, Garbage, Waste	12	8.3%
Upholstered Furniture e.g. Chairs, Sofas, Beds, Vehicle Seats	10	6.9%
Bedding e.g. Blankets, Sheets, Duvet	9	6.2%
Flammable liquid and gases (not aerosols or propellants)	7	4.8%
Bedding e.g. Mattress, Pillow	6	4.1%
Rubbish in bin inside a structure, Ashtray	6	4.1%
Paper; excluding newspaper or rolled paper	5	3.4%
Box, Carton, Bag	5	3.4%
Framing, Structural member, Interior walls and doors	4	2.8%
Clothing (Not being worn)	4	2.8%
Special items - not classified above	3	2.1%
Linen e.g. Towels, Tablecloths (NOT Bedding)	3	2.1%
Other object first ignited	21	14.5%
Total	**145**	**100.0%**

Table 3.13: Items most frequently ignited in deliberately lit fires in New Zealand temporary accommodation premises between 1996 and 2006 (FIRS statistics).

3.8.4 Temporary Accommodation Premises: Casualty Rate

Between 1996 and 2006, there have been nine incidents where people have been injured in deliberately lit fires in temporary accommodation. This has resulted in one fatality, two life threatening injuries, four moderate injuries and seven slight injuries. This is much higher than what has been encountered in most other premises.

The fatality was involved in a fire where petrol had been used to accelerate the fire growth, however on arrival of the fire service the fire was classed as a small fire. The victim was recorded as being involved with the fires ignition with nothing preventing their escape[59] suggesting that this may have been a case of suicide by fire.

The two most significant fire scenarios, accounting for over half of the remaining events, was the ignition of either bedding or furniture in a bedroom or lounge. These incidents accounted for eight of the injuries including both of the life threatening injuries.

Deliberately lit fires are over-represented in the casualty statistics for temporary accommodation premises making up 16.7% of all fatalities and 16.2% of all injuries in this type of premises.

3.9 Care Accommodation Premises: Overall Trends

Care accommodation covers all locations where people reside for a period of time under professional care. It covers all hospitals, hospices, old aged care and psychiatric institutions. The common element in this type of premises is that the residents, for some reason, are unable to look after themselves. These premises require particular consideration by the fire engineer as the ability for most occupants to escape is likely to be impaired.

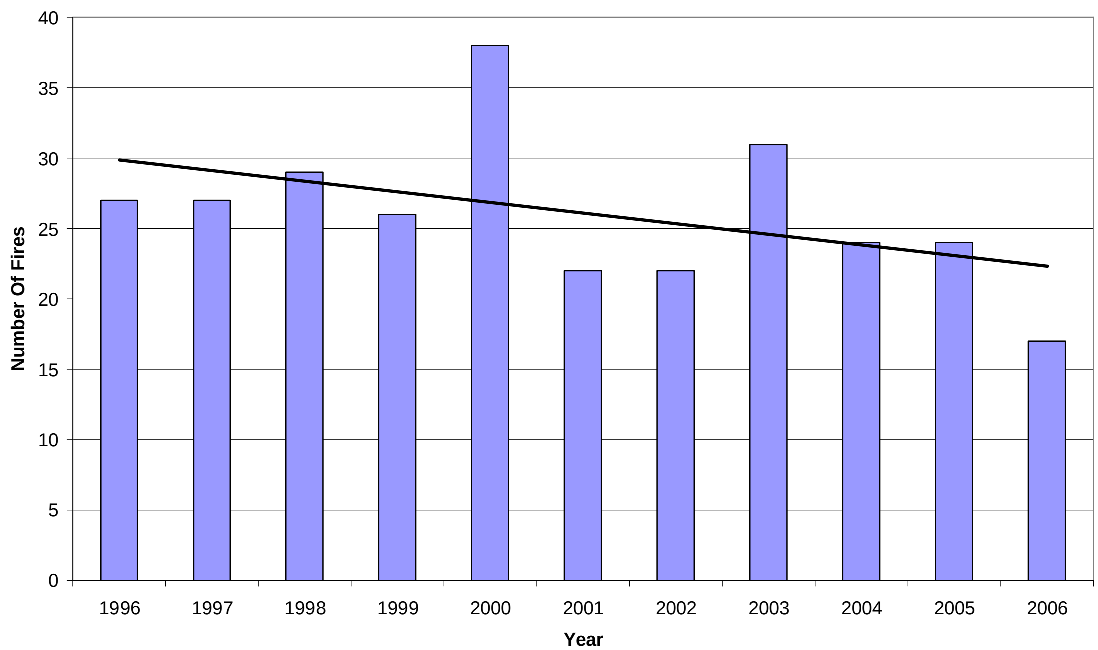

Figure 3.23: New Zealand care accommodation premises annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

Between 1996 and 2006, there were 287 deliberately lit fires in care accommodation premises. This represents 16.6% of all fires in this building category. Deliberately lit fires in this building category are dominated by fires in facilities for the mentally handicapped, accounting for 64.5% of all deliberately lit fires in this category of building. Approximately half of all fires in psychiatric institutions are deliberately lit. If deliberately lit fires in psychiatric institutions are excluded, the proportion of fires that is deliberately lit drops to 7.5%. The average number of incidents has decreased from 29 incidents per year to 24 incidents per year, a decrease of 19.7%. The annual deliberately lit fire rate is given as Figure 3.23.

3.9.1 Care Accommodation Premises: Time of Occurrence

Deliberately lit fires in care premises show little bias towards occurring on any specific day. As these incidents are dominated by fires in psychiatric institutions this is not unexpected. The daily deliberately lit fire rate is given as Figure 3.24.

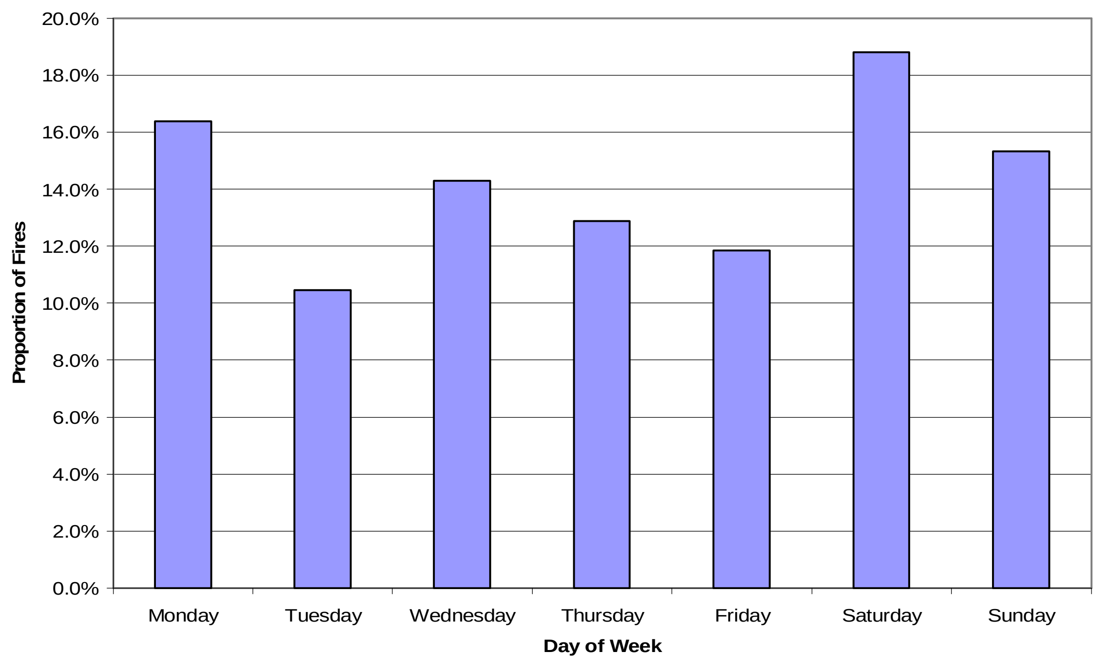

Figure 3.24: New Zealand care accommodation premises deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

There is considerable scatter in the hourly distribution of deliberately lit fires as shown in Figure 3.25. The plot may be divided into two roughly equal periods. Deliberately lit fires are twice as likely to occur during the afternoon and evening period, compared with the morning period. The peak incidence occurs earlier at 8 p.m. and the minimum rate occurs between 5 and 9 a.m.

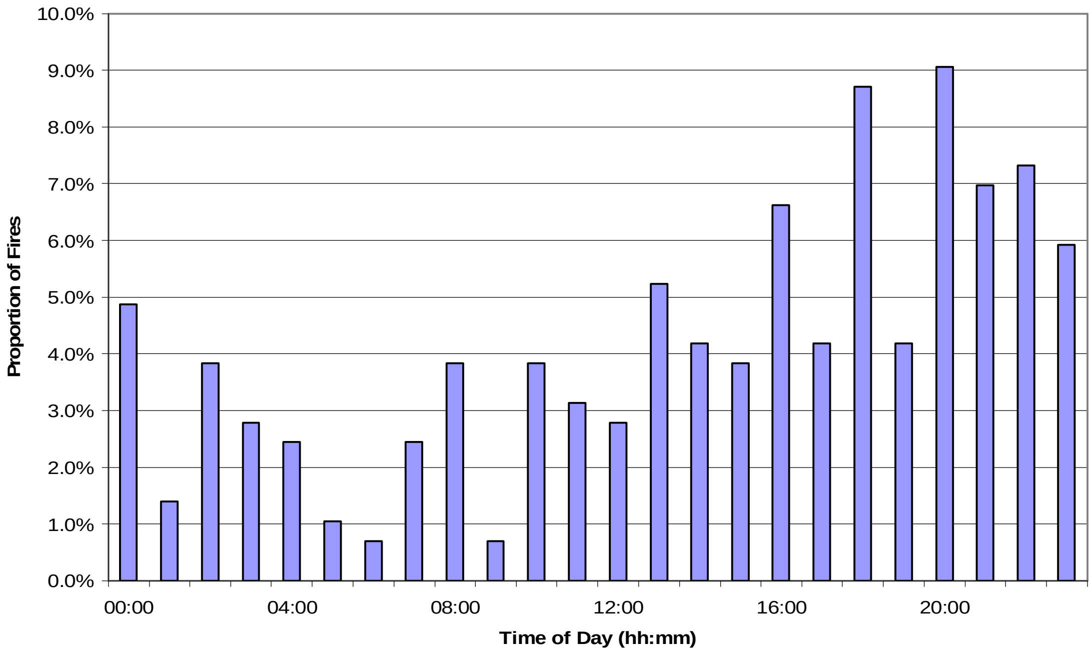

Figure 3.25: New Zealand care accommodation premises deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.9.2 Care Accommodation Premises: Compartment of Origin

There is much less variation in the choice of location to origin in care accommodation premises. This suggests that the typical perpetrator does not have the same access to the structure as those who light fires in other premises. Most deliberately lit fires are started in either the toilets or bedroom. Table 3.14 lists the other common locations of origin. Overall, the distribution of location of origin is very highly skewed, with the top three items accounting for 76.4% of all incidents and three entries achieving more than 5% of the total. The incidence of fires being lit in multiple compartments is low at 0.3%.

Most Common Location Of Origin	Frequency	% of Total
Bedroom, Sleeping area, Cell: under 5 persons	130	45.3%
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	59	20.6%
Lounge, Common room, TV room, Sitting room, Music room	30	10.5%
Hallway, Passageway, Corridor, Walkway in mall	10	3.5%
Bedroom, Sleeping area, Cell: 5 or more persons	8	2.8%
Wall surface (exterior)	7	2.4%
Other compartment of origin	43	15.0%
Total	**287**	**100.0%**

Table 3.14: Most frequent location of fire origin for deliberately lit fires in New Zealand care accommodation premises between 1996 and 2006 (FIRS statistics).

3.9.3 Care Accommodation Premises: Object First Ignited

As shown in Table 3.15, most deliberately lit fires in care accommodation premises are started using paper, cloth products or upholstered furniture, none of which would be considered out of the ordinary in these premises. With only 1.4% of fires lit using accelerants it is likely that access to accelerants may be limiting activity. The ignition of multiple fires is also low, only 1.4% of fires having multiple objects ignited. Based on this only 2.8% of fires are likely to challenge an appropriately selected design fire. The typical object ignited, combined with the location, time of day and the fact that the majority of deliberately lit fires in these premises occur in psychiatric institutions suggests that it is the patients that are responsible for lighting the majority of the fires.

Most Common Object First Ignited	No. of Incidents	% of Total
Bedding e.g. Blankets, Sheets, Duvet	51	17.8%
Rubbish, Garbage, Waste	28	9.8%
Bedding e.g. Mattress, Pillow	25	8.7%
Linen e.g. Towels, Tablecloths (NOT Bedding)	19	6.6%
Newspaper, Magazine, Files	18	6.3%
Curtains, Blinds, Drapes	18	6.3%
Upholstered Furniture e.g. Chairs, Sofas, Beds, Vehicle Seats	15	5.2%
Paper; excluding newspaper or rolled paper	15	5.2%
Clothing (Not being worn)	15	5.2%
Rolled material, Rolled paper (not newspaper)	14	4.9%
Box, Carton, Bag	11	3.8%
Rubbish in bin inside a structure, Ashtray	8	2.8%
Cabinetry e.g. Desks, Tables, Drawers, Shelving, Wardrobe, Piano	6	2.1%
Other object first ignited	43	15.0%
Total	**287**	**100.0%**

Table 3.15: Items most frequently ignited in deliberately lit fires in New Zealand care accommodation premises between 1996 and 2006 (FIRS statistics).

3.9.4 Care Accommodation Premises: Casualty Rate

Between 1996 and 2006, there were eighteen casualty incidents resulting in eight moderate and eighteen slight injuries. The eight moderate injuries represent 30.8% of all moderate and life threatening injuries in care accommodation during the study period. Deliberately lit fires are over-represented in the injury statistics for care accommodation; however, with no fatalities attributed to deliberately lit fires they are under-represented in the fatality statistics. As deliberately lit fires are over-represented in the injury statistics for old aged care, care of the sick and injured, care of the physically disabled, the exclusion of psychiatric institutions from the statistics does not change these results significantly.

While the majority of casualty incidents started in a bedroom, those fires that started in the lounges and television rooms represent a greater threat to life safety. Such rooms typically have a greater occupancy than bedrooms and therefore removing building occupants from the compartment of fire origin is likely to be more difficult to achieve within the limited time available. Deliberately lit fires in lounges were twice as likely to result in a casualty incident compared with deliberately lit fires in bedrooms. With nine injuries attributed to fires in lounges, they resulted in almost as many injuries as the much more numerous bedroom fires.

3.10 Detention Accommodation Premises: Overall Trends

Detention accommodation covers all premises where most of the occupants reside and are not permitted to leave under normal circumstances. This covers prisons, the cells of police stations and detention facilities for youths. These structures face particular issues for fire engineers due to the requirement that occupants remain confined.

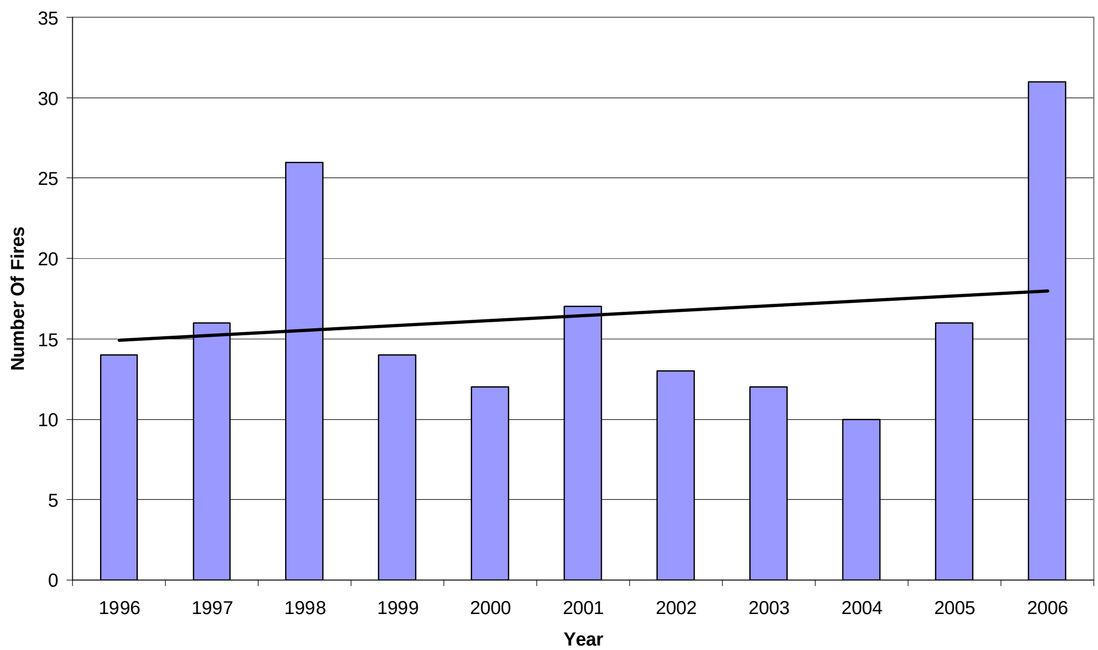

Figure 3.26: New Zealand detention accommodation annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

Between 1996 and 2006, there were 181 deliberately lit fires in detention accommodation premises. Deliberately lit fires make up 67.9% of all fires in these premises. These premises are more likely to experience a fire that is deliberately lit than one which is accidental. As illustrated in Figure 3.26, the long term trend for detention accommodation is distorted by a large number of incidents in 2006. Prior to 2006, these premises experienced an average of 15 incidents per year during the study period. There were 31 incidents in 2006, resulting in a 20% increase in the long term trend. If 2006 is treated as an anomalous year and not included in the trending then this building category has experienced a slight decrease in the number of incidents occurring each year.

3.10.1 Detention Accommodation Premises: Time of Occurrence

Detention facilities have an unusual daily trend, illustrated as Figure 3.27; they are the only type of premises that show a decrease in the rate of deliberately lit fires during the weekend. This may be due to activities that help to combat boredom such as visitation by family members which, due to other commitments, are more likely to occur at weekends.

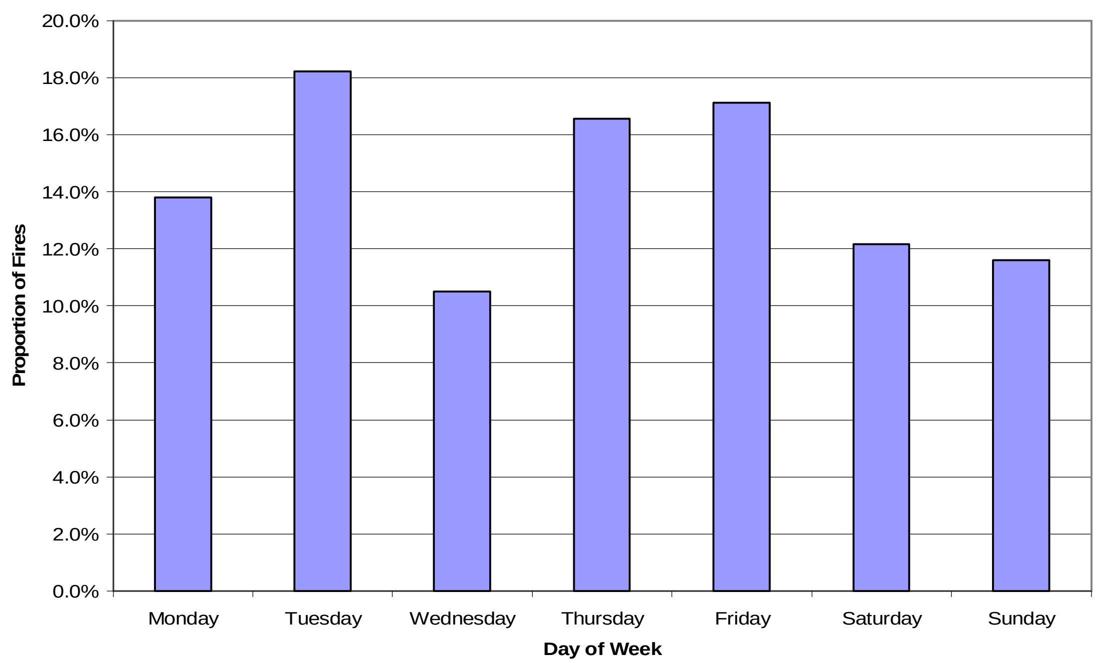

Figure 3.27: New Zealand detention accommodation deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

The distribution of deliberately lit fires throughout the day is strongly biased towards the evening period. One third of all deliberately lit prison fires are started between 6 and 8 p.m. This is likely to correspond to 'free' time where inmates do not have activities organised for them. Between the hours of 9 p.m. and 8 a.m. the incidence of deliberately lit fires decreases significantly. Prisoners are likely to be in their cells during this time and losses are likely to be borne by those who have lit the fire, a self correcting situation. Apart from a dip shortly after midday the incidence of deliberately lit fires in detention premises is essentially constant during daylight hours as shown in Figure 3.28.

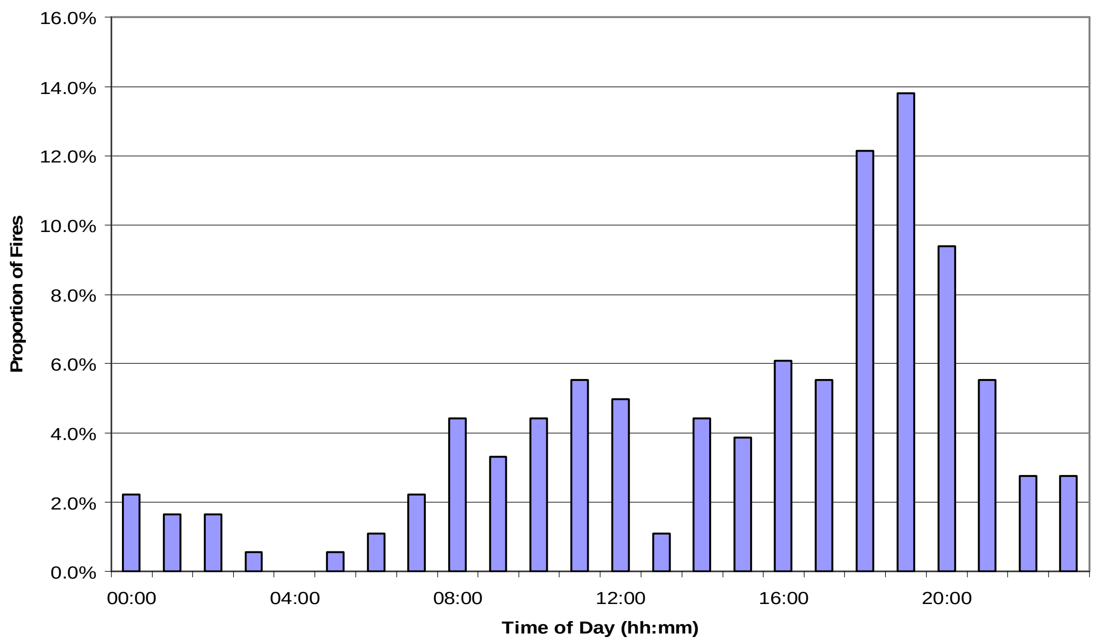

Figure 3.28: New Zealand detention accommodation deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.10.2 Detention Accommodation Premises: Compartment of Origin

Not surprisingly, the most likely compartment of origin for deliberately lit fires in prisons is a cell or other sleeping area. If the fires have been lit as an act of revenge then the most effective target is another inmate's personal possessions, which are likely to be in their cell. Other fires may be lit as an act of vandalism to get back at the authorities and these may be lit in other locations. The most common locations to light fires are given as Table

3.16. Overall, the distribution of location of origin is very highly skewed, with the top three items accounting for 76.2% of all incidents and three entries achieving more than 5% of the total. During the study period there were no fires which had multiple compartments of origin, considering the restrictions on mobility of the likely offender this is not considered surprising.

Most Common Location Of Origin	**No. of Incidents**	**% of Total**
Bedroom, Sleeping area, Cell: under 5 persons	113	62.4%
Hallway, Passageway, Corridor, Walkway in mall	16	8.8%
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	9	5.0%
Machinery room/area, Engine room, Refrigeration room, Pump room, Lift motor room	6	3.3%
Lounge, Common room, TV room, Sitting room, Music room	5	2.8%
Supply room/area, Tool room, Maintenance supply room	5	2.8%
Bedroom, Sleeping area, Cell: 5 or more persons	4	2.2%
Small assembly area: Classroom, Meeting room, Multi-purpose room	4	2.2%
Other location of origin	19	10.5%
Total	**181**	**100.0%**

Table 3.16: Most frequent location of fire origin for deliberately lit fires in New Zealand detention accommodation between 1996 and 2006 (FIRS statistics).

3.10.3 Detention Accommodation Premises: Object First Ignited

The use of paper, rubbish and bedding items dominate deliberately lit fires in detention facilities as shown in Table 3.17. Again only flammable liquids are likely to be considered as an introduced fuel. As expected, the use of accelerants in detention accommodation facilities is lower than in most other property types. This is almost certainly due to restrictions placed on the individuals. Only 3.3% of fires are assisted through the use of accelerants. Multiple items are ignited in 2.2% of cases giving a total of 5.5% of deliberately lit fires where an appropriately selected design fire may be inadequate.

Most Common Object First Ignited	No. of Incidents	% of Total
Newspaper, Magazine, Files	37	20.4%
Bedding e.g. Mattress, Pillow	24	13.3%
Bedding e.g. Blankets, Sheets, Duvet	21	11.6%
Rubbish, Garbage, Waste	20	11.0%
Paper; excluding newspaper or rolled paper	13	7.2%
Unknown	11	6.1%
Rolled material, Rolled paper (not newspaper)	9	5.0%
Flammable liquid and gases (not aerosols or propellants)	6	3.3%
Upholstered Furniture e.g. Chairs, Sofas, Beds, Vehicle Seats	5	2.8%
Clothing (Not being worn)	5	2.8%
Multiple items	4	2.2%
Other object first ignited	26	14.4%
Total	**181**	**100.0%**

Table 3.17: Items most frequently ignited in deliberately lit fires in New Zealand detention accommodation between 1996 and 2006 (FIRS statistics).

3.10.4 Detention Accommodation Premises: Casualty Rate

There were fifteen casualty incidents caused by deliberately lit fires in detention accommodation premises. These resulted in one fatality, two life threatening injuries, twenty-five moderate injuries and eleven slight injuries. This represents 50.0% of the fatalities and 96.4% of the life threatening and moderate injuries for this type of structure. Despite the fact that a fire in a prison being twice as likely to be deliberately lit as any other cause, deliberately lit fires totally dominate the casualty statistics.

Due to the mobility restrictions placed on inmates there is the opportunity to injure a number of individuals, there have been three separate incidents where more than four people have been injured including one where seventeen people were injured, one fatally. In virtually all casualty incidents the fire was started in a sleeping area or cell, with only a single casualty incident occurring in a lounge area. This incident resulted in only a single injury.

The ignition of bedding and blankets is the fire scenario most likely to result in a casualty. One in five deliberately lit fires started using these materials results in a casualty.

3.11 Detached Dwellings: Overall Trends

Detached dwellings cover all structures that are not physically attached to another inhabited building where people normally reside. This building category also includes granny flats and other freestanding buildings on private land. It does not cover structures such as apartments where multiple ownership titles exist for a single ratable block of land.

Between 1996 and 2006, there were 3735 deliberately lit fires in detached dwellings or an average of 340 such fires per year. This represents 8.5% of the total number of fires experienced by this building category of structure. This figure is very similar to Norwegian data for residential property[39]. Over the last ten years the number of deliberately lit fires has dropped from 368 to 323 incidents per year, a decrease of 12.3%, the annual deliberately lit fire rate is given in Figure 3.29.

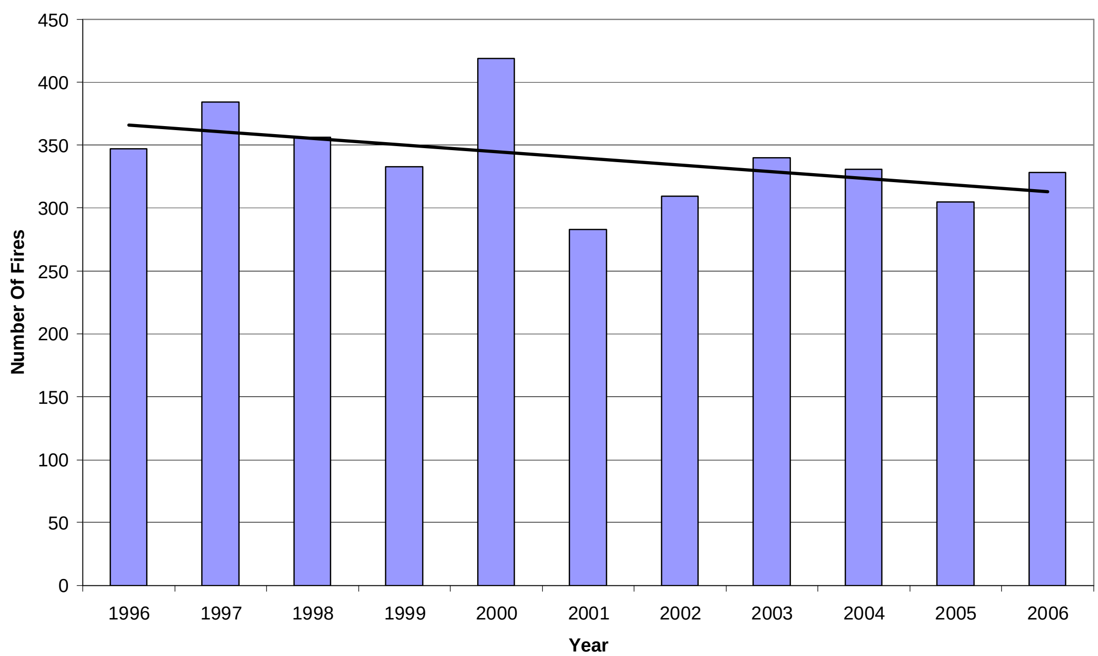

Figure 3.29: New Zealand detached dwelling annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

Detached dwellings dominate the annual statistics, both for the number of fires experienced and for the number of people injured and killed. Because of this, Figures 3.29, 3.30 and 3.31 are very similar to the overall deliberately lit fire data given as Figures 3.3, 3.4 and 3.5 respectively. While still required to meet the requirements of the New Zealand Building Code, logistical problems prevent effective policing of the regulations. Many private houses have been modified without any thought towards fire safety. This section has been included mainly for the sake of completeness.

3.11.1 Detached Dwellings: Time of Occurrence

As expected deliberately lit fires in private houses shows the normal bias. An incident is more likely to occur during the weekend with 36.8% of fires occurring during weekend hours. This is illustrated in Figure 3.30.

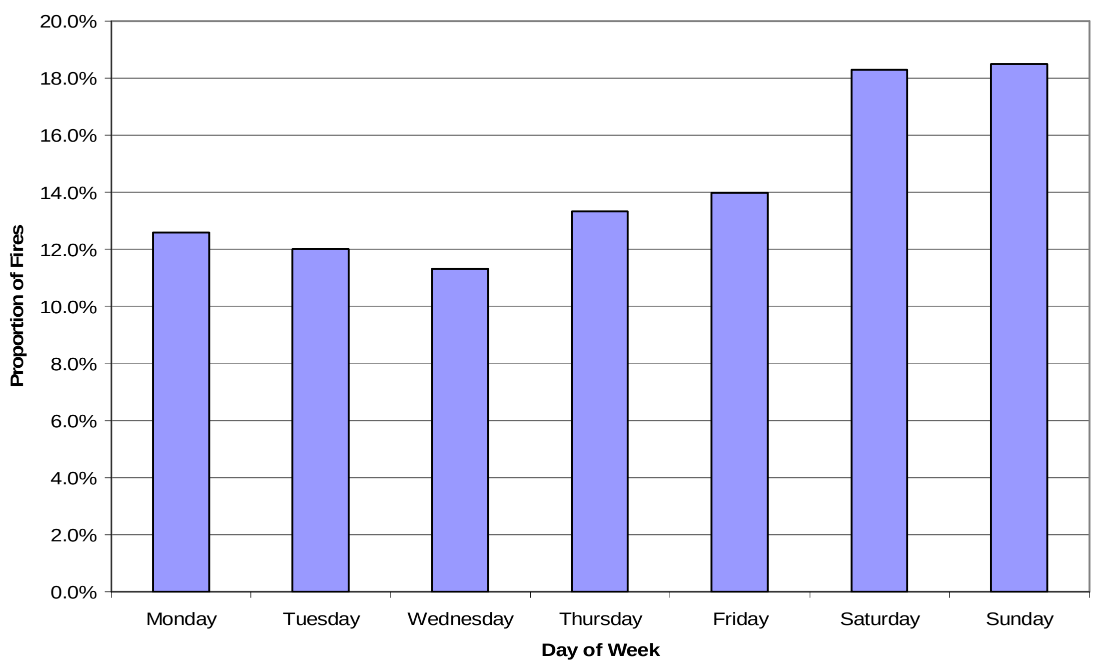

Figure 3.30: New Zealand detached dwelling deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

The hourly distribution of incidents is shown as Figure 3.31. It also shows the normal frequency distribution with the peak occurring at midnight followed by a rapid decrease in the frequency of incidents until the minimum frequency is reached, occurring at 9 a.m. There is a steady increase through the day and early evening.

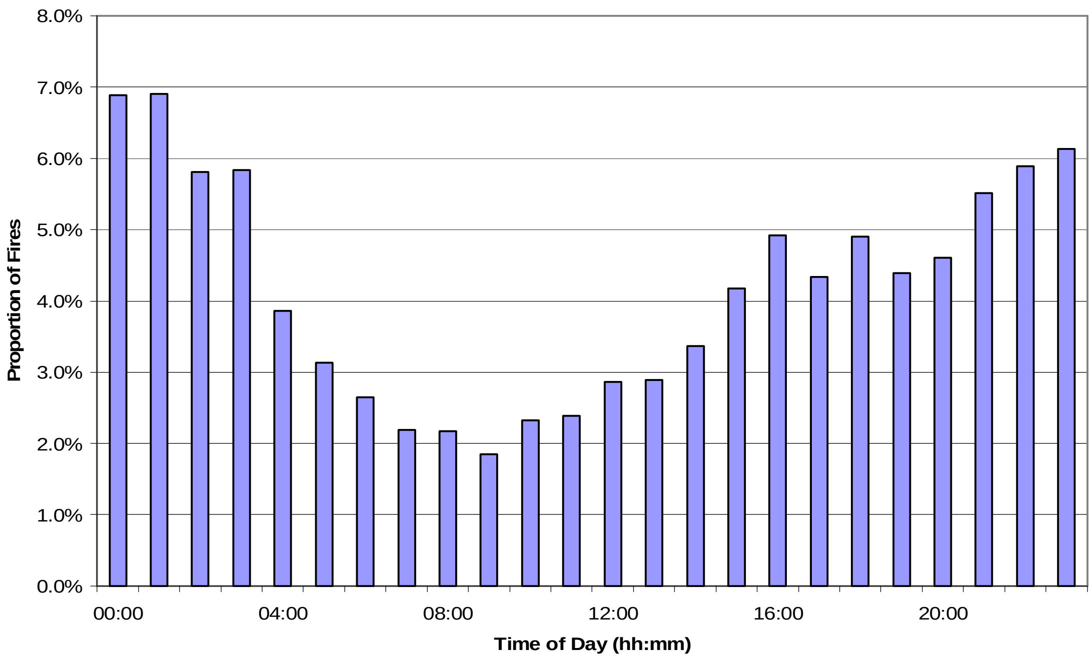

Figure 3.31: New Zealand detached dwelling premises deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.11.2 Detached Dwellings: Compartment of Origin

The most common location to start deliberate fires in detached dwellings is listed as Table 3.18. While generally similar to the overall statistics, the incidence of fires being lit in multiple areas is higher than most property types. Overall, the distribution of location of origin is highly skewed, with the top three items accounting for 52.6% of all incidents and four entries achieving more than 5% of the total.

Most Common Location Of Origin	**No. of Incidents**	**% of Total**
Garage, Carport, Vehicle storage, Storage Shed	802	21.5%
Bedroom, Sleeping area, Cell: under 5 persons	620	16.6%
Lounge, Common room, TV room, Sitting room, Music room	541	14.5%
Kitchen, Cooking area	240	6.4%
Wall surface (exterior)	178	4.8%
Not Recorded	149	4.0%
Product storage, Tank, Bin, Agricultural storage, Hay barn, Hay stack	141	3.8%
Multiple areas of origin	113	3.0%
Hallway, Passageway, Corridor, Walkway in mall	87	2.3%
Other location of origin	864	23.1%
Total	**3735**	**100.0%**

Table 3.18: Most frequent location of fire origin for deliberately lit fires in New Zealand detached dwellings between 1996 and 2006 (FIRS statistics).

3.11.3 Detached Dwellings: Object First Ignited

The objects most commonly used to start fires in detached dwellings are listed in Table 3.19. There is considerable variation in the object used to start the fire as indicated by the fact that no positively identified object accounts for more than 8.2% of the total number of incidents. The high number of unknown objects is likely to be due to a combination of a lower level of post fire investigation (due to a lower monetary value of the structure) and the lack of fire protection in most houses resulting in more of the structure being destroyed.

The high incidence of accelerant use may be accounted for by the fact that many properties keep small quantities of solvents for domestic use and petrol for equipment such as lawnmowers. With this in mind, the use of accelerants may be over-represented and no item stands out as an introduced fuel. Accelerants are used more frequently in house fires than in any other property type, accounting for 8.6% of all fires. The ignition of multiple items accounts for another 6.1% of deliberately lit fires so 14.7% of deliberately lit fires may be more severe than an appropriately selected design fire.

Most Common Object First Ignited	No. of Incidents	% of Total
Unknown	550	14.7%
Rubbish, Garbage, Waste	307	8.2%
Flammable liquid and gases (not aerosols or propellants)	287	7.7%
Multiple items	227	6.1%
Newspaper, Magazine, Files	225	6.0%
Upholstered Furniture e.g. Chairs, Sofas, Beds, Vehicle Seats	203	5.4%
Framing, Structural member, Interior walls and doors	186	5.0%
Exterior side wall covering surface, Cladding (including eaves)	135	3.6%
Bedding e.g. Blankets, Sheets, Duvet	131	3.5%
Floor coverings: Carpets, Mats, Rugs	120	3.2%
Bedding e.g. Mattress, Pillow	116	3.1%
Interior wall covering	114	3.1%
Information not recorded	112	3.0%
Clothing (Not being worn)	109	2.9%
Agricultural: Hay, Straw (NOT food for human consumption)	107	2.9%
Curtains, Blinds, Drapes	103	2.8%
Box, Carton, Bag	92	2.5%
Other object first ignited	864	23.1%
Total	**3735**	**100.0%**

Table 3.19: Items most frequently ignited in deliberately lit fires in New Zealand detached dwellings between 1996 and 2006 (FIRS statistics).

3.11.4 Detached Dwellings: Casualty Rate

As stated, fires in detached dwellings dominate the overall fire casualty rate[60]. They also dominate the deliberately lit fire casualty statistics with 21 fatalities, 22 life threatening injuries 56 moderate injuries and 52 slight injuries. Three quarters of all deliberately lit fires deaths and 46.3% of all deliberately lit fire injuries occur in detached dwellings.

The casualties in deliberately lit fires represent 10.3% of all fatalities and 7.6% of all injuries in detached dwellings so deliberately lit fires are slightly overrepresented in the fatality statistics but slightly underrepresented in the injury statistics for detached dwellings. The only deliberately lit fires responsible for multiple deaths during the study period occurred in detached accommodation.

The most likely area for a fatal fire to occur was the bedroom or lounge with six fatal fires in each compartment. The next most common area for fatal fires was the kitchen with three fatal fires. One possible reason for this is result the probability that, in many house designs, a fire in a kitchen or lounge is able to prevent the use of the normal escape paths. When considering all casualty fires these three locations account for 60.6% of all casualty incidents.

With regards to the object first ignited, accelerants were used in 50.0% of all fatal fires and in 22.0% of all casualty incidents. This suggests that if accelerants are used an individual is twice as likely to be injured and 5.8 times as likely to be killed. While some of these fires may be attributed to suicide by fire, this is unlikely to reverse this trend.

3.12 Attached Dwellings: Overall Trends

Attached dwellings cover all cases where multiple property titles are present on a single section of ratable land. This covers all apartment buildings, units that share a common boundary (e.g. a wall) as well as residential units located above shops. Between 1996 and 2006, there were a total of 577 deliberately lit fires in attached dwellings, an average of 52 per year. Deliberately lit fires make up 8.6% of all fires in this building category. The long term trend has increased from an average of 50 fires per year to 56 fires per year, an increase of 10.7%. The annual deliberately lit fire rate for attached dwellings is given as Figure 3.32.

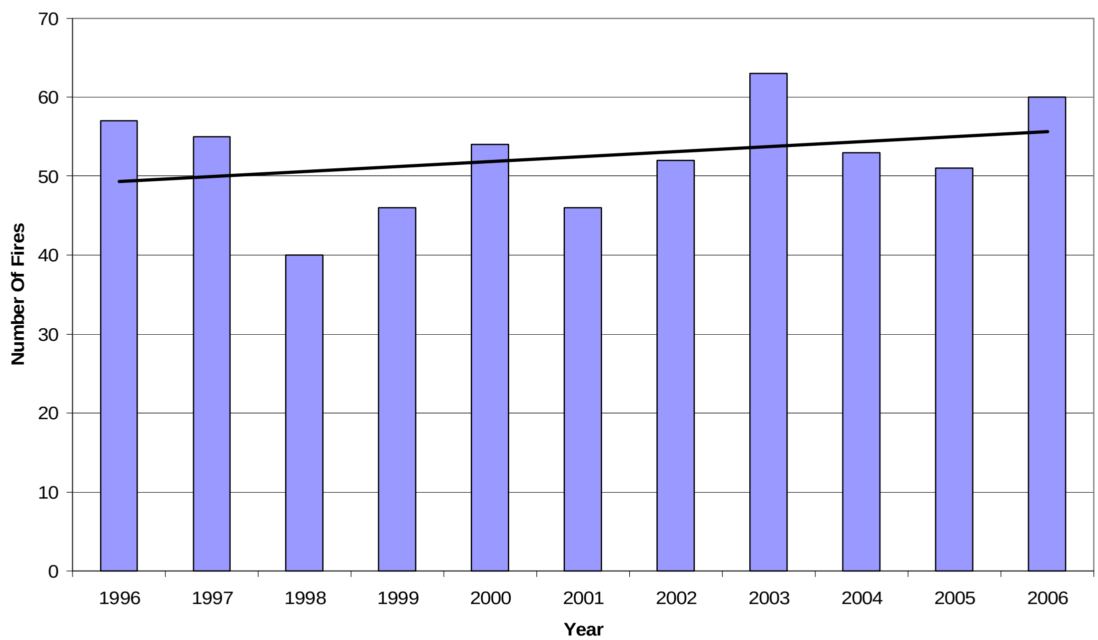

Figure 3.32: New Zealand attached dwelling annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

3.12.1 Attached Dwellings: Time of Occurrence

As shown in Figure 3.33, the daily distribution of deliberately lit fires is biased towards the weekend days with 39.0% of fires occurring on a either a Saturday or Sunday. The distribution during the week is essentially flat with no weekday standing out.

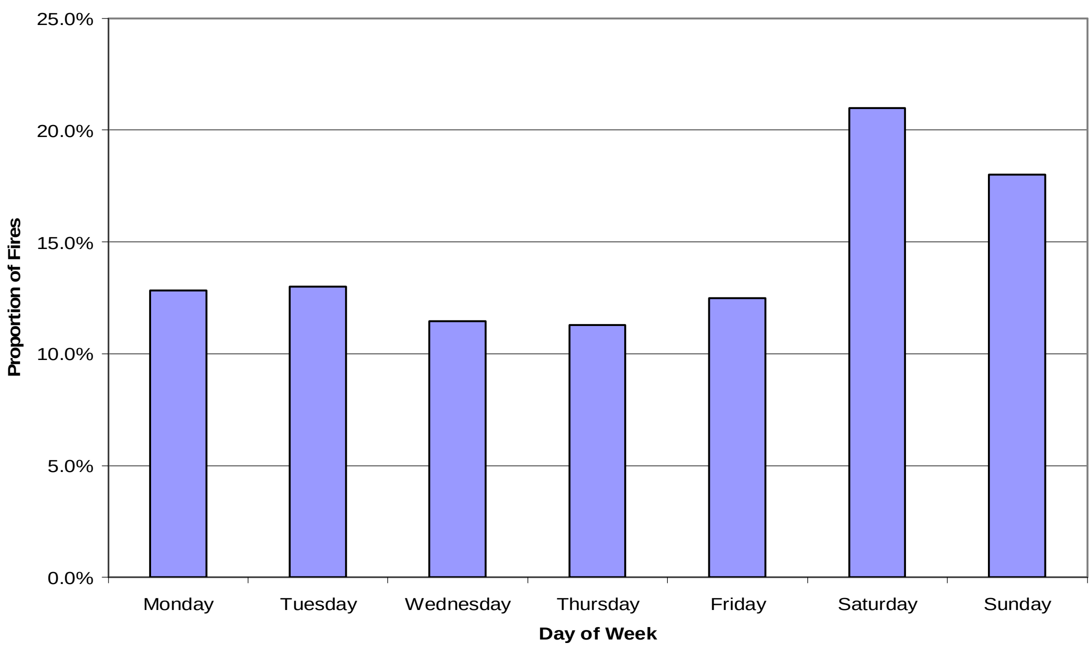

Figure 3.33: New Zealand attached dwelling deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

When looking at the distribution of deliberately lit fires by hour, in Figure 3.34, the amount of scatter in the results is readily apparent. While the peak and trough occur at approximately the same time as the overall trend, the chart is punctuated by a number of peaks in the data. The main issue for the fire engineer is that the time where most deliberately lit fires occur in attached dwellings corresponds with both the time of the highest occupancy and the lowest awareness of the building occupants, during the night hours.

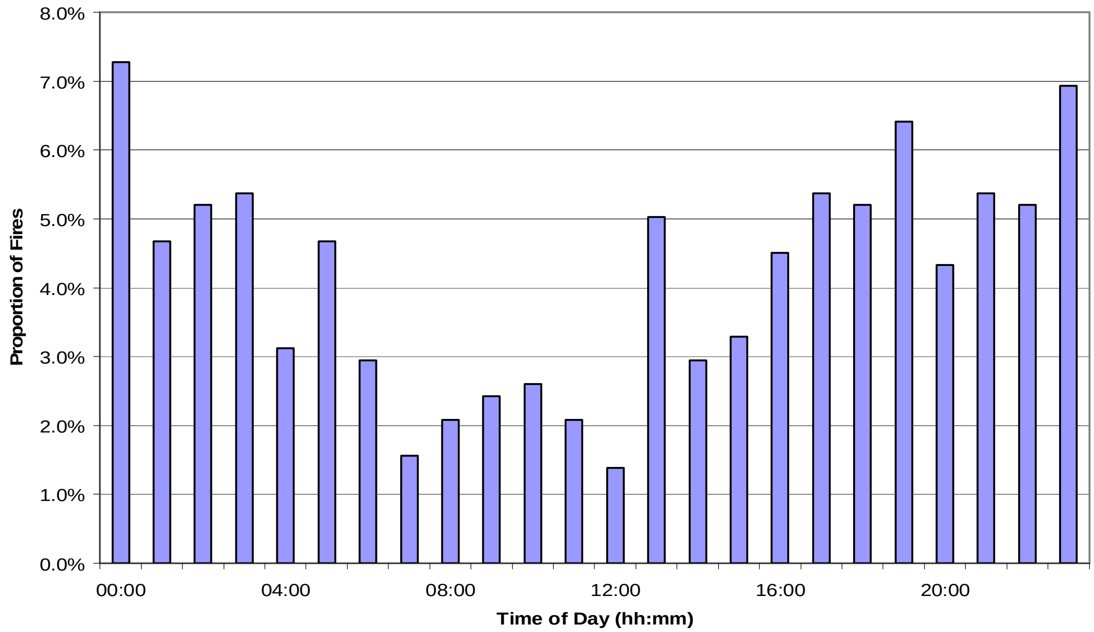

Figure 3.34: New Zealand attached dwelling premises deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.12.2 Attached Dwellings: Compartment of Origin

Three of the four most common compartments of origin for attached dwellings are bedrooms, lounges and kitchens which are all typically located within the apartment unit. This suggests that access beyond building security is not a strong barrier to the perpetrators.

The incidence of fires being lit in multiple compartments is not high with 1.2% of fires having multiple compartments of origin. Table 3.20 summarises the most likely compartments of origin. Overall, the distribution of location of origin is highly skewed, with the top three items accounting for 53.8% of all incidents and five entries achieving more than 5% of the total.

Most Common Location Of Origin	**No. of Incidents**	**% of Total**
Bedroom, Sleeping area, Cell: under 5 persons	112	19.4%
Garage, Carport, Vehicle storage, Storage Shed	103	17.9%
Lounge, Common room, TV room, Sitting room, Music room	95	16.5%
Kitchen, Cooking area	44	7.6%
Wall surface (exterior)	34	5.9%
Hallway, Passageway, Corridor, Walkway in mall	24	4.2%
Lobby, Entrance way	19	3.3%
Rubbish, Industrial waste, Waste container	15	2.6%
Patio, Court, Terrace, Gazebo	14	2.4%
Other location of origin	117	20.3%
Total	**577**	**100.0%**

Table 3.20: Most frequent location of fire origin for deliberately lit fires in New Zealand attached dwellings between 1996 and 2006 (FIRS statistics).

3.12.3 Attached Dwellings: Object First Ignited

Most Common Object First Ignited	**No. of Incidents**	**% of Total**
Rubbish, Garbage, Waste	94	16.3%
Newspaper, Magazine, Files	61	10.6%
Upholstered Furniture e.g. Chairs, Sofas, Beds, Vehicle Seats	54	9.4%
Flammable liquid and gases (not aerosols or propellants)	43	7.5%
Unknown	36	6.2%
Bedding e.g. Blankets, Sheets, Duvet	32	5.5%
Clothing (Not being worn)	27	4.7%
Bedding e.g. Mattress, Pillow	26	4.5%
Curtains, Blinds, Drapes	26	4.5%
Multiple items	24	4.2%
Box, Carton, Bag	17	2.9%
Floor coverings: Carpets, Mats, Rugs	17	2.9%
Exterior side wall covering surface, Cladding (including eaves)	12	2.1%
Other object first ignited	108	18.7%
Total	**577**	**100.0%**

Table 3.21: Items most frequently ignited in deliberately lit fires in New Zealand attached dwellings between 1996 and 2006 (FIRS statistics).

As illustrated by Table 3.21, the items most likely to be ignited in deliberately lit fires in attached dwellings are rubbish, paper items, upholstered furniture and cloth items. While not as common as in detached dwellings, there is a significant proportion of fires where the item first ignited is not positively identified. There are no items in the data that stands out as introduced fuels. Accelerants are used in 8.3% of deliberately lit fires and multiple fires within a single fire compartment are lit in 4.2% of deliberately lit fires. This results in 12.5% of fires where an appropriately selected design fire may be inadequate.

3.12.4 Attached Dwellings: Casualty Rate

Between 1996 and 2006, there have been 47 casualty incidents in attached dwellings resulting in 4 fatalities, 10 life threatening injuries, 17 moderate injuries and 25 slight injuries. Thus the 8.6% of deliberately lit fires result in 9.4% of all fatalities and 8.8% of all injuries, indicating that deliberately lit fires are fairly evenly represented in the casualty statistics for this category of building. The distribution of casualty incidents by compartment of origin is similar to what is observed in detached dwellings with bedrooms, lounges and kitchens making up over three quarters of casualty incidents.

The distribution of casualty incidents by object first ignited shows that the most hazardous scenarios are related to the fire being started in bedding material where one in five fires started on bedding results in a casualty. The presence of polyurethane in many mattresses is likely to be a contributing factor. Other fast fires such as upholstered furniture and drapes are also over-represented in the casualty statistics. This is consistent with the conclusions of US studies which have identified upholstered furniture and mattresses as the most likely cause of death in fires[61]. Accelerated fires are also over-represented in the casualty statistics with one in seven fires where accelerants have been used resulting in a casualty.

3.13 Working Premises: Overall Trends

The working premises category covers buildings where people go to complete their business activities. It covers all office buildings, banks, embassies and buildings operated by the defense forces. Between 1996 and 2006, there were 272 fires that were identified as being deliberately lit or 25 fires per year. This corresponds to 15.5% of the total number of fires in this building category. The overall trend is down for this category is downwards, decreasing from 29 to 21 fires per year, a decrease of 24.5%. From Figure 3.35 below it is apparent that there were considerably more deliberately lit fires in 1996 than in other years of the study. If this year is omitted as an outlier then the reduction in fires in this category is reduced to 10.7%.

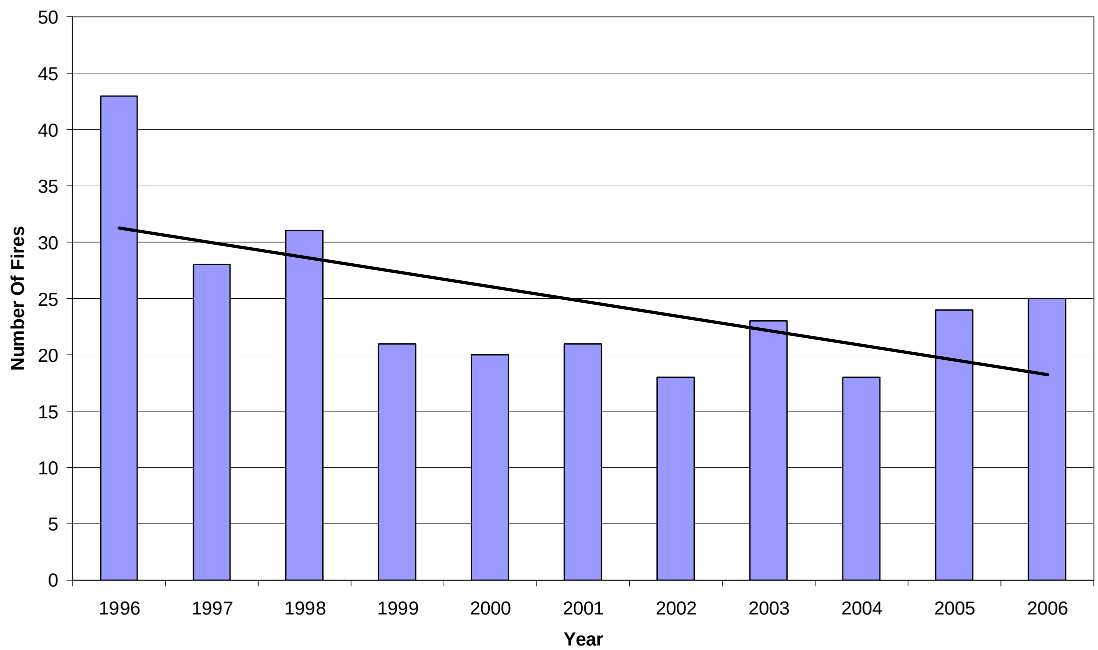

Figure 3.35: New Zealand working premises annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

3.13.1 Working Premises: Time of Occurrence

While this building category shows some bias towards fires occurring during the weekend, this bias is less than what is observed with most other property categories. As shown by Figure 3.36, 36.7% of all fires occurred on a Saturday or Sunday. The daily incidence of deliberately lit fires is essentially flat during the working week before increasing over the course of the weekend.

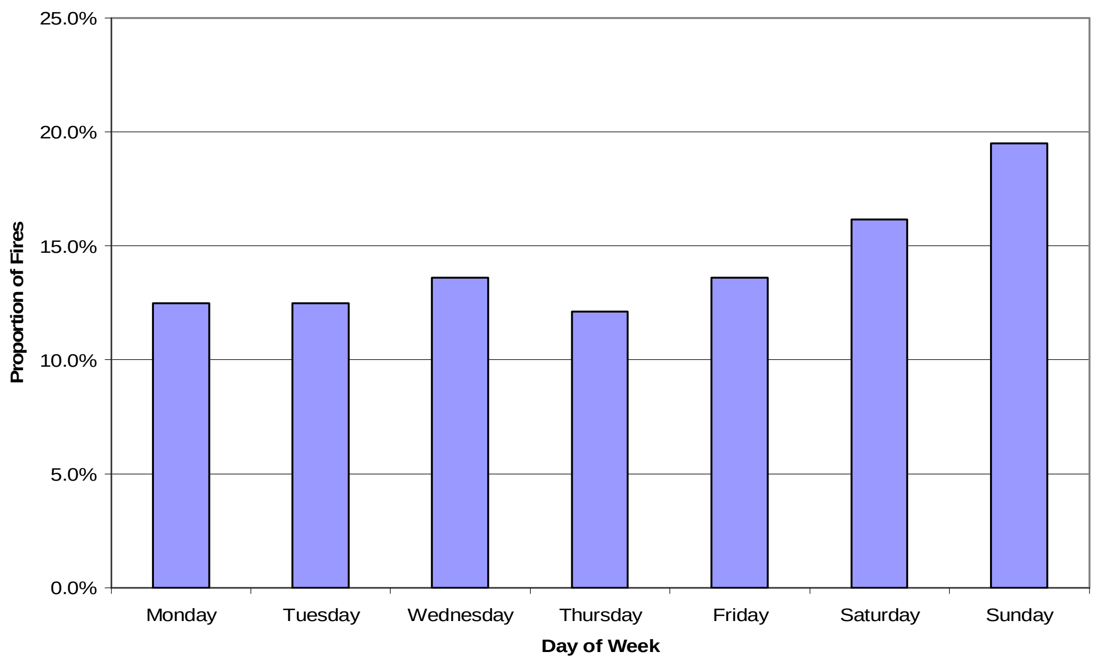

Figure 3.36: New Zealand working premises deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

The distribution of deliberately lit fires by hour (shown as Figure 3.37) is unusual as it has the presence of a second peak occurring during the middle of the afternoon. This drop off at 5 p.m. is likely to correspond with workers departing their place of work and the increased activity increasing the risk to the perpetrator. Both the most likely and least likely times for a deliberately lit fire to occur appear to be delayed slightly compared with the overall statistics. As the majority of these fires are recorded as fires in offices and the like, then this is unlikely to correspond to changes of shift. With the exception of the daily minimum at 10 a.m. and the afternoon peak at 2 p.m., the incidence of deliberately lit fires between 4 a.m. and 6 p.m. is essentially constant.

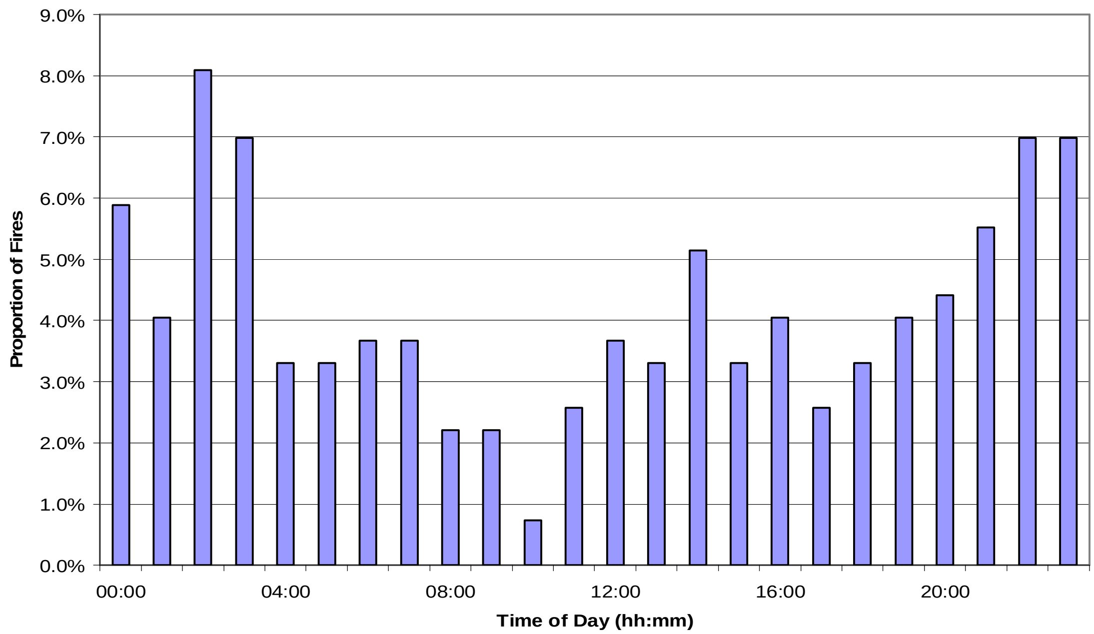

Figure 3.37: New Zealand working premises deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.13.2 Working Premises: Compartment of Origin

The most common compartment of origin in working premises is given as Table 3.22. Overall, the distribution of location of origin is flat, with the top three items accounting for 29.8% of all incidents and six entries achieving more than 5% of the total. While the most common locations for fires in working premises are in locations where the public have ready access, the flat distribution of the most common locations prevents clear identification of trends. The incidence of fires being lit in multiple compartments is low at 1.5%.

Most Common Location Of Origin	No. of Incidents	% of Total
Wall surface (exterior)	33	12.1%
Lobby, Entrance way	25	9.2%
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	23	8.5%
Garage, Carport, Vehicle storage, Storage Shed	19	7.0%
Office	19	7.0%
Hallway, Passageway, Corridor, Walkway in mall	15	5.5%
Bedroom, Sleeping area, Cell: under 5 persons	10	3.7%
Supply room/area, Tool room, Maintenance supply room	9	3.3%
Rubbish, Industrial waste, Waste container	8	2.9%
Manufacturing, Process, Work room	8	2.9%
Unable to classify	7	2.6%
Small assembly area: Classroom, Meeting room, Multi-purpose room	6	2.2%
Showroom, Sales area	6	2.2%
Other location of origin	84	30.8%
Total	**272**	**100.0%**

Table 3.22: Most frequent location of fire origin for deliberately lit fires in New Zealand working premises between 1996 and 2006 (FIRS statistics).

3.13.3 Working Premises: Object First Ignited

The objects most likely to be ignited first are listed in Table 3.23. The high incidence of paper materials is not unsurprising; most offices contain a large quantity of files giving a ready source of fuel that is easily ignited. With the exception of flammable liquids, all of the items listed in Table 3.23 are likely to be present in a typical office environment indicating the use of transitory fuel loads is unlikely. Accelerants are used in 4.8% of deliberately lit fires and multiple fires within a single fire compartment are lit in 1.8% of deliberately lit fires for this property type. In 6.6% of fire incidents an appropriately selected design fire may be inadequate.

Most Common Object First Ignited	No. of Incidents	% of Total
Rubbish, Garbage, Waste	61	22.4%
Newspaper, Magazine, Files	29	10.7%
Paper; excluding newspaper or rolled paper	29	10.7%
Unknown	14	5.1%
Box, Carton, Bag	14	5.1%
Rolled material, Rolled paper (not newspaper)	14	5.1%
Flammable liquid and gases (not aerosols or propellants)	9	3.3%
Rubbish in bin inside a structure, Ashtray	9	3.3%
Floor coverings: Carpets, Mats, Rugs	7	2.6%
Exterior side wall covering surface, Cladding (including eaves)	7	2.6%
Basket, Barrel, Rubbish bin (NOT rubbish in bin)	7	2.6%
Curtains, Blinds, Drapes	6	2.2%
Packing, Wrapping material	6	2.2%
Other object first ignited	60	22.1%
Total	**272**	**100.0%**

Table 3.23: Items most frequently ignited in deliberately lit fires in New Zealand working premises between 1996 and 2006 (FIRS statistics).

3.13.4 Working Premises: Casualty Rate

Between 1996 and 2006, there were no casualties recorded for fires that were deliberately lit. There were no fatalities and seven injuries recorded for all fires in the working premises category. The lack of casualties prevents further analysis.

3.14 Manufacturing and Storage Premises: Overall Trends

Manufacturing and storage premises cover all industrial and storage facilities. It covers all manufacturing sites, both for primary and secondary industries as well as all forms of storage facilities, ranging from finished product storage though to domestic storage companies. Between 1996 and 2006, these premises experienced 723 deliberately lit fires, an average of 66 fires per year. This represents 11.0% of the total number of fires that occurred in this property category. The annual incidence of deliberately lit fires in this property type is given as Figure 3.38. During the course of the study the annual number of incidents in this property group has declined from 70 incidents per year to 63 incidents per year, a decrease of 10.5%.

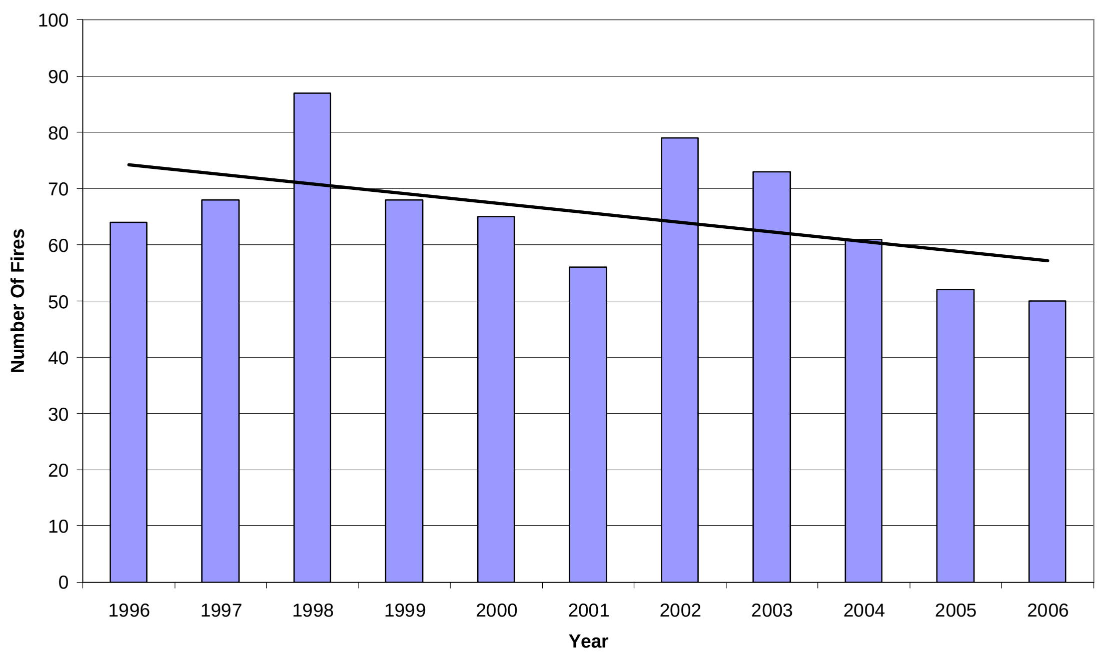

Figure 3.38: New Zealand manufacturing and storage premises annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

Deliberately lit fires in these premises are dominated by fires in storage facilities, 46% of all deliberately lit fires in this building category occurred in storage facilities. A significantly higher proportion of fires in storage premises are deliberately lit (25% compared with 6.3% for manufacturing premises). This is broadly in line with UK data on the proportion of warehouse fires which listed malicious intent as the leading cause of ignition with 29% of warehouse fires being started in this manner[62].

3.14.1 Manufacturing and Storage Premises: Time of Occurrence

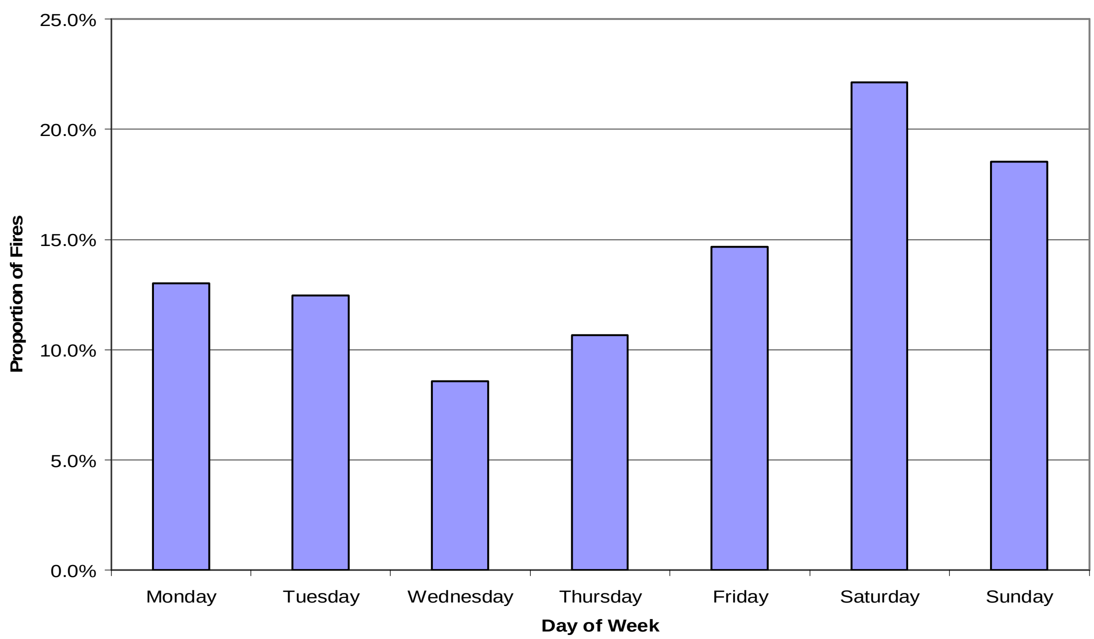

Figure 3.39: New Zealand manufacturing and storage premises deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

The daily distribution of incidents shows a strong bias towards weekend fire setting. As shown in Figure 3.39, 40.7% of all deliberately lit fires occur on either a Saturday or Sunday. There is a steady increase in the incidence of deliberately lit fires from Wednesday up until the peak of Saturday, before declining at the start of the week. The high incidence during the weekend is not considered unusual as while a number of manufacturing and storage sites are seven days per week operations, the majority of such facilities are operational during the working week only.

The distribution of incidents by hour is given as Figure 3.40, it shows the typical peak in activity occurring shortly after midnight followed by a sharp decline until 7 a.m. followed by a steady increase throughout the working day and evening. The presence of a secondary peak at 5 p.m. is likely to correspond to fire setting activity by staff as they leave the premises.

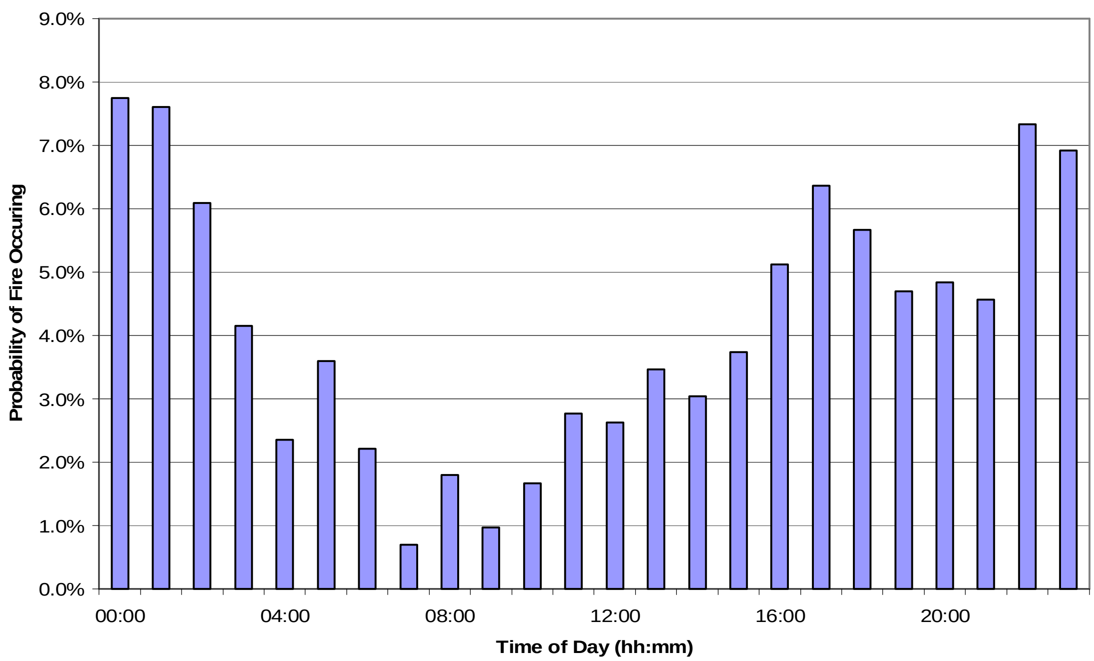

Figure 3.40: New Zealand manufacturing and storage premises deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.14.2 Manufacturing and Storage Premises: Compartment of Origin

Due to the wide range of businesses in this category it was expected that the distribution of deliberately lit fires would be very flat. Table 3.24 shows that this is not the case with the one in six fires being lit in a vehicle garage. The compartment of origin is biased towards the exterior of the structure. Overall, the distribution of location of origin is skewed, with the top three items accounting for 40.6% of all incidents and four entries achieving more than 5% of the total. The incidence of fires being lit in multiple compartments is low at 1.8%.

Most Common Location Of Origin	**No. of Incidents**	**% of Total**
Garage, Carport, Vehicle storage, Storage Shed	130	18.0%
Product storage, Tank, Bin, Agricultural storage, Hay barn, Hay stack	88	12.2%
Wall surface (exterior)	75	10.4%
Supply room/area, Tool room, Maintenance supply room	47	6.5%
Not Recorded	35	4.8%
Manufacturing, Process, Work room	27	3.7%
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	25	3.5%
Shipping area, Receiving area, Loading area, Packing area	25	3.5%
Lobby, Entrance way	20	2.8%
Rubbish, Industrial waste, Waste container	17	2.4%
Road, Street, Parking lot, Highway, Motorway	17	2.4%
Storage and garage area - not classified above	17	2.4%
Maintenance shop, Repair, Welding, Paint shop, Paint spraying area	15	2.1%
Other location of origin	185	25.6%
Total	**723**	**100.0%**

Table 3.24: Most frequent location of fire origin for deliberately lit fires in New Zealand manufacturing and storage premises between 1996 and 2006 (FIRS statistics).

3.14.3 Manufacturing and Storage Premises: Object First Ignited

The most commonly used items to start deliberately lit fires in manufacturing and storage facilities are listed as Table 3.25. There are no items in this data that are considered unusual in a typical manufacturing site, however, unless designed specifically for their storage, storage facilities typically do not permit storage of hazardous products such as flammable liquids or gases so these should be considered introduced fuels in these cases. Accelerants are used in 5.5% of deliberately lit fires and multiple fires within a single fire compartment are lit in 3.9% of deliberately lit fires for this property type. In 9.4% of fire incidents an appropriately selected design fire may be inadequate.

Most Common Object First Ignited	**No. of Incidents**	**% of Total**
Rubbish, Garbage, Waste	104	14.4%
Unknown	103	14.2%
Newspaper, Magazine, Files	43	5.9%
Framing, Structural member, Interior walls and doors	35	4.8%
Paper; excluding newspaper or rolled paper	33	4.6%
Flammable liquid and gases (not aerosols or propellants)	33	4.6%
Box, Carton, Bag	30	4.1%
Exterior side wall covering surface, Cladding (including eaves)	28	3.9%
Multiple items	28	3.9%
Packing, Wrapping material	27	3.7%
Information not recorded	27	3.7%
Upholstered Furniture e.g. Chairs, Sofas, Beds, Vehicle Seats	20	2.8%
Dust, Lint, Fibre, Wood chips, Sawdust, Shavings, Bark	17	2.4%
Interior wall covering	15	2.1%
Other object first ignited	185	25.6%
Total	**723**	**100.0%**

Table 3.25: Items most frequently ignited in deliberately lit fires in New Zealand manufacturing and storage premises between 1996 and 2006 (FIRS statistics).

3.14.4 Manufacturing and Storage Premises: Casualty Rate

Between 1996 and 2006, there were six separate incidents in manufacturing and storage premises resulting in one moderate injury and five slight injuries. This represents 3.8% of the total fire injuries in this building category. Overall there were three fatal fire incidents resulting in three fatalities in this building category. Deliberately lit fires are therefore under-represented in both the injury and fatality statistics in this category of building.

No clear trends were identifiable when looking at the casualty incidents; every incident was started in a different compartment with a different object first ignited. The UK data indicates that over a similar period of time there were five fatalities and 51 injuries, giving an injury to fatality ratio of 10:1. The New Zealand casualty data does not contradict this ratio.

3.15 Intermittent Use Premises

This building category describes structures that are occupied intermittently such as car parks, telephone exchanges and phone boxes. Between 1996 and 2006, there were 130 incidents in these structures corresponding to 12 incidents per year. The five year average trend is distorted by a large number of incidents occurring in 2003, where they occurred at twice the frequency of other years. If 2003 is omitted from the data the overall trend shows a decline of 3.8%. The overall trend is given in Figure 3.41.

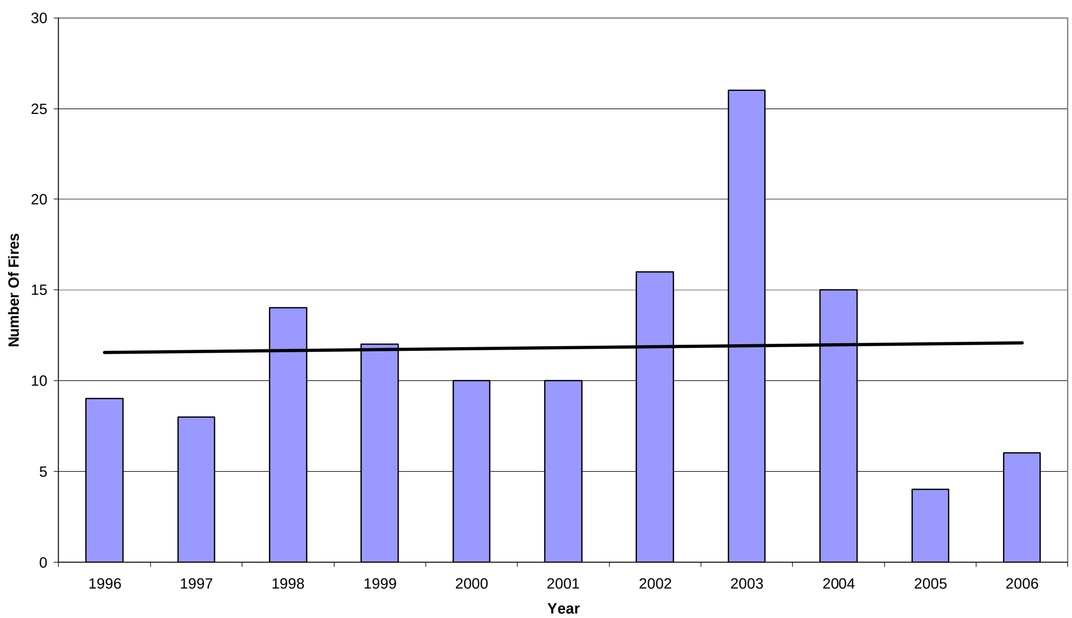

Figure 3.41: New Zealand intermittent use premises annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

Incidents in this building category are totally dominated by fires in phone boxes with 93% of the 130 fires in this category occurring in phone boxes. Three quarters of these fires are lit using paper material, most likely the phone book.

With the increasing use of mobile phones and a decline in the number of pay phones in service the number of fires in this property group is expected to decline. Due to the small size of a phone box, anyone present in the phone box at the time of ignition is likely to be directly involved with starting the fire. They also have a negligible travel time to escape making fire engineering a trivial exercise. As there have been no injuries in this building category and, excluding phone boxes, there have been few incidents in this category further analysis is not justified.

3.16 Other Premises: Overall Trends

The other premises cover all structures that are not captured by any of the previous building categories. This includes all structures on railway property, vacant buildings and structures at construction and demolition sites. The fire safety systems of vacant buildings will have been designed based on the most recent use and the fire safety requirements of buildings under construction (once the systems are installed) are designed around the buildings' future use. During the construction and vacant phases of the buildings' life the fuel loads are typically assumed to be less than normal use and therefore a fire will be less severe but this assumption has little impact on the initial fire growth inside the structure.

Between 1996 and 2006, there were 963 incidents in 'other' premises, an average of 88 incidents per year. Over the last eleven years the incidence of events in these structures has declined 14.8% from 96 to 82 incidents per year. This represents 42.6% of all fires for these structures. A total of 267 fires, or 27.7% of all of these incidents occurred in vacant buildings with another 17.4% occurring in buildings under construction. Fires in vacant buildings and buildings are more likely to be lit deliberately than all other fire causes combined. This high likelihood of vacant buildings being involved in deliberately lit fires has been well documented in literature[39,63]. The annual distribution of deliberately lit fires in 'other' structures is given as Figure 3.42.

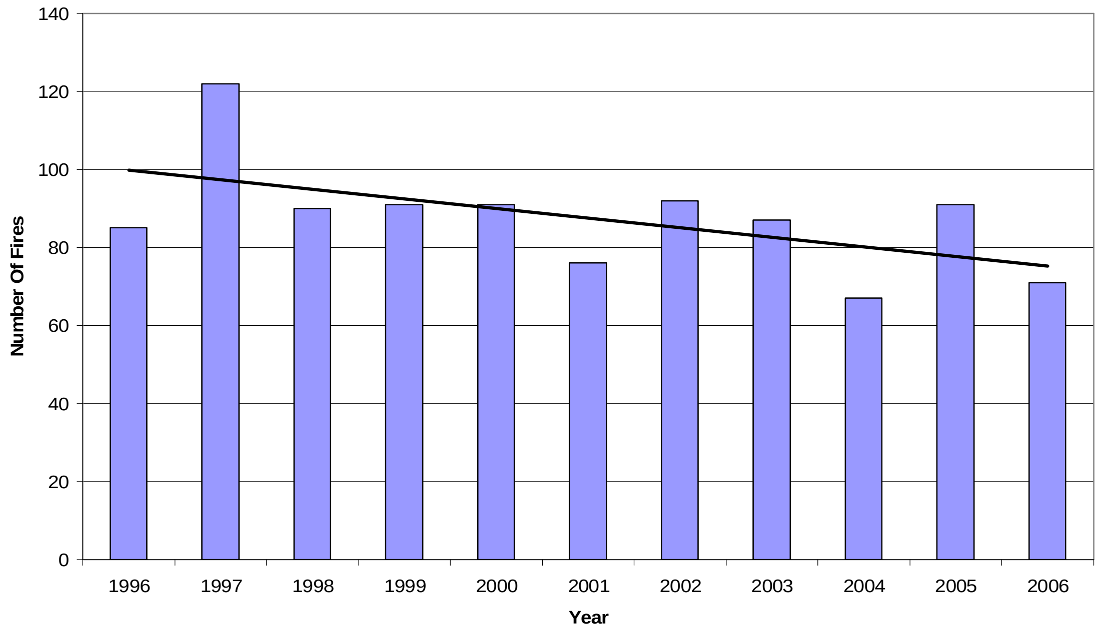

Figure 3.42: New Zealand 'other' premises annual deliberately lit fire rate between 1996 and 2006 (FIRS statistics).

3.16.1 Other Premises: Time of Occurrence

There is a significant bias towards fires occurring during the weekend with 42.4% of all deliberately lit fires occurring on a Saturday or Sunday. Apart from a slightly higher probability of a fire occurring on a Friday there is no identifiable trend during the week. The daily distribution of fire incidents is shown in Figure 3.43.

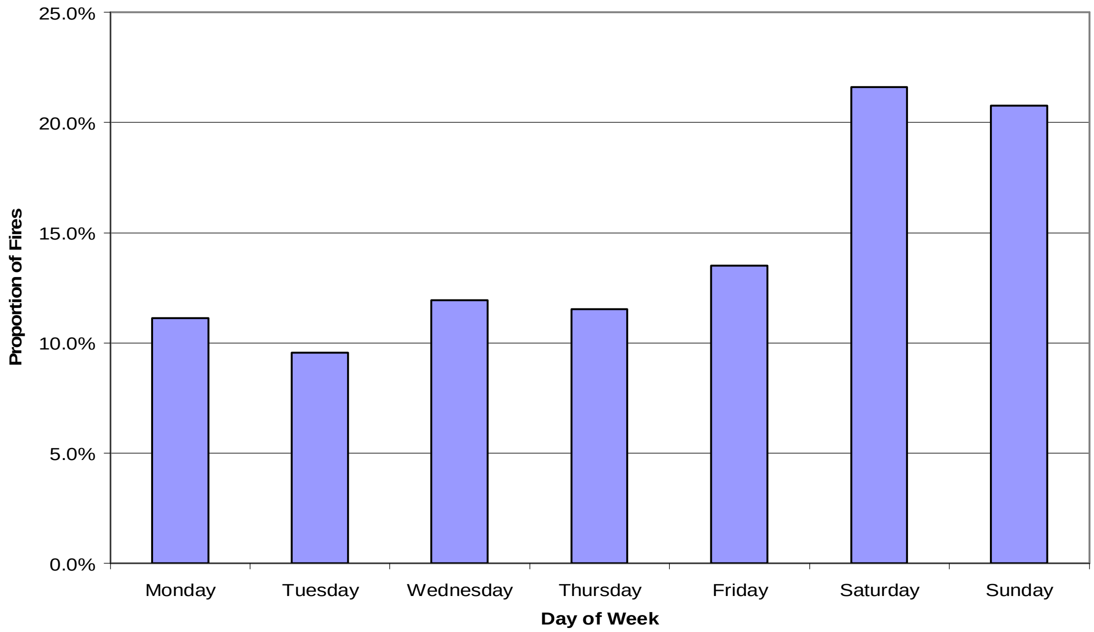

Figure 3.43: New Zealand 'other' premises deliberately lit fire rate by day between 1996 and 2006 (FIRS statistics).

With regards to the hourly distribution of deliberately lit fires in the 'other' building category the trends are virtually identical to the overall trend with the peak incidence occurring shortly before midnight and the minimum frequency occurring at 9 a.m. The hourly distribution of fire incidents is shown in Figure 3.44.

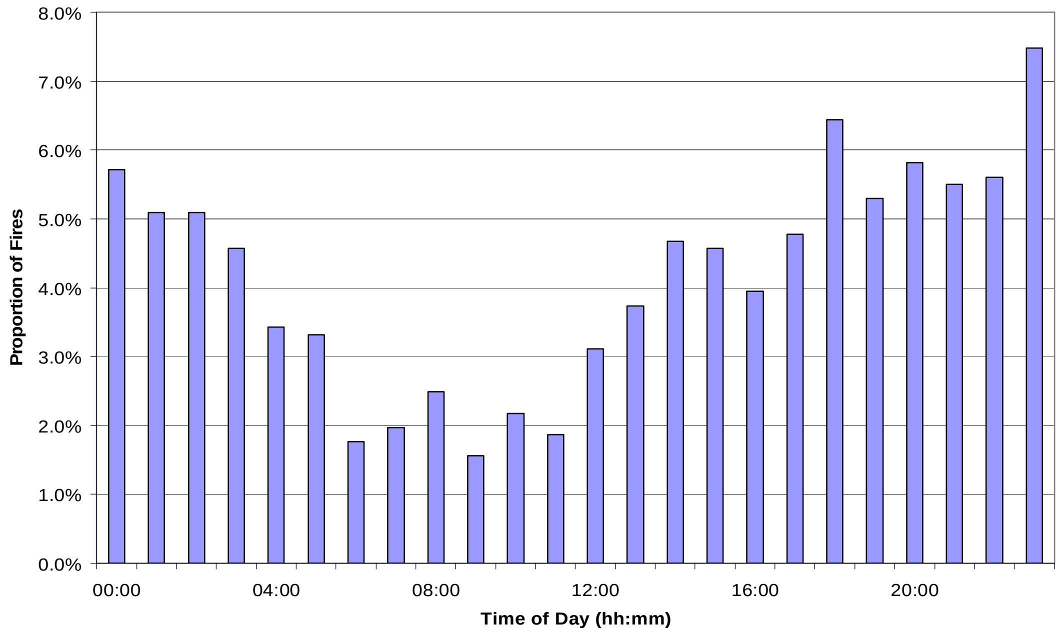

Figure 3.44: New Zealand 'other' premises deliberately lit fire rate by hour between 1996 and 2006 (FIRS statistics).

3.16.2 Other Premises: Compartment of Origin

The compartments most likely to be involved in a deliberately lit fire are listed as Table 3.26. The entries in Table 3.26 are biased towards the exterior of the structure. Overall, the distribution of location of origin is flat, with the top three items accounting for 29.8% of all incidents and six entries achieving more than 5% of the total. While higher than many other building types the incidence of fires being lit in multiple compartments is low at 2.5%.

Most Common Location Of Origin	Frequency	% of Total
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	139	14.4%
Garage, Carport, Vehicle storage, Storage Shed	77	8.0%
Not Recorded	71	7.4%
Vacant structural area	66	6.9%
Wall surface (exterior)	62	6.4%
Road, Street, Parking lot, Highway, Motorway	55	5.7%
Unable to classify	42	4.4%
Lounge, Common room, TV room, Sitting room, Music room	33	3.4%
Product storage, Tank, Bin, Agricultural storage, Hay barn, Hay stack	31	3.2%
Supply room/area, Tool room, Maintenance supply room	29	3.0%
Area under construction or major renovation	22	2.3%
Wall assembly: Concealed wall space	21	2.2%
Other compartment of origin	315	32.7%
Total	**963**	**100.0%**

Table 3.26: Most frequent location of fire origin for deliberately lit fires in New Zealand other premises between 1996 and 2006 (FIRS statistics).

3.16.3 Other Premises: Object First Ignited

The most commonly used items to start fires in this building category are still rubbish and paper however the proportion of structural timbers and wall coverings is much higher. This is likely to be due to an absence of other readily available materials. Books and upholstered material may be considered introduced fuels in some cases; however their use is unlikely to result in a more severe fire than an appropriately selected design fire. The most common items used are given as Table 3.27. Accelerants are used in 4.3% of deliberately lit fires and multiple fires within a single fire compartment are lit in 3.9% of deliberately lit fires for this property type. In 8.2% of fire incidents an appropriately selected design fire may be inadequate.

Most Common Object First Ignited	Frequency	% of Total
Rubbish, Garbage, Waste	162	16.8%
Unknown	93	9.7%
Framing, Structural member, Interior walls and doors	70	7.3%
Newspaper, Magazine, Files	63	6.5%
Information not recorded	60	6.2%
Rolled material, Rolled paper (not newspaper)	44	4.6%
Paper; excluding newspaper or rolled paper	43	4.5%
Interior wall covering	40	4.2%
Exterior side wall covering surface, Cladding (including eaves)	39	4.0%
Multiple items	38	3.9%
Flammable liquid and gases (not aerosols or propellants)	33	3.4%
Books	32	3.3%
Upholstered Furniture e.g. Chairs, Sofas, Beds, Vehicle Seats	21	2.2%
Other object first ignited	225	23.4%
Total	**963**	**100.0%**

Table 3.27: Items most frequently ignited in deliberately lit fires in New Zealand 'other' premises between 1996 and 2006 (FIRS statistics).

3.16.4 Other Premises: Casualty Rate

Between 1996 and 2006, there were two deliberately lit fire incidents that resulted in a casualty; these incidents resulted in two moderate injuries. This corresponds to 37.5% of the overall injury rate for this type of structure. There were no fatal fires in the 'other' premises category. The two events have different compartments of origin and were started in different ways preventing any meaningful conclusions from being drawn.

3.17 Considering Deliberately Lit Fires For Design Purposes

At present, deliberately lit fires are not required to be considered in a systematic manner for any structure in New Zealand. An examination of the New Zealand deliberately lit fire statistics has highlighted several factors that need to be considered when assessing the risk from deliberately lit fires. Clearly this risk is not the same for all buildings so it is not appropriate to consider a single rule for all structures. The factors identified from the incident statistics are:

- The probability that a given fire in the building will be deliberately lit.
- The likelihood that a deliberately lit fire scenario will differ from an appropriately selected design fire.
- The life safety benefits of considering deliberately lit fires.

In addition to these factors, fire engineering literature has identified an additional two factors that may impact on the decision to include deliberately lit fires for specific projects, namely:

- Property protection.
- Cost to the end user

All building categories will be assessed against the first three of these criteria. The final two categories are too specific to the individual building to be considered at the overarching level examined in this work.

3.17.1 Probability That A Fire Is Deliberately Lit.

To determine which types of structures are more prone to deliberately lit fires the total number of deliberately lit fires and the proportion of all fires that are deliberately lit are given as Table 3.28. It is readily apparent that a fire in a detention facility such as a prison is more likely to be deliberately lit than any other cause. As already identified, fires in care facilities are dominated by fires in psychiatric institutions which, with 50.2% of fires in psychiatric institutions being deliberately lit, are also more likely to be deliberately lit than any other cause. Fires in education and crowd premises such as public houses are also highly likely to be deliberately lit. In both categories over 40% of all fires in these buildings are deliberately lit.

Building Category	**Total Number of Deliberately Lit Fires**	**Proportion Of All Fires For Building Category**
Detention Accommodation	181	67.9%
Education	983	47.8%
Crowd	947	42.6%
Open Grandstands	123	32.2%
Care Accommodation	287	16.6%
Working	272	15.5%
Retail	540	14.7%
Storage/Manufacturing	723	11.0%
Attached Dwelling	577	8.6%
Temporary Accommodation	145	8.6%
Detached Dwelling	3735	8.5%
Intermittent Use	130	-
Other	-	-
- Vacant buildings/ Construction sites	435	57.6%
- Rest of other buildings	528	37.1%
Overall	**9606**	**13.3%**

Table 3.28: The likelihood that a fire will be deliberately lit by building category (FIRS Statistics)

Fires in the 'other' building category are dominated by fires in vacant structures and construction sites. While fires in these buildings are also highly likely to be deliberately lit; the low occupancy of these structures means that they will not be considered further.

The intended use of the building should always be considered here, some buildings may experience an increased risk of attack for political, religious or ideological reasons and accurate statistics on these specific buildings may require a more detailed examination of the fire incident statistics.

3.17.2 Deliberately Lit Fire Severity

Fortunately, most deliberately lit fires are the result of the opportunistic ignition of items already present in the compartment and the fact that the fire has been ignited deliberately is not a significant factor in the resulting fire growth rate. In such cases, use of published data from organizations such as the SFPE[64] and other literature[65] will result in a design fire that adequately protects against these opportunistic fires. There is a second group of deliberately lit fires where the use of standard design fire curves would be considered inadequate. The most commonly identified incidents involve the ignition of multiple fires or the use of accelerants and their frequency is summarised as Table 3.29.

The ignition of fires in multiple compartments does not appear to be a common situation. In virtually all building categories it accounts for less than 1.8% of all deliberately lit fires. More likely is the ignition of a number of fires in a single compartment. While fires in multiple compartments have the potential to block off escape paths for building occupants the ignition of fires within a single compartment will impact on the time required for the compartment to reach flashover. This will be discussed in further detail in the next Chapter. The use of accelerants can either act to spread the fire to secondary objects, effectively acting to ignite secondary fires earlier, or they may accelerate the initial growth stage of the fire. The use of accelerants will be discussed in Chapters five and six.

While the point where the frequency of accelerated/multiple fires transitions from an unlikely threat to a credible threat is open to debate, retail buildings, attached and detached dwellings experience the greatest proportion of these fires. Detention, care and temporary accommodation and working use structures experience the least of these severely challenging fires.

Building Category	Proportion of Fires in Multiple Compartments	Proportion of Multiple Fires in Single Compartment	Proportion of Fires Where Accelerants Used	Overall Proportion of Challenging Fires
Detached Dwelling	3.0%	6.1%	8.6%	17.7%
Attached Dwelling	1.2%	4.2%	8.3%	13.7%
Retail	1.7%	3.5%	6.1%	11.3%
Storage/Manufacturing	1.8%	3.9%	5.5%	11.2%
Education	1.3%	3.7%	5.9%	10.9%
Crowd	1.7%	3.7%	5.3%	10.7%
Open Grandstands	1.6%	1.6%	7.3%	10.5%
Working	1.5%	1.8%	4.8%	8.1%
Temp. Accommodation	0.7%	0.7%	4.8%	6.2%
Detention Accommodation	0.0%	2.2%	3.3%	5.5%
Care Accommodation	0.3%	1.4%	1.4%	3.1%
Intermittent Use	-	-	-	-
Other				
- Vacant Buildings/ Construction sites	6.0%	8.6%	2.2%	16.8%
- Rest of other buildings	1.3%	2.2%	5.0%	8.5%
Overall	**2.2%**	**4.4%**	**6.2%**	**12.8%**

Table 3.29: The proportion of deliberately lit fires likely to challenge existing design fires by building category and type of fire (FIRS statistics).

3.17.3 Life Safety Considerations

The number of people injured and killed in deliberately lit fires in New Zealand is given as Table 3.30. The ratio between the number of injuries and deaths is very similar to the UK data for deliberately lit fires in warehouses[62]; however the US overall data gives an injury to fatality ratio nearer 3:1[13]. The overall fatality rate per fire in the US deliberately lit structure fires is calculated as 0.0081 for the 2003 year. This is nearly three times higher than the New Zealand rate and accounts for the difference in these statistics.

Building Category	Fatalities	Total Injuries
Detached Dwelling	21	130
Attached Dwelling	4	52
Detention Accommodation	1	38
Temporary Accommodation	1	13
Retail	1	0
Care Accommodation	0	26
Education	0	8
Storage/Manufacturing	0	6
Crowd	0	5
Open Grandstands	0	1
Working	0	0
Intermittent Use	0	0
Other	0	2
Overall	**28**	**281**

Table 3.30: New Zealand deliberately lit casualty rate by building category (FIRS statistics).

Clearly, the deliberately lit fire casualty statistics are dominated by incidents in detached dwellings. When looking at the fatality and casualty rates on a per fire basis, the impact of the number of incidents is removed. This is presented as Table 3.31. When considering the fatality rate in isolation, the most significant property types are attached dwellings and temporary accommodation closely followed by detached dwellings and detention accommodation. Due to the relatively small number of fires in each category, the fatality rate per fire for the open grandstand, temporary accommodation and intermittent use categories is vulnerable to distortion. A single fatality in any of these building categories results may result in the significance of that category being overstated. To minimise the impact that this can cause the fatality rate has been combined with the injury rate to obtain an overall casualty rate. The casualty rate per fire presented in Table 3.31 has assumed that all injuries are weighted the same as a fatality. When considering the risk of being injured in a deliberately lit fire, detention facilities dominate the injury statistics followed by all other forms of sleeping accommodation.

Building Category	Fatality Rate/fire	Injury Rate/fire	Casualty Rate/fire
Detention Accommodation	0.0055	0.2099	0.2155
Attached Dwelling	0.0069	0.0901	0.0971
Temporary Accommodation	0.0069	0.0897	0.0966
Care Accommodation	0.0000	0.0906	0.0906
Detached Dwelling	0.0056	0.0348	0.0404
Storage/Manufacturing	0.0000	0.0083	0.0083
Open Grandstands	0.0000	0.0081	0.0081
Education	0.0000	0.0081	0.0081
Crowd	0.0000	0.0053	0.0053
Retail	0.0019	0.0000	0.0019
Working	0.0000	0.0000	0.0000
Intermittent Use	0.0000	0.0000	0.0000
Other	0.0000	0.0021	0.0021
Overall	**0.0029**	**0.0293**	**0.0322**

Table 3.31: Probability of fatality, injury and unweighted casualty per fire by building category.

Due to its contentious nature, reliable estimates of how many injuries are considered equal to a single fatality are difficult to obtain. However some estimates of the economic cost of injury are available[66] and this data may be used as a means of weighting the different levels of injury when calculating the overall burden on society on a per fire basis. Details of the calculation process are included as Appendix B, with the final estimate of the lifetime cost of an injury due to a deliberately lit fire presented as Table 3.32. The lifetime injury costs for most of the accommodation categories are significantly higher than for the other categories.

Building Category	Estimated Injury Cost/Fire (NZ$)
Attached Dwelling	3386.13
Temporary Accommodation	3202.31
Detention Accommodation	3127.73
Detached Dwelling	2313.32
Retail	645.86
Care Accommodation	162.97
Crowd	104.41
Education	12.64
Storage/Manufacturing	9.93
Open Grandstands	3.95
Working	0.00
Intermittent Use	0.00
Other	9.87
Overall	**1263.69**

Table 3.32: Estimated lifetime injury cost per deliberately lit fire.

3.17.4 Property Protection

The contents of structures such as museums, historical structures and art galleries have significance beyond their monetary value. In the case of a museum or art gallery it is the contents of the building that determines its value while it the case of many historical structures it is the significance of the building itself that derives its special significance for the community.

The value of a structure may be determined based on cultural reasons, religious reasons, or it may be derived from some historical event. While not required to meet the requirements of the New Zealand Building Code, the protection of property may be a goal of the fire engineering brief. For example, in the fire engineering design of school buildings the Ministry of Education recommends[67]:

'The sprinkler design brief should be extended to consider providing protection under canopies, verandahs and accessible areas under wooden floors. Similarly allowances for potential multiple fire starts or the use of accelerants should be considered.'

The Ministry of Education recommendations serve to confirm the importance of the two severe fire scenarios identified from the incident statistics.

3.17.5 Cost Considerations

The final consideration for any engineering design is the cost of the project. Unless required by regulation, the cost of any design must be balanced against the benefits it offers and if the project does not offer benefits in proportion with the project cost it is unlikely to be accepted by the client.

3.17.6 FIRS Analysis Results

This chapter has presented an analysis of all deliberately recorded by the New Zealand Fire Service from 1996 through to 2006. The analysis was completed by breaking up all fire incidents into building categories, roughly corresponding with the purpose group classification used in C/AS1 and then examining each category to determine the most likely fire scenarios. It concluded by outlining some proposed criteria to estimate the risk to a building from deliberately lit fires.

In many cases, designing buildings around deliberately lit fires is not warranted. No building category was identified by all criteria considered, however detention accommodation, attached dwellings and detached dwellings were identified through multiple criteria, and therefore including provision for deliberately lit fires in the design brief for these buildings should certainly be considered. For the other building categories, the decision to include or exclude deliberately lit fires as a potential design scenario requires further examination of the individual building.

3.18 Issues With Using Fire Incident Statistics

While a useful source of data, there are a number of issues that need to be considered when using fire incident statistics to gauge the rate of deliberately lit fires in a particular type of structure.

- **Unreported fires:** The majority of fires are not reported to authorities and therefore do not appear in the fire statistics. While no reliable method exists to quantify the number of fires that are not reported to the Fire Service, their effect on the casualty statistics is likely to be small. The justification for this is that a fire that results in a fatality or injury requiring hospitalisation is likely to be a non-trivial fire and therefore help is more likely to be sought from the Fire Service.

- **Missing Data:** For a number of reasons there are a significant number of incidents where some of the data is either not recorded or recorded as 'unknown'. The method of dealing with this for this study has been to acknowledge this but not include the incidents further. For the known entries, this effectively results in the data giving a lower boundary of the true situation.

- **Coding Inconsistencies:** Despite the best intentions of database authors, there are inconsistencies in the coding of fires. For example, in the case of a fire in a bulk petrol storage tank, the storage tank could be coded as either the location of origin or object first ignited. Another example of this is the coding of a fire in a flat. If a group of adults are in a flatting situation in a freestanding house then this could be legitimately coded as either a 'flat' or a 'house'.

- **Coding Priorities:** Fire databases have a priority in recording data. From discussions with the Fire Service the FIRS database records any fire that involves a structure as a structure fire, even if the fire started in vegetation and spread to the structure. This is consistent with the US NFIRS database, where any fire under or touching a structure that involves the structure is considered a structure fire[68]. This means that for structures where fires are permitted outside for the purpose of rubbish disposal, the incidence of deliberately lit fires may be slightly over-represented and the incidence of rubbish or garden waste may also be over-represented as an object first ignited. As a source of error, this is unlikely to be a significant cause of error for structures other than detached accommodation.

- **Resources allocated to fire investigation:** The amount of resources devoted to investigating fires can have a significant effect on the statistics. If insufficient resources are allocated to the detection of deliberately lit fires then the probability that an incident is coded as either accidental or unknown cause increases. This will result in the erroneous conclusion that deliberately lit fires are less of a problem than the true situation.

- **Identification of Accelerants:** Many synthetic materials share the same petroleum based origin as accelerants and these may also result in false positive readings. The positive detection of accelerants in a post fire investigation may also be countered by the legitimate presence of solvents and fuels. Small quantities of fuels and industrial solvents such as mineral turpentine are present in many houses and after a fire; their presence can lead to the erroneous conclusion that accelerants have been used. Conversely, in industrial or working structures, where solvents are used frequently the presence of an accelerant may be logically explained away, leading a false negative result. In all of these cases the correct conclusions are dependent on the skill and experience of the fire investigator.

4.0 Multiple Fires

The ignition of multiple fires represents fire scenarios where there is a potential for loss of life and the current design philosophy may prove to be inadequate. Two individual scenarios have been identified from the FIRS analysis:

- The ignition of fires in multiple compartments.
- The ignition of multiple fires in a single compartment.

The combined incidence of these two scenarios represents 5.4% of deliberately lit fires. While during the study period there were few casualties attributed to either scenario the risks posed by these fire scenarios cannot be discounted.

Each of these scenarios raises different issues for the fire engineer so they will be discussed separately. As the most appropriate solution to each of the issues raised in this chapter will depend on the individual structure, no attempt has been made to provide ‘the solution’, rather the purpose of this chapter is to highlight the key issues that need to be considered by the designer in the event multiple fires is used as a design scenario.

4.1 Ignition of Fires in Multiple Compartments

The ignition of fires in multiple compartments is not a common scenario accounting for 2.2% of all deliberately lit fires. From a practical perspective it poses a low risk to life safety as the time taken to light a number of fires in separate locations increases the risk of discovery, making this an unlikely event in an occupied building. From a life safety perspective however, the ignition of multiple fires can close off escape paths, raising the risk to those building occupants that are present.

The building groups that are at most risk from the ignition of fires in multiple compartments are detached accommodation buildings such as houses or farms and soft targets such as vacant buildings or buildings under construction none of which are heavily occupied.

An examination of the FIRS data reveals that in the 213 recorded incidents where fires have been lit in multiple compartments there have only been three casualties; all in detached dwellings. One fire resulted in a fatality as well as a moderate injury while the second casualty incident resulted in second moderate injury. The low casualty rate from these fires is likely to be partially due to the rarity of these events and the relatively small number of fires in New Zealand so firm conclusions as to the actual life safety risk of these fires cannot be drawn.

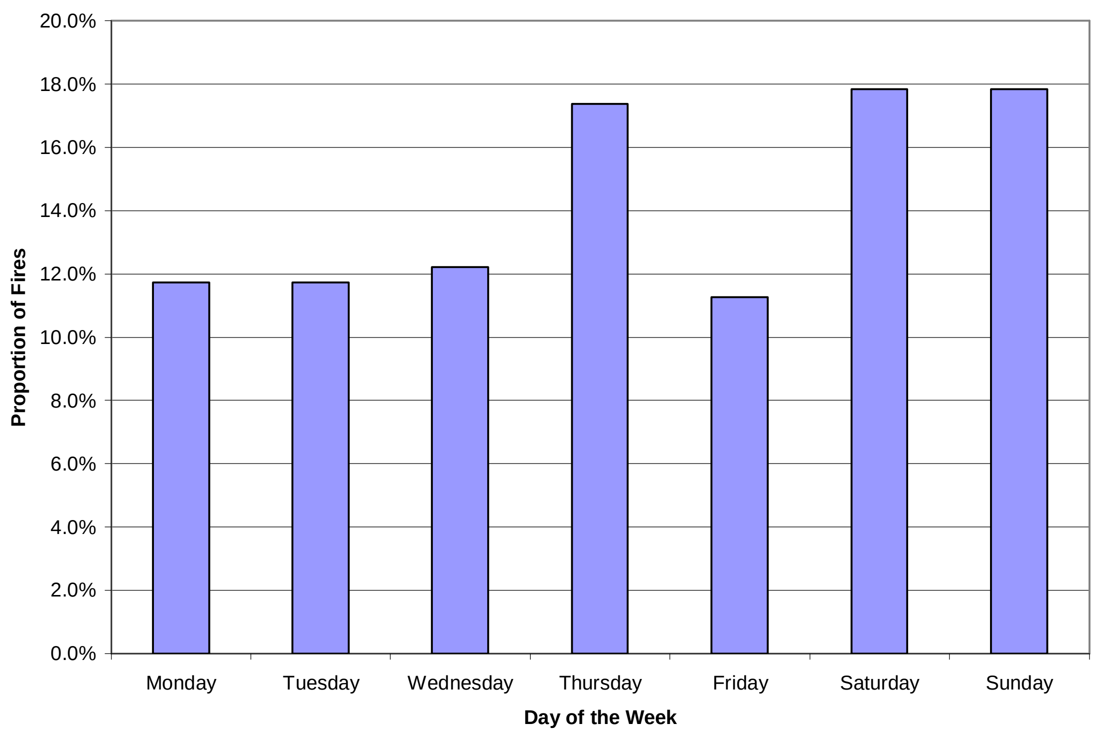

Figure 4.1: New Zealand deliberate ignition of fires in multiple compartments rate by day between 1996 and 2006 (FIRS statistics).

The ignition of fires in multiple compartments is strongly biased towards those times where the risk of discovery is low. The distribution between the days of the week is presented as Figure 4.1 and it shows a bias towards weekend activity, with 35.7% of all incidents occurring on either a Saturday or Sunday. The number of incidents that occurred on a Thursday is also higher than the balance of the working week with no clear cause.

The distribution of such fires over the course of the day also shows a strong bias towards night activity with 52.6% of incidents occurring between 9 p.m. and 3 a.m. This is presented as Figure 4.2. This strong bias towards night time activity indicates that there is little life safety benefit to considering the ignition of fires in multiple compartments in buildings that are occupied only during the day. Because of this, when talking about life safety, the discussion will focus on accommodation and crowd activity structures.

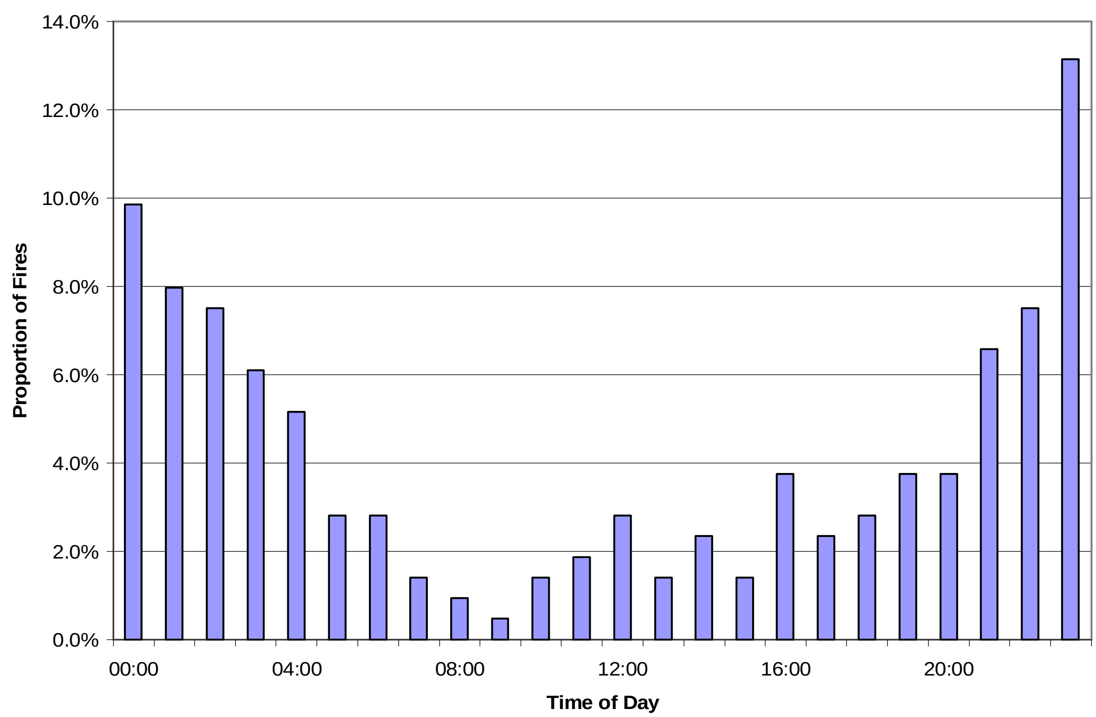

Figure 4.2: New Zealand deliberate ignition of fires in multiple compartments rate by hour between 1996 and 2006 (FIRS statistics).

The most commonly ignited items in cases where fires are lit in multiple compartments are summarised in Table 4.1. At first glance it appears that the ignition of fires in multiple compartments differs from ‘normal’ deliberately lit fires in that accelerants and the ignition of multiple items within individual compartments are more common, however this is misleading.

Most Common Items First Ignited	**Frequency**	**% Of Total**
Multiple materials first ignited	56	26.3%
Unknown	39	18.3%
Rubbish (material having no value in the same container or pile)	20	9.4%
Wood: sawn, finished timber	18	8.5%
Petrol	15	7.0%
Flammable Liquid e.g. Kerosene, Methylated spirit, Ethanol, Turpentine	14	6.6%
Treated paper e.g. building paper, wax or tar paper, wallpaper	13	6.1%
Fabric, Fibre (finished)	6	2.8%
Paper e.g. Uncoated, untreated, ground up & recycled, used as insulation	3	1.4%
PVC e.g. Floor Tiles, Guttering/Pipes, Plastic Bags, Elec. Insulation	3	1.4%
Wood pulp	3	1.4%
Cardboard	2	0.9%
Hay, Straw, Chaff	2	0.9%
Plastics - not classified above	2	0.9%
Processed wood, Paper - not classified above	2	0.9%
Vinyl e.g. Floor coverings, Wallpaper (but NOT vinyl-coated)	2	0.9%
Wool, Wool mixtures (finished goods)	2	0.9%
Other	23	10.8%
Total	**213**	**100.0%**

Table 4.1: Most common objects first ignited in incidents where fires are lit in multiple compartments (FIRS statistics).

The most commonly ignited item recorded appears to be the use of multiple materials; however this is likely to be due to the structure of the FIRS database and the reporting officers’ intention to populate the field in an appropriate manner. The FIRS database does not give the option to provide ignition information on the individual seats of fire in such cases.

Accelerants also appear to be used more frequently in this sort of incident, comprising 14.6% of cases where fires are lit in multiple compartments compared with 6.2% of cases for all deliberately lit fires. However, of the 31 cases where accelerants were used, 25 of them occurred in detached dwellings. If this building category is excluded then the proportion of fires where accelerants are used drops to 6.1%, virtually identical to the rate of accelerant use for all deliberately lit fires.

Other than these two points the items most frequently used to start fires in multiple compartments are similar to a typical deliberately lit fire with rubbish, paper and wooden products being used most frequently. The high frequency of the item first ignited being recorded as 'unknown' results from a lower level of investigation into fires in detached dwellings combined with an increased likelihood that the structure experiences significant damage making conclusive identification of the seat of fire difficult.

4.1.1 Early Fire Behaviour

As the fires are located in separate compartments, energy transfer from one fuel package to another will be limited or nonexistent. The initial growth stage for each individual fire will be identical to what it would be if the fire had been ignited in isolation. Once the fires reach a certain size, there exists the possibility that energy transfer from the hot fire gases to the fuel package of another fire may become significant but this will depend on the configuration of the structure and actual locations of the fires.

There is also the possibility that one fire may retard the growth of another due to ventilation limitations imposed by the structure. Further work is required to quantify what will happen in a given situation.

4.1.2 Detection

A key parameter that influences the response time of a detection system is the distance from the detector to the fire[69]. Other important parameters are the type of detector used, the presence of obstructions between the fire and detector and the growth rate of the fire. In New Zealand, the type of detector and detector spacing are governed by NZS 4512:2003[70]. Because of this, the response time of a given detector will be dependent only on the distance to the closest fire and the fire growth rate. A secondary fire, located further from the detector is unlikely to significantly alter the detector activation time so the response time for the overall system will be determined by the individual detector with the most favorable detection conditions.

The detection time for the system as a whole is determined by the first detector to activate. Less favorable detector/fire combinations will not improve the response of the overall system. So for design purposes, the activation time of the detector in the most favorable location should be used when calculating the required safe egress time.

4.1.3 Escape Provisions

One issue that needs to be addressed when looking at the ignition of fires in multiple compartments is the possibility that both primary and secondary escape routes can be blocked off. If this were to be included, then the life safety objectives of the Building Act are likely to only be achievable by providing places of refuge for building occupants or excessive levels of security.

Consistent with the boundaries outlined in Chapter one, such actions will not be considered as a design fire scenario. Many crowd activity buildings have a relatively large number of exits and accommodation buildings are likely have some level of security, so the targeting of escape paths is considered to be an unlikely event. If fires in multiple compartments is required to be considered for other structures a scenario where one escape route is blocked and a secondary fire directly threatens building occupants should be considered. Currently when designing an unsprinklered building to C/AS1, one exit from a compartment is considered unavailable so this approach may be considered to be an extension of this philosophy. Safe egress from a building with two exits would be difficult to achieve under this constraint. Further examination of individual incidents is required to determine the actual risk from this fire scenario.

The most common method used to determine escape times is by calculating the Available Safe Egress Time (ASET) and comparing this to the Required Safe Egress Time. The RSET in minutes is given by equation 4.1[71].

$$RSET = t_{\det} + t_{pre} + t_{mov} \qquad 4.1$$

Where: t_{det} = Detection time (min).

t_{pre} = Pre-movement time (min).

t_{mov} = Movement time (min).

The ASET is normally taken as the time taken for the first tenability criteria to be exceeded. If RSET is less than ASET then the design is considered safe. When considering escape from an incident where fires have been lit in multiple compartments the detection time is unlikely to be significantly reduced as described above. The pre-movement time will be unchanged but the actual movement time is likely to be increased due to the longer travel time required to use a secondary exit.

4.1.4 Smoke Control

The smoke control system of a building is typically designed based on a single fire. In the event of fires in multiple compartments any surplus in the design is likely to be quickly taken up from the additional fires. To design a smoke control system to have the capacity to deal with multiple fires will be significantly more expensive.

The mass flow rate of the smoke plume is proportional to the heat release rate in kilowatts raised to the one third power[72], assuming the same convective heat release rate and height to the base of the smoke layer for each fire, in the cases of *n* fires the total mass flow rate is given by equation 4.2, adapted from Klote & Milke.

$$\dot{m}_{tot,n} = 0.071.k^{2/3}.n^{1/3}.\dot{Q}_c^{\ 1/3} Z^{5/3} + 0.0018.n.Q_c \qquad 4.2$$

Where: $\dot{m}_{tot,n}$ = Total smoke mass flow rate of *n* fires (kg/s).

k = Wall factor.

n = Number of individual fires.

$\dot{Q}_c$ = Convective heat release rate of one fire (kW)

Z = Height above the top of fuel (m)

Assuming that each fire has the same convective heat release rate and height of rise this may be simplified through the use of a multiple fire factor, a_n as given in equation 4.3.

$$\dot{m}_{tot,n} = a_n.\dot{m}_s \qquad 4.3$$

Where: $\dot{m}_{tot,n}$ = Total smoke mass flow rate of *n* fires.

a_n = Multiple fire factor (taken from Table 4.2).

$\dot{m}_s$ = Smoke mass flow rate of a single fire (kg/s).

From discussions with the Fire Service and Police it would be considered rare for fires to be lit in more than five compartments. Because of this Table 4.2 has not been extended beyond five fires. If the smoke control system is not improved to meet this greater smoke volume then the available time for egress will be reduced due to this greater smoke volume.

HRR of single fire (kW)	Number of Fires			
	2	3	4	5
100	1.37	1.67	1.94	2.19
200	1.42	1.78	2.10	2.42
500	1.51	1.96	2.39	2.81
1000	1.59	2.13	2.66	3.17
2000	1.67	2.31	2.94	3.55
5000	1.78	2.53	3.28	4.01

Table 4.2: Additional Fire Factor a_n for use in equation 4.3.

4.1.5 Sprinkler Design

Unless rendered inoperable by the arsonist, sprinklers have proven effective at controlling fires that are deliberately lit with over 68% of fires extinguished by the activation of a single sprinkler head and over 90% extinguished by four or fewer heads[73]. Fires lit in a large number of compartments do have the possibility of overwhelming the sprinkler system by activating an extremely large number of heads however this is considered unlikely. Marryatt's data on the number of sprinklers that activate in deliberately lit fires gives a mean of 1.9 sprinklers operating on a given fire. Physically partial activation of a sprinkler makes little sense, however it can be interpreted as one sprinkler does activate and a second sprinkler has a high probability of activation.

Based on a practical upper limit of five fires and the mean number of sprinklers activating, it is expected that nine or ten sprinklers will activate in a typical multiple incident with ignition in multiple compartments. This is broadly consistent with the incidents given in Marryatt's and other researchers[74] work.

In New Zealand sprinkler installation is governed by NZS 4541: 2003[75] which the hazard determines both the number of sprinklers and floor area that the designer must work to. This ensures that the minimum water coverage based on the hazard class of the compartment is not exceeded at any point in the compartment. The difference between extinguishment, containment and a runaway fire for a given hazard class depends on the water coverage rate[75] which is dependent on the available water pressure at the sprinkler head. The likelihood that fires in multiple compartments will overwhelm the sprinkler system is therefore dependent on the pressure drop along the supply lines and on the location of the fires. With larger diameter pipes having smaller pressure drops per unit length[76], there is some advantage in system effectiveness against multiple fires to be gained by the use of larger diameter pipes however this will impact on the sprinkler system cost.

4.1.6 Computer Modeling

Zone models such as BRANZFire[77] are designed to predict the smoke behaviour of a single fire. There is typically no provision to include a second fire in a simulation. This raises serious questions as to the ability of such models to predict conditions in cases where multiple fires have been lit. Running the simulation with a single fire in each location cannot give correct answers once the ceiling jets start to mix. Alternatively running the simulation with a single large fire is likely to over predict hazards in the compartment selected as the origin. When attempting to simulate fires in multiple compartments in this way, the onset of flashover is also likely to be incorrect.

A Computation Fluid Dynamics (CFD) model such as the Fire Dynamics Simulator (FDS)[78] is likely to be more accurate when predicting the complex interactions between the ceiling jets of multiple fires. It has the advantage that the growth rates of each fire do not have to be the same, enabling a high level of flexibility when modeling such events. However the single reaction chemistry used to predict yields of smoke products is likely to be the main cause of problems. This simplification is adequate in many cases with a single fire however; its reliability becomes suspect when considering multiple fires with markedly different fuel packages. The yields of toxic species from one fire may be considerably different to what is generated from the other fires and this currently cannot be modeled in programs such as FDS.

4.2 Ignition of Multiple Fires Within A Compartment

The other scenario that has been considered is the ignition of a number of fires within a single compartment. This is a more common fire scenario, accounting for 4.4% of all deliberately lit fires or an average of 39 incidents per year. Like the ignition of fires in multiple compartments the time taken to light a number of fires increases the risk of discovery, making it far more likely that this will be done in a building that is not highly occupied. As indicated in Table 3.29, the ignition of multiple fires is primarily an accommodation issue; over half of all such fires are lit in detached dwellings. Education, vacant buildings and buildings under construction are also significant targets for this sort of attack.

An examination of the FIRS data reveals that in the 424 incidents there have only been nine incidents which have resulted in one or more casualties. One of these incidents resulted in a single fatality, one resulted in two moderate injuries, one incident resulted in a single slight injury and the remaining six incidents resulted in a single moderate injury each. Two of the nine incidents occurred in an attached accommodation structure and the remaining seven occurred in detached houses. These incidents account for 3.6% of the fatalities and 3.2% of the injuries suggesting that multiple fires are under-represented in the casualty statistics. This is likely to be due to a low occupancy of the building at the time of the attack due to a desire to avoid detection by the perpetrator, so firm conclusions about the life safety hazards of the ignition of multiple fires within a compartment cannot be drawn.

Deliberately lit fires where multiple items are ignited within a single compartment are more likely to occur during the weekend; 38.2% of incidents occur on either a Saturday or Sunday. Activity during the week is fairly constant. The distribution of incident during the week is presented as Figure 4.3.

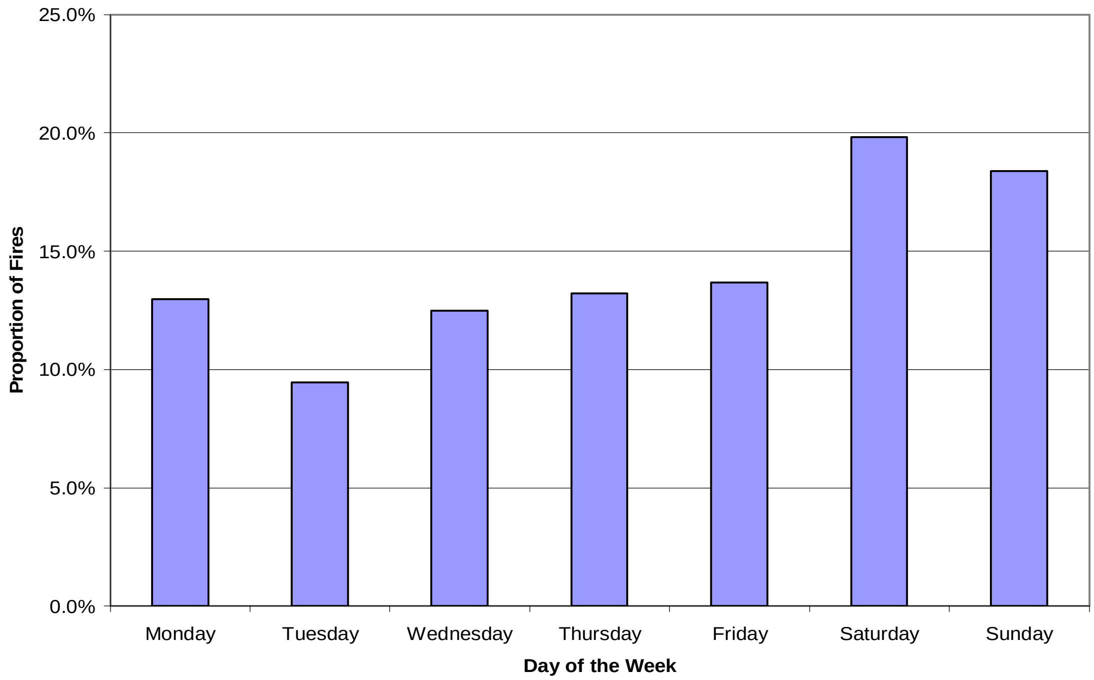

Figure 4.3: New Zealand deliberate ignition of multiple fires in a single compartment rate by day between 1996 and 2006 (FIRS statistics).

The distribution of incidents during the day is illustrated as Figure 4.4. It shows a significant increase in the number of incidents that occur between the hours of 9 p.m. and 4 a.m. For most the day the rate is fairly evenly distributed, however there is a small increase during the afternoon and early evening. The overall distribution is flatter than for fires in multiple compartments with 46.0% of incidents occurring between the hours of 9 p.m. and 3 a.m. While biased towards evening, a quarter of such fires do occur between the hours of 8 a.m. and 6 p.m. so a scenario in a working environment cannot be completely discounted.

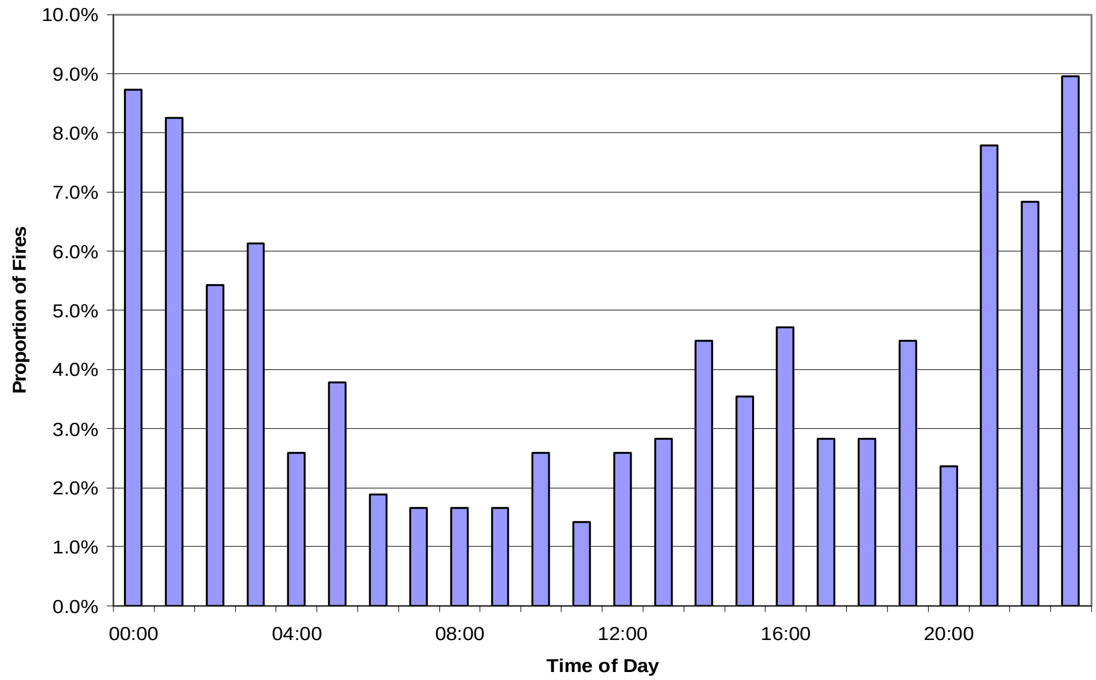

Figure 4.4: New Zealand deliberate ignition of multiple fires in a single compartment rate by hour between 1996 and 2006 (FIRS statistics).

The compartment most likely to be targeted for the ignition of multiple fires is included as Table 4.3. As expected with a dataset dominated by detached dwellings, the compartments most likely to be subjected to an attack of this sort are garages, lounges and bedrooms. If detached dwellings are excluded from the list then there is only a slight change in the results. The top two items are unchanged, bathrooms, supply rooms, kitchens and the lobby become more common as initial fire compartments and lounges and kitchens are less common as initial fire compartments. From this, it is clear that the fire compartment is not particularly sensitive to the inclusion of detached dwellings.

Compartment of Origin	Frequency	% of Total
Garage, Carport, Vehicle storage, Storage Shed	78	18.4%
Multiple areas of origin	59	13.9%
Lounge, Common room, TV room, Sitting room, Music room	39	9.2%
Bedroom, Sleeping area, Cell: under 5 persons	36	8.5%
Kitchen, Cooking area	19	4.5%
Supply room/area, Tool room, Maintenance supply room	18	4.2%
Toilet, Locker room, Washroom, Rest room, Bathroom, Sauna, Out house, Portable toilet	17	4.0%
Wall surface (exterior)	13	3.1%
Not Recorded	12	2.8%
Unable to classify	9	2.1%
Other locations of origin	124	29.2%
Total	**424**	100.0%

Table 4.3: Most common compartment of origin for multiple fires within a single compartment.

4.2.1 Early Fire Behaviour

The ignition of multiple fires within a single compartment may impact on many of the assumptions made in fire engineering calculations. In the initial stages of each fires growth, the upper layer will still be relatively cool and the early behaviour of each fire is unlikely to be significantly affected by the presence of additional fires within the compartment. Once radiation becomes more significant as a heat transfer medium each fire is able to radiate energy directly to the other fuel packages and the interactions between the fires become more significant. From this point in time the fires begin to deviate from their isolated behaviour due to energy transfer between the fuel packages. It is expected that the growth of each individual fire will be accelerated compared to that fire burning in isolation.

There is also the impact of the heat released by the secondary fires themselves. The onset of flashover is determined by the total energy released within the compartment. A number of smaller fires may initiate flashover significantly faster than a single large fire.

Once flashover has occurred, all objects within the compartment will be burning and the resulting post flashover fire will be the same as in the case of a single fire being ignited. That is, post flashover behaviour will not be impacted by the presence of the additional fires. These two issues are illustrated qualitatively in Figure 4.5.

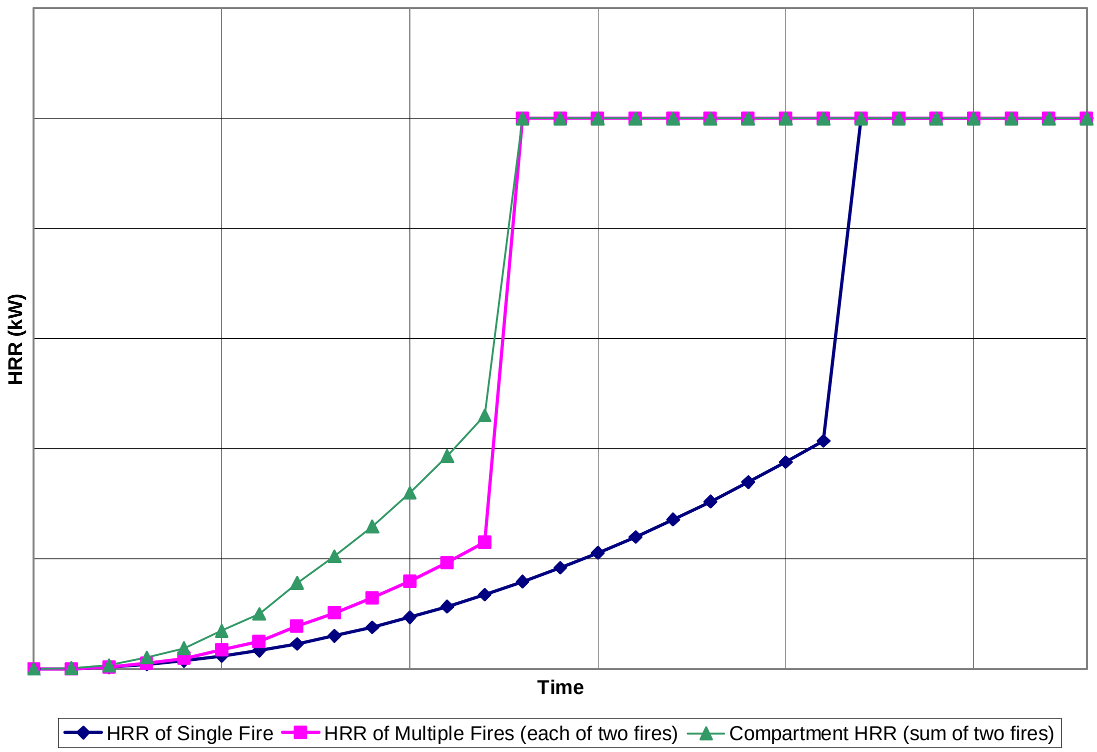

Figure 4.5: Generalised fire growth showing the impact of a second fire on the heat release rate of the individual fires and the total compartment heat release rate

4.2.2 Detection

With the additional energy and smoke released into the upper layer by the additional fires in the compartment the detection time may be less than that of a single fire. The magnitude of any reduction will be determined the combined fire heat release rate and the distribution of fires within the compartment. The actual detection time for such a scenario would best be obtained by modeling.

4.2.3 Escape Provisions

The ignition of multiple fires within a single compartment is unlikely to significantly affect escape times. Both pre-movement and travel times will be the same as in the case where only a single fire has been lit, and the location of the individual relative to the fire and their exit will determine travel times. The earlier detection time discussed above will result in a reduced RSET compared to a single fire; however the faster fire growth will also result in a reduced ASET. The impact on building occupants must be determined on a case by case basis.

4.2.4 Smoke Control

The fundamental smoke control issues will be similar to those indicated with fires in multiple compartments, however there is an additional constraint imposed in that the maximum combined heat release rate within the compartment will also be limited by the compartment ventilation. While the capacity of the smoke control system, and therefore its cost, are likely to be larger than what would be obtained under the current design philosophy, the ventilation limit is likely to limit the magnitude of these increases.

4.2.5 Sprinkler Design

In small compartments (smaller area than the design area for the sprinkler system) the ignition of multiple fires is unlikely to impact on sprinkler performance. A sprinkler system designed to NZS 4541:2003, will be able to handle the operation of all sprinklers in the design area so, if the sprinkler has been designed according to the hazard present, a compliant system should cope with the presence of the additional fires.

In the case of large fire compartments, defined as those larger than the design area, the presence of additional fires may cause problems due to insufficient water pressure. It is expected that as the compartment size (and the number of sprinkler heads) increases, the risk of overwhelming the sprinkler system will increase. Based on the three to five fires typically experienced in these cases, if the sprinkler system is able to cope with the simultaneous delivery from ten sprinkler heads then it is likely to cope with the majority of such fires.

4.2.6 Computer Modeling

Modeling multiple fires within a single compartment is easier in a zone model than modeling fires in multiple compartments. While the model cannot have more than a single fire, the ‘black box’ approach to the fire compartment means that there is little difference between two fires contributing to the smoke layer or one, larger fire.

Obtaining parameters such as layer height in a zone model for multiple fires is difficult at best. Reverse engineering a single heat release rate to get one parameter correct is likely to result in errors for other parameters. For example if a number of small fires is modeled as a single large fire the calculated smoke layer is likely to be smaller but hotter compared to the true situation. Results from such simulations should be treated with caution. This approach also ignores the effect of radiation between fuel packages so is likely to under predict the overall energy release rate.

Modeling multiple fires in a single compartment using FDS is likely to give reasonable results for occupants located outside the fire compartment. FDS does include radiation transfer from the fire to its surroundings and except in cases where the production of soot is low[79], the program is able to give reasonable predictions of the radiation transfer. The limitations of the single reaction chemistry is also likely to be reduced as, outside the fire compartment the smoke is likely to be well mixed so an appropriately selected yield is likely to give an adequate prediction as to the concentration of airborne contaminants.

5.0 Accelerated Fires

The second severe fire scenario identified in the New Zealand FIRS database analysis was the use of accelerants. Any introduced fuel package that makes a fire burn more rapidly or spread faster than normal may be considered an accelerant, however due to the increased quantity of plastic materials present in a typical compartment, fires in modern buildings have faster growth rates than fires in similar structures in the 1960's[80], so the definition of an accelerant is now typically applied to the use of flammable liquids or solid chemical compounds such as those found in pyrotechnics.

Holborn et al. has obtained estimates of the growth rates of accelerated fires based on an analysis of fires in London. Based on a αt^2 fire growth, they obtained a value 0.085 kW/s^2 for α when the fire was lit using flammable liquids or gases[81]. This puts the use of accelerants into the boundary of an ultra fast fire which is likely to be faster than what is typically assumed during the design process. From an investigative perspective the use of an ultra fast fire may be adequate however, for design purposes this is may be insufficient to adequately characterize the risk to building occupants.

5.1 Contribution to Casualty Statistics

Accelerants are used in 6.2% of deliberately lit fires in New Zealand yet they account for 52% of all fatalities from deliberately lit fires. For injury statistics they are similarly over-represented, accounting for 28% of life threatening injuries, 29% of moderate injuries and 11% of slight injuries. Clearly, the use of accelerants results in a fire that is more hazardous to individuals within the structure. As the severity of the injury increases, the probability that an accelerant has been used also increases. If deliberately lit fires are to be considered as a potential design scenario, then the maximum life safety benefits will be achieved if accelerants are considered as part of the design brief.

5.2 Types of Accelerant Used

While fires may be accelerated by a large number of fuels, petrol is by far the most common accelerant encountered in forensic casework, both here in New Zealand[82] and in the United States[21]. The United States data, taken from the Ohio Arson Crime Laboratory, indicates that petrol is positively identified almost five times more frequently than any other accelerant, accounting for just over half of the positive accelerant tests. The other accelerants frequently detected in accelerated fires in the United States are summarised as Figure 5.1. The high incidence of using petrol as the accelerant may be due to its ready availability, low cost, lack of traceability and its high flammability.

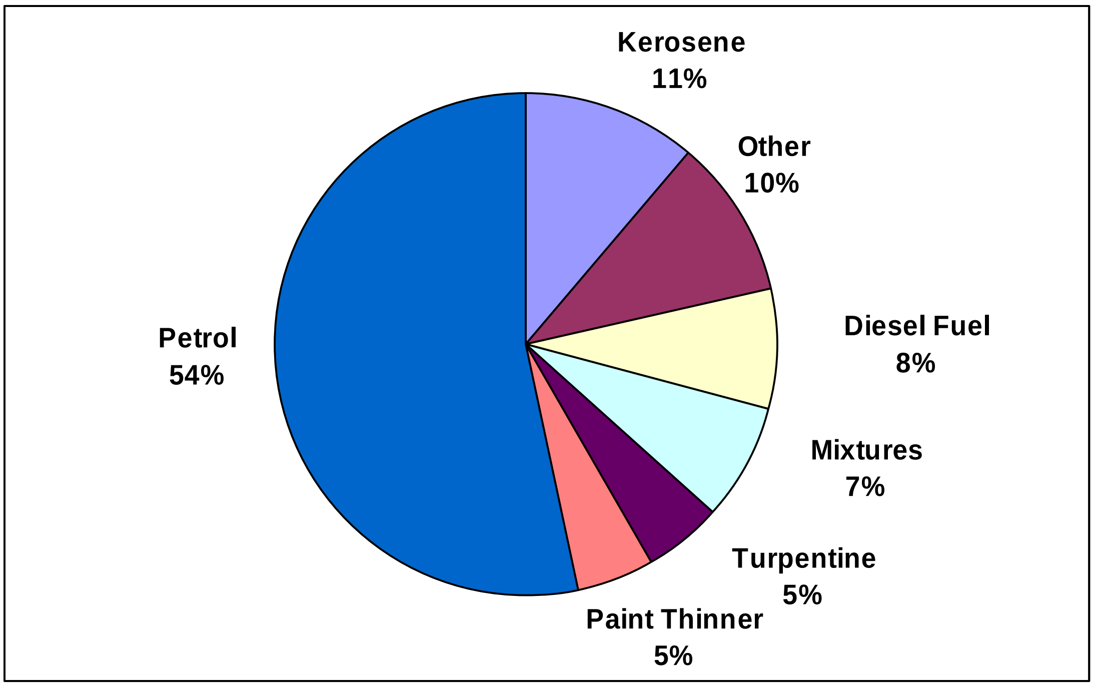

Figure 5.1: Breakdown of the accelerants used in US deliberately lit fires as identified by the Ohio Arson Crime Laboratory.

Because of its frequent use in fire incidents, petrol has been selected as the accelerant to be used in the experimental program. Petrol is the most volatile of the common liquid hydrocarbon fuels; it is a complex mixture of over two hundred different compounds and is readily ignitable with a flash point of approximately -40°C. In New Zealand, its physical properties are controlled by schedules one and two of the Petroleum Products Specification Regulations, 2002[83]. Due to its complex composition, petrol does not have a set composition however New Zealand regular grade fuel has the following compositional limits:

- Total aromatic content 42% maximum. The most common molecules present are toluene and xylene but it also may include a benzene content of up to 1%.
- Olefin content 18% maximum. These compounds are unsaturated molecules consisting of alkenes and cycloalkenes.
- Oxygenates are not permitted to be added to New Zealand fuels so the oxygen content of New Zealand petrol may be assumed to be zero.

The balance of the fuel is made up of saturated alkanes, with molecule sizes ranging from four carbon atoms through to nine carbon atoms. Both straight and branched carbon chain molecules will be present in a typical sample of fuel. The relevant properties from a fire engineering perspective are:

- Density: A typical density of regular grade fuel is 0.73 kg/m^3.
- Calorific Value: This is not a specification item but the gross calorific value of petrol is 47.8 MJ/kg[84].
- Flammable range: This is not a specification item but it ranges from 0.6% to 8.0%[85].
- Reid Vapour Pressure: This is a measure of the volatility of the fuel and is seasonally adjusted to enable easy starting of vehicles. The vapour pressure of New Zealand fuels ranges between 60 and 90 kPa. Because of this high vapour pressure, the concentration of gaseous petrol in a confined container is usually above the upper flammable limit and ignition or an explosion is not possible. A small volume of petrol in a relatively large space may result in vapour concentrations within the flammable range.

- Autoignition Temperature: This is not a specification item and strongly depends on the octane number of the fuel. Results ranging from 248°C for 65 Octane fuel to 412°C for 87 Octane fuel have been reported[21]. In New Zealand the octane number of petrol is obtained using the Research Octane (RON) test method while the octane number of US fuels is typically based on the calculated Anti-Knock Index (AKI). The New Zealand regular grade (91 RON) fuel has an AKI of 86.5, giving an autoignition temperature of approximately 410°C.

The certificates of quality for the fuel used during the experimental program have been included as Appendix C.

Even if only a single flammable liquid is considered there are still a number of ways that it may be utilised as an accelerant. These include:

- Pouring a quantity of fuel on a surface and lighting it to get the target object burning such as occurred in the Happyland Social Club fire[86].
- Using a trail of fuel to spread a fire quickly from one target object to another.
- Throwing a fragile container of fuel with a lit wick at a hard object to get the target ignited. This is known as a Molotov cocktail.

Pouring a quantity of flammable liquid on the floor or an object is one of the most common forms of accelerated fire; however this is difficult to recreate in a laboratory environment. The airflow required to measure oxygen depletion is much greater than what would be encountered in a typical compartment. This airflow removes a portion of the vapour that builds up prior to ignition, rendering any resulting fire curves unrepresentative of a real fire. There are also a number of safety issues with the ignition of the fuel vapour. Because of this safety concern, pours of flammable liquids have not been investigated as part of this research.

Many offenders take steps to avoid being observed when they commit crimes. In the case of deliberately lit fires, minimising the time that the offender is at the seat of the fire reduces the risk that they are observed. The fastest method of utilising an accelerant is through the use of a Molotov cocktail where the offender is able to stand back and throw the lit fuel package. The applicability of this fire scenario was demonstrated by a number of incidents that occurred in New Zealand during the study period where Molotov cocktails were deployed. These incidents contributed to the casualty statistics including at least one fatality. The deployment of a Molotov cocktail has also been identified as a gap in the fire engineering literature; in recent determinations this fire scenario has been identified as a potential fire scenario where there is currently no established heat release rate data available[88].

5.3 The Furniture Calorimeter

The University of Canterbury furniture calorimeter is based on Thornton's rule, which states that for a large number of organic liquids and gases, a more or less constant amount of heat is released per unit mass of oxygen consumed. Huggett found this to be true for organic solids as well as obtaining an average value for this constant of 13.1MJ/kg of oxygen[89]. The University of Canterbury calorimeter measures oxygen, carbon dioxide and carbon monoxide using a Seimans Ultramat/Oxymat 6 analyzer sampling from the exhaust duct. The extraction hood is located 3.0 meters above the floor of the fire laboratory however a temporary floor was installed to prevent damage to the laboratory floor, reducing the distance to the base of the extraction hood to approximately 2.8 meters. The extraction system removes air at the rate of approximately $4m^3/s$ from the laboratory with make up air being supplied through vents and the laboratory door. The raw data is recorded at one second intervals and then exported into an Excel spreadsheet to calculate the gas concentrations and heat release rate.

When the fuel is able to be accurately characterised, values of the heat released per unit mass of oxygen consumed and the heat released per unit mass of oxygen for the combustion of CO to CO_2 may be adjusted to improve the accuracy of the measurement.

As the chemical properties of petrol are not well defined, the default values of 13.1MJ/kg and 17.6MJ/kg have been used for these two parameters.

5.3.1 Experimental Setup

Calorimeter test standards usually require an unrestricted airflow around all four sides of the exhaust duct with at least two meters between the edge of the exhaust hood and a wall. The University of Canterbury calorimeter has two walls within two meters of the exhaust hood but this is not considered to be an issue for this work. To be effective, Molotov cocktails are required to be broken against a hard surface so the resulting fire will usually have airflow restricted on one or more sides. As part of the later experimental setup and to contain the resulting fire, a concrete block wall was built on two sides of the extraction hood so the fire had an unrestricted supply of oxygen on only two sides. This concrete block wall is shown in Figure 5.2.

Figure 5.2: The overall experimental configuration showing the concrete block wall on two sides of the extraction hood.

To maximise the probability that the bottle broke in a repeatable manner the bottle was suspended from a chain attached to the center of the extraction hood. The bottle was then drawn back and suspended at a height of approximately two and a half meters above the temporary floor as illustrated in Figure 5.3. The release mechanism consisted of a pin, connected to a length of wire that could be pulled from within the control room to release the bottle. The bottle would swing down and break against a steel bar with a beveled knife edge. The fuel was ignited by an electrical spark from two electrodes located one either side of the steel knife edge. With the bottle breaking between the two electrodes there was a spark on either side of the fuel package and ignition was effectively instantaneous. The knife edge and the two electrodes used to ignite the breaking fuel are illustrated as Figure 5.4.

Figure 5.3: One liter bottle of petrol suspended prior to run.

Figure 5.4: Steel knife edge and electrodes used to ignite the petrol.

To minimise the quantity of smoke that escaped collection via the extraction hood fire blankets were suspended around the perimeter of the hood. For the initial trial runs three blankets were used with the unenclosed side facing the point of release; however it was observed that with the larger fuel volumes a significant quantity of smoke escaped the extraction hood. In an attempt to quantify these losses, a number of trials were completed with a fourth fire blanket positioned along the front edge of the extraction hood to prevent smoke escaping out the front of the extraction hood. A photograph showing fire blankets suspended from two sides of the extraction hood is shown as Figure 5.5.

Figure 5.5: Fire blankets suspended from extraction hood perimeter (two sides only).

In addition to the gas analysis, two video cameras were used to film each experimental run. One of these cameras was located in line with the drop chain and the other was located at an angle of approximately 60° to the drop chain. The approximate location and viewing angle of each of these cameras is shown in Figure 5.6. Additional compartment temperature measurements were not taken during any of the experimental runs as the compartment temperatures in real fire situations are a function of the compartment size and ventilation. This diagram also shows the location of the steel target in the center of the fume hood and the line of approach for the Molotov cocktails.

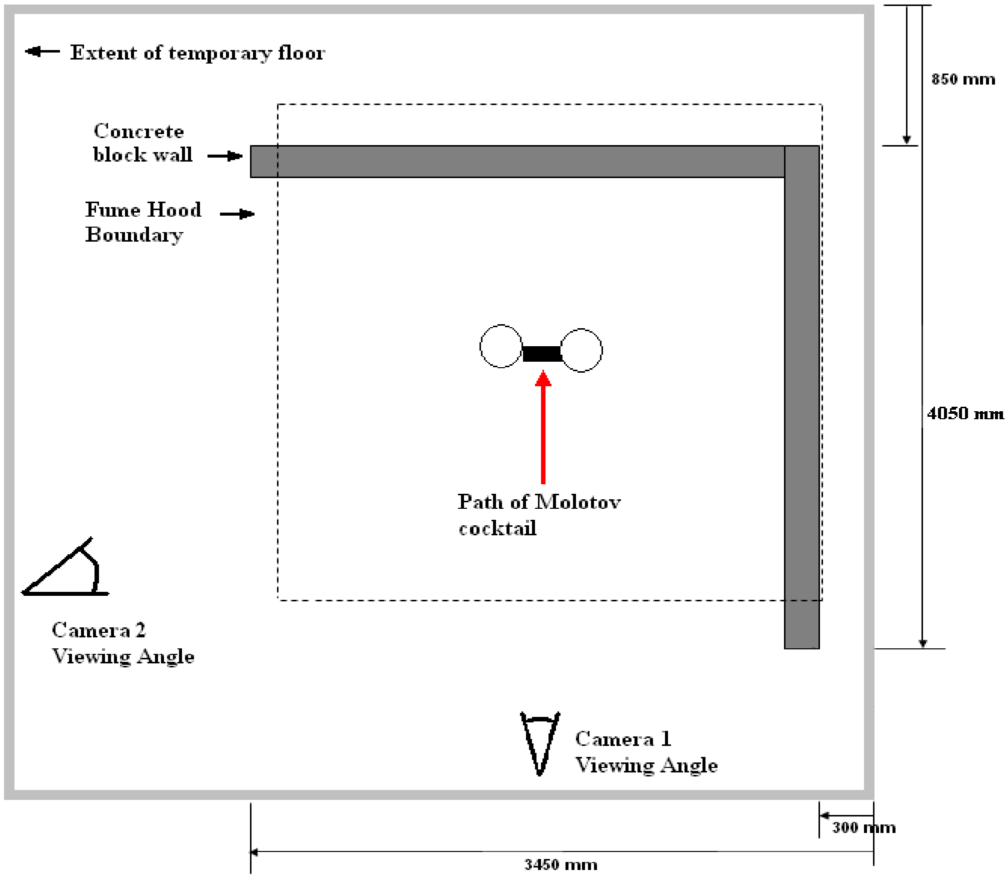

Figure 5.6: Schematic of the initial experimental arrangement.

5.4 Experimental Issues

A Molotov cocktail reaches its peak heat release rate within only a few seconds of ignition. Due to this rapid growth in the heat release rate the curves are sensitive a number of issues normally neglected when dealing with fire curves. The major sources of error that were considered as part of this research were:

- The methodology used to smooth the data.
- The response of the sensors.

To account for these two issues a detailed examination of how the data was collected and manipulated was required. The methods used to deal with these two issues are discussed below.

5.4.1 Experimental Noise

To reduce the amount of noise in the data five point averaging has been applied to the raw data to produce the heat release rate curve obtained. A five point averaging method was selected to be used for the noise reduction as it provided a reasonable smoothing function yet still maintains the general shape of the raw data. Due to the rapid growth and short duration of these fires, averaging over a longer interval of time had a significant impact on the shape of the heat release rate curve obtained, particularly around the peak heat release rate. As the averaging interval increases, there is a significant decrease in the peak heat release rate obtained along with an increase in the time taken to reach the peak. An experimentally obtained heat release rate history with and without the averaging is given as Figure 5.7. It shows the minimal impact of the five point smoothing on the shape of the heat release rate curve while eliminating the majority of the noise from the raw data.

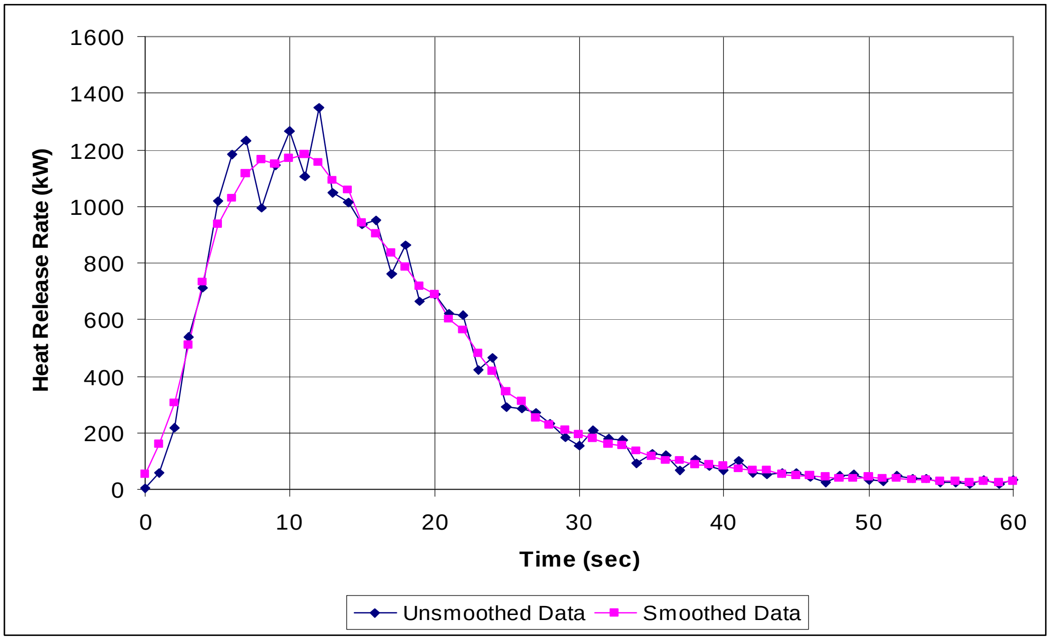

Figure 5.7: The impact of five-point averaging on experimental results from the furniture calorimeter.

5.4.2 Time Delays and Instrument Response

All physical measurements suffer from measurement errors. When measuring a parameter that changes with time, the ability of the sensor to follow these changes is one potential source of error as the measured result will follow behind the true value of the parameter measured. For parameters that do not change rapidly with time these delays do not significantly impact of the accuracy of the measurement however for variables that change significantly over a short time interval these delays may introduce significant errors.

The furniture calorimeter is subject to two major delays in measurement. There is the time it takes for the fire gases to physically move from the fire through to the detectors, this is known as the *transport lag*. There is also the time that the instruments take to measure a property, process the result and send it to the data logging software. This lag is known as the *sensor lag*. As the sensors are located in at different points in the exhaust system and process inputs at different rates these lags are different for each parameter recorded. The effect of these delays on a unit step change in an input variable is illustrated in Figure 5.8.

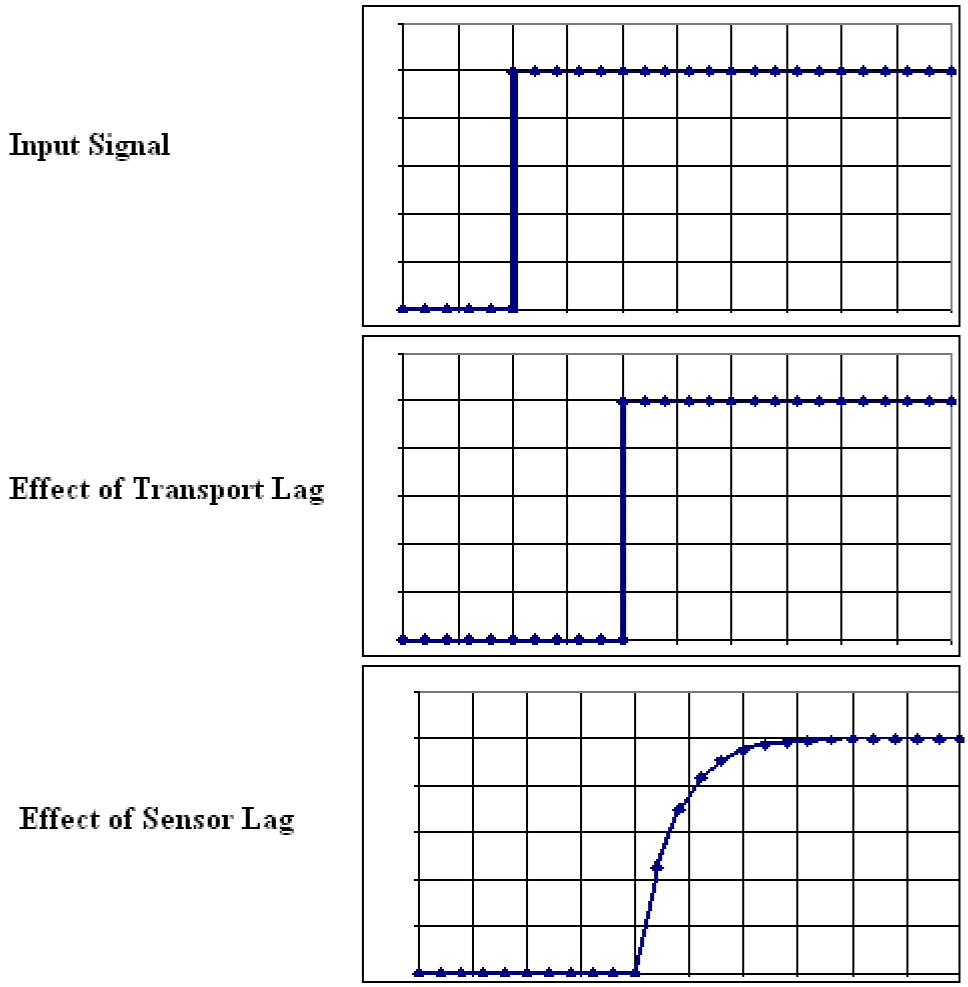

Figure 5.8: Impact of delays on a unit step change in input signal.

The spreadsheet used to generate the fire curves accounts for both of these two lags through a single time shift. In most fire tests the rate of change in the measured parameters is slow relative to these delays and the sensor lag may be incorporated within the transport lag without significantly impacting on the accuracy of the results. In the case of a Molotov cocktail, the resulting fire rapidly grows from ignition to the peak heat release rate so these delays may become a significant source of error if handled in this manner.

The transport lag for each parameter was removed by manually shifting the data along the time axis within the results spreadsheet. The sensor lag for the various sensors was examined using a ‘sampled-data’ method outlined by Goodeve[90]. The intent of this method is to assess the magnitude of the change between successive time steps and use this to apply a correction to the output of the next time step. The basis of this method is that the response function, ***H(t)*** of the oxygen sensor to a unit step change may be represented by a first order exponential lag, i.e.

$$H((t) = 1 - e^{-b_{inst}t} \qquad 5.1$$

Where: β_{inst} = Correction coefficient (fixed for the instrument).

Under this assumption it is possible to work backwards from the measured output and determine what the input function must have been to produce the response obtained. If the instrument coefficient is appropriately selected the corrected output will more closely represent the actual inputs.

Two tests were completed with a gas burner fueled by propane to characterise the lags for the oxygen, carbon dioxide and carbon monoxide sensors. In each test the heat release rate was manually adjusted in a stepwise manner using a mass flow controller to create a step function and the response of the furniture calorimeter was measured. The output from the sensors was then corrected to obtain the best fit to the input data.

The sampling interval used by the furniture calorimeter is 1 second and it was found that best results were obtained with β_{inst}=1.0. However this correction did not provide any significant improvement in data quality when applied to the temperature measurements or to the individual gas concentration results. The effects of sensor lag on the measured parameters is therefore acknowledged to be present, but no further manipulation will be done to correct for this source of error.

5.5 Characterising A Molotov Cocktail

Characterising a Molotov cocktail for fire engineering design purposes requires obtaining the heat release rate and toxic species production rates for the petrol used. The principle fire product species that will be included in this analysis are carbon dioxide and carbon monoxide, obtained directly from the furniture calorimeter tests. At the time of the experimental work there was no provision to measure soot levels in the furniture calorimeter so this data was obtained by examining a number of samples in the cone calorimeter.

In the figures to follow those trials where only three fire blankets were used to contain the smoke are shown as the unenclosed runs in the following figures (Unen Run 1 and Unen Run 2). The trials where the hood was completely surrounded by fire blankets are shown as the enclosed runs (Enc Run 1 and Enc Run 2).

As a check of the energy losses in each trial, the total energy released during the fire was compared against the amount of energy deployed based on the mass of fuel used and the heat of combustion. The heat of combustion of petrol is available in literature however there is considerable variation in the data. The gross heat of combustion used by the oil industry[83] is 47.8MJ/kg. As this is a gross figure, it represents an upper limit of the heat of combustion. Fire engineering literature[64] quotes a more conservative value of 43.7MJ/kg and due to these differences; samples of petrol were tested in the cone calorimeter to obtain an experimental value for the heat of combustion.

5.5.1 Cone Calorimeter Experiments

Three replicate trials were completed to obtain both the heat of combustion for use in the calculations and to obtain an estimate of the quantity of soot produced in the unrestricted combustion of petrol. A sample of fuel was placed in a container and ignited under the cone. Measurements were taken of the following variables at one second intervals:

- Mass loss rate
- Gas species in the flue gas (Oxygen carbon dioxide and carbon monoxide)
- Pressure in the duct
- Temperature in the duct

This data was manipulated using an Excel spreadsheet similar to that used for the furniture calorimeter to obtain the heat release rate history of the test run. The heat release rate history for one of these runs is given below as Figure 5.9.

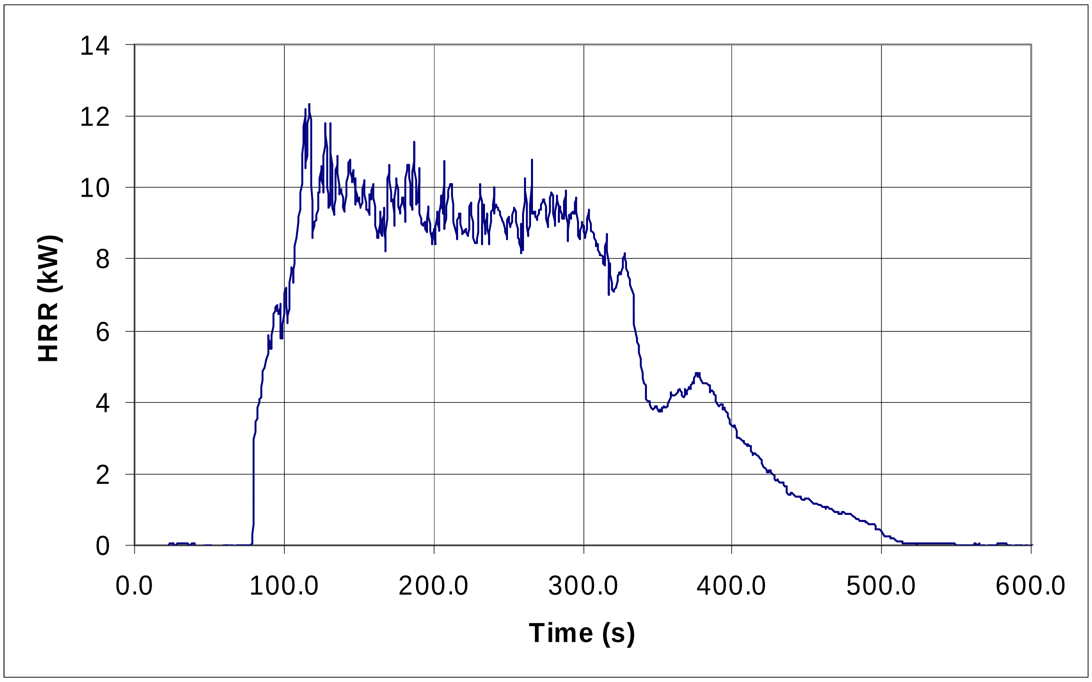

Figure 5.9: Heat release rate history for a petrol sample in the cone calorimeter.

During the period of steady state burning, between 150 and 300 seconds in Figure 5.9, the heat release rate obtained was divided by the mass loss rate to obtain a heat of combustion. The average heat of combustion for the three trials was 39.5MJ/kg. As this is lower than the value quoted by Brabrauskas this has been taken as a lower limit for the calculations to follow.

The cone calorimeter experiments also served to measure the amount soot produced during the combustion of petrol. In each trial a quantity of the flue gas was drawn through filter paper and the paper weighed to obtain the amount of soot collected.

5.5.2 Quantity of Fuel

The most significant parameter when characterising a Molotov cocktail is the quantity of fuel used. If the ultimate goal is to meet the life safety requirements of the Building Act then the requirement that the building be occupied places practical limits on the quantity of fuel that may be deployed. An individual carrying more fuel than they can effectively conceal on their person is likely to arouse suspicion and this limits the fuel volume to a few liters. The size of a single container also limits the volume of fuel that can be employed. Glass bottles are frequently used as the container for Molotov cocktails and these bottles generally have a maximum volume of 1000 milliliters although the 1125 milliliter bottles used by alcohol suppliers are still in circulation. Larger bottles are occasionally used for promotions by the alcohol suppliers but these bottles are not as commonly sold. Initially three commonly used bottle sizes (350 milliliters, 750 milliliters and 1000 milliliters) were selected for the experimental program but during the experimental program a 1500 milliliter bottle was obtained and this was also tested.

5.5.3 Results: Heat Release Rate History

Four trials were completed using 350mL of petrol. The five point averaged heat release rate history for the 350mL trials is given as Figure 5.10. All four runs show very similar characteristics with the growth rate, peak heat release rate and decay phase being similar in all four runs. All runs reached their peak heat release rate within thirteen seconds of ignition and all fires had decayed back below 50kW after forty seconds. The peak heat release rate obtained in these experiments ranges between 340 and 380kW. The effect of the additional fire curtain is minimal, as is expected with these relatively small fires.

The peak heat release rates with the additional fire blanket are, on average, 35 kW or 9% greater than when only three fire blankets were used. In these small fires, a proportion of this discrepancy is likely to be due to the normal scatter of test results rather than any real difference between the two test conditions.

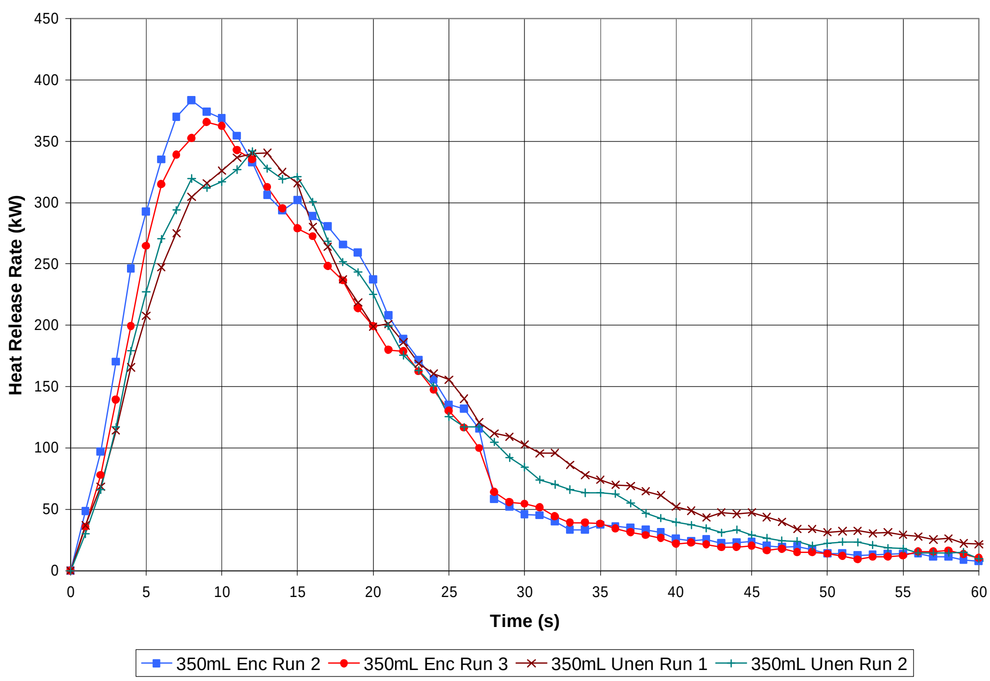

Figure 5.10: Heat release rate history for the four 350mL fuel trials.

Energy losses from the 350mL trials ranged between 5.9 and 20% based on a heat release rate of 39.5MJ/kg. Due to the small nature of these fires the extraction system was able to capture almost all of the smoke indicating that these losses are likely to be due to a combination of experimental error and heating of the area around where the Molotov cocktail was deployed.

Four trials were completed using 750mL of petrol. Figure 5.11 shows the heat release rate histories for these trials. Three of the four trials show very similar growth rates, decay rates and time to peak heat release rate. Unenclosed test run one had a slower growth rate and a less sharply defined peak heat release rate compared to the other tests at this fuel volume. All four tests show a similar decay rate, three tests dropping below 100kW within forty seconds and all test curves below this threshold within fifty seconds. The effect of the fourth fire blanket is more significant; peak heat release rates with the additional blanket are, on average, 140 kW or 16% greater than when three fire blankets are present.

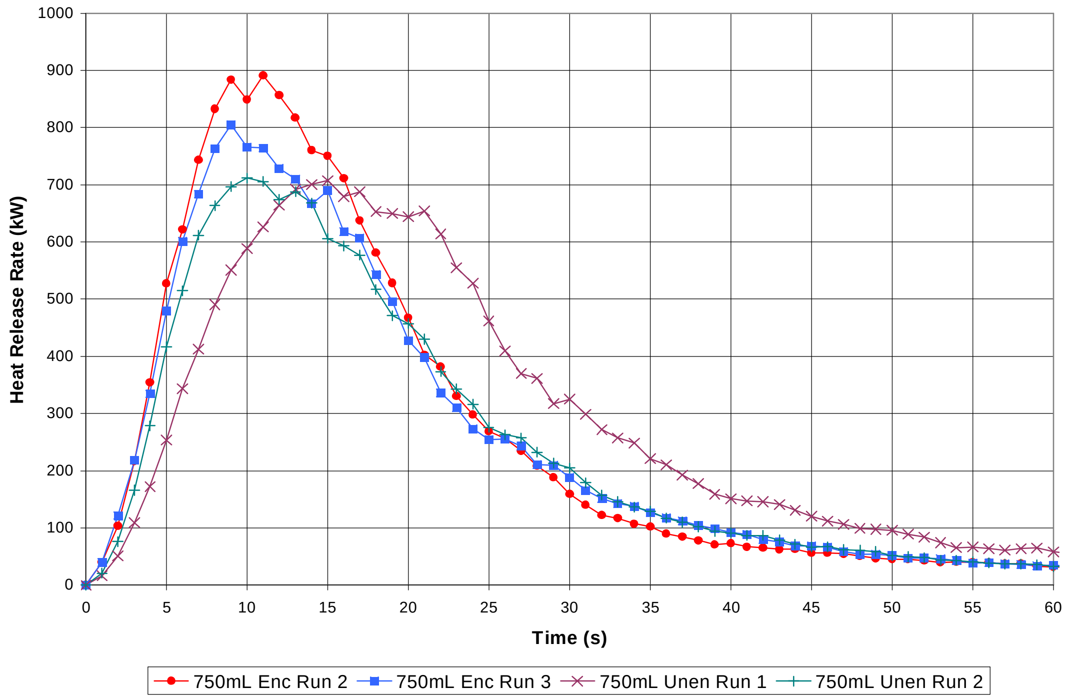

Figure 5.11: Heat release rate curves for the four 750mL fuel trials.

Energy losses from the 750mL trials ranged between 3.7 and 20% with an average loss of 12.2% based on a heat release rate of 39.5MJ/kg. Visually these fires produced more smoke that was not captured by the extraction system however the calculated energy losses do not support this observation. Again the losses are likely to be due to a combination of experimental error and heating of area around the fire

Four trials were completed using 1000mL of petrol. Figure 5.12 shows the heat release rate histories for these trials. The three enclosed trials and the second unenclosed trial show virtually the same growth rate and decay rate. The heat release rate for these four trials dropped below 100kW within forty seconds and all five were below 100kW after fifty seconds. The contribution of the fourth fire blanket is more significant again; peak heat release rates with the addition blanket are, on average, 240 kW or 21% greater than when only three fire blankets are present. This is not unexpected as the extraction hood has a constant capacity and as the fire size increases, the proportion of smoke lost from the bottom edge of the extraction hood also increases.

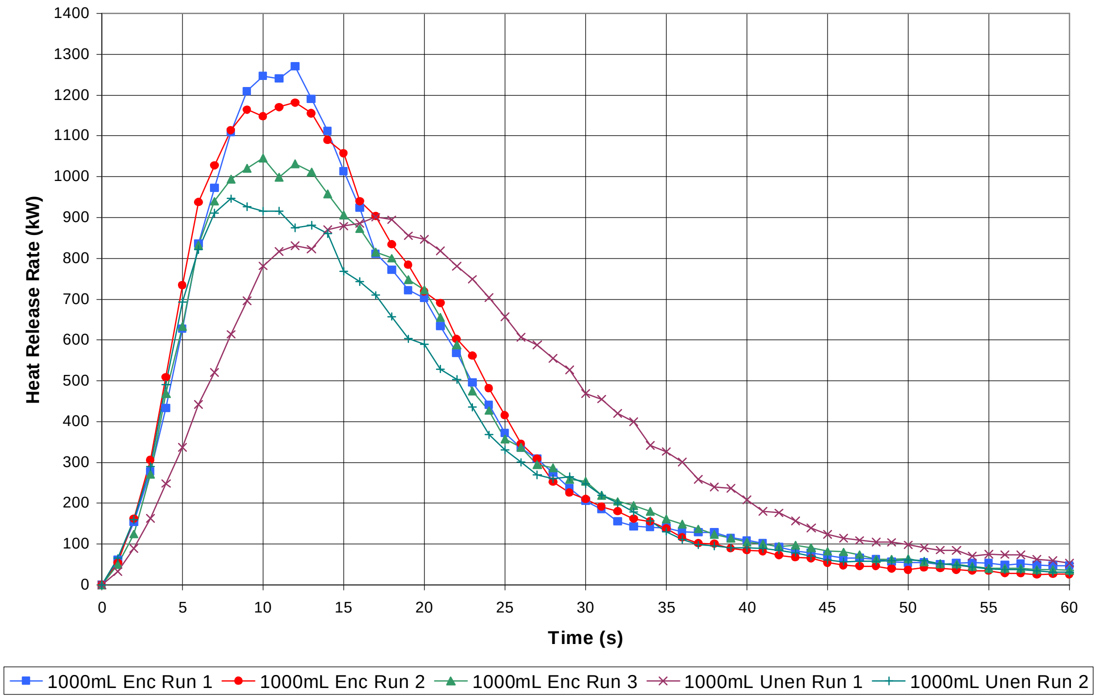

Figure 5.12: Heat release rate curves for the five 1000mL fuel trials.

Energy losses from the 1000mL trials ranged between 4.2 and 23% with an average loss of 13.8% based on a heat release rate of 39.5MJ/kg. The increase in heat release rate observed for the fully enclosed trials is confirmed by a lower average energy loss- 12.6% versus 13.8% energy losses for the unenclosed trails. Again the losses are likely to be due to a combination of experimental error and heating of area around where the Molotov cocktail was deployed.

The heat release rate curve for the single 1500mL trial is shown below as Figure 5.13. To minimise the energy losses this trial was completed with the extraction hood fully enclosed. It shows a similar shaped growth stage to the 1000mL fire curves, peaking between ten and fifteen seconds and decaying back below 100kW after approximately forty seconds. As only a single test was completed at this fuel volume it is not possible to compare test runs to examine the repeatability at this fuel volume.

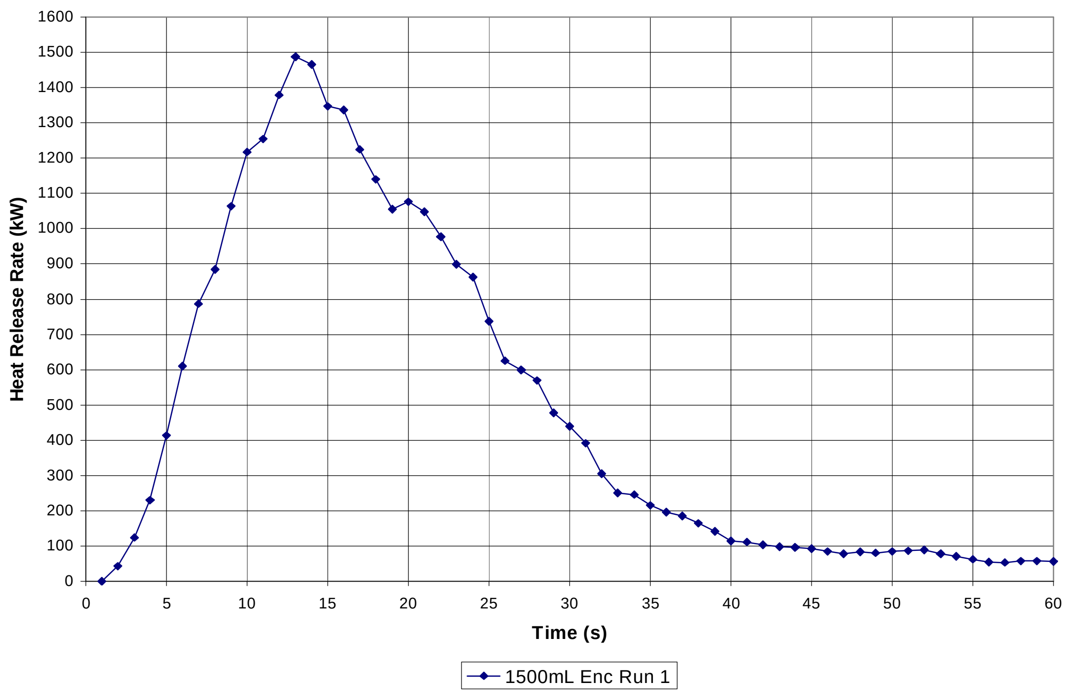

Figure 5.13: Heat release rate curve for 1500mL fuel trial.

5.5.4 Results: Peak Heat Release Rate

The peak heat release rate for all samples tested is summarised as Figure 5.14. As the intent is to obtain a worst case design fire, peak heat release rates given in this section have not been smoothed by averaging. Over the fuel volume range examined, there is a strong correlation between the maximum heat release rate for each sample and the fuel volume used. The peak heat release rate may be characterized in terms of the volume of the container used to deliver the fuel. The constant of proportionality ranges from a minimum of 1.07kW/mL of fuel to 1.34kW/mL of fuel. At lower fuel volumes, the peak heat release rate shows little scatter however as the volume of the container increases the amount of scatter in the data also increases.

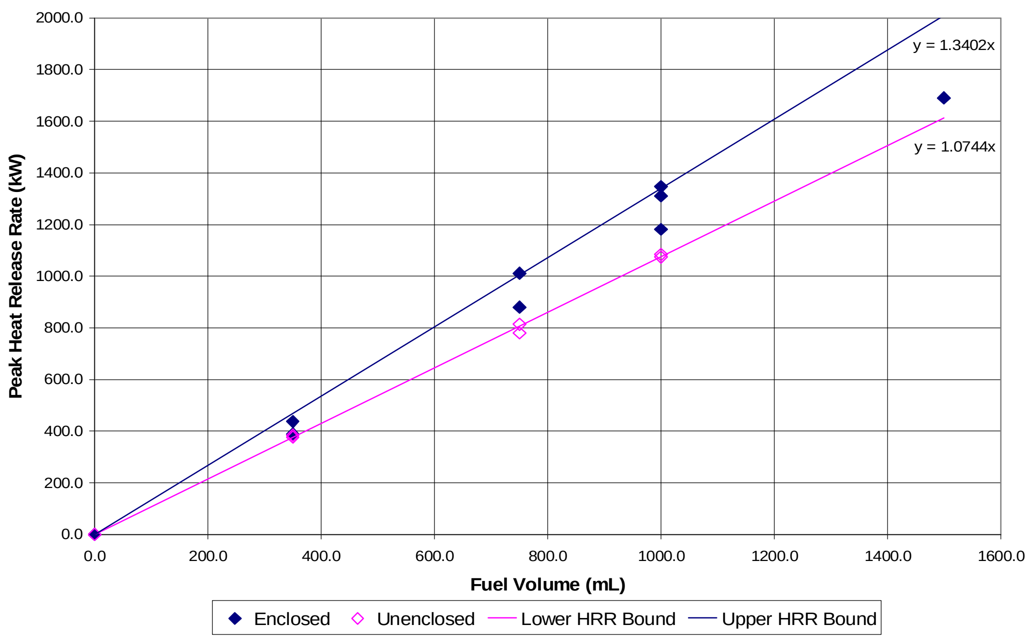

Figure 5.14: Molotov cocktail peak heat release rate against fuel volume.

While the 1500mL test lies within the range given, there was a noticeably different fuel behaviour observed during this fire. In all of the smaller samples there was little or no pooling of liquid petrol on the floor while during the 1500mL test pooling of liquid fuel was apparent. This suggests that there is a transition from a momentum controlled fuel spread to some other limiting mechanism between 1000 and 1500 millilitres.

5.5.5 Results: Growth Phase

A selection of the tests, selected to illustrate the full range of growth rates encountered in the test program, are plotted as Figure 5.15.

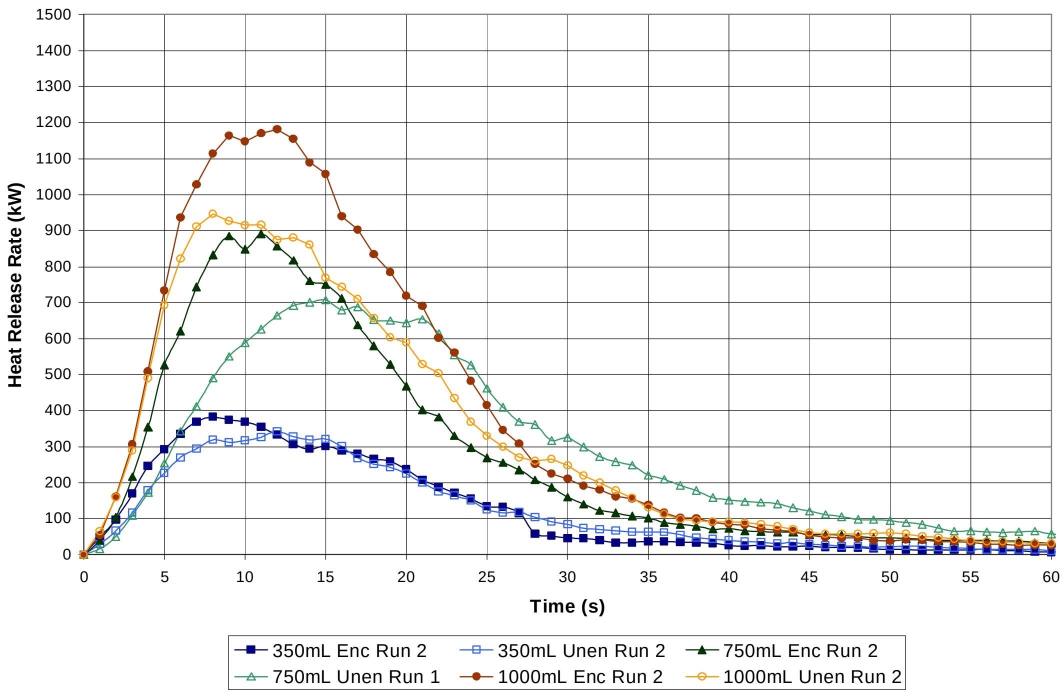

Figure 5.15: Heat release rate histories for Molotov cocktails deployed in an open space showing the impact of fuel volume on the fire growth rates.

Irrespective of the quantity of fuel used, the maximum heat release rate was reached between nine and eighteen seconds after ignition. In general, as the fuel volume increased the time taken to reach the peak heat release rate also increased however this difference is relatively small with the average difference in time between the 350mL tests and the 1500mL test being approximately two seconds as shown in Table 5.1.

Sample Volume (mL)	Enclosed Tests			Unenclosed Tests		Average Time (sec)
	Run 1	Run 2	Run 3	Run 1	Run 2	
350	9	10	-	14	13	11.5
750	12	10	-	16	11	12.3
1000	13	13	11	18	9	12.8
1500	13	-	-	-	-	13.0

Table 5.1: Measured time to peak heat release rate for a Molotov cocktail for fuel volumes between 350 and 1500mL.

Equation 5.2 gives a reasonable approximation of the time to peak heat release rate.

$$t_{pk} = 11 + \frac{V}{700} \qquad 5.2$$

Where: t_{pk} = Time to peak heat release rate (seconds)
V = Fuel volume (mL)

Plotting the initial growth rate against the commonly used t-squared and t-cubed fire growth curves shows that the growth rate is significantly greater than both of these fire curves. To obtain a growth rate that reaches the required peak heat release rate in the short time available necessitates the use of very large constants, in the case of the t-squared fire curve the constant α must have a value of approximately 9.0 kW/s^2.

The test curves were also compared against exponential fire growth as described by Law[91]. The value of the initial fire heat release rate was taken as 10kW as recommended in Law's paper. Unless the exponential constant has a value of approximately 0.4/s it will also fail to reach the required heat release rate in the time available.

The shape of the growth phase part of the heat release rate curve is illustrated below as Figure 5.16. Clearly a Molotov cocktail has a much faster growth rate than the standard t-squared or t-cubed fire curves. Even the use of an exponential fire growth curve underestimates early fire behavior. The best fit to the data is obtained by using a linear growth rate over a growth period until the peak heat release rate is achieved.

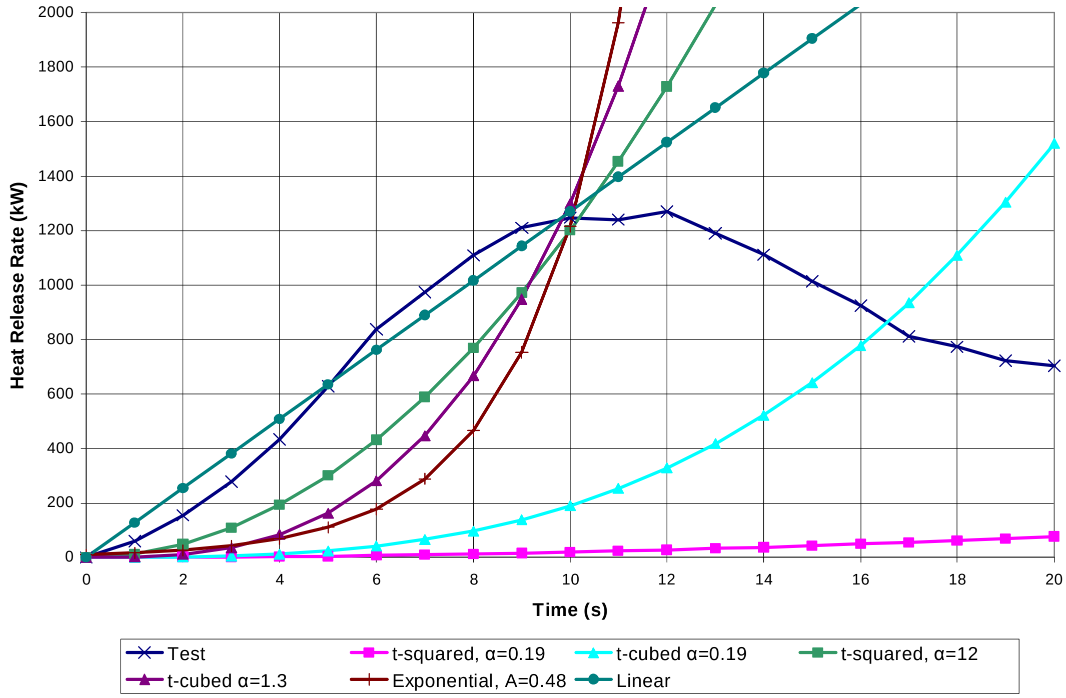

Figure 5.16: Initial heat release growth rate comparison.

5.5.6 Results: Decay Phase

Due to the extremely transient nature of a Molotov cocktail fire there is no steady state phase. Consequently the fire moves directly from the peak heat release rate into the decay phase. At larger fuel volumes, the shape of the decay phase is largely independent of the fuel volume used. In the majority of tests above 350mL volume, the heat release rate drops from approximately 70% of its peak value (at approximately five seconds after the peak heat release rate) to approximately 100kW over a period of approximately twenty five seconds. An exponential decay function provides a good fit to the data over this time as shown in Figure 5.17.

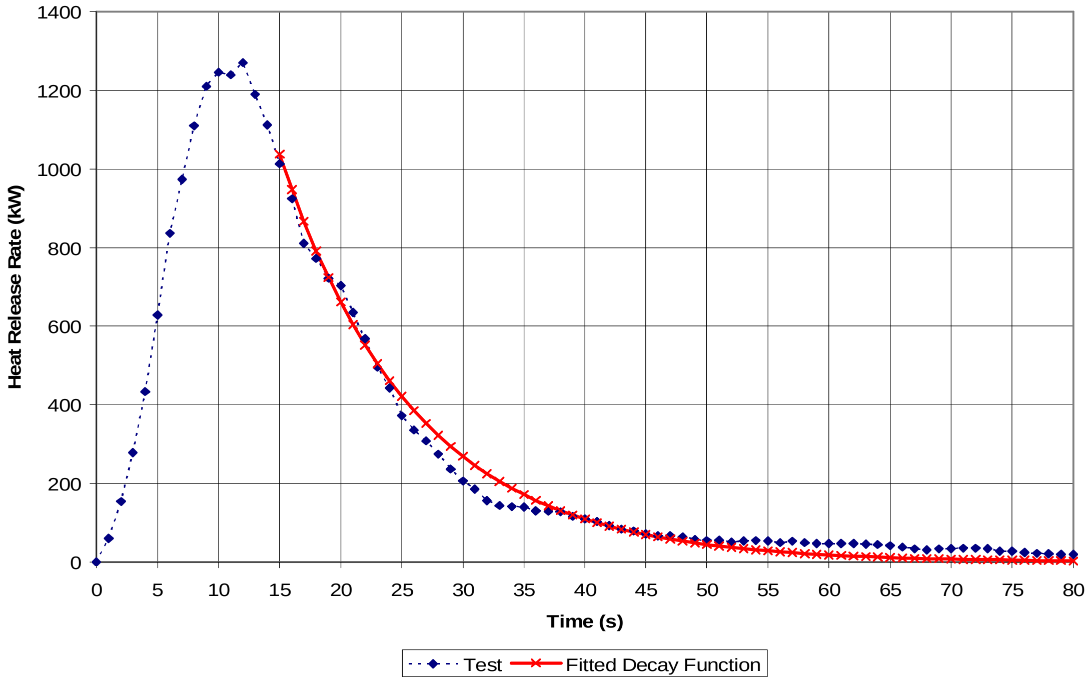

Figure 5.17: Decay function of Molotov cocktail between fifteen and eighty seconds.

This function provides an adequate approximation out to about eighty seconds where the fire may be assumed to have consumed the available fuel and self extinguished. Extending the exponential decay out this long has been done only to complete the design fire for a Molotov cocktail in isolation. In situations of interest to the fire engineer, the Molotov will have been used as a means to ignite a secondary object and the heat release rate of this object is likely to dominate the overall heat release rate during this time period. The decay function that is applied between fifteen and eighty seconds is of the form:

$$\dot{Q} = C_1 \times V \times \exp^{-C_2 \times t} \qquad 5.3$$

Where $\dot{Q}$ = Heat release rate of the fire (kW)

V = Fuel volume (mL)

t = Time after ignition (seconds)

The constants C_1 and C_2 depend on the fuel volume used. Constant C_1 varies slightly with the fuel volume and a value of 3.9kW/mL of fuel gives the best results over the fuel volume range examined. Constant C_2 does not vary much with the fuel volume and a value of 0.09 provides an adequate result over the range of fuel volumes investigated.

5.5.7 Results: Overall Heat Release Curve

The previous sections may be combined to obtain the overall heat release rate curve as a function of the fuel volume. A predicted heat release rate curve has been calculated and compared against the heat release rate curve for one of the actual tests included for comparison. This comparison has been included as Figure 5.18.

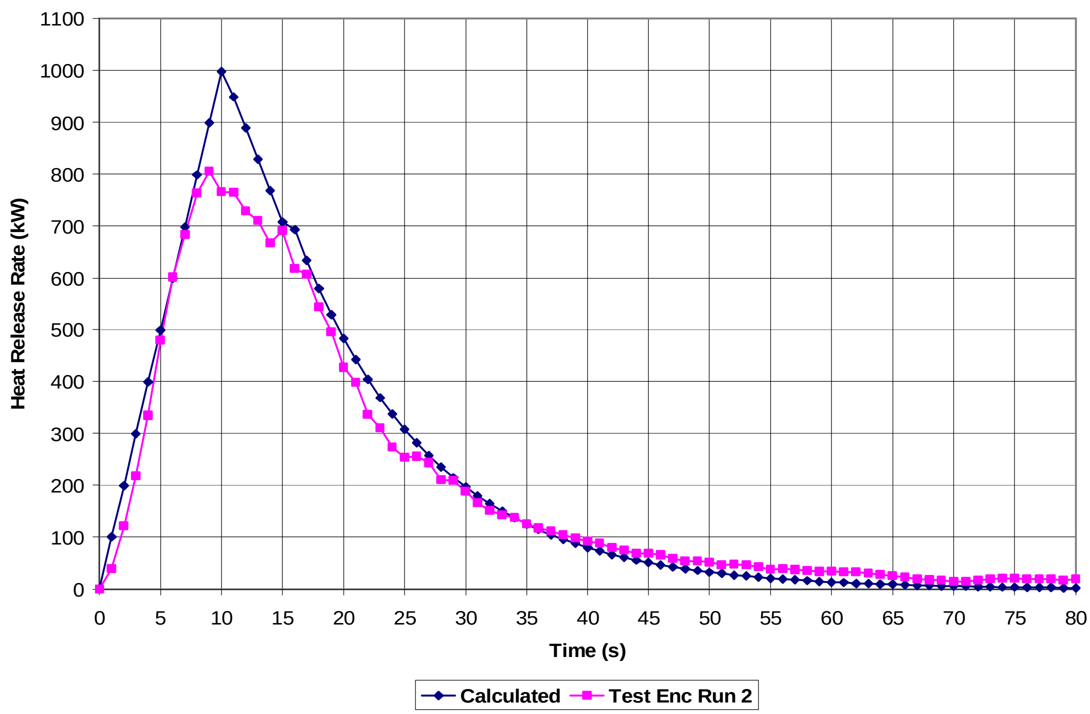

Figure 5.18: Comparison between the predicted and actual heat release rate curves

Due to the fact that the peak heat release rate is obtained using point data and the balance of the curve is obtained using averaged data there is a slight over prediction of the peak heat release rate. Due to the short nature of this phase of the fire this difference is not likely to result in excessive conservatism. The balance of the predicted heat release rate curve follows the experimentally obtained data closely.

5.5.8 Results: Yield of Carbon Dioxide

The yield of toxic gases is also important, both for the fire engineer and for the fire investigator. The variable composition of petrol makes exact assessment of the yields of fire products both unreliable and of little use, however the results are likely to fall within a relatively narrow range. In the case of carbon dioxide the theoretical yield may be estimated based on an assumed fuel composition.

Compound	Formula	Carbon Fraction (%)
Butane	C_4H_{10}	82.8%
Hezane	C_6H_{14}	83.7%
Octane	C_8H_{18}	84.2%
Decane	$C_{10}H_{22}$	84.5%
Alkenes & Cycloalkanes	C_nH_{2n}	85.7%
Benzene	C_6H_6	92.3%
Toluene	C_7H_8	91.3%
Xylene	C_8H_{10}	90.6%

Table 5.2: The carbon fractions of the main components of petrol.

The component of petrol with the greatest carbon fraction is benzene (C_6H_6) with a carbon content of 92%. The component with the lowest carbon content is butane (C_4H_{10}) with a carbon content of 82%. These two compounds form the boundary of typical carbon to hydrogen ratios encountered in petrol. As the benzene component is restricted by regulation to less than one percent the mean carbon content is likely to be closer to that of the butane. Carbon to hydrogen ratios for molecules of various forms are given in Table 5.2.

The average carbon fraction for petrol lies in the range 85-90%, roughly corresponding to a composition of C_nH_{2n}. Based on this assumed composition, the theoretical maximum yield of carbon dioxide is therefore given by equation 5.4:

$$C_nH_{2n} + 1.5.nO_2 \rightarrow nCO_2 + nH_2O \qquad 5.4$$

In mass terms this is:

$$n \times 14 + 1.5 \times n \times 32 \rightarrow n \times 44 + n \times 18$$

Or, for every gram of petrol consumed 44/14= 3.14g of carbon dioxide are produced.

As the mass of the fuel was not directly measured during the furniture calorimeter trials, the mass loss rate (and the yield of carbon dioxide) cannot be obtained directly and must be calculated by back calculating based on the heat release rate.

The mass loss rate of the fuel was estimated by dividing the heat release rate obtained by heat of combustion as in Equation 5.5.

$$\dot{m} = \frac{\dot{Q}}{\Delta H_C} \qquad 5.5$$

Where: $\dot{m}$ = Mass loss rate of the fuel (kg/s)

$\dot{Q}$ = Heat release rate of the fire (kW)

ΔH_c = Heat of combustion for petrol (MJ/kg)

Use of the lower experimental heat of combustion will result in a higher mass loss rate and therefore is likely to underestimate the actual yield of carbon dioxide. Use of the higher oil industry heat of combustion will give a lower mass loss rate and is likely to overestimate the yield of carbon dioxide. Separate calculations were done using both figures to bracket the expected yield of carbon dioxide.

The mass of carbon dioxide was obtained by converting the molar fraction of carbon dioxide in the exhaust gases from the furniture calorimeter to a mass fraction using equation 5.6.

$$\dot{m}_{CO2} = \frac{\dot{m}_{Air} X_{CO2} M_{CO2}}{M_{Air}} \quad 5.6$$

Where: $\dot{m}_{CO2}$ = Mass flow rate of carbon dioxide (g/s)

$\dot{m}_{Air}$ = Mass flow rate of air in exhaust duct (g/s)

X_{CO2} = Molar fraction of carbon dioxide in exhaust duct (from sensors).

M_{CO2} = Molar mass of Carbon dioxide (=44g/mol).

M_{Air} = Molar mass of Air (=29g/mol).

Five-point averaging has been applied to both the mass of air and the molar fraction of carbon dioxide as the calculations are sensitive to fluctuations in both parameters. The yield of carbon dioxide was averaged only during those times when the mass loss rate was greater than 10g/s as is shown in Figure 5.19. The average yield of carbon dioxide for all furniture calorimeter trials is given as Figure 5.20. A linear curve of best fit using ΔH_c = 47.8MJ/kg is represented by the 'Upper bound CO2 Yield' and a similar curve using ΔH_c = 39.5MJ/kg is represented by the 'Lower Bound CO2 Yield'.

The theoretical carbon dioxide yield of 3.14g/g lies between these two boundaries and an average yield of carbon dioxide of 3.0g/g is obtained. Considering the very transient nature of these fires this is considered acceptable. While there appears to be an increase in the yield of carbon dioxide with fuel volume, the magnitude of this increase is small and cannot be supported on either theoretical grounds or confirmed based on the test results obtained.

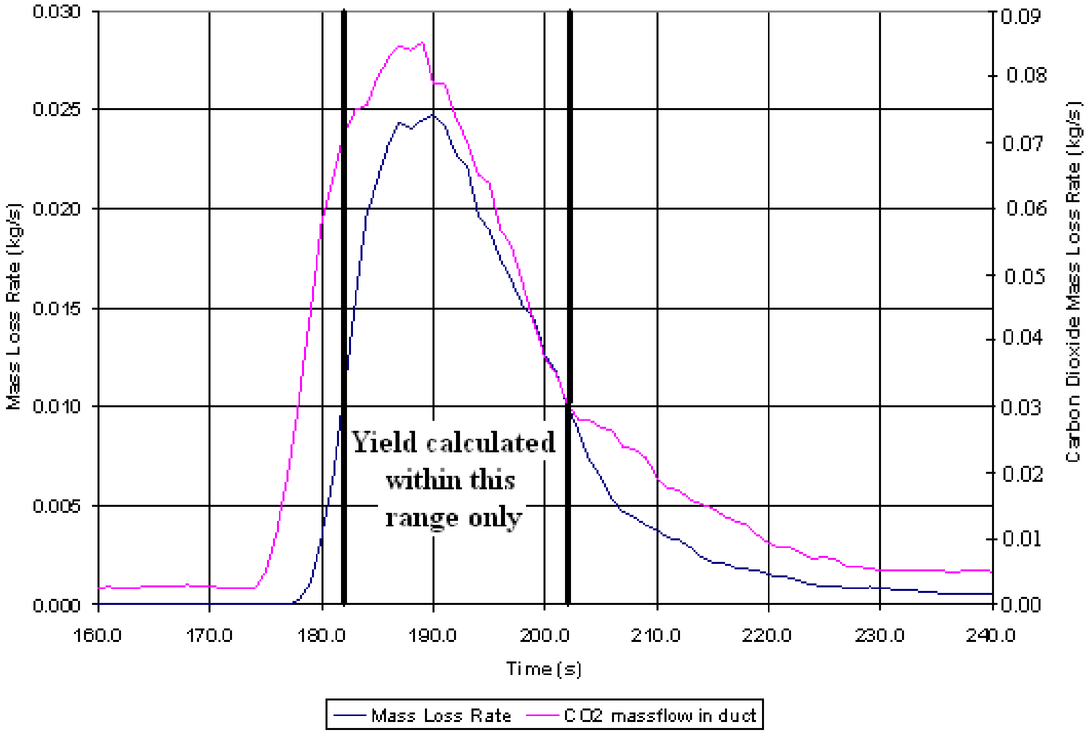

Figure 5.19: Calculation range used to determine the yield of carbon dioxide

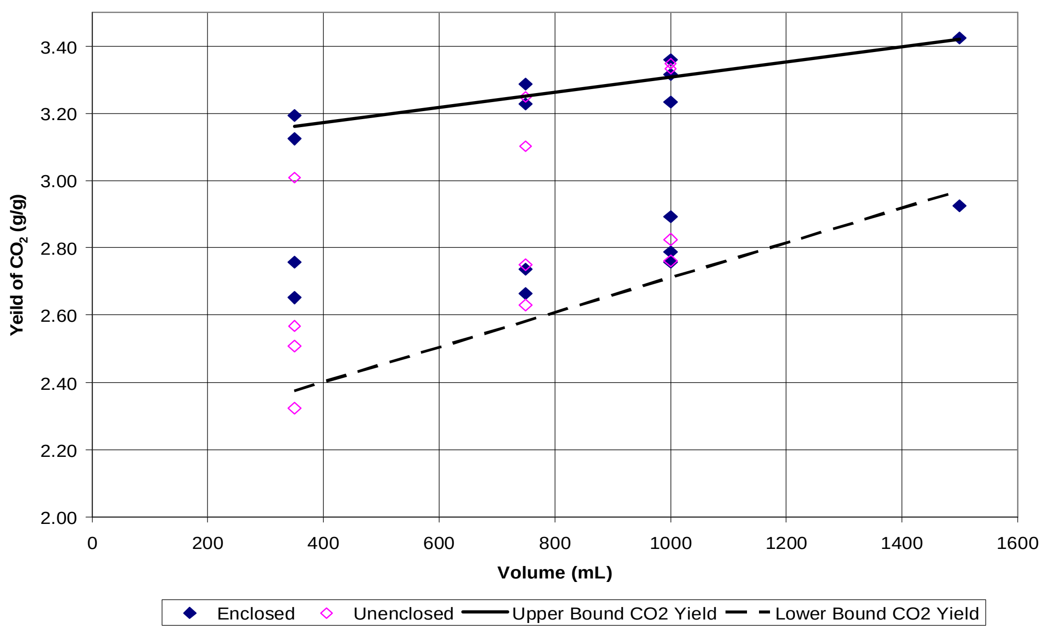

Figure 5.20: Yield of carbon dioxide as a function of fuel volume.

5.5.9 Results: Yield of Carbon Monoxide

The yield of carbon monoxide was obtained using the same method used previously to obtain the yield of carbon dioxide with Equation 5.7 used in place of Equation 5.6.

$$\dot{m}_{CO} = \frac{\dot{m}_{Air} X_{CO} M_{CO}}{M_{Air}} \qquad 5.7$$

Where: $\dot{m}_{CO}$ = Mass flow rate of carbon monoxide (g/s)

$\dot{m}_{Air}$ = Mass flow rate of air in exhaust duct (g/s)

X_{CO} = Molar fraction of carbon monoxide in exhaust duct (from sensors).

M_{CO} = Molar mass of Carbon monoxide (=28g/mol).

M_{Air} = Molar mass of Air (=29g/mol).

Carbon monoxide yields were plotted for both ΔH_c = 47.8MJ/kg and ΔH_c = 39.5MJ/kg as before and the results are given as Figure 5.21. The test results suggest an increase in the yield of carbon monoxide with fuel volume. This is likely to be a real phenomenon rather than a false product of a limited number of tests as it may be explained by a decrease in the completeness of combustion with increasing fuel volume caused by oxygen depletion at a local level within the heart of the fire.

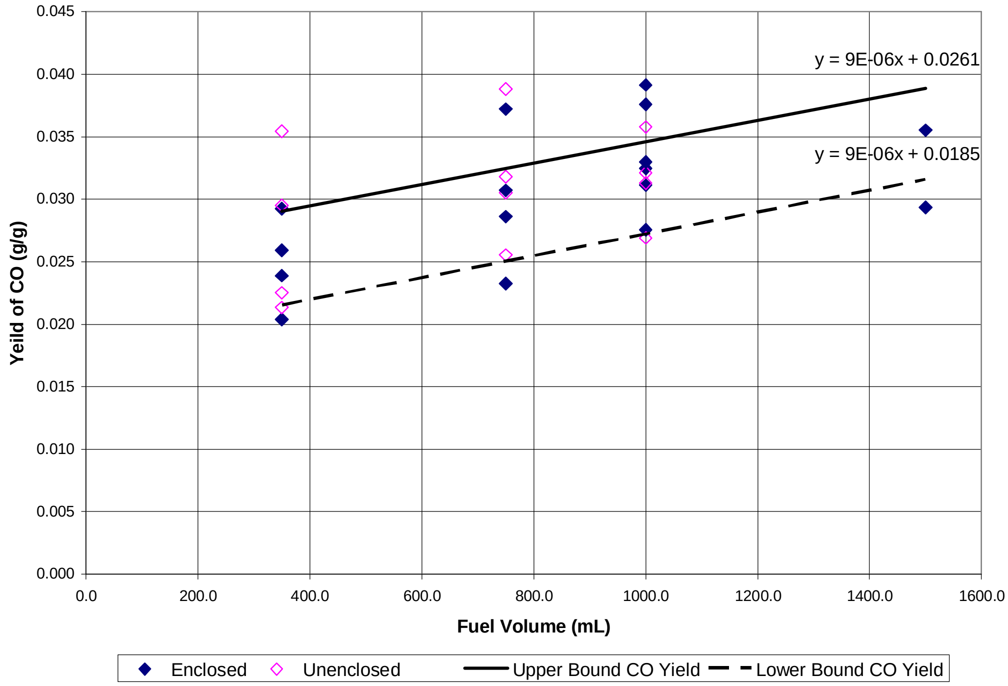

Figure 5.21: The yield of carbon monoxide as a function of fuel volume.

The yield of carbon monoxide does show some dependency with the fuel volume with an average expected yield given by equation 5.8, based on the data in Figure 5.18.

$$y_{CO} = 9 \times 10^{-6} V + 0.022 \qquad 5.8$$

Where: y_{CO} = Yield of carbon monoxide (g/g)

V = Volume of fuel deployed (mL)

5.5.10 Results: Yield of Soot

At the time of testing the furniture calorimeter was unable to measure soot yields. The soot yields were obtained from the cone calorimeter test runs and should therefore be considered as a guide only. The three test runs completed gave an average soot yield of

0.038g/g. As the tests were run separately, the yield of soot cannot be compared to the volume of fuel used though it is likely to follow the same trend as the carbon monoxide due to the fact that both are measures of the completeness of combustion.

5.6 Computer Simulation

The heat release rate data may be utilized directly using either zone models or CFD models. If the fires are being simulated in isolation the yields of fire products may also be directly used. When trying to simulate the ignition of secondary items the single reaction chemistry used in models such as FDS is likely to require some manipulation of the fire products data to give meaningful results.

6.0 Impact of the Surroundings

A fire burning in an empty space is different to a fire burning in a real compartment where objects provide obstructions to the transfer of oxygen to the fire and reflect energy back onto the fuel package. Especially in the case of liquid fuel, the shape and surface roughness of the impact surface can also impact on the resulting fire spread and therefore the heat release rate. To examine the impact of these variables a series of tests were conducted to simulate a Molotov cocktail deployed within a stairwell.

6.1 Scenario Significance

Attached accommodation structures such as apartment buildings are second most likely structure type to be subjected to a fire where accelerants are used with accelerants of some form being used in 8.3% of deliberately lit fires. Within this building category, flammable liquids are the fourth most common item ignited in such fires. When these points are combined with the facts that such buildings are likely to have a greater occupancy during the time of peak risk from deliberately lit fires and that occupants may be asleep during this time, the life safety risks from such fires is readily apparent.

The New Zealand building code requires protection of other people's property so in the case of apartment buildings designed to C/AS1[51], each individual apartment is required to be a separate firecell so unless the fire is in an escape path, building occupants outside the compartment of origin are likely to have a high chance of escaping the effects of the fire. Because of this, the greatest risk to building occupants comes from a fire started in a common area such as the entrance or within a hallway.

C/AS1 allows buildings with a building height of up to ten meters to be designed without sprinklers and have a single means of escape. This height limitation effectively limits the structure size to four floors. C/AS1 also permits up to fifty occupants per floor, resulting in up to two hundred occupants having their only escape cut off by a single fire located within the escape path.

In attached accommodation buildings the proportion of fires that occur in those common areas which may be used for escape is relatively low with 10.1% (or 58 incidents) of all deliberately lit fires occurring in lobbies, hallways and internal stairwells. These fires represent a risk to all building occupants and are typically the result of an introduced fuel load. Accelerants are used in 13% of these incidents. It is these scenarios that are the focus of this portion of the testing program.

6.2 Experimental Arrangement

The experimental arrangement is similar to what was used in the preliminary testing. The two concrete walls were used to contain the fire and they also had the additional requirement to provide support for the flight of stairs that were included in this portion of the test program. The stairs were positioned with no space between the edge of the stairs and the rear wall, much as stairs are installed within many real structures. The top end of the flight of stairs was positioned against the other wall. For the tests with a Gibb plasterboard wall, timber framing was placed against the block wall and sheets of standard plasterboard were screwed to the timber frame with screws located at 400mm centers. The joins between the sheets of plasterboard were left unfinished. The flight of stairs was then positioned against the surface of the plasterboard.

The stairs themselves were constructed to meet the requirements of D1/AS1[92]. The wooden stairs consisted of ten particle board steps with a 180mm riser and a 285mm tread. The width of each step was 1000mm and each timber stringer was 45mm wide and 250mm deep. Each flight of stairs was given two coats of polyurethane to seal the timber. The steel stairs consisted of the same riser and tread profile as well as the same stringer depth however the thickness of the stringer was reduced to approximately 6mm, the thickness of the steel plate used.

The physical arrangement of the flight of stairs within the test space is illustrated in Figure 6.1.

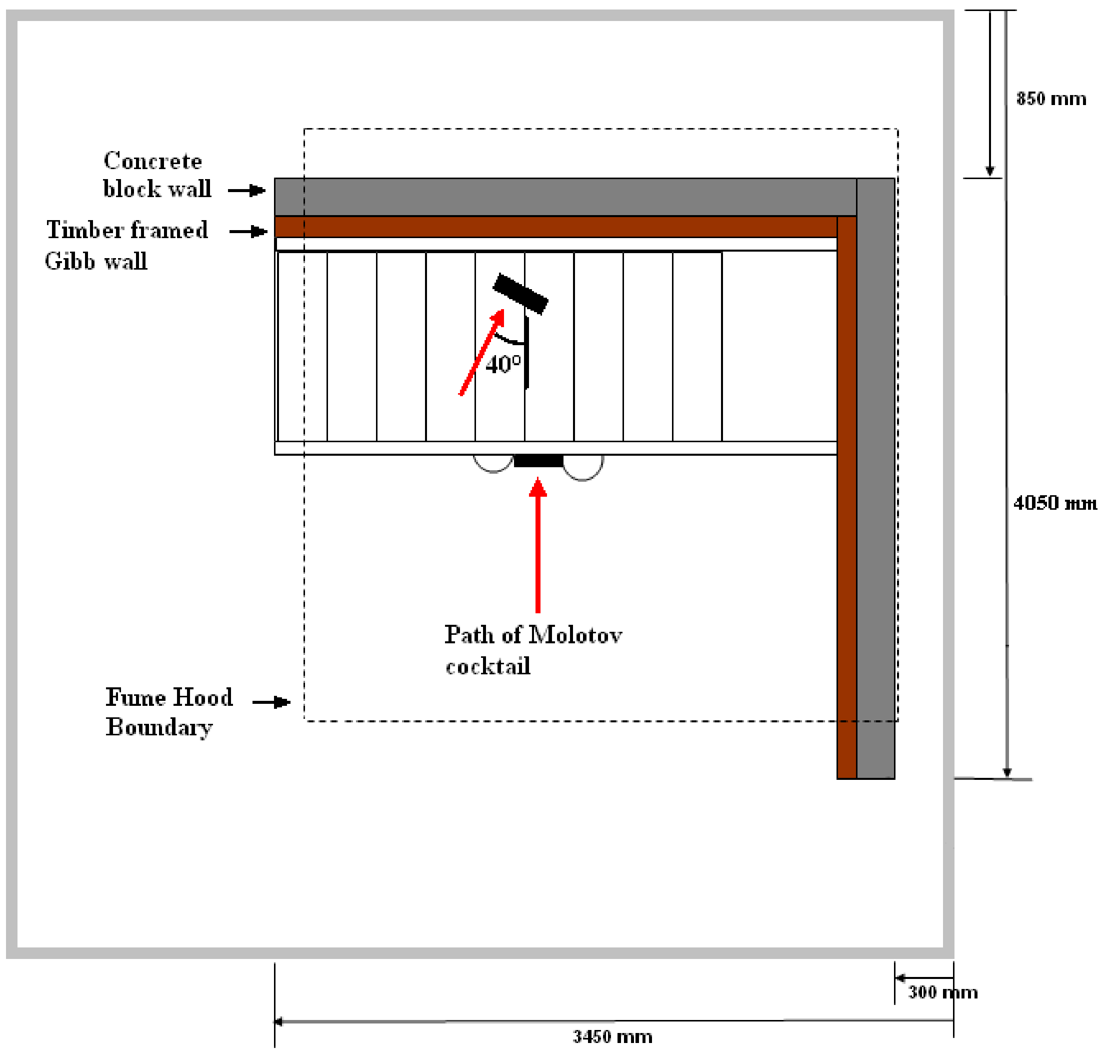

Figure 6.1: Schematic of stair arrangement.

As indicated in Figure 6.1, two separate test configurations were examined. Tests were completed deploying the Molotov cocktail under the stairwell with an approach perpendicular to the path of the stairs. A second test configuration where the Molotov cocktail was deployed on the top surface of the stairs, six steps up from the base of the step. The angle of the swing was approximately 40° off perpendicular to the stairs.

To eliminate the impact of previous tests each set of wooden stairs was only used twice, one test was completed on top of the steps and the second was under the steps. To ensure that this practice did not impact on subsequent tests, the order of the tests were varied with the first test on one flight of stairs being the on top and the first test of the repeat series being below the stairs.

6.3 Parameters Under Investigation

The volume of fuel used and the fuel were not varied during this phase of the test program, 1000 milliliters was used in all tests as it represents a reasonable worst case for a Molotov cocktail. This also provided some consistency to examine the parameters that were under investigation in this portion of the test program.

Two target points were selected in this portion of the test program. The first target location was effectively the same as what was used in the previous chapter representing a Molotov cocktail thrown under a flight of stairs that is unenclosed underneath the steps. The second target was located approximately half way up the stairs and represents a Molotov thrown on the stairs.

The impact of the stairs themselves was examined by having stairs manufactured from two different materials, one combustible and the second made from a non-combustible material. The combustible configuration involved stairs made from timber and particle board as outlined above while the second, non-combustible configuration involved stairs made from steel plate.

The impact of the surroundings was examined by looking at two of the most common wall construction methods, concrete blocks and plasterboard over a timber frame.

To keep the test program manageable there were a number of variables that are likely to impact on the resulting fire that were not examined. These variables and their potential impacts include:

- Design of the flight of stairs. Use of stairs with no solid risers is likely to allow additional oxygen to reach the fire or allow a Molotov deployed on top of the stairs to have significant burning on the ground below.
- Changing the impact surface. The presence of carpet or other porous surface is likely to significantly impact the spread of fuel from the breaking bottle. A porous surface may absorb some of the fuel impacting on the spread of fuel over the surface and hence the shape of the resulting heat release rate curve. If the surface is combustible it may also directly contribute to the fire.
- Delivery of the fuel package. To keep the tests as repeatable as possible all Molotov cocktails were deployed using the swing arrangement outlined in chapter five with the bottle breaking against a steel edge. Changing the delivery is likely to impact on how the petrol spreads out from the point of impact and the resulting fire.

6.4 Results: Heat Release Rate History

With three variables under investigation- target location, stair material and wall material there was a total of eight test configurations. At two experimental trails were completed for each test configuration with an additional trial of the Molotov being deployed above the steel stairs with a block surround. This gave a total of seventeen experimental trails completed in this stage of the test program. The heat release rate curves for these seventeen trials are given as Figures 6.2 to 6.9.

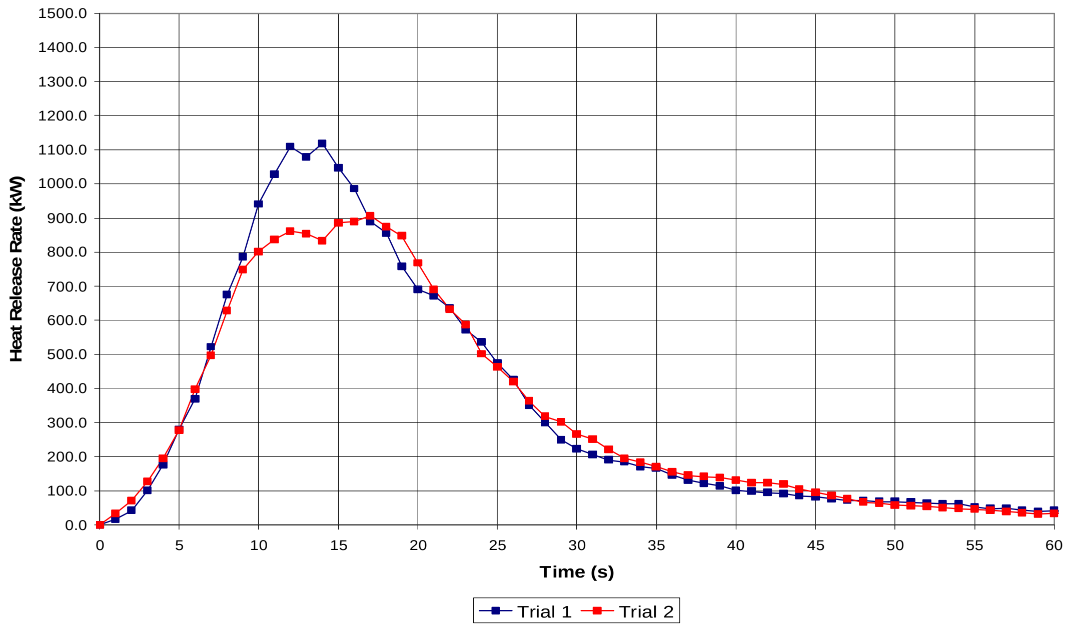

Figure 6.2: Five point averaged heat release rate curves for the two trials where 1 Liter of petrol is deployed above the wooden stairs surrounded by block wall.

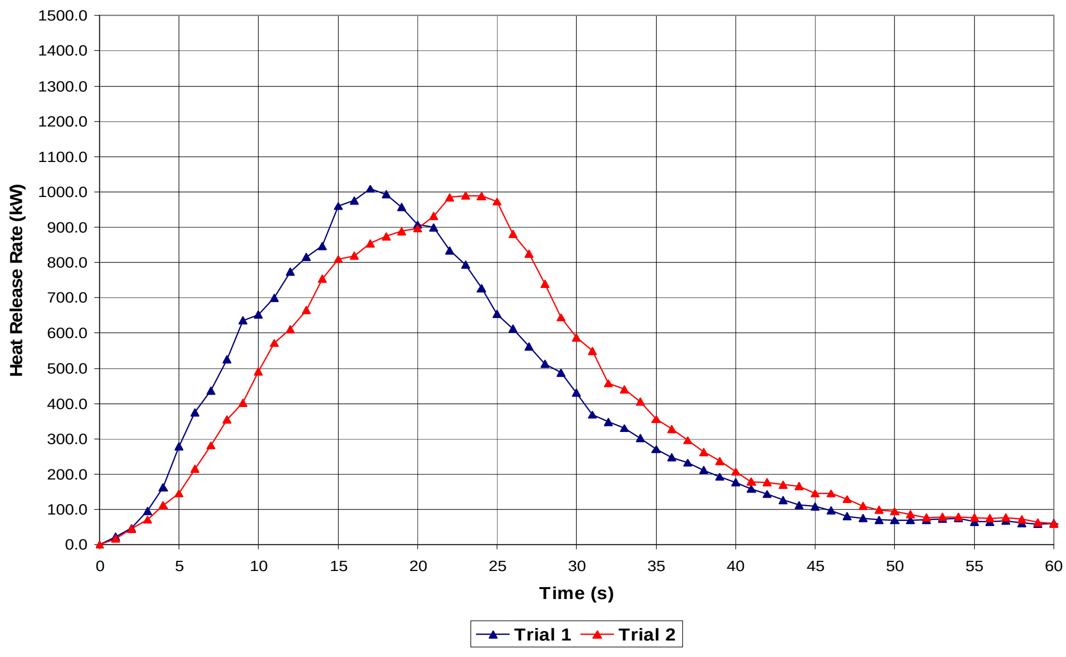

Figure 6.3: Five point averaged heat release rate curves for the two trials where 1 Liter of petrol is deployed below the wooden stairs surrounded by block walls.

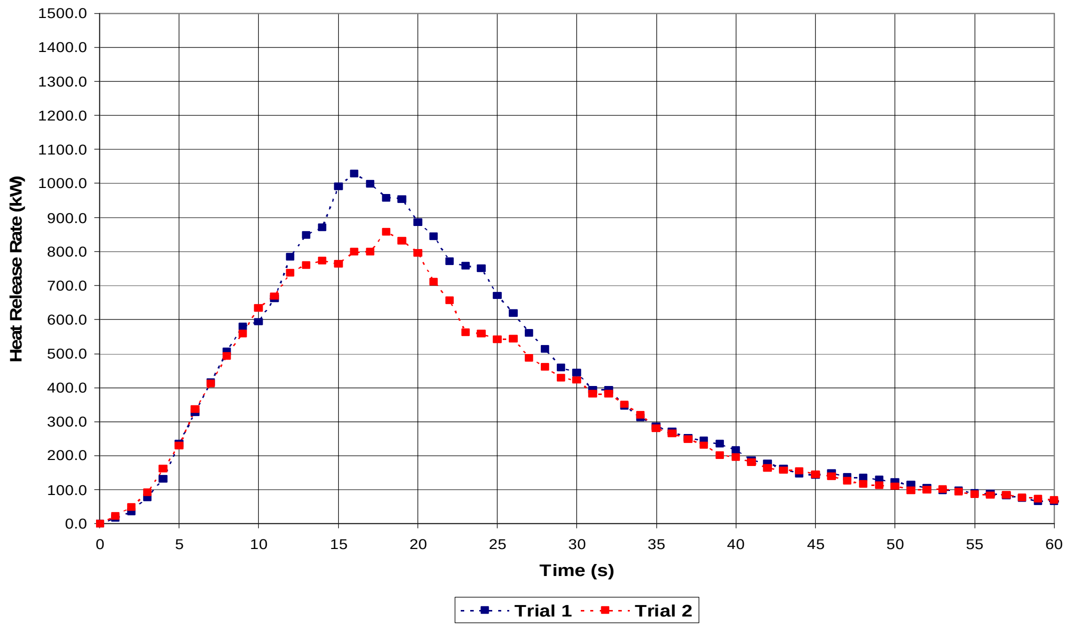

Figure 6.4: Five point averaged heat release rate curves for the two trials where 1 Liter of petrol is deployed above the wooden stairs surrounded by Gibb walls.

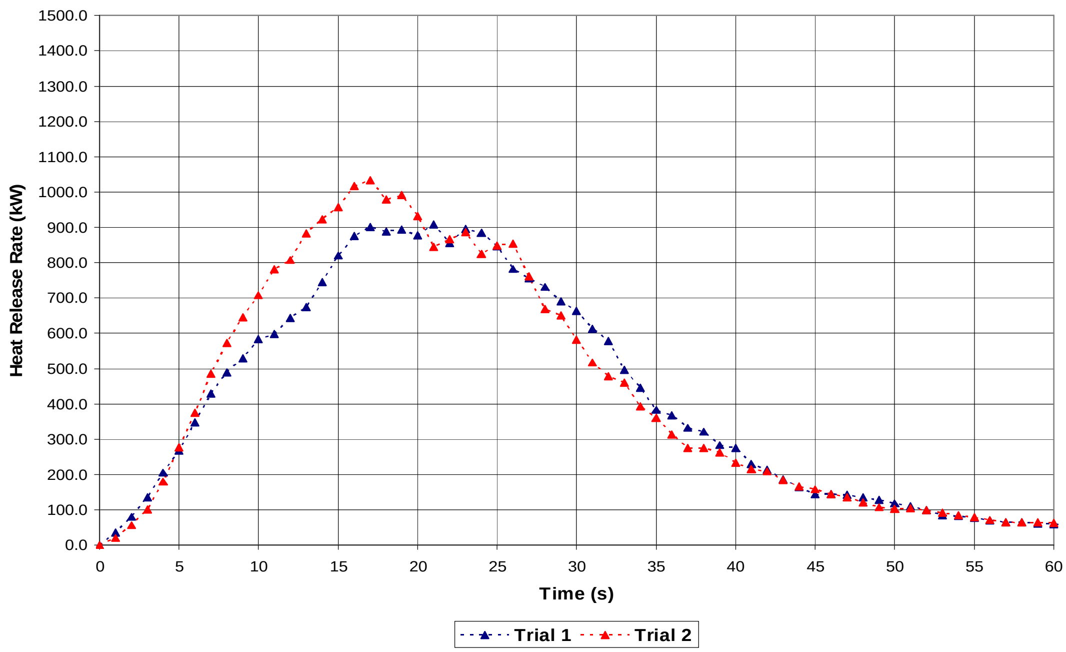

Figure 6.5: Five point averaged heat release rate curves for the two trials where 1 Liter of petrol is deployed below the wooden stairs surrounded by Gibb walls.

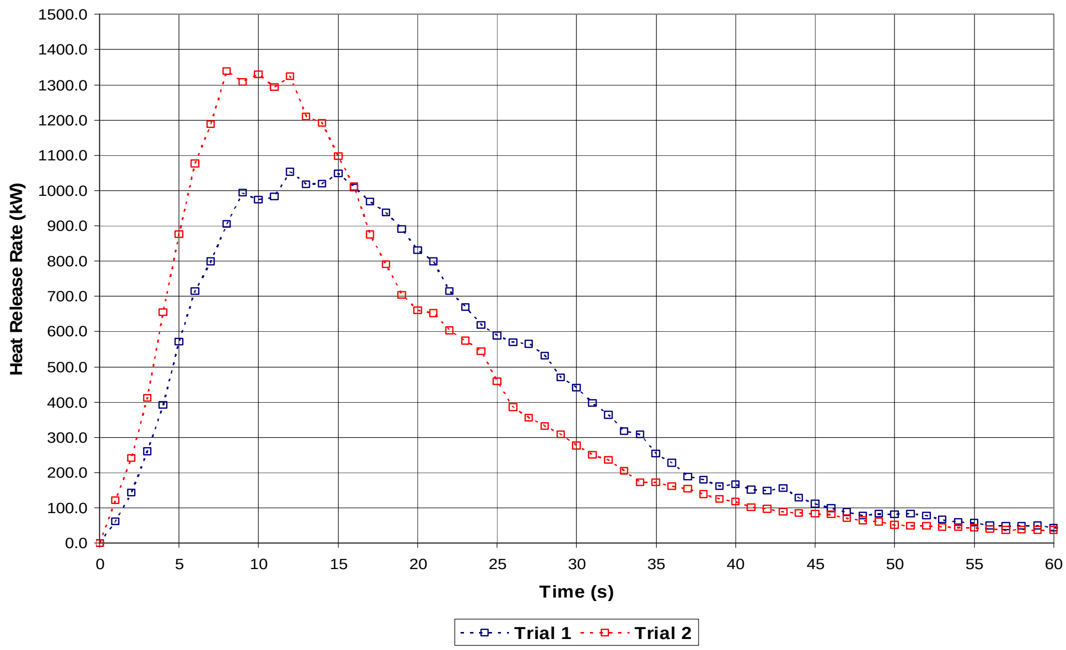

Figure 6.6: Five point averaged heat release rate curves for the two trials where 1 Liter of petrol is deployed above the steel stairs surrounded by Gibb wall.

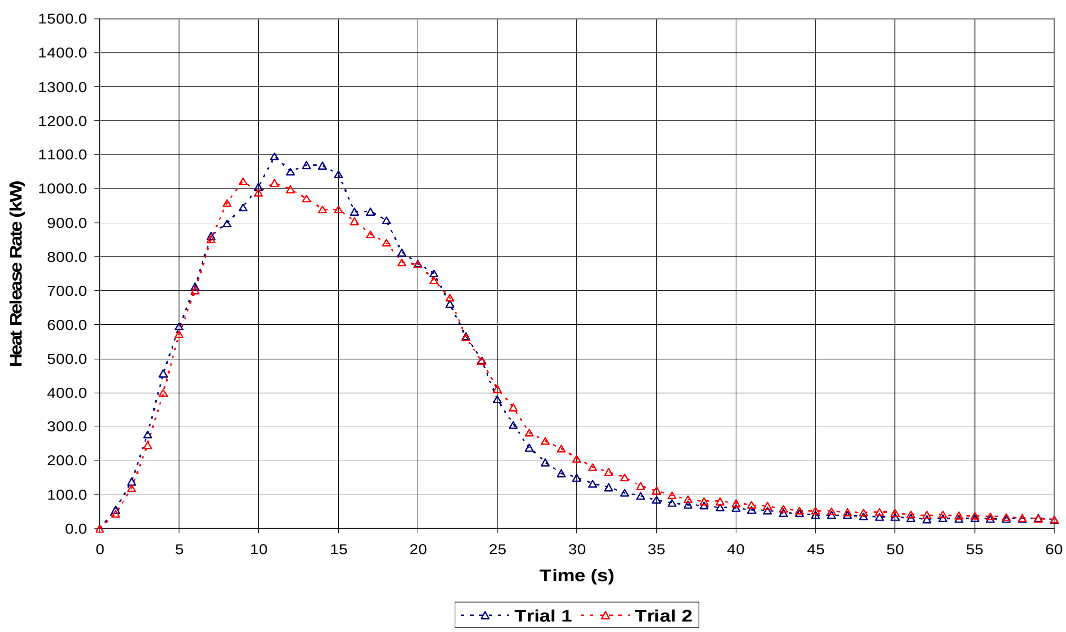

Figure 6.7: Five point averaged heat release rate curves for the two trials where 1 Liter of petrol is deployed below the steel stairs surrounded by Gibb wall.

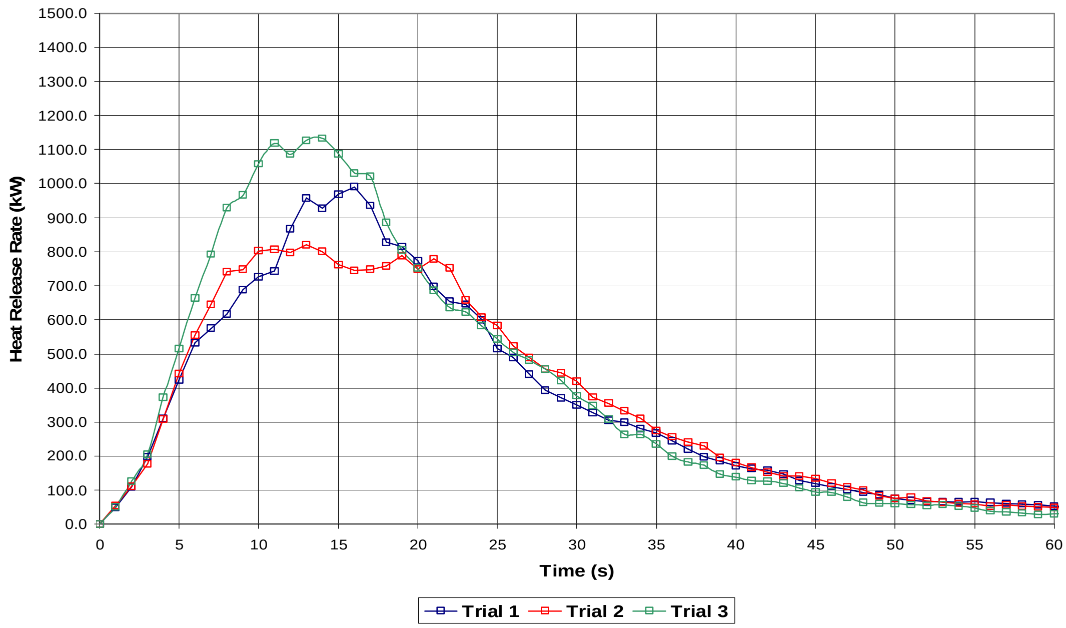

Figure 6.8: Five point averaged heat release rate curves for the three trials where 1 Liter of petrol is deployed above the steel stairs surrounded by block walls.

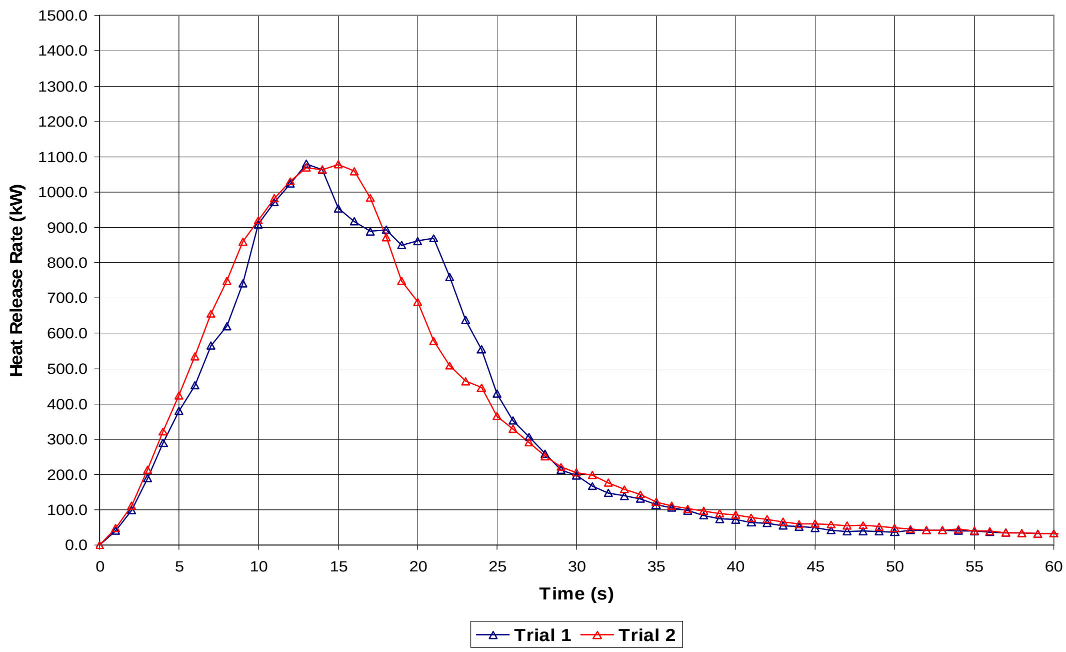

Figure 6.9: Five point averaged heat release rate curves for the two trials where 1 Liter of petrol is deployed below the steel stairs surrounded by block walls.

As discussed in the previous chapter, five-point averaging has been applied to the raw data to obtain smoothed heat release rate curves. With only a few exceptions the peak heat release rate fell within the boundaries obtained in previous results without the stairs, with a maximum observed heat release rate for all tests of 1.6MW and a minimum observed heat release rate of 1.0MW. The average heat release rate observed during these tests was 1.2MW which lies in the middle of the boundaries determined in the previous chapter.

The location of the fire plays only a minor impact on the resulting fire heat release rate. It has virtually no impact on the peak heat release rate obtained and locating the fire below the stairs delayed the time to peak heat release rate only when combined with the wooden stairs. The limited impact of the target location is surprising as it was expected that, in the case of a Molotov deployed on top of the stairs, the surface area that is covered by the fuel would be greater resulting in a higher heat release rate. The fact that this did not occur suggests that, for the fuel volumes and configurations considered, the area covered by the fuel, and hence the resulting fire heat release rate, is limited more by the momentum given to the bottle of petrol than the surface area available for coverage. The increased time to peak heat release rate that occurred when the petrol was deployed below the flight of wooden stairs suggests that the wooden stairs act to retard radiation feedback to the liquid fuel compared to the unrestricted flames or steel stairs.

The steel stairs had very little impact on the time taken to reach the peak heat release rate, with an average time to peak heat release rate of 12.8 seconds, identical to what was obtained for the fires within a clear compartment. For the wooden stairs, the time to peak HRR was increased by a little less than six seconds, or by nearly 50% to an average time of 18.5 seconds. The reason for this delay is not clear but as the stairs survived with only surface charring, it suggests that they make a negligible contribution to the overall heat release rate. For the peak heat release rate the wooden stairs gave an average result that was roughly 100kW less than for the steel stairs. While the peak heat release rate results for both the steel and wooden stairs lie within the range obtained in chapter five, the time delay to the peak heat release rate for the wooden stairs suggests that the wooden stair retard the fire growth rate rather than the steel stairs giving a more rapid growth. This is likely to be due to retarded heat transfer back to the fuel package as a result of the lower thermal conductivity of the wooden members[93].

The wall material plays very little role in a fire of such short duration, there is essentially no impact on both the time taken for the fire to reach its peak heat release rate and the peak heat release rate itself. The difference in peak heat release rate between the block and plasterboard lined wall is only 30kW and this difference may be explained by a combination of the contribution from the paper coating on the plaster board and experimental error.

The comparison for the peak and growth parameter is summarised in Table 6.1.

Parameter	**Peak Heat Release Rate (kW)**	**Time to Peak HRR (s)**
All above stairs trials	1190	14.6
All below stairs trials	1190	16.5
All wooden stairs trials	1140	18.5
All steel stairs trials	1240	12.8
All Gibb wall trials	1210	15.6
All block wall trials	1180	15.5
Average of all trials	1190	15.5

Figure 6.1: Average peak heat release rate and time to peak heat release rate for all trials involving the stairs.

The decay rate showed the greatest similarity to the results obtained in the empty compartment. In virtually all cases the fire had dropped below 100kW within twenty five to thirty seconds after the peak heat release rate had occurred.

As the fuel volume was not a variable examined during this phase of the test program, equation 5.2 cannot be reconstructed to directly incorporate the impact of the variables above with confidence. It is expected that the form of the equation has some dependence on the thermal properties of the stair material however, due to the fact that only two stair materials were examined this cannot be verified. From a practical perspective, there are only three materials commonly used to form stairs in buildings, namely steel, wood and concrete so this level of detail is not warranted. Based on the assumption that the impact of the fuel volume is independent of both the impact location and stair material, equation 6.1 provides an adequate representation of the impact of the stairs and location:

$$t_{pk} = 11 + k_{sm} \times k_{loc} + \frac{V}{700} \qquad 6.1$$

Where: k_{sm} = Constant for the stair material (taken from Table 6.2).

k_{loc} = Constant for the target location (taken from Table 6.3).

Fitting the test data to the equation gave the following values for the constants k_{sm} and k_{loc}.

Stair Material	**Value of k_{sm}**
Steel	0.3
Wooden	4.5
No stairs	0.0

Table 6.2: Recommended values of k_{sm}

Target location	**Value of k_{loc}**
Above stairs	0.9
Below stairs	1.8

Table 6.3: Recommended values of k_{loc}

The balance of the heat release rate curve is similar to what was obtained in the previous chapter so the equations developed to describe the rest of the heat release rate curve may be used without modification.

While the number of tests is not sufficient to demonstrate that these differences are statistically significant they do indicate that the surroundings do have an impact on the heat release rate curves and suggest that the mechanism for this impact is through energy transfer from the fire to the surroundings and back to the fuel package.

6.5 Results: Yield of Carbon Dioxide

The yield of carbon dioxide was calculated using the same method used for when the stairs were not present. As before, the upper bound carbon dioxide yield was calculated based on a heat of combustion of 47.8 MJ/kg and the lower bound carbon dioxide yield has been calculated based on a heat of combustion of 39.5MJ/kg. The result of these calculations for all seventeen trials is included as Figure 6.10. The upper bound for the yield of carbon dioxide ranges between 3.1g/g through to a maximum value of just over 3.6g/g. The lower bound results are approximately 0.5g/g less than these values. In the case of the wooden stair there is no clear trend that may be inferred from the data with almost all results falling within the range 3.34 to 3.40g/g. For the steel stairs the trend is more apparent, every result that was lower than the average was obtained in a test where the fuel was deployed under the stairs and every result that was above the average was obtained in a test where the fuel deployed above the flight of stairs.

This suggests that the steel stairs do restrict the oxygen supply to the fire however there is no clear reason why this difference was not observed for the wooden stairs. Two options that could explain the absence of the drop in carbon dioxide production from under the wooden stairs is the oxygen content of the polyurethane coating or alternatively the drop may have been lost in noise of the short duration of the fire.

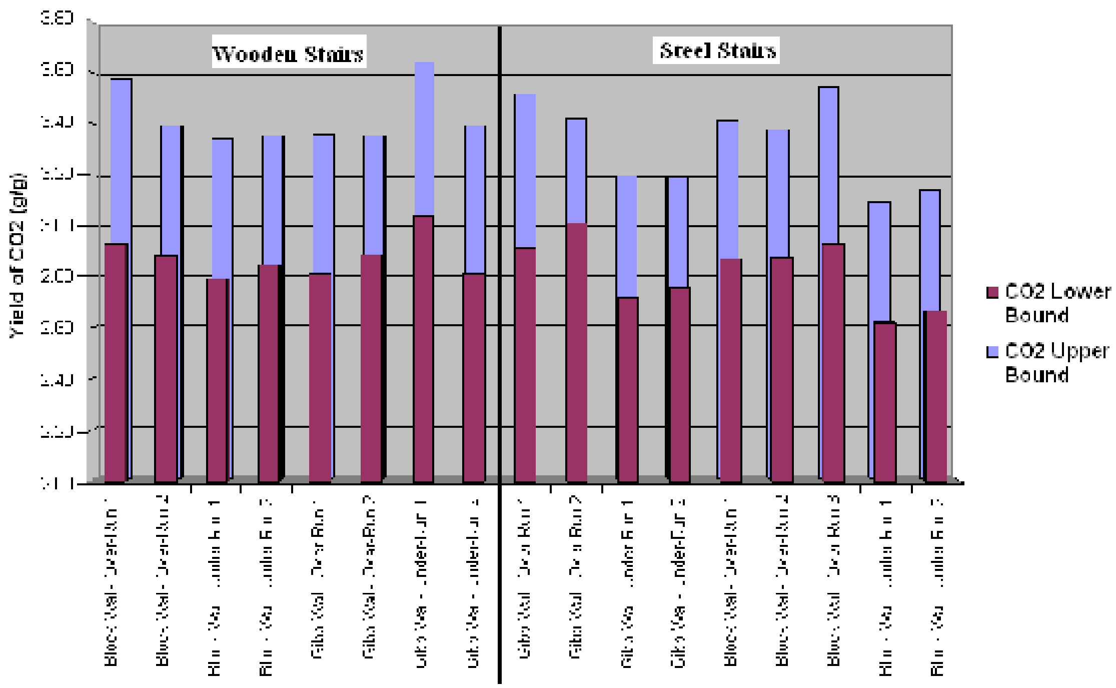

Figure 6.10: Yield of carbon dioxide from all of the stair runs.

6.6 Results: Yield of Carbon Monoxide

The yield of carbon monoxide was obtained using the same methodology as before and the results are given as Figure 6.11. As expected when a Molotov cocktail is deployed on the top of the stairs the average yield of carbon monoxide is virtually identical to what was obtained during testing in the open. The range for the typical carbon monoxide yield was between 00.027 and 0.032 g/g fuel. These yield results were not sensitive to the material that the stairs are made of.

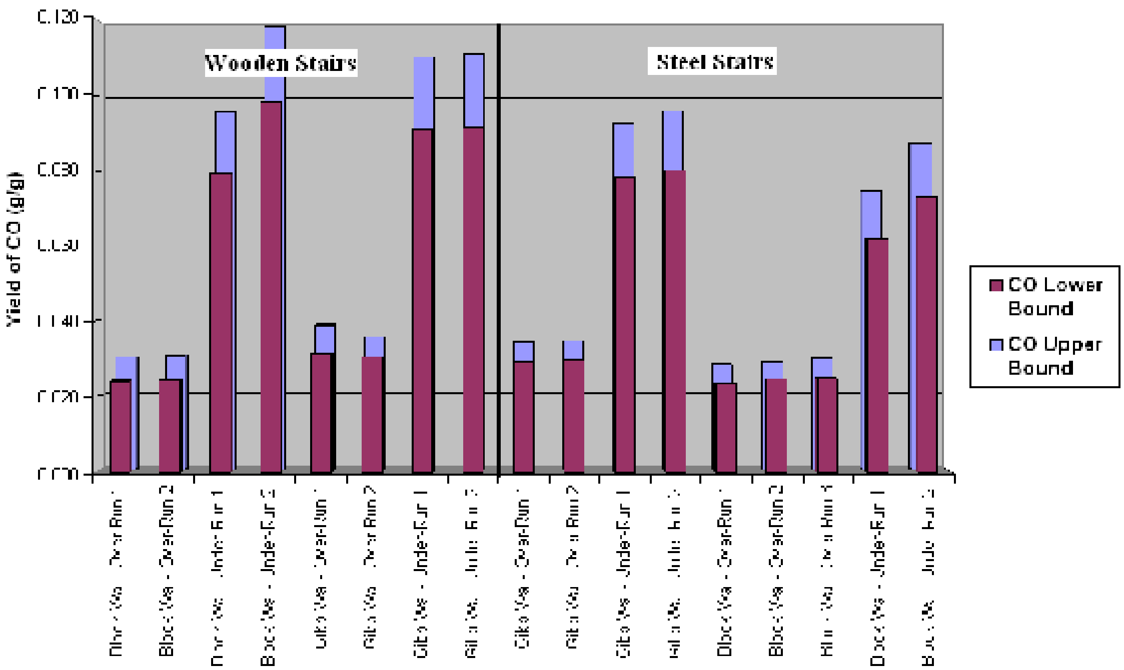

Figure 6.11: Yield of carbon monoxide from stair runs.

When looking at the target location, there was a clear delineation between the tests on the top of the stairs and those deployed below the stairs with the average carbon monoxide yield three times greater when the Molotov is deployed under the stairs. The average yields of carbon monoxide when the Molotov is deployed below the stairs range between 0.82 and 0.99 g/g fuel.

Based on this data equation 5.8 requires modification to account for the influence of ventilation on the yield of carbon monoxide. Fire engineering literature normally calculates the yield of carbon monoxide as a function of the equivalence ratio via equations of the form[94]:

$$y_{CO} = y_{CO,\infty}\left[1 + \frac{a}{\exp(\Phi/b)^{-x}}\right] \qquad 6.2$$

Where: y_{CO} = Yield of carbon monoxide (g/g fuel)

$y_{CO,\infty}$ = Yield of carbon monoxide under well ventilated conditions. (g/g fuel)

α, β & ζ = Correlation coefficients for the fuel package

Φ = Equivalence ratio.

At this stage there is insufficient data to obtain this level of precision as only two ventilation conditions were examined. As the yield of carbon monoxide is affected by both the volume of petrol deployed and the ventilation conditions of the space further testing is required to confirm the appropriateness of the form of equation 5.7. Reducing the availability of oxygen is results in increased production of carbon monoxide, so the yield of carbon monoxide is be inversely proportional to the available ventilation. As only two ventilation conditions were examined, this impact cannot be characterised in terms of an open area with any confidence so it has been characterised in terms of a ventilation factor. Equation 6.3, a modified version of equation 5.7 to include the impact of ventilation, provides an adequate fit to the test results completed in this work however, this has not been validated with small fuel volumes under a flight of stairs and it is expected to over predict the carbon monoxide yield in such cases.

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$$y_{CO} = \frac{9 \times 10^{-6} \times V + 0.022}{C_{vent}} \qquad 6.3$$

Where: Y_{CO} = Yield of carbon monoxide (g/g)

V = Volume of fuel deployed (mL)

C_{vent} = Ventilation factor.

The ventilation factor has a value of 0.33 for a Molotov cocktail deployed under a stairwell with enclosed risers and a value of 1 for a Molotov cocktail deployed in an unenclosed space.

6.7 Ignition of Secondary Items

In every test completed using the wooden stairs, the stairs survived with only minimal charring. The mass and physical arrangement of the combustible material resisted the ignition of the wooden stairs for the short duration of the fire. While it cannot be said that it is not possible to ignite the stairs directly from a 1000 milliliter Molotov cocktail, the direct ignition of heavy combustible material such as the stairs by a Molotov cocktail appears to be an unlikely event.

Figure 6.12: Wooden cribs in position under the stairs

To obtain some insight into the true risks from a Molotov cocktail two trials were completed with the presence of additional combustible material under the stairs. The space under a flight of stairs is frequently used for the storage of goods and this material represents a fuel load that is much more ignitable than the heavy frame of the flight of stairs. Rather than place a quantity of miscellaneous items under the stairs, wooden cribs were used to simulate a generic fuel load. The positioning of the cribs is illustrated as Figure 6.12.

The timber cribs were made from rough sawn timber pieces arranged as outlined in Table 6.4.

Parameter	**Value**
Timber pieces length	600 mm
Timber pieces end section	50 x 50 mm
Pieces per layer	6
Spacing between pieces	50 mm
Number of layers	5
Total mass	24.5 kg (average)

Table 6.4: Physical dimensions and characteristics of timber cribs

As the cribs had been assembled from radiate pine with a net heat complete combustion of ΔH_c=17.9 MJ/kg[93]. Based on this figure and the mass above, the wooden cribs represent a fuel load of 454 MJ. As many synthetic materials have a much higher heat of combustion this is equivalent to a mass of 15kg for a typical synthetic polymer (based on a heat of combustion of 30 MJ/kg). Such a mass could be reasonably expected to be stored in the cupboard space under a typical stairway.

A Molotov cocktail containing 1000 milliliters of petrol was deployed under the stairs and it proved sufficient to ignite the wooden cribs. Even though the fire was much less intense, with peak heat release rate of little more than 200 kW, the much longer burning duration of the wooden cribs resulted was able to ignite the heavy timber of the stairs. This indicates that the presence of additional light combustible materials significantly increases the risk of the fire becoming established. The heat release rate curves of the wooden crib in isolation and the wooden crib under the stairs are given as Figures 6.13 and 6.14 respectively.

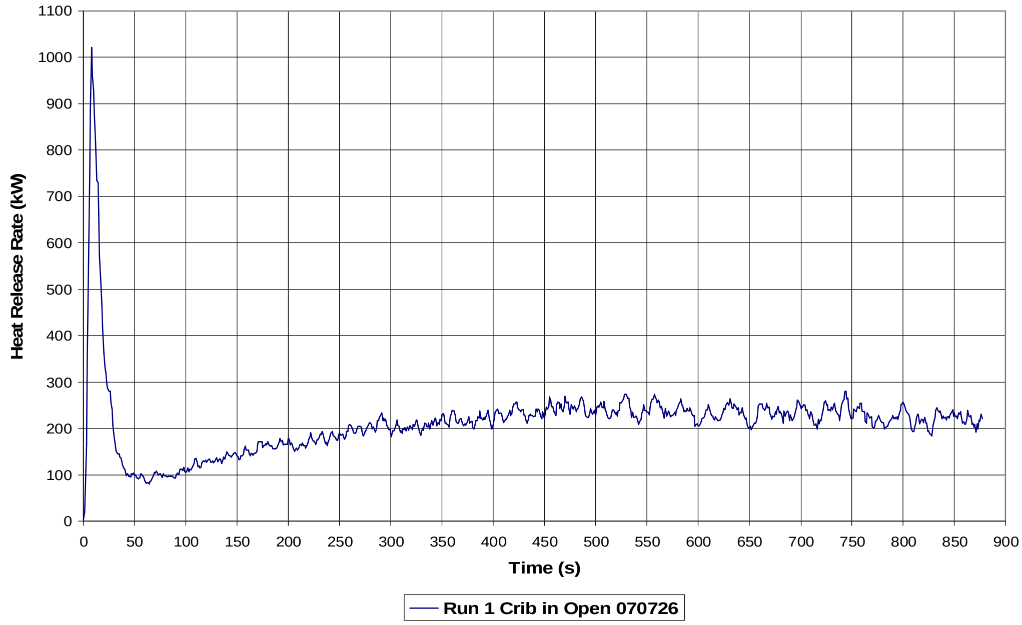

Figure 6.13: Heat release rate curve for wooden crib in the open ignited by a 1000mL Molotov cocktail

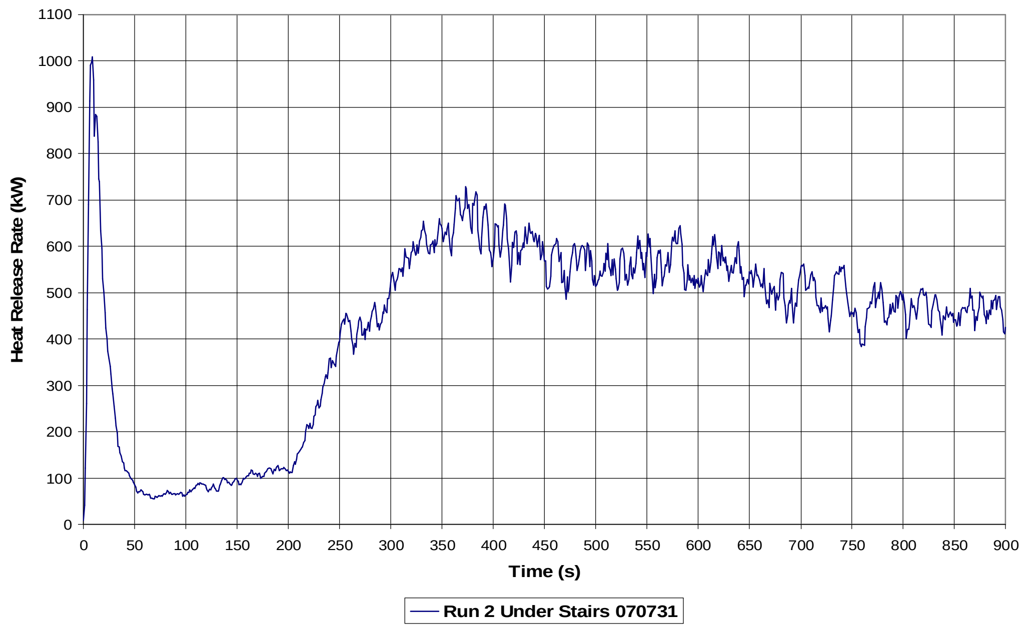

Figure 6.14: Heat release rate curve for wooden crib under stars ignited by a 1000mL Molotov cocktail.

From the results above it is apparent that the stairs start to contribute to the heat release rate approximately 200 seconds after ignition. The impact of the Molotov cocktail on the heat release rate curve for the wooden crib was not examined in detail however evidence suggests that the use of a Molotov cocktail resulted in a reduction in the time taken for the wooden crib to reach its peak heat release rate of between one and two minutes. This has a direct impact on the available time for escape for building occupants.

While the wooden cribs were not dried prior to the test they had been stored under cover for a long period of time so the moisture content of the timber is estimated at 8-12% based on the local ambient conditions. This is likely to have increased the likelihood that a Molotov would be able to ignite them however this is expected to be true for most other combustible products in storage.

7.0 Conclusion: Designing For Deliberately Lit Fires

This research aimed to identify those structures which are at most risk of deliberately lit fires and identify potential fire scenarios that cover the majority of deliberately lit fire events. Finally it takes one of the fire scenarios identified and constructs a reasonable worst case fire curve for a Molotov cocktail.

Like accidental fires, the majority of deliberately lit fires are relatively trivial in nature, posing little life safety risk, however there are a proportion of such fires that do cause significant property damage and result in injury and/or death. As the proportion of people injured or killed in deliberately lit fires is similar to the proportion fires that are deliberately lit, the life safety risk from deliberately lit fires is comparable to the overall fire life safety risk.

One of the objectives of the New Zealand Building Code is to protect people from injury or illness caused by the effects of fire. The building code does not distinguish between fires that are deliberately lit and those that are accidental yet the majority of current fire engineering designs specifically exclude deliberately lit fires as a fire scenario. For some buildings deliberately lit fires represent a significant fraction of a structure's overall fire risk so excluding deliberately lit fires may compromise the safety of building occupants. By excluding deliberately lit fires at the beginning of the design process, fire engineers are not satisfying the objectives of the Building Code.

7.1 When Should Deliberately Lit Fires Be Considered?

From the analysis of the New Zealand fire statistics, different types of structures face different levels of risk from fires that are deliberately lit. Both the probability that the fire is deliberately lit and the distribution of such incidents during the week are strongly dependent on the structures use. In the case of prisons and mental institutions, fires are more likely to be deliberately lit than all other fire causes combined, so ignoring deliberately lit fires as a potential ignition scenario is effectively ignoring the most common cause of fire for these structures. Education facilities and crowd structures such as bars and restaurants are also popular targets with over forty percent of all fires being deliberately lit. In the case of crowd structures such as bars, restaurants and nightclubs their greatest risk from deliberately lit fires also coincides with their period of greatest occupancy.

The second approach used to assess the life safety risk from a deliberately lit fire is the risk that a person will be injured or killed from a particular event. Based on the historical records, the number of people injured or killed in deliberately lit fires is much greater for accommodation facilities including temporary accommodation, prisons, apartments and detached homes. Deliberately lit fires in these types of structures are more likely to result in a casualty due to the slower response of sleeping building occupants. The low life safety risk for fires in education facilities is a result of 80% of deliberately lit fires occurring outside school hours.

The final decision as to when deliberately lit fires should be included in the design process is a matter for the regulatory authorities and the clients' property protection goals. However, the structures mentioned above face a significant risk from deliberately lit fires that needs to be considered. The decision to include or exclude deliberately lit fires for these structures should be raised early in the design process.

7.2 What Additional Fire Scenarios Are Required to Address Deliberately Lit Fires?

Approximately ninety percent of deliberately lit fires are simply the malicious ignition of items already present within the compartment or introduced fuel packages that result in fires of similar intensity. The majority of deliberately lit fire incidents are likely to be covered by existing design fires. In a fire engineered building, the growth rate of such a fire should be no greater than that of the appropriate design fire. In such an incident, the fact that the fire was deliberately lit will have little or no impact on conditions within the structure. Incorporating this group of deliberately lit fires into the design process could be achieved by ensuring that the ignition locations and any assumptions made in developing the fire curve result in a reasonable worst case fire curve for the object considered. If this is achieved then the resulting fire curve will be adequate for both accidental and deliberately lit fires. Design fire heat release rate curves that are not based on a worst case ignition for the object concerned may be inadequate for use when deliberate ignition is included within the design brief.

Two fire scenarios were identified from the FIRS database as not being covered by existing fire curves, these two scenarios account for approximately ten percent of deliberately lit fires. The two fire scenarios are:

- The ignition of multiple fires.
- The use of accelerants.

The ignition of multiple fires poses a number of issues for the fire engineer particularly with regards to smoke management and sprinkler system design, however based on the New Zealand fire statistics; the life safety risk from this fire scenario is not significantly greater than for any other deliberately lit fire scenario. The low life safety risk is due to the low occupancy close to the seats of the fires required to prevent discovery of the perpetrator.

The second scenario, the use of accelerants, represents a much greater risk to building occupants. Between 1996 and 2006 these fires resulted in one third of all deliberately lit fire injuries and one half of all deliberately lit fire fatalities so from a life safety perspective they represent the single largest component of the overall deliberately lit fire risk. In virtually all buildings, including the use of accelerants as a potential fire scenario would result in increased fire protection costs so this is unlikely to strike an appropriate balance between economics and life safety. Designing attached dwellings and retail buildings around the use of accelerants has the potential for life safety benefits with a much reduced cost to society.

7.3 A Design Fire For A Molotov Cocktail

A Molotov cocktail may be characterised by the type of fuel deployed. In the experimental program petrol was used as the fuel and a Molotov produced using other fuels may not have the same characteristics presented in this work. Another significant variable required to characterise a Molotov is the quantity of fuel used. Once this is obtained the heat release rate curve may be readily predicted based on the fuel volume. The following equations provide a reasonable worst case design heat release rate curve for a Molotov of up to 1500 milliliters.

The surroundings do have an impact on the initial heat release rate growth however unless other material is ignited they have little impact on the rest of the heat release rate curve. The likely mechanism for this impact is via retarding of the heat transfer back to the fuel package. The time to peak heat release rate may be estimated from:

$$t_{pk} = 11 + k_{sm} \times k_{loc} + \frac{V}{700}$$

and the worst case peak heat release rate may be found from:

$$Q_{pk} = 1.34 \times V$$

A linear growth from zero time to t_{pk} provides an adequate representation of the data. There is a short period of approximately five seconds duration where the heat release rate decays linearly to 70% of the peak heat release rate. From this point through to extinction at approximately eighty seconds, the decay phase may be modeled by:

$$Q = C_1 \times V \times \exp^{-C_2 \times t}$$

The yields of carbon dioxide and soot have not been characterised in terms of the fuel. The average yield of carbon dioxide during the experimental runs was 3.0 g/g and the surroundings only have a small impact on this result. The yield of carbon monoxide may be estimated from:

$$y_{CO} = \frac{9 \times 10^{-6} \times V + 0.022}{C_{vent}}$$

There appears to be some dependence on the fuel volume and a strong dependence on the surroundings. The yield of soot may be taken as 0.038g/g. The impact from the fuel volume and surroundings could not be confirmed due to the different experimental technique used to obtain the soot measurements.

Due to the low mass of fuel typically used, accelerants represent an ignition scenario for a secondary object rather than a full fire scenario. When accelerants are used in safe paths and other areas where little or no combustible materials are present, they are unlikely to pose a high risk to building occupants due to the short duration of the fire. The presence of additional combustible material will significantly increase the life safety risks from accelerants.

Like all deliberately lit fires, accelerants are frequently relegated to a housekeeping issue rather than a fire engineering issue under the logic that if there is no fuel to burn then the use of an accelerant, or lighting of materials, is unlikely to cause significant damage. This approach ignores the introduction of combustible materials into critical areas such as safe paths by individuals who are unaware of the requirements such spaces. It will only be effective in areas where there is tight control of housekeeping and maintenance to remove all unwanted combustible materials.

A second commonly recommended method of reducing the risk from deliberately lit fires is through the use of security measures to prevent unauthorized access. While these will have an impact on opportunistic arson from exterior sources, increased security will provide little barrier to those individuals who are lawfully able to be present in the building.

The ideal solution is for the fire engineer to identify if a particular structure is more likely to be exposed to a deliberately lit fire and, for those projects that are at risk, to identify whether accelerants or multiple fires need to be considered. Where a significant risk is identified then this must be communicated to the other stakeholders. The best solution for the individual building, considering housekeeping, building security and fire protection may then be found. This enables the risk of deliberately lit fires to be managed in the most effective way for all stakeholders while meeting the requirements of the building code.

7.4 Recommendations For Further Research

One limitation of the statistical analysis was the small size of the New Zealand fire incident database. Comparisons to international data were made when such data was available and several attempts were made to obtain deliberately lit fire data from the United States but these were unsuccessful. The statistical component of this work would be much stronger if the analysis was repeated using deliberately lit fire data from the United States. The larger size of the US database would also be useful to identify any additional fire scenarios that were not identified from the New Zealand fire statistics due to a low frequency of occurrence.

The ignition of secondary items from the short duration of the Molotov fire was not investigated in detail. The ignition of heavy structural timbers by a Molotov cocktail appears to be unlikely however it was able to ignite the rough sawn timber of the wooden cribs. It is highly likely that fabrics and furniture items would be ignited from an attack of this nature. Some attempt to characterise the ignition capabilities of a Molotov cocktail would provide guidance as to when the use of such devices may be safely neglected.

In those cases where the use of a Molotov cocktail is considered during the design, its impact on the initial growth of the secondary object would also be of use. Some reduction in the time to peak heat release was observed but no attempt was made to characterise the magnitude of this impact. Adequately characterization of this impact would enable fire engineers to use a combined Molotov cocktail – secondary item fire curve with confidence in their designs.

The other significant unknown area where more research is required is to address the generation of carbon monoxide as a function of the equivalence ratio. Due to the variable nature of the composition of petrol such data is expected show some scatter; the testing of fuels from a number of different refineries should provide an estimate of the magnitude of this scatter.

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Appendix A - Purpose Group Breakdown

Fires have been assigned to the purpose groups outlined in C/AS1 based on table A1.

General Property Use	Number of Fires	Purpose Group
Airport	3	CM
Boarding house, Half-way house, Dormitory, Rooming, Lodging, Home stay, Backpacker	90	SA
Church, Cemetery, Religious use	87	CL
Commercial – not classified above	118	WM
Communications, Research – not classified above	18	WM
Community hall, Marae, Maori cultural use	95	CL
Conservation, Recreation park, Reserve	20	NA
Construction, Renovation – not classified above	9	NA
Construction, Renovation, Demolition site	168	NA
Defence, Military use	11	WL
Doctors/Dentists emergency clinic, Medical centre	25	WL
Educational, Health, Institutional – not classified above	35	CE
Farming, Horticulture, Agricultural use	239	SH
Flat, Apartment, Home unit	577	SR
Hospital, Hospice, Rest home, Rehabilitation centre	287	SC
Hotel, Motel, Lodge, Timeshare	55	SA
Industrial, Manufacturing	157	WM
Laboratory, Research use	1	WM
Library, Museum, Art gallery, Court etc	55	CL
Lifestyle block	17	SH
Mine, Quarry, Oil well	4	NA
Non existent address	2	NA
Office, Bank, Embassy, Fire/Ambulance station	236	WL
Open land	40	NA
Passenger terminal	35	CL
Power station	5	WM
Prison, Correctional institution	181	SD
Railway property	78	NA
Recreational use, Theatre, Indoor sports, Pool, Park, Zoo, Aquarium	329	CL
Recreational, Assembly – not classified above	80	CL
Residential – not classified above	78	SH
Restaurant, Pub, Tavern	123	CL
Road, Street, Motorway	145	NA
Rubbish tip, Transfer station, Hazardous waste disposal	49	NA

Table A1: FIRS database property use by purpose group.

General Property Use, Continued	**Number of Fires**	**Purpose Group**
Rural – not classified above	10	NA
School: Pre-school through to Secondary/High	879	CE
Service/Repair use, Dry cleaner, Laundromat, Mechanical workshop	91	WM
Shop, Shopping mall, Supermarket, Service station, Car yard, Other sales use	537	CM
Single house	3401	SH
Sports club, Health club	143	CL
Sportsfield, Stadium	123	CO
Storage, Warehousing	333	WM
Stormwater, Harbour, Lake, River, Beach, Waterfront area	39	NA
Telephone exchange, Communications use, Control room, Data processing	130	IA
Unable to classify	132	NA
University, Polytech, Teachers college, Other post-secondary	69	CE
Vacant building, Section	267	NA
TOTAL	**9606**	

Table A1 cont: FIRS database property use by purpose group.

Appendix B: Weighting The Casualty Rate

The National Center for Injury Prevention and Control data gave the following costs per injured person for fire incidents:

Injury Severity	**Cost ($US)**
Fatality	249,367.00
Injury requiring hospitalisation	33,303.00
Injury not requiring hospitalisation	347.00

Table B2: Costs of injury by fire.

One issue with using this data was that it only identified two levels of injury whereas the New Zealand Fire Services statistics identified three levels of injury. This issue was resolved by assuming the following relationships.

- A fatality in both statistics corresponds cleanly
- An injury requiring hospitalisation has been assumed to be equivalent to a Life threatening injury in the NZ Fire Statistics.
- An injury not requiring hospitalisation has been assumed to be equivalent to a slight injury in the NZ Fire Statistics.

To obtain a cost for a moderate injury it was noted that the costs presented above decrease by approximately an order of magnitude for the step between fatality and hospitalisation but decreases by two orders of magnitude when moving down to an injury not requiring hospitalisation. The cost of a moderate injury was interpolated between these two points, giving a cost of US$3400 per moderate injury.
These costs were then converted into New Zealand dollars using an exchange rate of US$ 0.715= NZ $1.00

Appendix C: Petrol Certificates of Quality

The following certificates of quality were in effect during the testing program.

29.Jun. 2007 18:37 SEPL BUKOM CENT LAB No.9208 P. 1

SR549

Shell Eastern Petroleum (Pte) Limited

Pulau Bukom P.O. Box 1908 Singapore 903808 Company Reg No. 196000089G

Certificate of Quality

Page: 1 of 1

Product	: ULP		
Product Code	: 3391CZ	Sample No	: 070021460
Vessel	: FORMOSA TWELVE	Destination	: ONE OR MORE SAFE PORTS IN NEW ZEALAND
Certificate No	: 2007/002256	Date	: 29/06/2007

Properties	Unit	Sample Source / Batch Number / Method	Line Composite
Research Octane Number	ON	ASTM D2699-A	92.7
Motor Octane Number	ON	ASTM D2700-A	82.7
Lead content	mg/L	AAS Method	<1.000
Distillation Evaporated at 70 degree C	%vol	ASTM D86	26.6
Distillation Evaporated at 100 degree C	%vol	ASTM D86	48.3
Distillation Evaporated at 150 degree C	%vol	ASTM D86	94.1
Distillation End point	deg C	ASTM D86	177.5
Distillation residue	%vol	ASTM D86	1.0
Reid Vapour Pressure	kPa	ASTM D323-B	70.75
FVI (RVP, KPA + 0.7E70)		ASTM D86D323-B	89.4
Density at 15 degree C	kg/L	ASTM D4052	0.7439
Appearance		VISUAL	Bright & Clear
Colour		VISUAL	UNDYED
Sulphur content	mg/kg	ASTM D2622	40
Copper corrosion (2h/100 deg C)		ASTM D130	1
Silver corrosion (3h/50 deg C)		ASTM D130 MOD	0
Doctor test		ASTM D4952	Negative
Mercaptan Sulphur	%m	ASTM D3227	-
Odour		PBM 172T	Marketable
Solvent washed gum	mg/100mL	ASTM D381	1.0
Unwashed gum	mg/100mL	ASTM D381	4.0
Induction period	min	ASTM D525	>360
Anti-Oxidant (AO-32)	mg/L	DERD:RDE/A/610	16.0
Benzene content	%vol	ASTM D5580	0.55
Olefins	%vol	ASTM D1319	9.9
Total Aromatics content	%vol	ASTM D5580	33.12
Oxygenate content	%m	ASTM D4815	<0.10
Phosphorus content	mg/L	ASTM D3231	0.2

No Manganese, Iron and Steam-Cracked Naphtha added

Remarks : Blend 9761/1

CERTIFIED ORIGINAL

SHORE LOADING OFFICER

Date: 29/6/7

Shell Eastern Petroleum (Pte) Ltd

PULAU BUKOM LABORATORY

ORIGINAL SIGNED

[illegible] LEONG

CERTIFICATE OF QUALITY

BP Refinery (Kwinana) Proprietary Limited

P.O. Box 2181
Rockingham, W.A. 6168
Australia
Tel (08) 9419 9498 Fax (08) 9419 9831

Batch Number	: 0253	Report Number	: 343946 1	Page 1 of 1
Sample Number	: 343946	Report Date	: 06-JUN-2007	
Product	: Regular Unleaded Petrol			
Date Sampled	: 02-JUN-2007			
Sampled From	: Kwinana Tank 503			

Analysis	Method	Units	Result
Density @ 15 deg C (Average)	ASTM D4052	kg/L	0.7171
Visual Appearance	Visual		Clear & Bright
Visual Colour			Bronze
Odour			Merchantable
Total Sulphur	ASTM D5453	mg/kg	77.8
Mercaptan Sulfur	ASTM D3227	%mass	0.0002
Corrosion Test (Copper Strip) 3 hrs @ 100 deg C	ASTM D130		1a
Silver Corrosion (3hr/50degC)	ASTM D130		2
Dry Vapour Pressure Equivalent	ASTM D5191	kPa	82.8
Distillation	ASTM D86		
10% Evaporated		deg_C	49
50% Evaporated		deg_C	76
90% Evaporated		deg_C	148
Final Boiling Point		deg_C	186
Residue		%vol	1.2
Loss		%vol	1.3
% Evaporated @ 70 deg C		%vol	44.6
% Evaporated @ 100 deg C		%vol	65.8
% Evaporated @ 150 deg C		%vol	90.6
% Evaporated @ 180 deg C		%vol	98.0
Flexible Volatility Index	Calculation		114.0
Gum Content in Fuels by Jet Evaporation	ASTM D381		
Unwashed Gum		mg/100ml	<30*
Washed Gum		mg/100ml	<4*
Oxidation Stability	ASTM D873		
Potential Gum		mg/100ml	<6*
Ageing Time		hr	>4*
Induction Period @ 100 deg C	ASTM D525	min	>360*
Benzene	ASTM D5580	%vol	0.76
Total Aromatics	ASTM D5580	%vol	21.63
Toluene plus Xylene	ASTM D5580	%vol	12.32
Lead Content	IP 352	mg/L	<3.0
Manganese Content	ASTM D3831		NIL ADDED
Phosphorus Content	ASTM D3231	mg/L	<1.3*
Olefins	ASTM D1319	%vol	15.5
Polygas Content	By declaration	%vol	<10
Unhydrotreated Steamed Cracked Naptha	By declaration	%vol	NIL ADDED
Total Oxygenates	By declaration	%mass	NIL ADDED
MTBE Content	By declaration	%mass	NIL ADDED
Ethanol Content	By declaration	%vol	NIL ADDED
Knock Rating (Research ON)	ASTM D2699	ON	92.2
Knock Rating (Motor ON)	ASTM D2700	ON	82.4

A 1:1 Trial Blend of Tanks 503/0253 (id 343946) and 504/0354 (id 343947) has been performed for Total Aromatics and FVI and returned results of 25.60 %vol and 103 respectively.

* Estimated value based on known data.

All tests have been performed with the latest revision of the methods indicated. This report relates specifically to the sample tested.
This document shall not be reproduced except in full without the written approval of this Laboratory.
This product conforms to the BP Manufacturing Specification.
This product conforms to the NZRC and User Company Product Specification for Regular Unleaded Motor Gasoline Issue 17 of October 2003 and the New Zealand Government Requirements for Regular Grade Petrol effective August 2002 and January 1st 2004.

The Antioxidant, UOP 3452, was added at a dose rate of 1.8ppm.
The Metal Deactivator, Betz Spansin 8LP00, was added at a dose rate of 3.8ppm

Destination	: Mt Maunganui, New Zealand via British Harmony	BAD Number	: 34177
DISTRIBUTION	: Original - Laboratory File		

1-Jun-2007 23:12 SEPL BUKOM CENT LAB No.7848 P. 1

Shell Eastern Petroleum (Pte) Limited

Pulau Bukom P.O. Box 1908 Singapore 903808 Company Reg No. 196000089G

Certificate of Quality

Page: 1 of 1

Product : ULPNZ
Product Code : 3391CZ
Vessel : IVER EXACT
Certificate No : 2007/001847

Sample No : 070018370
Destination : ONE OR MORE SAFE PORTS IN NEW ZEALAND
Date : 01/06/2007

Properties	Unit	Sample Source / Batch Number / Method	Line Composite
Research Octane Number	ON	ASTM D2699-A	91.8
Motor Octane Number	ON	ASTM D2700-A	82.6
Lead content	mg/L	AAS Method	<1.000
Distillation Evaporated at 70 degree C	%vol	ASTM D86	25.7
Distillation Evaporated at 100 degree C	%vol	ASTM D86	51.2
Distillation Evaporated at 150 degree C	%vol	ASTM D86	94.3
Distillation End point	deg C	ASTM D86	173.6
Distillation residue	%vol	ASTM D86	1.5
Reid Vapour Pressure	kPa	ASTM D323-B	60.75
FVI (RVP, KPA + 0.7E70)		ASTM D86D323-B	78.7
Density at 15 degree C	kg/L	ASTM D4052	0.7325
Appearance		VISUAL	Bright & Clear
Colour		VISUAL	UNDYED
Sulphur content	mg/kg	ASTM D2622	48
Copper corrosion (2h/100 deg C)		ASTM D130	1
Silver corrosion (3h/50 deg.C)		ASTM D130 MOD	0
Doctor test		ASTM D4952	Negative
Mercaptan Sulphur	%m	ASTM D3227	-
Odour		PBM 172T	Marketable
Solvent washed gum	mg/100mL	ASTM D381	0.5
Unwashed gum	mg/100mL	ASTM D381	2.0
Induction period	min	ASTM D525	>360
Anti-Oxidant (AO-32)	mg/L	DERD:RDE/A/610	15.8
Benzene content	%vol	ASTM D5580	0.70
Olefins	%vol	ASTM D1319	14.3
Total Aromatics content	%vol	ASTM D5580	30.09
Oxygenate content	%m	ASTM D4815	<0.10
Phosphorus content	mg/L	ASTM D3231	0.2

No Manganese, Iron and Steam-Cracked Naphtha added.

Remarks : Blend ; 7979/1

CERTIFIED ORIGINAL

SHORE LOADING OFFICER

Date: 01 JUNE 2007

Shell Eastern Petroleum (Pte) Ltd

PULAU BUKOM LABORATORY

ORIGINAL SIGNED
CHU MUN KONG

COQ Number	07.R180

The New Zealand REFINING COMPANY LTD

Marsden Point, Whangarei, New Zealand

Regular Motor Gasoline Certificate of Quality

LAB SEQ NUMBER: **240400**	ACCOUNT: **MOBIL OIL (NZ) Ltd**
SAMPLE UNIT: **TK 60 Regular Mogas**	
SAMPLE DATE: **29/06/07**	DESTINATIONS: **Bluff**
	Dunedin
VESSEL: ***Kakariki - KK296***	**Lyttelton**

METHOD USED	TEST	UNIT	RESULT	TYPICAL (3)	SPEC RMS 91 95
D4052	Density @ 15°C	kg/L	**0.7337**		
D86	Distillation I.B.P	°C	**29.9**		
	10% Recovered @	°C	**45.5**		
	20% Recovered @	°C	**53.3**		
	30% Recovered @	°C	**61.8**		
	40% Recovered @	°C	**71.9**		
	50% Recovered @	°C	**82.9**		
	60% Recovered @	°C	**97.7**		
	70% Recovered @	°C	**114.9**		
	80% Recovered @	°C	**131.0**		
	90% Recovered @	°C	**148.3**		
	Final Boiling Point	°C	**178.7**		max 210.0
	Recovery	% Vol	**96.6**		
	Residue	% Vol	**0.8**		max 2.0
	Loss	% Vol	**2.6**		
	Barometer	mmHg	**760**		
	% Evaporated @ 70°C	% Vol	**40.6**		23.0 - 48.0
	% Evaporated @ 100°C	% Vol	**64.2**		45.0 - 68.0
	% Evaporated @ 150°C	% Vol	**93.4**		min 75.0
D5191	DVPE	kPa	**82.8**		55.0 - 95
D5191/D86	Flexible Volatility Index		**111.2**		max 115.0
(1) NZRM 071	Appearance at 20°C		**C & B**		C & B
	Colour		**Red**		Red/Orange
	Odour		**Market**		Market
D5580	Benzene	% vol	**0.92**		max 1.00
D5580	Total Aromatics	% Vol	**38.34**		22.00 - 45.00
D2699	Octane Number (Research)		**91.3**		min 91.0
D2700	Octane Number (Motor)		**83.5**		min 82.0
D4814 Annex A1	Silver Corrosion (3hrs @50°C)		**0**		max 2
IP30	Doctor Test		**Negative**		Negative
IP497	Sulphur	ppm(mass)	**10**		max 150
(2) D1319	Olefins	% Vol	**1.0**		max 18.0
(2) D3831	Manganese	mg/L	**0.0**		max 2.0
(2) D3231	Phosphorus	mg/L	**0.0**		max 1.3
Declaration	Steam Cracked naphtha		**Nil**		Nil
(2) D4815	Oxygenates	% mass	**0.01**		max 0.20

COQ Number 07.R160

The New Zealand
REFINING COMPANY LTD

Marsden Point, Whangarei, New Zealand

Regular Motor Gasoline Certificate of Quality

LAB SEQ NUMBER: **240400** SAMPLE UNIT: **TK 60 Regular Mogas** SAMPLE DATE: **29/06/07** VESSEL: ***Kakariki - KK296***	ACCOUNT: **MOBIL OIL (NZ) Ltd** DESTINATIONS: **Bluff** **Dunedin** **Lyttelton**

METHOD USED	***TEST***	***UNIT***	***RESULT***	***TYPICAL*** (3)	***SPEC*** ***RMS 91 95***
D130	Corrosion Copper Strip	2h @ 100°C		**1a**	max 1
D381	Gum, Existent (unwashed)	mg/100ml		**1**	max 30.0
	Gum, Existent (washed)	mg/100ml		**0.5**	max 4.0
D525	Oxidation Stability	min		**>360**	min 360
(4) IP224	Lead Content	mgPb/L		**<0.4**	max 3.0

(1) Not IANZ Accredited
(2) Calculated result from Commercial Division
(3) Typical Sample from Tank No: 65, Date: 29/5/07, Original Sample Seq # 238158 , Typical Test Seq # 238323
(4) Typical Sample Date: 30.05.07 Typical Test Seq # 238323

This report relates specifically to the samples as received.
The latest issue of the relevant test methods was used unless otherwise stated.
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REMARKS

SIGNED: [signature]
IPL Chemist in Charge
Robert Anderson

DATE: **03-Jul-07**

iPL
"Your Testing Partner"

Tested on behalf of NZRC by
Independent Petroleum Laboratory Limited

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