ANALYSIS OF ONTARIO FIRES AND RELIABILITY OF ACTIVE FIRE PROTECTION SYSTEMS

by

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ABSTRACT

As countries move towards the development and implementation of performance-based building codes, it is expected that there will be an increase in the use of scientific and engineering techniques and methods for the design of fire protection systems in buildings. Some of these calculation methods which evaluate the risk from fire to building occupants and contents require statistical data on the performance of active fire protection systems such as sprinklers and smoke detectors. This study aimed at obtaining reliability estimates for these systems using fire incident data from the Ontario Fire Marshal's office.

The study also analyzed the data to obtain the main causes and location of origin of fires in buildings, for all occupancies, and to see the impact of detectors and sprinkler systems on life safety and property damage.

The performance of smoke detectors, heat detectors, and sprinkler systems was analyzed for various occupancies to obtain mean and 95% confidence limits of reliability. The findings show that operational reliability for these systems is lower than commonly used figures. The computer model DETACT was used to explore reasons for failure of sprinkler systems and heat detectors in some occupancies.

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Chapter 1

1. Introduction

There are few things which are more frightening to contemplate than fire. Fires kill, destroy homes, leave survivors with painful disfiguring injuries, and result in huge property damages. Traditionally, fire protection systems of a building are designed in compliance with detailed prescriptions given in prescriptive codes, which are used in most countries. As countries, however, move towards the development and implementation of performance-based building codes, design of fire protection systems is being undertaken using scientific and engineering techniques and methods. Prescriptive codes prescribe in detail what is required and how to implement the requirements in a fashion similar to that found in a cook book. As such, once the requirements of the code are followed to the letter, acceptance is guaranteed. The prescriptive approach is not flexible, restricts innovation, limits the application of new construction technologies, and does not provide clear statements of the safety objectives to be achieved. On the other hand, performance-based codes clearly indicate the objectives and safety criteria that need to be achieved while the means to achieve them are left to the designer. This approach is more flexible, promotes innovation and cost-effective designs, and facilitates international trade, as engineering principles do not vary from country to country. Designs developed following a performance-based approach however, are not automatically accepted by authorities. Their approval process is more time consuming as a full review of the proposed design is required to determine if objectives are satisfied [1].

To facilitate both the design and approval process, there is a need to develop methodologies and risk analysis tools. A research effort at Carleton University aims at developing a fire risk assessment model for commercial buildings. Using a number of sub-models, each dealing with one aspect of fire, this model will calculate the expected risk to life as well as the expected fire costs from fires in a building during its lifetime. For each major fire scenario, the model calculates fire growth and fire spread, smoke movement, and the impact of fire on building elements. In addition, the model simulates occupant response and evacuation based on the installed fire detectors and alarm systems, and egress routes. For each scenario, the model calculates the expected life hazard and expected economic loss. The outputs of each scenario together with the probabilities of each scenario occurring are used to calculate the expected fire risk to life and expected fire costs. To calculate the expected fire risk to life and expected fire costs the risk assessment model requires reliability data for active fire protection systems. These data can be obtained from fire statistics or from an evaluation of the actual condition of the systems. This work aims at developing reliability data for active fire protection systems for use as an input to the fire risk assessment model.

Active fire protection systems include fire detection systems, fire alarm systems, and fire suppression systems [2]. This study is focused on heat detectors, smoke detectors and sprinklers. To be effective, these systems should operate as early as possible during a fire. Operational reliability is a measure of the probability that a fire protection system will operate as intended when needed; that is, it is a measure of component or system operability and is given by the ratio of number of times the component/system operates to the total number of incidents. Performance reliability or effectiveness is a measure of the adequacy of the feature to successfully perform its intended function under specific fire exposure conditions; that is, it is a measure of the adequacy of the system design [3]. For example, during the growth stage of fire, a fire detection system should be able to detect the fire and give an alarm, so as to warn the occupants for early escape, provide fire service notification, and, in a few cases, activate some other fire protection features like smoke management systems. Similarly, a sprinkler system should operate and control or extinguish the fire. The overall reliability of a system is the product of its operational reliability and its performance reliability. Generally fire incident data do not have sufficient information for calculating the performance reliability and the additional information required may include:

- For smoke detectors or heat detectors; details of the occupant response i.e. whether on hearing the alarm, all the occupants were able to evacuate safely.
- For sprinklers; details of the extent of flame spread and damage to property, and time to control or extinguish the fire.

In the absence of above information, the performance reliability can be estimated using past experience or expert judgment. Operational reliability can however be determined from the available data. Because of that, the scope of this study is limited to evaluate the operational reliability of fire protection systems from statistical data.

Statistical data for a period of eight years (1995-2002) obtained from the office of the Ontario Fire Marshal (OFM) [4] were used in this study to evaluate the operational reliability of smoke detectors, heat detectors and sprinkler systems. A detailed analysis of the data was performed to determine 95% confidence interval estimates (rather than single estimates) for the operational reliability of these systems. The 95 percent confidence limits were selected as these are typically used for quality assurance estimates for manufactured machine parts. However any other confidence limits can be used depending upon the required certainty associated with a particular product or system [5].

The main objectives of this work are the following:

1. To perform a statistical analysis of the OFM data (1995–2002) [4] to investigate fire loss trends, patterns, origin and causes of fire in all structures.

2. To perform a statistical analysis of the OFM data [4] to study fire loss trends, patterns, origin and causes of fire for residential dwellings including single-family dwellings, semi-detached dwellings, and townhouses or row houses.

3. To determine the impact of providing active fire protection systems on life safety and losses.

4. To use statistical methods to calculate the operational reliability of heat detectors, smoke detectors, and sprinklers for each occupancy using the OFM data [4], in order to provide input data for risk assessment models.

5. To use the computer program DETACT [6] to study the impact of different parameters such as heat release rate, location of detectors and sprinklers, actuation temperature of detectors and sprinklers, and RTI (Response Time Index) on activation time.

Chapter 2

2. Literature Review

A literature review was done to find out if any reliability analysis (95% confidence interval estimates) for building occupancies had been done in USA or Canada for the last 8 to 10 years. No such study related to various occupancies could be found. Further it was noticed that although Canadian fire data are collected by the provincial Fire Marshal and Fire Commissioner offices, no statistical analysis had been done to determine the operational reliability of active fire protection systems. Literature relevant to this study is reviewed in this chapter.

2.1. Performance – based codes

Hadjisophocleous and Benichou [1] presented the results of a literature survey on efforts to move from prescriptive building regulations to performance based regulations. They revealed that there is an increasing world-wide tendency to move from prescriptive to performance-based codes. Their paper discussed the elements of a performance-based code, as well as, the need to establish performance criteria that can be used to evaluate fire safety designs. The paper also reports on the need of reliability data for active fire protection systems.

2.2. General statistical analysis

Hall and Cote [2] provide a perspective on the size, trends, and patterns of fires in the U.S.A. They reported that, for the period 1977-1994, fire incidents, civilian deaths and civilian injuries decreased whereas property damage increased. Fire was stated to be the second highest cause of accidental deaths in homes, and the number one cause of death for children and young adults. Fire deaths had fallen to less than half whereas the rate of deaths per 100,000 population had fallen to below twenty percent in a period of 76 years starting from 1913. 25% of the total fires from 1989 to 1993 were in homes and garages. These fires however, caused nearly 75% of the civilian deaths and injuries, and more than half of the total property damages. Cooking equipment followed by heating equipment and incendiary or suspicious causes were the main causes of the majority of these fires. Fires due to smoking materials, however, accounted for most of the deaths whereas fires due to incendiary or suspicious causes were responsible for the highest property damages. In industrial establishments fires caused by other equipment accounted for the maximum number of fire incidents, deaths, injuries, as well as property damage. It was stated that U.S.A. has been able to bring down the average severity of fires due to improved fire safety provisions, but fares poorly in reducing the fire incident rate.

The Canada Safety Council [7] in its issue of October 2002 reported that smoking is not only bad for health but a fire hazard as well. Fires started by cigarettes cause one out of every five fire fatalities, and careless smoking is a leading cause of home fire deaths in Canada. Careless smoking may lead to fires which can burn for hours before bursting into flame. Around 95% of Canadian homes have at least one smoke alarm, according to a 1998 Canada Safety Council survey. Photoelectric type smoke alarms, designed to detect smoldering fires may help in reducing smoking-related fire deaths [7].

The office of the Ontario Fire Marshal (OFM) [8] studied fire loss statistics from 1985 to 1994 and from 1995 to 1999 to explore the fire problem in Ontario. Both studies show that the majority of fires, majority of deaths, highest death rates, and half or more of the total property loss occur in residential properties. Most fires start in the kitchen with cooking equipment being the ignition source. Most fire deaths, however, occur in fires ignited by smoker's materials, specifically lit cigarettes, pipes or cigars. While "flammable liquids" are the most commonly reported object first ignited, more fatal fires begin with the ignition of upholstered furniture. Data from 1995 to 1999 showed that 75% of structural fires occur in residential properties. Fires in residential buildings are most likely to start in the kitchen, living room, bedroom or chimneys. Successful operation of smoke detector/alarm in residential structures was 67.6 %. The main reasons for non operation of smoke detectors/alarm were power failure/no battery/dead battery at 37% followed by remote/separated from fire at 31%, undetermined at 16%, other than listed reasons at 9%, possible failure of unit at 3%, improper installation at 2%, and tampered with at 2%. Based on Ontario's 1995-2002 fire incidents, fire departments reported that 79% of homes where they attended had a smoke alarm. This eight year data showed successful operation of smoke detector/ alarm in residential structures at 66.7 %.

The OFM report [8] also showed that commercial (3%) and industrial (12%) fires, had the highest property loss of 9% and 20% respectively; that is, they were the most expensive.

2.3. Reliability of sprinkler systems

Papers reviewed in this section address the reliability of sprinklers and they are arranged in chronological order according to their date of publication.

Morgan and Hansell [9] reported that the measure of fire-damaged area can be used as a good indication of the maximum size of the fire. This fire size can further be related to the maximum heat output during the fire, which is the most useful design parameter for smoke ventilation calculations. They analyzed U.K. Fire Statistics for 2 years (1978 and 1979), to find the proportion of reported fires exceeding any given size (the relative frequency), for both sprinklered and unsprinklered offices. The paper showed how the fire damaged area could be used to determine whether the fire had been ventilation or fuel bed-controlled. It further showed how the heat carried by the gases leaving the office (e.g., into an atrium) could be estimated, for either ventilation or fuel-bed controlled fires, whether sprinklered or not. The study suggested that fitting sprinklers in open plan offices might give a major advantage in reducing the capacity required of a smoke ventilation system, but much less of an advantage for cellular offices. The data also included information on the presence and operation (or not) of sprinklers, and an attempt was made to find their effectiveness in combating office fires. It was reported that in offices where sprinklers were installed, 40% did not operate (for whatever reason), 58% controlled or extinguished the fire, and 2% failed to control the fire.

The instances where sprinklers were installed but did not operate may be due to:

- Fire controlled by first-aid fire-fighting (by the staff) before becoming large enough to produce enough heat to operate sprinklers.
- Insufficient heat output to generate the required operating temperature.
- Mechanical failure.
- Water turned off for repairs or alterations.

Above a fire size of $5m^2$ there were few instances (10%) of sprinkler failure to operate. Where the sprinklers were deemed to have controlled or extinguished the fires, it was noticed that they could control a fire with an area even up to 100 m^2. The use of sprinklers in an office considerably reduced the risk of a large fire occurring. For example in sprinklered offices, the statistical probability of a fire exceeding 10 m^2 is 12%, whilst in unsprinklered offices this probability is 26%.

Richardson [10] reported on the reliability of automatic sprinkler systems and stated that they have played a key role in the protection of property and lives from fire. Based on a review of statistical data from NFPA (1897-1969), this digest shows the reliability of such systems in place to be in excess of 96%. Means are suggested to improve this reliability to 99% through proper design, inspection and maintenance of systems. It was further stated that the Australian Fire Protection Association had published data on virtually all fires involving sprinkler systems in Australia and New Zealand for the period 1886 to 1968 (over 5,700 incidents) and revealed a still higher reliability rate. Only 0.25% of these systems were considered to have given unsatisfactory performance. As such, the reported operational reliability of sprinklers was as high as 99.7%.

Marryatt [11], based on a 100 year study of fires in sprinkler protected buildings (approximately 900 fires) in Australia and New Zealand, reported that:

- Sprinklers controlled 99.46% of all fires reported.
- In 64.55 % of fires, only one sprinkler operated.
- Five or fewer sprinklers controlled over 90% of reported fires.
- In institutional and residential occupancies, there were three fire deaths in the 100 year period. In these cases, the deceased was "intimate with the source of ignition".

Koffel [12] reported that smoke detection and automatic sprinkler protection may not be very helpful in reducing fire deaths in health care facilities because most of the deaths are due to the victim being intimate with ignition. However, quick response sprinklers may be able to reduce fire deaths of both the occupants of the room of origin and occupants outside the room of origin. Furthermore, smoke detectors or standard sprinklers should be able to reduce the number of fire fatalities occurring outside the room of origin. Alternative strategies such as control of furnishings, smoke control or staff training may be used in these facilities. The material first ignited is generally clothing, linen or bedding intimate with the fire victim and hence it would be good to use flame retardant clothing and bedding. The author states that staff training for meeting emergencies, identifying fire hazards, and preventing fires from occurring, may provide most effective results in reducing fire fatalities in health care occupancies. Special emphasis should be placed on controlling smoking in patient rooms since the leading source of ignition in the fatal fires is smoking materials.

Koffel [13] reviewed recent fire experience in the United States and reported that the reliability of automatic sprinkler systems, while still good, may not be as high as reported by several studies done earlier. It was stated that, while NFPA fire incident data from 1989 to 1998 clearly demonstrate that property loss and life loss are reduced in buildings protected throughout with an automatic sprinkler system, the data also indicate (with statistical support) that sprinklers fail to operate in 1 of every 6 fires (i.e. about 16% of the time) that are large enough to activate a sprinkler. As such the operational reliability of sprinkler system is 84% (5 in every 6 fires) whereas historically the commonly stated value is in the range of 96% (24 in every 25 fires). It was however stressed that whether the operational reliability is considered as 84% or some other value, the NFPA data seem to indicate that the commonly stated reliability of automatic sprinkler systems in the range of 96% is overstating the operational reliability of sprinkler systems. It should also be noted that even if the reliability of sprinkler systems is only 84%, automatic sprinkler systems still have a dramatic impact on reducing life and property loss from fire.

Bukowski, Budnik and Schemel [3] reviewed the reported operational reliability and performance estimates for fire detection and automatic suppression. A limited, statistical based analysis was performed for the reported data on detection (largely smoke detection/ fire alarm systems) and suppression (sprinklers). The analyzed reports addressed different occupancies (residential, institutional, commercial, etc) and different periods (broken periods from 1959 to 1993) both for sprinklers, as well as smoke detectors. The authors stated that based on the results of their study, the use of the mean value for operational reliability of a fire protection strategy, together with its 95% confidence limits, is significantly better than a single value. For different occupancies, the 95% confidence interval estimates of operational reliability for sprinklers and smoke detectors indicating mean probability of operation and its lower and upper confidence limits are as given in Table 2.1.

Table 2.1 Operational reliability estimates

Device	**Occupancy**	**Mean probability of operation**	**95% confidence lower limit**	**95% confidence upper limit**
Sprinklers	Commercial	93%	88%	98%
Smoke detectors	Commercial	72%	70.2%	73.7%
	Residential	77.8%	75.1%	80.6%
	Institutional	83.5%	82.3%	84.6%

This is a generally accepted statistical approach when comparing one system to many others. However it should be noted that the quality of the data in the literature is an important consideration and the range of the reliability results may depend upon the size and quality of the data-base. Specific input data for a broader population of systems could provide the basis for significant improvements in estimates of operational reliability for fire protection strategies of interest to design engineers and authorities. This technical information is also necessary for engineering based analysis associated with rapidly progressing performance based design concepts.

Rohr [14] reported that automatic sprinklers are highly effective elements of total system designs for fire protection in buildings. When sprinklers are present, the chances of dying in a fire and the average property loss per fire are both cut by one-half to two-thirds, compared to fires where sprinklers are not present. The sprinklers presence and operationality in structure fires by property use taken from National estimates based on a 1989-1998 NFIRS and NFPA survey [15] showed that the operational reliability for sprinklers was in the range 73.9% to 91.1%. Fires which were coded as too small to test the operational status of sprinklers were not considered. The NFPA analysis using data from 1989 to 1998 showed a good reduction in the rates of civilian deaths (except for public assembly and educational properties already showing zero deaths) as well as property damages in various property classes having sprinklers. Further it was stated that NFPA has no record of a fire killing more than two people in a completely sprinklered building where the system was properly operating, except in an explosion or flash fire or where industrial fire brigade members or employees were killed during fire suppression operations. When sprinklers do not produce satisfactory results, the reasons usually involve one or more of the following:

- Partial, antiquated, poorly maintained, or inappropriate systems.
- Explosions or flash fires that overpower the system before it can react.

- Fires very close to people or close to sensitive, valuable property such that fatal injury or expensive damage, respectively, can occur before a system can react.

"Poor maintenance" refers primarily to the problem of valves being shut off and inadvertently left shut off. "Inappropriate" systems are systems whose design is not adequate for the current level of hazard in a building. An NFPA report [16] cites a total of 3,134 fires for the period 1925 to 1969 in which sprinkler performance was deemed unsatisfactory, and failure to maintain the operational status contributed to most cases. Approximately 15% of commercial building fires in the U.S. are arson related. An arsonist's objective is to cause damage and destruction, and in most cases it is an easy matter for a perpetrator to disable the sprinkler system before setting a fire. Yet such instances may not be considered or reported as sprinkler failures. Monitoring and maintenance of sprinkler systems is most important for better reliance on these systems. In view of this, it was concluded that it is not reasonable to rely solely or primarily on sprinkler systems for fire protection and that building codes should define a balanced level of protection by integrating the proven elements of detection, suppression, and compartmentation. For a balanced approach, accurate and reliable reliability and effectiveness values for sprinklers as well as other active systems is required.

Budnick [5] summarized published sprinkler reliability studies that were more than 15 years old and gave single value estimates, and developed 95% confidence interval estimates to account for the uncertainties associated with these estimates. It was shown that the mean reliability estimates for sprinkler systems for three occupancies are commercial 93.1%, general 96%, and combined 94.6%. Similar estimates were prepared for several existing sprinkler systems from their Inspection, Testing and Maintenance

(ITM) data by considering 66 month records of monthly tests of manual valves, sprinklers, and piping (gasket failure), and quarterly records for other components (in terms of "pass" or "fail") [5]. Component failure rates were developed using the Exponential Model for Life Testing (EMLT) [5]. System schematics were used to develop fault trees for individual systems to find overall system reliability estimates. Once the system reliability information was obtained, further analysis was done to examine testing and inspection intervals and how altering these intervals affected the system's reliability. The results showed that reduction in ITM frequencies decreases the system reliability, and also the uncertainty associated with the lower reliability estimates of the uncertainty interval becomes larger [5].

Budnick [5] in addition to the concepts of operational and performance reliability, introduced two other concepts failed-safe and failed-dangerous. When a sprinkler system fails safe, it operates when no fire event has occurred, e.g. an accidental discharge of a sprinkler. A failed-dangerous condition occurs when a system does not function when needed, e.g. a sprinkler fails to open, or the water supply is unavailable. Estimates prepared from fire incident data, combine both the operational and performance reliability elements and typically do not include failed-safe incidents in the analysis. On the other hand, studies that rely on testing and maintenance data are for the most part providing estimates of operational reliability. It has been reported that the range of estimates giving mean reliability values along with upper and lower confidence limits provides greater confidence as compared to single value estimates. This information reduces the uncertainty in estimating the impact of sprinkler system reliability in risk based design evaluations.

Thomas [17] introduced a concept of fire safety system effectiveness incorporating two elements, efficacy and reliability. Efficacy has been defined as the degree to which a system achieves an objective given that it operates. For example, if a fire safety system (such as sprinklers, smoke or heat detectors or fire resistant barriers) is intended to prevent fatalities its efficacy is:

- 100% if there were no fatalities whenever it was present and operated
- between 0 and 100% if the rate of fatalities whenever it was present and operated reduced compared with otherwise identical situations with that system not present
- 0% if the fatality rate remained the same whether it was present or not
- negative if the fatality rate increased in fires when it was present and operating

It can thus be seen that efficacy with regard to another objective, for example avoidance of property damage, might be quite different. Reliability has however been defined as the probability that the system operates when required. Thus effectiveness as a combination of efficacy and reliability may not be the same for different objectives. Thomas has used ten or thirteen years of data (1983 to 1993 excluding 1986, or 1983 to 1995 depending on the occupancy) from the USA NFIRS database for a range of occupancies. The estimates have been prepared for finding the levels of effectiveness of fire safety systems incorporating sprinklers or detectors or protected construction, or their probable combinations. It was observed that:

- The percentage of detectors in the area of fire origin that did not operate is always less than the percentage of detectors not in the area of origin that did not operate.

- There needs to be a large number of fires in the database for it to be possible to estimate with confidence quantities like rates of injuries, fatalities, and property loss.
- Fire data records very few "inputs" to the fire, particularly about fire safety systems e.g. whether they are present or not, whether they operated as intended, etc.(if indeed it is possible to observe this after the fire has been extinguished). Most of the items recorded are "outputs" of the fires e.g. how far smoke spread, how widespread smoke damage was, the number of injuries or fatalities, or property damage, etc.

Thomas [17] further reported that generally sprinklers have greater estimated apparent effectiveness than detectors or protected construction. For civilian fatality rates, sprinklers are expected to have effectiveness greater than 0.5 in about 60% of occupancies, while detectors have such effectiveness in less than 10% and protected construction in about 20%. The analysis concluded that, "Based on the data analyzed it appears that sprinklers are generally more effective in reducing fire spread, civilian fatalities, fire fighter injuries and property losses than either detectors or protected construction".

Berrin [18] reported that sprinklers are the single most effective fire fighting tool. They operate automatically in the early stages of fire, hence minimizing the need for manual extinguishment by occupants or the fire department. Where the sprinklers operate, the fire damage is extremely limited, keeping dollar losses down. They rarely fail and need much less water; as water is applied directly over the fire in a limited area, reducing water damages. In Australia and New Zealand where every fire is reported by law, fire incident data show that 99.7% of fires in sprinklered properties are controlled or extinguished by sprinklers.

Melinek [19] reported that if it is assumed that providing sprinklers in all buildings (including dwellings) would have the same effect on fire spread as in existing sprinklered installations and also that the number of fatal and non-fatal casualties per thousand fires depend only on the extent of fire spread, then provision of sprinklers in all buildings is likely to reduce the number of fatal fire casualties by about 50% and the number of non-fatal fire casualties by about 20%. Sprinklers to a large extent reduce the number of deaths in multi-fatality and single-fatality fires.

Melinek [20] examined the effectiveness of sprinklers in reducing fire severity. The figures for fire size (horizontal area damaged by heat) and structural damage were taken from unpublished fire brigade data for occupied industrial & commercial buildings in the UK in 1987. The figures for losses were taken from Rogers [21]. Data on structural damage indicated that sprinklered buildings differed substantially from unsprinklered buildings in compartment size and hazard. It was therefore not possible to assess sprinkler effectiveness by directly comparing fires in these buildings. Hence, the effectiveness of sprinklers was examined by comparing fires they extinguished or controlled, with fires they failed to extinguish or control. The main conclusions are:

- Sprinklers substantially reduced the probability of fire area exceeding 100 m^2 (by 80%), but they normally had little effect until the fire area reached 3 m^2.
- Sprinklers reduced the probability of heat damage to the building by a factor of about 2.5.

- Sprinklers reduced optimal fire resistance times by about 25%. This effect was explained as follows: The fire resistance required by any structure to survive a fully developed fire is generally assumed to be proportional to the fire load density. It has been recommended that the design fire load density be the value which has a 20% probability of being exceeded. Optimal design entails keeping the overall probability of failure approximately constant. Hence, if sprinklers reduce the number of fires causing heat damage to the building by a factor of 2.5 the probability of structural failure in each such fire can be allowed to increase by a factor of 2.5 which corresponds to reducing the design fire density to the value which has a 50% probability of being exceeded. Fire load density typically has a coefficient of variation of about 0.5. It can be shown that the fire load with a 50% probability of being exceeded is then approximately 25% less than that with an 80% probability of being exceeded. Hence, the optimum level of fire resistance with sprinklers is about 25% less than that without sprinklers.
- About half the large fires with area over 100 m^2 in sprinklered buildings and three quarters of the fires causing damage to the building were fires in which sprinklers operated. Hence the effectiveness of a sprinkler system in general, can not be assessed solely from the probability that it will operate.

The probability of fires in sprinklered buildings becoming large was reported to be far lower in Australasia than in the UK or the USA [22]. This reduction might result from:

- A low incidence of freezing
- Frequent monitoring of sprinkler systems, including electronic monitoring
- Automatic call to fire departments, leading to rapid fire brigade response.

In addition, automatic call systems in Australia will result in many more small fires being recorded. The recording of more small fires will decrease the apparent probability of fires becoming large.

Feeney [23] analyzed the significance of sprinkler effectiveness relating to performance of steel structures in fire for New Zealand as well as Australia. Traditionally, steel structures have been protected from the effects of fire by applying insulative fire protection. The past experience exhibited that in both these countries the performance of automatic sprinklers to control the growth and spread of fire was very successful and hence, sprinkler protection could be regarded as an alternative to passive fire protection. This study analyzed the results of Marryatt's study (1988) [11] based upon fire reports for 100 years (1886-1986) as well as fire reports for the period 1986 onwards for Australia and New Zealand, to obtain conditional probabilities (i.e. fire controlled or not, given that sprinklers operated) that confirm the effectiveness of sprinklers to control fires. This study is based on the concept of effectiveness as a combination of reliability and efficacy, and in this case the desired objective for sprinkler operation is, "control of a fire to the extent that the stability of an unprotected steel structure is not threatened". Feeney [23] concluded that for a specific range of building types and occupancies, the likelihood that a fire will grow to reach full development in a sprinklered building is extremely low. Provided the capacity of the steel structural system is verified to withstand the deformations and ductility demand at connections and in cross-sections corresponding to exposure to temperatures associated with fully developed fires, there appears to be no fundamental reason to apply passive fire protection to the structural steel members in sprinklered buildings. Not withstanding this, project specific requirements for passive fire protection may still apply.

The American Architectural Manufacturers Association (AAMA) [24] reported that although sprinkler systems can certainly be quite effective in reducing fatalities and property loss and are widely reported to be 90 to 95% reliable, there are strong indications that the actual reliability is less than this. In fact, some recent Consumer Product Safety Commission statistics suggest a failure rate as high as 67%. Sprinklers can simply fail to activate, be overwhelmed by the fire or prematurely deplete the water supply. Even when sprinklers work, they do little to reduce smoke, which is the cause of most fire fatalities.

2.4. New trends in fire protection

McEwen [25] reported that, fire alarm systems are often associated only with pull boxes and alarm bells. However, they are usually much more complex. They may include numerous components such as smoke detectors, heat detectors, sprinklers, enunciator panels, loudspeakers, telephones, control panels and pull boxes. In addition to the alarm function, fire alarm and detection systems can also actuate other fire safety measures in a building. Fire alarm systems are required by law through building codes, fire codes and special acts or bylaws. The choice of a particular type of equipment to be used in a fire alarm system depends on the nature of the occupancy, the size of the building, the number of occupants and the level of protection desired. To be effective, a fire alarm system must be tailored to the building and the types of fire that could develop. The designer of the system must understand the functions and limitations of the equipment chosen to obtain maximum efficiency and safety.

Lougheed [26] reported that for high ceiling occupancies like aircraft hangers with a potential for large fires with high associated costs, deluge foam systems are frequently used. Optical detection methods are frequently used as an alternative to thermal or conventional smoke detection in such cases. Optical or photo-electric detectors work on the principle of light scattering. Smoke from fire scatters the continuous light beam emitting from an LED (light emitting device) in a sensing chamber, resulting in an electrical signal which activates the optical detector. Optical detectors must be able to distinguish, however, between the fires which require activation of the suppression system, and signals (from natural or man made sources) which do not require suppression activation. An unwanted activation of the suppression system can cause the loss of expensive fire suppression agents and could seriously damage the aircraft housed there. Due to concerns about false alarms and other criteria having an impact on the performance of these detectors, performance specifications for these detectors as well as their testing facilities, were also developed. The study recommends the usage of optical fire detectors for protecting high ceiling spaces.

Cholin and Marrion [27] reported that although heat detectors and smoke detectors have been used widely for a very long period of time, there are no clear cut performance metrics to assist designers to design and predict their performance with confidence. They explained that to confidently and accurately design a heat-detection system in a performance-based design environment the designer must know the operating temperature, and the Thermal Response Coefficient (TRC) of the detector. TRC is an expected constant for heat detectors as is RTI for the sprinklers. RTI stands for Response Time Index and is a measure of sprinkler's sensitivity. Without both of these metrics, the designer is forced to estimate response by using a correlation between the listed spacing of the detector and RTI. Since there are unknown inaccuracies in the listed spacing to RTI correlation, it would be wise to perform the design calculations using a range of RTI values and analyze the sensitivity of the design to inaccuracies in the correlation. Designers use large safety factors to account for possible inaccuracies in these calculations. In view of the above the authors recommended publication of a TRC that had the same form as RTI to enable engineers to use existing performance prediction correlations and fire models originally developed for sprinklers, to predict the performance of detection systems using heat detectors. The authors also point out the difficulty in predicting the performance of smoke detectors due to the lack of performance metrics.

Su [28] reported a 40% decline in Canadian fire fatalities between 1985 and 1995. He attributes this to the use of residential smoke alarms and the enforcement of the relevant codes and standards. A series of full-scale fire suppression experiments were conducted at NRC's Fire Risk Management Program in a wood-framed two-storey house (90 m^2 per floor, 180 m^2 total). A residential sprinkler system with quick response sprinkler heads (temperature rating of 68.3^{0}C) was installed in the basement recreation room and on the main floor to prevent flashover in the room of fire origin. In addition to sprinklers, heat detectors (rated at 57^{0}C and a temperature rise of 8.4^{0}C/min) and smoke detectors were also installed as per the code requirement to study their effectiveness.

Four experiments were conducted with different conditions and the following summarizes the findings:

- In all four experiments, a single sprinkler controlled and contained the fire within the room of fire origin within 1 minute of sprinkler activation.
- Sprinklers installed between open wood joists actuated at higher temperatures than heads that were installed under a gypsum board ceiling.
- Plastic pipes (unprotected cross-linked-polyethylene pipes rated for 93^0C temperature at 552 kPa for 140 s) and fittings were exposed to a maximum temperature of 140^0C, but there was no damage and the same pipes could be used for additional experiments.
- During the experiments, the temperatures in the egress routes were around the ambient temperatures when the fire compartment door was kept closed.
- As expected, heat detectors actuated earlier than sprinklers. The rate of temperature rise triggered the detectors. A smoke alarm, installed in the egress route, actuated before sprinkler activation when the fire room door to the egress route was open. It actuated after the sprinkler activation when the fire room door was closed.

This study indicates the relative activation times of smoke detectors, heat detectors and sprinklers during home fires.

Liu and Kim [29] reviewed the progress in fire detection technologies over the last decade, including various emerging sensing technologies (e.g., computer vision systems, distributed fiber optic temperature sensors, and intelligent multiple sensors), signal processing and monitoring technology (e.g., real-time control via internet) and integrated fire detection systems. The authors concluded that:

- Many new fire detection technologies developed over the last decade have strong potential to reduce false alarms, increase sensitivity and dynamic response to a fire and improve fire safety. Brillouin scattering-based distributed fiber optic sensors have a long sensing range, respond quickly to temperature fluctuation and are immune to all kinds of interference emission. They have the potential to provide fire detection in applications where small fires might be encountered (e.g., telecommunication facilities), and areas with restricted access or with difficult ambient conditions (e.g., tunnels, underground railways and stations, nuclear and petrochemical plants).
- Video fire detection systems have also demonstrated great advantages for use in sensing and monitoring a fire as well as on multi-function applications. Cameras and corresponding facilities required in the video sensor system are already standard features of many buildings. With further development in microelectronics and information technologies, video information can be sent out or accessed via Internet or a wireless network. It is expected that video sensor systems will play a more important role in providing cost-effective fire safety and other building management and services.
- In recent years, fire detectors tend to be more intelligent in discriminating between fire and non-threatening or deceptive conditions due to the introduction of artificial intelligence techniques as well as the development of microelectronics technology. Multiple sensors that combine smoke and thermal sensors or CO sensors are capable of overcoming the drawbacks of a single sensor in fire

detection, and provide better fire detection by discriminating many nuisance sources and extend detection capability for many fire sources.

- The use of advanced control panels with advanced fire signal processing and sensor-driven fire models would substantially reduce false alarms and provide more accurate information on fire and smoke spread in the building. This will allow building operators and firefighters to make a more accurate and responsive evaluation of any fire-related incident in the building and to control fires and supervise the evacuation from the building more efficiently.

The use of real-time control via the internet or wireless network will extend the monitoring and control of fire safety systems outside of the building. The status of the fire safety system and other building systems can be monitored at anytime and from anywhere via the Internet or wireless network. The fire safety systems located in many buildings will be controlled from one central facility office. This will increase the efficiency and reduce costs for building management operations, more efficiently discriminate between fire and non-fire threats and increase the time available for property and life protection. However, Internet-based monitoring and control of building service systems will need security protection to prevent false information being provided to building owners and fire brigades.

Su, [30] demonstrated through full scale experiments that combined ionization-photoelectric smoke detectors, can be, in some cases, more effective than ionization or photoelectric detectors used alone in homes. The experiments were done in two houses ($90m^2$ and $140m^2$ per floor) by installing three types of detectors photoelectric, ionization and combined photoelectric-ionization to determine the response time to various types of fires. Combined ionization-photoelectric detectors responded at the same time, or in some cases, sooner than ionization detectors or photoelectric detectors alone. Surprisingly, however, smoke detectors installed in the "dead air space" (the triangular area 10 cm from ceiling and wall joints in each direction) were among the first to detect fires. Theoretically, smoke detectors installed in this space are not expected to quickly detect fires, and Canadian standards for placement of smoke detectors require that this space be avoided. As such the new results show that this area deserves further study to determine to what extent, if any, the detector response times were influenced by the temperature in the unconditioned houses (the ambient temperature was around 12^{0}C).

2.5. Trade-offs

An exchange of one thing in return for another, especially relinquishment of one benefit or advantage for another regarded as more desirable, is termed as trade-off. For example a provision of active fire protection system such as sprinklers is expected to reduce the need for passive fire protection construction.

Sultan, [31] reported that each year in Canada, building fires cause hundreds of deaths, thousands of injuries and billions of dollars worth of property damage. Canada has the second highest fire death rate among 15 industrialized countries. In Canada in 1988, about 72% of fire deaths and 40 percent of fire property losses occurred in small buildings, such as one- and two-family homes, apartment buildings and hotels/motels. The paper proposes four ways to reduce fire hazards:

- Containing fire within a compartment
- Controlling the spread of fire between compartments through interior separations

- Controlling the spread of fire between compartments through openings in exterior walls
- Providing early warning to building occupants.

Sultan states that the use of sound insulation in the cavities of fire resistant wall assemblies improves fire performance in walls. Sprinklers are quite effective in fighting fire but cost factors restrict their use. By using sprinklers, designers can provide glazing in fire resistant wall assemblies.

Licht [32] reported that recent trends in code making tend to emphasize sprinkler over passive fire-protection strategies. It is estimated that new codes will reduce the cost of new construction by 2% to 5% due to the allowed increase in heights and area of construction and reductions in fire resistant construction requirements. These less restrictive construction regulations and fire resistant construction requirements are based on an absolute reliance on sprinkler systems to do the job of preventing severe fire damage and fire spread. He states that reduction or elimination of ratings of fire protection features such as protected steel columns, doors and firewalls and other fire resistant wall assemblies, such as in corridors may place occupants and firefighters at greater risk in the event of a fire. Fire resistant construction helps in restricting spread of toxic fumes, flame and smoke in building fires, and helps save lives. The controversies surrounding active/passive trade-offs have strongly been influenced by building ownership and building management interests on one side, and the fire resistant construction industry on the other. Although sprinklers are clearly a life safety asset for commercial and industrial buildings, it must be acknowledged that sprinkler systems can and do fail on occasion, because of human error, neglect, and mechanical malfunction.

Sprinklers can and do malfunction in buildings due to accidental deactivation, malfunction or improper maintenance. Licht [32] felt that due to vested interests the actual performance of sprinklers was not being highlighted. He stated that the simple, practical and inescapable fact is that when a sprinkler system is in place but does not operate or effectively control a fire, for whatever reason, it must be acknowledged as a sprinkler failure.

Licht [32] further stated that a report of September 2001, "U.S. Experience with Sprinklers", based on the NFPA fire data (1989-1998) [15] indicated that sprinklers operated during 82.7% of fire instances, and failed to operate in 17.3% of fire instances, wherein fires which were coded as too small to test operational status of sprinklers were not considered. Licht [32] finally concludes that, "Unsatisfactory fire protection performance can occur if the building's design does not address all five elements of an integrated system – slowing the growth of fire, automatic detection, automatic suppression, confining the fire, and occupant evacuation."

2.6. Summary

In summary the literature survey demonstrates that there is an increasing world-wide tendency to move from prescriptive to performance-based codes. It is however expected that a large number of buildings will still actually be designed following prescriptive-based codes. In a performance-based design, the ultimate evaluation may be whether the outcome is consistent with the expected performance as documented during the design process.

Reliability values found in the literature review are summarized in Table 2.2.

Table 2.2 Operational reliability of sprinklers and smoke detectors

Literature Reference	Source of information	Sprinkler's reliability (%)	Smoke detectors reliability (%)
Bukowski et.al.[3]	Analyzed past studies results and developed 95% confidence interval estimates	$(94.6 \pm 2.4)\%$	Commercial $(72 \pm 1.7)\%$ Residential $(77.8 \pm 2.7)\%$ Institutional $(83.5 \pm 1.2)\%$
Budnick [5]	Analyzed 15 year old published studies	Commercial (93.1%) General 96% Combined (94.6%)	
Morgan and Hansell [9]	Analyzed U.K. fire statistics for offices for two years (1978 -1979)	60%	
Richardson [10]	NFPA (1897 - 1969) Australia and New Zeeland (1886 - 1968)	96% 99.7%	
Marryatt [11]	Australia and New Zeeland (100 year study)	99.5%	
Koffel [13]	NFPA data Historical value (overstated value)	84% 96%	
Rohr [14]	NFIRS and NFPA survey (1989 - 1998)	73.9% to 91.1%	
	NFPA report 1925 - 1969	Unsatisfactory	
Berrin [18]	Australia and New Zeeland (all fires reported by law)	99.7%	
AAMA [24]	Widely reported value	(90 to 95)%	
	Consumer product safety commission	33%	
Litch [33]	A report "U.S. Experience with sprinklers" September 2001, based on NFPA data (1989 - 1998)	82.7%	

Note:

1. As per Bukowski [3] paper, heat detector's reliability is 89% to 90% for flaming fires.
2. NFPA stated that data collection during 1925-1969 was biased toward cases of poor sprinkler performance resulting in unsatisfactory performance.

Results of the Table 2.2 will be used for comparison with the mean reliability values of sprinklers, smoke detectors, and heat detectors computed in the current study.

Seventy five percent of structural fires occur in residential properties and they account for the majority of fires, deaths, and property loss. Residential properties accounted for the highest rate of deaths per hundred fires. Industrial fires, however, had the highest property damage. Fires in residential buildings are more likely to start in a kitchen, living area, and bedroom. More fires start in the kitchen with cooking equipment being the ignition source than elsewhere. Flammable liquids are the most commonly reported objects first ignited. Most fire deaths occur in fires ignited by smoker's materials, specifically lit cigarettes, pipes or cigars and most fatal fires begin with the ignition of upholstered furniture as compared to other objects first ignited.

Functional fire detection systems provide early detection of fire, and ensure timely action for escape as well as reporting to the fire department. Sprinklers are the most effective fire protection system. They operate automatically in the early stages of fire, hence minimizing the need for manual extinguishment by occupants or the fire department. Where sprinklers operate, the fire damage is limited, keeping dollar losses down. Sprinklers, to a large extent, reduce the number of deaths in fires with fatalities. New ways and means for efficient detection and suppression systems such as, combination of ionization and photoelectric detectors, residential sprinklers, etc may help in reducing life loss and property loss. A range of estimates giving mean reliability values along with upper and lower confidence limits provides greater confidence as compared to single value estimates.

Chapter 3

3. Statistical Data

3.1. Introduction

Fires attended by local fire departments are reported to the provincial authorities. Fire reporting is mandated by the Fire Services Act of Canada which requires provinces to make a legal record of fires in their jurisdiction, and to develop a computerized data-base for statistical evaluation [33]. The National Fire Protection Association (NFPA) is a recognized leader in the development of codes and standards used throughout the United States and Canada. To maintain uniformity in fire reporting, the NFPA Technical Committee on Fire Reporting has developed NFPA 901, Standard Classifications for Incident Reporting and Fire Protection Data [34]. It provides the common language and definitions used by nearly all the states and national data bases in the U.S.A., Canada, and many other countries around the world. NFPA 901 [34] does not provide a reporting system or related forms. The U.S.A. uses National Fire Incident Reporting System (NFIRS) forms for reporting of fire incidents [35]. Ontario however uses a different form of fire reporting as compared to NFIRS forms used by the U.S.A.

The office of Fire Marshal or Fire Commissioner in each province collects and analyses information on all fires which occur in the province, and investigates fatal fires. Annual reports of Fire Losses in Canada are prepared by the Occupational Safety and Health and Fire Prevention Division of Human Resources Development Canada, and are compiled from information supplied by the Council of Canadian Fire Marshals and Fire

Commissioners (CCFM & FC), Indian and Northern Affairs Canada (INAC) and Statistics Canada. These reports are published by the Council of Canadian Fire Marshals and Fire Commissioners [36].

3.2. Description of Ontario Fire Marshal (OFM) data.

Fire incidents data have been obtained from the office of the Ontario Fire Marshal (OFM), covering the period from 1995 to 2002 [4]. The data are divided into seven major categories of properties based on the type of occupancy as follows:

1. Assembly
2. Institutional
3. Residential
4. Mercantile
5. Industrial
6. Business/ Personal services, and
7. Miscellaneous Structures/ Properties.

The details of various types of properties covered under each of the above major categories and their codes are given in Appendix I (List of occupancies) [4]

For the Residential occupancies data are divided into two groups:

3a. Residential (multi-storey apartment buildings, etc)

3b. Residential dwellings (detached/semi-detached dwellings/townhouses or row houses)

The complete data consist of two sub sets of data: one covering fire incidents in Group 3b residential dwellings (i.e. detached dwellings/semi-detached dwellings/ townhouses or row houses), and the other set giving the information of fire incidents for all other structures but Group 3b. In the present study, the data have been analyzed in two parts: Part I considers the evaluation of the complete set of data (i.e. combination of both data sets) containing 81,810 fire incidents for the province of Ontario, whereas Part II considers the data only for Group 3b Residential dwellings which include detached dwellings, semi-detached dwellings, and townhouses or row houses and contain 36,688 fire incidents [4].

The data-base provided by OFM [4] contains five tables with various fields requiring the detailed information of reported fire incidents. These table's headings are the following:

1. Selected fires with loss 1995 to 2002
2. Detection or suppression devices
3. Fatal fires structure and fire spread
4. Fire fatalities
5. Fire injuries

3.2.1. Selected fires with loss 1995 to 2002

This table contains the following fields of information about selected fires with loss during 1995 to 2002:

- Year
- Month
- Day
- Estimated dollar loss

- Property type code, and property type (e.g. apartment/ flat/ tenement with business, convenience store, multi-unit dwelling – 2 to 6 units/ 7 to 12 units/ over 12 units, church, theatre, public/ private hospital, school, etc.)
- Property class (e.g. assembly occupancy, residential, industrial, institutional, mercantile, business and personal services, or other structures/ properties)
- Property sub-class (other residential, other assembly, other mercantile, multi unit dwelling, education facility, food/beverage sales, or persons under supervisory care, etc.)
- Area of origin code, and area of origin (e.g. cooking area or kitchen, dining or beverage area, sleeping area or bedroom, washroom or bathroom, living area, laundry area, garage, or undetermined, etc)
- Area of origin class (e.g. structural area, functional area, storage area, building services/ support facilities, means of egress, outside area, vehicle areas, miscellaneous, or undetermined)
- Ignition source code, and ignition source (e.g. stove/ range-top burner, clothes dryer, open fired barbeque – fixed or portable, matches – open flame, multiple ignition source or ignition equipment, meter, or undetermined)
- Ignition source class (e.g. cooking equipment, open flame tools/ smokers articles, electrical distribution equipment, appliance, or undetermined)
- Fuel energy associated code, and fuel energy associated (e.g. gasoline, alcohol – methanol, electricity, propane, or undetermined)

- Object first ignited code, and object first ignited (e.g. rug/ carpet, alcohol – methanol, electrical wiring insulation, cooking oil/ grease, paper/ cardboard, upholstered sofa/ chair, non-upholstered chair, exterior cladding, or floor)
- Object first ignited class (gases, furniture, soft goods wearing apparel, flammable/ combustible liquids, building component, or undetermined)
- Possible cause code, and possible cause (e.g. misuse of material ignited – improper handling or improper storage or other, misused ignition source/ equipment – left unattended or too close to combustibles or improperly discarded, electrical failure, mechanical failure, design deficiency, installation deficiency, maintenance deficiency, arson, vandalism, or youth vandalism ages 12 to 17)
- Occupancy code, and occupancy (e.g. permanent – persons present/ no person present, vacant, or not applicable)
- Building status code, and building status (e.g. normal – no change, under renovation, under construction, or not applicable)
- Building height (e.g. 1 storey, 2 storey, up to 100 storey, or not applicable)
- Level of origin code, and level of origin (e.g. 1st floor, 2nd floor, up to 100th floor, 1st floor below grade, 2nd floor below grade, up to 10th floor below grade, roof level, undetermined, or not applicable)

3.2.2. Detection or Suppression Devices

This table contains data about the detection or suppression devices as indicated below:

- Type of fire protection device present (e.g. smoke alarm – battery operated/ hard wired, heat detector, sprinkler, none, or undetermined)

- Location of fire protection device (e.g. in area of origin, beyond area of origin same floor or different floor, not applicable, or undetermined)
- Operation of fire protection device (e.g. alarm operated, suppression operated, alarm and suppression both operated, nothing operated, not applicable, or undetermined)
- Reason for non-operation (e.g. power failure, power not connected, vandalism, not applicable, undetermined, remote from fire, or separated from fire).

3.2.3. Fatal fires structure and fire spread

This table contains the following information about the structure and fire spread in buildings experiencing fatal fires:

Construction date code and construction date (e.g. prior to 1945, 1945-1975, or after 1975)

- Number of stories
- Building area code and building area in square meters(e.g. less than 100 m^2, 100-600 m^2, 601-2000 m^2 , 2001- 4500 m^2, or undetermined)
- Floor construction code and construction date (e.g. non-combustible, combustible, or unknown)
- Roof construction code and roof construction (e.g. non-combustible, combustible, or unknown)
- Interior construction code and interior construction (e.g. gypsum board on studs, masonry or concrete, wood finish on studs, or other)

- Ceiling construction code and ceiling construction (e.g. gypsum board, wood finish, exposed wood joists, or unknown)
- Level of fire origin (e.g. 1st floor, 2nd floor, roof level, undetermined, or not applicable)
- Fire spread code and fire spread description (e.g. confined to object of origin, spread to portion of room of origin, spread to entire room of origin, spread beyond room of origin, or entire structure)
- Reasons for fire spread (e.g. door left open, fire did not spread beyond room, interior walls not a complete enclosure, lack of fire stops), and codes for fire spread
- Flashover (e.g. yes, no, or undetermined)
- Smoke spread description (e.g. confined to object of origin, spread to portion of room of origin, beyond room of fire origin – same floor/ different floor, entire structure), and codes for smoke spread.
- Reasons for smoke spread (e.g. interior walls not a complete enclosure, door left open, multiple points of origin, enclosing walls/ doors breached by fire, closures not smoke tight).

3.2.4. Fire fatalities

This table contains the following fields of information about fire fatalities [4]:

- Number of fatalities (e.g. 1, 2 or more)
- Date of birth

- Fatality status (e.g. fire fighter, occupant in domestic activity/ leisure activity, or other, or non-occupant - bystander), and status code
- Fatality gender (e.g. male, or female), and gender code
- Age (in years)
- Fatality condition (e.g. normal, physical disability – ambulatory, or asleep – no known impairment, or impaired – drugs, or physical disability – mental impairment, impaired – alcohol, or unknown, or infant too young to act in the age group 0 to 4 years), and condition code
- Fatality action (e.g. attempting escape, action unknown, no action, or involved in firefighting activities, or panic/loss of judgment, escaped – returned to attempt rescue), and action code
- Cause of death (e.g. asphyxia –CO/HCN, burns/scalds, suicide, or other), and cause of death code
- CO level of fire gases
- Alcohol level in blood
- Drugs involved in fatality (e.g. none detected, not examined for drugs, not reported, prescription drugs above usual range, or prescription drugs therapeutic range), and drug use code
- Clothing ignition (e.g. yes, no, or unknown)
- Fatality's ignition fibre/material (e.g. sleepwear, outer clothing, underclothing, or not applicable), and ignition of material code
- Type of fibre/material (e.g. cotton, mixture of fibres, unknown, not applicable), and material type code

- Structure familiarity (e.g. 8 to 30 days, 1 to 2 months, 3 to 6 months, 7 to 12 months, or greater than 1 year), and structural familiarity code
- Fatality location (e.g. room of origin of fire, floor of origin of fire – other room, or other floor – above area of origin, or not applicable), and location code
- Fatality smoker (e.g. yes, no, or unknown), and smoker code.

3.2.5. Fire injuries

This table contains the following fields of information about fire injuries [4]:

- Injury status code, and injury status (e.g. occupant, firefighter, or non-occupant)
- Gender code, and gender (male or female)
- Age
- Physical condition code, and physical condition (e.g. normal – business/ occupational/ domestic/ household/ leisure/ recreational activity, or impaired – alcohol, or bedridden/ other physical or mental condition, or asleep, or infant – too young to act, or unknown)
- Action code, and action (e.g. involved in firefighting activity, or involved in rescue activity, no action, or unknown)
- Cause code, and cause (e.g. smoke or fire, falling debris, unknown, explosion, or accident-occurrence related)
- Injury type code, and injury type (e.g. asphyxia/ respiratory condition, burns or scalds, minor cuts or bruises, heat illness/ cold exposure/ fatigue, or head/ neck/spine injury, wounds, or unknown)
- Injury severity code, and injury severity (e.g. minor, serious)

- Injury to firefighter, adult male/ female, or child under12.

Chapter 4

4. Statistical methods used in analysis

4.1. Introduction

The data base [4] contains a very large number of fire incidents that occurred between 1995 and 2002 in Ontario. The data have been analyzed to determine trends in Ontario of fire injuries, deaths and property damage, during the eight year period of 1995-2002. Analysis of the data was also done to evaluate 95% confidence interval estimates of operational reliability for heat detectors, smoke detectors, and sprinklers for various types of occupancies. This chapter describes the methods used for this analysis.

4.2. Statistical analysis

The fire incident data [4] were received in the form of tables in Microsoft Access. Separate tables for statistical analysis of fire incident data have been developed by raising a query in Microsoft Access for each scenario. For example, Table 5.1 (Chapter 5 in this document) for Ontario's fire incidents with loss for the period 1995 to 2002 was developed as one scenario. Each of the tables developed for evaluating fire loss trends, patterns, origins, and causes of fire are considered as a different scenario. All these tables were made by raising a query in Microsoft Access in line with the example given above. Statistical analysis has been done as follows:

- Evaluation of fire loss trends and patterns was done by making line graphs, or pie charts from the tables developed for annual fire record and fires by property class.

- Evaluation of fire origins and causes has been done from the tables developed for the areas of origin of fire and the causes of fire.
- To calculate operational reliability of heat detectors, smoke detectors, or sprinklers for different locations and occupancies, a query was created in Microsoft Access from the tables available in both data sets obtained. The results indicating the fire incidents in which a protection device operated or did not operate were transformed into a Microsoft Excel sheet for detailed evaluation. Random samples were taken from these results by using the statistical software MINITAB.
- As per the central limit theorem [37], if random samples of n observations are drawn from a non-normal population with finite mean μ and standard deviation σ, when n is large ($\geq$ 30), the sampling distribution of sample mean $\bar{x}$ is approximately normally distributed, with mean μ and standard deviation $\sigma / \sqrt{n}$. Consequently, the spread of the distribution of sample means is considerably less than the spread of the sampled population [37]. In the current study, this concept was used by taking random samples of size 30 or more for each scenario where data permitted.
- If it was not possible to use the central limit theorem because of limited data, efforts were made to use the binomial theorem [37].
- As per the binomial theorem, if a random sample of n observations is selected from a binomial population with parameter p, then the sampling distribution of sample proportion

$\hat{p}$ = x / n will have a mean p, and

Standard error SE ($\hat{p}$) = $\sqrt{pq}$ / n, where q = 1 – p

When the sample size n is large, the sampling distribution of $\hat{p}$ can be approximated by a normal distribution. The approximation will be adequate if np > 5 and nq > 5 [37]. This concept was used when data were limited and we were not able to take a random sample of 30 or more. For example, if fire incidents were 25 and in 15 cases the detector operated then p = 0.6 and q = 0.4. If we select n = 13 or more then np > 5 as well as nq > 5, and hence the size of random sample was selected as ≥ 13.

- Selected random samples were transformed into Microsoft Excel and its statistical options were used to find the mean probability of operation of the detector or sprinkler along with its 95% confidence interval estimates. For example Table 7.45 (Chapter 7 in this document) was developed to find the 95% confidence interval estimates for heat detectors in the area of origin for assembly occupancies.
- In each case of random sampling, the sample size (n) was selected such that either n ≥ 30 (as per central limit theorem) or the conditions np > 5 and nq > 5 (as per binomial theorem) were met. Here p is the probability of success (i.e. probability of operation of detector or sprinkler) and q is the probability of failure (1 – p) of the sample, and n is the sample size, from the population of interest.

- 50 random samples were taken from the fire incident data set of each of the scenarios for performing the detailed analysis. It was assumed that fifty is a good number of random samples for the purpose of detailed analysis.
- The mean of sample means and its 95% confidence level were calculated for each scenario using Microsoft Excel.
- The upper limit of the 95% confidence interval estimate was obtained by adding the mean value and the 95% confidence level value, whereas the lower limit was calculated by subtracting 95% confidence level value from the mean value.
- The process was repeated for all the scenarios of interest and the 95% confidence interval estimates were computed for all the occupancies for heat detectors, smoke detectors and sprinklers when they were located in the area of origin or beyond the area of origin either at the same floor or at a different floor.

The final results were tabulated using Microsoft Excel.

Chapter 5

5. Analysis of Ontario Fire Data

A Statistical analysis of the OFM data [4] was undertaken to assess the overall fire problem for the province of Ontario as well as to get insight into fires in residential dwellings (i.e. detached dwellings, semi-detached dwellings, and townhouses or row houses). The analysis included the following:

- The annual fire problem in Ontario for all occupancies from 1995 to 2002.
- The total number of fires, deaths, injuries and losses for each occupancy over the period 1995 – 2002.
- The origins and causes of fire for each occupancy over the period 1995 – 2002.
- The impact of fire protection systems on life safety and losses.
- An analysis of residential dwellings i.e. single-family houses, semi-detached houses, and townhouses or row houses. (Chapter 6)
- The operational reliability of active fire protection systems such as sprinklers, smoke detectors and heat detectors. (Chapter 7)

5.1 Fire loss trends, patterns, origins and causes of fire

This part of the evaluation assesses the size of the fire problem in the province of Ontario from 1995 to 2002.

5.1.1 Fire losses

The data [4] have been used to determine the annual number of fire incidents, civilian deaths, civilian injuries, and property damage. Table 5.1 and Figures 5.1 through 5.4, show the values obtained from this analysis for each of the 8 years considered.

Table 5.1. Ontario fire record (1995-2002)

Year	Number of fire incidents	Number of fatalities	Number of injuries	Property damages ($)*
1995	12,309	128	1,450	297,447,910
1996	11,532	113	1,176	273,328,920
1997	10,749	129	1,397	268,563,930
1998	9,864	122	900	246,179,396
1999	9,652	106	867	313,005,558
2000	9,177	93	855	287,836,621
2001	9,162	109	721	313,825,066
2002	9,365	86	730	317,275,358

* Not adjusted for inflation

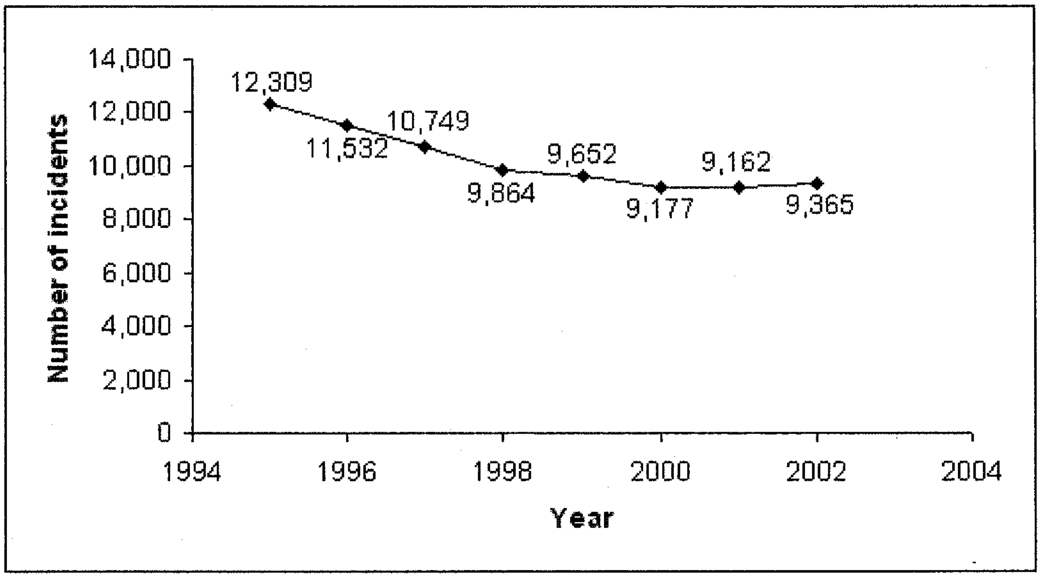

Figure 5.1 Ontario annual fire incidents

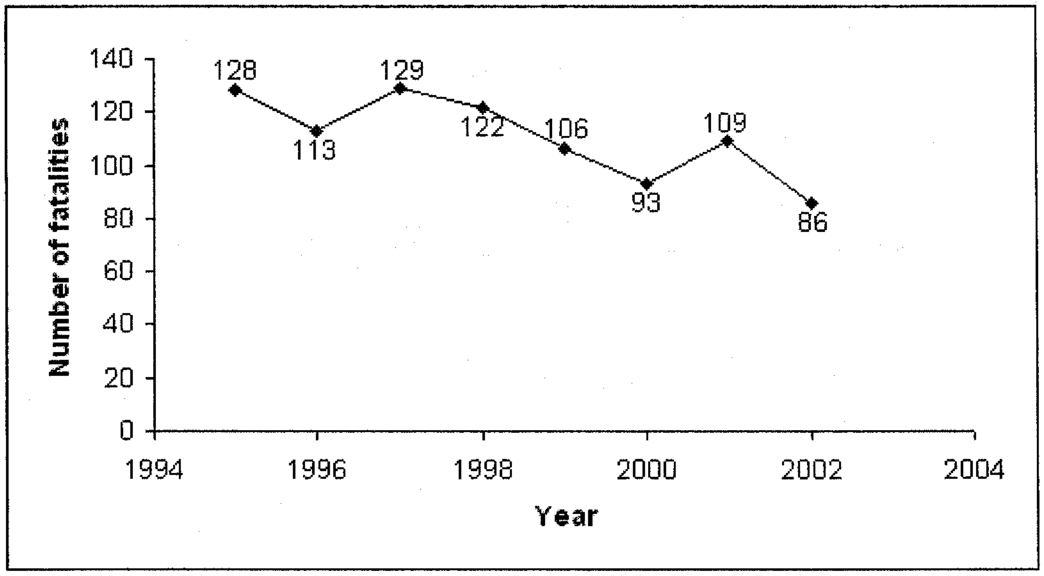

Figure 5.2 Ontario annual fire deaths

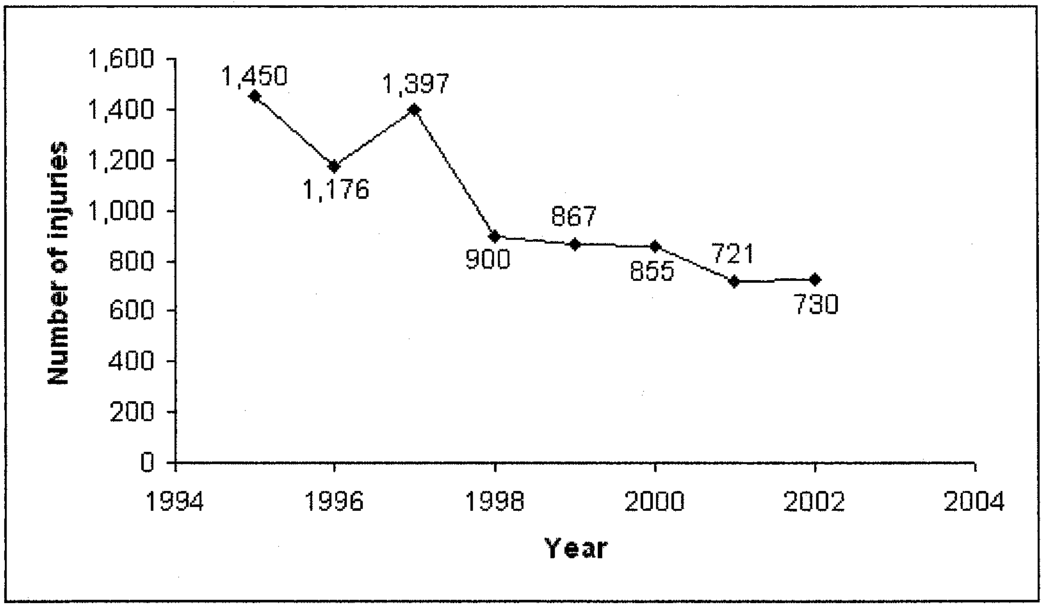

Figure 5.3 Ontario annual fire injuries

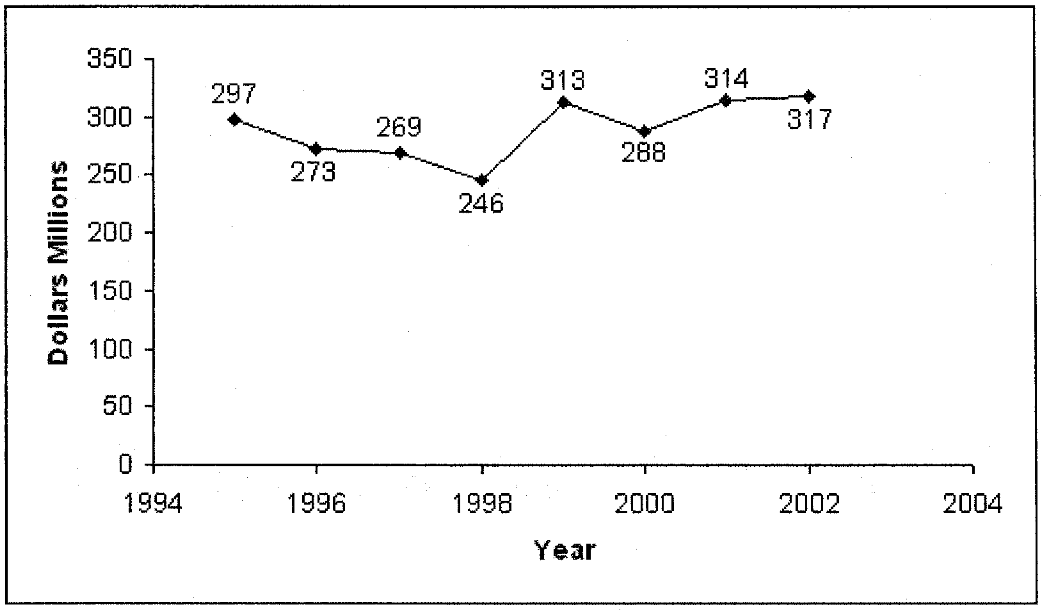

Figure 5.4 Ontario annual property damage

Figure 5.1 shows the number of fire incidents from 1995 to 2002. From the figure it can be seen that the number of fire incidents declined steadily from 12,309 in 1995 to 9,162 in 2001. In 2002 the number of fire incidents increased to 9,365.

The annual fire deaths shown in Figure 5.2, have been declining over the period of analysis, however the decline is not steady. The highest number of deaths, 129, occurred in 1997 and the lowest, 86, in 2002.

The numbers of injuries per year have also declined as shown in Figure 5.3, falling from 1,450 in 1995 to 730 in 2002.

Similar results have also been reported by the OFM [8]. An analysis of fire incident data (1977-1994) of the USA done by NFPA [2] show similar trends for all three areas; number of fires, fire deaths and fire injuries.

The annual direct property damage, shown in Figure 5.4 was decreasing from 1995 to 1998, but that trend was reversed from 1999 to 2002. Hall and Cote [2] reported an overall increase in property damage for USA during the period 1984 to 1994. This increase of fire damage may be attributed to inflation.

Table 5.2, and Figures 5.5 and 5.6 show the annual fatality rate in terms of number of deaths per 100 fires and injury rate per 100 fires.

Table 5.2. Ontario deaths and injuries per fire incident

Year	**Number of fire incidents**	**Number of fatalities**	**Fatality rate (per 100 fires)**	**Number of injuries**	**Injury rate (per 100 fires)**
1995	12,309	128	1.04	1,450	11.78
1996	11,532	113	0.98	1,176	10.20
1997	10,749	129	1.20	1,397	13.00
1998	9,864	122	1.24	900	9.12
1999	9,652	106	1.10	867	8.98
2000	9,177	93	1.01	855	9.32
2001	9,162	109	1.19	721	7.87
2002	9,365	86	0.92	730	7.79
8 years Average	**10,226**	**111**	**1.08**	**1,012**	**9.76**

Source: OFM (Ontario Fire Marshal) Data [4]

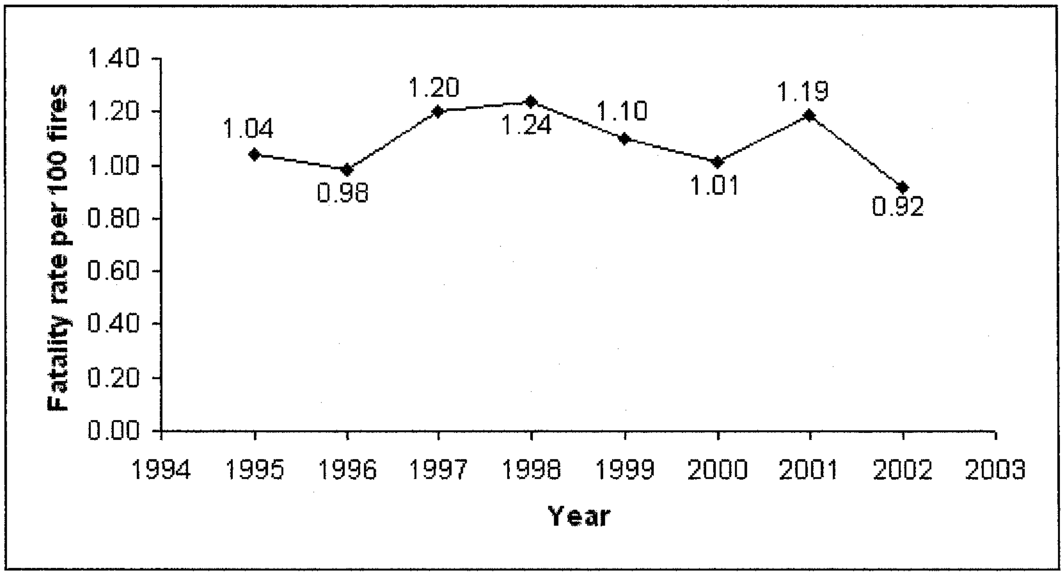

Figure 5.5 Ontario annual fatality rate per 100 fires

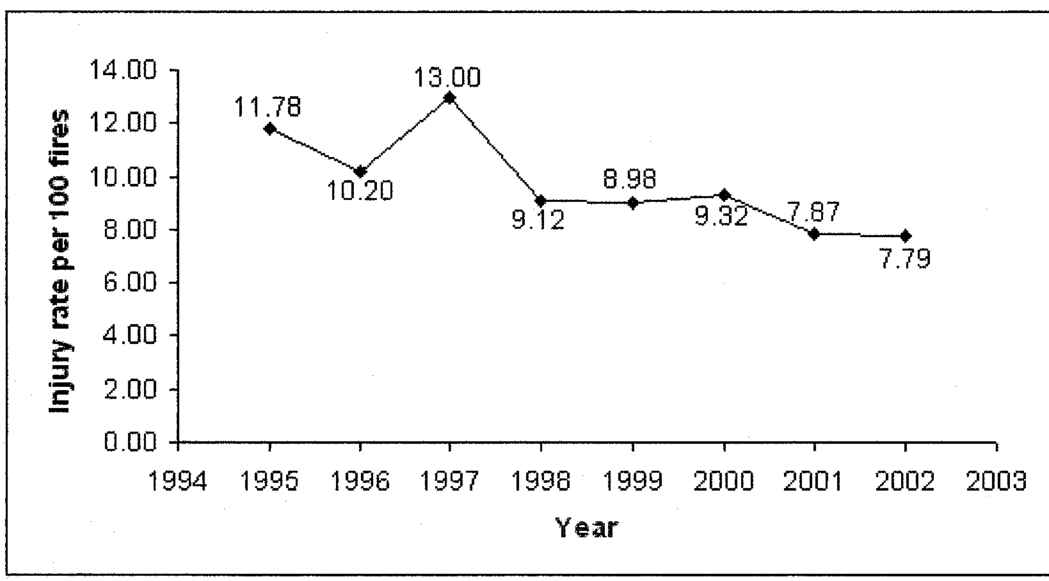

Figure 5.6 Ontario annual injury rate per 100 fires

Table 5.3 Ontario annual property damages per fire

Year	Number of fire incidents	Property damages ($)	Rate of property damages per fire ($)
1995	12,309	297,447,910	24,165
1996	11,532	273,328,920	23,702
1997	10,749	268,563,930	24,985
1998	9,864	246,179,396	24,957
1999	9,652	313,005,558	32,429
2000	9,177	287,836,621	31,365
2001	9,162	313,825,066	34,253
2002	9,365	317,275,358	33,879
8 years Average	**10,226**	**289,682,845**	**28,717**

Source: OFM (Ontario Fire Marshal) Data [4]

Table 5.4 Ontario's deaths and injuries per 100,000 population

Year	Population* (thousands)	Number of fatalities	Fatalities per 100,000 population	Number of injuries	Injuries per 100,000 population
1995	10,950	128	1.2	1,450	13.2
1996	11,083	113	1	1,176	10.6
1997	11,228	129	1.1	1,397	12.4
1998	11,367	122	1.1	900	7.9
1999	11,506	106	0.9	867	7.5
2000	11,685	93	0.8	855	7.3
2001	11,898	109	0.9	721	6.1
2002	12,097	86	0.7	730	6
8 years Average	**11,477**	**111**	**1**	**1,012**	**9**

* Source: Statistics Canada 2001 Census-based population estimates [38].

Table 5.2 and Figure 5.5 show that there is not much difference in the rate of civilian fatalities as they have been fluctuating around one fatality per 100 fires with an average value of 1.08. Table 5.2 and Figure 5.6 show that the rate of injuries per 100 fires decreased steadily from 11.78 to 7.79 with the exception of 1997 when the injury rate jumped to 13.00.

Table 5.3 shows the annual property damage per fire which has been increasing from 1995 to 2002. The property damage rate has its highest value of $34,253 per fire in 2001 which is well above the average value of $28,717.

The death rate and injury rate per 100,000 population have also been computed and shown in Table 5.4. Both rates have been decreasing steadily during the analysis period. The fatality rate dropped from a high of 1.2 in 1995 to a low of 0.7 in 2002. The injury rate dropped from a high of 13.2 in 1995 to 6 in 2002. Similar values of rate of deaths, as well as rate of injuries per hundred thousand population have also been reported by OFM [8]. A gradual decrease in the rate of deaths per 100,000 population from 1913 to 1993 in U.S. has also been documented [2]. The death rate in USA in 1999 was 1.3 per 100,000 population [8]. For a better assessment and comparison of the data with other countries or of different regions it is necessary to use rates instead of absolute numbers. For example during the reported eight year period, civilian fire deaths have declined by about 1/3 whereas the rate of deaths per fire has only been marginally reduced. A gradual decrease in the rate of deaths as well as injuries may be attributed to the increased awareness and usage of fire protection systems [9]. Reviewing the performance of fire protection systems may further decrease the rate of deaths as well as property damage by identifying areas where improvements can be made.

Table 5.5 shows a comparison of civilian death rates and Table 5.6 of civilian injury rates per 100,000 population for a few selected countries. As indicated in the tables, only limited data could be found.

Table 5.5 Comparison (various countries) of fire death-rate per 100,000 population

Year	Ontario*	Canada**	U.S.A***	Sweden***	U.K***
1995	1.2	1.36	1.7	1.1	1.3
1996	1.0	1.26	1.9	1.2	1.2
1997	1.1	1.39	1.5	1.3	1.2
1998	1.1	1.11	1.5		1.1
1999	0.9	1.27	1.3		1.1
2000	0.8	1.06			
2001	0.9				
2002	0.7				

* Source: Calculated from OFM (Ontario Fire Marshal) data [4]
** Source: Canadian fire statistics (Council of Fire Marshals and Fire Commissioners) [36]
*** Source: OFM (Ontario Fire Marshal) report [8]

Table 5.6 Comparison of fire injuries-rate per 100,000 population

Year	Ontario*	Canada**	U.S.A.***	U.S. West***
1995	13.2	12.10	9.8	7
1996	10.6	10.62	9.7	7.2
1997	12.4	10.50	8.9	7.4
1998	7.9	8.90	8.6	6
1999	7.5	7.51	8.0	6.5
2000	7.3	8.10		
2001	6.1			
2002	6.0			

* Source: Calculated from OFM (Ontario Fire Marshal) data [4]
** Source: Canadian fire statistics (Council of Fire Marshals and Fire Commissioners) [36]
*** Source: OFM (Ontario Fire Marshal) report [8]

Table 5.5 shows that the USA has the highest civilian death rates followed by Canada. The province of Ontario has the lowest death rates. All countries compared have shown a trend of decreasing death rates, except Sweden which showed an increase in the civilian death rate by about ten percent every year from 1995 to 1997. Another comparison of fire deaths per million population, done by the O.F.M. [8] from 1990 to 1995 is shown in Table 5.7.

Table 5.7 Comparison done by the office of O.F.M. for fire deaths per million population

Year	Ontario	Canada	U.S.A.	Sweden	U.K.	U.S. West
1990	14.4	16.6	20.8	15.3	14.8	14.9
1991	13.2	13.8	17.7	13.3	13.9	12.4
1992	11.1	14.1	18.5	11.4	13.1	11.4
1993	12.8	14.5	18.0	12.2	11.8	12.8
1994	11.9	13.0	16.4	12.0	11.1	12.1
1995	13.0	13.6	17.4	10.5	12.6	12.4
1996	11.4	12.6	18.8	12.1	12.1	11.7
1997	13.8	13.9	15.2	13.1	12.3	9.9
1998	11.7	11.1	14.9	-	11.1	9.2
1999	10.3	12.7	13.1	-	10.5	7.4

Source: O.F.M. (Ontario Fire Marshal) report [8]

Tables 5.5 and 5.7 show that the Ontario's rate of deaths per 100,000 population, obtained in the current study, are relatively lower than those shown by OFM. This difference may be due to the variation in the population size considered in the current study.

A comparison of civilian fire injuries in Ontario, Canada and USA is shown in Table 5.6. From 1995 to 1997 Ontario had the highest injury rates however the sharp decline in subsequent years made the Ontario injury rate the lowest. Western USA has consistently the lowest injury rates. Canada has the second highest injury rate followed by USA and U.S. West. Both Canada and USA have shown a decreasing trend of injury rate, except for U.S. West that showed an increasing trend during 1995-1997.

5.1.2 Fire patterns by property classification

This analysis was performed to determine the extent of the fire problem in various property classes (occupancies). Table 5.8 and Figures 5.7 through 5.10 summarize the fire losses of the seven property classes for the eight year period from 1995 to 2002.

Table 5.8 Ontario fire statistics by property class (1995-2002)

Property Class/Type	Number of fire incidents	Civilian deaths	Civilian injuries	Direct property damage* ($)
Assembly	4,706	1	282	126,168,373
Business and Personal Services	1,829	1	76	62,641,824
Industrial	6,829	8	946	458,693,606
Institutional	1,268	14	139	15,993,094
Mercantile	2,858	6	156	122,530,664
Residential	59,217	848	6,411	1,365,470,729
Miscellaneous Structures/Properties	5,103	8	86	165,964,469

* Direct property damage figures do not include indirect losses, such as business interruption, and have not been adjusted for inflation.
Source: O.F.M. (Ontario Fire Marshal) data [4].

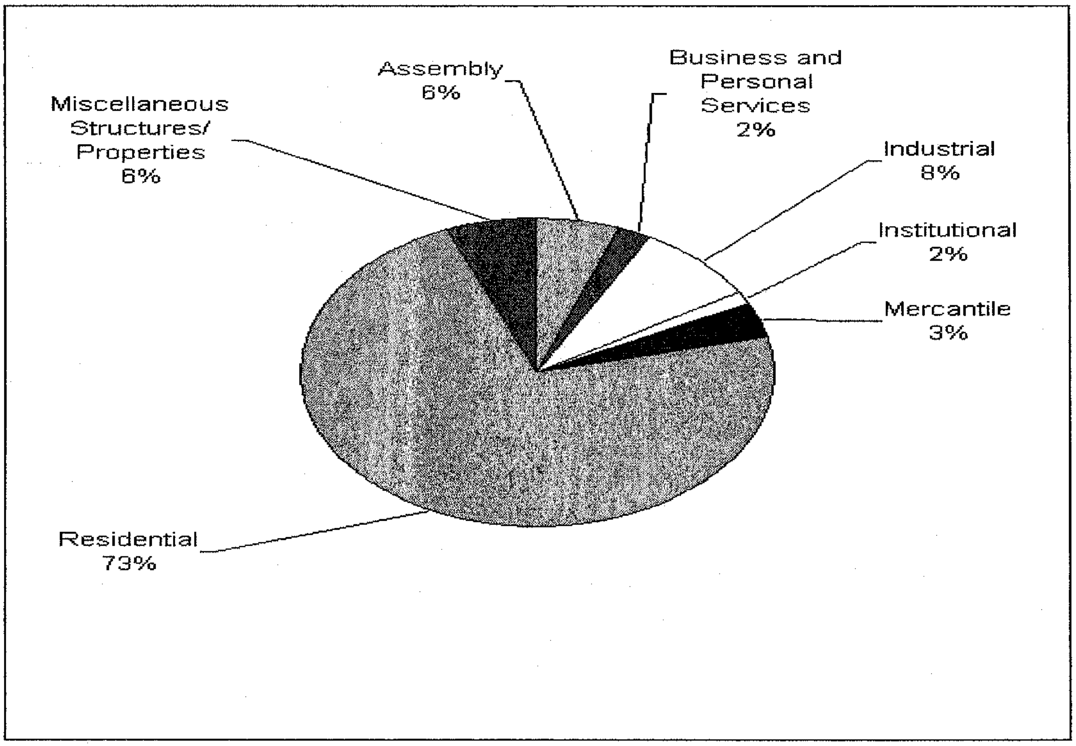

Figure 5.7 Fire incidents by property use

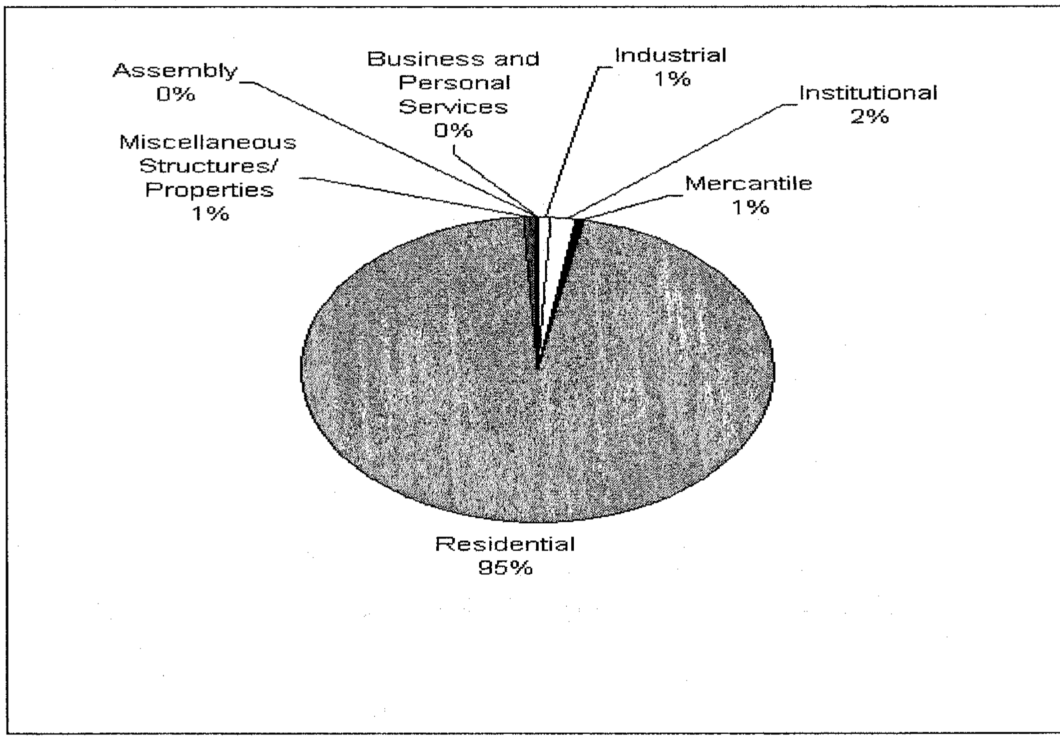

Figure 5.8 Civilian deaths by property use

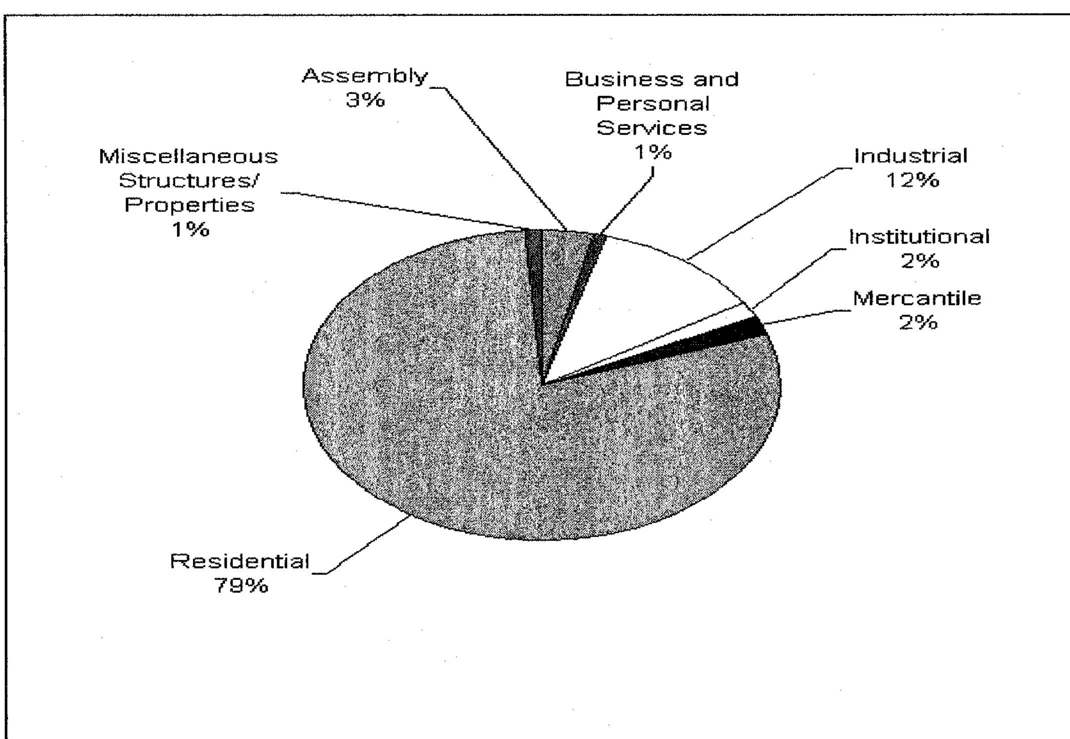

Figure 5.9 Civilian injuries by property use

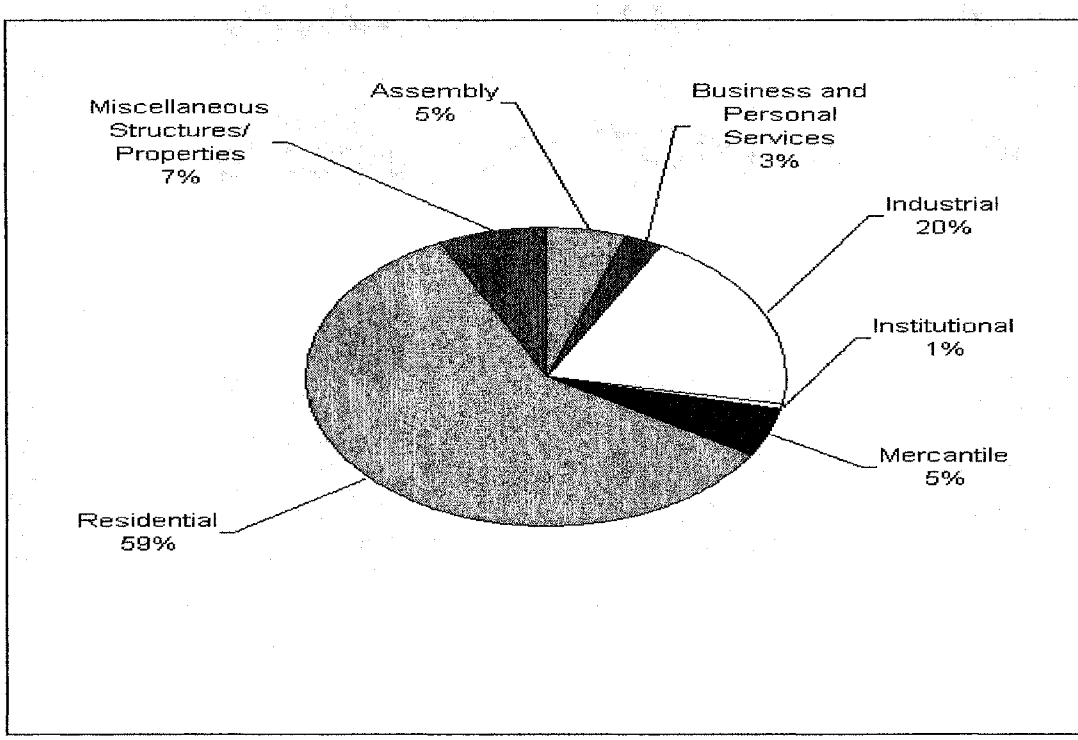

Figure 5.10 Direct property damage by property use

The figures show that residential properties have the highest number of fire incidents, civilian deaths, civilian injuries, and to a lesser degree property damages among the seven property classes. Similar conclusions for deaths, injuries, and property damage for residential properties has been observed in the NFPA National Fire Experience Survey [2] which analyzed USA data from 1989 to 1993 and in the OFM report [8] that analyzed data from 1985 to 1999. It can be seen that the residential category accounts for the largest share of fire reported incidents (73%), fire deaths (95%), fire injuries (79%) as well as the property losses (59%). The industrial category has the second highest property loss (20%), fire incidents (8%) as well as fire injuries (12%). Industrial properties had the second highest damages in the USA, as reported by NFIRS and NFPA National Fire Experience Survey [2].

Table 5.9 shows the rates of deaths and injuries per 100 fires for the seven property classes.

TABLE 5.9. Ontario deaths and injuries per 100 fire incidents (1995-2002)

Property class	Number of fire incidents	Number of fatalities	Fatality rate (per 100 fires)	Number of injuries	Injury rate (per 100 fires)
Assembly	4,706	1	0.02	282	6.0
Business and Personal Services	1,829	1	0.05	76	4.2
Industrial	6,829	8	0.12	946	13.9
Institutional	1,268	14	1.10	139	11.0
Mercantile	2,858	6	0.21	156	5.5
Residential	59,217	848	1.43	6,411	10.8
Miscellaneous Structures/Properties	5,103	8	0.16	86	1.7

Source: OFM (Ontario Fire Marshal Data) Data [4]

TABLE 5.10. Ontario property damage per fire incident (1995-2002)

Property class	Number of fire incidents	Direct property damage* ($)	Rate of property damages per fire ($)
Assembly	4,706	126,168,373	26,810
Business and Personal Services	1,829	62,641,824	34,249
Industrial	6,829	458,693,606	67,168
Institutional	1,268	15,993,094	12,613

TABLE 5.10. (cont.) Ontario property damage per fire incident (1995-2002)

Property class	Number of fire incidents	Direct property damage* ($)	Rate of property damages per fire ($)
Mercantile	2,858	122,530,664	42,873
Residential	59,217	1,365,470,729	23,059
Miscellaneous Structures/Properties	5,103	165,964,469	32,523

* Direct property damage figures do not include indirect losses, such as business interruption, and have not been adjusted for inflation.
Source: O.F.M. (Ontario Fire Marshal) data [4].

Table 5.9 shows that residential occupancies have the highest rate of deaths per 100 fires at 1.43 followed by institutional occupancies which have a rate of 1.1. Assembly occupancies have the lowest rate of deaths. The rate of injuries in industrial occupancies is the highest at 13.9 per 100,000 fires, followed by institutional occupancies at 11.0 and residential occupancies at 10.8. All other occupancies have relatively lower injury rates. Table 5.10 shows the rate of property damages per fire for the seven property classifications. Industrial occupancies have the highest rate of property damages followed by mercantile, and business and personal services. The lowest rate of damage occurs in institutional occupancies and the second lowest in residential occupancies.

From this analysis it can be seen that although residential occupancies have the highest number of fire incidents, deaths, injuries as well as property damage, they only have the highest death rate per fire as there are more chances of people getting intimidated to the fire. The highest rates of injuries as well as property damages per fire are found in industrial occupancies probably because of the expected efforts in fighting the fire and involvement of the costly machinery in industrial setups.

5.1.3 Origin of fire

In this section the OFM data [4] were analyzed to determine the origin of fire, that is, the location in buildings where fire started, for the seven major property classes. Specific evaluation has also been undertaken to identify the source of ignition and the objects first ignited for basement fires.

Tables 5.11 to 5.24 have been developed to show the areas of origin of fire as well as property damages as a function of areas of origin, for each of the property classes. To facilitate the analysis, only areas of fire origin having a number of fire incidents over 1% of total fire incidents for a particular occupancy are shown.

5.1.3.1 Origin of fire for Assembly Occupancies

Table 5.11 shows the fire data and Table 5.12 indicates the property damage for assembly occupancies.

Table 5.11. Areas of origin of fire for Assembly Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Number of Deaths	% of Total Deaths	Number of Injuries	% of Total Injuries	Injury rate per 100 fires
Cooking Area or Kitchen	648	13.8	0	0	54	19.1	8.3
Washroom or Bathroom (inc toilet, rest/locker rooms)	539	11.5	0	0	18	6.4	3.3
Exterior Wall	233	5.0	0	0	9	3.2	3.9
Lobby, Entranceway	208	4.4	0	0	7	2.5	3.4
Roof	204	4.3	0	0	13	4.6	6.4
Dining or Beverage Area (inc lunchroom, café, mess, etc)	187	4.0	0	0	17	6.0	9.1

Table 5.11. (cont.) Areas of origin of fire for Assembly Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Number of Deaths	% of Total Deaths	Number of Injuries	% of Total Injuries	Injury rate per 100 fires
Mechanical/Electrical Services Room	176	3.7	0	0	3	1.1	1.7
Trash, Rubbish Storage (inc chute room, industrial. waste area etc)	171	3.6	0	0	3	1.1	1.8
Other Functional Area	165	3.5	0	0	8	2.8	4.8
Assembly Area (inc school room, spectator area, church, etc)	155	3.3	0	0	17	6.0	11.0
Hallway, Corridor, Mall	154	3.3	0	0	10	3.5	6.5
HVAC Equipment Room (furnace room, water heater closet, boiler room etc)	126	2.7	0	0	11	3.9	8.7
Other - unclassified	118	2.5	0	0	5	1.8	4.2
Stairway, Escalator, Lobby, hallway	114	2.4	0	0	6	2.1	5.3
Supply Storage Room (inc maintenance/document storage etc)	106	2.3	0	0	5	1.8	4.7
Other Storage Area	103	2.2	0	0	7	2.5	6.8
Undetermined	84	1.8	0	0	10	3.5	11.9
Laundry Area	79	1.7	0	0	9	3.2	11.4
Office	74	1.6	0	0	8	2.8	10.8
Porch or Balcony	53	1.1	0	0	1	0.4	1.9
Open Area (inc lawn, field, farmyard, park, playing field)	52	1.1	0	0	0	0	0.0
Other Structural Area	49	1.0	0	0	3	1.1	6.1
Ducting - Heating, Air Conditioning	48	1.0	0	0	0	0	0.0

Table 5.12. Damage as a function of area of origin of fire for Assembly Occupancies

Area of origin of fire	**Number of fires**	**% of Total Fires**	**Direct Property Damage ($)**	**% of Total Damages**	**Damages per fire ($)**
Cooking Area or Kitchen	648	13.8	14,693,710	11.6	22,675
Washroom or Bathroom (inc toilet, rest/locker rooms)	539	11.5	2,137,949	1.7	3,967
Exterior Wall	233	5.0	2,512,827	2.0	10,785
Lobby, Entranceway	208	4.4	2,161,818	1.7	10,393
Roof	204	4.3	5,888,872	4.7	28,867
Dining or Beverage Area (inc lunchroom, café, mess, etc)	187	4.0	7,902,787	6.3	42,261
Mechanical/Electrical Services Room	176	3.7	4,832,150	3.8	27,455
Trash, Rubbish Storage (inc chute room, industrial. waste area etc)	171	3.6	449,803	0.4	2,630
Other Functional Area	165	3.5	9,076,160	7.2	55,007
Assembly Area (inc school room, spectator area, church, etc)	155	3.3	12,187,014	9.7	78,626
Hallway, Corridor, Mall	154	3.3	550,450	0.4	3,574
HVAC Equipment Room (furnace room, water heater closet, boiler room etc)	126	2.7	2,306,274	1.8	18,304
Other - unclassified	118	2.5	3,675,369	2.9	31,147
Stairway, Escalator, Lobby, hallway	114	2.4	608,868	0.5	5,341
Supply Storage Room (inc maintenance/document storage etc)	106	2.3	2,930,016	2.3	27,642
Other Storage Area	103	2.2	3,872,947	3.1	37,601
Undetermined	84	1.8	17,543,902	13.9	208,856
Laundry Area	79	1.7	243,876	0.2	3,087
Office	74	1.6	1,914,607	1.5	25,873
Porch or Balcony	53	1.1	91,936	0.1	1,735
Open Area (inc lawn, field, farmyard, park, playing field)	52	1.1	55,259	0.0	1,063
Other Structural Area	49	1.0	2,282,021	1.8	46,572
Ducting - Heating, Air Conditioning	48	1.0	349,412	0.3	7,279

The data of Table 5.11 indicate that in assembly occupancies the majority of fires, 13.8%, originate in a cooking area or kitchen. The location with the second highest number of fires was washroom or bathroom with 11.5 % of the total. Other areas contributed 5% or less to the total. In all the tables, other will mean that other than the listed ones. Fires in assembly occupancies caused only one death but resulted in many injuries (Table 5.8). 19.1% of the injuries were from fires that originated in a cooking or kitchen area. Fires that originated in a washroom or bathroom resulted in 6.4 % of the injuries, fires in dining or beverage area 6% and fires in assembly areas 6%. Fires originating from laundry areas showed the highest, 11.4, injuries per 100 fires followed by assembly area fires at 11 and offices at 10.8. Other areas showing higher rates of injuries per 100 fires were dining areas 9.1, HVAC rooms 8.7 and cooking areas 8.3.

Table 5.12 shows the property damage caused by fires in assembly occupancies. Cooking area fires resulted in the highest property damages of 11.6% of the total damages followed by assembly area fires at 9.7%, other functional area fires at 7.2%, dining or beverage area fires at 6.3%, and other areas had contributions of less than 5%. Fires originating from assembly areas however show the highest damage at $78,626 per fire. Cooking area or kitchen fires caused an average of $22,675 losses per fire. Other high loss fire origin areas are storage areas, dining areas, other structural areas and other functional areas, where the range of losses is $37,600 to $55,000 per fire. From Tables 5.11 and 5.12 it can be concluded that from known areas of fire origin of assembly occupancies, cooking area or kitchen fires are the most common ones and result in the highest injuries, and property damage. Moreover other high risk areas are washroom or bathroom, assembly areas and dining or beverage areas.

5.1.3.2 Origin of fire for Business and Personal Services Occupancies

Table 5.13 and Table 5.14 show the fire data and property damage for business and services occupancies respectively.

Table 5.13. Areas of origin of fire for Business and Personal Services Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Number of Deaths	% of Total Deaths	Number of Injuries	% of Total Injuries	Injury rate per 100 fires
Office	169	9.2	0	0.0	16	21.1	9.5
Mechanical/Electrical Services Room	148	8.1	0	0.0	6	7.9	4.1
Lobby, Entranceway	120	6.6	1	100.0	0	0.0	0.0
Laundry Area	119	6.5	0	0.0	1	1.3	0.8
Exterior Wall	95	5.2	0	0.0	2	2.6	2.1
Roof	87	4.8	0	0.0	3	3.9	3.4
HVAC Equipment Room (furnace room, water heater closet, boiler room etc)	70	3.8	0	0.0	1	1.3	1.4
Trash, Rubbish Storage (inc chute room, industrial, waste area etc)	55	3.0	0	0.0	2	2.6	3.6
Other Functional Area	55	3.0	0	0.0	4	5.3	7.3
Supply Storage Room (inc maintenance/ document storage etc)	53	2.9	0	0.0	2	2.6	3.8
Cooking Area or Kitchen	52	2.8	0	0.0	2	2.6	3.8
Other - unclassified	50	2.7	0	0.0	3	3.9	6.0
Undetermined	48	2.6	0	0.0	4	5.3	8.3

Table 5.13. (cont.) Areas of origin of fire for Business and Personal Services Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Number of Deaths	% of Total Deaths	Number of Injuries	% of Total Injuries	Injury rate per 100 fires
Washroom or Bathroom (inc toilet, rest/locker rooms)	45	2.5	0	0.0	3	3.9	6.7
Other Storage Area	43	2.4	0	0.0	3	3.9	7.0
Electronic Equipment	40	2.2	0	0.0	1	1.3	2.5
Other Structural Area	37	2.0	0	0.0	1	1.3	2.7
Other Building Services /Support Facilities	32	1.7	0	0.0	0	0.0	0.0
Dining or Beverage Area (inc lunchroom, café, mess, etc)	29	1.6	0	0.0	2	2.6	6.9
Hallway, Corridor, Mall	29	1.6	0	0.0	0	0.0	0.0
Elevator (includes shaft)	28	1.5	0	0.0	1	1.3	3.6
Concealed Ceiling Area	27	1.5	0	0.0	3	3.9	11.1
Ducting - Exhaust (inc cooking, fumes)	26	1.4	0	0.0	2	2.6	7.7
Garage	26	1.4	0	0.0	2	2.6	7.7
Sales, Showroom Area	22	1.2	0	0.0	1	1.3	4.5
Process Manufact. (inc product assembly, repair, etc)	22	1.2	0	0.0	2	2.6	9.1
Other Outside Area	20	1.1	0	0.0	0	0.0	0.0
Shipping/Receiving /Loading Platform	19	1.0	0	0.0	0	0.0	0.0
Other Means of Egress	19	1.0	0	0.0	3	3.9	15.8

Table 5.14. Damage as a function of areas of origin of fire for Business and Personal Services Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Direct Property Damage ($)	% of Total Damages	Damages per fire ($)
Office	169	9.2	7,397,962	11.8	43,775
Mechanical/Electrical Services Room	148	8.1	2,152,372	3.4	14,543
Lobby, Entranceway	120	6.6	3,688,618	5.9	30,738
Laundry Area	119	6.5	738,417	1.2	6,205
Exterior Wall	95	5.2	907,296	1.4	9,550
Roof	87	4.8	994,957	1.6	11,436
HVAC Equipment Room (furnace room, water heater closet, boiler room etc)	70	3.8	602,248	1.0	8,604
Trash, Rubbish Storage (inc chute room, industrial waste area etc)	55	3.0	759,506	1.2	13,809
Other Functional Area	55	3.0	3,234,939	5.2	58,817
Supply Storage Room (inc maintenance/ document storage etc)	53	2.9	3,289,640	5.3	62,069
Cooking Area or Kitchen	52	2.8	1,158,030	1.8	22,270
Other - unclassified	50	2.7	2,717,435	4.3	54,349
Undetermined	48	2.6	9,076,742	14.5	189,099

Table 5.14. (cont.) Damage as a function of areas of origin of fire for Business and Personal Services Occupancies (1995-2002)

Area of origin of fire	**Number of fires**	**% of Total Fires**	**Direct Property Damage ($)**	**% of Total Damages**	**Damages per fire ($)**
Washroom or Bathroom (inc toilet, rest/locker rooms)	45	2.5	169,876	0.3	3,775
Other Storage Area	43	2.4	1,490,530	2.4	34,663
Electronic Equipment	40	2.2	1,765,775	2.8	44,144
Other Structural Area	37	2.0	2,051,551	3.3	55,447
Other Building Services /Support Facilities	32	1.7	356,095	0.6	11,128
Dining or Beverage Area (inc lunchroom, café, mess, etc)	29	1.6	109,665	0.2	3,782
Hallway, Corridor, Mall	29	1.6	657,681	1.0	22,679
Elevator (includes shaft)	28	1.5	278,565	0.4	9,949
Concealed Ceiling Area	27	1.5	1,488,101	2.4	55,115
Ducting - Exhaust (inc cooking, fumes)	26	1.4	209,727	0.3	8,066
Garage	26	1.4	630,350	1.0	24,244
Sales, Showroom Area	22	1.2	1,837,325	2.9	83,515
Process Manufact. (inc product assembly, repair, etc)	22	1.2	2,092,952	3.3	95,134
Other Outside Area	20	1.1	74,331	0.1	3,717
Shipping/Receiving /Loading Platform	19	1.0	504,075	0.8	26,530
Other Means of Egress	19	1.0	1,376,300	2.2	72,437

Table 5.13 shows data for business and personal occupancies. The data indicate that the majority of fires, 9.2%, originate in an office area. The second highest numbers of fires occur in a mechanical or electrical services room with 8.1% of the total, followed by a lobby or entrance area at 6.6%, laundry area at 6.5% and exterior wall at 5.2%. Other areas have a contribution to the total of less than 5%. Business and personal occupancy fires caused only one death which resulted from a fire starting in lobby or entrance area. In these occupancies 21.1% of the injuries are from fires that originated in an office area. Fires that originated in a mechanical or electrical services room resulted in 7.9% of the injuries, fires in other functional areas accounted for 5.3% and the remaining were at less than 4% each. Fires originating from other means of egress showed the highest, 15.8, injuries per 100 fires followed by fires in concealed ceiling areas at 11.1, office areas at 9.5, process manufacturing areas at 9.1, garage and exhaust ducting each at 7.7, dining or beverage areas at 6.9, washroom or bathroom at 6.7, other unclassified area at 6 and the remaining at less than 5.

Table 5.14 shows the property damage from fires in business and personal occupancies. Amongst the known fire origin areas, office area fires showed the highest property damage at 11.8% of the total damages followed by lobby or entrance way fires at 5.9%, supply storage room at 5.3%, other functional area at 5.2% and the remaining areas having a contribution of less than 5% each. Only 2.6% of the fires remained undetermined, but they accounted for the highest property damage at 14.5% of the total damages. These undetermined fires showed extremely high damage rates of $189,099 per fire. Amongst the known area fires, process manufacturing area fires showed the highest damages of $95,134 per fire. Office area fires cause an average of $43,775 losses per fire.

Other high loss fire origin areas are sales showroom areas, other means of egress, supply storage room, other functional area, other structural area, concealed ceiling areas, other unclassified areas, and electronic equipment areas, wherein the losses range from $44,000 to $84,000 per fire. From Table 5.13 and 5.14 it can be concluded that for business and personal occupancies, office area fires are the most common ones and result in the highest injuries, and property damage. Other high risk areas are mechanical or electrical services rooms, lobbies or entranceways, and laundry areas.

5.1.3.3 Origin of fire for Industrial Occupancies

Table 5.15 shows the fire data and Table 5.16 indicates the property damage for industrial occupancies.

Table 5.15 Areas of origin of fire for Industrial Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Number of Deaths	% of Total Deaths	Number of Injuries	% of Total Injuries	Injury rate per 100 fires
Process Manufact. (inc product assembly, repair, etc)	1461	21.4	1	12.5	233	24.6	15.9
Product Storage (inc prod to be assembled, sold, shipped etc)	442	6.5	2	25.0	90	9.5	20.4
Other - unclassified	375	5.5	0	0.0	81	8.6	21.6
Mechanical/Electrical Services Room	343	5.0	0	0.0	40	4.2	11.7
Ducting - Exhaust (inc cooking, fumes, etc.)	310	4.5	0	0.0	19	2.0	6.1
Roof	309	4.5	0	0.0	11	1.2	3.6
Undetermined	306	4.5	0	0.0	208	22.0	68.0
Other Storage Area	287	4.2	0	0.0	30	3.2	10.5

Table 5.15. (cont.) Areas of origin of fire for Industrial Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Number of Deaths	% of Total Deaths	Number of Injuries	% of Total Injuries	Injury rate per 100 fires
Other Building Services /Support Facilities	230	3.4	0	0.0	12	1.3	5.2
Exterior Wall	216	3.2	0	0.0	13	1.4	6.0
Garage	211	3.1	2	25.0	31	3.3	14.7
Trash, Rubbish Storage (inc chute room, indust. waste area etc)	187	2.7	0	0.0	12	1.3	6.4
Other Functional Area	168	2.5	0	0.0	39	4.1	23.2
HVAC Equipment Room (furnace room, water heater closet, boil	166	2.4	0	0.0	6	0.6	3.6
Shipping/Receiving/ Loading Platform	150	2.2	0	0.0	9	1.0	6.0
Office	126	1.8	1	12.5	12	1.3	9.5
Engine Area	113	1.7	0	0.0	0	0.0	0.0
Other Structural Area	106	1.6	0	0.0	12	1.3	11.3
Supply Storage Room (inc maintenance/ document storage etc)	84	1.2	0	0.0	6	0.6	7.1
Chimney/Flue Pipe	83	1.2	0	0.0	4	0.4	4.8
Conv. Shaft or Chute (inc dumbwaiter, laundry/garbage chute)	81	1.2	0	0.0	7	0.7	8.6

Table 5.16. Damage as a function of areas of origin of fire for Industrial Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Direct Property Damage ($)	% of Total Damages	Damage per fire ($)
Process Manufact. (inc product assembly, repair, etc)	1461	21.4	118,062,127	25.7	80,809
Product Storage (inc prod to be assembled, sold, shipped etc)	442	6.5	69,435,153	15.1	157,093
Other - unclassified	375	5.5	17,008,200	3.7	45,355
Mechanical/Electrical Services Room	343	5.0	14,079,675	3.1	41,049
Ducting - Exhaust (inc cooking, fumes, etc.)	310	4.5	4,791,768	1.0	15,457
Roof	309	4.5	6,974,554	1.5	22,571
Undetermined	306	4.5	58,501,659	12.8	191,182
Other Storage Area	287	4.2	11,547,128	2.5	40,234
Other Building Services /Support Facilities	230	3.4	14,238,112	3.1	61,905
Exterior Wall	216	3.2	7,431,094	1.6	34,403
Garage	211	3.1	14,717,573	3.2	69,752
Trash, Rubbish Storage (inc chute room, industrial waste area etc)	187	2.7	4,687,882	1.0	25,069
Other Functional Area	168	2.5	8,097,725	1.8	48,201

Table 5.16. (cont.) Damage as a function of areas of origin of fire for Industrial Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Direct Property Damage ($)	% of Total Damages	Damage per fire ($)
HVAC Equipment Room (furnace room, water heater closet, boil	166	2.4	12,936,777	2.8	77,932
Shipping/Receiving/ Loading Platform	150	2.2	3,154,362	0.7	21,029
Office	126	1.8	11,436,644	2.5	90,767
Engine Area	113	1.7	3,809,530	0.8	33,713
Other Structural Area	106	1.6	7,240,473	1.6	68,306
Supply Storage Room (inc maintenance/ document storage etc)	84	1.2	5,932,072	1.3	70,620
Chimney/Flue Pipe	83	1.2	3,081,802	0.7	37,130
Conv. Shaft or Chute (inc dumbwaiter, laundry/garbage chute)	81	1.2	4,256,234	0.9	52,546

The data of Table 5.15 indicate that the majority of fires, 21.4%, originate in process manufacturing areas. The second highest number of fires start in product storage areas with 6.5 % of the total, followed by other unclassified areas at 5.5%. The remaining areas have a contribution of 5% or less. Fires in industrial occupancies caused 8 deaths (2 deaths in <1% fires, not shown) in the eight year period from 1995 to 2002. Fires originating from both, product storage areas and garages, accounted for 2 deaths each, followed by 1 in process manufacturing area and 1 for office. Industrial fires resulted in many injuries. 24.6% of the injuries are from fires that originated in a process manufacturing area. Fires that originated in product storage areas resulted in 9.5 % of the injuries, fires in other unclassified areas 8.6% and in remaining areas less than 5%. Only 4.5% of the total fires remained undetermined but they showed extremely high, 68 injuries per 100 fires. Amongst the known fire origin areas, fires originating from other functional areas showed the highest, 23.2 injuries per 100 fires. Other areas showing high rates of injuries per 100 fires were other unclassified area 21.6, product storage areas 20.4, process manufacturing areas 15.9, mechanical or electrical services rooms 11.7, other storage areas 10.5, and the remaining at less than 10.

Table 5.16 shows the property damage due to fires in industrial occupancies. Process manufacturing area fires resulted in the highest property damage at 25.7% of the total damages, followed by product storage area fires at 15.1%, and other areas having a contribution of less than 5%. Undetermined fires were only 4.5% of the total fires but they accounted for 12.8% of the total damage. These undetermined fires showed extremely high, $191,182, damages per fire. Amongst the known fire origin areas, fires originating from product storage areas showed the highest damage of $157,093 per fire. Process manufacturing area fires caused an average of $80,809 losses per fire. Other high loss fire origin areas are office areas, HVAC equipment rooms and supply storage rooms wherein the range of losses is $70,000 to $91,000 per fire. From Tables 5.15 and 5.16 it can be concluded that for industrial occupancies, process manufacturing area fires are the most common ones and result in the highest injuries, and property damage. Moreover other high risk areas are product storage, other unclassified, and mechanical or electrical services rooms.

5.1.3.4 Origin of fire for Institutional Occupancies

Table 5.17 shows the fire data and Table 5.18 indicates the property damage for institutional occupancies.

Table 5.17 Areas of origin of fire for Institutional Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Number of Deaths	% of Total Deaths	Number of Injuries	% of Total Injuries	Injury rate per 100 fires
Sleeping Area or Bedroom (inc patient's room, dormitory, etc)	350	27.6	7	50.0	59	42.4	16.9
Cooking Area or Kitchen	126	9.9	0	0.0	6	4.3	4.8
Laundry Area	120	9.5	0	0.0	17	12.2	14.2
Washroom or Bathroom (inc toilet, rest/ locker rooms)	86	6.8	1	7.1	13	9.4	15.1
Living Area (e.g. living, T.V., recreation, etc)	74	5.8	4	28.6	7	5.0	9.5
Hallway, Corridor, Mall	53	4.2	0	0.0	1	0.7	1.9
Mechanical/Electrical Services Room	52	4.1	0	0.0	2	1.4	3.8
Dining or Beverage Area (inc lunchroom, café, mess, etc)	33	2.6	0	0.0	7	5.0	21.2
Roof	33	2.6	0	0.0	0	0.0	0.0
HVAC Equipment Room (furnace room, water heater closet, boil	28	2.2	0	0.0	2	1.4	7.1
Other Functional Area	28	2.2	1	7.1	11	7.9	39.3

Table 5.17 (cont.) Areas of origin of fire for Institutional Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Number of Deaths	% of Total Deaths	Number of Injuries	% of Total Injuries	Injury rate per 100 fires
Office	25	2.0	0	0.0	1	0.7	4.0
Other - unclassified	18	1.4	0	0.0	1	0.7	5.6
Supply Storage Room (inc maintenance/ document storage etc)	17	1.3	0	0.0	1	0.7	5.9
Other Building Services /Support Facilities	17	1.3	0	0.0	0	0.0	0.0
Trash, Rubbish Storage (inc chute room, indust. waste area etc)	14	1.1	0	0.0	0	0.0	0.0
Closet (e.g. clothes, broom, linen closet, etc.)	14	1.1	0	0.0	1	0.7	7.1

Table 5.18. Damage as a function of areas of origin of fire for Institutional Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Direct Property Damage ($)	% of Total Damages	Damage per fire ($)
Sleeping Area or Bedroom (inc patient's room, dormitory, etc)	350	27.6	2,010,920	12.6	5,745
Cooking Area or Kitchen	126	9.9	211,689	1.3	1,680
Laundry Area	120	9.5	638,281	4.0	5,319
Washroom or Bathroom (inc toilet, rest/ locker rooms)	86	6.8	138,794	0.9	1,614
Living Area (e.g. living, T.V., recreation, etc)	74	5.8	566,042	3.5	7,649
Hallway, Corridor, Mall	53	4.2	64,920	0.4	1,225

Table 5.18. (cont.) Damage as a function of areas of origin of fire for Institutional Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Direct Property Damage ($)	% of Total Damages	Damage per fire ($)
Mechanical/Electrical Services Room	52	4.1	225,641	1.4	4,339
Dining or Beverage Area (inc lunchroom, café, mess, etc)	33	2.6	183,172	1.1	5,551
Roof	33	2.6	178,836	1.1	5,419
HVAC Equipment Room (furnace room, water heater closet, boil	28	2.2	139,615	0.9	4,986
Other Functional Area	28	2.2	7,301,182	45.7	260,757
Office	25	2.0	86,205	0.5	3,448
Other - unclassified	18	1.4	16,053	0.1	892
Supply Storage Room (inc maintenance/ document storage etc)	17	1.3	177,772	1.1	10,457
Other Building Services /Support Facilities	17	1.3	53,276	0.3	3,134
Trash, Rubbish Storage (inc chute room, indust. waste area etc)	14	1.1	10,307	0.1	736
Closet (e.g. clothes, broom, linen closet, etc.)	14	1.1	115,150	0.7	8,225

Table 5.17 shows data for institutional occupancies. The data indicate that in institutional occupancies, the majority of fires, 27.6%, originate in sleeping areas or bedrooms. The second highest number of fires occurs in a cooking area or kitchen with 9.9% of the total, followed by laundry areas at 9.5%, washrooms or bathrooms at 6.8%, and living areas at 5.8%. Other areas have a contribution of less than 5% each. Institutional fires accounted for a total of 14 deaths (1 death in <1% fires, not shown) in the eight year period 1995 to 2002. Bedroom or sleeping area fires resulted in half of the total deaths with a figure of 7, followed by living area at 4, other functional area and

washroom or bathroom at 1 each. These occupancies however resulted in many injuries. 42.4% of the injuries are from fires that originated in bedrooms or sleeping areas. Fires that originated in laundry areas resulted in 12.2% of the injuries, washrooms or bathrooms accounted for 9.4%, other functional areas showed 7.9% and the remaining were 5% or less. Fires originating from other functional areas caused the highest, 39.3 injuries per 100 fires followed by dining or beverage areas at 21.2, bedroom or sleeping areas at 16.9, washrooms or bathrooms at 15.1, laundry areas at 14.2, and others were at less than 10.

Table 5.18 shows the property damage due to fires in institutional occupancies. Fires in other functional areas resulted in the highest property damage at 45.7% of the total damages, followed by sleeping area or bedroom fires at 12.6% and others having a contribution of less than 5%. Other functional area fires showed the highest damage of $260,757 per fire. Bedroom or sleeping area fires caused an average of $5,745 losses per fire. Other fire origin areas of concern are supply storage rooms, living areas, dining or beverage areas, wherein the losses are in the range of $5,500 to $10,500 per fire. From Tables 5.17 and 5.18 it can be concluded that for institutional occupancies, bedroom or sleeping area fires are the most common ones and result in the highest injuries and deaths whereas they are the second highest in property damage. Moreover other high risk areas are cooking areas or kitchens and laundry areas.

5.1.3.5 Origin of fire for Mercantile Occupancies

Table 5.19 shows the fire data and Table 5.20 indicates the property damage for mercantile occupancies.

Table 5.19 Areas of origin of fire for Mercantile Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Number of Deaths	% of Total Deaths	Number of Injuries	% of Total Injuries	Injury rate per 100 fires
Cooking Area or Kitchen	459	16.1	1	16.7	19	12.2	4.1
Sales, Showroom Area	207	7.2	2	33.3	19	12.2	9.2
Exterior Wall	194	6.8	0	0.0	4	2.6	2.1
Trash, Rubbish Storage (inc chute room, industrial waste area etc)	165	5.8	0	0.0	6	3.8	3.6
Product Storage (inc prod to be assembled, sold, shipped etc)	148	5.2	0	0.0	9	5.8	6.1
Roof	118	4.1	0	0.0	2	1.3	1.7
Mechanical/Electrical Services Room	105	3.7	0	0.0	9	5.8	8.6
Washroom or Bathroom (inc toilet, rest/ locker rooms)	98	3.4	0	0.0	2	1.3	2.0
Other Storage Area	88	3.1	0	0.0	10	6.4	11.4
Other - unclassified	82	2.9	0	0.0	2	1.3	2.4
Lobby, Entranceway	75	2.6	0	0.0	1	0.6	1.3
Undetermined	73	2.6	0	0.0	13	8.3	17.8
Shipping/Receiving/ Loading Platform	70	2.4	1	16.7	2	1.3	2.9
Supply Storage Room (inc maintenance/ document storage etc)	67	2.3	0	0.0	6	3.8	9.0
HVAC Equipment Room (furnace room, water heater closet, boil	66	2.3	0	0.0	3	1.9	4.5

Table 5.19. (cont.) Areas of origin of fire for Mercantile Occupancies (1995-2002)

Area of origin of fire	**Number of fires**	**% of Total Fires**	**Number of Deaths**	**% of Total Deaths**	**Number of Injuries**	**% of Total Injuries**	**Injury rate per 100 fires**
Dining or Beverage Area (inc lunchroom, café, mess, etc)	64	2.2	0	0.0	3	1.9	4.7
Other Functional Area	61	2.1	1	16.7	6	3.8	9.8
Office	46	1.6	0	0.0	2	1.3	4.3
Concealed Ceiling Area	45	1.6	0	0.0	2	1.3	4.4
Hallway, Corridor, Mall	44	1.5	0	0.0	8	5.1	18.2
Awning or Canopy	39	1.4	0	0.0	0	0.0	0.0
Other Structural Area	39	1.4	0	0.0	2	1.3	5.1
Ducting - Exhaust (inc cooking, fumes, etc.)	37	1.3	0	0.0	1	0.6	2.7
Other Building Services /Support Facilities	36	1.3	0	0.0	0	0.0	0.0
Process Manufact. (inc product assembly, repair)	35	1.2	0	0.0	4	2.6	11.4
Other Outside Area	35	1.2	0	0.0	1	0.6	2.9
Parking Area, Parking Lot	30	1.0	0	0.0	0	0.0	0.0

Table 5.20 Damage as a function of areas of origin of fire for Mercantile Occupancies (1995-2002)

Area of origin of fire	**Number of fires**	**% of Total Fires**	**Direct Property Damage ($)**	**% of Total Damages**	**Damage per fire ($)**
Cooking Area or Kitchen	459	16.1	8,001,025	6.5	17,431
Sales, Showroom Area	207	7.2	13,245,012	10.8	63,986
Exterior Wall	194	6.8	3,726,800	3.0	19,210
Trash, Rubbish Storage (inc chute room, industrial waste area etc)	165	5.8	3,394,042	2.8	20,570
Product Storage (inc prod to be assembled, sold, shipped etc)	148	5.2	12,645,690	10.3	85,444
Roof	118	4.1	3,120,563	2.5	26,445
Mechanical/Electrical Services Room	105	3.7	3,768,341	3.1	35,889
Washroom or Bathroom (inc toilet, rest/ locker rooms)	98	3.4	1,018,177	0.8	10,390
Other Storage Area	88	3.1	4,889,385	4.0	55,561
Other - unclassified	82	2.9	3,361,621	2.7	40,995
Lobby, Entranceway	75	2.6	823,693	0.7	10,983
Undetermined	73	2.6	13,366,025	10.9	183,096
Shipping/Receiving/ Loading Platform	70	2.4	3,394,502	2.8	48,493
Supply Storage Room (inc maintenance/ document storage etc)	67	2.3	3,905,920	3.2	58,297

Table 5.20 (cont.) Damage as a function of areas of origin of fire for Mercantile Occupancies (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Direct Property Damage ($)	% of Total Damages	Damage per fire ($)
HVAC Equipment Room (furnace room, water heater closet, boil	66	2.3	1,807,993	1.5	27,394
Dining or Beverage Area (inc lunchroom, café, mess, etc)	64	2.2	3,233,925	2.6	50,530
Other Functional Area	61	2.1	4,091,800	3.3	67,079
Office	46	1.6	3,518,050	2.9	76,479
Concealed Ceiling Area	45	1.6	2,870,326	2.3	63,785
Hallway, Corridor, Mall	44	1.5	476,130	0.4	10,821
Awning or Canopy	39	1.4	45,486	0.0	1,166
Other Structural Area	39	1.4	945,431	0.8	24,242
Ducting - Exhaust (inc cooking, fumes, etc.)	37	1.3	365,400	0.3	9,876
Other Building Services /Support Facilities	36	1.3	165,236	0.1	4,590
Process Manufact. (inc product assembly, repair)	35	1.2	1,143,076	0.9	32,659
Other Outside Area	35	1.2	306,652	0.3	8,761
Parking Area, Parking Lot	30	1.0	174,152	0.1	5,805

The data of Table 5.19 indicate that the majority of fires, 16.1%, originate in cooking areas or kitchens. The second highest number of fires starts in sales or showroom areas with 7.2 % of the total, followed by exterior wall at 6.8%, trash or rubbish storage areas at 5.8% and product storage areas at 5.2%. Other areas have a contribution of less than 5% each. Fires in mercantile occupancies caused 6 deaths (1 death in <1% fires, not shown) in the eight year period from 1995 to 2002. Fires originating from sales or showroom areas accounted for 2 deaths, followed by 1 in each of the cooking area or kitchen, other functional area, and shipping or receiving or loading area. Fires originating in cooking areas or kitchens, and sales or showroom areas, each caused 12.2% of the total injuries. Injuries in the range of 5% to 7% were shown by the fires originating from product storage areas, mechanical or electrical services rooms, other storage areas, and hallways or corridors or malls, and remaining areas showed less than 5%. Only 2.6% of the total fires remained undetermined but they caused 17.8 injuries per 100 fires. Amongst the known fire origin areas, fires originating from hallways, corridors or malls showed the highest, 18.2 injuries per 100 fires. Other areas showing high rates of injuries per 100 fires were process manufacturing areas at 11.4, other storage areas at 11.4, other functional areas at 9.8, sales or showroom areas at 9.2, and supply storage rooms at 9.0.

Table 5.20 shows the property damage due to fires in mercantile occupancies. Undetermined fires were only 2.6% of the total fires but they accounted for 10.9% of the total damages. These undetermined fires showed extremely high, $183,096 damages per fire. Amongst known fire origin areas, sales or showroom area fires resulted in the highest property damages of 10.8% of the total damages followed by product storage area fires at 10.3%, cooking areas or kitchens at 6.5%, and other areas having a contribution of less than 5%. From the known fire origin areas, fires originating from product storage areas showed the highest damages of $85,444 per fire. Kitchen or cooking area fires cause an average of $17,431 losses per fire. Other high loss fire origin areas are office areas, other functional areas, sales or showroom areas, concealed ceiling areas, other storage areas, and dining or beverage areas, with the losses of $50,000 to $77,000 per fire. From Tables 5.19 and 5.20 it can be concluded that for mercantile occupancies, cooking areas or kitchen fires are the most common ones and result in the highest occurrences and injuries. Moreover other high risk areas are sales or showroom area, and product storage areas [4].

5.1.3.6 Origin of fire for Residential Occupancies

Table 5.21 shows the fire data and Table 5.22 indicates the property damage for residential occupancies including residential dwellings.

Table 5.21 Areas of origin of fire for Residential Occupancies (inc residential dwellings) (1995-2002)

Area of origin of fire	No. of fires	% of Total Fires	No. of Deaths	% of Total Deaths	Death rate per 100 fires	No. of Injuries	% of Total Injuries	Injury rate per 100 fires
Cooking Area or Kitchen	15,772	26.6	135	15.9	0.9	2,009	31.3	12.7
Living Area (e.g. living, T.V., recreation, etc)	6,865	11.6	342	40.3	5.0	1,161	18.1	16.9

Table 5.21 (cont.) Areas of origin of fire for Residential Occupancies (inc residential dwellings) (1995-2002)

Area of origin of fire	No. of fires	% of Total Fires	No. of Deaths	% of Total Deaths	Death rate per 100 fires	No. of Injuries	% of Total Injuries	Injury rate per 100 fires
Sleeping Area or Bedroom (inc patient's room, dormitory, etc)	6,124	10.3	144	17.0	2.4	1,189	18.5	19.4
Garage	3,424	5.8	10	1.2	0.3	235	3.7	6.9
Chimney/Flue Pipe	3,132	5.3	3	0.4	0.1	47	0.7	1.5
Laundry Area	2,914	4.9	13	1.5	0.4	151	2.4	5.2
Exterior Wall	1,892	3.2	1	0.1	0.1	96	1.5	5.1
Porch or Balcony	1,829	3.1	4	0.5	0.2	109	1.7	6.0
Undetermined	1,650	2.8	57	6.7	3.5	211	3.3	12.8
HVAC Equipment Room (furnace room, water heater closet, boil	1,346	2.3	10	1.2	0.7	110	1.7	8.2
Washroom or Bathroom (inc toilet, rest /locker rooms)	1,109	1.9	5	0.6	0.5	84	1.3	7.6
Hallway, Corridor, Mall	1,095	1.8	5	0.6	0.5	97	1.5	8.9
Trash, Rubbish Storage (inc chute room, industrial. waste area etc)	1,022	1.7	1	0.1	0.1	42	0.7	4.1
Lobby, Entranceway	824	1.4	9	1.1	1.1	44	0.7	5.3
Attic Area	735	1.2	0	0	0	53	0.8	7.2
Roof	688	1.2	0	0	0	37	0.6	5.4
Other Functional Area	650	1.1	1	0.1	0.2	73	1.1	11.2
Other - unclassified	598	1.0	10	1.2	1.7	52	0.8	8.7

Table 5.22 Damage as a function of areas of origin of fire for Residential Occupancies (inc residential dwellings) (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Direct Property Damage ($)	% of Total Damages	Damages per fire ($)
Cooking Area or Kitchen	15,772	26.6	197,242,462	11.7	12,506
Living Area (e.g. living, T.V., recreation, etc)	6,865	11.6	242,975,498	14.4	35,393
Sleeping Area or Bedroom (inc patient's room, dormitory, etc)	6,124	10.3	159,331,450	9.4	26,018
Garage	3,424	5.8	96,984,416	5.7	28,325
Chimney/Flue Pipe	3,132	5.3	25,432,790	1.5	8,120
Laundry Area	2,914	4.9	39,783,925	2.4	13,653
Exterior Wall	1,892	3.2	30,819,035	1.8	16,289
Porch or Balcony	1,829	3.1	27,001,148	1.6	14,763
Undetermined	1,650	2.8	163,487,751	9.7	99,083
HVAC Equipment Room (furnace room, water heater closet, boil	1,346	2.3	39,466,864	2.3	29,322
Washroom or Bathroom (inc toilet, rest /locker rooms)	1,109	1.9	19,454,765	1.2	17,543
Hallway, Corridor, Mall	1,095	1.8	11,432,916	0.7	10,441

Table 5.22 (cont.) Damage as a function of areas of origin of fire for Residential Occupancies (inc residential dwellings) (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Direct Property Damage ($)	% of Total Damages	Damages per fire ($)
Trash, Rubbish Storage (inc chute room, industrial waste area etc)	1,022	1.7	2,647,666	0.2	2,591
Lobby, Entranceway	824	1.4	12,160,730	0.7	14,758
Attic Area	735	1.2	360,275,504	21.3	490,171
Roof	688	1.2	15,937,842	0.9	23,165
Other Functional Area	650	1.1	26,929,822	1.6	41,430
Other - unclassified	598	1.0	11,338,339	0.7	18,960

Table 5.21 shows data for residential occupancies including residential dwellings. The data indicate that the majority of fires, 26.6%, originate from cooking areas or kitchens. The second highest number of fires occurs in living areas with 11.6% of the total, followed by sleeping areas or bedrooms at 10.3%, garage at 5.8%, and chimney or flue pipe at 5.3%. Other areas have contributions to the total of less than 5% each.

Residential fires result in large number of deaths and a high rate of deaths per hundred fires. Fires originating in living areas caused the highest, 40.3% of the total deaths, followed by sleeping areas or bedrooms at 17%, and cooking areas or kitchens at 15.9%. Each other area contributed to less than 2% of the total deaths. However, the area of fire origin could not be determined in fires involving 6.7% of the total deaths. Fires originating in living areas caused highest death rate of 5 deaths per 100 fires, followed by undetermined fires at 3.5, sleeping area or bedroom fires at 2.4, and lobby or entranceway fires at 1.1. Fires starting in each of the remaining areas contributed to less than one death per hundred fires. It may be noted here that though cooking area or kitchen fires are the most common ones but they account for only 0.9 deaths per 100 fires.

Residential occupancies showed that 31.3% of the injuries are from fires that originated in cooking areas or kitchens. Fires that originated in sleeping areas or bedrooms resulted in 18.5% of the injuries, and fires in living areas 18.1%. Fires originating in sleeping areas or bedrooms showed the highest, 19.4 injuries per 100 fires followed by living areas at 16.9, cooking areas or kitchens at 12.7, and other functional areas at 11.2.

Table 5.22 shows the property damage caused by fires in residential occupancies. Attic area fires resulted in the highest property damage of 21.3% of the total damages followed by living area fires at 14.4%, cooking area or kitchen fires at 11.7%, sleeping area or bedroom at 9.4%, garage at 5.7%, and other areas having a contribution of less than 3% each. Fires originating in attic areas show the highest damages of $490,171 per fire. Cooking area or kitchen fires cause an average of $12,506 losses per fire. Other high loss fire origin areas are other functional area, living area, HVAC equipment room, garage, and sleeping area, wherein the losses are in the range of $26,000 to $42,000 per fire. The fire origin area for 2.8% of the total fires could not be determined but these fires contributed to 9.7% of the total damages. These undetermined fires resulted in losses of $99,083 per fire. From Tables 5.21 and 5.22 it can be concluded that for residential occupancies, cooking or kitchen area fires are the most common ones, and result in the highest number of injuries. Most fatal fires however originate from living areas followed by sleeping areas or bedrooms. Attic area fires though less in numbers, but account for extremely high rate of property damage [4].

5.1.3.7 Origin of fire for Miscellaneous Structures/ Properties

Table 5.23 shows the fire data and Table 5.24 indicates the property damage for miscellaneous structures/ properties.

Table 5.23 Areas of origin of fire for Miscellaneous structures/properties (1995-2002)

Area of origin of fire	**Number of fires**	**% of Total Fires**	**Number of Deaths**	**% of Total Deaths**	**Number of Injuries**	**% of Total Injuries**	**Injury rate per 100 fires**
Undetermined	1065	20.9	2	25	23	26.7	2.2
Open Area (inc lawn, field, farmyard, park, playing field)	523	10.2	0	0	4	4.7	0.8
Other Storage Area	494	9.7	2	25	14	16.3	2.8
Exterior Wall	451	8.8	0	0	5	5.8	1.1
Other - unclassified	429	8.4	1	12.5	8	9.3	1.9
Other Structural Area	347	6.8	0	0	4	4.7	1.2
Storage Area (outside)	297	5.8	0	0	9	10.5	3.0
Other Outside Area	241	4.7	0	0	3	3.5	1.2
Roof	102	2.0	0	0	1	1.2	1.0
Other Functional Area	99	1.9	0	0	5	5.8	5.1
Product Storage (inc prod to be assembled, sold, shipped etc)	93	1.8	1	12.5	2	2.3	2.2
Washroom or Bathroom (inc toilet, rest/locker rooms)	90	1.8	0	0	1	1.2	1.1

Table 5.23 (cont.) Areas of origin of fire for Miscellaneous structures/properties (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Number of Deaths	% of Total Deaths	Number of Injuries	% of Total Injuries	Injury rate per 100 fires
Parking Area, Parking Lot	83	1.6	0	0	0	0.0	0.0
Trash, Rubbish Storage (inc chute room, indust. waste area etc)	73	1.4	0	0	0	0.0	0.0
Garage	61	1.2	1	12.5	0	0.0	0.0
Mechanical/Electrical Services Room	54	1.1	0	0	3	3.5	5.6
Sauna	52	1.0	0	0	0	0.0	0.0
Chimney/Flue Pipe	51	1.0	0	0	0	0.0	0.0

Table 5.24 Damages as a function of areas of origin of fire for Miscellaneous Structures/Properties (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Direct Property Damage ($)	% of Total Damages	Damage per fire ($)
Undetermined	1065	20.9	73,003,526	44.0	68,548
Open Area (inc lawn, field, farmyard, park, playing field)	523	10.2	4,983,504	3.0	9,529
Other Storage Area	494	9.7	19,031,054	11.5	38,524
Exterior Wall	451	8.8	8,275,762	5.0	18,350
Other - unclassified	429	8.4	9,463,073	5.7	22,058
Other Structural Area	347	6.8	12,008,669	7.2	34,607
Storage Area (outside)	297	5.8	2,754,985	1.7	9,276
Other Outside Area	241	4.7	1,827,296	1.1	7,582
Roof	102	2.0	3,436,490	2.1	33,691
Other Functional Area	99	1.9	3,343,855	2.0	33,776
Product Storage (inc prod to be assembled, sold, shipped etc)	93	1.8	3,971,880	2.4	42,708

Table 5.24 (cont.) Damages as a function of areas of origin of fire for Miscellaneous Structures/Properties (1995-2002)

Area of origin of fire	Number of fires	% of Total Fires	Direct Property Damage ($)	% of Total Damages	Damage per fire ($)
Washroom or Bathroom (inc toilet, rest/locker rooms)	90	1.8	235,045	0.1	2,612
Parking Area, Parking Lot	83	1.6	243,244	0.1	2,931
Trash, Rubbish Storage (inc chute room, industrial waste area etc)	73	1.4	174,220	0.1	2,387
Garage	61	1.2	1,611,053	1.0	26,411
Mechanical/Electrical Services Room	54	1.1	4,633,000	2.8	85,796
Sauna	52	1.0	708,200	0.4	13,619
Chimney/Flue Pipe	51	1.0	563,900	0.3	11,057

Table 5.23 shows data for miscellaneous structures/ properties. The data indicate that for the majority of fires, 20.9%, the fire origin area could not be determined. Amongst the known fire origin areas, most fires 10.2%, originate in open areas. The second highest numbers of fires occur in other storage areas with 9.7% of the total, followed by exterior wall areas at 8.8, other unclassified areas at 8.4, other structural areas at 6.8 and outside storage areas at 5.8. Other areas have a contribution of less than 5% each. Miscellaneous structure fires caused 8 deaths in the eight year period from 1995 to 2002. Fires originating in other storage areas account for 2 deaths, followed by 1 in each of the product storage areas, garages, and other unclassified areas. Fires in these structures caused fewer injuries than other occupancies. 16.3% of the injuries are from fires that originated in other storage areas. Fires that originated in outside storage areas resulted in 10.5% of the injuries, fires in other unclassified areas 9.3%, fires in each of the exterior

wall areas and other functional areas 5.8%. Fires originating in mechanical or electrical services rooms caused the highest, 5.6 injuries per 100 fires followed by other functional area at 5.1.

Table 5.24 shows the property damage due to fires in miscellaneous structures. The fire origin areas for the majority of property damages, 44%, remained undetermined. Amongst the known fires, other storage area fires resulted in the highest property damages at 11.5% of the total damages followed by other structural area fires at 7.2%, other unclassified area fires at 5.7%, exterior walls at 5%, and other areas having a contribution of less than 3%. Fires originating in mechanical or electrical services rooms caused the highest damage at $85,796 per fire. The fire origin area for 20.9% of the total fires could not be determined. These fires contributed to 44% of the total damages and resulted in losses of $68,548 per fire. Other high loss fire origin areas are product storage areas, other storage areas, other structural areas, other functional areas, roofs, and garages with losses in the range of $26,000 to $43,000 per fire. From Tables 5.23 and 5.24 it can be concluded that for miscellaneous structures or properties, most of the fires remain undetermined and result in the highest deaths, injuries and property damages. Other high risk areas are open areas and other storage areas, and mechanical or electrical services rooms.

5.1.4. Causes of Fire

To start a fire it is necessary to have an initial heat source, an initial fuel source, and sufficient amount of air to permit oxidation. Tables 5.25 to 5.38 show the causes of fire for the different property classes. To facilitate the analysis and ensure statistically significant results, only causes of fire having a number of fire incidents of over 1% of the total fire incidents for a particular occupancy are shown.

5.1.4.1 Causes of fire for Assembly Occupancies

Table 5.25 shows the fire data and Table 5.26 indicates the property damage for assembly occupancies. The causes, arson and vandalism used in the table are defined as follows: Arson is the act or crime of willfully, wrongly, and unjustifiably setting property on fire often for the purpose of committing fraud, as to collect insurance. Vandalism is willful or malicious destruction or defacement of the property of others.

Table 5.25. Major fire causes for Assembly occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Number of Injuries	% of total injuries	Injury rate per 100 fires
Arson	790	16.8%	0	0.0%	33	11.7%	4.2
Undetermined	647	13.7%	0	0.0%	89	31.6%	13.8
Electrical Failure	638	13.6%	0	0.0%	21	7.4%	3.3
Vandalism	505	10.7%	0	0.0%	12	4.3%	2.4
Youth Vandalism/ Ages 12 to 17	352	7.5%	0	0.0%	11	3.9%	3.1
Maintenance Deficiency	300	6.4%	0	0.0%	24	8.5%	8.0
Misused Ignition source/equipment Improperly Discarded	271	5.8%	0	0.0%	11	3.9%	4.1
Other	246	5.2%	0	0.0%	14	5.0%	5.7
Misused Ignition source/equipment Unattended	164	3.5%	0	0.0%	16	5.7%	9.8

Table 5.25. (cont.) Major fire causes for Assembly occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Number of Injuries	% of total injuries	Injury rate per 100 fires
Misused Ignition source/equipment Too Close to Combustibles	156	3.3%	0	0.0%	9	3.2%	5.8
Mechanical Failure	118	2.5%	0	0.0%	7	2.5%	5.9
Misuse of Material ignited: Improper Storage	79	1.7%	0	0.0%	4	1.4%	5.1
Misuse of Material ignited: Improper Handling	74	1.6%	0	0.0%	12	4.3%	16.2
Misused Ignition source/equipment Other	69	1.5%	1	100.0%	6	2.1%	8.7
Installation Deficiency	50	1.1%	0	0.0%	4	1.4%	8.0
Design Deficiency: Other	47	1.0%	0	0.0%	1	0.4%	2.1

Table 5.26 Damages as a function of fire causes for Assembly Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damage per fire ($)
Arson	790	16.8%	18,204,607	14.4%	23,044
Undetermined	647	13.7%	55,456,640	44.0%	85,714
Electrical Failure	638	13.6%	13,524,138	10.7%	21,198
Vandalism	505	10.7%	4,061,788	3.2%	8,043
Youth Vandalism/ Ages 12 to 17	352	7.5%	2,104,349	1.7%	5,978
Maintenance Deficiency	300	6.4%	5,932,092	4.7%	19,774

Table 5.26 (cont.) Damages by fire causes for Assembly Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damage per fire ($)
Misused Ignit source/ equip: Improperly Discarded	271	5.8%	2,383,873	1.9%	8,797
Other	246	5.2%	4,851,310	3.8%	19,721
Misused Ignition source/equip: Unattended	164	3.5%	2,890,233	2.3%	17,623
Misused Ignition source/equip: Too Close to Combustibles	156	3.3%	3,966,957	3.1%	25,429
Mechanical Failure	118	2.5%	1,303,986	1.0%	11,051
Misuse of Material ignited: Improper Storage	79	1.7%	382,829	0.3%	4,846
Misuse of Material ignited: Improper Handling	74	1.6%	760,098	0.6%	10,272
Misused Ignit source/equip: Other	69	1.5%	2,943,516	2.3%	42,660
Installation Deficiency	50	1.1%	1,038,990	0.8%	20,780
Design Deficiency: Other	47	1.0%	961,561	0.8%	20,459

Table 5.25 shows that the majority of fires, 16.8%, in assembly occupancies are due to arson, followed by electrical failure at 13.6%, vandalism 10.7%, youth vandalism ages 12 to 17 at 7.5%, maintenance deficiency at 6.4% and misused ignition source equipment: improperly discarded at 5.8%. The causes for about fourteen percent of the fires could not be determined. During the eight year period there was only one death observed in these occupancies which was due to a fire caused by an un-specified misused ignition source/ equipment. The cause of fires that resulted in about 1/3 of the total

injuries remained undetermined. Amongst the known causes of fires, arson fires resulted in 11.7% of the total injuries, followed by maintenance deficiency at 8.5%, electrical failure at 7.4%, misused ignition source/ equipment left unattended at 5.7%, and other causes at 5%. Fires caused by improper handling of ignited material resulted in the highest injury rate of 16.2 per 100 fires, followed by ignition source left unattended at 9.8 and other misuse of ignition source at 8.7 injuries per 100 fires. Fires due to maintenance deficiency and installation deficiency had an injury rate of 8 injuries per 100 fires. It can be seen that although arson, electric failure and vandalism had very high fire occurrences, the injury rate in these cases was in the range of 2 to 4 injuries per 100 fires.

Table 5.26 shows property damages in Assembly occupancies as a function of cause of fire. The causes of fire responsible for the majority (44%) of property damages could not be determined. Amongst the known causes, most property damages occurred due to arson (14.4%), followed by vandalism at 10.7%. Each of the remaining causes accounted for less than 5% of the total property damages. Undetermined causes of fire show the highest damages of $85,714 per fire. Fires due to unspecified misuse of ignition source show the second highest damages of $42,660 per fire. Other major causes of fire accounting for high damage rates ranging from $20 to 25 thousand per fire are: the presence of ignition source too close to combustibles; arson; electric failure; installation deficiency; and design deficiency.

5.1.4.2 Causes of fire for Business and Personal Occupancies

Table 5.27 shows the fire data and Table 5.28 indicates the property damage for business and personal occupancies. The term unreported means that the details were not reported by the fire fighter (on the fire reporting form) who attended the fire site.

Table 5.27. Major fire causes for Business and Personal Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Number of Injuries	% of total injuries	Injury rate per 100 fires
Electrical Failure	405	22.1%	0	0.0%	7	9.2%	1.7
Undetermined	340	18.6%	0	0.0%	34	44.7%	10.0
Arson	224	12.2%	1	100.0%	8	10.5%	3.6
Misused Ignition source/equip :Improperly Discarded	142	7.8%	0	0.0%	3	3.9%	2.1
Vandalism	103	5.6%	0	0.0%	1	1.3%	1.0
Maintenance Deficiency	98	5.4%	0	0.0%	2	2.6%	2.0
Other	87	4.8%	0	0.0%	5	6.6%	5.7
Misused Ignition source/equip: Too Close to Combustibles	83	4.5%	0	0.0%	4	5.3%	4.8
Mechanical Failure	57	3.1%	0	0.0%	2	2.6%	3.5
Misused Ignition source/equip: Unattended	46	2.5%	0	0.0%	1	1.3%	2.2
Misuse of Material ignited: Improper Storage	37	2.0%	0	0.0%	0	0.0%	0.0
Youth Vandalism/ Ages 12 to 17	33	1.8%	0	0.0%	0	0.0%	0.0
Misuse of Material ignited: Improper Handling	28	1.5%	0	0.0%	3	3.9%	10.7
Misused Ignition source/equip: Other	25	1.4%	0	0.0%	2	2.6%	8.0
Unreported	24	1.3%	0	0.0%	0	0.0%	0.0
Installation Deficiency	23	1.3%	0	0.0%	1	1.3%	4.3

Table 5.28 Damages by fire causes for Business and Personal Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damage per fire ($)
Electrical Failure	405	22.1%	8,966,578	14.3%	22,140
Undetermined	340	18.6%	23,869,155	38.1%	70,203
Arson	224	12.2%	12,862,808	20.5%	57,423
Misused Ignit source/equip :Improperly Discarded	142	7.8%	822,297	1.3%	5,791
Vandalism	103	5.6%	2,736,403	4.4%	26,567
Maintenance Deficiency	98	5.4%	807,241	1.3%	8,237
Other	87	4.8%	6,324,683	10.1%	72,698
Misused Ignit source/equip: Too Close to Combustibles	83	4.5%	1,137,580	1.8%	13,706
Mechanical Failure	57	3.1%	286,037	0.5%	5,018
Misused Ignition source/equip: Unattended	46	2.5%	642,480	1.0%	13,967
Misuse of Material ignited: Improper Storage	37	2.0%	376,975	0.6%	10,189
Youth Vandalism/ Ages 12 to 17	33	1.8%	120,705	0.2%	3,658
Misuse of Material ignited: Improper Handling	28	1.5%	109,510	0.2%	3,911
Misused Ignit source/equip: Other	25	1.4%	536,168	0.9%	21,447
Unreported	24	1.3%	1,032,555	1.6%	43,023
Installation Deficiency	23	1.3%	336,250	0.5%	14,620

Table 5.27 shows that in business and personal occupancies the majority of fires, 22.1%, occur due to electric failure, followed by arson at 12.2%, misused ignition source or equipment: improperly discarded at 7.8%, vandalism at 5.6%, and maintenance

deficiency at 5.4%. The causes for about nineteen percent of the fires could not be determined. During the eight year period there was only one death observed in these occupancies which was due to fire caused by arson. The cause of fires that resulted in nearly half (44.7%) of the total injuries remained undetermined. Amongst the known causes, fires due to arson resulted in 10.5% of the total injuries, followed by electrical failure at 9.2%, other causes at 6.6%, and misused ignition source or equipment too close to combustibles at 5.3%. Fires caused by improper handling of ignited material resulted in the highest injury rate of 10.7 per 100 fires, followed by other misuse of ignition source at 8.0, and other causes at 5.7. Fires due to undetermined causes had an injury rate of 10 injuries per 100 fires. It can be seen that although electric failure, arson, improperly discarded ignition source and vandalism had very high fire occurrences, their injury rate was less than 4 injuries per 100 fires.

Table 5.28 shows property damage in business and personal occupancies as a function of cause of fire. The causes of fire responsible for the majority (38.1%) of property damages could not be determined. Amongst the known causes, most property damages occurred due to arson (20.5%), followed by electric failure at 14.3%, and other causes of fire at 10.1%. Each of the remaining causes accounted for less than 5% of the total property damages. Other causes of fire show the highest damages of $72,698 per fire. Fires due to undetermined causes show the second highest damages of $70,203 per fire. Other major causes of fire accounting for high damage rates per fire are arson at $57,423, vandalism at $26,567, electric failure at $22,140, and other misused ignition source or equipment at $21,447. However, 1.3% of the total fires, accounting for high property damage rate of $43,023 per fire, remained unreported.

5.1.4.3 Causes of fire for Industrial Occupancies

Table 5.29 shows the fire data and Table 5.30 indicates the property damage for industrial occupancies.

Table 5.29. Major fire causes for Industrial Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Number of Injuries	% of total injuries	Injury rate per 100 fires
Undetermined	1484	21.7%	1	12.5%	371	39.2%	25.0
Electrical Failure	977	14.3%	0	0.0%	54	5.7%	5.5
Other	706	10.3%	1	12.5%	120	12.7%	17.0
Maintenance Deficiency	631	9.2%	0	0.0%	56	5.9%	8.9
Mechanical Failure	511	7.5%	0	0.0%	72	7.6%	14.1
Misused Ignition source/equip: Too Close to Combustibles	483	7.1%	2	25.0%	62	6.6%	12.8
Arson	353	5.2%	3	37.5%	26	2.7%	7.4
Misuse of Material ignited: Improper Handling	201	2.9%	0	0.0%	42	4.4%	20.9
Vandalism	191	2.8%	0	0.0%	23	2.4%	12.0
Misuse of Material ignited: Improper Storage	173	2.5%	0	0.0%	11	1.2%	6.4
Misused Ignition source/equip: Improperly Discarded	164	2.4%	0	0.0%	20	2.1%	12.2

Table 5.29. (cont.) Major fire causes for Industrial Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Number of Injuries	% of total injuries	Injury rate per 100 fires
Design Deficiency: Other	164	2.4%	0	0.0%	17	1.8%	10.4
Misused Ignition source/equip: Unattended	135	2.0%	0	0.0%	8	0.8%	5.9
Misused Ignition source/equip: Other	129	1.9%	0	0.0%	22	2.3%	17.1
Design Deficiency	120	1.8%	0	0.0%	9	1.0%	7.5
Installation Deficiency	92	1.3%	0	0.0%	12	1.3%	13.0
Unreported	67	1.0%	0	0.0%	4	0.4%	6.0

Table 5.30 Damages by fire causes for Industrial Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damage per fire ($)
Undetermined	1484	21.7%	196,189,467	42.8%	132,203
Electrical Failure	977	14.3%	52,232,950	11.4%	53,463
Other	706	10.3%	39,665,069	8.6%	56,183
Maintenance Deficiency	631	9.2%	18,449,101	4.0%	29,238
Mechanical Failure	511	7.5%	30,343,520	6.6%	59,381
Misused Ignition source/equip: Too Close to Combustibles	483	7.1%	16,413,750	3.6%	33,983
Arson	353	5.2%	25,284,581	5.5%	71,628
Misuse of Material ignited: Improper Handling	201	2.9%	24,034,899	5.2%	119,577
Vandalism	191	2.8%	3,903,723	0.9%	20,438
Misuse of Material ignited: Improper Storage	173	2.5%	14,907,292	3.2%	86,169

Table 5.30 (cont.) Damages by fire causes for Industrial Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damage per fire ($)
Misused Ignition source/equip: Improperly Discarded	164	2.4%	2,217,386	0.5%	13,521
Design Deficiency: Other	164	2.4%	5,195,951	1.1%	31,683
Misused Ignition source/equip: Unattended	135	2.0%	3,360,132	0.7%	24,890
Misused Ignition source/equip: Other	129	1.9%	3,169,689	0.7%	24,571
Design Deficiency	120	1.8%	3,839,839	0.8%	31,999
Installation Deficiency	92	1.3%	2,711,790	0.6%	29,476
Unreported	67	1.0%	6,277,476	1.4%	93,694

Table 5.29 shows that in industrial occupancies, for the majority of fires, 21.7%, the causes of fire could not be determined. Amongst the known fire causes in these occupancies, most of the fires are due to electrical failure at 14.3%, followed by other causes at 10.3%, maintenance deficiency at 9.2%, mechanical failure at 7.5%, misused ignition source or equipment too close to combustibles at 7.1%, and arson at 5.2%. During the eight year period 8 deaths were observed in these occupancies. Arson fires accounted for the highest number of deaths at 3, followed by misused ignition source too close to combustibles at 2, other cause at 1, and undetermined cause at 1. The cause of fires that resulted in more than 1/3 (39.2%) of the total injuries remained undetermined. Amongst the known causes of fires, fires due to other causes resulted in 12.7% of the total injuries, followed by mechanical failure at 7.6%, misused ignition source or equipment too close to combustibles at 6.6%, maintenance deficiency at 5.9%, and

electrical failure at 5.7%. Undetermined fires showed the highest injury rate of 25 injuries per 100 fires. Amongst the known causes, fires caused by improper handling of ignited material resulted in highest injury rate of 20.9 per 100 fires, followed by other misused ignition source or equipment at 17.1, and other causes at 17. Other causes of fire accounting for 10 to 15 injuries per 100 fires are mechanical failure, installation deficiency, ignition source too close to combustibles, improperly discarded ignition source, vandalism, and other design deficiency.

Table 5.30 shows property damage in industrial occupancies as a function of cause of fire. The causes of fire responsible for the majority (42.8%) of property damages could not be determined. Amongst the known causes, most property damages occurred due to electrical failure (11.4%), followed by other causes at 8.6%, mechanical failure at 6.6%, arson at 5.5%, and improper handling of ignited material at 5.2%. Each of the remaining causes accounted for less than 5% of the total property damages. Undetermined causes of fire show the highest damages of $132,203 per fire. Fires due to improper handling of ignited material show the second highest damages of $119,577 per fire. Other major causes of fire accounting for more than $50,000 damages per fire are, improper storage of ignited material, arson, mechanical failure, other causes, and electrical failure. However, 1.0 % of the total fires, accounting for high property damage rate of $93,694 per fire, remained unreported.

5.1.4.4 Causes of fire for Institutional Occupancies

Table 5.31 shows the fire data and Table 5.32 indicates the property damage for institutional occupancies.

Table 5.31 Major fire causes for Institutional occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Number of Injuries	% of total injuries	Injury rate per 100 fires
Electrical Failure	228	18.0%	0	0.0%	14	10.1%	6.1
Arson	197	15.5%	3	21.4%	29	20.9%	14.7
Undetermined	121	9.5%	0	0.0%	28	20.1%	23.1
Misused Ignition source/equip: Improperly Discarded	113	8.9%	2	14.3%	9	6.5%	8.0
Vandalism	86	6.8%	3	21.4%	18	12.9%	20.9
Misused Ignition source/equip: Unattended	73	5.8%	2	14.3%	7	5.0%	9.6
Misused Ignition source/equip: Too Close to Combustibles	69	5.4%	1	7.1%	8	5.8%	11.6
Other	67	5.3%	1	7.1%	7	5.0%	10.4
Maintenance Deficiency	66	5.2%	0	0.0%	9	6.5%	13.6
Mechanical Failure	42	3.3%	0	0.0%	1	0.7%	2.4
Misuse of Material ignited: Improper Handling	38	3.0%	0	0.0%	1	0.7%	2.6
Misused Ignition source/equip: Other	33	2.6%	1	7.1%	2	1.4%	6.1
Misuse of Material ignited: Improper Storage	20	1.6%	0	0.0%	1	0.7%	5.0

Table 5.31 (cont.) Major fire causes for Institutional occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Number of Injuries	% of total injuries	Injury rate per 100 fires
Installation Deficiency	16	1.3%	0	0.0%	0	0.0%	0.0
Misused Ignition source/equip: for purpose not Intended	15	1.2%	0	0.0%	2	1.4%	13.3
Riot/Civil Commotion	15	1.2%	0	0.0%	2	1.4%	13.3
Misuse of Material ignited: Other	14	1.1%	1	7.1%	1	0.7%	7.1

Table 5.32 Damages by fire causes for Institutional occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damage per fire ($)
Electrical Failure	228	18.0%	1,235,816	7.7%	5,420
Arson	197	15.5%	879,625	5.5%	4,465
Undetermined	121	9.5%	8,919,671	55.8%	73,716
Misused Ignition source/equip: Improperly Discarded	113	8.9%	472,209	3.0%	4,179
Vandalism	86	6.8%	235,546	1.5%	2,739
Misused Ignition source/equip: Unattended	73	5.8%	478,755	3.0%	6,558
Misused Ignition source/equip: Too Close to Combustibles	69	5.4%	2,236,098	14.0%	32,407
Other	67	5.3%	316,822	2.0%	4,729
Maintenance Deficiency	66	5.2%	118,500	0.7%	1,795
Mechanical Failure	42	3.3%	255,476	1.6%	6,083

Table 5.32 (cont.) Damages by fire causes for Institutional occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damage per fire ($)
Misuse of Material ignited: Improper Handling	38	3.0%	39,313	0.2%	1,035
Misused Ignition source/equip: Other	33	2.6%	96,906	0.6%	2,937
Misuse of Material ignited: Improper Storage	20	1.6%	21,396	0.1%	1,070
Installation Deficiency	16	1.3%	53,600	0.3%	3,350
Misused Ignition source/equip: for purpose not Intended	15	1.2%	5,330	0.0%	355
Riot/Civil Commotion	15	1.2%	386,421	2.4%	25,761
Misuse of Material ignited: Other	14	1.1%	26,642	0.2%	1,903

Table 5.31 shows that in institutional occupancies the majority of fires, 18.0%, are caused by electrical failure, followed by arson at 15.5%, improperly discarded ignition source at 8.9%, vandalism at 6.8%, misused ignition source left unattended at 5.8%, misused ignition source too close to combustibles at 5.4%, other causes at 5.3%, and maintenance deficiency at 5.2 %. The cause of about ten percent of the fires could not be determined. During the eight year period 15 deaths were observed in these occupancies. The highest numbers of deaths were caused by fires due to arson, and vandalism at 3 each, followed by misused ignition source improperly discarded at 2, misused ignition source left unattended at 2, other cause at 1, and undetermined cause at 1.

The cause of fires that resulted in 1/5 of the total injuries remained undetermined. Fires due to arson resulted in the highest, 20.9%, of the total injuries, followed by vandalism 12.9%, and electrical failure 10.1%. Other causes of fire injuries in the range of 5% to 7% are, misused ignition source left unattended, maintenance deficiency, misused ignition source too close to combustibles, misused ignition source left unattended, and other causes. Undetermined fires showed the highest injury rate of 23.1 injuries per 100 fires. Amongst the known causes, fires due to vandalism resulted in 20.9% injuries per 100 fires, followed by arson at 14.7, maintenance deficiency at 13.6, riot or civil commotion at 13.3, unintentional misuse of ignition source at 13.3, misused ignition source too close to combustibles at 11.6, and other causes at 10.4. Other causes of fire that caused injuries in the range of 5% to 10% are, misused ignition source left unattended, improperly discarded misused ignition source, other misused ignited material or source, electrical failure, and improper storage of ignited material.

Table 5.32 shows property damages in institutional occupancies as a function of cause of fire. The causes of fire responsible for more than half (55.8%) of property damages could not be determined. Amongst the known causes, most property damages occurred due to misused ignition source too close to combustibles (14.0%), followed by electrical failure at 7.7%, and arson at 5.5%. Each of the remaining causes accounted for less than 5% of the total property damages. The undetermined causes of fire caused the highest damage of $73,716 per fire. Fires due to misused ignition source too close to combustibles show the second highest damage of $32,407 per fire, followed by riot or civil commotion at $25,761. All other causes of fire contributed to property damage of less than six thousand dollars per fire.

5.1.4.5 Causes of fire for Mercantile Occupancies

Table 5.33 shows the fire data and Table 5.34 indicates the property damage for mercantile occupancies.

Table 5.33 Major fire causes for Mercantile Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Number of Injuries	% of total injuries	Injury rate per 100 fires
Undetermined	573	20.0%	0	0.0%	49	31.4%	8.6
Electrical Failure	526	18.4%	0	0.0%	13	8.3%	2.5
Arson	303	10.6%	2	33.3%	37	23.7%	12.2
Vandalism	225	7.9%	1	16.7%	6	3.8%	2.7
Other	191	6.7%	0	0.0%	2	1.3%	1.0
Maintenance Deficiency	178	6.2%	0	0.0%	5	3.2%	2.8
Misused Ignition source/equip: Improperly Discarded	145	5.1%	0	0.0%	12	7.7%	8.3
Misused Ignition source/equip: Too Close to Combustibles	117	4.1%	0	0.0%	7	4.5%	6.0
Misused Ignition source/equip: Unattended	108	3.8%	0	0.0%	7	4.5%	6.5
Youth Vandalism/ Ages 12 to 17	82	2.9%	0	0.0%	1	0.6%	1.2
Mechanical Failure	73	2.6%	0	0.0%	2	1.3%	2.7
Misuse of Material ignited: Improper Storage	66	2.3%	1	16.7%	1	0.6%	1.5

Table 5.33 (cont.) Major fire causes for Mercantile Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Number of Injuries	% of total injuries	Injury rate per 100 fires
Misuse of Material ignited: Improper Handling	43	1.5%	0	0.0%	3	1.9%	7.0
Misused Ignition source/equip: Other	43	1.5%	1	16.7%	5	3.2%	11.6
Installation Deficiency	42	1.5%	0	0.0%	0	0.0%	0.0
Unreported	34	1.2%	0	0.0%	2	1.3%	5.9
Design Deficiency: Other	31	1.1%	0	0.0%	2	1.3%	6.5

Table 5.34 Damages by fire causes for Mercantile Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damage per fire ($)
Undetermined	573	20.0%	55,469,954	45.3%	96,806
Electrical Failure	526	18.4%	16,047,332	13.1%	30,508
Arson	303	10.6%	21,663,025	17.7%	71,495
Vandalism	225	7.9%	3,629,634	3.0%	16,132
Other	191	6.7%	1,899,141	1.5%	9,943
Maintenance Deficiency	178	6.2%	3,249,601	2.7%	18,256
Misused Ignition source/equip: Improperly Discarded	145	5.1%	2,882,092	2.4%	19,876
Misused Ignition source/equip: Too Close to Combustibles	117	4.1%	3,789,321	3.1%	32,387
Misused Ignition source/equip: Unattended	108	3.8%	1,256,847	1.0%	11,637
Youth Vandalism/ Ages 12 to 17	82	2.9%	2,724,309	2.2%	33,223

Table 5.34 (cont.) Damages by fire causes for Mercantile Occupancies (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damage per fire ($)
Mechanical Failure	73	2.6%	2,335,560	1.9%	31,994
Misuse of Material ignited: Improper Storage	66	2.3%	3,394,028	2.8%	51,425
Misuse of Material ignited: Improper Handling	43	1.5%	500,352	0.4%	11,636
Misused Ignition source/equip: Other	43	1.5%	578,281	0.5%	13,448
Installation Deficiency	42	1.5%	530,545	0.4%	12,632
Unreported	34	1.2%	577,251	0.5%	16,978
Design Deficiency: Other	31	1.1%	174,600	0.1%	5,632

Table 5.33 shows that in mercantile occupancies, for 20% of the total fires, the causes of fire could not be determined. Amongst the known fire causes in these occupancies, most of the fires are due to electrical failure at 18.4%, followed by arson at 10.6%, vandalism at 7.9%, other causes at 6.7%, maintenance deficiency at 6.2%, and improperly discarded ignition source at 5.1%. During the eight year period there were 6 deaths observed in these occupancies. Arson fires caused the highest number of deaths at 2, followed by 1 each due to vandalism, other misused ignition source, and improper storage of ignited material. The cause of fires that resulted in about 1/3 (31.4%) of the total injuries remained undetermined. Amongst the known causes, fires due to arson resulted in 23.7% of the total injuries, followed by electrical failure at 8.3%, and improperly discarded ignition source at 7.7%. Fires caused by arson resulted in the highest injury rate of 12.2 per 100 fires, followed by other misuse of ignition source at

11.6. Other causes of fire accounting for 6 to 9 injuries per 100 fires are improperly discarded ignition source, improper handling of ignited material, and misused ignition source left unattended or too close to ignition source. Fires due to undetermined causes had an injury rate of 8.6 injuries per 100 fires.

Table 5.34 shows property damages in mercantile occupancies as a function of cause of fire. The causes of fire responsible for nearly half (45.3%) of the property damages could not be determined. Amongst the known causes, most property damages occurred due to arson (17.7%), followed by electric failure at 13.1%. Each of the remaining causes accounted for less than 4% of the total property damages. Undetermined fires show the highest damages of $96,806 per fire. Fires due to arson show the second highest damages of $71,495 per fire. Other major causes of fire accounting for high damage rates per fire are improper storage of ignited material at $51,425, youth vandalism (ages 12 to 17) at $33,223, mechanical failure at $31,994, and electrical failure at $30,508.

5.1.4.6 Causes of fire for Residential Occupancies

Table 5.35 shows the fire data and Table 5.36 indicates the property damage for residential occupancies including residential dwellings i.e. single-family homes, semi-detached dwellings, and townhouses or row houses.

Table 5.35. Major fire causes for All Residential occupancies including residential dwellings (1995-2002)

Cause of fire	No. of fires	% of total fires	No. of Deaths	% of total deaths	Deaths per 100 fires	No. of Injuries	% of total injuries	Injuries per 100 fires
Misused Ignition source/equip: Unattended	9833	16.6%	51	6.0%	0.5	1508	23.5%	15.3
Undetermined	8911	15.0%	243	28.7%	2.7	1149	17.9%	12.9
Electrical Failure	6809	11.5%	18	2.1%	0.3	436	6.8%	6.4
Maintenance Deficiency	4354	7.4%	2	0.2%	0.0	101	1.6%	2.3
Other	4186	7.1%	48	5.7%	1.1	358	5.6%	8.6
Arson	3949	6.7%	96	11.3%	2.4	459	7.2%	11.6
Misused Ignition source/equip: Improperly Discarded	3939	6.7%	48	5.7%	1.2	494	7.7%	12.5
Misused Ignition source/equip: Too Close to Combustibles	3524	6.0%	50	5.9%	1.4	466	7.3%	13.2
Misuse of Material ignited: Improper Handling	2060	3.5%	36	4.2%	1.7	377	5.9%	18.3
Installation Deficiency	1526	2.6%	19	2.2%	1.2	81	1.3%	5.3
Children Playing (Ages 11 and under)	1492	2.5%	22	2.6%	1.5	233	3.6%	15.6
Vandalism	1350	2.3%	9	1.1%	0.7	72	1.1%	5.3
Misused Ignition source/equip: Other	1232	2.1%	95	11.2%	7.7	213	3.3%	17.3
Mechanical Failure	966	1.6%	4	0.5%	0.4	41	0.6%	4.2
Misuse of Material ignited: Improper Storage	885	1.5%	1	0.1%	0.1	56	0.9%	6.3

Table 5.36 Damages by fire causes for all Residential occupancies i/c residential dwellings (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damages per fire ($)
Misused Ignition source/equip: Unattended	9833	16.6%	130,620,941	9.6%	13,284
Undetermined	8911	15.0%	483,979,009	35.4%	54,313
Electrical Failure	6809	11.5%	156,655,079	11.5%	23,007
Maintenance Deficiency	4354	7.4%	34,613,633	2.5%	7,950
Other	4186	7.1%	67,949,289	5.0%	16,233
Arson	3949	6.7%	107,070,505	7.8%	27,113
Misused Ignition source/equip: Improperly Discarded	3939	6.7%	54,454,293	4.0%	13,824
Misused Ignition source/equip: Too Close to Combustibles	3524	6.0%	71,798,145	5.3%	20,374
Misuse of Material ignited: Improper Handling	2060	3.5%	33,873,812	2.5%	16,444
Installation Deficiency	1526	2.6%	33,717,022	2.5%	22,095
Children Playing (Ages 11 and under)	1492	2.5%	31,506,647	2.3%	21,117
Vandalism	1350	2.3%	11,744,839	0.9%	8,700
Misused Ignition source/equip: Other	1232	2.1%	21,577,150	1.6%	17,514
Misuse of Material ignited: Improper Storage	885	1.5%	12,328,641	0.9%	13,931
Mechanical Failure	966	1.6%	15,598,774	1.1%	16,148

Table 5.35 shows that in residential occupancies the majority of fires, 16.6%, occur due to misused ignition source left unattended, followed by electrical failure at 11.5%,

maintenance deficiency at 7.4%, other causes at 7.1%, arson at 6.7%, improperly discarded ignition source at 6.7%, and misused ignition source too close to combustibles at 6.0%. The causes for fifteen percent of the fires could not be determined. Undetermined fires accounted for the highest number of deaths of 28.7% of the total. Amongst the known causes, deaths due to arson are at 11.3%, followed by other misused ignition sources at 11.2%, misused ignition source left unattended at 6.0%, misused ignition source too close to combustibles at 5.9%, improperly discarded ignition source at 5.7 %, and other causes at 5.7%. Other causes of fires accounted for less than 5% of the total deaths. Misused ignition source (other than listed) accounted for highest rate of deaths per 100 fires at 7.7 followed by undetermined causes at 2.7, and arson at 2.4. Fires due to misused ignition source left unattended resulted in highest injuries of 23.5% of the total injuries. Undetermined fires caused the second highest number of injuries of 17.9%. Other causes of fire accounting for 5% to 8% of the total injuries are improperly discarded ignition source, misused ignition source too close to combustibles, arson, electrical failure, improper handling of ignited material, and other causes. Fires caused by improper handling of ignited material resulted in the highest injury rate of 18.3 per 100 fires, followed by other misuse of ignition source at 17.3, children playing (ages 11 and under) at 15.6, and misused ignition source left unattended at 15.3. Other causes of fire resulting in 11 to 14 injuries per 100 fires are, misused ignition source too close to combustibles, improperly discarded ignition source, and arson. Fires due to undetermined causes had an injuries rate of 12.9 injuries per 100 fires.

Table 5.36 shows property damages in residential occupancies as a function of cause of fire. The causes of fire responsible for the majority (35.4%) of property damages could not be determined. Amongst the known causes most property damages occurred due to electrical failure (11.5%), followed by misused ignition source left unattended at 9.6%, arson at 7.8%, and misused ignition source too close to combustibles at 5.3%. Each of the remaining causes accounted for 5% or less of the total property damages. Undetermined fires show the highest damages of $54,313 per fire. Fires due to arson show the second highest damages of $27,113 per fire. Other major causes of fire accounting for high damage rates per fire are electrical failure at $23,007, installation deficiency at $22,095, children playing (ages 11 and under) at $21,117, and misused ignition source too close to combustibles at $20,374.

5.1.4.7 Causes of fire for Miscellaneous Structures or Properties

Table 5.37 shows the fire data and Table 5.38 indicates the property damage for miscellaneous structures or properties.

Table 5.37. Major fire causes for Miscellaneous Structures/Properties (1995-2002)

Cause of fire	**Number of fires**	**% of total fires**	**Number of Deaths**	**% of total deaths**	**Number of Injuries**	**% of total injuries**	**Injury rate per 100 fires**
Undetermined	1413	27.7%	5	62.5%	26	30.2%	1.8
Vandalism	703	13.8%	0	0.0%	3	3.5%	0.4
Arson	567	11.1%	0	0.0%	11	12.8%	1.9
Other	373	7.3%	1	12.5%	10	11.6%	2.7
Electrical Failure	349	6.8%	0	0.0%	7	8.1%	2.0
Youth Vandalism/ Ages 12 to 17	323	6.3%	0	0.0%	2	2.3%	0.6
Misused Ignition source/equip: Too Close to Combustibles	285	5.6%	2	25.0%	5	5.8%	1.8

Table 5.37. (cont.) Major fire causes for Miscellaneous Structures/Properties (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Number of Injuries	% of total injuries	Injury rate per 100 fires
Misused Ignition source/equip: Unattended	194	3.8%	0	0.0%	3	3.5%	1.5
Misused Ignition source/equip: Improperly Discarded	153	3.0%	0	0.0%	3	3.5%	2.0
Children Playing (Ages 11 and under)	117	2.3%	0	0.0%	4	4.7%	3.4
Installation Deficiency	116	2.3%	0	0.0%	4	4.7%	3.4
Maintenance Deficiency	87	1.7%	0	0.0%	1	1.2%	1.1
Misuse of Material ignited: Improper Storage	72	1.4%	0	0.0%	2	2.3%	2.8
Mechanical Failure	69	1.4%	0	0.0%	1	1.2%	1.4
Misuse of Material ignited: Improper Handling	61	1.2%	0	0.0%	2	2.3%	3.3

Table 5.38 Damages by fire causes for Miscellaneous Structures/Properties (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damage per fire ($)
Undetermined	1413	27.7%	90,096,327	54.3%	63,762
Vandalism	703	13.8%	1,717,741	1.0%	2,443
Arson	567	11.1%	6,770,655	4.1%	11,941
Other	373	7.3%	16,301,685	9.8%	43,704
Electrical Failure	349	6.8%	17,428,315	10.5%	49,938
Youth Vandalism/ Ages 12 to 17	323	6.3%	1,813,318	1.1%	5,614

Table 5.38 (cont.) Damages by fire causes for Miscellaneous Structures/Properties (1995-2002)

Cause of fire	Number of fires	% of total fires	Direct Property Damage ($)	% of total damages	Damage per fire ($)
Misused Ignition source/equip: Too Close to Combustibles	285	5.6%	6,770,537	4.1%	23,756
Misused Ignition source/equip: Unattended	194	3.8%	3,487,552	2.1%	17,977
Misused Ignition source/equip: Improperly Discarded	153	3.0%	902,096	0.5%	5,896
Children Playing (Ages 11 and under)	117	2.3%	3,125,634	1.9%	26,715
Installation Deficiency	116	2.3%	1,884,251	1.1%	16,244
Maintenance Deficiency	87	1.7%	2,893,552	1.7%	33,259
Misuse of Material ignited: Improper Storage	72	1.4%	2,944,375	1.8%	40,894
Mechanical Failure	69	1.4%	4,027,478	2.4%	58,369
Misuse of Material ignited: Improper Handling	61	1.2%	1,623,251	1.0%	26,611

Table 5.37 shows that in miscellaneous structures or properties, for 27.7% of the fires the causes of fire could not be determined. Amongst the known fire causes in these occupancies, most of the fires are due to vandalism at 13.8%, followed by arson at 11.1%, other causes at 7.3%, electrical failure at 6.8%, youth vandalism (ages 12 to 17) at 6.3%, and misused ignition source too close to combustibles at 5.6%. During the eight year period 8 deaths were observed in these occupancies. The cause of fire for the majority of deaths remained undetermined at 5, followed by misused ignition source too

close to combustibles at 2, and other causes accounted for 1. The cause of fires that resulted in about 1/3rd (30.2%) of the total injuries remained undetermined. Amongst the known causes of fires, arson fires resulted in 12.8% of the total injuries, followed by other causes 11.6%, electrical failure at 8.1%, and misused ignition source too close to combustibles at 5.8%. Fires caused by each of the installation deficiency or children playing (ages 11 and under), resulted in the highest injury rate of 3.4 injuries per 100 fires. The second highest rate of 3.3 injuries per 100 fires was caused by fires due to improper handling of ignited material. It can be seen that although vandalism, arson, electrical failure had very high fire occurrences, the injury rate in these cases was less than 3 per 100 fires.

Table 5.38 shows property damages in miscellaneous structures as a function of cause of fire. The causes of fire responsible for more than half (54.3%) of property damages could not be determined. Amongst the known causes, most property damages occurred due to electrical failure (10.5%), followed by other causes at 9.8%. Each of the remaining causes accounted for less than 5% of the total property damages. Undetermined causes of fire show the highest damages of $63,762 per fire. Fires due to mechanical failure show the second highest damages of $58,369 per fire. Other major causes of fire accounting for high damage rates ranging from $40 to 50 thousand per fire are electrical failure, other causes, and improper storage of ignited material.

5.1.5 Basement fires

This section provides details on fires that originate in basements. Tables 5.39 through 5.42 and Figures 5.11 and 5.12 have been developed to study basement fires using the OFM data [4]. Table 5.39 and Fig. 5.11 show the number of basement fires by major property classes. Basement fires account for only a small percentage of the total fires, 0.1%, however they are becoming a concern as new construction materials are proposed especially for residential dwellings. In fact, the NRC has been instructed to undertake research into the performance of new construction materials experienced in basement fires [39].

Table 5.39 Ontario's basement fires by property class (1995-2002)

Property Class	Number of fires	% of total fires
Residential	81	92.0%
Mercantile	3	3.4%
Industrial	2	2.3%
Miscellaneous Structures/Properties	1	1.1%
Business and Personal Services	1	1.1%

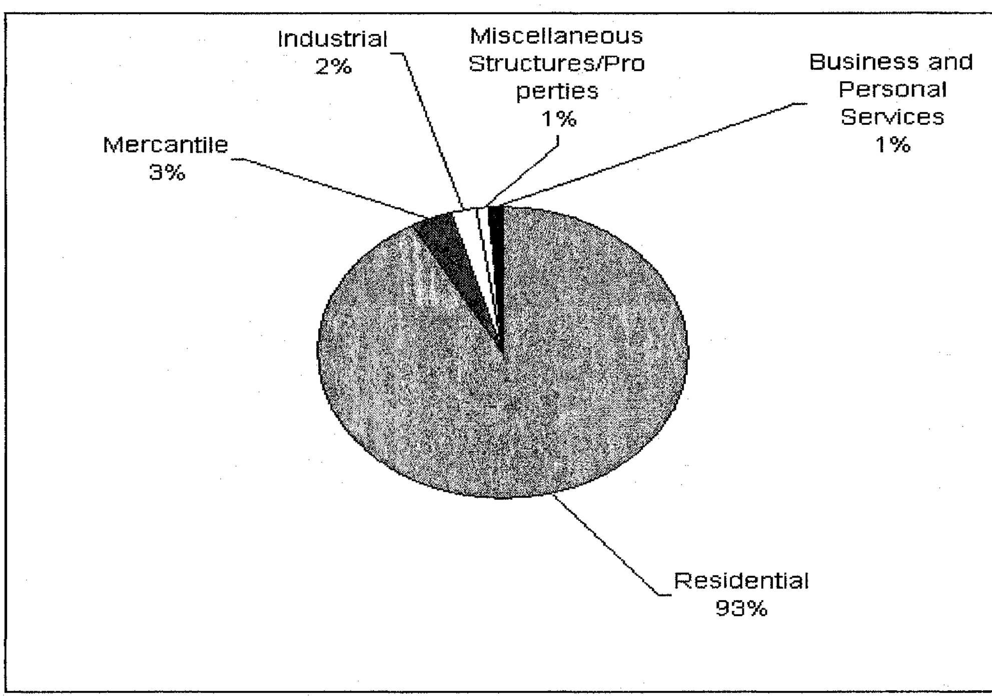

Figure 5.11 Ontario basement fires

Table 5.39 and Figure 5.11 show that the majority, 92% of basement fires occur in residential occupancies (Figure 5.11 shows round numbers), followed by mercantile occupancies at 3.4% and industrial occupancies at 2.2%. Table 5.40 and Figure 5.12 show the distribution of residential basement fires by type of property.

Table 5.40. Ontario's residential basement fires (1995-2002)

Type of property	Number of fires	% of total residential basement fires
Single-family dwellings	58	71.6%
Semi-detached dwellings	5	6.2%
Townhouses/ Row houses	6	7.4%
Other residential structures	12	14.8%

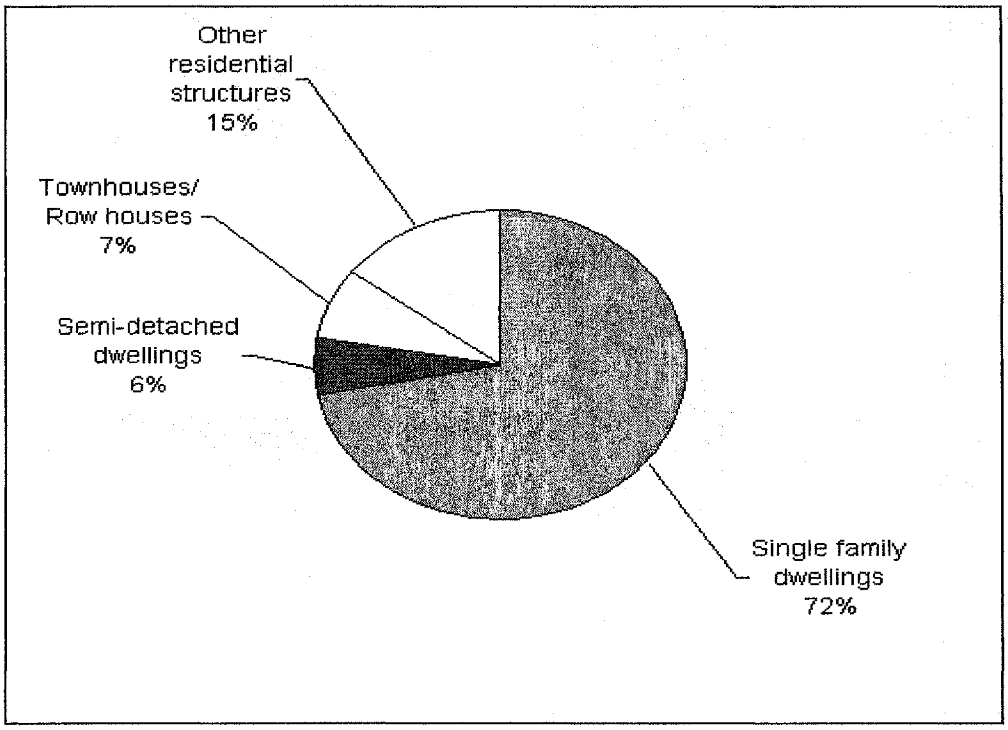

Figure 5.12 Ontario residential dwellings basement fires

Table 5.40 and Fig. 5.12 show that typical residential dwellings such as single family dwellings, semi-detached dwellings, and townhouses or row houses (large in numbers) account for a total of eighty five percent of basement fires whereas all other residential structures account for only fifteen percent of basement fires. The highest numbers of basement fires occur in single family dwellings in which 72% of the fires occurred.

Table 5.41. Source of ignition of Basement fires

Source of ignition	**Number of fires**	**% of total fires**
Undetermined	25	28.4%
Distribution Equipment (includes panel boards, fuses, circuit breaker etc)	9	10.2%
Other Electrical	6	6.8%
Clothes Dryer	5	5.7%
Circuit Wiring - Copper	5	5.7%
Smokers' Articles (e.g. cigarettes, cigars, pipes already ignited)	5	5.7%
Wood burning stove	3	3.4%
Central Heating/Cooling Unit	3	3.4%
Water Heater	3	3.4%
Matches (open flame)	2	2.3%
Refrigerator, Freezer (includes vending machine)	2	2.3%
Other Electrical Distribution Item	2	2.3%
Cutting/Welding Equipment	2	2.3%
Other Open Flame Tools/Smokers' Articles	2	2.3%
Oven	1	1.1%
Cord, Cable for Appliance, Electrical Articles	1	1.1%
Space Heater - Portable	1	1.1%
Fireplace - Masonry	1	1.1%
Stove, Range-top burner	1	1.1%
Flue Pipe	1	1.1%
Lighters (open flame)	1	1.1%
Vehicle - Mechanical	1	1.1%
Hot Ashes, Embers, Spark	1	1.1%
Chemical Reaction (e.g. spontaneous combustion, etc.)	1	1.1%
Other	1	1.1%
Chimney - Factory Built	1	1.1%
Other Mechanical	1	1.1%
Blow Torch, Bunsen Burner.	1	1.1%
TOTAL	88	100.0%

The data of Table 5.41 show that 28.4 % of the total fires that originate in basements have an undetermined source of ignition. Amongst the known sources of ignition, 10.2% of the fires originated from electrical distribution equipment, such as panel boards, fuses and circuit breaker, followed by other electrical sources at 6.8%, clothes dryer, copper circuit wiring and smoker's articles (e.g. cigarettes, cigars, pipes already ignited etc) accounted at 5.7% each. Wood burning stove, central heating/cooling unit and water heater accounted for a still lower share 3.4% each. Because of the large number of undetermined cause of ignitions it may be possible that some other causes may be important but they can not be identified.

Table 5.42. First ignited item for Basement fires

Item first ignited	**Number of fires**	**% of total fires**
Undetermined	22	25.0%
Electrical Wiring Insulation	10	11.4%
Structural Member	6	6.8%
Other	6	6.8%
Wood	5	5.7%
Other Soft Goods, Wearing Apparel	4	4.5%
Multiple Objects or Materials	3	3.4%
Floor	3	3.4%
Other Flammable, Combustible Liquid	3	3.4%
Mattress, Pillow	2	2.3%
Wearing Apparel on a Person	2	2.3%
Upholstered Sofa, Chair, etc.	2	2.3%
Interior Wall/Ceiling	2	2.3%
Diesel Fuel/Fuel Oil	2	2.3%
Agricultural Product - Grown (e.g. straw, seeds, etc.)	2	2.3%
Plastic	2	2.3%
Paper, Cardboard	2	2.3%
Natural Gas	2	2.3%
Other Building Component	1	1.1%
Linen Other than Bedding	1	1.1%
Cabinetry	1	1.1%

Table 5.42. (cont.) First ignited item for Basement fires

Item first ignited	Number of fires	% of total fires
Nest	1	1.1%
Other Gases	1	1.1%
Gasoline	1	1.1%
Creosote (chimney, flue pipe)	1	1.1%
Insulation	1	1.1%
TOTAL	88	100.0%

Table 5.42 shows the number of basement fires as a function of first ignited item. The first ignited item could not be determined for 25% of the total fires. Among the known first ignited items, electrical wiring insulation accounted for 11.4% of the fires, followed by structural members at 6.8%, other objects at 6.8%, wood at 5.7%, other soft goods and wearing apparel at 4.5%.

This analysis shows that majority (about 85%) of residential basement fires occur in residential dwellings and the single family homes alone account for about 72%. From the known causes of ignition, electrical distribution equipment causes the majority of basement fires, and from the known items first ignited electrical wiring has the highest contribution at 11.4%.

5.2. Impact of fire protection systems in Residential Occupancies

Residential properties are considered in more detail in this section as they account for the highest percentage of fire deaths 95%, the highest percentage of fire injuries 79%, the highest percentage of fire incidents 73%, and the highest percentage 59% of property losses as shown in Figures 5.7 through 5.10. It was therefore decided to select only residential properties for the purpose of studying the impact of active fire protection systems on life safety and losses. The impact was determined by evaluating the number of deaths, injuries, and amount of property damage occurring in fire incidents where any one of the fire protection systems (heat detector/ smoke detector or sprinklers) was present, as compared to those having no fire protection at all. The impact of fire protection systems was evaluated separately for residential dwellings (i.e. single family homes, semi-detached dwellings and townhouses or row houses) and for all other residential structures excluding these dwellings.

5.2.1. Impact of fire protection systems on residential properties

This analysis was done by evaluating residential groups which included multi unit dwellings with 2-6 units, 7-12 units, over 12 units; detached garages; apartment buildings with some businesses, and rooming-boarding-lodging houses. These groups were selected on the basis of frequency of fire incidents, and the selected groups account for more than eighty five percent of all residential fires excluding fires in residential dwellings. The evaluation for residential dwellings which include detached dwellings, semi-attached dwellings, and townhouses or row houses, has been done separately. To find the impact of active fire protection systems, the fire incidents having one of or a combination of smoke alarms (battery operated or hard wired), smoke detectors (connected to fire alarm system), heat detectors, and sprinklers, have been compared with those incidents having none of the fire protection systems, in terms of life loss and property loss. Efforts have also been made to evaluate the relative performance of smoke detectors, heat detectors and sprinklers. For this analysis battery operated smoke alarms and interconnected battery operated smoke alarms have been grouped together. A similar grouping has been made for hard wired smoke alarms and interconnected hard wired smoke alarms. All sprinkler installations are required to be associated with the provision of detectors for life safety reasons because it has been experienced that detectors respond faster than the sprinkler systems. Table 5.43 shows all the losses for residential units.

Table 5.43 Selected Residential Occupancies Fires (1995-2002)

Type of unit	Number of Fires	% of total fires	Number of Deaths	Deaths per 100 fires	Number of Injuries	Injuries per 100 fires
Multi-Unit Dwelling - Over 12 Units	14422	51.2%	220	1.5	2474	17.2
Multi-Unit Dwelling - 2 to 6 Units	4515	16.0%	102	2.3	948	21.0
Detached Garage	1927	6.8%	5	0.3	114	5.9
Multi-Unit Dwelling - 7 to 12 Units	1585	5.6%	20	1.3	341	21.5
Apartment, Flat, Tenement with Business	1062	3.8%	25	2.4	178	16.8
Rooming/Boarding/Lodging House	912	3.2%	19	2.1	262	28.7

Table 5.44 Property damage for Residential Occupancies (1995-2002)

Type of unit	Number of Fires	Direct Property Damage	Property Damage per Fire
Multi-Unit Dwelling - Over 12 Units	14422	$ 129,525,235	$ 8,981
Multi-Unit Dwelling - 2 to 6 Units	4515	$ 100,870,151	$ 22,341
Detached Garage	1927	$ 32,225,123	$ 16,723
Multi-Unit Dwelling - 7 to 12 Units	1585	$ 22,801,230	$ 14,386
Apartment, Flat, Tenement with Business	1062	$ 30,323,140	$ 28,553
Rooming/Boarding/Lodging House	912	$ 20,102,924	$ 22,043

Table 5.43 shows that the multi-unit dwelling (MUD) – over 12 units, accounts for the highest (51.2%) reported fire incidents, followed by MUD – 2 to 6 units at 16%. Apartment/ flat/ tenement with business show the highest rate of deaths per 100 fires at 2.4, followed by MUD – 2 to 6 units at 2.3, and rooming/ boarding/ lodging house at 2.1.

The rate of injuries was found to be the highest for rooming/ boarding/ lodging houses at 28.7 injuries per 100 fires, followed by MUD – 7 to 12 units at 21.5.

Table 5.44 shows the property damages for the selected occupancies. The rate of property damage has been found to be the highest for apartment/ flat/ tenement with business at $28,553 per fire, followed by MUD – 2 to 6 units at $22,341, and rooming/ boarding/ lodging house at $22,043.

5.2.1.1. Multi unit dwelling (MUD) – Over 12 units

This section describes the impact of fire protection systems on fire losses and property damage for multi unit dwellings over 12 units.

Table 5.45 Impact of fire protection systems in MUD (multi-unit dwellings: Over 12 units)

Device	Number of Fires	% of total fires	Number of Deaths	Deaths per 100 fires	Number of Injuries	Injuries per 100 fires
Smoke Alarm (hard wired)	3167	23.3%	76	2.4	501	15.8
Smoke Alarm (battery operated)	2115	15.6%	60	2.8	508	24.0
Smoke Detector (connected to fire alarm system)	1261	9.3%	11	0.9	228	18.1
Sprinkler + detector	1075	7.9%	7	0.7	102	9.5
Heat Detector	1006	7.4%	13	1.3	182	18.1
None	460	3.4%	3	0.7	30	6.5

Table 5.46 Property damage for MUD (multi-unit dwellings: Over 12 units)

Type of device	Number of Fires	Direct Property Damage	Property Damage per Fire
Smoke Alarm (hard wired)	3167	$ 32,786,203	$ 10,352
Smoke Alarm (battery operated)	2115	$ 20,915,002	$ 9,889
Smoke Detector (connected to fire alarm system)	1261	$ 11,169,312	$ 8,858
Sprinkler + detector	1075	$ 4,293,899	$ 3,994
Heat Detector	1006	$ 10,311,493	$ 10,250
None	460	$ 3,711,126	$ 8,068

Table 5.45 shows the fire incidents having some kind of fire protection system as well as those with no fire protection at all. Sprinkler installations are always associated with detectors. In the reported fires, the majority of the dwellings experiencing fires (23.3%) have hard wired smoke alarms, followed by battery operated smoke alarms at 15.6%, smoke detectors connected to fire alarm system at 9.3%, sprinklers at 7.9%, and heat detectors at 7.4%. Only 3.4% of these dwellings did not have any kind of fire protection system. Fires in dwellings with no fire protection of any kind, as well as those with sprinklers, show the minimum deaths per 100 fires at 0.7. The dwellings with no fire protection show a minimum rate of injuries per 100 fires at 6.5, whereas those with sprinklers are at 9.5. Provision of either of heat detectors, smoke alarms or smoke detectors shows higher rates of deaths and injuries as compared to those for sprinklers.

Table 5.46 shows that fires in dwellings with sprinklers show the minimum property damage at $3,994 per fire, and those with no fire protection are at $8,068. The smoke detectors connected to fire alarm however show the property damage at $8,858 per fire. The results show that performance of sprinklers is better than others followed by smoke detectors connected to fire alarm system is better than heat detectors and smoke alarms or smoke detectors. Results also indicate that provision of sprinklers is likely to minimize the rate of deaths, injuries, and the property damages.

The values of Table 5.45 show that buildings with no active fire protection systems performed better than buildings with systems installed. In fact, the numbers of fires which result in deaths or injuries are very small especially in case of buildings without any fire protection and hence no clear-cut decision can be made. However, when we look at the property damage rates, the results are clear as the installations with sprinklers clearly show the lowest rate of property damage when compared with those with no fire protection system.

5.2.1.2. Multi unit dwelling (2 to 6 units)

This section describes the impact of fire protection systems on fire losses and property damages for multi unit dwellings having 2 to 6 units.

TABLE 5.47 Impact of fire protection systems in MUD (multi-unit dwellings: 2 to 6 units)

Device	Number of Fires	% of total fires	Number of Deaths	Deaths per 100 fires	Number of Injuries	Injuries per 100 fires
Smoke Alarm (battery operated)	2069	51.4%	62	3.0	514	24.8
Smoke Alarm (hard wired)	867	21.5%	19	2.2	161	18.6
None	580	14.4%	10	1.7	83	14.3
Smoke Detector (connected to fire alarm system)	103	2.6%	1	1.0	19	18.4
Heat Detector	57	1.4%	1	1.8	13	22.8
Sprinkler + detector	27	0.7%	0	0.0	1	3.7

TABLE 5.48 Property damages for MUD (multi-unit dwellings: 2 to 6 Units)

Type of device	Number of Fires	Direct Property Damage	Property Damage per Fire
Smoke Alarm (battery operated)	2069	$ 47,007,869	$ 22,720
Smoke Alarm (hard wired)	867	$ 15,448,578	$ 17,818
None	580	$ 12,704,238	$ 21,904
Smoke Detector (connected to fire alarm system)	103	$ 1,989,461	$ 19,315
Heat Detector	57	$ 997,229	$ 17,495
Sprinkler + detector	27	$ 162,885	$ 6,033

Table 5.47 shows the fire incidents in dwellings having either of sprinklers, heat detectors, smoke alarms or smoke detectors, as well as those with no fire protection at all. In the reported fires, the majority of the dwellings have battery operated smoke alarms 51.4%, followed by hard wired smoke alarms at 21.5%, smoke detectors connected to fire alarm system at 2.6%, sprinklers at 0.7%, and heat detectors at 1.4%. 14.4% of these dwellings did not have any kind of fire protection system. Fires in dwellings with no fire protection of any kind show a rate of deaths per 100 fires at 1.7, whereas those with smoke detectors are at 1.0, and those with sprinklers show a zero rate of deaths. The dwellings with no fire protection show a rate of injuries per 100 fires at 14.3, whereas those with sprinklers are at 3.7.

Table 5.48 shows that fires in dwellings with no fire protection show the second highest rate of property damages at $21, 904 per fire, whereas sprinklers show the minimum at $6,033. Results indicate that for multi-unit dwellings with 2 to 6 units, the performance of sprinklers is better than other fire protection devices, as they minimize the rate of deaths, injuries as well as the property damage. It is also shown that performance of hard wired smoke alarms is better than battery operated smoke alarms due to lesser rates of deaths, injuries and the property damage.

5.2.1.3. Multi unit dwelling (7 to 12 units)

This section describes the impact of fire protection systems on fire losses and property damage for multi unit dwellings having 7 to 12 units.

TABLE 5.49 Impact of fire protection systems in MUD (multi-unit dwellings: 7 to 12 units)

Device	Number of Fires	% of total fires	Number of Deaths	Deaths per 100 fires	Number of Injuries	Injuries per 100 fires
Smoke Alarm (battery operated)	392	26.4%	1	0.3	84	21.4
Smoke Alarm (hard wired)	404	27.2%	10	2.5	92	22.8
Smoke Detector (connected to fire alarm system)	138	9.3%	1	0.7	29	21.0
Heat Detector	88	5.9%	1	1.1	13	14.8
None	85	5.7%	5	5.9	15	17.6
Sprinkler + detector	34	2.3%	0	0.0	4	11.8

TABLE 5.50 Property damage for MUD (multi-unit dwellings: 7 to 12 Units)

Type of device	Number of Fires	Direct Property Damage	Property Damage per Fire
Smoke Alarm (battery operated)	392	$ 6,324,634	$ 16,134
Smoke Alarm (hard wired)	404	$ 6,566,197	$ 16,253
Smoke Detector (connected to fire alarm system)	138	$ 1,304,505	$ 9,453
Heat Detector	88	$ 790,884	$ 8,987
None	85	$ 1,995,027	$ 23,471
Sprinkler	34	$ 87,528	$ 2,574

Table 5.49 shows the fire incidents of dwellings having either of sprinklers, heat detectors, smoke alarms or smoke detectors, as well as those having no fire protection at all. In the reported fires, majority of the dwellings have hard wired smoke alarms 27.2%, followed by battery operated smoke alarms at 26.4%, smoke detectors connected to fire alarm system at 9.3%, heat detectors at 5.9%, and sprinklers at 2.3%. 5.7% of these dwellings did not have any kind of fire protection system. Fires in dwellings with no fire protection of any kind show the highest rate of deaths per 100 fires at 5.9. The dwellings with hard wired smoke alarm show a death rate of 2.5 deaths per 100 fires, followed by those with heat detectors at 1.1, smoke detectors connected to fire alarm at 0.7, battery operated smoke alarms at 0.3, and sprinklers at zero. The dwellings with no fire protection show a rate of injuries per 100 fires at 17.6, whereas those with heat detectors are at 14.8, and sprinklers at the minimum of 11.8.

Table 5.50 shows that fires in dwellings with no fire protection show the highest rate of property damages at $23,471 per fire, whereas sprinklers show the minimum at $2,574. The dwellings with hard wired smoke alarm show the rate of property damages at $16,253 per fire, followed by battery operated smoke alarms at $16,134, smoke detectors connected to fire alarm at $9,453, and heat detectors at $8,987. The results indicate that the performance of sprinklers is better than all other fire protection devices. The results also show that provision of either smoke alarms or smoke detectors, heat detectors, or sprinklers, is likely to reduce the rate of deaths as well as the rate of property damages in the multi-unit dwellings having 7 to 12 units.

5.2.1.4 Rooming/Boarding/Lodging Houses

This section describes the impact of fire protection systems on fire losses and property damage for rooming, boarding, or lodging houses.

TABLE 5.51 Impact of fire protection systems in Rooming/ Boarding/ Lodging Houses

Device	Number of Fires	% of total fires	Number of Deaths	Deaths per 100 fires	Number of Injuries	Injuries per 100 fires
Smoke Alarm (battery operated)	270	31.6%	5	1.9	68	25.2
Smoke Alarm (hard wired)	258	30.2%	6	2.3	70	27.1
Smoke Detector (connected to fire alarm system)	71	8.3%	0	0.0	19	26.8
None	57	6.7%	2	3.5	11	19.3
Heat Detector	28	3.3%	1	3.6	15	53.6
Sprinkler	21	2.5%	1	4.8	10	47.6

TABLE 5.52 Property damages for rooming/ boarding/ lodging houses

Type of device	Number of Fires	Direct Property Damage	Property Damage per Fire
Smoke Alarm (battery operated)	270	$ 3,157,718	$ 11,695
Smoke Alarm (hard wired)	258	$ 4,281,029	$ 16,593
Smoke Detector (connected to fire alarm system)	71	$ 279,887	$ 3,942
None	57	$ 952,006	$ 16,702
Heat Detector	28	$ 562,180	$ 20,078
Sprinkler	21	$ 188,715	$ 8,986

Table 5.51 shows the fire incidents in rooming, boarding, or lodging houses having fire protection systems, as well as those having no fire protection of any kind. Table

shows that the majority of these houses that had fires have battery operated smoke alarms 31.6%, followed by hard wired smoke alarms at 30.2%, smoke detectors connected to fire alarm system at 8.3%, heat detectors at 3.3%, and sprinklers at 2.5%. 6.7% of these houses did not have any kind of fire protection system. For these houses, the table shows a death rate of 3.5 deaths per 100 fires in the absence of fire protection devices, whereas those with hard wired smoke detectors show 2.3 deaths per 100 fires, followed by battery operated smoke alarms at 1.9, and smoke detectors connected to fire alarms at zero. Rooming/ boarding/ lodging houses with no fire protection however show the minimum rate of injuries per 100 fires at 19.3.

Table 5.52 shows that fires in rooming/ boarding/ lodging houses with no fire protection arrangement show the second highest rate of property damage at $16,702 per fire, whereas smoke detectors connected to fire alarm system show the minimum at $3,942 and sprinklers are the second lowest at $8,986. The results indicate that for rooming, boarding, or lodging houses, the provision of smoke detectors connected to fire alarm system is likely to minimize the rate of deaths as well as property damage, and is a better choice than sprinklers.

Due to the limited data used in the analysis, the findings are not considered accurate with a high confidence level.

5.2.1.5 Detached Garages

This section describes the impact of fire protection systems on fire losses and property damage for detached garages.

TABLE 5.53 Impact of fire protection systems in Detached Garages

Device	Number of Fires	% of total fires	Number of Deaths	Deaths per 100 fires	Number of Injuries	Injuries per 100 fires
None	1487	94.4%	5	0.3	90	6.1
Smoke Alarm (battery operated)	28	1.8%	0	0.0	6	21.4
Smoke Alarm (hard wired)	5	0.3%	0	0.0	0	0.0
Heat Detector	2	0.1%	0	0.0	0	0.0

TABLE 5.54 Property damages for Detached Garages

Type of device	Number of Fires	Direct Property Damage	Property Damage per Fire
None	1487	$ 24,781,298	$ 16,665
Smoke Alarm (battery operated)	28	$ 620,100	$ 22,146
Smoke Alarm (hard wired)	5	$ 73,020	$ 14,604
Heat Detector	2	$ 5,500	$ 2,750

Table 5.53 shows the fire incidents in detached garages having either heat detectors, or smoke alarms as well as those having no fire protection of any kind. The table shows that the majority of these garages (94.4%) that experienced fires, do not have any kind of fire protection system, however 1.8% of them have battery operated smoke alarms, 0.3% have hard wired smoke alarms, and 0.1% have heat detectors. Garages without any protection show a death rate of 0.3 deaths per 100 fires, whereas no death is shown by those having either of heat detector or a smoke alarm. Garages with no fire protection show the rate of injuries per 100 fires at 6.1 but those with a heat detector or a hard wired smoke alarm show zero injuries.

Table 5.54 shows that fires in garages with no fire protection show the second highest rate of property damages at $16,665 per fire but those with a heat detector show the minimum at $5,500 and the second lowest is hard wired smoke alarm at $14,604. The results indicate that for detached garages, the provision of heat detectors is likely to minimize the rates of deaths, injuries, as well as property damages.

5.2.1.6 Apartment, Flat, Tenement with business

The apartment, flat, and tenement with business are dual purpose buildings wherein the residential and business functions can be performed in separate quarters in same building. This section describes the impact of fire protection systems on fire losses and property damage for these occupancies.

TABLE 5.55 Impact of fire protection systems in Apartment, Flat, Tenement with business

Device	Number of Fires	% of total fires	Number of Deaths	Deaths per 100 fires	Number of Injuries	Injuries per 100 fires
Heat Detector	36	3.7%	0	0.0	4	11.1
None	180	18.7%	2	1.1	34	18.9
Smoke Alarm (battery operated)	287	29.9%	11	3.8	38	13.2
Smoke Alarm (hard wired)	206	21.4%	8	3.9	36	17.5
Smoke Detector (connected to fire alarm system)	70	7.3%	2	2.9	16	22.9
Sprinkler	35	3.6%	0	0.0	1	2.9

TABLE 5.56 Property damages for Apartment, Flat, Tenement with business

Type of device	Number of Fires	Direct Property Damage	Property Damage per Fire
Heat Detector	36	$ 398,130	$ 11,059
None	180	$ 5,059,004	$ 28,106
Smoke Alarm (battery operated)	287	$ 11,610,611	$ 40,455
Smoke Alarm (hard wired)	206	$ 4,579,162	$ 22,229
Smoke Detector (connected to fire alarm system)	70	$ 636,863	$ 9,098
Sprinkler	35	$ 208,525	$ 5,958

Table 5.55 shows the fire incidents for these residential with business units having either of sprinklers, heat detectors, smoke alarms or smoke detectors, as well as those with no fire protection at all. In the reported fires, the majority of the units that experienced fires have battery operated smoke alarms 29.9%, followed by hard wired smoke alarms at 21.4%, smoke detectors connected to fire alarm system at 7.3%, heat detectors at 3.7%, and sprinklers at 3.6%. 18.7% of these units did not have any kind of fire protection system. Fires in these residential with business units having no fire protection of any kind show a rate of deaths per 100 fires at 1.1, whereas those with sprinklers or heat detectors show a zero rate of deaths. Units with no fire protection show the second highest rate of injuries per 100 fires at 18.9 whereas those with sprinklers are the minimum at 2.9 and those with heat detectors stand as second lowest at 11.1.

Table 5.56 shows that fires in the units with no fire protection show the second highest rate of property damages at $28,106 per fire, whereas the sprinklers show the minimum at $5,958 and those with heat detectors are at $11,059. The results indicate that the performance of sprinklers is the best of all, followed by heat detectors. The results also show that provision of sprinklers for apartment, flat, and tenement with business, is likely to bring down the rate of deaths to zero, and minimize the rate of injuries as well as the property damage.

5.2.2 Impact of fire protection systems on Residential dwellings

This section analyses residential dwellings which include single-family dwellings, semi-detached homes, and townhouses or row houses. To find the impact of active fire protection systems in these dwellings, fire incidents having either of smoke alarms, smoke detectors, heat detectors, or sprinklers, have been compared with those incidents having no fire protection device at all, in terms of life loss and property loss. Efforts have also been made to evaluate the relative performance of smoke detectors, heat detectors and sprinklers. For this analysis battery operated smoke alarms and interconnected battery operated smoke alarms have been grouped together. A similar grouping has been done for hard wired smoke alarms and interconnected hard wired smoke alarms. Table 5.57 shows all the losses for residential dwellings.

Table 5.57 Residential dwellings fires (1995-2002)

Type of unit	Number of Fires	% of total fires	Number of Deaths	Deaths per 100 fires	Number of Injuries	Injuries per 100 fires
Detached Dwelling	27981	78.9%	460	1.6	2679	9.6
Attached Dwelling (e.g. row house, townhouse, etc.)	3890	11.0%	67	1.7	657	16.9
Semi-Detached Dwelling	3584	10.1%	45	1.3	630	17.6

Table 5.58 Property damage for fires in Residential dwellings (1995-2002)

Type of unit	Number of Fires	Direct Property Damage	Property Damage per Fire
Detached Dwelling	27981	$ 817,708,895	$ 29,224
Attached Dwelling (e.g. row house, townhouse, etc.)	3890	$ 103,286,624	$ 26,552
Semi-Detached Dwelling	3584	$ 66,186,191	$ 18,467

Table 5.57 shows that detached dwellings account for the highest (78.9%) fire incidents (indicating higher population of single homes and thus higher living standards of Canadians), followed by attached dwellings at 11%, and semi-detached dwellings at 10.1%. Attached dwellings show the highest rate of deaths per 100 fires which is at 1.7, followed by detached dwellings at 1.6, and semi-detached dwellings at 1.3. The rate of

injuries was found to be the highest for semi-detached dwellings at 17.6 injuries per 100 fires, followed by attached dwellings at 16.9, and detached dwellings at 9.6.

Table 5.58 shows the property damages for the residential dwellings. The rate of property damages has been found to be the highest for detached dwellings at $29,224 per fire, followed by attached dwellings at $26,552 and semi-detached dwellings at $18,467.

5.2.2.1 Impact of fire protection systems in detached dwellings

Detached dwellings are single family houses. This section describes the impact of fire protection systems on fire losses and property damage for detached dwellings.

Table 5.59 Impact of fire protection systems in Detached dwellings

Device	Number of Fires	% of total fires	Number of Deaths	Deaths per 100 fires	Number of Injuries	Injuries per 100 fires
Smoke Alarm (battery operated)	13,277	57.4%	208	1.6	1329	10.0
Smoke Alarm (hard wired)	3,926	17.0%	62	1.6	425	10.8
Smoke Detector (connected to fire alarm system)	245	1.1%	3	1.2	21	8.6
Heat Detector	32	0.1%	1	3.1	3	9.4
Sprinkler	8	<1%	0	0.0	1	12.5
None	4885	21.1%	124	2.5	439	9.0

Table 5.60 Property damages for fires in detached dwellings

Type of device	Number of Fires	Direct Property Damage	Property Damage per Fire
Smoke Alarm (battery operated)	13,277	$ 367,399,555	$ 27,672
Smoke Alarm (hard wired)	3,926	$ 113,433,436	$ 28,893
Smoke Detector (connected to fire alarm system)	245	$ 10,473,932	$ 42,751
Heat Detector	32	$ 1,204,111	$ 37,628
Sprinkler	8	$ 92,600	$ 11,575
None	4885	$ 134,787,687	$ 27,592

Table 5.59 shows the fire incidents for detached dwellings having either sprinklers, heat detectors, smoke alarms or smoke detectors, as well as those with no fire protection at all. In the reported fires, the majority of these dwellings have battery operated smoke alarms 57.4%, followed by hard wired smoke alarms at 17%, smoke detectors connected to fire alarm system at 1.1%, and heat detectors and sprinklers at <1%. 21.1% of these units did not have any kind of fire protection system. Fires in the detached dwellings having no fire protection of any kind show a rate of deaths per 100 fires of 2.5, whereas those with smoke alarms battery operated or hard wired are at 1.6 each, followed by smoke detectors connected to fire alarm system at 1.2, and sprinklers with zero deaths. Detached dwellings with no fire protection show a rate of injuries per 100 fires of 9 whereas those with smoke detectors connected to fire alarm system are at 8.6. The rate of injuries in these dwellings with sprinklers are shown at 12.5 injuries per 100 fires, followed by hard wired smoke alarms at 10.8, and battery operated smoke alarms at 10, however these numbers are not accurate due to insufficient data.

Table 5.60 shows that fires in the units with no fire protection show a rate of property damages at $27,592 per fire, but those having sprinklers show the lowest rate at $11,575. The dwellings with battery operated smoke alarms however show the rate of $27,672 per fire which is similar to that for no protection incidents. The results indicate that performance of sprinklers is better than all other devices. The results also show that provision of sprinklers for detached dwellings is likely to minimize the rate of deaths as well as the rate of property damage. The numbers of incidents having sprinklers are however very small and hence no concrete conclusion can be made.

5.2.2.3 Impact of fire protection systems in semi-detached dwellings

This section describes the impact of fire protection systems on fire losses and property damages for semi-detached dwellings.

Table 5.61 Impact of fire protection systems in Semi-detached dwellings

Device	Number of Fires	% of total fires	Number of Deaths	Deaths per 100 fires	Number of Injuries	Injuries per 100 fires
Smoke Alarm (battery operated)	1,912	62.3%	28	1.5	369	19.3
Smoke Alarm (hard wired)	481	15.7%	11	2.3	93	19.3
Smoke Detector (connected to fire alarm system)	18	0.6%	4	22.2	1	5.6
Heat Detector	2	0.1%	0	0.0	0	0.0
None	552	18.0%	2	0.4	79	14.3

Table 5.62 Property damages for fires in semi-detached dwellings

Device	Number of fire incidents	Direct property damage ($)	Rate per fire
Smoke Alarm (battery operated)	1,912	$ 31,863,449	$ 16,665
Smoke Alarm (hard wired)	481	$ 9,525,040	$ 19,803
Smoke Detector (connected to fire alarm system)	18	$ 402,765	$ 22,376
Heat Detector	2	$ 10,000	$ 5,000
None	552	$ 11,830,529	$ 21,432

Table 5.61 shows the fire incidents for semi-detached dwellings having either sprinklers, heat detectors, smoke alarms or smoke detectors, as well as those with no fire protection at all. In the reported fires, the majority of these dwellings have battery operated smoke alarms 62.3%, followed by hard wired smoke alarms at 15.7%, smoke detectors connected to fire alarm system at 0.6%, heat detectors at 0.1%. Sprinklers were not reported for these buildings. 18% of these units did not have any kind of fire protection system. Fires in semi-detached dwellings with no fire protection of any kind show a rate of deaths per 100 fires at 0.4, whereas the incident having heat detectors show zero deaths. The fire incidents with smoke detector connected to fire alarm system show the highest rate of deaths per 100 fires at 22.2, followed by hard wired smoke alarms at 2.3, and battery operated smoke alarms at 1.5. Semi-detached dwellings with no fire protection show the rate of injuries per 100 fires at 14.3, but those with smoke detectors connected to fire alarm system are at 5.6, and heat detectors show zero injuries. The values however are not statistically significant due to the low number of incidents reported.

Table 5.62 shows that fire incidents in the dwellings with no fire protection show the rate of property damages at $21,432 per fire, but those having heat detectors are at $5,000. Fire incidents with hard wired smoke alarms show property damages at $19,803 per fire, followed by battery operated smoke alarms at $16,665. The results indicate that performance of heat detectors is better than all others, but due to the low number of fire incidents, the results can not lead to any conclusions.

5.2.2.4 Impact of fire protection systems in Townhouses or Row houses

These are a set of homes constructed in a row or one above the other with common side walls. This section describes the impact of fire protection systems on fire losses and property damages for townhouses or row houses.

Table 5.63 Impact of fire protection systems in Townhouse/ Row houses

Device	Number of Fires	% of total fires	Number of Deaths	Deaths per 100 fires	Number of Injuries	Injuries per 100 fires
Smoke Alarm (battery operated)	1,563	46.1%	40	2.6	313	20.0
Smoke Alarm (hard wired)	1,229	36.2%	14	1.1	192	15.6
Smoke Detector (connected to fire alarm system)	24	0.7%	0	0.0	4	16.7
Heat Detector	8	0.2%	0	0.0	1	12.5
Sprinkler	8	0.2%	0	0.0	0	0.0
None	437	12.9%	8	1.8	69	15.8

Table 5.64 Property damage for fires in Townhouse/ Row houses

Device	Number of fire incidents	Direct property damage ($)	Rate per fire
Smoke Alarm (battery operated)	1,563	$ 29,454,975	$ 18,845
Smoke Alarm (hard wired)	1,229	$ 26,094,661	$ 21,232
Smoke Detector (connected to fire alarm system)	24	$ 146,329	$ 6,097
Heat Detector	8	$ 29,750	$ 3,719
Sprinkler	8	$ 37,875	$ 4,734
None	437	$ 34,531,928	$ 79,020

Table 5.63 shows the fire incidents for townhouses or row houses having either of sprinklers, heat detectors, smoke alarms or smoke detectors, as well as those with no fire protection at all. In the reported fires, majority of these houses have battery operated

smoke alarms 46.1%, followed by hard wired smoke alarms at 36.2%, smoke detectors connected to fire alarm system at 0.7%, heat detectors at 0.2%, and sprinklers at 0.2%. 12.9% of these houses did not have any kind of fire protection system. Fires in the houses having no fire protection of any kind show the rate of deaths per 100 fires at 1.8, but those with hard wired smoke alarms are at 1.1, and zero deaths are shown by each of the, smoke detectors connected to fire alarm system, heat detectors and sprinklers. Fire incidents in townhouses or row houses with no fire protection show the rate of injuries per 100 fires at 15.8 whereas those with hard wired smoke alarms show 15.6, followed by heat detectors at 12.5, and sprinklers at 0.

Table 5.64 shows that fires in the townhouses or row houses with no fire protection show the highest rate of property damages at $79,020 per fire, but those having hard wired smoke alarms show $21,232 per fire, followed by battery operated smoke alarms at $18,845, smoke detectors connected to fire alarm at $6,097, sprinklers at $4,734, and heat detectors at $3,719.

The results indicate that performance of sprinklers followed by heat detectors, smoke detectors connected to fire alarm, and hard wired smoke alarms is better than those with no fire protection.

5.3 Summary

Overall, the analysis of fires in residential properties leads to the following conclusions:

1. Multi-unit dwellings (Over 12 units) alone, account for half of the total residential fires. If these are considered along with MUD (2 to 6 units) and MUD (7 to 12 units) then all together account for nearly 3/4 of the total residential fires, and are

responsible for the majority of deaths, injuries, and property damage. Based on the results of Tables 5.45 through 5.50, provision of sprinklers reduces the rate of deaths, injuries and property damage for multi-unit dwellings with 2 to 6 units as well as 7 to 12 units. For multi-unit dwellings over 12 units, provision of sprinklers however resulted in the lowest rate of deaths as well as the property damage.

2. When sufficient data were available, the analysis showed that generally the occupancies having no fire protection devices have higher deaths and injuries, and incur high property damage when compared to those with fire protection systems. Tables 5.59 to 5.64 show that in general the provision of a fire protection system for single family homes and townhouses or row houses, reduces the rates of deaths, injuries and property damage. No concrete conclusion could however be made for semi-detached homes in the absence of sufficient data. Smoke detectors connected to fire alarm systems are preferred over smoke alarms, especially for multi-unit dwellings over 12 units as well as those with 2 to 6 units (both together accounting for about 2/3 of total fires), as their presence reduces the rate of deaths, injuries and property damage. In general, smoke detectors connected to a fire alarm system performed better than other smoke detectors. One of the reasons may be the fact that central alarm system may detect malfunctioning units and trigger a warning. Hardwired smoke alarms, which are expected to be always connected to a power supply performed better than battery operated smoke alarms, which may have dead batteries or batteries taken out to avoid nuisance

alarms. Earlier studies have indicated that provision of smoke alarms in Canadian homes has helped in reducing death rates by about forty percent [22].

3. Tables 5.45 through 5.64 for different occupancies clearly show that in general the performance of sprinklers is better than all other fire protection devices and they help in reducing rates of deaths, injuries, and property damages.

In addition to the above, a recently published statistical report of October 2004 prepared by NFPA [40] regarding structure fires in selected occupancies by extent of damage and sprinkler presence for the period 1980 to 1998, also shows that the presence of sprinklers help in restricting fire spread and reducing property damage. Table 5.65 shows some of the findings of the NFPA study.

Table 5.65. NFPA statistical report for the period 1980 to 1998

Occupancy	**Confined to part of room or area of origin (inc object of origin) (%)**	**Extended beyond structure (%)**	**Total fires**	**Total deaths**	**Total injuries**	**$ loss (Millions)**	**Average $ loss per fire (Millions)**
Assembly (with sprinkler)	560 (89.6%)	0 (0.3%)	620	3	16	5.6	9,100
No sprinkler	2,010 (65.5%)	90 (3%)	3,080	3	46	63.6	20,700
Educational (with sprinkler)	970 (90.8%)	0 (0.2%)	1,060	0	34	3.5	3,300
No sprinkler	4,000 (81.8%)	50 (1%)	4,890	1	126	57.1	11,700

Table 5.65. (cont.) NFPA statistical report for the period 1980 to 1998

Occupancy	Confined to part of room or area of origin (inc object of origin) (%)	Extended beyond structure (%)	Total fires	Total deaths	Total injuries	$ loss (Millions)	Average $ loss per fire (Millions)
Business & office (with sprinkler)	830 (89.4%)	0 (0.3%)	940	0	22	8	8,600
No sprinkler	2,720 (68.7%)	100 (2.5%)	3,950	2	61	73.1	18,500
Mercantile (with sprinkler)	2,480 (87.5%)	20 (0.6%)	2,840	1	80	32.3	11,400
No sprinkler	8,960 (62.8%)	600 (4.2%)	14,250	15	299	293.1	20,600
Non residential combined (with sprinkler)	17,470 (87.5%)	120 (0.6%)	19,960	20	759	215.1	10,800
No sprinkler	57,280 (51.1%)	7,990 (7.1%)	112,040	124	1,889	1,531.20	13,700

Source: NFIRS and NFPA survey

Table 5.65 shows that in all the occupancies, higher percentage of the total fires was confined to part of the room or area of origin for the fire incidents having sprinklers, as compared to those having no sprinklers. It is also noticed that the percentage of fires extending beyond the structure of origin is much higher in the case of fire incidents with no sprinklers. The last column showing average dollar loss per fire clearly shows that in all occupancies the presence of sprinklers reduces property damage.

Chapter 6

6. Analysis of Residential dwellings

Residential dwellings include single-family houses, semi-detached dwellings and townhouses or row houses. The analysis of residential dwellings has been done to evaluate the following:

- Changes in the fire loss records (life safety and property damage) for single family dwellings, semi-detached dwellings, and townhouses or row houses from 1995 to 2002
- The fire problem for these types of properties as reflected in the total number of fires, deaths, injuries, and losses from 1995 to 2002
- Origin and causes of fire for each of these types of dwellings from 1995 to 2002

6.1. Fire loss trends, patterns, origin of fire, and causes of fire

This part of the evaluation assesses the size of the fire problem for residential dwellings in Ontario.

6.1.1. Fire loss trend

The fire trends have been examined for each year from the OFM data [4], with reference to fire incidents, civilian deaths, civilian injuries, and property damage. Table 6.1 and Figures 6.1 through 6.4 show the trends in fire losses in different periods in terms of the rates of deaths, injuries and damage per fire.

Table 6.1. Ontario Residential Home Fires (1995-2002)

Year	Number of Fires	Civilian Deaths	Civilian Injuries	Direct Property Damage
1995	5492	67	629	$ 117,423,652
1996	5080	66	506	$ 114,711,605
1997	4760	68	481	$ 115,649,210
1998	4487	76	456	$ 120,025,169
1999	4254	65	396	$ 115,872,962
2000	4164	48	352	$ 120,219,621
2001	4165	71	322	$ 157,391,039
2002	4286	55	345	$ 146,263,127

Note: Direct property damage figures do not include indirect losses, such as business interruption, and have not been adjusted for inflation.
Source: OFM data [4]

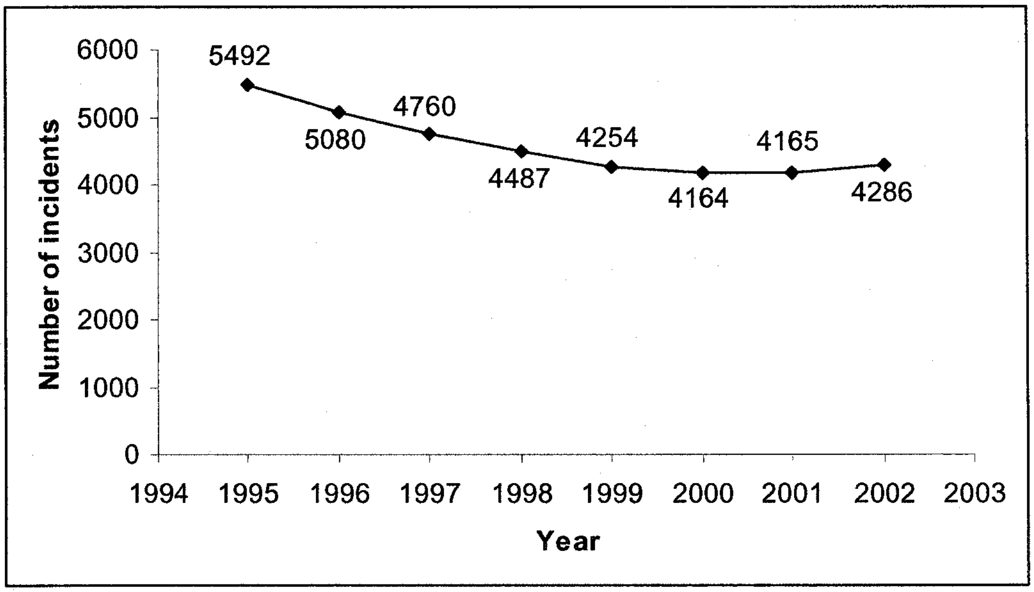

Figure 6.1 Ontario residential dwellings fire incidents

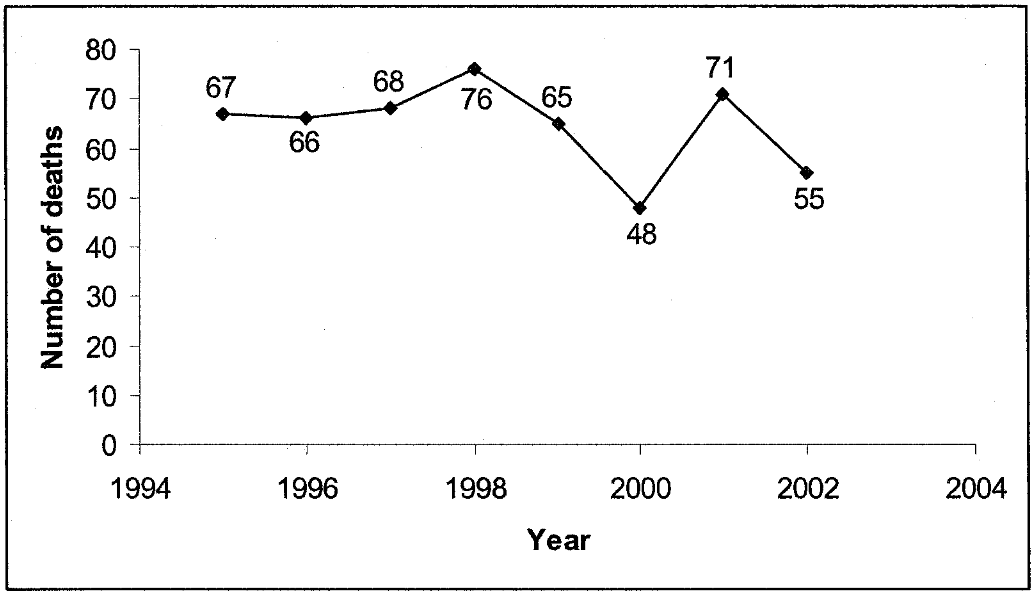

Figure 6.2 Ontario residential dwellings fire deaths

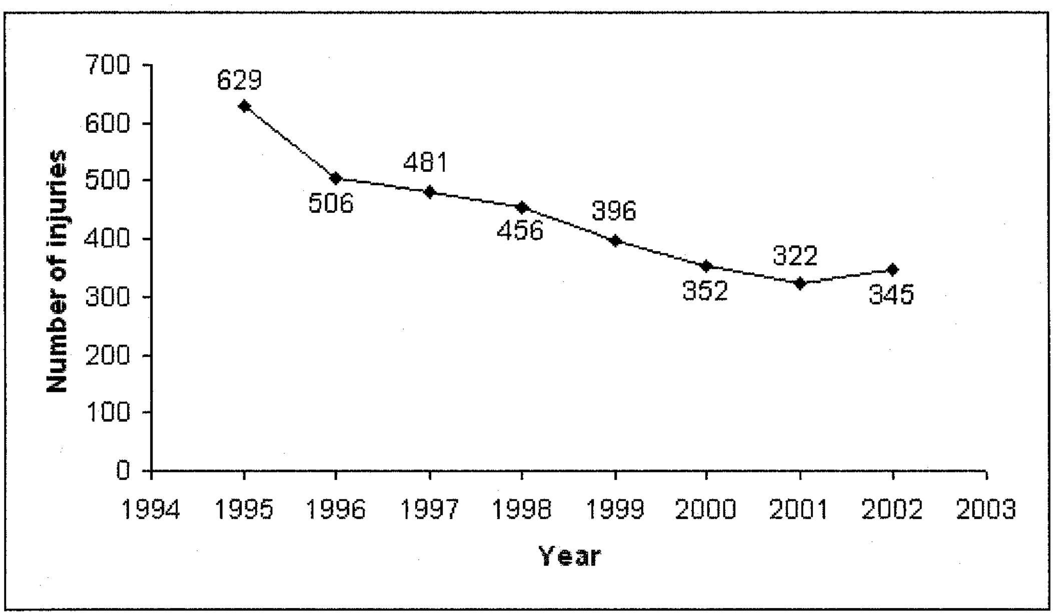

Figure 6.3 Ontario residential dwellings fire injuries

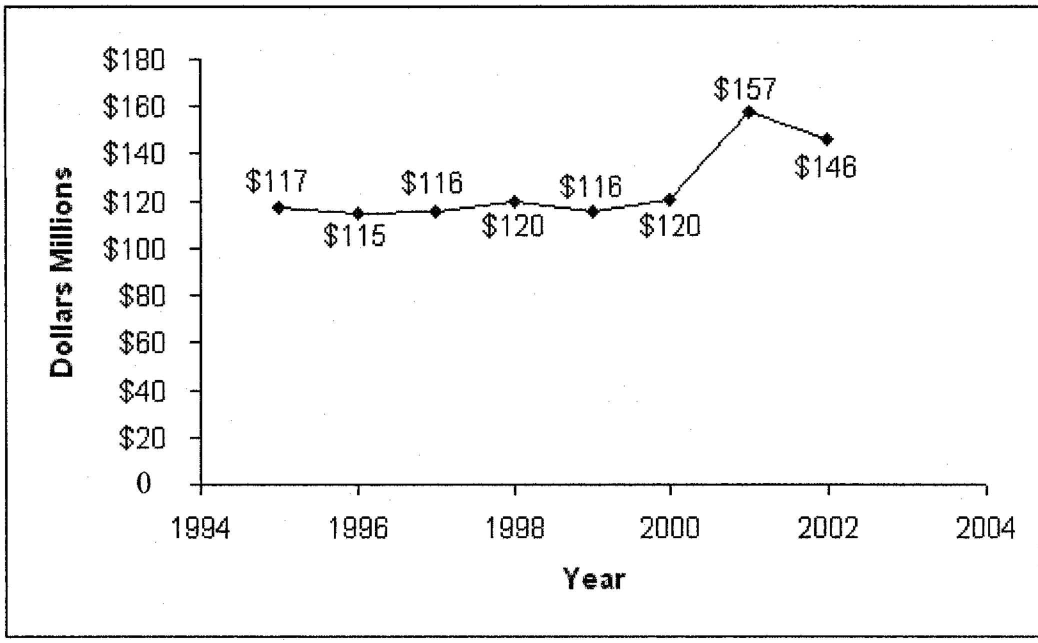

Figure 6.4 Ontario residential dwellings property damage

Table 6.1 and Figures 6.1 to 6.4 show that the number of fires have declined over the last eight years by about twenty percent, but it has remained at around four thousand for the last four years. Civilian fire deaths have also declined by about eighteen percent since 1995, but these figures have been fluctuating up and down from 1997 onwards. Civilian fire injuries have declined to nearly half since 1995. The declining trend in fire incidents as well as deaths during the same period has also been shown in the studies by OFM [8]. The direct property damage which has nearly been stable during the period 1995 to 2000 shows a steep rise thereafter, but much of that may be due to inflation.

Table 6.2. Rate of deaths and injuries

Year	Number of fires	Civilian deaths	Deaths per 100 fires	Civilian injuries	Injuries per 100 fires
1995	5492	67	1.2	629	11.5
1996	5080	66	1.3	506	10.0
1997	4760	68	1.4	481	10.1
1998	4487	76	1.7	456	10.2
1999	4254	65	1.5	396	9.3
2000	4164	48	1.2	352	8.5
2001	4165	71	1.7	322	7.7
2002	4286	55	1.3	345	8.0
8 Years Average	**4586**	**65**	**1.4**	**436**	**9.5**

Source: OFM data [4]

Table 6.3 Rate of property damage

Year	Number of fires	Direct property damage*	Property damage per fire
1995	5,492	$ 117,423,652	$ 21,381
1996	5,080	$ 114,711,605	$ 22,581
1997	4,760	$ 115,649,210	$ 24,296
1998	4,487	$ 120,025,169	$ 26,750
1999	4,254	$ 115,872,962	$ 27,239
2000	4,164	$ 120,219,621	$ 28,871
2001	4,165	$ 157,391,039	$ 37,789
2002	4,286	$ 146,263,127	$ 34,126
8 Years Average	**4,586**	**$ 125,944,548**	**$ 27,879**

*Direct property damage figures do not include indirect losses, such as business interruption, and have not been adjusted for inflation.
Source: OFM data [4].

It can be seen from Table 6.2 that during the eight year period, although there was a decline in the number of deaths, the rate of deaths has not gone down but has marginally increased. On the other hand the data for fire injuries shows that the number of injuries has declined to nearly half while the rate of injuries per 100 fires decreased by about 30%.

Table 6.3 shows that property damage has seen an up and down trend during the eight year period but that there has been a continuous rise in the rate of property damage from 1995 to 2001 except in 2002 when they dropped by about 10%. The rising trend in the rate of property damage may be due to inflation and increasing prosperity of Canadians.

6.1.2. Fire patterns by property type

Fire patterns have been examined with reference to the type of property i.e. whether it's a single-family house, a semi-detached house or a town house/row house. Table 6.4 and Figures 6.5 through 6.8 summarize the patterns of fire loss in these three types of residential dwellings.

Table 6.4 Ontario fire incidents as per residential property type

Type of residential property	Number of fires	Civilian deaths	Civilian injuries	Direct property damage*
Single-family dwellings	29257	415	2348	$ 841,096,762
Semi-detached dwellings	3562	44	560	$ 64,325,243
Townhouses or Row houses	3869	57	579	$ 102,134,380

*Direct property damage figures do not include indirect losses, such as business interruption, and have not been adjusted for inflation.
Source: OFM data [4].

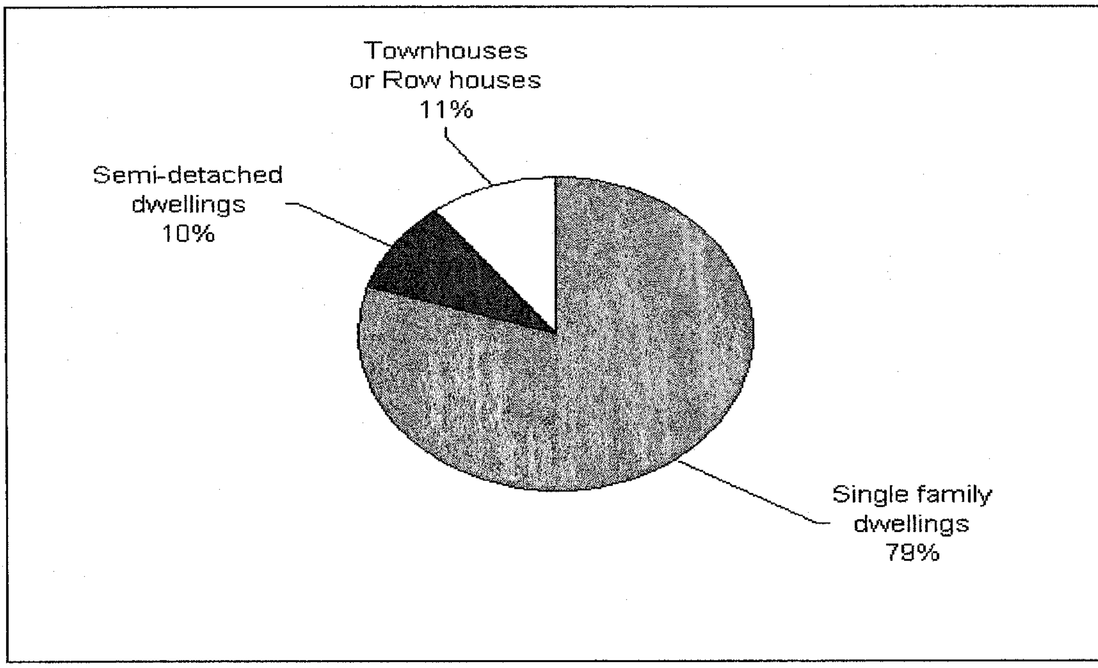

Figure 6.5 Residential fire incidents by property type

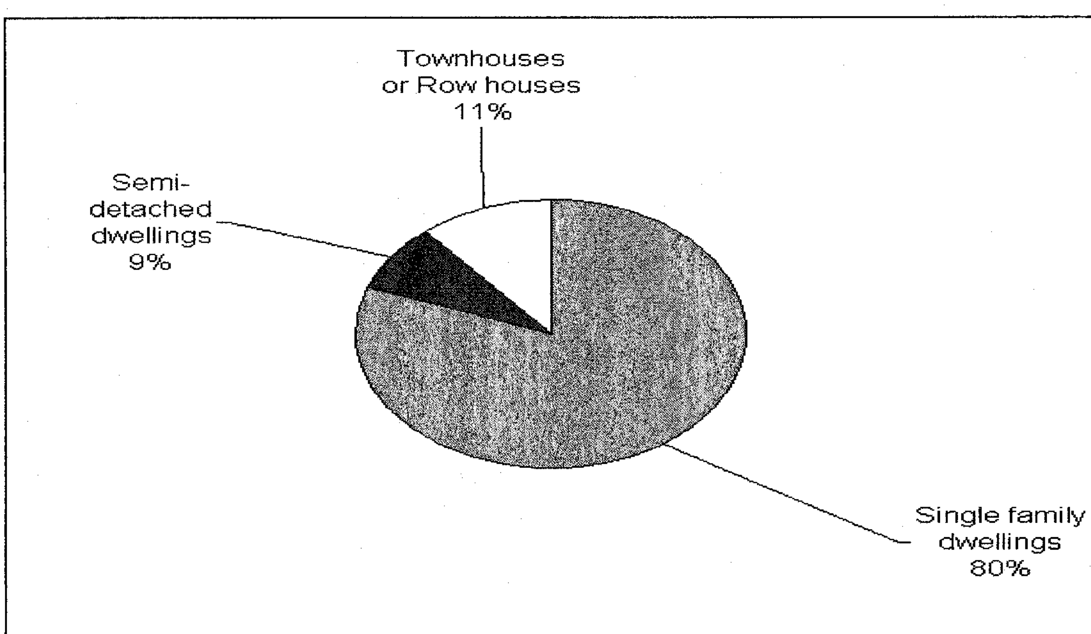

Figure 6.6 Residential fire deaths by property type

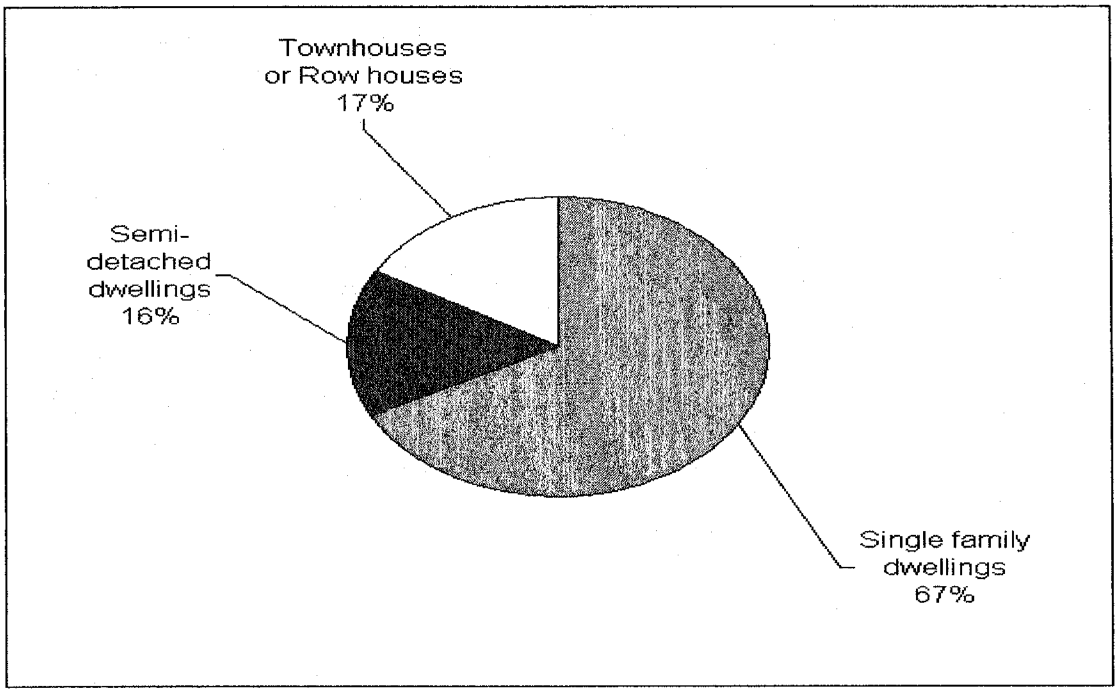

Figure 6.7 Residential fire injuries by property type

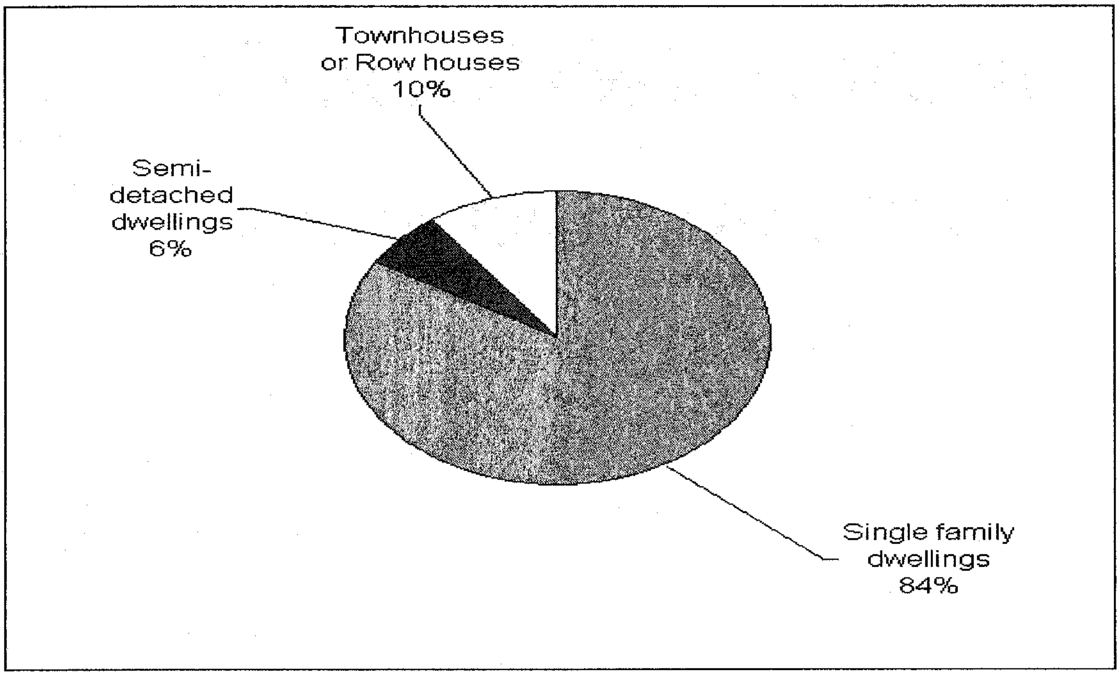

Figure 6.8 Residential property damage by property type

Table 6.4 and Figures 6.5 to 6.8 show that the majority of fire incidents (79%), civilian deaths (80%), civilian injuries (67%), and the property damage (84%), occurred in single family dwellings. In reviewing these statistics it should be kept in mind that many more Canadians live in single family houses than in other two types of residential property.

Table 6.5 Rate of deaths and injuries by property type (1995-2002)

Type of residential property	**Number of fires**	**% of total fires**	**Civilian deaths**	**% of total deaths**	**Deaths per 100 fires**	**Civilian injuries**	**Injuries per 100 fires**
Detached dwellings	29,257	79.7%	415	80.4%	1.4	2,348	8.0
Townhouses/ Row houses	3,869	10.5%	57	11.1%	1.5	579	15.0
Semi-detached dwellings	3,562	9.7%	44	8.5%	1.2	560	15.7
8 Years Average	**4586**	**12.5%**	**65**	**12.5%**	**1.4**	**436**	**9.5**

Table 6.6 Rate of property damage by property type (1995-2002)

Type of residential property	**Number of fires**	**Direct property damage**	**Property damage per fire**
Detached dwellings	29,257	$ 841,096,762	$ 28,749
Townhouses/ Row houses etc.	3,869	$ 102,134,380	$ 26,398
Semi-detached dwellings	3,562	$ 64,325,243	$ 18,059
8 Years Average	**4,586**	**$ 125,944,548**	**$ 9,151**

Table 6.5 shows that townhouses or row houses have the highest rate of deaths per 100 fires at 1.5, followed by the detached dwellings at 1.4 and the semi-detached

dwellings at 1.2. Semi-detached dwellings have a rate of injuries of 15.7 per 100 fires, followed by townhouses or row houses at 15, and detached dwellings at 8.

Table 6.6 shows that single-family dwellings have the highest property damages as per fire as well at $28,749 per fire. Town houses/ row houses have the second highest rate at $26,398 per fire.

6.1.3. Origin of fire in residential dwellings

This section analyses the fire data for residential dwellings to determine the origin of fires in these dwellings and to compare the findings of the three types of dwellings considered:

Tables 6.7 to 6.12 show areas of origin of fire with more than one percent contribution to the total fires. These areas of origin account for nearly ninety percent of the total reported fires.

Table 6.7 Areas of origin of fire for detached dwellings (1995-2002)

Area of origin of fire	No. of fire incidents	% of Total Fires	No. of Deaths	% of Total Deaths	Deaths per 100 fires	No. of Injuries	% of Total Injuries	Injuries per 100 fires
Cooking Area or Kitchen	7,155	24.5%	71	17.1%	1.0	691	29.4%	9.7
Living Area (eg. living, T.V., recreation)	3,691	12.6%	151	36.4%	4.1	379	16.1%	10.3
Chimney/Flue Pipe	2,841	9.7%	3	0.7%	0.1	38	1.6%	1.3
Sleeping Area or Bedroom (inc patient's room, dormitory)	2,463	8.4%	57	13.7%	2.3	369	15.7%	15.0
Laundry Area	1,610	5.5%	9	2.2%	0.6	69	2.9%	4.3

Table 6.7 (cont.)Areas of origin of fire for detached dwellings (1995-2002)

Area of origin of fire	**No. of fire inci-dents**	**% of Total Fires**	**No. of Deaths**	**% of Total Deaths**	**Deaths per 100 fires**	**No. of Inju-ries**	**% of Total Inju-ries**	**Inju-ries per 100 fires**
Garage	1,593	5.4%	4	1.0%	0.3	105	4.5%	6.6
Exterior Wall	1,139	3.9%	1	0.2%	0.1	58	2.5%	5.1
Undetermined	966	3.3%	45	10.8%	4.7	103	4.4%	10.7
HVAC Equiment Room (furnace room, water heater closet, boiler)	919	3.1%	10	2.4%	1.1	72	3.1%	7.8
Porch or Balcony	801	2.7%	3	0.7%	0.4	44	1.9%	5.5
Attic Area	577	2.0%	0	0.0%	0.0	34	1.4%	5.9
Washroom or Bathroom (inc toilet, rest/locker rooms)	511	1.7%	2	0.5%	0.4	39	1.7%	7.6
Other Functional Area	404	1.4%	0	0.0%	0.0	37	1.6%	9.2
Roof	343	1.2%	0	0.0%	0.0	18	0.8%	5.2
Crawl Space (includes sub-structure)	324	1.1%	0	0.0%	0.0	29	1.2%	9.0
Other Structural Area	313	1.1%	2	0.5%	0.6	27	1.1%	8.6
Concealed Wall Area	296	1.0%	0	0.0%	0.0	10	0.4%	3.4
Other - unclassified	295	1.0%	6	1.4%	2.0	23	1.0%	7.8
Other Storage Area	280	1.0%	3	0.7%	1.1	28	1.2%	10.0

Table 6.8 Damage by areas of origin of fire for detached dwellings (1995-2002)

Area of origin of fire	Number of fire incidents	Direct property damage	% of Total Damages	Damage per fire
Cooking Area or Kitchen	7,155	$ 122,471,983	14.6%	$ 17,117
Living Area (e.g. living, T.V., recreation)	3,691	$ 154,285,776	18.3%	$ 41,801
Chimney/Flue Pipe	2,841	$ 22,084,022	2.6%	$ 7,773
Sleeping Area or Bedroom (inc patient's room, dormitory)	2,463	$ 81,187,451	9.7%	$ 32,963
Laundry Area	1,610	$ 28,604,764	3.4%	$ 17,767
Garage	1,593	$ 64,876,282	7.7%	$ 40,726
Exterior Wall	1,139	$ 21,738,097	2.6%	$ 19,085
Undetermined	966	$ 90,927,593	10.8%	$ 94,128
HVAC Equiment Room (furnace room, water heater closet, boiler)	919	$ 30,049,780	3.6%	$ 32,698
Porch or Balcony	801	$ 14,605,701	1.7%	$ 18,234
Attic Area	577	$ 25,566,399	3.0%	$ 44,309
Washroom or Bathroom (inc toilet, rest/locker rooms)	511	$ 12,738,439	1.5%	$ 24,928
Other Functional Area	404	$ 19,073,724	2.3%	$ 47,212
Roof	343	$ 10,802,189	1.3%	$ 31,493
Crawl Space (includes sub-structure)	324	$ 14,656,643	1.7%	$ 45,237
Other Structural Area	313	$ 15,676,816	1.9%	$ 50,086
Concealed Wall Area	296	$ 8,296,294	1.0%	$ 28,028
Other - unclassified	295	$ 7,259,866	0.9%	$ 24,610
Other Storage Area	280	$ 10,567,820	1.3%	$ 37,742

Table 6.7 shows the fire incidents data for detached dwellings (i.e. single-family homes). The data shows that the majority of fires (24.5%) originate in cooking areas or kitchens, followed by living areas at 12.6%, chimney/ flu pipes at 9.7%, sleeping areas or bed rooms at 8.4%, laundry areas at 5.5%, and garages at 5.4%. Majority of deaths (36.4%) are from fires that started in a living area, followed by the fires in a cooking area or kitchen at 17.1%, and a sleeping area at 13.7%. Table 6.7 also shows that cooking area fires account for the majority of the injuries at 29.4%, followed by living area fires at 16.1%, and sleeping area fires at 15.7%. On the other hand, fires originating from living areas showed a death rate of 4.1 per 100 fires followed by sleeping areas or bedrooms at 2.3. The rate of injuries was however the highest for the fires originating from sleeping areas or bedrooms at 15 injuries per 100 fires, followed by living areas at 10.3, and storage areas at 10 injuries per 100 fires.

Table 6.8 shows that amongst the known areas of origin, living area fires exhibit the highest property damage followed by cooking area or kitchen fires and sleeping area fires. Fires originating from structural areas, functional areas, crawl spaces, attic area, living area, and garage show high rates of property damages in the range of $40,000 to $50,000 per fire for single-family dwellings.

Tables 6.7 and 6.8 however show that undetermined fires with a small share of 3.3% of total fires have 10.8% of total deaths with the highest rate of deaths per 100 fires at 4.7. They also showed 10.8% of the total property damages with the highest loss rate of $94,128 per fire.

Table 6.9 Areas of origin of fire for semi-detached dwellings (1995-2002)

Area of origin of fire	No. of fire incidents	% of Total Fires	No. of Deaths	% of Total Deaths	Deaths per 100 fires	No. of Injuries	% of Total Injuries	Injuries per 100 fires
Cooking Area or Kitchen	1,205	33.8%	10	22.7%	0.8	195	34.8%	16.2
Sleeping Area or Bedroom (inc patient's room, dormitory)	469	13.2%	11	25.0%	2.3	114	20.4%	24.3
Living Area (e.g. living, T.V., recreation)	353	9.9%	12	27.3%	3.4	65	11.6%	18.4
Laundry Area	228	6.4%	2	4.5%	0.9	27	4.8%	11.8
Porch or Balcony	184	5.2%	1	2.3%	0.5	18	3.2%	9.8
Garage	123	3.5%	1	2.3%	0.8	9	1.6%	7.3
HVAC Equipment Room (furnace room, water heater closet, boiler)	95	2.7%	0	0.0%	0.0	15	2.7%	15.8
Chimney/Flue Pipe	91	2.6%	0	0.0%	0.0	6	1.1%	6.6
Exterior Wall	87	2.4%	0	0.0%	0.0	12	2.1%	13.8
Washroom or Bathroom (inc toilet, rest/locker rooms)	76	2.1%	0	0.0%	0.0	5	0.9%	6.6
Roof	65	1.8%	0	0.0%	0.0	6	1.1%	9.2
Other - unclassified	53	1.5%	1	2.3%	1.9	9	1.6%	17.0
Attic Area	53	1.5%	0	0.0%	0.0	13	2.3%	24.5
Undetermined	52	1.5%	2	4.5%	3.8	7	1.3%	13.5
Other Functional Area	38	1.1%	0	0.0%	0.0	8	1.4%	21.1

Table 6.10 Damages by areas of origin of fire for semi-detached dwellings (1995-2002)

Area of origin of fire	Number of fire incidents	Direct property damage	% of Total Damages	Damage per fire
Cooking Area or Kitchen	1,205	$ 10,695,531	16.6%	$ 8,876
Sleeping Area or Bedroom (inc patient's room, dormitory)	469	$ 10,242,244	15.9%	$ 21,838
Living Area (e.g. living, T.V., recreation)	353	$ 9,480,425	14.7%	$ 26,857
Laundry Area	228	$ 2,185,653	3.4%	$ 9,586
Porch or Balcony	184	$ 3,534,887	5.5%	$ 19,211
Garage	123	$ 3,278,908	5.1%	$ 26,658
HVAC Equipment Room (furnace room, water heater closet, boiler)	95	$ 1,496,226	2.3%	$ 15,750
Chimney/Flue Pipe	91	$ 632,384	1.0%	$ 6,949
Exterior Wall	87	$ 1,346,399	2.1%	$ 15,476
Washroom or Bathroom (inc toilet, rest/locker rooms)	76	$ 734,575	1.1%	$ 9,665
Roof	65	$ 894,265	1.4%	$ 13,758
Other - unclassified	53	$ 582,357	0.9%	$ 10,988
Attic Area	53	$ 3,697,005	5.7%	$ 69,755
Undetermined	52	$ 5,066,446	7.9%	$ 97,432
Other Functional Area	38	$ 1,706,870	2.7%	$ 44,918

Table 6.9 shows the fire incident data for semi-detached dwellings by area of origin. The table shows that the majority of fires (33.8%) originate in cooking areas or kitchens, followed by sleeping areas or bedrooms at 13.2%, living areas at 9.9%, laundry areas at 6.4%, and porch or balcony areas at 5.2 %. Table 6.9 shows that the majority of deaths (27.3%), are from fires that started in living area followed by sleeping area at 25%, and cooking area or kitchen at 22.7%. Table 6.9 also shows that cooking area fires account

for the majority of the injuries at 34.8%, followed by sleeping area fires at 20.4%, and living area fires at 11.6%. On the other hand, fires originating from living area showed the highest death rate of 3.4 per 100 fires followed by sleeping area or bedroom fires at 2.3. The rate of injuries was however the highest for fires originating from attic area at 24.5 injuries per 100 fires followed by, sleeping area or bedroom at 24.3, living area at 18.4, cooking area or kitchen at 16.2, and HVAC equipment room at 15.8 injuries per 100 fires.

Table 6.10 shows that amongst the known areas of origin, the attic area fires exhibit the highest property damages at $69,755 per fire, followed by functional area fires at $44,918 per fire, living area fires at $26,857 per fire, and garage fires at $26,658.

Tables 6.9 and 6.10 show that the undetermined fires with a small share of 1.5% of total fires showed the highest rate of property damage at $97,432 per fire as well as the highest rate of deaths at 3.8 per hundred fires.

Table 6.11 Areas of origin of fire for townhouses or row houses (1995-2002)

Area of origin of fire	No. of fire inci-dents	% of Total Fires	No. of Deaths	% of Total Deaths	Deaths per 100 fires	Number of Inju-ries	% of Total Inju-ries	Inju-ries per 100 fires
Cooking Area or Kitchen	1,466	37.9%	4	7.0%	0.3	217	37.5%	14.8
Sleeping Area or Bedroom (inc patient's room, dormitory)	570	14.7%	11	19.3%	1.9	111	19.2%	19.5
Living Area (e.g. living, T.V., recreation, etc)	375	9.7%	29	50.9%	7.7	102	17.6%	27.2
Laundry Area	334	8.6%	1	1.8%	0.3	25	4.3%	7.5
Garage	107	2.8%	0	0.0%	0.0	6	1.0%	5.6

Table 6.11. (cont.) Areas of origin of fire for townhouses or row houses (1995-2002)

Area of origin of fire	No. of fire incidents	% of Total Fires	No. of Deaths	% of Total Deaths	Deaths per 100 fires	Number of Injuries	% of Total Injuries	Injuries per 100 fires
Exterior Wall	105	2.7%	0	0.0%	0.0	2	0.3%	1.9
Porch or Balcony	99	2.6%	0	0.0%	0.0	4	0.7%	4.0
Washroom or Bathroom (inc toilet, rest/locker rooms)	77	2.0%	0	0.0%	0.0	1	0.2%	1.3
HVAC Equipment Room (furnace room, water heater closet, boiler)	73	1.9%	0	0.0%	0.0	7	1.2%	9.6
Undetermined	56	1.4%	1	1.8%	1.8	29	5.0%	51.8
Roof	50	1.3%	0	0.0%	0.0	2	0.3%	4.0
Other - unclassified	48	1.2%	1	1.8%	2.1	6	1.0%	12.5
Other Functional Area	40	1.0%	0	0.0%	0.0	12	2.1%	30.0

Table 6.12 Damage by areas of origin of fire for townhouses or row houses (1995-2002)

Area of origin of fire	Number of fire incidents	Direct property damage	% of Total Damages	Damage per fire
Cooking Area or Kitchen	1,466	$ 13,640,765	13.4%	$ 9,305
Sleeping Area or Bedroom (inc patient's room, dormitory)	570	$ 14,306,454	14.0%	$ 25,099
Living Area (e.g. living, T.V., recreation)	375	$ 15,160,648	14.8%	$ 40,428
Laundry Area	334	$ 4,306,764	4.2%	$ 12,895
Garage	107	$ 1,492,026	1.5%	$ 13,944

Table 6.12. (cont.) Damage by areas of origin of fire for townhouses or row houses (1995-2002)

Area of origin of fire	Number of fire incidents	Direct property damage	% of Total Damages	Damage per fire
Exterior Wall	105	$ 1,570,822	1.5%	$ 14,960
Porch or Balcony	99	$ 921,363	0.9%	$ 9,307
Washroom or Bathroom (inc toilet, rest/locker rooms)	77	$ 692,180	0.7%	$ 8,989
HVAC Equipment Room (furnace room, water heater closet, boil	73	$ 2,257,166	2.2%	$ 30,920
Undetermined	56	$ 35,471,444	34.7%	$ 633,419
Roof	50	$ 446,626	0.4%	$ 8,933
Other - unclassified	48	$ 256,570	0.3%	$ 5,345
Other Functional Area	40	$ 929,945	0.9%	$ 23,249

Table 6.11 shows the fire incident data for townhouses or row houses by area of origin. The table shows that the majority of fires (37.9%) originate in cooking areas or kitchens, followed by sleeping areas or bedrooms at 14.7%, living areas at 9.7%, and laundry areas at 8.6%. Table 6.11 shows that the majority of deaths (50.9%), are from fires that started in living area followed by sleeping area at 19.3%, and cooking area or kitchen at 7%. Table 6.11 also shows that cooking area fires account for the majority of the injuries at 37.5%, followed by sleeping area fires at 19.2%, and living area fires at 17.6%. On the other hand, fires originating from living area showed the highest death rate of 7.7 per 100 fires followed by sleeping area or bedroom fires at 1.9. The rate of injuries for fires originating from functional areas caused 30 injuries per 100 fires followed by, living area at 27.2, sleeping area or bedroom at 19.5, and cooking area or kitchen at 14.8.

Table 6.11 shows that amongst the known areas of origin, the living area fires exhibit the highest property damages followed by sleeping area or bed room fires, and cooking area or kitchen fires. Fires originating from living areas caused the highest property damages at $40,428 per fire, followed by HVAC equipment room fires at $30,920, and sleeping area or bed room fires at $25,099 per fire.

Tables 6.11 and 6.12 show that the undetermined fires with a little share of 1.4 % of total fires showed the extremely high rate of property damage of $633,419 per fire as well as the highest rate of injuries at 51.8 per hundred fires.

Tables 6.13 and 6.14 are developed to show the first three areas of origin that resulted in the highest life loss and property loss. Table 6.13 shows the total number of fire incidents, civilian deaths and civilian injuries and Table 6.14 shows property damage for each of the three kinds of residential dwellings.

Table 6.13 Ranking of total fires, deaths and injuries for Residential dwellings by areas of origin of fire

Area of origin of fire	**Number of Fires (Rank)**			**Number of Deaths (Rank)**			**Number Of Injuries (Rank)**		
	Single home	Semi-detached	Town house	Single home	Semi-detached	Town house	Single home	Semi-detached	Town house
Cooking Area or Kitchen	7,155 (1)	1,205 (1)	1,466 (1)	71 (2)	10 (3)	4 (3)	691 (1)	195 (1)	217 (1)
Sleeping area or bed room	2,463 (4)	469 (2)	570 (2)	57 (3)	11 (2)	11 (2)	369 (3)	114 (2)	111 (2)
Living Area	3,691 (2)	353 (3)	375 (3)	151 (1)	12 (1)	29 (1)	379 (2)	65 (3)	102 (3)
Chimney /Flue Pipe	2,841 (3)								

Table 6.14 Ranking of total damages for residential dwellings by areas of origin of fire

Area of origin of fire	Damages (million $)		
	Single home	Semi-detached	Town house
Cooking Area or Kitchen	122.5 (2)	10.7 (1)	13.6 (3)
Sleeping area or bed room	81.2 (3)	10.2 (2)	14.3 (2)
Living Area	154.3 (1)	9.5 (3)	15.2 (1)

Table 6.13 shows that cooking areas, sleeping areas, and living areas are the three main areas of origin of fire for all the three types of residential dwellings. For single-family homes however, the third highest number of fires start from chimney/ flue pipes. Fires originating from cooking areas or kitchens result in the highest number of fires (Rank 1), and highest number of injuries (Rank 1) for single homes, semi-detached dwellings, and townhouses or row houses. Fires starting in living areas result in the majority of the deaths (Rank 1) for all the three types of residential dwellings.

Table 6.14 shows that fires originating from living areas result in the majority of the property damage (Rank 1) for single-family homes and townhouses or row houses. Fires starting from cooking area or kitchen however show the highest property damages for semi-detached homes.

Similar results were shown in an analysis by OFM for Ontario data (1995-1999) and U.S.A. data (1994-1998) for general homes [8]. The analysis indicated that majority of the fires in Ontario originate in kitchens, followed by living area, sleeping area and chimneys whereas for U.S. majority of fires originated in kitchens, followed mainly by bedrooms, living rooms, and chimneys.

6.1.4. Causes of fire

This section analyses the fire data [4] for residential dwellings to determine the cause of fires in these dwellings and to compare the findings of the three types of dwellings considered: single-family, semi-detached and row houses.

Tables 6.15 to 6.20 show causes of fire with more than one percent contribution to the total fires. These cause of fires account for 97% of the total reported fires.

Table 6.15 Causes of fire for detached dwellings (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of deaths	% of total deaths	Deaths per 100 fires	Number of injuries	% of total injuries	Inju-ries per 100 fires
Undetermined	4,513	15.4%	144	34.7%	3.2	517	22.0%	11.5
Misused Ignition source/equip: Unattended	3,962	13.5%	22	5.3%	0.6	466	19.8%	11.8
Electrical Failure	3,775	12.9%	12	2.9%	0.3	176	7.5%	4.7
Maintenance Deficiency	3,451	11.8%	2	0.5%	0.1	57	2.4%	1.7
Other	2,357	8.1%	31	7.5%	1.3	135	5.7%	5.7
Misused Ignition source/equip: Too Close to Combustibles	1,833	6.3%	17	4.1%	0.9	184	7.8%	10.0
Misused Ignition source/equip: Improperly Discarded	1,295	4.4%	18	4.3%	1.4	127	5.4%	9.8
Arson	1,185	4.1%	53	12.8%	4.5	128	5.5%	10.8
Installation Deficiency	1,062	3.6%	15	3.6%	1.4	53	2.3%	5.0

Table 6.15 (cont.) Causes of fire for detached dwellings (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of deaths	% of total deaths	Deaths per 100 fires	Number of injuries	% of total injuries	Inju-ries per 100 fires
Misuse of Material ignited: Improper Handling	954	3.3%	12	2.9%	1.3	150	6.4%	15.7
Children Playing (Ages 11 and under)	657	2.2%	3	0.7%	0.5	66	2.8%	10.0
Mechanical Failure	591	2.0%	3	0.7%	0.5	13	0.6%	2.2
Misused Ignition source/equip: Other	566	1.9%	30	7.2%	5.3	72	3.1%	12.7
Construction Deficiency	488	1.7%	0	0.0%	0.0	14	0.6%	2.9
Design Deficiency: Other	459	1.6%	3	0.7%	0.7	20	0.9%	4.4
Misuse of Material ignited: Improper Storage	435	1.5%	0	0.0%	0.0	16	0.7%	3.7
Design Deficiency	323	1.1%	1	0.2%	0.3	13	0.6%	4.0
Misused Ignition source/equip: for purpose not Intended	321	1.1%	1	0.2%	0.3	50	2.1%	15.6
Misuse of Material ignited: Other	301	1.0%	34	8.2%	11.3	37	1.6%	12.3

Table 6.16 Damages by causes of fire for detached dwellings (1995-2002)

Cause of fire	Number of fires	Direct Property Damage	% of total damages	Damages per fire
Undetermined	4,513	$ 288,640,439	34.3%	$ 63,958
Misused Ignition source/equip: Unattended	3,962	$ 76,272,733	9.1%	$ 19,251
Electrical Failure	3,775	$ 106,800,809	12.7%	$ 28,292
Maintenance Deficiency	3,451	$ 27,223,275	3.2%	$ 7,889
Other	2,357	$ 45,802,806	5.4%	$ 19,433
Misused Ignition source/equip: Too Close to Combustibles	1,833	$ 44,905,446	5.3%	$ 24,498
Misused Ignition source/equip: Improperly Discarded	1,295	$ 30,572,373	3.6%	$ 23,608
Arson	1,185	$ 56,116,728	6.7%	$ 47,356
Installation Deficiency	1,062	$ 26,909,984	3.2%	$ 25,339
Misuse of Material ignited: Improper Handling	954	$ 21,825,493	2.6%	$ 22,878
Children Playing (Ages 11 and under)	657	$ 15,087,006	1.8%	$ 22,963
Mechanical Failure	591	$ 10,673,058	1.3%	$ 18,059
Misused Ignition source/equip: Other	566	$ 12,770,530	1.5%	$ 22,563
Construction Deficiency	488	$ 11,588,502	1.4%	$ 23,747
Design Deficiency: Other	459	$ 12,407,992	1.5%	$ 27,033
Misuse of Material ignited: Improper Storage	435	$ 7,976,583	0.9%	$ 18,337
Design Deficiency	323	$ 8,318,118	1.0%	$ 25,753
Misused Ignition source/equip: for purpose not Intended	321	$ 8,313,757	1.0%	$ 25,900
Misuse of Material ignited: Other	301	$ 9,874,695	1.2%	$ 32,806

Table 6.15 shows the fire incidents data for single-family dwellings. The data shows that causes for the majority of fires (15.4%) could not be determined. 13.5% of the total fires are caused due to misused ignition source or equipment left unattended, followed by electrical failure at 12.9%, maintenance deficiency at 11.8%, other causes at 8.1%, and misused ignition source or equipment too close to combustibles at 6.3%. Table shows that cause for majority of the deaths (34.7%) could not be found. From the known causes,

arson resulted in 12.8% of the total deaths followed by other than listed causes at 7.5%, other than listed misused ignition source or equipment at 7.2%, and misused ignition source or equipment left unattended at 5.3%. The highest death rate of 5.3 per 100 fires was however caused by fires due to misuse of other ignition source or equipment, followed by arson at 4.5.

Table 6.15 also shows that in the majority of cases (22%), the cause of injuries could not be found. 19.8% injuries are caused due to misused ignition source or equipment left unattended, misused ignition source or equipment too close to combustibles at 7.8%, electrical failure at 7.5%, improper handling of ignited material at 6.4%, other causes at 5.7%, arson at 5.5%, and improperly discarded ignition source or equipment at 5.4%. The highest injuries of 15.7 per 100 fires were caused by improper handling of ignited material, followed by misused other ignition source or equipment at 12.7, misused ignition source or equipment left unattended at 11.8, undetermined cause at 11.5, and arson at 10.8.

Table 6.16 shows that fires for which no cause could be determined result in the majority of the property damages at 34.3%. Fires due to electrical failure showed 12.7% of the total damages, followed by misused ignition source or equipment left unattended at 9.1%, arson at 6.7%, other than listed causes at 5.4%, and misused ignition source or equipment too close to combustibles at 5.3%. Undetermined fires however showed the highest rate of property damage at $63,958 per fire. From the fires with known causes, arson accounted for the highest damage of $47,356 per fire, followed by misuse of ignited material at $32,806 per fire, and electrical failure at $28,292 per fire. Damage due to fires caused by design deficiency, installation deficiency, or misuse of ignition source or equipment for the purpose not intended, remained in the range of $25,000 to $27,000 per fire for single family dwellings.

It can be noted that the data for single family homes show that the undetermined fires accounted for highest percentage of total fire incidents, civilian deaths, civilian injuries, and property damages, as well as the highest rate of property damages per fire.

Table 6.17 Causes of fire for semi-detached dwellings (1995-2002)

Cause of fire	**Number of fires**	**% of total fires**	**Number of Deaths**	**% of total deaths**	**Deaths per 100 fires**	**Number of Injuries**	**% of total injuries**	**Inju-ries per 100 fires**
Misused Ignition source/equip: Unattended	765	21.5%	3	6.8%	0.4	167	29.8%	21.8
Electrical Failure	475	13.3%	2	4.5%	0.4	41	7.3%	8.6
Undetermined	413	11.6%	13	29.5%	3.1	70	12.5%	16.9
Other	270	7.6%	0	0.0%	0.0	37	6.6%	13.7
Misused Ignition source/equip: Too Close to Combustibles	265	7.4%	0	0.0%	0.0	47	8.4%	17.7
Misused Ignition source/equip: Improperly Discarded	212	6.0%	2	4.5%	0.9	30	5.4%	14.2
Maintenance Deficiency	169	4.7%	0	0.0%	0.0	11	2.0%	6.5
Arson	152	4.3%	4	9.1%	2.6	27	4.8%	17.8
Misuse of Material ignited: Improper Handling	142	4.0%	3	6.8%	2.1	35	6.3%	24.6

Table 6.17 (cont.) Causes of fire for semi-detached dwellings (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Deaths per 100 fires	Number of Injuries	% of total injuries	Inju-ries per 100 fires
Children Playing (Ages 11 and under)	136	3.8%	9	20.5%	6.6	30	5.4%	22.1
Misused Ignition source/equip: Other	92	2.6%	2	4.5%	2.2	18	3.2%	19.6
Misuse of Material ignited: Improper Storage	74	2.1%	0	0.0%	0.0	13	2.3%	17.6
Installation Deficiency	70	2.0%	0	0.0%	0.0	8	1.4%	11.4
Mechanical Failure	60	1.7%	0	0.0%	0.0	3	0.5%	5.0
Vandalism	43	1.2%	1	2.3%	2.3	6	1.1%	14.0
Misuse of Material ignited: Other	40	1.1%	4	9.1%	10.0	4	0.7%	10.0
Misused Ignition source/equip: for purpose not Intended	37	1.0%	0	0.0%	0.0	2	0.4%	5.4

Table 6.18 Damage by causes of fire for semi-detached dwellings (1995-2002)

Cause of fire	Number of fires	Direct Property Damage	% of total damages	Damages per fire
Misused Ignition source/equip: Unattended	765	$ 9,390,383	14.6%	$ 12,275
Electrical Failure	475	$ 7,259,946	11.3%	$ 15,284
Undetermined	413	$ 16,968,241	26.4%	$ 41,085
Other	270	$ 3,295,422	5.1%	$ 12,205
Misused Ignition source/equip: Too Close to Combustibles	265	$ 4,485,489	7.0%	$ 16,926
Misused Ignition source/equip: Improperly Discarded	212	$ 2,959,871	4.6%	$ 13,962
Maintenance Deficiency	169	$ 1,009,000	1.6%	$ 5,970
Arson	152	$ 4,925,299	7.7%	$ 32,403
Misuse of Material ignited: Improper Handling	142	$ 1,518,679	2.4%	$ 10,695
Children Playing (Ages 11 and under)	136	$ 2,853,871	4.4%	$ 20,984
Misused Ignition source/equip: Other	92	$ 796,637	1.2%	$ 8,659
Misuse of Material ignited: Improper Storage	74	$ 866,642	1.3%	$ 11,711
Installation Deficiency	70	$ 905,216	1.4%	$ 12,932
Mechanical Failure	60	$ 692,876	1.1%	$ 11,548
Vandalism	43	$ 313,877	0.5%	$ 7,299
Misuse of Material ignited: Other	40	$ 549,514	0.9%	$ 13,738
Misused Ignition source/equip: for purpose not Intended	37	$ 702,910	1.1%	$ 18,998

Table 6.17 shows the fire incidents data for semi-detached dwellings. The data shows that majority of the fires are caused by misuse of ignition source left unattended at 21.5%, followed by electrical failure at 13.3%, undetermined causes at 11.6%, other than listed causes at 7.6%, misused ignition source or equipment too close to combustibles at 7.4%, and improperly discarded ignition source or equipment at 6%.

Table 6.17 shows that the cause for the majority of the deaths (29.5%) could not be found. From the known causes, fires caused by children playing (ages 11 and under) resulted in 20.5 % of the total deaths, followed by arson at 9.1%, misused ignition source or equipment left unattended at 6.8%, and improper handling of ignited material at 6.8%. The highest death rate of 6.6 per 100 fires was however shown due to the fires caused by children playing (ages 11 and under), followed by undetermined causes at 3.1, arson at 2.6, vandalism at 2.3, other misused ignition source or equipment at 2.2, and improper handling of ignited material at 2.1.

Table 6.17 also shows that the majority of injuries were caused due to misused ignition source or equipment left unattended at 29.8%, followed by undetermined causes at 12.5%, misused ignition source or equipment too close to combustibles at 8.4%, electrical failure at 7.3%, other causes at 6.6%, improperly discarded ignition source or equipment at 5.4%, and the cause of injuries could not be found. 19.8% injuries are caused due to misused ignition source or equipment left unattended, misused ignition source or equipment too close to combustibles at 7.8%, improper handling of ignited material at 6.4%, other causes at 5.7%, arson at 5.5%, and improperly discarded ignition source or equipment at 5.4%, and children playing (ages 11 and under) at 5.4%. The highest injury rate of 24.6 per 100 fires was however caused by fires due to improper handling of ignited material, followed by children playing (ages 11 and under) at 22.1, and misused ignition source or equipment left unattended at 21.8.

Table 6.18 shows that fires for which no cause could be determined result in the majority of the property damages at 26.4%. Fires due to misused ignition source or equipment left unattended, showed 14.6% of the total damages, followed by electrical failure at 11.3%, arson at 7.7%, misused ignition source or equipment too close to combustibles at 7%, and other than listed causes at 5.1 %. Undetermined fires however account for the highest rate of property damage at $41,085 per fire followed by arson at $32,403 per fire. Damage due to electrical failure, misused ignition source or equipment too close to combustibles, children playing (ages 11 and under), misused ignition source or equipment for the purpose not intended, remained in the range of $15,000 to $21,000 per fire.

It can be noted that data for semi-detached homes show that fires due to misused ignition source or equipment left unattended account for the majority of the fires, civilian injuries and rate of injuries per 100 fires. Undetermined fires however accounted for the highest percentage of total deaths and property damages, as well as the rate of property damages per fire.

Table 6.19 Causes of fire for townhouses or row houses (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Deaths per 100 fires	Number of Injuries	% of total injuries	Inju-ries per 100 fires
Misused Ignition source/equip: Unattended	916	23.7%	1	1.8%	0.1	168	29.0%	18.3
Undetermined	525	13.6%	13	22.8%	2.5	95	16.4%	18.1
Electrical Failure	421	10.9%	0	0.0%	0.0	29	5.0%	6.9
Other	289	7.5%	5	8.8%	1.7	30	5.2%	10.4
Misused Ignition source/equip: Too Close to Combustibles	243	6.3%	7	12.3%	2.9	54	9.3%	22.2

Table 6.19 (cont.) Causes of fire for townhouses or row houses (1995-2002)

Cause of fire	Number of fires	% of total fires	Number of Deaths	% of total deaths	Deaths per 100 fires	Number of Injuries	% of total injuries	Inju-ries per 100 fires
Children Playing (Ages 11 and under)	235	6.1%	3	5.3%	1.3	43	7.4%	18.3
Misused Ignition source/equip: Improperly Discarded	198	5.1%	6	10.5%	3.0	38	6.6%	19.2
Misuse of Material ignited :Improper Handling	175	4.5%	1	1.8%	0.6	38	6.6%	21.7
Arson	169	4.4%	7	12.3%	4.1	27	4.7%	16.0
Maintenance Deficiency	155	4.0%	0	0.0%	0.0	6	1.0%	3.9
Misused Ignition source/equip: Other	89	2.3%	4	7.0%	4.5	14	2.4%	15.7
Misuse of Material ignited: Improper Storage	74	1.9%	0	0.0%	0.0	6	1.0%	8.1
Mechanical Failure	60	1.6%	0	0.0%	0.0	1	0.2%	1.7
Vandalism	52	1.3%	4	7.0%	7.7	3	0.5%	5.8
Misuse of Material ignited: Other	41	1.1%	2	3.5%	4.9	3	0.5%	7.3
Misused Ignition source/equip: for purpose not Intended	40	1.0%	0	0.0%	0.0	8	1.4%	20.0
Installation Deficiency	38	1.0%	0	0.0%	0.0	2	0.3%	5.3

Table 6.20 Damage by causes of fire for townhouses or row houses (1995-2002)

Cause of fire	Number of fires	Direct Property Damage	% of total damages	Damage per fire
Misused Ignition source/equip: Unattended	916	$ 9,962,281	9.8%	$ 10,876
Undetermined	525	$ 54,235,099	53.1%	$ 103,305
Electrical Failure	421	$ 5,546,390	5.4%	$ 13,174
Other	289	$ 3,106,623	3.0%	$ 10,750
Misused Ignition source/equip: Too Close to Combustibles	243	$ 4,953,377	4.8%	$ 20,384
Children Playing (Ages 11 and under)	235	$ 4,605,635	4.5%	$ 19,598
Misused Ignition source/equip: Improperly Discarded	198	$ 3,082,290	3.0%	$ 15,567
Misuse of Material ignited: Improper Handling	175	$ 1,493,288	1.5%	$ 8,533
Arson	169	$ 4,836,197	4.7%	$ 28,617
Maintenance Deficiency	155	$ 426,813	0.4%	$ 2,754
Misused Ignition source/equip: Other	89	$ 1,269,807	1.2%	$ 14,267
Misuse of Material ignited: Improper Storage	74	$ 733,817	0.7%	$ 9,916
Mechanical Failure	60	$ 318,978	0.3%	$ 5,316
Vandalism	52	$ 2,072,514	2.0%	$ 39,856
Misuse of Material ignited: Other	41	$ 995,515	1.0%	$ 24,281
Misused Ignition source/equip: for purpose not Intended	40	$ 1,041,160	1.0%	$ 26,029
Installation Deficiency	38	$ 512,825	0.5%	$ 13,495

Table 6.19 shows the fire incidents data for townhouses or row houses. The data shows that the majority of the fires are caused by misuse of ignition source left unattended at 23.7%, followed by undetermined causes at 13.6%, electrical failure at 10.9%, other than listed causes at 7.5%, misused ignition source or equipment too close to combustibles at 6.3%, children playing (ages 11 and under) at 6.1%, and improperly discarded ignition source or equipment at 5.1%.

Table 6.19 shows that causes for the majority of the deaths (22.8%) could not be found. From the known causes, fires caused by misused ignition source or equipment too close to combustibles resulted in 12.3% of the total deaths, followed by arson at 12.3%, improperly discarded ignition source or equipment at 10.5%, other causes at 8.8%, vandalism at 7%, other misused ignition source or equipment at 7%, and children playing (ages 11 and under) at 5.3%. Fires caused by vandalism however showed the highest death rate of 7.7 per 100 fires, followed by other misuse of ignited material at 4.9, other misuse of ignition source or equipment at 4.5, and arson at 4.1.

Table 6.19 also shows that the majority of injuries were caused due to misused ignition source or equipment left unattended at 29%, followed by undetermined causes at 16.4%, misused ignition source or equipment too close to combustibles at 9.3%, children playing (ages 11 and under) at 7.4%, improperly discarded ignition source or equipment at 6.6%, and electrical failure at 7.3%, other causes at 6.6%, improper handling of ignited material at 6.6%. The highest injury rate of 22.2 injuries per 100 fires was, however, caused by fires due to misused ignition source or equipment too close to combustibles, followed by improper handling of ignited material at 21.7. Fires due to improperly discarded ignition source, children playing (ages 11 and under), undetermined causes, arson, other misused ignition source or equipment, and other causes remained in the range of 10 to 20 injuries per 100 fires.

Table 6.20 shows that no cause of fire could be determined for more than half (53.1%) of the total property damage. Fires due to misused ignition source or equipment left unattended resulted in 9.8% of the total damage, followed by electrical failure at 5.4%. Undetermined fires also account for the highest rate of property damage at

$103,305 per fire followed by vandalism at $39,856 per fire. Damage due to arson, misused ignition source or equipment for the purpose not intended, other misuse of material ignited, and misused ignition source or equipment too close to combustibles remained in the range of $20,000 to $29,000 per fire.

It can be noted that the data for townhouses or row houses show that fires due to misused ignition source or equipment left unattended account for the highest percentage of the total fire incidents and civilian injuries. Fires due to undetermined causes however account for the highest percentage of total deaths and property damage, as well as the rate of property damage per fire.

6.1.4.1. Ranking of three types of residential dwellings by causes of fire

Tables 6.21 through 6.24 are developed to show the first three causes of fire that resulted in the highest life loss and property loss. Tables 6.21 to 6.23 show the cause of fire by number of fire incidents, deaths and injuries respectively, and Table 6.24 shows property damage, for each of the three types of residential dwellings.

Table 6.21 Ranking of total fires for residential dwellings by cause of fire

Building Type	Cause of fire by number of incidents		
	1	2	3
Single family homes	Undetermined 4513	Misused ignition source/ equipment: unattended 3,962	Electrical failure 3,775
Semi-detached homes	Misused ignition source/ equipment: unattended 765	Electrical failure 475	Undetermined 413
Townhouses/ Row houses	Misused ignition source/ equipment: unattended 916	Undetermined 525	Electrical failure 421

Table 6.22 Ranking of civilian deaths for residential dwellings by cause of fire

Building Type	Cause of fire by number of deaths		
	1	2	3
Single family homes	Undetermined 144	Arson 53	Other 31
Semi-detached homes	Undetermined 13	Children playing (ages 11 and under) 9	Arson 4 Misuse of material ignited: Other 4
Townhouses/ Row houses	Undetermined 13	Arson 7 Misused ignition source/ equipment: Too close to combustibles 7	Misused ignition source/ equipment: Improperly discarded 6

Table 6.23 Ranking of civilian injuries for residential dwellings by cause of fire

Building Type	**Cause of fire by number of injuries**		
	1	**2**	**3**
Single family homes	Undetermined 517	Misused ignition source/ equipment: unattended 466	Misused ignition source/ equip: Too close to combustibles 184
Semi-detached homes	Misused ignition source/ equip: unattended 167	Undetermined 70	Misused ignition source/ equipment: Too close to combustibles 47
Townhouses/ Row houses	Misused ignition source/ equipment: unattended 168	Undetermined 95	Misused ignition source/ equipment: Too close to combustibles 54

Table 6.24 Ranking of total damages for residential dwellings by cause of fire

Area of origin of fire	**Damage (million $)**		
	Single homes	Semi-detached houses	Townhouses/ Row houses
Undetermined	288.6 (1)	16.9 (1)	54.2 (1)
Misused ignition source/ equipment: unattended	76.2 (3)	9.3 (2)	9.9 (2)
Electrical failure	106.8 (2)	7.2 (3)	5.4 (3)
Arson	56.1 (4)	4.9 (4)	
Misused ignition source/ equipment: Too close to combustibles			4.9 (4)

Tables 6.21 to 6.23 show that among the known fire causes, misused ignition sources left unattended and electrical failures are the two main causes for the majority of fires and civilian injuries in all the three residential dwellings. Undetermined fires account for a sizable number of fire incidents as well as civilian injuries, and cause the highest number of deaths for all residential dwellings. From known causes, arson fires result in sizeable deaths in all dwellings.

Table 6.24 shows that fires causing the majority of property damage in all three types of residential dwellings remain undetermined. Amongst the known fire causes, misused ignition sources left unattended and electrical failures are the two main causes of property damage in all the three types of homes. Arson followed by misused ignition source or equipment too close to combustibles are, other main causes of fire resulting into higher property damage.

An analysis by OFM [8] for the causes of home fires for Ontario, and the U.S.A., also shows that cooking equipment is the main cause of fires followed by heating equipment, incendiary or suspicious causes, and electrical distribution. Fires due to incendiary or suspicious causes result in second highest deaths for Ontario as well as the USA.

6.2. Comparison of the fire problem between single family dwellings, semi-detached homes and townhouses or row houses

6.2.1. Fatality rates

Fatality rates have been calculated using the reported fire incidents from 1995 to 2002 [4]. Tables 6.25 through 6.27 and Figures 6.9 through 6.11 show the fatality rates in different types of homes during the years from 1995 to 2002, whereas Table 6.28 and

Figures 6.12 through 6.14 compare the number of fires, fatalities, and fatality rates amongst these three types of homes.

Table 6.25 Fatality rates in single family dwellings

Year	Number of fires	Number of fatalities	Rate of fatalities per 100 fires
1995	4403	57	1.3
1996	4108	54	1.3
1997	3806	57	1.5
1998	3544	59	1.7
1999	3347	41	1.2
2000	3270	43	1.3
2001	3353	60	1.8
2002	3426	44	1.3
Total	29257	415	1.4

Table 6.26 Fatality rates in semi-detached dwellings

Year	Number of fires	Number of fatalities	Rate of fatalities per 100 fires
1995	552	3	0.5
1996	477	8	1.7
1997	456	7	1.5
1998	454	8	1.8
1999	404	14	3.5
2000	436	2	0.5
2001	377	1	0.3
2002	406	1	0.2
Total	3562	44	1.2

Table 6.27 Fatality rates in Townhouse/Row house

Year	Number of fires	Number of fatalities	Rate of fatalities per 100 fires
1995	537	7	1.3
1996	495	4	0.8
1997	498	4	0.8
1998	489	9	1.8
1999	503	10	2.0

Table 6.27. (cont.) Fatality rates in Townhouse/Row house

Year	Number of fires	Number of fatalities	Rate of fatalities per 100 fires
2000	458	3	0.7
2001	435	10	2.3
2002	454	10	2.2
Total	3869	57	1.5

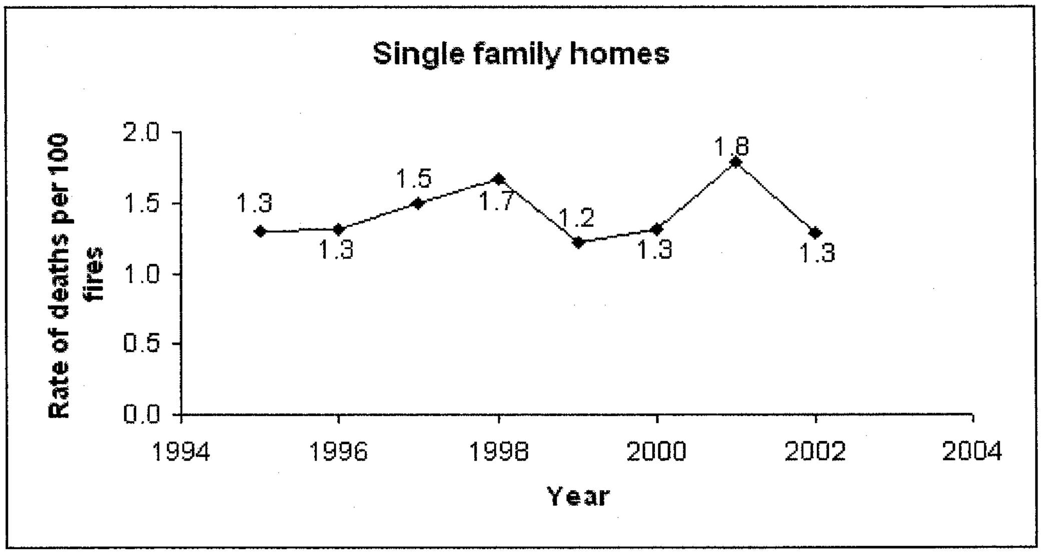

Figure 6.9 Annual death rates in single family homes

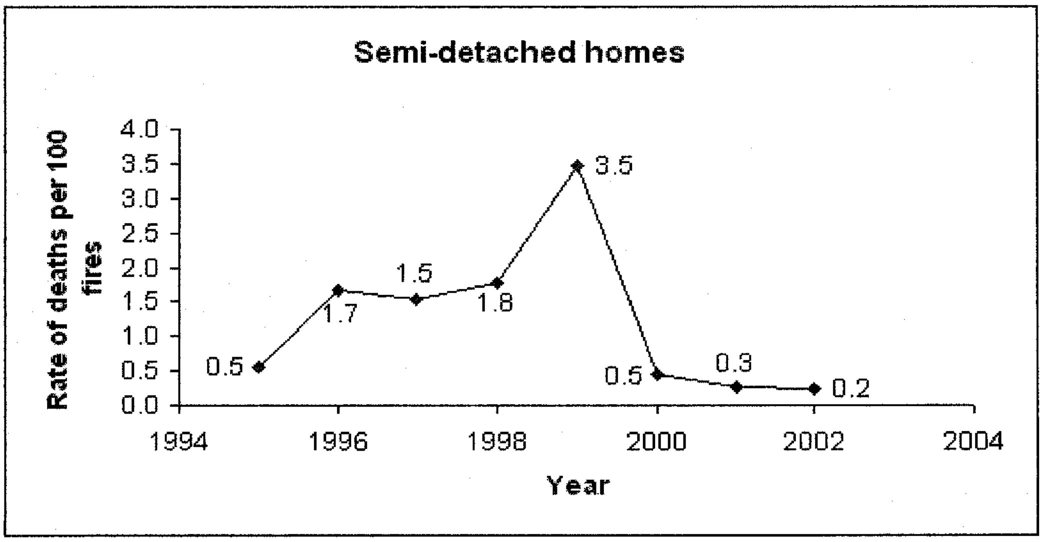

Figure 6.10 Annual death rates in semi-detached homes

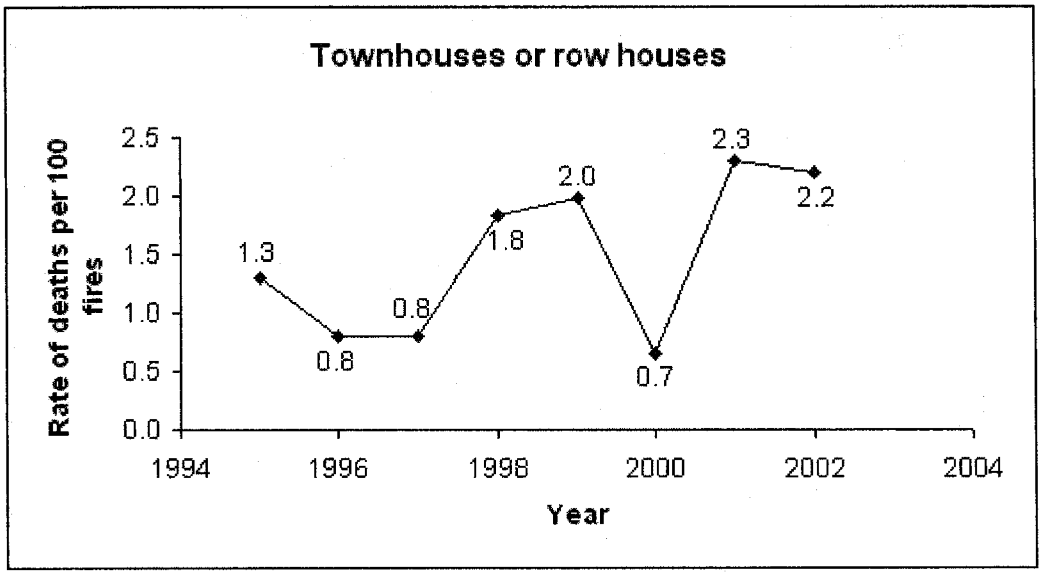

Figure 6.11 Annual death rates in townhouses or row houses

Table 25 and Figure 6.9 show that the fatality rates in single family dwellings have an up and down trend during the entire eight year period. The lowest rate was observed in 1999 and the highest is seen in 2001 with a fifty percent range of fluctuation. Although the number of fires in single-family dwellings has been reduced during the past eight years by more than twenty percent, the fatality rates have not decreased.

Table 26 and Figure 6.10 show that the fatality rate in semi-detached dwellings has shown an almost upward trend from 1995 onwards with a steep rise in 1999, but then it fell dramatically in 2000 followed by a consistent drop thereafter. During the last eight years, the number of fires in semi-detached homes has been reduced by about 1/4 whereas the fatality rates have reduced to less than half.

Table 27 and Figure 6.11 show that the fatality rates in town houses/row houses have shown a downward trend in the beginning until 1998, but an upwards trend thereafter except for a dramatically sharp fall in 2000. During the eight years, the number of fires in town houses/row houses has been reduced by about fifteen percent, but the fatality rates have rather increased by a big margin of about seventy percent.

Overall it has been seen that fatality rates have increased in town houses/ row houses, almost stayed the same for detached dwellings, and decreased in semi-detached dwellings. Generally fluctuations have been observed except for the last three year period for semi-detached dwellings.

Table 6.28 Fatalities during 1995-2002

Type of building	Number of fires	Number of fatalities	Rate of fatalities per 100 fires
Single family homes	29,257	415	1.4
Semi detached	3,562	44	1.2
Townhouse/Row house	3,869	57	1.5

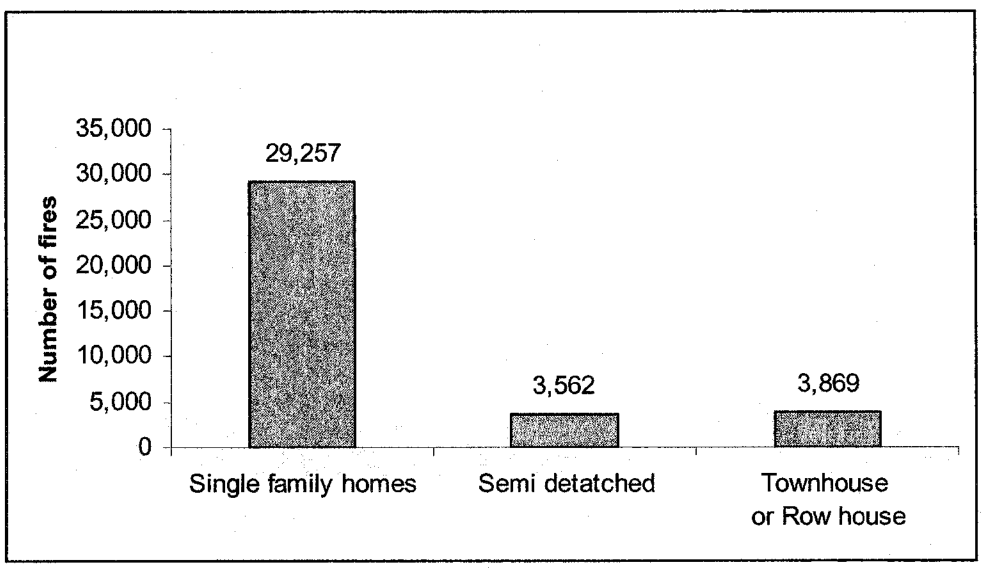

Figure 6.12 Ontario residential dwellings fires during 1995-2002

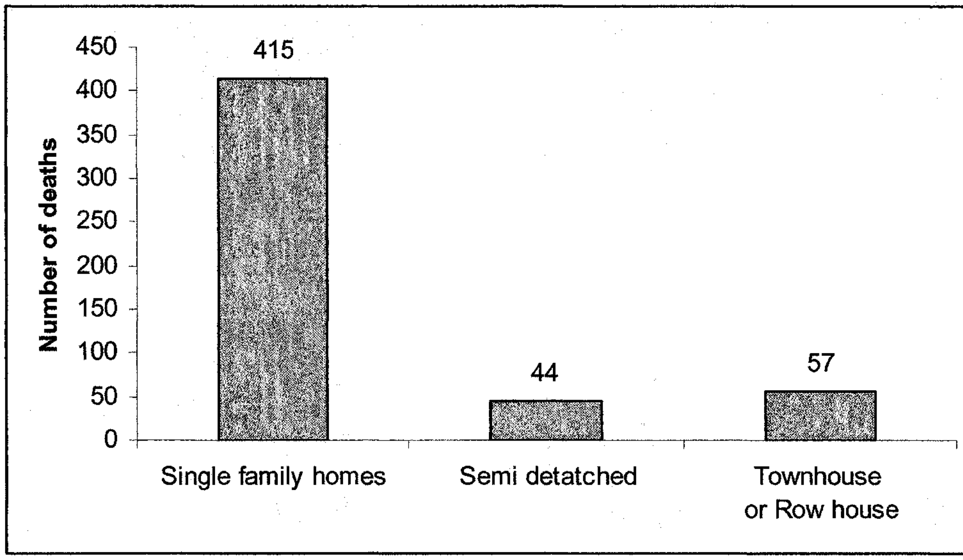

Figure 6.13 Ontario residential dwellings fire deaths during 1995-2002

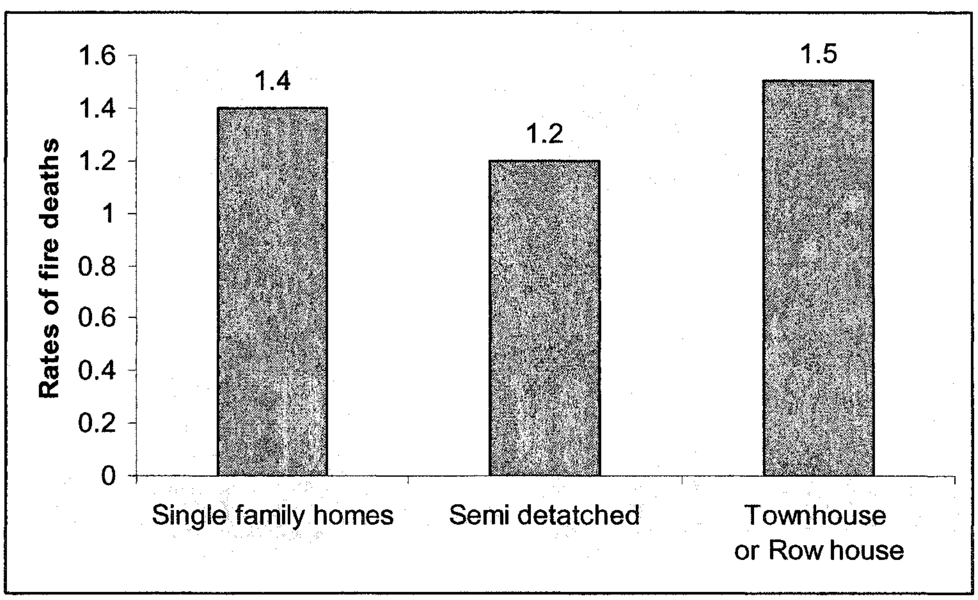

Figure 6.14 Ontario residential dwellings fire death rates during 1995-2002

Table 6.28 and Figures 6.12 through 6.14 show that the number of fire incidents as well as the number of deaths in single-family dwellings are about four times higher than semi-detached and town houses/row houses taken together. However the rate of fatalities per 100 fires is the highest in town houses/row houses, followed by the rate of single-family dwellings. OFM [8] during their evaluation of data for 1995 to 1999 for major property classes in Ontario as well as the U.S.A. has reported that, one and two family dwellings account for 50% of fire deaths in Ontario and 58% fire deaths in U.S.A..

6.2.2. Causes of fatalities

Efforts have been made to determine the major causes of death in single-family dwellings, semi-detached dwellings, and town houses/row houses. Table 6.29 indicates various causes associated with these deaths for all the three types of homes. Table values show the percentage of total deaths in each category of residential dwellings. The values may not total to hundred because other causes like suicides or not reported incidents, have not been shown in the table.

Table 6.29 Causes of death in residential dwellings during 1995-2002

Cause	**Single family**	**Semi-detached**	**Townhouse or Row house**
Asphyxia (CO, HCN)	72.3%	61.9%	83.8%
Complication from asphyxia	4.7%	20.2%	2.0%
Total asphyxia	**77.0%**	**82.1%**	**85.8%**
Burns or scalds	8.7%	9.5%	5.1%
Complication from burns	3.3%	3.6%	2.0%
Total burns	**12.0%**	**13.1%**	**7.1%**

The table shows that asphyxia (CO, HCN) is the main cause of deaths in all three types of homes. Of the total deaths in a particular category of homes, asphyxia accounts for the majority of deaths in case of town houses/row houses at 85.8%, semi-detached dwellings stand at 82.1%, and the single family dwellings at 77%. The other possible causes of deaths are suicide, and injuries while escaping, which have not been shown as they account for a very small percentage of deaths.

6.2.3. Fatality condition in buildings

The fatality conditions have also been studied to find out whether any compelling circumstances existed in the buildings which resulted in deaths. Table 6.30 has been developed to show fatality conditions for the three types of dwellings. Unknown or not reported conditions have not been considered and hence the total may not add to hundred percent.

Table 6.30 Fatality condition in residential dwellings during 1995-2002

Fatality condition	Single family	Semi-detached	Townhouse or Row house
Normal (awake)	18.3%	25.0%	22.2%
Asleep	21.9%	19.0%	22.2%
Impaired alcohol	18.3%	14.3%	6.1%
Infant too young	6.3%	16.7%	20.2%
Physical disabilities	13.1%	10.8%	15.1%
Unattended child	0.5%	1.2%	2.0%

The main fatality condition in all types of homes is "Asleep", which ranges from about 19% to 22% in all types of homes. Normal deaths range from 25% in semi-detached homes to 18.3% for single homes. Deaths due to impairment with alcohol are the highest in single family homes at 18.3% followed by semi-detached dwellings at 14.3% and townhouses/row houses 6.1%. The infant (0-4 yrs) deaths are highest in townhouses/row houses at 20.2%, followed by semi-detached dwellings at 16.7%, and single family dwellings at 6.3%. In addition to the above, it can be seen that physical disability (whether ambulatory, bed ridden, mentally ill, or deaf etc.) all combined, account for about 10% to 15% deaths in all types of homes. Some of the other fatality conditions include children left unattended (4-12 yrs) accounting for maximum of up to two percent of deaths in any of the residential dwellings.

In general it can be seen that about 1/4 deaths occur while sleeping, another 1/4 occur under normal conditions. It is interesting to note that the deaths in single family homes because of impairment due to alcohol are three times higher than the value for townhouses/row houses. It may also mean that probably the consumption of alcohol is much more by single family home owners. Another interesting observation is the infant deaths, which is three times higher for townhouses/ row houses than in single family homes. This may also mean that expected smaller sized rooms of townhouses or row houses might quickly get suffocated with smoke, resulting in higher infant deaths.

6.2.4. Types of fire

The types of fires have also been evaluated to find out which fuels or energy associated with ignition equipment, are generally responsible for fires resulting in fatalities. Tables 6.31 through 6.33 have been developed to indicate the number of fatalities associated with different types of fires. In the Tables ahead:

"Not Applicable" (e.g. Table 6.31) means, this category of data does not apply to the fire incident (e.g. if the ignition source is lightning, there is no "fuel" associated with this. "Fuel" is primarily associated with appliances that are ignition sources).

"Bad Code" occurs when a non-valid code number is reported.

"Not reported" means, no information was reported on this category of data.

Table 6.31 Single family dwellings

Type of fire	Percentage of total fatalities	Number of fatalities
Undetermined	46.9 %	298
Not Applicable	17.0 %	108
Other	9.3 %	59
Electricity	8.7 %	55
Wood	6.9 %	44
Propane	4.4 %	28
Not reported	2.2 %	14
Natural Gas	1.9 %	12
Gasoline	1.6 %	10
Mixed Fuel	0.9 %	6
Bad code	0.2 %	1
Total	100 %	635

Table 6.32 Semi-detached dwellings

Type of fire	Percentage of total fatalities	Number of fatalities
Undetermined	51.2 %	43
Other	23.8 %	20
Electricity	11.9 %	10
Not Applicable	8.3 %	7
Gasoline	2.4 %	2
Natural Gas	1.2 %	1
Bad code	1.2 %	1
Total	100 %	84

Table 6.33 Townhouses/row houses

Type of fire	Percentage of total fatalities	Number of fatalities
Undetermined	45.5 %	45
Not Applicable	37.4 %	37
Gasoline	10.1 %	10
Other	3.0 %	3
Electricity	3.0 %	3
Mixed Fuel	1.0 %	1
Total	100 %	99

The type of fire could not be determined for about half of the total number of fires in each of the three categories of homes. Another 25% to 35% fires have been categorized as not applicable/others/not reported etc., hence there are only about 25% known types of fires in single family dwellings and about 15% known types of fires in each of semi-detached dwellings and townhouses/row houses. Amongst the known fuels or ignition sources, electricity accounts for the highest share in single family dwellings and semi-detached dwellings, but in townhouses/row houses gasoline caused the highest number of fires followed by electricity. For single homes, the other fuels found to cause a fire are wood, followed by propane, natural gas, gasoline and mixed fuel. Moreover in the case of semi-detached homes, gasoline stands 2nd and is followed by natural gas. Thus it can be concluded that amongst the known sources, electricity and gasoline are the main sources for semi-detached and townhouses/row houses whereas for single family homes electricity is the main cause of fire followed by propane, natural gas, and gasoline.

6.2.5. Location of fatalities

The location of fatalities has also been analyzed to determine if there are differences in the three types of buildings. Table 6.34 has been developed for this purpose. Unknown/ not applicable/ not reported incidents and corridor (1% for single family only) have not been included.

Table 6.34 Location of fatalities

Location	**Single family**	**Semi-detached**	**Townhouse or row house**
Room of fire	41%	18%	14%
Other floor above	39%	62%	62%
Other floor below	6%	5%	2%
Floor of fire	1%	14%	14%
Stairwell	1%	0%	1%

The table shows that more than 3/4 of fatalities in each category of homes occur, either inside the room of origin of fire or on another floor above the area of origin of fire.

In the case of single family dwellings the numbers of fatalities in the room of fire origin are much higher than the values for the other two types of buildings. The majority of deaths in semi-detached dwellings as well as townhouses/ row houses occur on a floor, above the area of origin. It is interesting to note that in semi-detached dwellings as well as townhouses/row houses, a significant number of fatalities occur on the floor of fire origin (other room) 14%. For almost all the categories of homes, other locations in the decreasing order of fatalities are another floor below the area of origin, followed by the stairwell.

Chapter 7

7. Operational reliability of active fire protection systems

This chapter describes analysis of the OFM data [4] to determine the operational reliability of active fire protection systems. Where possible, the data were used to obtain mean operational reliability estimates with 95% confidence limits for smoke detectors, heat detectors and sprinkler systems for all occupancies included in the OFM data. This information is required for use in risk assessment models. A comparison of the obtained mean operational reliability estimates with other reliability studies, for smoke detectors, heat detectors and sprinklers, is also performed.

7.1 Mean operational reliability estimates

Reliability of individual fire protection strategies such as detection or automatic suppression is a very important input for detailed engineering analysis associated with performance based design. Reliability is generally expressed in terms of probability of success, and is expressed as [5]

$$P\text{ (success)} = \text{Number of successes / Total number of incidents}$$

Reliability can be expressed as operational and performance reliability. Operational reliability provides a measure of the probability that a fire protection system will operate as intended when needed. Performance reliability is a measure of the adequacy of the system design, meaning that the system will successfully perform its intended function under specific fire exposure conditions e.g. controlling or extinguishing the fire [3]. The scope of this work is limited to the evaluation of the operational reliability of active fire protection systems based on the OFM data [4]. The reliability has been calculated for all occupancies combined, as well as for individual occupancies using various statistical tools like Microsoft Access, Excel and the software MINITAB. Tables have been developed to show the mean reliability estimates and the 95% confidence limits for smoke detectors, heat detectors and sprinklers for various occupancies. The 95% confidence limits were selected because they are generally used for quality assurance estimates for manufactured machine parts however; other confidence limits can also be used depending upon the required certainty level. This method is better than single point estimates because it provides more information on the estimated results that increases confidence levels [5]. Single point estimates have also been prepared to relate with the values obtained in 95% confidence interval estimates. The comparison of mean reliability of the various fire protection systems is performed only inside the area of fire origin.

7.2 Operational reliability of battery operated smoke detectors

Tables 7.1 through 7.11 show the 95% confidence interval estimates for battery operated smoke detectors for each of the occupancies of OFM data [4]. Table 7.12 combines all the results from Tables 7.1 to 7.11 for the purpose of quick reference and comparison. Tables 7.13 to 7.15 show the single-point estimates for battery operated smoke detectors when located in the area of fire origin, on the same floor, or, on a different floor, to enable comparison with the results of 95% confidence interval estimates.

Table 7.1. All combined occupancies (except residential dwellings)

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (Battery operated)	Inside the area of origin	**55.7**	**57**	**54.4**
	Beyond area of origin (same floor)	**47.7**	**49.1**	**46.3**
	Beyond area of origin (different floor)	**43.8**	**45.1**	**41.5**

Table 7.1 shows the mean reliability of battery operated smoke detectors and its associated 95% confidence upper and lower limits for all occupancies combined, except for residential dwellings which are dealt with separately. The table shows that the mean reliability of battery operated smoke detectors located in the area of origin is 55.7% with its 95% confidence upper limit at 57% and lower limit at 54.4%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 47.7% with its 95% confidence upper limit at 49.1% and lower limit at 46.3%. When detectors are located on different floors, the mean reliability further reduces to 43.8% with its 95% confidence upper limit at 45.1% and lower limit at 41.5%.

Table 7.2. Assembly occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (Battery operated)	Inside the area of origin	**80.7**	**82.2**	**79.2**
	Beyond area of origin (same floor)	**50.3**	**51.8**	**48.8**
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.2 shows the mean reliability of battery operated smoke detectors and its associated 95% confidence upper as well as lower limits for assembly occupancies. The table shows that the mean reliability of battery operated smoke detectors located in the area of origin is 80.7% with its 95% confidence upper limit at 82.2% and lower limit at 79.2%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 50.3 % with its 95% confidence upper limit at 51.8% and lower limit at 48.8%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.3. Institutional Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (Battery operated)	Inside the area of origin	**95.9**	**96.7**	**95.1**
	Beyond area of origin (same floor)	**53.9**	**55.8**	**52**
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.3 shows the mean reliability of battery operated smoke detectors and its associated 95% confidence upper as well as lower limits for institutional occupancies. The table shows that the mean reliability of battery operated smoke detectors located in the area of origin is 95.9% with its 95% confidence upper limit at 96.7% and lower limit at 95.1%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 53.9% with its 95% confidence upper limit at 55.8% and lower limit at 52%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.4. Residential Occupancies (other than residential dwellings)

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (Battery operated)	Inside the area of origin	**53.9**	**55**	**52.8**
	Beyond area of origin (same floor)	**47.9**	**49.1**	**46.7**
	Beyond area of origin (different floor)	**45.2**	**47.2**	**43.2**

Table 7.4 shows the mean reliability of battery operated smoke detectors and its associated 95% confidence upper as well as lower limits for residential occupancies, except for residential dwellings. Table shows that the mean reliability of battery operated smoke detectors located in the area of origin is 53.9% with its 95% confidence upper limit at 55% and lower limit at 52.8%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 47.9 % with its 95% confidence upper limit at 49.1% and lower limit at 46.7%. With detectors located on a different floor, the mean reliability further reduces to 45.2% with its 95% confidence upper limit at 47.2% and lower limit at 43.2%.

Table 7.5. Mercantile Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (Battery operated)	Inside the area of origin	**64.8**	**67.2**	**62.4**
	Beyond area of origin (same floor)	**39.1**	**41.8**	**36.4**
	Beyond area of origin (different floor)	**36.6**	**39**	**34.2**

Table 7.5 shows the mean reliability of battery operated smoke detectors and its associated 95% confidence upper as well as lower limits for mercantile occupancies. The table shows that the mean reliability of battery operated smoke detectors located in the area of origin is 64.8% with its 95% confidence upper limit at 67.2% and lower limit at 62.4%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 39.1% with its 95% confidence upper limit at 41.8% and lower limit at 36.4%. With detectors located on a different floor, the mean reliability further reduces to 36.6% with its 95% confidence upper limit at 39% and lower limit at 34.2%.

Table 7.6. Industrial Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (Battery operated)	Inside the area of origin	**69.1**	**70.6**	**67.6**
	Beyond area of origin (same floor)	**66.8**	**68.4**	**65.2**
	Beyond area of origin (different floor)	**47.7**	**49.5**	**45.9**

Table 7.6 shows the mean reliability of battery operated smoke detectors and its associated 95% confidence upper as well as lower limits for industrial occupancies. The table shows that the mean reliability of battery operated smoke detectors located in the area of origin is 69.1% with its 95% confidence upper limit at 70.6% and lower limit at 67.6%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 66.8 % with its 95% confidence upper limit at 68.4% and lower limit at 65.2%. With detectors located on a different floor, the mean reliability further reduces to 47.7% with its 95% confidence upper limit at 49.5% and lower limit at 45.9%.

Table 7.7. Business and Personal Services Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (Battery operated)	Inside the area of origin	**47**	**50.3**	**43.7**
	Beyond area of origin (same floor)	*	*	*
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.7 shows the mean reliability of battery operated smoke detectors and its associated 95% confidence upper as well as lower limits for business and personal services occupancies. The table shows that the mean reliability of battery operated smoke detectors located in the area of origin is 47% with its 95% confidence upper limit at 50.3% and lower limit at 43.7%. No reliability values could be computed for detectors located beyond the area of origin in the absence of sufficient data.

Table 7.8. All combined (Single family, semi-detached and townhouses or row houses)

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (Battery operated)	Inside the area of origin	**70.8**	**71.7**	**69.9**
	Beyond area of origin (same floor)	**57.1**	**58.1**	**56.1**
	Beyond area of origin (different floor)	**48.7**	**47.7**	**49.7**

Table 7.8 shows the mean reliability of battery operated smoke detectors and its associated 95% confidence upper as well as lower limits for single family homes, semi-

detached homes, and townhouses or row houses. Table shows that the mean reliability of battery operated smoke detectors located in the area of origin is 70.8% with its 95% confidence upper limit at 71.7% and lower limit at 69.9%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 57.1% with its 95% confidence upper limit at 58.1% and lower limit at 56.1%. With detectors located on a different floor, the mean reliability further reduces to 48.7% with its 95% confidence upper limit at 47.7% and lower limit at 49.7%.

Table 7.9. Single family dwellings

Device Type	**Location of Device**	**Mean Reliability (%)**	**95% Upper Confidence Limit (%)**	**95% Lower Confidence Limit (%)**
Smoke detector (Battery operated)	Inside the area of origin	**71.6**	**72.5**	**70.7**
	Beyond area of origin (same floor)	**59**	**59.9**	**58.1**
	Beyond area of origin (different floor)	**48.9**	**50**	**47.8**

Table 7.9 shows the mean reliability of battery operated smoke detectors and its associated 95% confidence upper as well as lower limits for single-family homes. The table shows that the mean reliability of battery operated smoke detectors located in the area of origin is 71.6%, with its 95% confidence upper limit at 72.5% and lower limit at 70.7%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 59.0 % with its 95% confidence upper limit at 59.9% and lower limit at 58.1%. With detectors located on a different floor, mean reliability further reduces to 48.9% with its 95% confidence upper limit at 50% and lower limit at 47.8%.

Table 7.10. Semi-detached dwellings

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (Battery operated)	Inside the area of origin	**64.4**	**66.2**	**62.6**
	Beyond area of origin (same floor)	**51.7**	**53.9**	**49.5**
	Beyond area of origin (different floor)	**42.5**	**44.4**	**40.6**

Table 7.10 shows the mean reliability of battery operated smoke detectors and its associated 95% confidence upper as well as lower limits for semi-detached homes. The table shows that the mean reliability of battery operated smoke detectors located in the area of origin is 64.4% with its 95% confidence upper limit at 66.2% and lower limit at 62.6%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 51.7% with its 95% confidence upper limit at 53.9% and lower limit at 49.5%. With detectors located on a different floor, the mean reliability further reduces to 42.5% with its 95% confidence upper limit at 44.4% and lower limit at 40.6%.

Table 7.11. Townhouses or Row houses

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (Battery operated)	Inside the area of origin	67.5	69.5	65.5
	Beyond area of origin (same floor)	52.6	54.6	50.6
	Beyond area of origin (different floor)	47.2	49.3	45.1

Table 7.11 shows the mean reliability of battery operated smoke detectors and its associated 95% confidence upper as well as lower limits for townhouses or row houses. The table shows that the mean reliability of battery operated smoke detectors located in the area of origin is 67.5%, with its 95% confidence upper limit at 69.5% and lower limit at 65.5%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 52.6 % with its 95% confidence upper limit at 54.6% and lower limit at 50.6%. With detectors located on a different floor, the mean reliability further reduces to 47.2% with its 95% confidence upper limit at 49.3% and lower limit at 45.1%.

Table 7.12 summarizes all the results of Tables 7.1 to 7.11. Tables 7.13 to 7.15 show the single point estimates of battery operated smoke detectors for comparison with the results of Table 7.12.

Table 7.12 Battery operated smoke detectors

Operational reliability of battery operated smoke detectors (95% confidence interval estimates)									
Occupancy	**Inside area of origin**			**Beyond area of origin (same floor)**			**Beyond area of origin (different floor)**		
	Mean (%)	**Upper limit (%)**	**Lower limit (%)**	**Mean (%)**	**Upper limit (%)**	**Lower limit (%)**	**Mean (%)**	**Upper limit (%)**	**Lower limit (%)**
All combined (other than residential dwellings)	**55.7**	57	54.4	**47.7**	49.1	46.3	**43.8**	45.1	41.5
Assembly	**80.7**	82.2	79.2	**50.3**	51.8	48.8	*	*	*
Institutional	**95.9**	96.7	95.1	**53.9**	55.8	52	*	*	*
Residential (except residential dwellings)	**53.9**	55	52.8	**47.9**	49.1	46.7	**45.2**	47.2	43.2
Mercantile	**64.8**	67.2	62.4	**39.1**	41.8	36.4	**36.6**	39	34.2
Industrial	**69.1**	70.6	67.6	**66.8**	68.4	65.2	**47.7**	49.5	45.9
Business and personal services	**47**	50.3	43.7	*	*	*	*	*	*
All combined residential dwellings	**70.8**	71.7	69.9	**57.1**	58.1	56.1	**48.7**	49.7	47.7
Single family homes	**71.6**	72.5	70.7	**59**	59.9	58.1	**48.9**	50	47.8
Semi-detached homes	**64.4**	66.2	62.6	**51.7**	53.9	49.5	**42.5**	44.4	40.6
Townhouses or Row houses	**67.5**	69.5	65.5	**52.6**	54.6	50.6	**47.2**	49.3	45.1

*Insufficient data

Note: Residential dwellings include single-family homes, semi-detached houses, townhouses or row houses.

Table 7.12 shows that in general the operational reliability values for systems in the area of fire origin are higher than those outside the area of origin. Further the reliability value for a device on the same floor is higher than that of the same device on a different floor. Overall, the mean operational reliability of battery operated smoke detectors in various occupancies is observed to vary in the range of 47% for business and personal services occupancies to 95.9% for institutional occupancy. Institutional occupancy shows the highest mean reliability of 95.9% followed by assembly occupancy at 80.7%, residential dwellings in the range of 64.4% to 71.6%, industrial at 69.1%, mercantile at 64.8%, residential (without residential dwellings) at 53.9%, and business and personal services at 47%. The highest operational reliability of 95.9% for battery operated smoke detectors in institutional occupancies is an indicative of adoption of very good inspection, testing and maintenance practices (including timely replacement of batteries) for these occupancies. In case of residential dwellings, single family homes showed the highest mean reliability of 71.6% followed by townhouses or row houses at 67.5% and semi-detached homes at 64.4%. All combined residential dwellings show a mean reliability of 70.8% whereas, all combined other structures is at 55.7%.

Table shows that 95% confidence upper and lower limits for most of the occupancies are observed to vary within ± 2 of their mean reliability estimates, with an exception for mercantile occupancies falling within ± 2.7 and business and personal services at ± 3.3. Overall, Table 7.12 indicates that no single value representing all occupancies could be assigned to the mean reliability of battery operated smoke detectors as they vary widely e.g. 47% to 95.9% when located in the area of origin depending upon the property classification.

Table 7.13 Single point estimates (Battery operated smoke detectors in the area of origin)

Occupancy	Inside area of origin		Probability of operation (%)
	Number of fire incidents	Number of times detector operated	
All combined (other than residential dwellings)	2432	1356	**55.8**
Assembly	61	49	**80.3**
Institutional	42	40	**95.2**
Residential (no dwellings)	2226	1153	**54.0**
Mercantile	32	20	**62.5**
Industrial	35	24	**68.6**
Business and personal services	26	12	**46.2**
All combined residential dwellings	3780	2686	**71.0**
Single family homes	3126	2251	**72.0**
Semi-detached homes	405	261	**64.4**
Townhouses or Row houses	324	219	**67.6**

Table 7.14 Single point estimates (Battery operated smoke detectors on the same floor)

Occupancy	**Inside area of origin**		
	Number of fire incidents	**Number of times detector operated**	**Probability of operation (%)**
All combined (other than residential dwellings)	2234	1065	**47.7**
Assembly	45	23	**51.1**
Institutional	15	8	**53.3**
Residential (no dwellings)	2098	1016	**48.4**
Mercantile	26	10	**38.5**
Industrial	21	14	**66.7**
Business and personal services	21	6	**28.0**
All combined residential dwellings	5617	3209	**57.1**
Single family homes	4607	2688	**58.3**
Semi-detached homes	661	331	**51.3**
Townhouses or Row houses	495	262	**52.9**

Table 7.15 Single point estimates (Battery operated smoke detectors on different floors)

Occupancy	Inside area of origin		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined (other than residential dwellings)	707	312	44.1
Assembly	18	4	22.2
Institutional	4	2	50.0
Residential (no dwellings)	633	288	45.5
Mercantile	22	8	36.4
Industrial	15	7	46.7
Business and personal services	13	5	38.5
All combined residential dwellings	4139	1995	48.2
Single family homes	3333	1627	48.8
Semi-detached homes	586	244	41.6
Townhouses or Row houses	538	253	47.0

Tables 7.13 to 7.15 show the single-point estimates of battery operated smoke detectors when located in the area of origin, on the same floor, and on a different floor respectively, for each of the occupancies of OFM data [4]. The probability of operation has been obtained by dividing the number of fire incidents in which detectors operated to the total number of fire incidents. The tables show the probability results in percentage. The results of Tables 7.13 to 7.15 show that there is a variation between single-point estimates and the mean values in Table 7.12. This variation for detectors located in the area of origin is in the order of ±2.3. All variations between single-point estimates of

Tables 7.13 to 7.15 and mean reliability estimates of Table 7.12 are however covered within the 95% confidences limits of Table 7.12.

7.3 Operational reliability of hard-wired smoke detectors

Tables 7.16 through 7.26 show the 95% confidence interval estimates for hard-wired smoke detectors for each of the occupancies of OFM data [4]. Table 7.27 combines all the results from tables 7.16 to 7.26 for the purpose of quick reference and comparison. Tables 7.28 to 7.30 show the single-point estimates for hard-wired smoke detectors when located in the area of origin, on the same floor, or, on a different floor, to enable comparison with the results of 95% confidence interval estimates.

Table 7.16 All combined occupancies

Device Type	**Location of Device**	**Mean Reliability (%)**	**95% Upper Confidence Limit (%)**	**95% Lower Confidence Limit (%)**
Smoke detector (hard-wired)	Inside the area of origin	**83.1**	**84**	**82.2**
	Beyond area of origin (same floor)	**65.5**	**66.5**	**64.5**
	Beyond area of origin (different floor)	**65.2**	**67**	**63.4**

Table 7.16 shows the mean reliability of hard-wired smoke detectors and its associated 95% confidence upper and lower limits for all occupancies combined, but for residential dwellings which are dealt with separately. The table shows that the mean reliability of hard-wired smoke detectors located in the area of origin is 83.1% with its 95% confidence upper limit at 84% and lower limit at 82.2%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 65.5%

with its 95% confidence upper limit at 66.5% and lower limit at 64.5%. When detectors are located on different floors, the mean reliability further reduces to 65.2% with its 95% confidence upper limit at 67% and lower limit at 63.4%.

Table 7.17 Assembly occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (hard-wired)	Inside the area of origin	**82**	**83.6**	**80.4**
	Beyond area of origin (same floor)	**55.2**	**57.1**	**53.3**
	Beyond area of origin (different floor)	**58.8**	**60.4**	**57.2**

Table 7.17 shows the mean reliability of hard-wired smoke detectors and its associated 95% confidence upper as well as lower limits for assembly occupancies. The table shows that the mean reliability of hard-wired smoke detectors located in the area of origin is 82% with its 95% confidence upper limit at 83.6% and lower limit at 80.4%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 55.2 % with its 95% confidence upper limit at 57.1% and lower limit at 53.3%. When detectors are located on different floors, the mean reliability does not reduce as for most of the occupancies, but it rather increases to 58.5% with its 95% confidence upper limit at 60.4% and lower limit at 57.2%. The reason for this maybe the fact that these occupancies have floors with large areas that may result in smoke entering upper floors before it spreads to other areas on the same floor.

Table 7.18 Institutional Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (hard-wired)	Inside the area of origin	92	93	91
	Beyond area of origin (same floor)	67.1	69.5	64.7
	Beyond area of origin (different floor)	*	*	*

* Insufficient data

Table 7.18 shows the mean reliability of hard-wired detectors and its associated 95% confidence upper as well as lower limits for institutional occupancies. The table shows that the mean reliability of hard-wired smoke detectors located in the area of origin is 92% with its 95% confidence upper limit at 93% and lower limit at 91%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 67.1% with its 95% confidence upper limit at 69.5% and lower limit at 64.7%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.19 Residential Occupancies (other than residential dwellings)

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (hard-wired)	Inside the area of origin	**82.8**	**83.6**	**82**
	Beyond area of origin (same floor)	**69.8**	**71**	**68.6**
	Beyond area of origin (different floor)	**64.9**	**67.5**	**62.3**

Table 7.19 shows the mean reliability of hard-wired smoke detectors and its associated 95% confidence upper as well as lower limits for residential occupancies, but for residential dwellings. Table shows that the mean reliability of hard-wired smoke detectors located in the area of origin is 82.8% with its 95% confidence upper limit at 83.6% and lower limit at 82%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 69.8 % with its 95% confidence upper limit at 71% and lower limit at 68.6%. With detectors located on a different floor, the mean reliability further reduces to 64.9% with its 95% confidence upper limit at 67.5% and lower limit at 62.3%.

Table 7.20 Mercantile Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (hard-wired)	Inside the area of origin	**80.3**	**82.5**	**78.1**
	Beyond area of origin (same floor)	**39.6**	**41.6**	**37.6**
	Beyond area of origin (different floor)	**65.1**	**67.7**	**62.5**

Table 7.20 shows the mean reliability of hard-wired smoke detectors and its associated 95% confidence upper as well as lower limits for mercantile occupancies. The table shows that the mean reliability of hard-wired smoke detectors located in the area of origin is 80.3% with its 95% confidence upper limit at 82.5% and lower limit at 78.1%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 39.6 % with its 95% confidence upper limit at 41.6% and lower limit at 37.6%. With detectors located on a different floor, the mean reliability does not reduce as for most of the occupancies, rather increases to 65.1% with its 95% confidence upper limit at 67.7% and lower limit at 62.5%. The reason for this maybe the fact that these occupancies have floors with large areas that may result in smoke entering upper floors before it spreads to other areas on the same floor.

Table 7.21 Industrial Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (hard-wired)	Inside the area of origin	**87.6**	**89.2**	**86**
	Beyond area of origin (same floor)	**61.9**	**64.1**	**59.7**
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.21 shows the mean reliability of hard-wired smoke detectors and its associated 95% confidence upper as well as lower limits for industrial occupancies. The table shows that the mean reliability of hard-wired smoke detectors located in the area of origin is 87.6% with its 95% confidence upper limit at 89.2% and lower limit at 86%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 61.9 % with its 95% confidence upper limit at 64.1% and lower limit at 59.7%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.22 Business and Personal Services Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (hard-wired)	Inside the area of origin	**85.2**	**87.1**	**83.3**
	Beyond area of origin (same floor)	**48.3**	**50.4**	**46.2**
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.22 shows the mean reliability of hard-wired smoke detectors and its associated 95% confidence upper as well as lower limits for business and personal services occupancies. The table shows that the mean reliability of hard-wired smoke detectors located in the area of origin is 85.2% with its 95% confidence upper limit at 87.1% and lower limit at 83.3%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 48.3 % with its 95% confidence upper limit at 50.4% and lower limit at 46.2%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.23 All combined (Single family, semi-detached and townhouses or row houses)

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (hard-wired)	Inside the area of origin	**78.9**	**80.4**	**77.4**
	Beyond area of origin (same floor)	**68.8**	**70.1**	**67.5**
	Beyond area of origin (different floor)	**55.0**	**56.4**	**53.6**

Table 7.23 shows the mean reliability of hard-wired smoke detectors and its associated 95% confidence upper as well as lower limits for single-family homes, semi-detached homes, and townhouses or row houses. Table shows that the mean reliability of hard-wired smoke detectors located in the area of origin is 78.9% with its 95% confidence upper limit at 80.4% and lower limit at 77.4%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 68.8% with its 95% confidence upper limit at 70.1% and lower limit at 67.5%. With detectors located on a different floor, the mean reliability further reduces to 55% with its 95% confidence upper limit at 56.4% and lower limit at 53.6%.

Table 7.24 Single family dwellings

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (hard-wired)	Inside the area of origin	**78.9**	**80.1**	**77.7**
	Beyond area of origin (same floor)	**69.6**	**70.9**	**68.3**
	Beyond area of origin (different floor)	**56.3**	**57.7**	**54.9**

Table 7.24 shows the mean reliability of hard-wired smoke detectors and its associated 95% confidence upper as well as lower limits for single-family homes. The table shows that the mean reliability of hard-wired smoke detectors located in the area of origin is 78.9%, with its 95% confidence upper limit at 80.1% and lower limit at 77.7%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 69.6 % with its 95% confidence upper limit at 70.9% and lower limit at 68.3%. With detectors located on a different floor, the mean reliability further reduces to 56.3% with its 95% confidence upper limit at 57.7% and lower limit at 54.9%.

Table 7.25 Semi-detached dwellings

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (hard-wired)	Inside the area of origin	**75**	**77.1**	**72.9**
	Beyond area of origin (same floor)	**61.1**	**63.8**	**58.4**
	Beyond area of origin (different floor)	**54**	**56.6**	**51.4**

Table 7.25 shows the mean reliability of hard-wired smoke detectors and its associated 95% confidence upper as well as lower limits for semi-detached homes. The table shows that the mean reliability of hard-wired smoke detectors located in the area of origin is 75% with its 95% confidence upper limit at 77.1% and lower limit at 72.9%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 61.1% with its 95% confidence upper limit at 63.8% and lower limit at 58.4%. With detectors located on a different floor, the mean reliability further reduces to 54% with its 95% confidence upper limit at 56.6% and lower limit at 51.4%.

Table 7.26 Townhouses or Row houses

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Smoke detector (hard-wired)	Inside the area of origin	**74.2**	**75.8**	**72.6**
	Beyond area of origin (same floor)	**71.6**	**73.4**	**69.8**
	Beyond area of origin (different floor)	**53.3**	**55.4**	**51.2**

Table 7.26 shows the mean reliability of hard-wired smoke detectors and its associated 95% confidence upper as well as lower limits for townhouses or row houses. The table shows that the mean reliability of hard-wired smoke detectors located in the area of origin is 74.2%, with its 95% confidence upper limit at 75.8% and lower limit at 72.6%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 71.6 % with its 95% confidence upper limit at 73.4% and lower limit at 69.8%. With detectors located on a different floor, the mean reliability further reduces to 53.3% with its 95% confidence upper limit at 55.4% and lower limit at 51.2%.

Table 7.27 summarizes all the results of Tables 7.16 to 7.26. Tables 7.28 to 7.30 show the single-point estimates of hard-wired smoke detectors for comparison with the results of Table 7.27.

Table 7.27 Hard wired smoke detectors

Operational reliability of hard-wired smoke detectors (95% confidence interval estimates)									
Occupancy	**Inside area of origin**			**Beyond area of origin (same floor)**			**Beyond area of origin (different floor)**		
	Mean (%)	**Upper limit (%)**	**Lower limit (%)**	**Mean (%)**	**Upper limit (%)**	**Lower limit (%)**	**Mean (%)**	**Upper limit (%)**	**Lower limit (%)**
All combined (other than residential dwellings)	**83.1**	84	82.2	**65.5**	66.5	64.5	**65.2**	67	63.4
Assembly	**82**	83.6	80.4	**55.2**	57.1	53.3	**58.8**	60.4	57.2
Institutional	**92**	93	91	**67.1**	69.5	64.7	*	*	*
Residential (no dwellings)	**82.8**	83.6	82	**69.8**	71	68.6	**64.9**	67.5	62.3
Mercantile	**80.3**	82.5	78.1	**39.6**	41.6	37.6	**65.1**	67.7	62.5
Industrial	**87.6**	89.2	86	**61.9**	64.1	59.7	*	*	*
Business and personal services	**85.2**	87.1	83.3	**48.3**	50.4	46.2	*	*	*
All combined residential dwellings	**78.9**	80.4	77.4	**68.8**	70.1	67.5	**55**	56.4	53.6
Single family homes	**78.9**	80.1	77.7	**69.6**	70.9	68.3	**56.3**	57.7	54.9
Semi-detached homes	**75**	77.1	72.9	**61.1**	63.8	58.4	**54**	56.6	51.4
Townhouses or Row houses	**74.2**	75.8	72.6	**71.6**	73.4	69.8	**53.3**	55.4	51.2

*Insufficient data

Note: Residential dwellings include single-family homes, semi-detached, townhouses or row houses.

Table 7.27 shows that in general the operational reliability values for systems in the area of origin are higher than those outside the area of origin. Further the reliability value for a device on the same floor is higher than that, the same device on a different floor. Overall, the mean operational reliability of hard wired smoke detectors located in the area of origin for various occupancies is observed to vary in the range of 74.2% for townhouses or row houses to 92.0% for institutional occupancy. Institutional occupancy shows the highest mean reliability of 92.0% followed by industrial occupancy at 85.7%, business and personal services at 85.2%, residential occupancies but for residential dwellings at 82.8%, assembly occupancies at 82%, mercantile occupancies at 80.3%, and residential dwellings in the range of 74.2% to 78.9%. In case of residential dwellings, single-family homes showed the highest mean reliability of 78.9% followed by semi-detached homes at 75%, and townhouses or row houses at 74.2%. All combined residential dwellings show a mean reliability of 78.9% whereas, all combined other structures is at 83.1%.

The table shows that 95% confidence upper and lower limits for all the occupancies are observed to vary within ± 2.7 (semi-detached homes) of their mean reliability estimates. Table 7.27 indicates that no single value representing all occupancies could be assigned to the mean reliability of hard-wired smoke detectors as they vary widely e.g. 74.2% to 92% when located in the area of origin, depending upon the property classification.

Table 7.28 Single point estimates (Hard wired smoke detectors in the area of origin)

Occupancy	Inside area of origin		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined (other than residential dwellings)	3483	2916	**83.7**
Assembly	414	339	**81.9**
Institutional	322	296	**91.9**
Residential (no dwellings)	2335	1933	**82.8**
Mercantile	124	99	**79.8**
Industrial	158	138	**87.3**
Business and personal services	123	105	**85.4**
All combined residential dwellings	1028	807	**78.5**
Single family homes	711	569	**80.0**
Semi-detached homes	109	82	**75.2**
Townhouses or Row houses	228	171	**75.0**

Table 7.29 Single point estimates (Hard wired smoke detectors on the same floor)

Occupancy	Beyond area of origin (same floor)		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined (other than residential dwellings)	2556	1694	**66.3**
Assembly	226	128	**56.6**
Institutional	83	56	**67.5**
Residential (no dwellings)	2031	1401	**69.0**
Mercantile	68	27	**39.7**
Industrial	70	43	**61.4**
Business and personal services	75	37	**49.3**
All combined residential dwellings	1826	1249	**68.4**
Single-family homes	1330	914	**68.7**
Semi-detached homes	152	95	**62.5**
Townhouses or Row houses	152	95	**62.5**

Table 7.30 Single point estimates (Hard wired smoke detectors on different floors)

Occupancy	Beyond area of origin (different floor)		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined (other than residential dwellings)	527	340	**64.5**
Assembly	53	32	**60.4**
Institutional	11	7	**63.6**
Residential (no dwellings)	401	258	**64.3**
Mercantile	33	21	**63.3**
Industrial	15	12	**80.0**
Business and personal services	13	9	**69.2**
All combined residential dwellings	1653	918	**55.6**
Single-family homes	1184	665	**56.2**
Semi-detached homes	144	75	**52.1**
Townhouses or Row houses	442	244	**55.2**

Tables 7.28 to 7.30 show the single-point estimates of hard-wired smoke detectors when located, in the area of origin, on the same floor, and on a different floor respectively for each of the occupancies of OFM data [4]. The probability of operation has been obtained by dividing the number of fire incidents in which detectors operated to the total number of fire incidents. The tables show the probability results in percentage. The results of Tables 7.28 to 7.30 show that there is a variation between single-point estimates and the mean values in Table 7.27. This variation is in the order of ±1.9. All

variations between single-point estimates of Tables 7.28 to 7.30 and mean reliability estimates of Table 7.27 are however covered within the 95% confidences limits of Table 7.27.

7.4 Operational reliability of smoke detectors connected to fire alarm system

Tables 7.31 through 7.39 show the 95% confidence interval estimates for smoke detectors connected to fire alarm for each of the occupancies of OFM data [4]. Table 7.40 combines all the results from tables 7.31 to 7.39 for the purpose of quick reference and comparison. Tables 7.41 to 7.43 show the single-point estimates for smoke detectors connected to fire alarm system, and located in the area of origin, on the same floor, or, on a different floor, to enable comparison with the results of 95% confidence interval estimates.

Table 7.31 All combined occupancies

Device Type	**Location of Device**	**Mean Reliability (%)**	**95% Upper Confidence Limit (%)**	**95% Lower Confidence Limit (%)**
smoke detectors connected to fire alarm	Inside the area of origin	**88.8**	**89.7**	**87.9**
	Beyond area of origin (same floor)	**69**	**70.8**	**67.2**
	Beyond area of origin (different floor)	**64.6**	**66.9**	**62.3**

Table 7.31 shows the mean reliability of smoke detectors connected to fire alarm, and its associated 95% confidence upper and lower limits for all occupancies combined, but

for residential dwellings which are dealt with separately. The table shows that the mean reliability of smoke detectors located in the area of origin and connected to fire alarm system is 88.8% with its 95% confidence upper limit at 89.7% and lower limit at 87.9%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 69% with its 95% confidence upper limit at 70.8% and lower limit at 67.2%. When detectors are located on different floors, the mean reliability further reduces to 64.6% with its 95% confidence upper limit at 66.9% and lower limit at 62.3%.

Table 7.32 Assembly occupancies

Device Type	**Location of Device**	**Mean Reliability (%)**	**95% Upper Confidence Limit (%)**	**95% Lower Confidence Limit (%)**
smoke detector connected to fire alarm	Inside the area of origin	**87.5**	**88.7**	**86.3**
	Beyond area of origin (same floor)	**47**	**49.2**	**44.8**
	Beyond area of origin (different floor)	**50.7**	**53.2**	**48.2**

Table 7.32 shows the mean reliability of smoke detectors connected to fire alarm, and its associated 95% confidence upper as well as lower limits for assembly occupancies. The table shows that the mean reliability of smoke detectors located in the area of origin, and connected to fire alarm is 87.5% with its 95% confidence upper limit at 88.7% and lower limit at 86.3%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 47% with its 95% confidence upper limit at 49.2% and lower limit at 44.8%. When detectors are located on a different floor the mean reliability does not reduce as for most of the properties, rather increases to 50.7% with its 95% confidence upper limit at 53.2% and lower limit at 48.2%.

Table 7.33 Institutional Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
smoke detector connected to fire alarm	Inside the area of origin	**92.4**	**93.5**	**91.3**
	Beyond area of origin (same floor)	79	**80.2**	**77.8**
	Beyond area of origin (different floor)	*	*	*

Table 7.33 shows the mean reliability of smoke detectors connected to fire alarm system, and its associated 95% confidence upper as well as lower limits for institutional occupancies. The table shows that the mean reliability of smoke detectors located in the area of origin, and connected to fire alarm is 92.4% with its 95% confidence upper limit at 93.5% and lower limit at 91.3%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 79% with its 95% confidence upper limit at 80.2% and lower limit at 77.8%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.34 Residential Occupancies (other than residential dwellings)

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
smoke detector connected to fire alarm	Inside the area of origin	**90.2**	**91.4**	**89**
	Beyond area of origin (same floor)	**77.1**	**78.8**	**75.4**
	Beyond area of origin (different floor)	**71.6**	**73.8**	**69.4**

Table 7.34 shows the mean reliability of smoke detectors connected to fire alarm, and its associated 95% confidence upper as well as lower limits for residential occupancies, but for residential dwellings. Table shows that the mean reliability of smoke detectors located in the area of origin, and connected to fire alarm is 90.2% with its 95% confidence upper limit at 91.4% and lower limit at 89%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 77.1 % with its 95% confidence upper limit at 78.8% and lower limit at 75.4%. With detectors located on a different floor, the mean reliability further reduces to 71.6% with its 95% confidence upper limit at 73.8% and lower limit at 69.4%.

Table 7.35 Mercantile Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
smoke detector	Inside the area of origin	**75.2**	**77.1**	**73.3**
connected to fire alarm	Beyond area of origin (same floor)	**42.8**	**46.4**	39.2
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.35 shows the mean reliability of smoke detectors connected to fire alarm, and its associated 95% confidence upper as well as lower limits for mercantile occupancies. The table shows that the mean reliability of smoke detectors located in the area of origin, and connected to fire alarm is 75.2% with its 95% confidence upper limit at 77.1% and lower limit at 73.3%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 42.8% with its 95% confidence upper limit at 46.4% and lower limit at 39.2%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.36 Industrial Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
smoke detector	Inside the area of origin	**87.3**	**88.9**	**85.7**
connected to fire alarm	Beyond area of origin (same floor)	**51.9**	**53.2**	**50.6**
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.36 shows the mean reliability of smoke detectors connected to fire alarm, and its associated 95% confidence upper as well as lower limits for industrial occupancies. The table shows that the mean reliability of smoke detectors located in the area of origin is 87.3% with its 95% confidence upper limit at 88.9% and lower limit at 85.7%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 51.9% with its 95% confidence upper limit at 53.2% and lower limit at 50.6%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.37 Business and Personal Services Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
smoke detector	Inside the area of origin	**86.1**	**87.9**	**84.3**
connected to fire alarm	Beyond area of origin (same floor)	**68**	**69.5**	**66.5**
	Beyond area of origin (different floor)	*	*	*

Table 7.37 shows the mean reliability of smoke detectors connected to fire alarm, and its associated 95% confidence upper as well as lower limits for business and personal services occupancies. The table shows that the mean reliability of smoke detectors located in the area of origin, and connected to fire alarm is 86.1% with its 95% confidence upper limit at 87.9% and lower limit at 84.3%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 68% with its 95% confidence upper limit at 69.5% and lower limit at 66.5%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.38 All combined (Single family, semi-detached and townhouses or row houses)

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
smoke detector connected to fire alarm	Inside the area of origin	**94.6**	**95.4**	**93.8**
	Beyond area of origin (same floor)	**88.9**	**90.2**	**87.6**
	Beyond area of origin (different floor)	**67.2**	**68.4**	**66**

Table 7.38 shows the mean reliability of smoke detectors connected to fire alarm, and its associated 95% confidence upper as well as lower limits for single-family homes, semi-detached homes, and townhouses or row houses. Table shows that the mean reliability of smoke detectors located in the area of origin, and connected to fire alarm is 94.6% with its 95% confidence upper limit at 95.4% and lower limit at 93.8%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 88.9% with its 95% confidence upper limit at 90.2% and lower limit at 87.6%. With detectors located on a different floor, the mean reliability further reduces to 67.2% with its 95% confidence upper limit at 68.4% and lower limit at 66%.

Table 7.39 Single family dwellings

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
smoke detector connected to fire alarm	Inside the area of origin	**94.3**	**95.4**	**93.2**
	Beyond area of origin (same floor)	**89.8**	**91.6**	**88**
	Beyond area of origin (different floor)	**71.6**	**73**	**70.2**

Table 7.39 shows the mean reliability of smoke detectors connected to fire alarm, and its associated 95% confidence upper as well as lower limits for single-family homes. The table shows that the mean reliability of smoke detectors located in the area of origin, and connected to fire alarm is 94.3%, with its 95% confidence upper limit at 95.4% and lower limit at 93.2%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 89.8 % with its 95% confidence upper limit at 91.6% and lower limit at 88%. With detectors located on a different floor, mean reliability further reduces to 71.6% with its 95% confidence upper limit at 73% and lower limit at 70.2%.

Note: No reliability values of smoke detectors connected to fire alarm could be computed for semi-detached homes as well as for townhouses or row houses in the absence of sufficient data.

Table 7.40 summarizes all the results of Tables 7.31 to 7.39. Tables 7.41 to 7.43 show the single-point estimates of smoke detectors connected to fire alarm for comparison with the results of Table 7.40.

Table 7.40 Smoke detectors connected to fire alarm system

Operational reliability of smoke detectors connected to fire alarm system (95% confidence interval estimates)									
Occupancy	**Inside area of origin**			**Beyond area of origin (same floor)**			**Beyond area of origin (different floor)**		
	Mean (%)	**Upper limit (%)**	**Lower limit (%)**	**Mean (%)**	**Upper limit (%)**	**Lower limit (%)**	**Mean (%)**	**Upper limit (%)**	**Lower limit (%)**
All combined (other than residential dwellings)	**88.8**	89.7	87.9	**69**	70.8	67.2	**64.6**	66.9	62.3
Assembly	**87.5**	88.7	86.3	**47**	49.2	44.8	**50.7**	53.2	48.2
Institutional	**92.4**	93.5	91.3	**79**	80.2	77.8	*	*	*
Residential (no dwellings)	**90.2**	91.4	89	**77.1**	78.8	75.4	**71.6**	73.8	69.4
Mercantile	**75.2**	77.1	73.3	**42.8**	46.4	39.2	*	*	*
Industrial	**87.3**	88.9	85.7	**51.9**	53.2	50.6	*	*	*
Business and personal services	**86.1**	87.9	84.3	**68**	69.5	66.5	*	*	*
All combined residential dwellings	**94.6**	95.4	93.8	**88.9**	90.2	87.6	**67.2**	68.4	66
Single family homes	**94.3**	95.4	93.2	**89.8**	91.6	88	**71.6**	73	70.2
Semi-detached homes	*	*	*	*	*	*	*	*	*
Townhouses or Row houses	*	*	*	*	*	*	*	*	*

*Insufficient data

Note: Residential dwellings include single-family homes, semi-detached, townhouses or row houses.

Table 7.40 shows that in general the operational reliability values for systems in the area of origin are higher than those outside the area of origin. Further the reliability value for a device on the same floor is higher than for the same device on a different floor. Overall for various occupancies, the mean operational reliability of smoke detectors in the area of origin and connected to fire alarm is observed to vary in the range of 75.2% for mercantile occupancies to 94.6 % for all combined residential dwellings. All combined residential dwellings show the highest mean reliability of 94.6% followed by single-family homes at 94.3 %, residential occupancy (other than residential dwellings) at 90.2%, assembly occupancy at 87.5%, industrial occupancy at 87.3%, and mercantile at 75.2%. No sufficient data for evaluation are available for semi-detached homes as well as townhouses or row houses. All combined other structures (other than residential dwellings) show a mean reliability value of 88.8%.

The table shows that 95% confidence upper and lower limits for all the occupancies vary within ± 3.6 of their mean reliability estimates. Table 7.40 indicates that no single value representing all occupancies could be assigned to the mean reliability of smoke detectors connected to fire alarm as they vary widely e.g. 75.2% to 94.6% when located in the area of origin, depending upon the property classification.

In general, consolidated Tables 7.12, 7.27, and 7.40 show that operational reliability of smoke detectors connected to fire alarm systems is better than that of hard-wired smoke detectors which is better than that of battery-operated smoke detectors. The reason behind is that batteries can run down in battery-operated smoke detectors; hard-wired smoke detectors are not subject to this problem; and central alarms or signals warn, if, even a remotely placed smoke detector connected to fire alarm system operates.

Table 7.41 Single point estimates (Smoke detectors in the area of origin connected to fire alarm)

Occupancy	**Inside area of origin**		
	Number of fire incidents	**Number of times detector operated**	**Probability of operation (%)**
All combined (other than residential dwellings)	1614	1435	**88.9**
Assembly	271	236	**87.1**
Institutional	197	182	**92.4**
Residential (no dwellings)	835	754	**90.3**
Mercantile	68	51	**75.0**
Industrial	144	126	**87.5**
Business and personal services	95	82	**86.3**
All combined residential dwellings	90	85	**94.4**
Single family homes	74	69	**93.2**
Semi-detached homes	9	9	**100.0**
Townhouses or Row houses	7	7	**100.0**

Table 7.42 Single point estimates (Smoke detectors on the same floor connected to fire alarm)

Occupancy	Beyond area of origin (same floor)		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined (other than residential dwellings)	1000	702	**70.2**
Assembly	123	60	**48.8**
Institutional	42	33	**78.6**
Residential (no dwellings)	714	542	**75.9**
Mercantile	35	14	**40.0**
Industrial	40	21	**52.5**
Business and personal services	45	31	**68.9**
All combined residential dwellings	110	99	**90.0**
Single family homes	97	87	**89.7**
Semi-detached homes	6	6	**100.0**
Townhouses or Row houses	9	8	**88.9**

Table 7.43 Single point estimates (Smoke detectors on different floors connected to fire alarm)

Occupancy	Beyond area of origin (different floor)		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined (other than residential dwellings)	165	107	**64.8**
Assembly	20	10	**50.0**
Institutional	7	3	**42.8**
Residential (no dwellings)	109	78	**71.6**
Mercantile	8	4	**50.0**
Industrial	12	7	**58.3**
Business and personal services	8	4	**50.0**
All combined residential dwellings	40	27	**67.5**
Single family homes	38	27	**71.1**
Semi-detached homes	0	1	**0.0**
Townhouses or Row houses	5	3	**60.0**

Tables 7.41 to 7.43 show the single-point estimates of smoke detectors connected to fire alarm, when located in the area of origin, on the same floor, and on a different floor respectively, for each of the occupancies of OFM data [4]. The probability of operation has been obtained by dividing the number of fire incidents in which detectors operated to the total number of fire incidents. The tables show the probability results in percentage. The results of Tables 7.41 to 7.43 show that there is a variation between single-point estimates and the mean values in Table 7.12. This variation for detectors located in the

area of origin is in the order of ±1. All variations between single-point estimates of Tables 7.41 to 7.43 and mean reliability estimates of Table 7.40 are however covered within the 95% confidences limits of Table 7.40.

7.5 Operational reliability of heat detectors

Tables 7.44 through 7.51 show the 95% confidence interval estimates for heat detectors for each of the occupancies of OFM data [4]. Table 7.52 combines all the results from tables 7.44 to 7.51 for the purpose of quick reference and comparison. Tables 7.53 to 7.55 show the single point estimates for heat detectors located in the area of origin, on the same floor, or, on a different floor, to enable comparison with the results of 95% confidence interval estimates.

Table 7.44 All combined occupancies

Device Type	**Location of Device**	**Mean Reliability (%)**	**95% Upper Confidence Limit (%)**	**95% Lower Confidence Limit (%)**
Heat detectors	Inside the area of origin	**61.4**	**62.9**	**59.9**
	Beyond area of origin (same floor)	**26.7**	**28.6**	**24.8**
	Beyond area of origin (different floor)	**12.5**	**13.5**	**11**

Table 7.44 shows the mean reliability of heat detectors and its associated 95% confidence upper and lower limits for all occupancies combined, but for residential dwellings which are dealt with separately. The table shows that the mean reliability of heat detectors located in the area of origin is 61.4% with its 95% confidence upper limit at 62.9% and lower limit at 59.9%. When detectors are located away from the area of

origin, but on the same floor, the mean reliability reduces to 26.7% with its 95% confidence upper limit at 28.6% and lower limit at 24.8%. When detectors are located on different floors, the mean reliability further reduces to 12.5% with its 95% confidence upper limit at 13.5% and lower limit at 11%.

Table 7.45 Assembly occupancies

Device Type	**Location of Device**	**Mean Reliability (%)**	**95% Upper Confidence Limit (%)**	**95% Lower Confidence Limit (%)**
Heat detectors	Inside the area of origin	**50.7**	**52.7**	**48.7**
	Beyond area of origin (same floor)	**13.7**	**15.4**	**12**
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.45 shows the mean reliability of heat detectors and its associated 95% confidence upper as well as lower limits for assembly occupancies. The table shows that the mean reliability of heat detectors located in the area of origin is 50.7% with its 95% confidence upper limit at 52.7% and lower limit at 48.7%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 13.7% with its 95% confidence upper limit at 15.4% and lower limit at 12%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.46 Institutional Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Heat detectors	Inside the area of origin	**48.6**	**51.1**	**46.1**
	Beyond area of origin (same floor)	**27.9**	**29.2**	**26.6**
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.46 shows the mean reliability of heat detectors and its associated 95% confidence upper as well as lower limits for institutional occupancies. The table shows that the mean reliability of heat detectors located in the area of origin is 48.6% with its 95% confidence upper limit at 51.1% and lower limit at 46.1%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 27.9% with its 95% confidence upper limit at 29.2% and lower limit at 26.6%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.47 Residential Occupancies (other than residential dwellings)

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Heat detectors	Inside the area of origin	**68.2**	**70**	**66.4**
	Beyond area of origin (same floor)	**31.9**	**34.4**	**29.4**
	Beyond area of origin (different floor)	**9.7**	**11.1**	**8.3**

Table 7.47 shows the mean reliability of heat detectors and its associated 95% confidence upper as well as lower limits for residential occupancies, but for residential dwellings. Table shows that the mean reliability of heat detectors located in the area of origin is 68.2% with its 95% confidence upper limit at 70% and lower limit at 66.4%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 31.9% with its 95% confidence upper limit at 34.4% and lower limit at 29.4%. With detectors located on a different floor, the mean reliability further reduces to 9.7% with its 95% confidence upper limit at 11.1% and lower limit at 8.3%.

Table 7.48 Mercantile Occupancies

Device Type	**Location of Device**	**Mean Reliability (%)**	**95% Upper Confidence Limit (%)**	**95% Lower Confidence Limit (%)**
Heat detectors	Inside the area of origin	**33.7**	**36**	**31.4**
	Beyond area of origin (same floor)	*	*	*
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.48 shows the mean reliability of heat detectors and its associated 95% confidence upper as well as lower limits for mercantile occupancies. The table shows that the mean reliability of heat detectors located in the area of origin is 33.7% with its 95% confidence upper limit at 36% and lower limit at 31.4%. No reliability values could be computed for detectors located beyond the area of origin, in the absence of sufficient data.

Table 7.49 Industrial Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Heat detectors	Inside the area of origin	**72**	**74.1**	**69.9**
	Beyond area of origin (same floor)	**23**	**24.7**	**21.3**
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.49 shows the mean reliability of heat detectors and its associated 95% confidence upper as well as lower limits for industrial occupancies. The table shows that the mean reliability of heat detectors located in the area of origin is 72% with its 95% confidence upper limit at 74.1% and lower limit at 69.9%. When detectors are located away from the area of origin, but on the same floor, the mean reliability reduces to 23% with its 95% confidence upper limit at 24.7% and lower limit at 21.3%. No reliability values could be computed for detectors located on a different floor in the absence of sufficient data.

Table 7.50 Business and Personal Services Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Heat detectors	Inside the area of origin	**60.5**	**62.6**	**58.4**
	Beyond area of origin (same floor)	*	*	*
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.50 shows the mean reliability of heat detectors and its associated 95% confidence upper as well as lower limits for business and personal services occupancies. The table shows that the mean reliability of heat detectors located in the area of origin is 60.5% with its 95% confidence upper limit at 62.6% and lower limit at 58.4%. No reliability values could be computed for detectors located beyond the area of origin, in the absence of sufficient data.

Note: No reliability values of heat detectors could be computed for single family homes, semi-detached homes and townhouses or row houses in the absence of sufficient data.

Table 7.51 summarizes all the results of Tables 7.44 to 7.50. Tables 7.52 to 7.54 show the single point estimates of heat detectors for comparison with the results of Table 7.51.

Table 7.51 Heat detectors

Operational reliability of heat detectors (95% confidence interval estimates)									
Occupancy	**Inside area of origin**			**Beyond area of origin (same floor)**			**Beyond area of origin (different floor)**		
	Mean (%)	**Upper limit (%)**	**Lower limit (%)**	**Mean (%)**	**Upper limit (%)**	**Lower limit (%)**	**Mean (%)**	**Upper limit (%)**	**Lower limit (%)**
All combined (other than residential dwellings)	**61.4**	62.9	59.9	**26.7**	28.6	24.8	**12.5**	13.5	11
Assembly	**50.7**	52.7	48.7	**13.7**	15.4	12	*	*	*
Institutional	**48.6**	51	46.2	**27.9**	29.2	26.6	*	*	*
Residential (no dwellings)	**68.2**	70	66.4	**31.9**	34.4	29.4	**9.7**	11.1	8.3
Mercantile	**33.7**	36	31.4	*	*	*	*	*	*
Industrial	**72**	74.1	69.9	**23**	24.7	21.3	*	*	*
Business and personal services	**60.5**	62.6	58.4	*	*	*	*	*	*
All combined residential dwellings	*	*	*	*	*	*	*	*	*
Single family homes	*	*	*	*	*	*	*	*	*
Semi-detached homes	*	*	*	*	*	*	*	*	*
Townhouses or Row houses	*	*	*	*	*	*	*	*	*

*Insufficient data

Note: Residential dwellings include single-family homes, semi-detached, townhouses or row houses.

Table 7.51 shows that in general the operational reliability values for heat detectors in the area of origin are higher than those outside the area of origin. Overall for various occupancies, the mean operational reliability of heat detectors in the area of origin varies in the range of the lowest 33.7% for mercantile occupancies to the highest 72% for industrial occupancies. Other occupancies reliability values in decreasing order are, all residential occupancies (other than residential dwellings) at 68.2%, all combined occupancies (other than residential dwellings) at 61.4%, business and personal services at 60.5%, assembly occupancies at 50.7%, and institutional at 48.6%. Sufficient data was not available for single-family homes, semi-detached homes and townhouses or row houses.

The table shows that 95% confidence upper and lower limits for all the occupancies vary within ± 2.4 of their mean reliability estimates. Table 7.51 indicates that no single value representing all occupancies could be assigned to the mean reliability of heat detectors as they vary widely e.g. 33.7% to 72% when located in the area of origin, depending upon the property classification.

Table 7.52 Single point estimates (Heat detectors in the area of origin)

Occupancy	**Inside area of origin**		
	Number of fire incidents	**Number of times detector operated**	**Probability of operation (%)**
All combined (other than residential dwellings)	1463	896	**61.2**
Assembly	290	147	**50.7**
Institutional	114	56	**49.1**
Residential (no dwellings)	764	520	**68.1**
Mercantile	83	28	**33.7**

Table 7.52 (cont.) Single point estimates
(Heat detectors in the area of origin)

Occupancy	Inside area of origin		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
Business and personal services	58	35	**60.3**
All combined residential dwellings	12	7	**58.3**
Single family homes	10	7	**70.0**
Semi-detached homes	*	*	*
Townhouses or Row houses	3	1	**33.3**

* nil incident

Table 7.53 Single point estimates
(Heat detectors on the same floor)

Occupancy	Beyond area of origin (same floor)		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined (other than residential dwellings)	585	152	**26.0**
Assembly	126	17	**13.5**
Institutional	26	7	**26.9**
Residential (no dwellings)	311	103	**33.1**
Mercantile	32	5	**15.6**
Industrial	56	13	**23.2**

Table 7.53 (cont.) Single point estimates (Heat detectors on the same floor)

Occupancy	Beyond area of origin (same floor)		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined residential dwellings	12	8	66.7
Single family homes	7	6	85.7
Semi-detached homes	2	1	50.0
Townhouses or Row houses	3	1	33.3

* nil incident

Table 7.54 Single point estimates (Heat detectors on different floors)

Occupancy	Beyond area of origin (different floor)		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined (other than residential dwellings)	111	15	13.5
Assembly	23	4	17.4
Institutional	3	1	33.3
Residential (no dwellings)	64	6	9.4
Mercantile	5	1	20.0
Industrial	10	2	20.0
Business and personal services	5	0	0.0

Table 7.54 (cont.) Single point estimates (Heat detectors on different floors)

Occupancy	Beyond area of origin (different floor)		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
Single family homes	5	3	**60.0**
Semi-detached homes	*	*	*
Townhouses or Row houses	1	0	**0.0**

* nil incident

Tables 7.52 to 7.54 show the single-point estimates of heat detectors when located in the area of origin, on the same floor, and on a different floor respectively, for each of the occupancies of OFM data [4]. The probability of operation has been obtained by dividing the number of fire incidents in which detectors operated to the total number of fire incidents. The tables show the probability results in percentage. The results of Tables 7.52 to 7.54 show that there is a variation between single-point estimates and the mean values in Table 7.51. This variation for heat detectors located in the area of origin is in the order of ±0.7. All variations between single-point estimates of Tables 7.52 to 7.54 and mean reliability estimates of Table 7.52 are however covered within the 95% confidences limits of Table 7.51.

7.6 Operational reliability of sprinklers

Tables 7.55 through 7.61 show the 95% confidence interval estimates for sprinklers for each of the occupancies of OFM data [4]. Table 7.62 combines all the results from tables 7.55 to 7.61 for the purpose of quick reference and comparison. Tables 7.63 to 7.65

show the single-point estimates for sprinklers located in the area of origin, on the same floor, or, on a different floor, to enable comparison with the results of 95% confidence interval estimates.

Table 7.55 All combined occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Sprinklers	Inside the area of origin	**70.1**	**71.3**	**68.9**
	Beyond area of origin (same floor)	**21.4**	**23.2**	**19.6**
	Beyond area of origin (different floor)	**16.9**	**18.4**	**15.4**

Table 7.55 shows the mean reliability of sprinklers and its associated 95% confidence upper and lower limits for all occupancies combined, but for residential dwellings which are dealt with separately. The table shows that the mean reliability of sprinklers located in the area of origin is 70.1% with its 95% confidence upper limit at 71.3% and lower limit at 68.9%. When sprinklers are located away from the area of origin, but on the same floor, the mean reliability reduces to 21.4% with its 95% confidence upper limit at 23.2% and lower limit at 19.6%. When sprinklers are located on different floors, the mean reliability further reduces to 16.9% with its 95% confidence upper limit at 18.4% and lower limit at 15.4%.

Table 7.56 Assembly occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Sprinklers	Inside the area of origin	55	56.9	53.1
	Beyond area of origin (same floor)	16.7	18.2	15.2
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.56 shows the mean reliability of sprinklers and its associated 95% confidence upper as well as lower limits for assembly occupancies. The table shows that the mean reliability of sprinklers located in the area of origin is 55% with its 95% confidence upper limit at 56.9% and lower limit at 53.1%. When sprinklers are located away from the area of origin, but on the same floor, the mean reliability reduces to 16.7% with its 95% confidence upper limit at 18.2% and lower limit at 15.2%. No reliability values could be computed for sprinklers located on a different floor in the absence of sufficient data.

Table 7.57 Institutional Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Sprinklers	Inside the area of origin	53.6	55.9	51.3
	Beyond area of origin (same floor)	*	*	*
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.57 shows the mean reliability of sprinklers and its associated 95% confidence upper as well as lower limits for institutional occupancies. The table shows that the mean reliability of sprinklers located in the area of origin is 53.6% with its 95% confidence upper limit at 55.9% and lower limit at 51.3%. No reliability values could be computed for sprinklers located beyond the area of origin in the absence of sufficient data.

Table 7.58 Residential Occupancies (other than residential dwellings)

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Sprinklers	Inside the area of origin	77.5	79.2	75.8
	Beyond area of origin (same floor)	15.9	17.8	14
	Beyond area of origin (different floor)	16.1	17.8	14.4

Table 7.58 shows the mean reliability of sprinklers and its associated 95% confidence upper as well as lower limits for residential occupancies, but for residential dwellings. Table shows that the mean reliability of sprinklers located in the area of origin is 77.5% with its 95% confidence upper limit at 79.2% and lower limit at 75.8%. When sprinklers are located away from the area of origin, but on the same floor, the mean reliability reduces to15.9% with its 95% confidence upper limit at 17.8% and lower limit at 14%. With sprinklers located on a different floor the mean reliability does not reduce as for most of the other occupancies, it rather increases to 16.1% with its 95% confidence upper limit at 17.8%, and lower limit at14.4%.

Table 7.59 Mercantile Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Sprinklers	Inside the area of origin	**26.4**	**28.1**	**24.7**
	Beyond area of origin (same floor)	*	*	*
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.59 shows the mean reliability of sprinklers and its associated 95% confidence upper as well as lower limits for mercantile occupancies. The table shows that the mean reliability of sprinklers located in the area of origin is 26.4% with its 95% confidence upper limit at 28.1% and lower limit at 24.7%. No reliability values could be computed for sprinklers located beyond the area of origin, in the absence of sufficient data.

Table 7.60 Industrial Occupancies

Device Type	Location of Device	Mean Reliability (%)	95% Upper Confidence Limit (%)	95% Lower Confidence Limit (%)
Sprinklers	Inside the area of origin	**73**	**74.4**	**71.6**
	Beyond area of origin (same floor)	**33**	**35.1**	**30.9**
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.60 shows the mean reliability of sprinklers and its associated 95% confidence upper as well as lower limits for industrial occupancies. The table shows that the mean reliability of sprinklers located in the area of origin is 73% with its 95% confidence upper limit at 74.4% and lower limit at 71.6%. When sprinklers are located away from the area of origin, but on the same floor, the mean reliability reduces to 33% with its 95% confidence upper limit at 35.1% and lower limit at 30.9%. No reliability values could be computed for sprinklers located on a different floor in the absence of sufficient data.

Table 7.61 Business and Personal Services Occupancies

Device Type	**Location of Device**	**Mean Reliability (%)**	**95% Upper Confidence Limit (%)**	**95% Lower Confidence Limit (%)**
Sprinklers	Inside the area of origin	**62.6**	**65.1**	**60.1**
	Beyond area of origin (same floor)	**15.7**	**16.6**	**14.8**
	Beyond area of origin (different floor)	*	*	*

*Insufficient data

Table 7.61 shows the mean reliability of sprinklers and its associated 95% confidence upper as well as lower limits for business and personal services occupancy. The table shows that the mean reliability of sprinklers located in the area of origin is 62.6% with its 95% confidence upper limit at 65.1% and lower limit at 60.1%. When sprinklers are located away from the area of origin, but on the same floor, the mean reliability reduces to 15.7% with its 95% confidence upper limit at 16.6% and lower limit at 14.8%. No reliability values could be computed for sprinklers located on a different floor in the absence of sufficient data. No reliability values of sprinklers could be computed for single family homes, semi-detached homes and for townhouses or row houses in the absence of sufficient data.

Table 7.62 summarizes all the results of Tables 7.55 to 7.61. Tables 7.63 to 7.65 show the single point estimates of sprinklers for comparison with the results of Table 7.62.

Table 7.62 Sprinklers

Operational reliability of sprinklers (95% confidence interval estimates)									
Occupancy	**Inside area of origin**			**Beyond area of origin (same floor)**			**Beyond area of origin (different floor)**		
	Mean (%)	**Upper limit (%)**	**Lower limit (%)**	**Mean (%)**	**Upper limit (%)**	**Lower limit (%)**	**Mean (%)**	**Upper limit (%)**	**Lower limit (%)**
All combined (other than residential dwellings)	**70.1**	71.3	68.9	**21.4**	23.2	19.6	**16.9**	18.4	15.4
Assembly	**55**	56.9	53.1	**16.7**	18.2	15.2	*	*	*
Institutional	**53.6**	55.9	51.3	*	*	*	*	*	*
Residential (no dwellings)	**77.5**	79.2	75.8	**15.9**	17.8	14	**16.1**	17.8	14.4
Mercantile	**26.4**	28.1	24.7	*	*	*	*	*	*
Industrial	**73**	74.4	71.6	**33**	35.1	30.9	*	*	*
Business and personal services	**62.6**	65.1	60.1	**15.7**	16.6	14.8	*	*	*
All combined residential dwellings	*	*	*	*	*	*	*	*	*
Single family homes	*	*	*	*	*	*	*	*	*
Semi-detached homes	*	*	*	*	*	*	*	*	*
Townhouses or Row houses	*	*	*	*	*	*	*	*	*

*Insufficient data

Note: Residential dwellings include single-family homes, semi-detached, townhouses or row houses.

Table 7.62 shows that in general the operational reliability values for sprinklers in the area of origin are higher than those outside the area of origin. Reliability values further decrease in general when sprinklers are located on a different floor, as compared to those at the same floor. Table 7.62 however shows an exception for residential occupancies (other than residential dwellings) when sprinklers located on a different floor show a mean reliability of 16.1%, as compared to 15.9% on the same floor. Overall for various occupancies, the mean operational reliability of sprinklers in the area of origin varies in the range of the lowest 26.4% for mercantile, to the highest 77.5% for residential occupancies (other than residential dwellings). Other reliability values in the decreasing order are, all occupancies combined (other than residential dwellings) at 70.1%, business and personal services at 62.6%, assembly occupancies at 55%, and institutional at 53.6%. No sufficient data were available for single-family homes, semi-detached homes and townhouses or row houses.

The table shows that 95% confidence upper and lower limits for all the occupancies vary within ± 2.5 of their mean reliability estimates. Table 7.62 indicates that no single value representing all occupancies could be assigned to the mean reliability of sprinklers as they vary widely e.g. 26.4% to 77.5% when located in the area of origin, depending upon the property classification.

Table 7.63 Single point estimates (Sprinklers in the area of origin)

Occupancy	Inside area of origin		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined (other than residential dwellings)	2536	1785	**70.4**
Assembly	227	128	**56.4**
Institutional	73	39	**53.4**
Residential (no dwellings)	735	564	**76.7**
Mercantile	132	35	**26.5**
Industrial	1061	773	**72.8**
Business and personal services	103	164	**62.8**
All combined residential dwellings	11	6	**54.5**
Single family homes	4	3	**75.0**
Semi-detached homes	*	*	*
Townhouses or Row houses	7	3	**42.8**

* nil incident

Table 7.64 Single point estimates (Sprinklers on the same floor)

Occupancy	Beyond area of origin (same floor)		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined (other than residential dwellings)	463	101	**21.8**
Assembly	68	12	**17.6**
Institutional	25	4	**16.0**
Residential (no dwellings)	146	23	**15.8**
Mercantile	38	3	**7.9**
Industrial	138	46	**33.3**
Business and personal services	40	6	**15.0**
All combined residential dwellings	2	0	**0.0**
Single family homes	1	0	**0.0**
Semi-detached homes	*	*	*
Townhouses or Row houses	1	0	**0.0**

* nil incident

Table 7.65 Single point estimates (Sprinklers on different floors)

Occupancy	Beyond area of origin (different floor)		
	Number of fire incidents	Number of times detector operated	Probability of operation (%)
All combined (other than residential dwellings)	239	41	**17.2**
Assembly	14	0	**0.0**
Institutional	5	2	**40.0**
Residential (no dwellings)	163	26	**16.0**
Mercantile	9	0	**0.0**
Industrial	14	1	**7.1**
Business and personal services	14	1	**7.1**
All combined residential dwellings	4	1	**25.0**
Single family homes	*	*	*
Semi-detached homes	*	*	*
Townhouses or Row houses	*	*	*

* nil incident

Tables 7.63 to 7.65 show the single-point estimates of sprinklers when located in the area of origin, on the same floor, and on a different floor respectively, for each of the occupancies of OFM data [4]. The probability of operation has been obtained by dividing the number of fire incidents in which detectors operated to the total number of fire incidents. The tables show the probability results in percentage. The results of Tables 7.63 to 7.65 show that there is a variation between single-point estimates and the mean values in Table 7.62. This variation for sprinklers located in the area of origin is in the order of ±1.4. All variations between single-point estimates of Tables 7.63 to 7.65 and mean reliability estimates of Table 7.62 are however covered within the 95% confidences limits of Table 7.62.

Overall it may be concluded that mean reliabilities of various fire protection devices, computed for different occupancies in this study, are very close to the single point estimates. The 95% confidence upper and lower limits account for the expected uncertainties of the mean value estimates. The present study shows that all the variations between single-point estimates and the mean reliability estimates are within the computed 95% confidence interval estimates. The range of 95% confidence lower and upper limits decreases with the increase in the random sample size and vice versa. Selection of the lower 95% confidence limit of operational reliability estimate will result in a conservative design.

7.7 Comparison of the computed mean reliability values of smoke detectors, heat detectors, and sprinklers with other reliability studies

To make the discussion simple only the mean reliability values for sprinklers, heat detectors, and hard wired smoke detectors (termed "smoke detectors") in the area of origin have been considered. As such the mean reliability values are summarized in Table 7.66 for all occupancies.

7.66. Mean reliability estimates for all occupancies

Occupancy	Sprinkler	Heat detector	Smoke detector
All combined (except residential dwellings)	70.1%	61.4%	83.1%
Assembly	55%	50.7%	82%
Institutional	53.6%	48.6%	92%
Residential (other than residential dwellings)	77.5%	68.2%	82.8%
Mercantile	26.4%	33.7%	80.3%
Industrial	73%	72%	87.6%
Business and Personal Services	62.6%	60.5%	85.2%
All combined dwellings	*	*	78.9%
Single family dwellings	*	*	78.9%
Semi-detached dwellings	*	*	75%
Townhouse/ Row house	*	*	74.2%

* Data Insufficient

For *all combined occupancies*, the obtained mean reliability of *sprinklers* is 70.1% [4] whereas the earlier studies have reported its value to be 94.6% [3] [5], 95% to 99% but with smoldering fires as low as 50% [3], 60% [9], 96% [10], 99.7% [10] [18], 99.5% [11], 84% [13], 73.9% to 91.1% [14], 33% [24], 82.7% [33]. However the scope, breadth, and reporting periods of the various studies vary significantly. Furthermore the very high values (>99%) have been associated with exceptionally good inspection, testing, and maintenance practices. The latest NFPA data (1989-98) evaluation however indicated the mean reliability value of sprinklers is 82.7% (without considering fires that are too small to activate sprinklers) and it was also stated that the earlier reported values were on the high side [31] [24] [33]. Considering this value of 82.7% to be more realistic, the obtained value of 70.1% [4] is still on the low side. The reason behind lower values found in this study may be that the present study accounts for all the fire incidents including those that are too small to activate the sprinklers because the data was not available to exclude small fires. The earlier studies, as reported, eliminate such incidents from consideration. Moreover it can be further reviewed for authenticity by evaluating more fire incident data from various authentic sources including other provinces.

Regarding *heat detectors*, the obtained mean value for detectors is 61.4% [4]. Earlier studies indicate its operational reliability in the range of 89% to 90% for flaming fires, whereas the value is zero for smoldering fires and 95% for post flashover fires [3]. The main reason for the lower value obtained in this study may be that all the fires reported have been considered without excluding either small fires or smoldering fires. However the earlier indicated value of 89% to 90% [3] appears to be on the high side and needs to be reviewed by evaluating more data from various sources.

In the case of *smoke detectors*, the value obtained is 83.1% [4]. The reported studies indicate the values of operational reliability of system home detectors in the range of 70% to 84.6% [3]. In the present study it has been noticed that residential occupancies account for majority of the structure fires and these occupancies are mostly equipped with smoke detectors. As such the obtained operational reliability of 83.1% for smoke detectors, for all *occupancies combined* as per the Table 7.66, is in the range of reliability values indicated by earlier studies. In fact current value of 83.1% being very close to the earlier studies values (obtained by excluding too small fires) may probably mean that very few fires in residential occupancies are expected to be too small to activate a smoke detector i.e. excluding of too small fires may not be required when smoke detectors are present.

For *residential dwellings all combined* (i.e. detached/ semi-detached/ townhouses or row houses), the computed mean reliability value for *smoke detectors* is 78.9% with lower and higher 95% confidence limits of 77.4% and 80.4% respectively. No reliability value for heat detectors or sprinklers could be computed in the absence of sufficient data. The earlier study indicates the value of mean operational reliability for smoke detectors as 77.8% [3]. As the earlier value of 77.8% lies within the presently computed 95% confidence limits of 77.4% to 80.4%, the reliability of smoke detectors obtained in the present study is consistent with the earlier study.

7.8 Modes of failure of sprinklers

Tables 7.67 to 7.71 have been developed to clarify the reasons for non operation of sprinklers and the probability of non-operation associated with these reasons, for the OFM data [4]. The probability of non-operation has been computed by dividing the number of fire incidents involving sprinkler failure for a given reason by the total number of fire incidents for a specified location of sprinklers. The figures in Table 7.67 are used to calculate the probabilities shown in Tables 7.68 to 7.71.

Table 7.67 Sprinkler details

Location of sprinklers	**Number of fire incidents**
In Area of Origin	2816
Beyond Area of Origin - Same Floor	638
Beyond Area of Origin - Different Floor	357
Total	3811

Table 7.67 shows the number of total fire incidents indicating the presence of sprinklers when they are located in the area of fire origin and beyond the area of origin. Table 7.68 shows the reasons for non-operation of sprinklers and the probabilities of non-operation associated with theses reasons, when sprinklers are located in the area of origin. The Table shows that overall there is a 27% probability of failure of sprinklers located in the area of fire origin. Amongst the given reasons of failure, sprinkler's remoteness from the fire (e.g. partially sprinklered) shows the highest probability of occurrence at 8.1% followed by operation not intended (i.e. operation not expected due to the fire being small) at 5.5%, other reasons at 5.1%, extinguishing agent supply impaired at 1.1%, separated from fire at 1.1%, and each of the other given reasons contributed to less than one percent. In 5.4% cases the reasons for non-operation of sprinklers could not be found.

Table 7.68 Non-operation of sprinklers (in the area of fire origin)

Device operation	Reason for non-operation	Number of fire incidents	Probability of non operation
Nothing Operated	Not reported	1	0.0%
Nothing Operated	Extinguishing Agent Supply Impaired (e.g. turned off, frozen)	30	1.1%
Nothing Operated	Improper Installation	3	0.1%
Nothing Operated	Not Applicable (e.g. partially sprinklered)	5	0.2%
Nothing Operated	Operation Not Intended (fire too small)	156	5.5%
Nothing Operated	Other	144	5.1%
Nothing Operated	Power Failure. (e.g. dead battery, hydro failure, etc.)	1	0.0%
Nothing Operated	Power Not Connected (e.g. no battery, hydro cut off, etc.)	1	0.0%
Nothing Operated	Remote from Fire	227	8.1%

Table 7.68 (cont.) Non-operation of sprinklers (in the area of fire origin)

Device operation	Reason for non-operation	Number of fire incidents	Probability of non operation
Nothing Operated	Separated from Fire (e.g. wall, etc.)	30	1.1%
Nothing Operated	Tampered With (vandalism)	2	0.1%
Nothing Operated	Undetermined	153	5.4%
Nothing Operated	Unit Failure (mechanical or electrical failure)	6	0.2%
Total		759	27.0%

Table 7.69 Non-operation of sprinklers beyond the area of fire origin (same floor)

Device operation	Reason for non-operation	Number of fire incidents	Probability of non operation
Nothing Operated	Extinguishing Agent Supply Impaired (e.g. turned off, frozen)	4	0.6%
Nothing Operated	Improper Installation	1	0.2%
Nothing Operated	Operation Not Intended	51	8.0%
Nothing Operated	Other	9	1.4%
Nothing Operated	Power Not Connected (e.g. no battery, hydro cut off, etc.)	1	0.2%
Nothing Operated	Remote from Fire	198	31.0%
Nothing Operated	Separated from Fire (e.g. wall, etc.)	34	5.3%
Nothing Operated	Undetermined	75	11.8%
Total		373	58.5%

Table 7.69 shows the reasons for non-operation of sprinklers and the probabilities of non operation associated with theses reasons, when sprinklers are located beyond the area of origin but on the same floor. The Table shows that there is a 58.5% probability of failure of sprinklers located outside the area of origin at the same floor. Amongst the

given reasons of failure, sprinkler's remoteness from fire shows the highest probability of 31% followed by operation not intended at 8%, separated from fire at 5.3%, other reasons at 1.4%, and each of the remaining reasons contributed to less than one percent. In 11.8% cases the reasons for non-operation of sprinklers could not be found.

Table 7.70 Non-operation of sprinklers beyond the area of fire origin (different floor)

Device operation	Reason for non-operation	Number of fire incidents	Probability of non operation
Nothing Operated	Extinguishing Agent Supply Impaired (e.g. turned off, frozen)	5	1.4%
Nothing Operated	Not Applicable	2	0.6%
Nothing Operated	Operation Not Intended	44	12.3%
Nothing Operated	Other	1	0.3%
Nothing Operated	Power Failure (e.g. dead battery, hydro failure, etc.)	2	0.6%
Nothing Operated	Remote from Fire	91	25.5%
Nothing Operated	Separated from Fire (e.g. wall, etc.)	16	4.5%
Nothing Operated	Undetermined	45	12.6%
Total		206	57.7%

Table 7.70 shows the reasons of non-operation of sprinklers and the probabilities of non-operation associated with theses reasons, when sprinklers are located outside the area of origin at a different floor. The Table shows that overall there is a 57.7% probability of failure for sprinklers located at a different floor. Amongst the given reasons of failure, sprinkler's remoteness from the fire shows the highest probability of occurrence at 25.5% followed by operation not intended at 12.3%, separated from fire at 4.5%, extinguishing

agent supply impaired at 1.4 %, and each of the other given reasons contributed to less than one percent. In 12.6% cases the reasons of non-operation of sprinklers could not be found.

Table 7.71 Non-operation of sprinklers (Overall)

Device operation	Reason for non-operation	Number of fire incidents	Probability of non operation
Nothing Operated	Tampered With (vandalism)	2	0.1%
Nothing Operated	Power Not Connected (e.g. no battery, hydro cut off, etc.)	2	0.1%
Nothing Operated	Power Failure (e.g. dead battery, hydro failure, etc.)	3	0.1%
Nothing Operated	Improper Installation	4	0.1%
Nothing Operated	Remote from Fire	532	14.0%
Nothing Operated	Separated from Fire (e.g. wall, etc.)	81	2.1%
Nothing Operated	Unit Failure (mechanical or electrical failure)	6	0.2%
Nothing Operated	Extinguishing Agent Supply Impaired (e.g. turned off, frozen)	40	1.0%
Nothing Operated	Operation Not Intended	256	6.7%
Nothing Operated	Other	158	4.1%
Nothing Operated	Undetermined	276	7.2%
Nothing Operated	Not Applicable	7	0.2%
Total		1367	35.9%

Table 7.71 shows the reasons of non-operation of sprinklers and the probabilities of non operation associated with theses reasons, as an overall view independent of the location of sprinklers. The table shows that overall there is an about 36% probability of failure of sprinklers independent of their location. Amongst the given reasons of failure,

sprinkler's remoteness from fire shows the highest probability of 14% followed by operation not intended at 6.7%, other reasons at 4.1%, separated from fire at 2.1%, and each of the remaining reasons contributed to less than one percent. In 7.2% of the cases the reasons for non-operation of sprinklers could not be found.

Overall it can be stated that probability of failure of sprinklers located in the area of origin is about 27%. The highest contributing two reasons to non-operation of sprinklers are their remoteness from fire and operation not intended. The reasons of remoteness from fire may include, high ceilings or large distance from the central axis of fire, or partially sprinklered areas. Operation not intended however means, the fire is too small to activate the sprinklers.

Chapter 8

8. Simulations employing the Computer Fire Model "DETACT-QS"

8.1. Introduction

The current study has shown a wide variation in the mean operational reliability values of sprinklers and heat detectors, computed for different occupancies. Table 7.66 shows that when located in the area of fire origin, sprinklers mean reliability is 70.1%, and heat detectors are at 61.4%. Two main reasons assessed for non-operation of sprinklers are remoteness from fire and operation not intended. These reasons have been assumed to be applicable for heat detectors as well because both sprinklers and heat detectors work on the principle of thermal heating. The reasons for remoteness from fire may include improper design, high ceilings, large distance from the central axis of fire, or partial coverage etc. Operation not intended however means, the fire is too small to activate the sprinklers/ heat detectors. In assembly occupancies, for example, where high ceiling may be present, Table 7.56 shows the mean reliability of sprinklers in the area of fire origin as 55%. It is possible that the reason for this low number is the high ceiling of the assembly buildings. Another example may be the distance of the sprinkler or heat detector from the central axis of the fire, which may lead to non activation of the detector/ sprinkler. For these cases the fire does not get big enough to activate a sprinkler or heat detector but causes damage to the contents resulting in lower reliability of the fire protection devices. To investigate the impact of these parameters on sprinkler activation time and heat release rate of fire needed to activate sprinklers and heat detectors, the computer model DETACT [6] is used. It predicts the response time of heat detectors and sprinklers based on the heat release rates and detector location.

8.1.1. Description of DETACT

DETACT-QS [6] is a model for predicting the response time of ceiling-mounted heat detectors and sprinklers installed under large unobstructed ceilings, for fires with user-defined, time-dependent heat release rate curves. It is based on quasi-steady fire plume and the resulting ceiling jet correlations. The thermally activated device must be located under the ceiling and within the ceiling jet. A ceiling jet is the flow of heated gas produced by a fire that moves across the ceiling of the compartment. The maximum temperature in the ceiling jet occurs within the uppermost 1% of the total ceiling height. The ceiling jet has a thickness of 5.5% to 12.5% of the total ceiling height.

The model [6] is composed of an empirical algorithm (developed by Alpert) that predicts the maximum temperature and velocity of an unconfined ceiling jet under a smooth, flat, horizontal ceiling for a given radius from the centerline of the fire. It also utilizes a lumped mass, convection heat transfer algorithm for predicting the activation time of the thermal detector.

The following are the main assumptions used in the development of DETACT-QS [6]:

- The detector is ceiling mounted and located at the point of maximum temperature and velocity within the ceiling jet below a ceiling.
- The ceiling is unconfined, unobstructed, smooth, flat, and horizontal. The model does not account for hot gas layer effects due to walls or obstructions. The

minimum wall-to-wall distance is 2 to 4 ceiling heights. Vertical obstructions are required to be less than 1% of the ceiling height for the ceiling to be considered smooth.

- Only convective heat transfer is considered between the ceiling jet and the thermal detector, no conductive or radiative heat transfer is considered. The heating of the detector is treated using a lumped heat capacity model. The lumped heat capacity model assumes that thermal gradients can be neglected within the thermal element.
- Within the plume impingement area, temperatures ($r/H \leq 0.18$) and velocities ($r/H \leq 0.15$) are uniform and assumed to be the maximum values in the plume. Here r is the horizontal distance of detector from the axis of fire (i.e. the central axis of expected symmetrical fire), and H is the height of ceiling above the fuel.
- The fuel package and the plume are assumed to be in an unobstructed vertical axis. No ventilation or stratification effects are considered. The heat release rate of the fire needs to be sufficiently large so that the plume can be assumed to be vertical and axisymetric.
- No transport time (or lag time) is considered for the hot gases to travel from the fuel to the detector; therefore, increases in heat release rate will affect the temperature and velocity of the ceiling jet immediately.
- The heat release rate curve is divided into many short time periods. Within each interval the heat release rate of the fire is assumed to remain constant.

- Fire heat release rate should not double in less than one minute because the model may not be suitable for predicting correct results as this fire situation is not within the assumptions of the model.

The *input data* required for the model includes following parameters:

- Height of ceiling above fuel, H (m)
- Distance of detector from axis of fire, r (m)
- Initial room temperature (^{0}C)
- Detector actuation temperature (^{0}C)
- Detector Response Time Index (RTI) ($m^{1/2}$ $s^{1/2}$)
- Total heat release rate (kW) time-dependent curve for a given fire; input in pairs of time in seconds vs. total heat release rate

For this work a t-square fire was used to calculate the heat release rate. The t-squared fire is given by an equation, $Q = \alpha t^2$

Q: heat release rate of the fire at any time (kW)

α: fire growth coefficient (kW/s^2)

Values of α: slow fire = 0.00293, medium fire = 0.01172, and fast fire = 0.0469.

The t-squared fires are categorized as slow, medium or fast based on the time they take to grow (i.e. growth rate) to a level when the heat release rate of fire becomes 1055 kW (or 1000 Btu per second). Fires taking $\geq$ 400 seconds are categorized as slow fires, those between 150 to 400 seconds as medium fires, and those with < 150 seconds as fast fires [43].

The *output* of model includes the following parameters:

- Gas temperature of the ceiling jet (^{0}C) at user specified intervals

- Detector temperature (^{0}C) at user specified intervals
- Detector actuation time (s).

The objective of this part of the work is to use DETACT [6] to determine the impact of changes in the values of RTI, or detector actuation temperature, or height of ceiling above the fire, or radial distance of detector from the centerline of fire, and heat release rates, on detector activation time. Here RTI is a constant (a measure of detector's sensitivity). This information will be used in conjunction with the reliability of sprinklers and detectors to assist in better understanding and quantifying their performance.

8.2. Impact of RTI on actuation time

In this section efforts are made to see the impact of changes in RTI on the response time of detectors, separately for t-squared slow fires, medium fires and fast fires. Sub section 8.2.1 shows how changes in RTI affect the detector actuation time and the heat release rates at actuation, when the three fires are visualized altogether.

To determine the impact of RTI on the response time of detectors a series of runs were made using DETACT [6]. For these runs the following parameters were assumed constant:

Height of ceiling above the fuel = 3.0 m

Distance of detector from axis of fire = 3.0m

Initial room temperature = 20 ^{0}C

Detector actuation temperature = 57 ^{0}C

Three sets of runs were made using these parameters, by considering three different t^2 fires i.e. slow, medium and fast. The results of these sets of runs are shown in Tables 8.1 to 8.3 as well as in Figures, 8.1 to 8.3.

TABLE 8.1 Detector actuation time (Slow Fire)

Run No.	RTI ($m^{1/2}s^{1/2}$)	Min. HRR required for actuation (kW)	HRR at actuation time (kW)	Ceiling Jet temperature at actuation time (°C)	Detector activation temperature (°C)	Detector actuation time (sec)
1	**30**	281	**341**	62	57	**341**
2	**40**	281	**362**	64	57	**351**
3	**50**	281	**382**	65	57	**361**
4	**60**	281	**402**	67	57	**371**
5	**70**	281	**424**	68	57	**380**
6	**80**	281	**443**	70	57	**389**
7	**90**	281	**462**	71	57	**398**
8	**100**	281	**484**	73	57	**406**
9	**110**	281	**503**	74	57	**414**
10	**120**	281	**522**	76	57	**422**
11	**130**	281	**540**	77	57	**430**
12	**140**	281	**560**	78	57	**437**
13	**150**	281	**578**	80	57	**444**
14	**160**	281	**596**	81	57	**451**

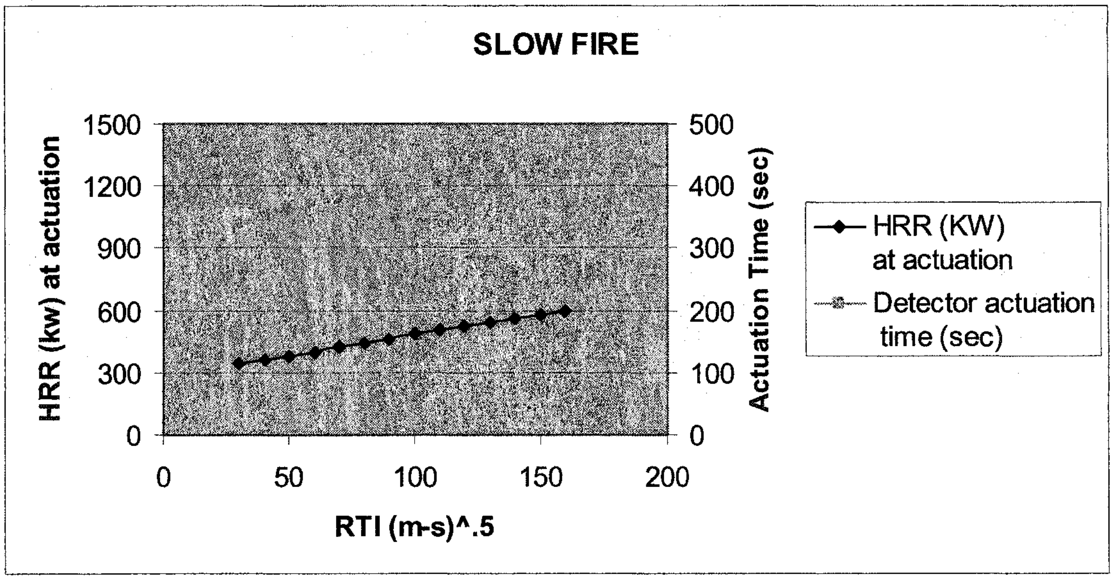

Figure 8.1 Effect of changes in RTI values (Slow fire)

Table 8.1 and Figure 8.1 show the impact of RTI on detector actuation time for a slow t-square fire. RTI values were varied from 30 $m^{1/2}$ $s^{1/2}$ to 160 $m^{1/2}$ $s^{1/2}$ representing the whole range of typical RTI values in use. For this fire, the predicted detector actuation time varies from 341 s to 451 s corresponding to RTI values of 30 and 160 respectively. The impact of RTI (Figure 8.1) on response time is almost linear with a gradient of 0.83 s/ $m^{1/2}s^{1/2}$. A typical range of RTI varies from 30 $m^{1/2}$ $s^{1/2}$ (for fast response sprinklers) to 150 $m^{1/2}$ $s^{1/2}$ (for soldered link sprinklers) but it may vary from 15 to 400 $m^{1/2}$ $s^{1/2}$.

Column 3 of Table 8.1 shows the minimum HRR (i.e. when r = 0) whereas column 4 shows the resulting HRR at the time of detector activation. As RTI increases the HRR of the fire required to activate the detector increases, resulting in increased detector actuation time. The relationship between RTI and HRR at actuation time is linear as shown in Figure 8.1, with a slope of 1.96 kW/ $m^{1/2}s^{1/2}$.

TABLE 8.2 Detector actuation time (Medium Fire)

Run No.	**RTI ($m^{1/2}s^{1/2}$)**	**Min. HRR required for actuation (kW)**	**HRR at actuation time (kW)**	**Ceiling Jet at actuation time (°C)**	**Detector activation temperature (°C)**	**Detector actuation time (sec)**
1	**30**	281	**405**	67	57	**186**
2	**40**	281	**445**	70	57	**195**
3	**50**	281	**482**	73	57	**204**
4	**60**	281	**521**	75	57	**212**
5	**70**	281	**561**	78	57	**219**
6	**80**	281	**598**	81	57	**226**
7	**90**	281	**635**	83	57	**233**
8	**100**	281	**668**	86	57	**239**
9	**110**	281	**702**	88	57	**246**
10	**120**	281	**737**	90	57	**251**
11	**130**	281	**767**	92	57	**257**
12	**140**	281	**803**	94	57	**262**
13	**150**	281	**834**	96	57	**267**
14	**160**	281	**866**	98	57	**272**

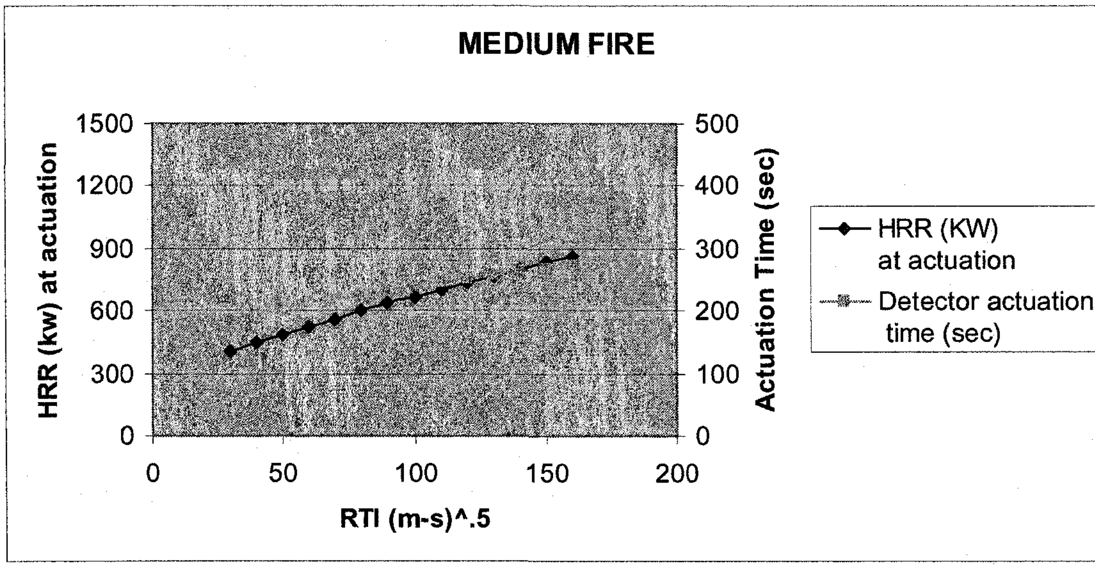

Figure 8.2 Effect of changes in RTI values (Medium fire)

Table 8.2 and Figure 8.2 show the results for the medium t-square fire. As this fire grows faster detectors respond faster as well resulting in smaller response times than the slow t-square fire. RTI also affects response times, however at a lower rate than before 0.63 s/ $m^{1/2}s^{1/2}$ as oppose to 0.83 s/ $m^{1/2}s^{1/2}$.

The resulting heat release rate for these fires is quite high with values ranging from 405 kW to 866 kW. The rate of change of HRR with RTI for this series of tests is 3.52 kW/ $m^{1/2}s^{1/2}$, much higher than 1.96 kW/ $m^{1/2}s^{1/2}$ for the slow fire case.

TABLE 8.3 Detector actuation time (Fast Fire)

Run No.	RTI ($m^{1/2}s^{1/2}$)	Min. HRR required for actuation (kW)	HRR at actuation time (kW)	Ceiling Jet at actuation time (°C)	Detector activation temperature (°C)	Detector actuation time (sec)
1	**30**	281	**524**	75	57	**107**
2	**40**	281	**595**	80	56	**114**
3	**50**	281	**671**	85	57	**120**
4	**60**	281	**740**	90	57	**126**
5	**70**	281	**800**	94	57	**132**

TABLE 8.3 (cont.) Detector actuation time (Fast Fire)

Run No.	RTI ($m^{1/2}s^{1/2}$)	Min. HRR required for actuation (kW)	HRR at actuation time (kW)	Ceiling Jet at actuation time (°C)	Detector activation temperature (°C)	Detector actuation time (sec)
6	**80**	281	**862**	97	57	**137**
7	**90**	281	**926**	101	57	**141**
8	**100**	281	**980**	104	56	**146**
9	**110**	281	**1049**	108	57	**150**
10	**120**	281	**1105**	111	57	**154**
11	**130**	281	**1149**	114	57	**158**
12	**140**	281	**1208**	117	57	**162**
13	**150**	281	**1269**	120	57	**165**
14	**160**	281	**1315**	123	57	**168**

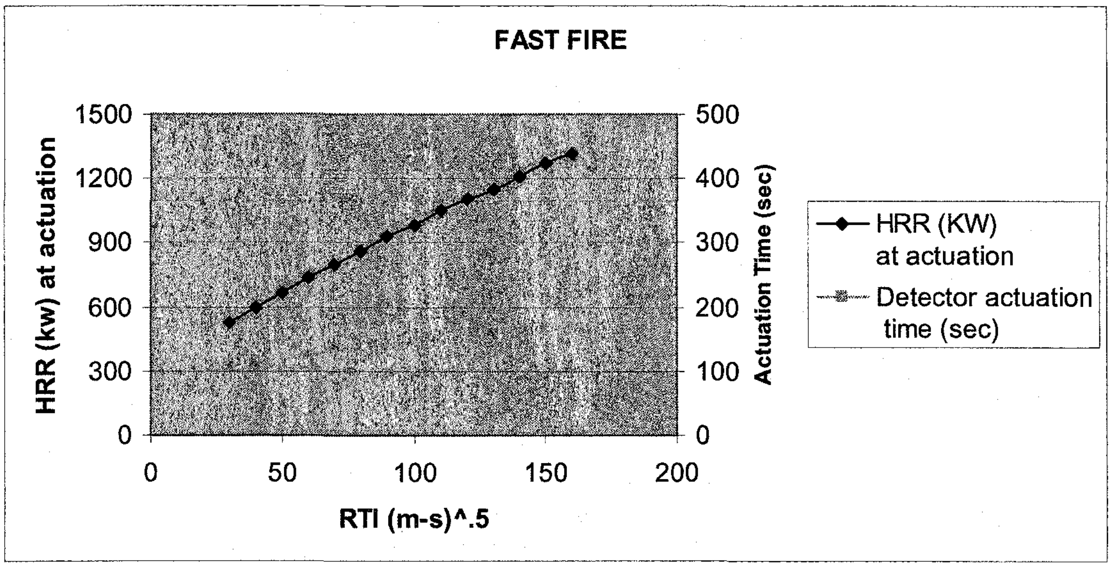

Figure 8.3 Effect of changes in RTI values (Fast fire)

Table 8.3 and Figure 8.3 show the results for the fast t-square fire. This fire grows much faster than medium t-squared fires and hence detectors too respond very fast and result in a lot smaller response times than the medium t-square fire. RTI also affects response times, however at a still lower rate than before 0.45 s/$m^{1/2}s^{1/2}$ as opposed to 0.63 s/ $m^{1/2}s^{1/2}$.

The resulting heat release rate at activation for these fires is very high with values ranging from 524 kW to 1315 kW. The rate of change of HRR with RTI for this series of tests is 5.88 kW/ $m^{1/2}s^{1/2}$, much higher than 3.52 kW/ $m^{1/2}s^{1/2}$ of the medium t-squared fire.

It has been noticed that the minimum HRR required (i.e. when the detector is located directly above the fire) to actuate the detector is constant (281 kW) for all the three fires, which indicates that it is independent of the RTI value. The detectors with higher RTI need greater HRR to reach their actuation temperature and thus take more time for actuation. As we move from slow to fast fires, the range of increase in HRR climbs, whereas the range of increase in detector actuation time goes down. Figures 8.1, 8.2, and 8.3 pictorially exhibit that for different fires, how variations in RTI values change the actuation time of detectors as well as the heat release rates at actuation.

In case of slow fires the detector actuation time is quite long on account of the slow development of the fire. The graphs show that the faster fires have lower actuation time but higher heat release rates at actuation. The HRR and Actuation Time, both increase with an increase in RTI values for all the fires. When we move from slow to fast fires, the detector actuation line shifts down and its slope decreases, whereas the HRR line climbs with an increase in its slope, thereby indicating that as the detectors RTI value increases, the fires with increasing HRR may be able to bring down the detector actuation time.

8.2.1. Effect of variations in RTI on detector actuation time, and HRR

To determine the impact of variations in RTI, on response time of detectors, and on heat release rates, a series of runs were made by considering three different fires, slow, medium and fast, using DETACT [6]. For these runs the following parameters were assumed constant:

Initial room temperature = 20 ^{0}C

Height of ceiling above the fuel = 3.0 m

Distance of detector from axis of fire = 3.0 m

Detector actuation temperature = 57 ^{0}C

The results of these sets of runs are shown in Tables 8.4 - 8.5, and Figures 8.4 - 8.5.

8.2.1.1. RTI vs. Actuation Time for various t^2 fires

Table 8.4 and Figure 8.4 show, how the variations in RTI will affect the detector actuation time in case of slow, medium, and fast fires. The figures shown in columns 2, 3 and 4 are same as in Tables 8.1, 8.2 and 8.3 respectively.

Table 8.4 RTI vs. Actuation Time for various t^2 fires

	SLOW FIRE	**MEDIUM FIRE**	**FAST FIRE**
RTI (m-s)^.5	**Detector actuation time (sec)**	**Detector actuation time (sec)**	**Detector actuation time (sec)**
30	341	186	107
40	351	195	114
50	361	204	120
60	371	212	126
70	380	219	132
80	389	226	137
90	398	233	141
100	406	239	146
110	414	246	150
120	422	251	154
130	430	257	158
140	437	262	162
150	444	267	165
160	451	272	168

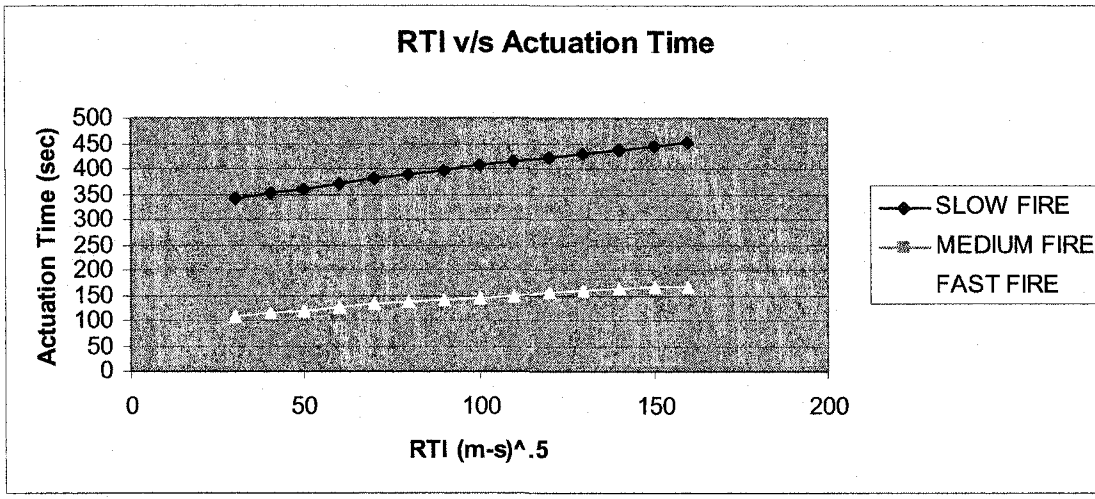

FIG. 8.4 RTI vs. Actuation Time for various t^2 fires

Table 8.4 and Figure 8.4 show the impact of RTI on detector activation time for all the three fires. RTI values were varied from 30 $m^{1/2}$ $s^{1/2}$ to 160 $m^{1/2}$ $s^{1/2}$ representing a wide range of RTI values. For these fires the predicted detector actuation time variations are for slow fires (341 s to 451 s), medium fires (186 s to 272 s), and fast fires (107 s to 168 s) respectively. The impact of RTI as seen in Figure 8.4 on response time is almost linear in all the three fires, with gradients of 0.85 s/ $m^{1/2}$ $s^{1/2}$, 0.66 s/ $m^{1/2}$ $s^{1/2}$, and 0.47 s/ $m^{1/2}$ $s^{1/2}$ respectively.

It is thus seen that, the fast fires exhibit smallest detector actuation time, medium fires have relatively higher actuation time whereas the slow fires have the highest actuation time probably on account of the slow development of fire. For all the fires, the detector actuation time increases with increase in RTI value. The rate of increase (i.e. slope) of the line of detector actuation time is slightly higher than others in case of slow fires and it decreases marginally as we move from slow to fast fires. It can therefore be stated that with increase in RTI, the increase in detector actuation time will be lowest for fast fires, marginally higher for medium fires and highest in case of slow fires.

8.2.1.2. RTI vs. HRR at actuation for various t^2 fires

Table 8.5 RTI vs. HRR for various t^2 fires

	SLOW FIRE	MEDIUM FIRE	FAST FIRE
RTI (m-s)^.5	HRR (kW)	HRR W(kW)	HRR (kW)
30	341	405	524
40	362	445	595
50	382	482	671
60	402	521	740
70	424	561	800
80	443	598	862
90	462	635	926
100	484	668	980
110	503	702	1049
120	522	737	1105
130	540	767	1149
140	560	803	1208
150	578	834	1269
160	596	866	1315

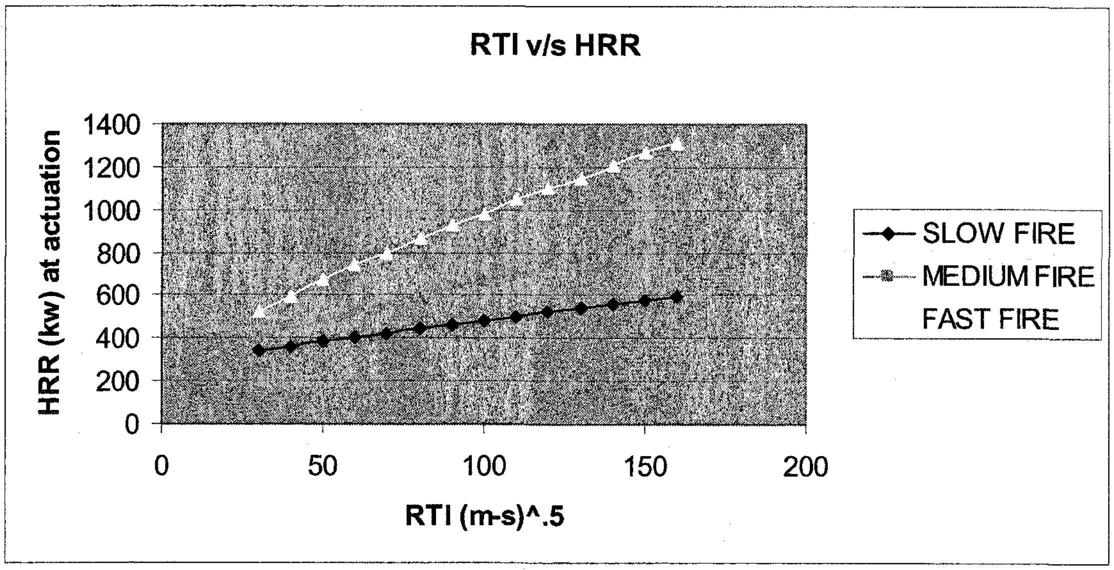

FIG. 8.5 RTI vs. HRR for various t^2 fires

Table 8.5 and Figure 8.5 show the impact of RTI on heat release rates for slow, medium and fast fires. The figures shown in columns 2, 3 and 4 are same as in Tables 8.1, 8.2 and 8.3 respectively.

RTI values were varied from 30 $m^{1/2}$ $s^{1/2}$ to 160 $m^{1/2}$ $s^{1/2}$ representing a wide range of RTI values. For these fires the predicted heat release rates variations are for slow fires (341 kW to 596 kW), medium fires (405 kW to 866 kW), and fast fires (524 kW to 1,315 kW) respectively. The impact of RTI as seen in Figure 8.5 on HRR is almost linear in all the three fires, with slopes of 1.96 kW/ $m^{1/2}$ $s^{1/2}$, 3.55 kW/ $m^{1/2}$ $s^{1/2}$, and 6.08 kW/ $m^{1/2}$ $s^{1/2}$ respectively.

It has been indicated above, that fast fires exhibit highest HRR followed by medium fires and then slow fires. For all fires, heat release rate increases with increase in RTI value. It has been seen that the rate of increase (i.e. slope) of HRR line is the smallest in case of slow fires and it increases as we move from slow to fast fires. It can thus be stated that with the increasing RTI values, the required increase (for detector actuation) in HRR will be lowest for slow fires, relatively higher for medium fires and highest for fast fires.

8.3. Variations with height of ceiling above the fuel

In this section efforts are made to see the impact of variations in height of ceiling above the fuel on the response time of detectors, separately for slow fires, medium fires and fast fires. Sub-section 8.3.1 shows how the changes in ceiling height above the fuel affect the detector actuation time and the heat release rate at actuation, when the three fires are visualized altogether.

To determine the impact of variations in the height of ceiling above the fuel on response time of detectors a series of runs were made using DETACT [6]. For these runs the following parameters were assumed constant:

Distance of detector from axis of fire = 3.0 m

Initial room temperature = 20 ^{0}C

Detector actuation temperature = 57 ^{0}C

Response Time Index (RTI) = 100 $m^{1/2}\ s^{1/2}$

The above values were chosen because these are the commonly used values for the said parameters. Three sets of runs were done using these parameters, by considering three different fires, slow, medium and fast. The results of these sets of runs are shown in Tables 8.6, 8.7 and 8.8 as well as in Figures, 8.6 to 8.8.

Table 8.6 Detector actuation time (Slow Fire)

Run No.	**Height above fuel (m)**	**Min HRR required for actuation (kW)**	**HRR at actuation time (kW)**	**Ceiling Jet at actuation time (°C)**	**Detector activation temperature (°C)**	**Detector actuation time (sec)**
1	**3**	281	**484**	73	57	**406**
2	**3.5**	354	**565**	70	57	**439**
3	**4**	433	**651**	68	57	**471**
4	**4.5**	516	**739**	67	57	**503**
5	**5**	605	**833**	66	57	**534**
6	**5.5**	698	**932**	65	57	**564**
7	**6**	795	**1034**	64	57	**594**
8	**6.5**	897	**1138**	63	57	**624**
9	**7**	1002	**1250**	63	57	**653**
10	**7.5**	1111	**1359**	62	57	**682**
11	**8**	1224	**1478**	62	57	**711**
12	**8.5**	1341	**1596**	61	57	**739**
13	**9**	1461	**1720**	61	57	**767**
14	**9.5**	1584	**1848**	61	57	**794**
15	**10**	1711	**1976**	61	57	**822**

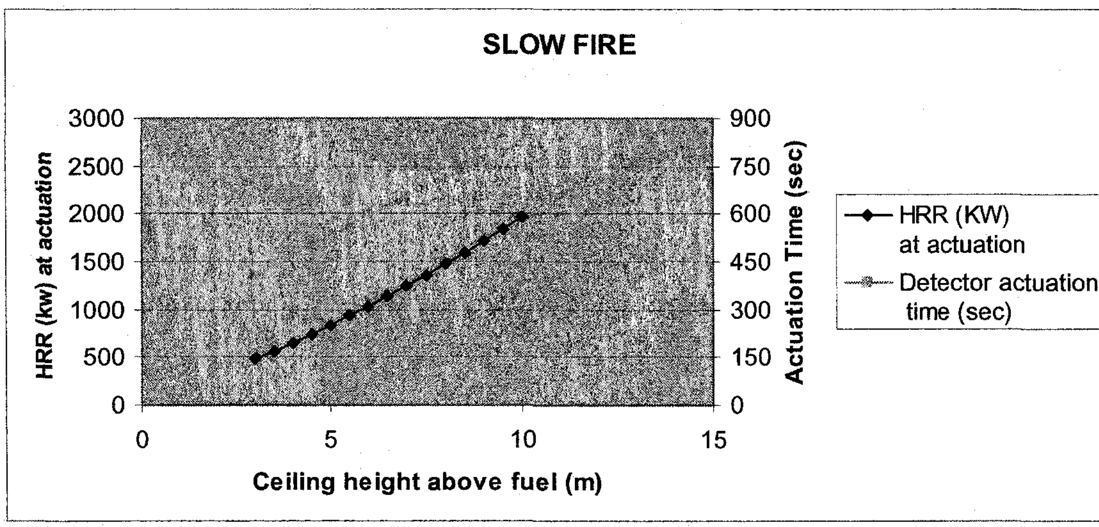

Figure 8.6 Effect of changes in height of ceiling above fuel (Slow fire)

Table 8.6 and Figure 8.6 show the impact of variations in the height of ceiling above the fuel on detector actuation time for a slow t-squared fire. Ceiling height values above the fuel were varied from 3m to 10m, representing a wide range of ceiling heights. For this fire the predicted detector actuation time varies from 406 s to 822 s corresponding to ceiling height above fuel values of 3m and 10m respectively. The impact of ceiling height, as seen in Figure 8.6 on response time is almost linear with a gradient of 59.4 s/ m

Column 4 of Table 8.6 shows the resulting HRR at the time of detector activation. As detector actuation time increases the HRR of the fire increases. The relationship between ceiling height above fuel and HRR at actuation time is also almost linear as shown in Figure 8.6, with a slope of 213 kW/ m.

Table 8.7 Detector actuation time (Medium Fire)

Run No.	Height above fuel (m)	Min. HRR required for actuation (kW)	HRR at actuation time (kW)	Ceiling Jet at actuation time (°C)	Detector activation temperature (°C)	Detector actuation time (sec)
1	**3**	281	**668**	86	57	**239**
2	**3.5**	354	**761**	81	57	**256**
3	**4**	433	**859**	78	57	**272**
4	**4.5**	516	**964**	76	57	**287**
5	**5**	605	**1067**	74	57	**302**
6	**5.5**	698	**1168**	72	57	**317**
7	**6**	795	**1274**	70	57	**331**
8	**6.5**	897	**1339**	69	57	**345**
9	**7**	1002	**1500**	68	57	**359**
10	**7.5**	1111	**1619**	67	57	**373**
11	**8**	1224	**1743**	67	57	**386**
12	**8.5**	1341	**1863**	66	57	**400**
13	**9**	1461	**1996**	65	57	**413**
14	**9.5**	1584	**2123**	65	57	**426**
15	**10**	1711	**2255**	64	57	**439**

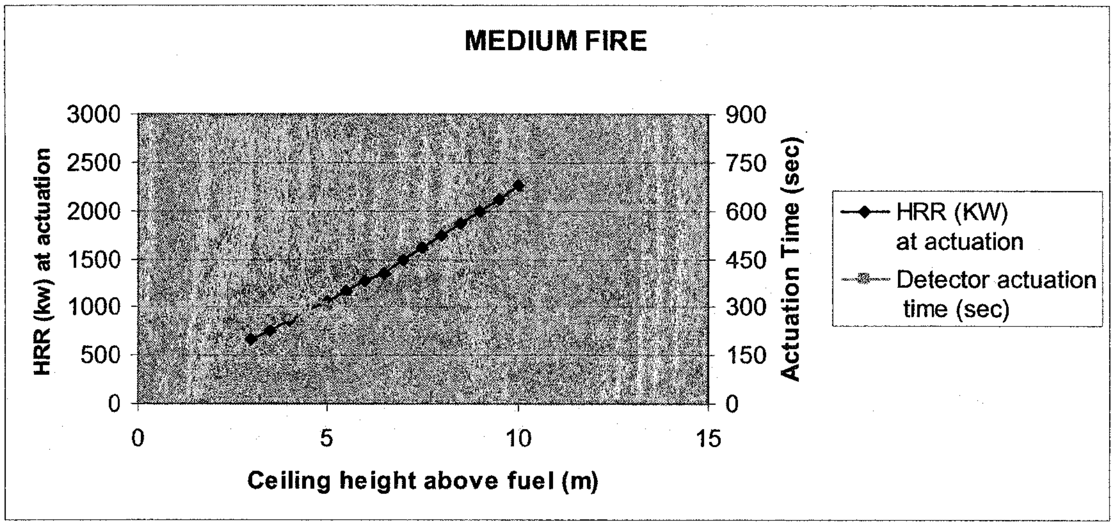

Figure 8.7 Effect of changes in height of ceiling above fuel (Medium fire)

Table 8.7 and Figure 8.7 show the results for the medium t-squared fire. As this fire grows faster detectors respond faster as well resulting in smaller response times than the slow t-square fire. Ceiling height above fuel also affects response times, however at a rate lower than before 28.5 s/ m as oppose to 59.4 s/ m.

The resulting heat release rate for these fires is higher with values ranging from 668 kW to 2,255 kW. The rate of change of HRR with ceiling height above fuel for this series of tests is 227 kW/ m, slightly higher than 213 kW/ m of the slow fire case.

Table 8.8 Detector actuation time (Fast Fire)

Run No.	**Height above fuel (m)**	**Min. HRR required for actuation (kW)**	**HRR at actuation time (kW)**	**Ceiling Jet at actuation time (°C)**	**Detector activation temperature (°C)**	**Detector actuation time (sec)**
1	**3**	281	**980**	104	56	**146**
2	**3.5**	354	**1105**	98	57	**155**
3	**4**	433	**1238**	94	57	**163**
4	**4.5**	516	**1363**	90	57	**171**
5	**5**	605	**1476**	87	57	**179**
6	**5.5**	698	**1612**	84	57	**186**
7	**6**	795	**1736**	82	57	**193**
8	**6.5**	897	**1864**	80	57	**200**
9	**7**	1002	**1997**	78	57	**207**
10	**7.5**	1111	**2114**	76	57	**214**
11	**8**	1224	**2255**	75	57	**220**
12	**8.5**	1341	**2380**	74	57	**227**
13	**9**	1461	**2530**	73	57	**233**
14	**9.5**	1584	**2662**	72	57	**240**
15	**10**	1711	**2797**	71	57	**246**

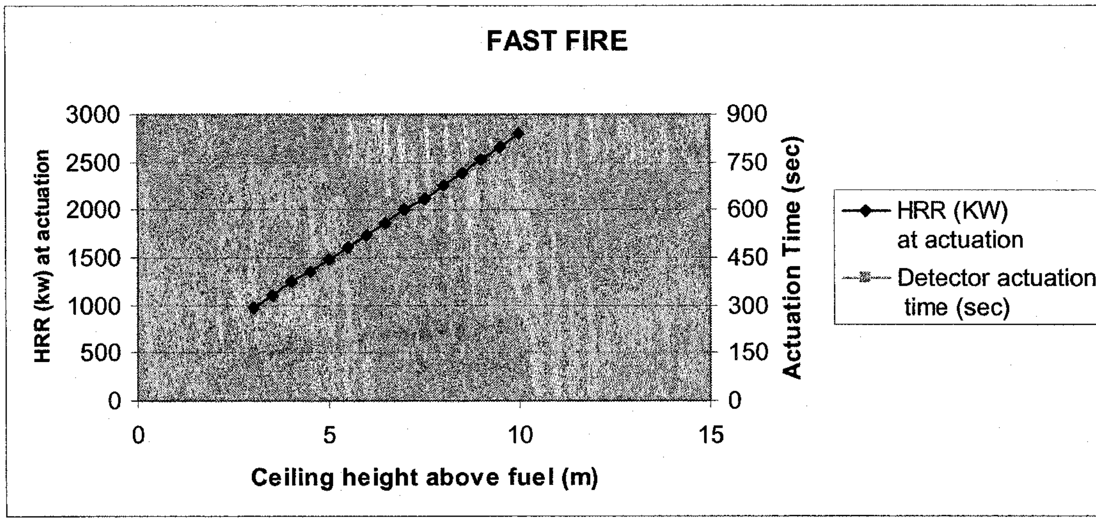

Figure 8.8 Effect of changes in height of ceiling above fuel (Fast fire)

Table 8.8 and Figure 8.8 show the results for the fast t-squared fire. This fire grows much faster than medium t-squared fires and hence detectors also respond very fast and result in a lot smaller response times than the medium t-squared fire. Ceiling height above fuel also affects response times, however at a still lower rate than before 14.2 s/ m as oppose to 28.5 s/ m of medium t-squared fire.

The resulting heat release rate for these fires is very high with values ranging from 980 kW to 2797 kW. The rate of change of HRR with ceiling height above fuel for this series of tests is 259 kW/ m, higher than 227 kW/ m of the medium t-square fire.

The minimum HRR required for actuation is independent of the type of fire, but it increases with the increase in height of ceiling above the fuel. An increase in height of ceiling above the fuel will require higher heat release rate to heat the detector element up to its actuation temperature and thus results in higher actuation time. As we move from slow to fast fires, the range of increase in HRR goes up whereas the range of increase in detector actuation time goes down. Figures 8.6, 8.7, and 8.8 exhibit the variations in HRR and Actuation Times as a function of the changes in the height of ceiling above fuel.

In case of slow fires, the detector actuation time is quite high on account of the slow development of the fire. It can be seen that faster fires have lower actuation time and higher heat release rates at actuation. For all the fires, the higher the ceiling above the fuel, the higher HRR is required for heating of the detector, thus taking more time for actuation. As we move from slow to fast fires, the detector actuation line shifts down and its slope also reduces whereas the HRR line climbs with an increase in its slope, indicating that as the height of ceiling above the fuel increases, the fires with increasing HRR may bring down the detector actuation time.

8.3.1. Effect of variations in height of ceiling above fuel on detector actuation time, and HRR

To determine the impact of variations in height of ceiling above the fuel, on response time of detectors as well as on heat release rates, a series of runs were made by considering three different fires, slow, medium and fast, using DETACT [6]. For these runs the following parameters were assumed constant:

Initial room temperature = 20 ^{0}C

Response Time Index (RTI) = 100 $m^{1/2}$ $s^{1/2}$

Distance of detector from axis of fire = 3.0 m

Detector actuation temperature = 57 ^{0}C

The results of these sets of runs are shown in Tables 8.9 - 8.10, and Figures 8.9 - 8.10.

8.3.1.1. Height of ceiling above fuel vs. Actuation Time for various t^2 fires

Table 8.9 and Figure 9 exhibit, how the variations in height of ceiling above fuel will affect the detector actuation time in case of slow, medium, and fast fires.

Table 8.9 Height of ceiling above fuel vs. Actuation Time for various t^2 fires

	SLOW FIRE	MEDIUM FIRE	FAST FIRE
Height above fuel (m)	Detector actuation time (sec)	Detector actuation time (sec)	Detector actuation time (sec)
3	406	239	146
3.5	439	256	155
4	471	272	163
4.5	503	287	171
5	534	302	179
6	594	331	193
6.5	624	345	200
7	653	359	207
7.5	682	373	214
8	711	386	220
8.5	739	400	227
9	767	413	233
9.5	794	426	240
10	822	439	246

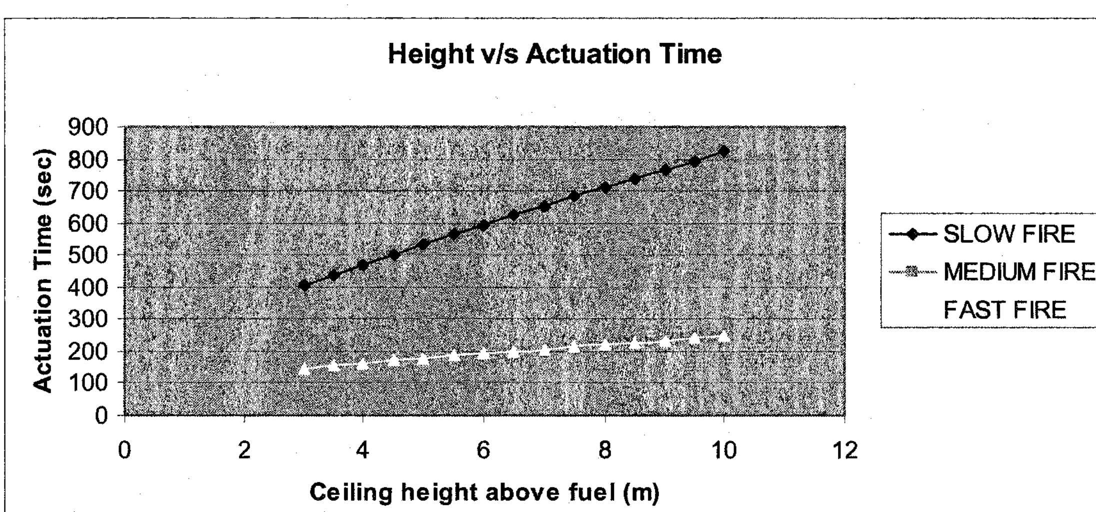

FIG. 8.9 Height of ceiling above fuel vs. Actuation Time for various t^2 fires

Table 8.9 and Figure 8.9 show the impact of height of ceiling above fuel, on detector activation time for all the three fires. Height of ceiling above fuel was varied from 3.0 m to 10.0 m representing a wide range of heights. For these fires the predicted detector actuation time variations are for slow fires (406 s to 822 s), medium fires (239 s to 439 s), and fast fires (146 s to 246 s) respectively. The impact of ceiling heights above the fuel (as seen in Figure 8.9) on response time, is almost linear for all the three fires, with gradients of 59.4 s/ m, 28.6 s/ m, and 14.3 s/ m respectively.

The fast fires exhibit the lowest detector actuation time followed by relatively lower value for medium fires and the lowest for slow fires. For all the fires, the detector actuation time increases with the increase in height of ceiling above the floor. The rate of increase of detector actuation time (i.e. the slope) is highest in case of slow fire and it decreases as we move from slow fire to the fast fire. It can therefore be stated that with increase in height of ceiling above the fuel, the increase in detector actuation time will be lowest for fast fires, marginally higher for medium fires and highest in case of slow fires.

8.3.1.2. Height of ceiling above fuel vs. heat release rates for various t^2 fires

Table 8.10 and Figure 8.10 show how the variations in height of ceiling above fuel will affect detector actuation time in case of slow, medium, and fast fires.

Table 8.10 Height of ceiling above fuel vs. HRR for various t^2 fires

Height of ceiling above fuel (m)	SLOW FIRE HRR (kW)	MEDIUM FIRE HRR (kW)	FAST FIRE HRR (kW)
3	484	668	980
3.5	565	761	1105
4	651	859	1238
4.5	739	964	1363
5	833	1067	1476
5.5	932	1168	1612
6	1034	1274	1736
6.5	1138	1339	1864
7	1250	1500	1997
7.5	1359	1619	2114
8	1478	1743	2255
8.5	1596	1863	2380
9	1720	1996	2530
9.5	1848	2123	2662
10	1976	2255	2797

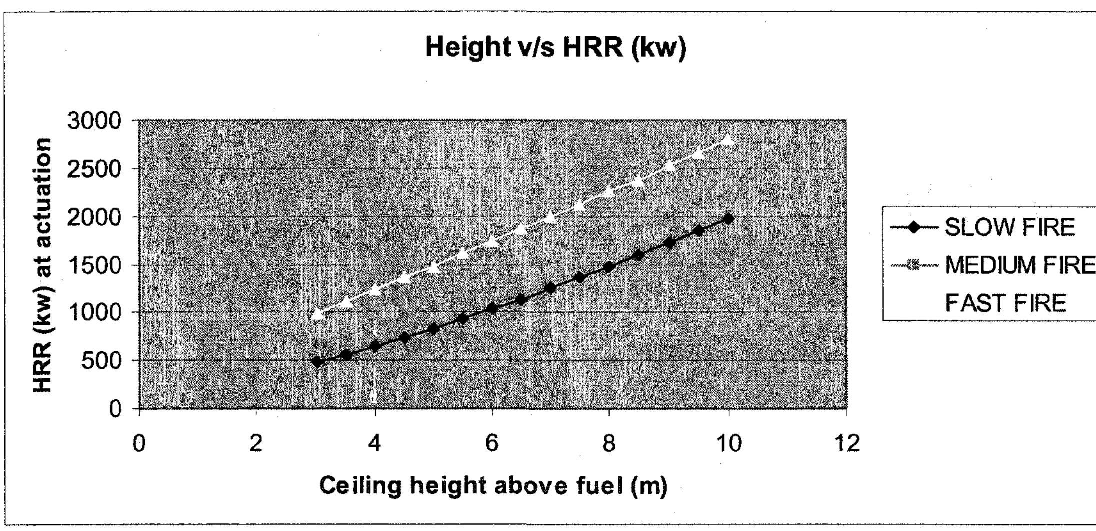

FIG. 8.10 Height of ceiling above fuel vs. HRR for various t^2 fires

Table 8.10 and Figure 8.10 show the impact of variations in height of ceiling above fuel, on heat release rates for slow, medium and fast fires. Ceiling heights above fuel were varied from 3.0 m to 10.0 m representing a wide range of heights. For these fires the predicted heat release rates variations are for slow fires (484 kW to 1,976 kW), medium fires (668 kW to 2,255 kW), and fast fires (980 kW to 2,797 kW) respectively. The impact of variations in ceiling heights above fuel (as seen in Figure 8.10) on HRR is almost linear in all the three fires, with slopes of 213 kW/ m, 227 kW/ m, and 260 kW/ m respectively.

The fast fires exhibit the highest HRR followed by relatively lower value for medium fires and the lowest for slow fires. For all the fires, the heat release rate increases with the increase in height of ceiling above the floor. The rate of increase of HRR (i.e. slope) is highest for fast fire, slightly lower for medium fire and lowest for slow fire. It can thus be stated that with increase in height of ceiling above fuel, the required increase (for detector actuation) in HRR will be lowest for slow fires, relatively higher for medium fires and highest for fast fires.

8.4. Variation with distance of detector from axis of fire, r

In this section efforts are made to see the impact of variations in distance of detector from the axis of fire on the response time of detectors, separately for each of the slow fires, medium fires and the fast fires. Sub-section 8.4.1 shows how the changes in distance of detector from the axis of fire affect the detector actuation time and the heat release rates at actuation, when the three fires are visualized altogether.

To determine the impact of variations in the distance of detector from axis of fire on response time of detectors a series of runs were made using DETACT [6]. For these runs the following parameters were assumed constant:

Height of ceiling above the fuel = 6.0 m

Initial room temperature = 20 ^{0}C

Detector actuation temperature = 57 ^{0}C

Response Time Index (RTI) = 100 $m^{1/2}$ $s^{1/2}$

The above values were chosen because these are the commonly used values for the said parameters. Three sets of runs were made using these parameters, by considering three different fires, slow, medium and fast. The results of these sets of runs are shown in Tables 8.11, 8.12 and 8.13 as well as in Figures, 8.11 to 8.13.

TABLE 8.11 Detector actuation time (Slow Fire)

Sl. No.	**Distance of detector from fire axis (m)**	**Min HRR required for actuation (kW)**	**HRR at actuation time (kW)**	**Temp. of Ceiling Jet at actuation time (°C)**	**Detector activation temperature (°C)**	**Detector actuation time (sec)**
1	**2**	530	**707**	65	57	**491**
2	**2.5**	663	**871**	64	57	**545**
3	**3**	795	**1034**	64	57	**594**
4	**3.5**	928	**1193**	64	57	**638**
5	**4**	1060	**1355**	63	57	**680**
6	**4.5**	1193	**1515**	63	57	**719**
7	**5**	1325	**1671**	63	57	**755**
8	**5.5**	1458	**1829**	63	57	**790**
9	**6**	1590	**1990**	63	57	**824**
10	**6.5**	1723	**2148**	63	57	**856**
11	**7**	1855	**2301**	63	57	**886**
12	**7.5**	1988	**2459**	63	57	**916**
13	**8**	2121	**2612**	63	57	**944**
14	**8.5**	2253	**2769**	62	57	**972**
15	**9**	2386	**2925**	62	57	**999**
16	**9.5**	2518	**3079**	62	57	**1025**
17	**10**	2651	**3230**	62	57	**1050**

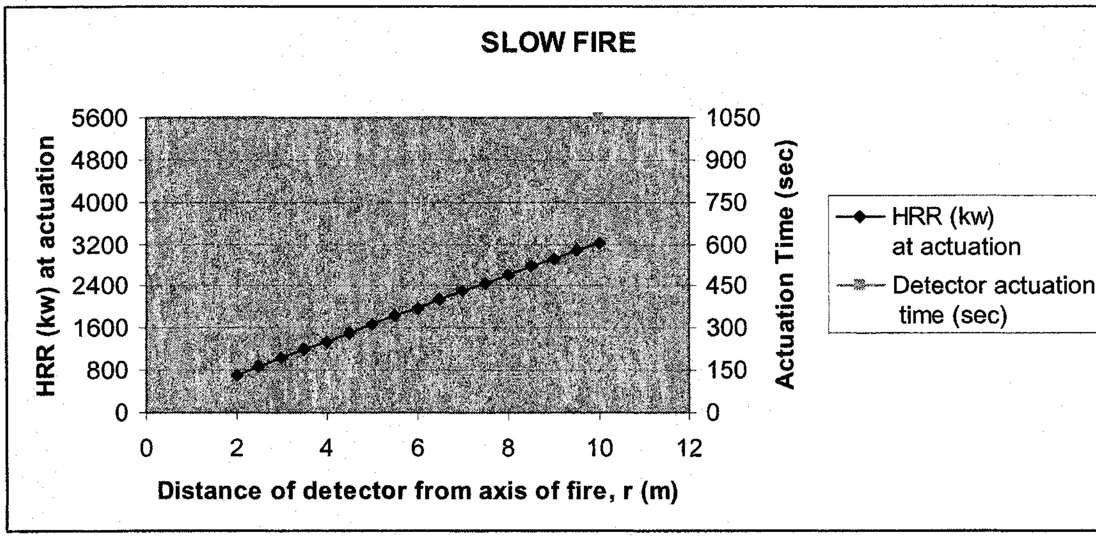

Figure 8.11 Effect of changes in distance of detector from axis of fire (Slow fire)

Table 8.11 and Figure 8.11 show the impact of variations in the distance of detector from axis of fire on detector actuation time for a slow t-square fire. Distance of detector from axis of fire was varied from 2 m to 10 m, representing a wide range of distances. For this fire the predicted detector actuation time varies from 491 s to 1050 s corresponding to distance of detector from axis of fire values of 2 m and 10 m respectively. The impact of detector distance, as seen in Figure 8.11 on response time is almost linear with a gradient of 69.9 s/ m.

Column 4 of Table 8.11 shows the resulting HRR at the time of detector activation. As detector actuation time increases the HRR of the fire increases. The relationship between distance of detector from axis of fire and HRR at actuation time is linear as shown in Figure 8.11, with a slope of 315.4 kW/ m.

TABLE 8.12 Detector actuation time (Medium Fire)

Sl. No.	Distance of detector from fire axis (m)	Min HRR required for actuation (kW)	HRR at actuation time (kW)	Temp. of Ceiling Jet at actuation time (°C)	Detector activation temperature (°C)	Detector actuation time (sec)
1	**2**	530	**885**	72	57	**276**
2	**2.5**	663	**1081**	71	57	**305**
3	**3**	795	**1274**	70	57	**331**
4	**3.5**	928	**1466**	70	57	**355**
5	**4**	1060	**1654**	70	57	**377**
6	**4.5**	1193	**1844**	69	57	**398**
7	**5**	1325	**2035**	69	57	**417**
8	**5.5**	1458	**2214**	69	57	**436**
9	**6**	1590	**2401**	69	57	**453**
10	**6.5**	1723	**2585**	68	57	**470**
11	**7**	1855	**2763**	68	57	**487**
12	**7.5**	1988	**2948**	68	57	**502**
13	**8**	2121	**3127**	68	57	**517**
14	**8.5**	2253	**3299**	68	57	**532**
15	**9**	2386	**3475**	67	57	**546**
16	**9.5**	2518	**3656**	67	57	**560**
17	**10**	2651	**3841**	67	57	**573**

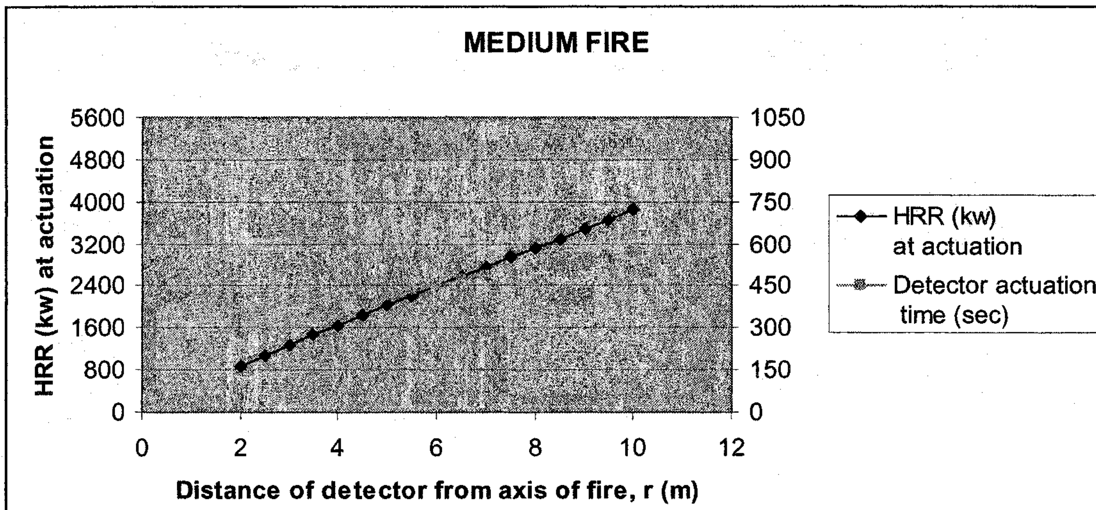

Figure 8.12 Effect of changes in distance of detector from axis of fire (Medium fire)

Table 8.12 and Figure 8.12 show the results for the medium t-square fire. As this fire grows faster detectors respond faster as well resulting in smaller response times than the slow t-square fire. Distance of detector from the axis of fire also affects response times, however at a rate much lower than before 37.1 s/ m as opposed to 69.9 s/ m.

The resulting heat release rate for these fires is higher with values ranging from 885 kW to 3,841 kW. The rate of change of HRR with distance of detector from axis of fire for this series of tests is 369.5 kW/ m, higher than 315.4 kW/ m of the slow fire case.

TABLE 8.13 Detector actuation time (Fast Fire)

Sl. No.	Distance of detector from fire axis (m)	Min HRR required for actuation (kW)	HRR at actuation time (kW)	Temp. of Ceiling Jet at actuation time (°C)	Detector activation temperature (°C)	Detector actuation time (sec)
1	**2**	530	**1208**	84	57	**162**
2	**2.5**	663	**1476**	83	57	**178**
3	**3**	795	**1736**	82	57	**193**
4	**3.5**	928	**1978**	81	57	**207**
5	**4**	1060	**2235**	80	57	**219**
6	**4.5**	1193	**2465**	80	57	**231**
7	**5**	1325	**2707**	79	57	**242**
8	**5.5**	1458	**2936**	79	57	**252**
9	**6**	1590	**3174**	78	57	**262**
10	**6.5**	1723	**3422**	78	57	**271**
11	**7**	1855	**3653**	78	57	**280**
12	**7.5**	1988	**3865**	77	57	**289**
13	**8**	2121	**4111**	77	57	**297**
14	**8.5**	2253	**4335**	77	57	**305**
15	**9**	2386	**4565**	77	57	**313**
16	**9.5**	2518	**4772**	76	57	**321**
17	**10**	2651	**4983**	76	57	**328**

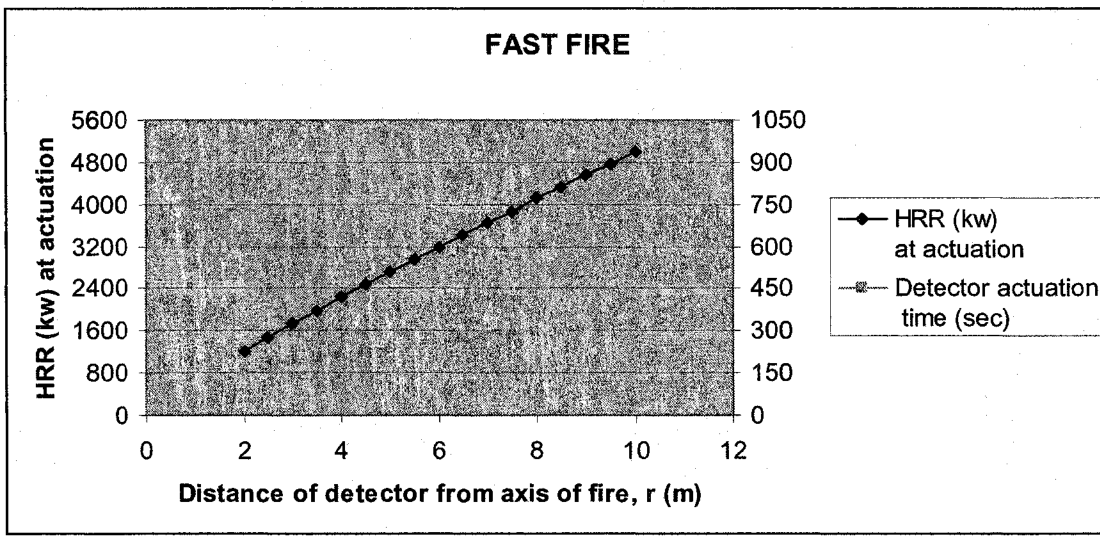

Figure 8.13 Effect of changes in distance of detector from axis of fire (Fast fire)

Table 8.13 and Figure 8.13 show the results for the fast t-square fire. This fire grows much faster than medium t-squared fires and hence detectors too respond very fast and result in a lot smaller response times than the medium t-square fire. Distance of detector from axis of fire also affects response times, however at a much lower rate than before 20.7 s/ m as opposed to 37.1 s/ m of medium t-squared fire.

The resulting heat release rate for these fires is very high with values ranging from 1,208 kW to 4,983 kW. The rate of change of HRR with distance of detector from fire axis for this series of tests is 471.9 kW/ m, a lot higher than 369.5 kW/ m of the medium t-squared fire.

It has been seen that the minimum HRR required for actuation is independent of the type of fire, but it increases with the increase in distance of detector from the fire axis. As the distance of detector from axis of fire increases, higher HRR will be required for actuation of the detector thereby increasing the time for detector actuation. As we move from slow to fast fire, the range of increase in HRR climbs up whereas the range of increase in detector actuation time goes down. Figures 8.11, 8.12, and 8.13 show the variations in HRR and Actuation Times on account of variations in the distance of detector from the fire axis.

In case of slow fires the detector actuation time is quite high on account of slow development of the fire. It has been exhibited that the faster fires have lower actuation time and higher heat release rates. For all the fires the HRR and Actuation Time, both increase with increase in the distance of detector from the fire axis. As we move from slow to fast fire, the line of detector actuation time shifts down and its slope also reduces whereas the HRR line climbs up with an increase in its slope, thereby indicating that as the distance of detector from the fire axis increases, "the fires with increasing HRR may bring down the detector actuation time".

8.4.1. Effect of variations in distance of detector from axis of fire on detector actuation time, and HRR

To determine the impact of variations in the distance of detector from the axis of fire, on response time of detectors as well as on heat release rates, a series of runs were made by considering three different fires, slow, medium and fast, using DETACT [6] . For these runs the following parameters were assumed constant:

Initial room temperature = 20 ^{0}C

Response Time Index (RTI) = 100 $m^{1/2}$ $s^{1/2}$

Height of ceiling above the fuel = 6.0 m

Detector actuation temperature = 57 ^{0}C

The results of these sets of runs are shown in Tables 8.14 - 8.15, and Figures 8.14 - 8.15.

8.4.1.1. Distance of detector from axis of fire vs. Actuation Time for various t^2 fires

Table 8.14 and Figure 8.14 show how the variations in distance of detector from the axis of fire will affect the detector actuation time in case of slow, medium, and fast fires.

Table 8.14 Distance of detector from axis of fire vs. Actuation Time for various t^2 fires

Detector distance from fire axis, r (m)	SLOW FIRE	MEDIUM FIRE	FAST FIRE
2	491	276	162
2.5	545	305	178
3	594	331	193
3.5	638	355	207
4	680	377	219
4.5	719	398	231
5	755	417	242
5.5	790	436	252
6	824	453	262
6.5	856	470	271
7	886	487	280
7.5	916	502	289
8	944	517	297
8.5	972	532	305
9	999	546	313
9.5	1025	560	321
10	1050	573	328

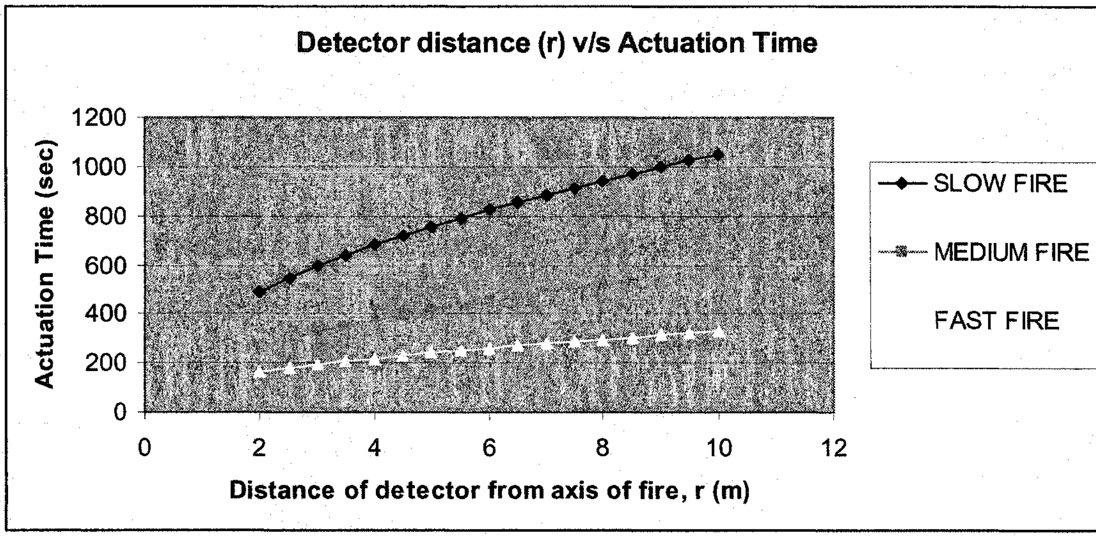

FIG. 8.14 Distance of detector from axis of fire vs. Actuation Time for various t^2 fires

Table 8.14 and Figure 8.14 show the impact of distance of detector from the axis of fire, on detector activation time, for all the three fires. Distance of detector from the axis of fire was varied from 2.0 m to 10.0 m representing a wide range of distance. For these fires the predicted detector actuation time variations are for slow fires (491 s to 1,050 s), medium fires (276 s to 573 s), and fast fires (162 s to 328 s) respectively. The impact of the distance of detector from the fire axis (as seen in Figure 8.14) on response time is almost linear for slow, medium and fast fires, with gradients of 69.9 s/ m, 37.1 s/ m, and 20.7 s/ m respectively.

The fast fires show the lowest detector actuation time followed by higher actuation time for medium fires and the highest for slow fires. For all the fires, the detector actuation time increases with the increase in distance of detector from the fire axis. The rate of increase of detector actuation time (i.e. the slope) is highest in case of slow fire and it decreases as we move from slow fire to the fast fire. It can thus be stated that with increase in distance of detector from the axis of fire, the increase in detector actuation time will be the highest in case of slow fires, relatively lower for medium fires and the lowest for fast fires.

8.4.1.2. Distance of detector from axis of fire vs. heat release rates for various t^2 fires

Table 8.15 and Figure 8.15 show that how the variations in distance of detector from axis of fire affect the heat release rates in case of slow, medium, and fast fires.

Table 8.15 Distance of detector from axis of fire vs. heat release rates for various t^2 fires

Detector distance from fire axis, r (m)	SLOW FIRE	MEDIUM FIRE	FAST FIRE
2	707	885	1208
2.5	871	1081	1476
3	1034	1274	1736
3.5	1193	1466	1978
4	1355	1654	2235
4.5	1515	1844	2465
5	1671	2035	2707
5.5	1829	2214	2936
6	1990	2401	3174
6.5	2148	2585	3422
7	2301	2763	3653
7.5	2459	2948	3865
8	2612	3127	4111
8.5	2769	3299	4335
9	2925	3475	4565
9.5	3079	3656	4772
10	3230	3841	4983

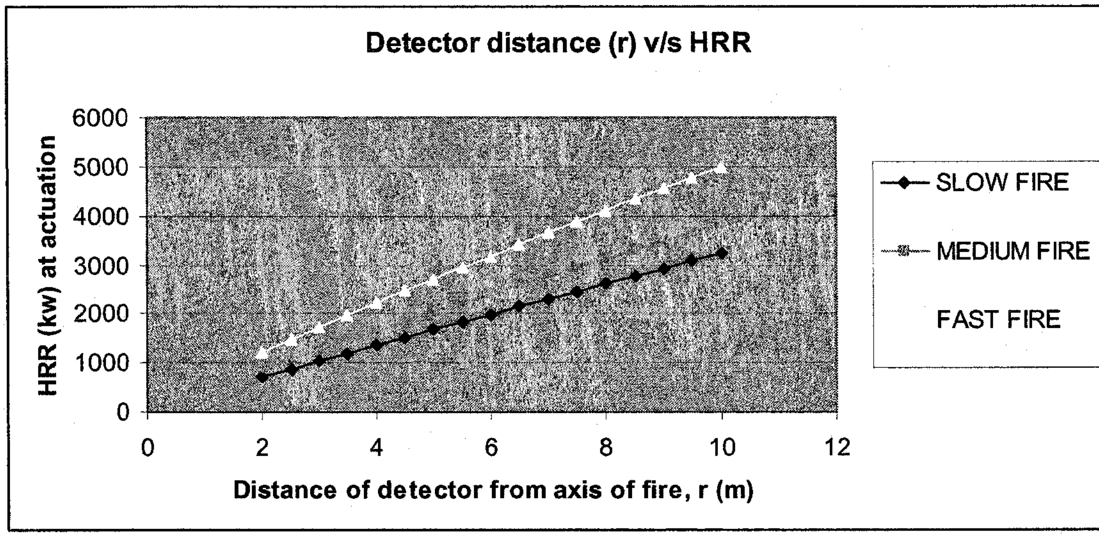

FIG. 8.15 Distance of detector from axis of fire vs. heat release rates for various t^2 fires

Table 8.15 and Figure 8.15 show the impact of variations in distance of detector from axis of fire, on heat release rates for slow, medium and fast fires. The distance of detector from axis of fire was varied from 2.0 m to 10.0 m representing a wide range of distances. For these fires the predicted heat release rate variations are for slow fires (707 kW to 3,230 kW), medium fires (885 kW to 3,841 kW), and fast fires (1,208 kW to 4,983 kW) respectively. The impact of variations in distance of detector from axis of fire (as seen in Figure 8.15) on HRR is almost linear in slow, medium and fast fires, with slopes of 315.4 kW/ m, 369.5 kW/ m, and 471.9 kW/ m respectively.

The fast fires show the highest HRR followed by lower value for medium fires and the lowest for slow fires. For all the fires, the heat release rate required for detector actuation increases with increase in the distance of detector from fire axis. The rate of increase (i.e. slope) of HRR is the smallest in case of slow fires and it increases as we move from slow to fast fires. It can thus be stated that with the increasing distance of detector from the fire axis, the increase in HRR required for detector actuation, will be lowest for slow fires, higher for medium fires and the highest for fast fires [1][6].

8.5. Variation with change in detector actuation temperature

In this section efforts are made to see the impact of variation in detector actuation temperature on the response time of detectors, separately for slow fires, medium fires and fast fires. Sub-section 8.5.1 shows how the changes in detector actuation temperature affect the detector actuation time and the heat release rates, when the three fires are visualized altogether.

To determine the impact of variations in the change of detector actuation temperature on response time of detectors a series of runs were made using DETACT [6]. For these runs the following parameters were assumed constant:

Height of ceiling above the fuel = 3.0 m

Distance of detector from axis of fire = 3.0 m

Initial room temperature = 20 ^{0}C

Response Time Index (RTI) = 100 $m^{1/2}$ $s^{1/2}$

The above values were chosen because these are the commonly used values for the said parameters. Three sets of runs were done using these parameters, by considering three different fires, slow, medium and fast. The results of these sets of runs are shown in Tables 8.16, 8.17 and 8.18 as well as in Figures, 8.16 to 8.18.

Table 8.16 Detector actuation time (Slow Fire)

Run No.	Detector actuation temperature (°C)	Min. HRR required for actuation (kW)	HRR at actuation time (kW)	Ceiling Jet at actuation time (°C)	Detector activation temperature (°C)	Detector actuation time (sec)
1	**40**	112	**255**	55	40	**295**
2	**42**	129	**280**	57	42	**310**
3	**44**	147	**306**	59	44	**323**
4	**46**	166	**331**	61	46	**337**
5	**48**	185	**360**	63	48	**350**
6	**50**	205	**386**	66	50	**363**
7	**52**	226	**413**	68	52	**376**
8	**54**	248	**441**	70	54	**388**
9	**56**	270	**469**	72	56	**400**
10	**58**	293	**498**	74	58	**412**
11	**60**	316	**527**	76	60	**424**
12	**62**	340	**555**	78	62	**436**
13	**64**	365	**586**	80	64	**447**
14	**66**	390	**615**	82	66	**459**
15	**68**	415	**645**	84	68	**470**
16	**70**	442	**678**	86	70	**481**
17	**72**	468	**710**	88	72	**492**
18	**74**	496	**739**	90	74	**503**
19	**76**	523	**771**	92	76	**514**
20	**78**	552	**805**	94	78	**524**
21	**80**	581	**839**	97	80	**535**

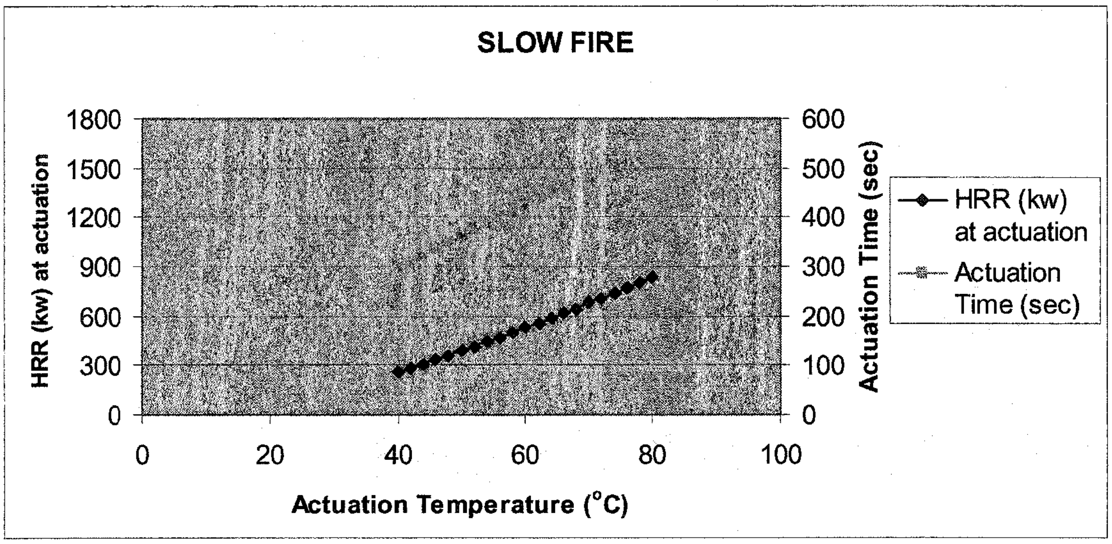

Figure 8.16 Effect of variations in detector actuation temp. (Slow fire)

Table 8.16 and Figure 8.16 show the impact of variations in the detector actuation temperature on detector actuation time for a slow t-square fire. Detector actuation temperature was varied from 40^0C to 80^0C, representing the whole range of typical detector actuation temperatures in use. For this fire the predicted detector actuation time varies from 295 s to 535 s corresponding to detector actuation temperature of 40^0C and 80^0C respectively. The impact of detector actuation temperature, as seen in Figure 8.10 on response time is almost linear with a gradient of 6 s/ ^{0}C.

Column 4 of Table 8.16 shows the resulting HRR at the time of detector activation. As detector actuation time increases the HRR of the fire increases. The relationship between detector actuation temperature and HRR at actuation time is linear as shown in Figure 8.16, with a slope of 14.6 kW/ ^{0}C.

Table 8.17 Detector actuation time (Medium Fire)

Run No.	**Detector actuation temperature (°C)**	**Min. HRR required for actuation (kW)**	**HRR at actuation time (kW)**	**Ceiling Jet at actuation time (°C)**	**Detector activation temperature (°C)**	**Detector actuation time (sec)**
1	**40**	112	**375**	64	40	**179**
2	**42**	129	**409**	67	42	**187**
3	**44**	147	**440**	70	44	**195**
4	**46**	166	**477**	72	46	**202**
5	**48**	185	**511**	75	48	**209**
6	**50**	205	**546**	77	50	**216**
7	**52**	226	**582**	80	52	**223**
8	**54**	248	**614**	82	54	**230**
9	**56**	270	**652**	84	56	**236**
10	**58**	293	**685**	87	58	**243**
11	**60**	316	**720**	89	60	**249**
12	**62**	340	**755**	91	62	**255**
13	**64**	365	**791**	93	64	**261**
14	**66**	390	**828**	96	66	**267**
15	**68**	415	**866**	98	68	**273**
16	**70**	442	**904**	100	70	**278**

Table 8.17 (cont.) Detector actuation time (Medium Fire)

Run No.	Detector actuation temperature (°C)	Min. HRR required for actuation (kW)	HRR at actuation time (kW)	Ceiling Jet at actuation time (°C)	Detector activation temperature (°C)	Detector actuation time (sec)
17	**72**	468	**937**	102	72	**284**
18	**74**	496	**977**	105	74	**290**
19	**76**	523	**1018**	107	76	**295**
20	**78**	552	**1053**	109	78	**301**
21	**80**	581	**1088**	111	80	**306**

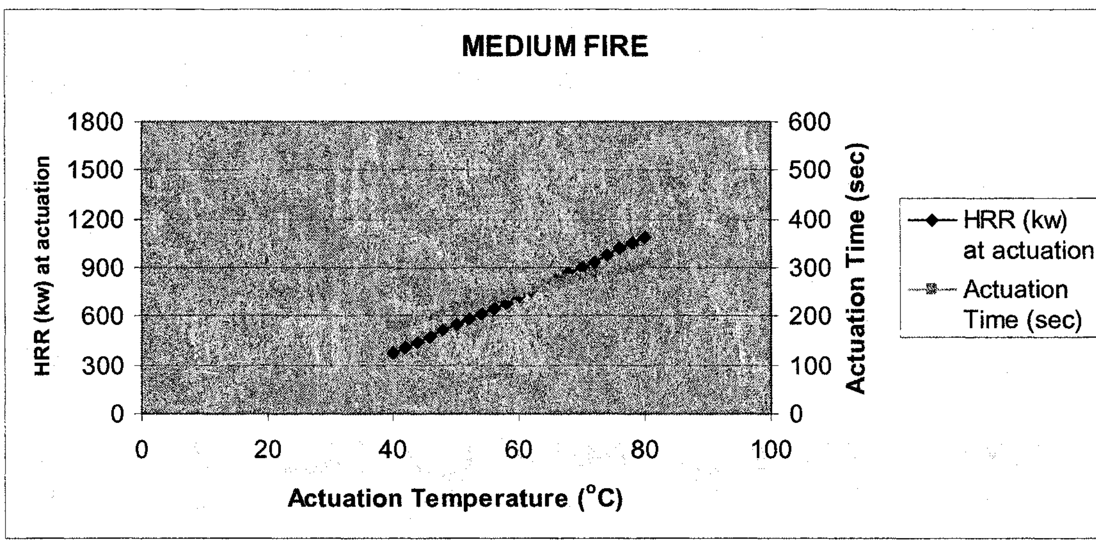

Figure 8.17 Effect of variations in detector actuation temp. (Medium fire)

Table 8.17 and Figure 8.17 show the results for the medium t-square fire. As this fire grows faster detectors respond faster as well resulting in smaller response times than the slow t-square fire. Detector actuation temperature also affects response times, however at a rate much lower than before 3.2 s/ ^{0}C as oppose to 6 s/ ^{0}C.

The resulting heat release rate for these fires is higher with values ranging from 375 kW to 1,088 kW. The rate of change of HRR with detector actuation temperature for this series of tests is 17.8 kW/ ^{0}C, much higher than 14.6 kW/ ^{0}C of the slow fire case.

Table 8.18 Detector actuation time (Fast Fire)

Run No.	Detector actuation temperature (°C)	Min. HRR required for actuation (kW)	HRR at actuation time (kW)	Ceiling Jet at actuation time (°C)	Detector activation temperature (°C)	Detector actuation time (sec)
1	**40**	112	**574**	79	40	**111**
2	**42**	129	**627**	82	42	**116**
3	**44**	147	**671**	85	44	**121**
4	**46**	166	**717**	88	46	**125**
5	**48**	185	**763**	91	48	**129**
6	**50**	205	**812**	94	50	**133**
7	**52**	226	**862**	97	52	**137**
8	**54**	248	**913**	100	54	**140**
9	**56**	270	**966**	103	56	**144**
10	**58**	293	**1007**	106	58	**148**
11	**60**	316	**1063**	109	60	**151**
12	**62**	340	**1105**	111	62	**155**
13	**64**	365	**1149**	114	63	**158**
14	**66**	390	**1208**	117	66	**161**
15	**68**	415	**1253**	119	68	**164**
16	**70**	442	**1300**	122	70	**167**
17	**72**	468	**1347**	124	72	**171**
18	**74**	496	**1395**	127	74	**174**
19	**76**	523	**1443**	129	76	**177**
20	**78**	552	**1493**	132	78	**180**
21	**80**	581	**1544**	134	80	**182**

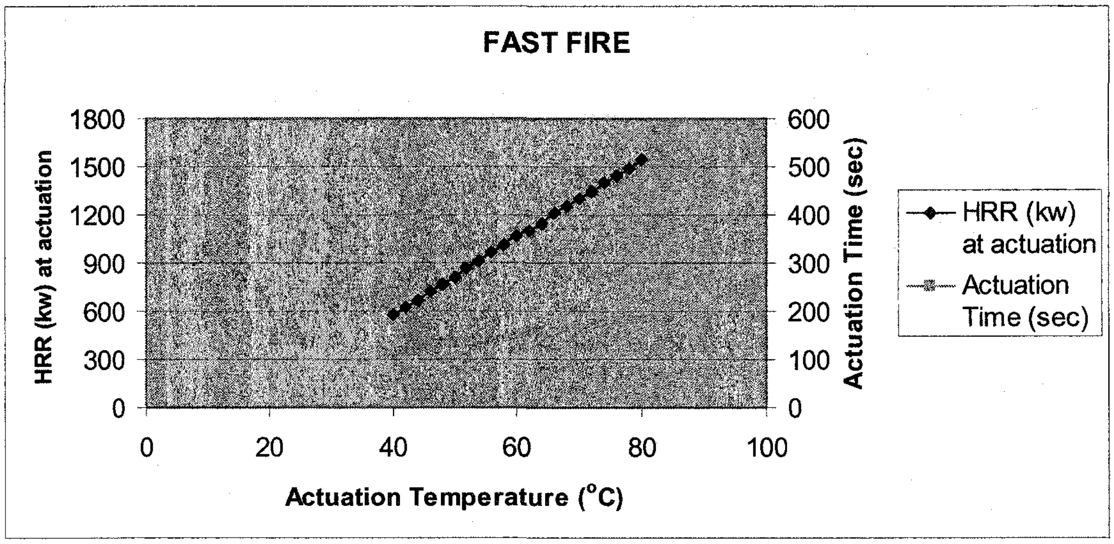

Figure 8.18 Effect of variations in detector actuation temp. (Fast fire)

Table 8.18 and Figure 8.18 show the results for the fast t-square fire. This fire grows much faster than medium t-squared fires and hence detectors as well respond very fast and result in a lot smaller response times than the medium t-square fire. Detector actuation temperature also affects response times, however at a much lower rate than before 1.8 s/ ^{0}C as oppose to 3.2 s/ ^{0}C of medium t-square fire.

The resulting heat release rate for these fires is very high with values ranging from 574 kW to 1,544 kW. The rate of change of HRR with detector actuation temperature for this series of tests is 24.2 kW/ ^{0}C, a lot higher than 17.8 kW/ ^{0}C of the medium t-squared fire.

The values of tables indicate that the minimum HRR required for actuation is independent of the type of fire, but it increases with the increase in detector actuation temperature. As the actuation temperature of the detector increases, higher HRR will be required for heating the detector so that it reaches its actuation temperature, and thus the detector actuation time increases. As we move from slow to fast fire, the range of increase in HRR climbs up (with slow fire having lower starting value and fast fire having higher starting value) whereas the range of increase in detector actuation time goes down (with slow fire having higher starting value and fast fire having lower starting value). Figures 8.16, 8.17, and 8.18 exhibit the changes in HRR and Actuation Times on account of variations in the actuation time of the detector.

In case of slow fires the detector actuation time is quite high on account of slow development of the fire. It has been seen that the faster fires have lower actuation time and higher heat release rates. For all the fires the HRR and Actuation Time, both increase with increase in the detector actuation temperature. As we move from slow to fast fire, the line of detector actuation time shifts down and its slope also reduces whereas the HRR line climbs up with an increase in its slope, thereby indicating that as the detector actuation temperature increases, "the fires with increasing HRR may bring down the detector actuation time".

8.5.1. Effect of variations in detector actuation temperature on detector actuation time, and HRR

To determine the impact of variations in the detector actuation temperature, on response time of detectors as well as on heat release rates, a series of runs were made by considering three different fires, slow, medium and fast, using DETACT [6]. For these runs the following parameters were assumed constant:

Initial room temperature = 20 ^{0}C

Response Time Index (RTI) = 100 $m^{1/2}$ $s^{1/2}$

Height of ceiling above the fuel = 3.0 m

Distance of detector from axis of fire = 3.0 m

The results of these sets of runs are shown in Tables 8.19 - 8.20, and Figures 8.19 - 8.20.

8.5.1.1. Detector actuation temperature vs. Actuation Time for various t^2 fires

Table 8.19 and Figure 8.19 show that how the variations in detector actuation temperature will effect the detector actuation time in case of slow, medium, and fast fires.

Table 8.19 Detector actuation temperature vs. Actuation time for various t^2 fires

Actuation Temperature (°C)	Detector actuation time (sec) SLOW FIRE	Detector actuation time (sec) MEDIUM FIRE	Detector actuation time (sec) FAST FIRE
40	295	179	111
42	310	187	116
44	323	195	121
46	337	202	125
48	350	209	129
50	363	216	133
52	376	223	137
54	388	230	140
56	400	236	144
58	412	243	148
60	424	249	151
62	436	255	155
64	447	261	158
66	459	267	161
68	470	273	164
70	481	278	167
72	492	284	171
74	503	290	174
76	514	295	177
78	524	301	180
80	535	306	182

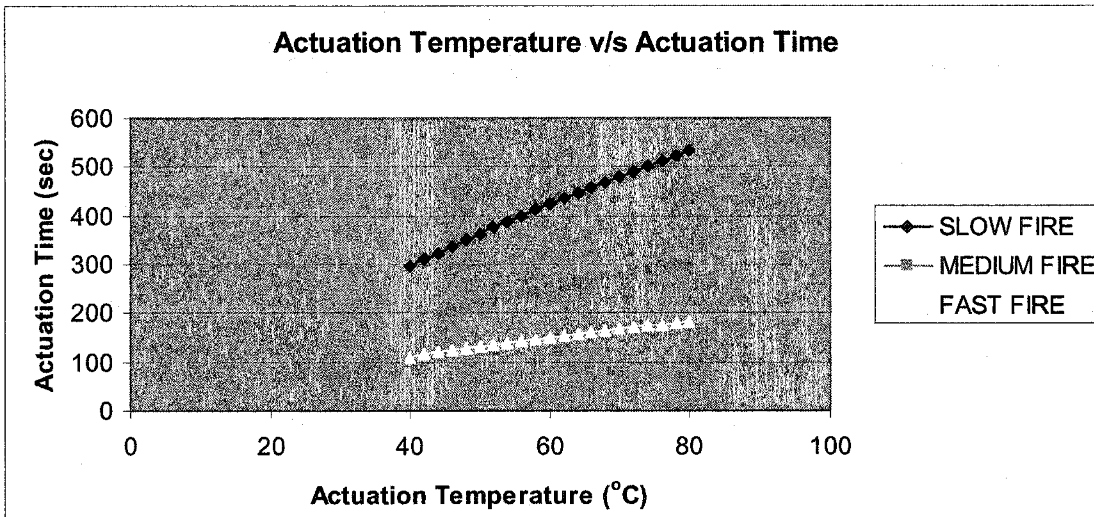

FIG. 8.19 Detector actuation temperature vs. Actuation time for various t^2 fires

Table 8.19 and Figure 8.19 show the impact of detector actuation temperature, on detector activation time, for all the three fires. The detector actuation temperature was varied from 40^0C to 80^0C representing a wide range of temperatures. For these fires the predicted variations in detector actuation time are, for slow fires (295 s to 535 s), medium fires (179 s to 306 s), and fast fires (111 s to 182 s) respectively. The impact of the detector actuation temperature (as seen in Figure 8.19) on response time is almost linear for all the three fires, with gradients of 6.0 s/ ^{0}C, 3.2 s/ ^{0}C, and 1.8 s/ ^{0}C respectively.

The slow fires show highest detector actuation time followed by relatively lower value for medium fires and the lowest for fast fires. For all the fires, the detector actuation time increases with the increase in actuation temperature of the detector. The rate of increase (i.e. slope) of detector actuation time is highest in case of slow fire and it decreases as we move from slow fire to the fast fire. It can thus be stated that with increase in the actuation temperature of the detector, the increase in detector actuation time will be the highest in case of slow fires, relatively lower for medium fires and lowest for the fast fires.

8.5.1.2. Detector actuation temperature vs. heat release rates for various t^2 fires

Table 8.20 and Figure 8.20 show that how the variations in distance of detector from axis of fire effect the heat release rates in case of slow, medium, and fast fires.

Table 8.20 Detector actuation temperature vs. heat release rates for various t^2 fires

Actuation Temperature (°C)	HRR (kW) SLOW FIRE	HRR (kW) MEDIUM FIRE	HRR (kW) FAST FIRE
40	255	375	574
42	280	409	627
44	306	440	671
46	331	477	717
48	360	511	763
50	386	546	812
52	413	582	862
54	441	614	913
56	469	652	966
58	498	685	1007
60	527	720	1063
62	555	755	1105
64	586	791	1149
66	615	828	1208
68	645	866	1253
70	678	904	1300
72	710	937	1347
74	739	977	1395
76	771	1018	1443
78	805	1053	1493
80	839	1088	1544

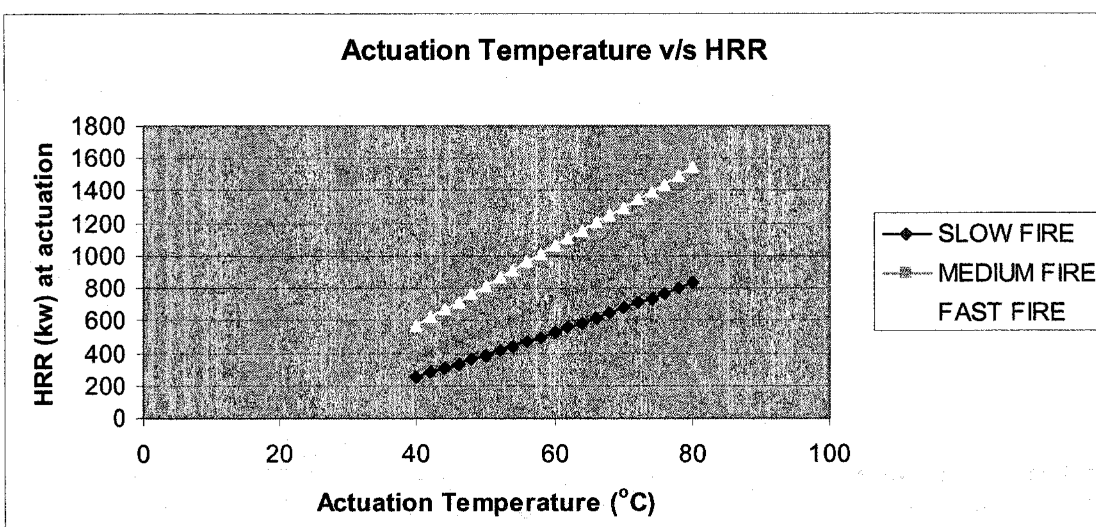

FIG. 8.20 Detector actuation temperature vs. heat release rates for various t^2 fires

Table 8.20 and Figure 8.20 show the impact of variations in detector actuation temperature on heat release rates for slow, medium and fast fires. The detector actuation temperature was varied from 40^0C to 80^0C representing a wide range of temperatures. For these fires the predicted heat release rate variations are for slow fires (255 kW to 839 kW), medium fires (375kW to 1,088 kW), and fast fires (574 kW to 1,544 kW) respectively. The impact of variations in detector actuation temperature (as seen in Figure 8.20) on HRR is almost linear in all the three fires, with slopes of 14.6 kW/ ^{0}C, 17.8kW/ ^{0}C, and 24.2 kW/ ^{0}C respectively.

The fast fires show highest heat release rate followed by relatively lower value for medium fires and the lowest for slow fires. In case of all the fires, the heat release rate increases with increase in the detector actuation temperature. The rate of increase (i.e. slope) of HRR is the lowest in case of slow fires, slightly higher for medium fires and highest for the fast fires. It can thus be stated that with the increase in detector actuation temperature, the increase in HRR required for detector actuation will be the least for slow fires, relatively higher for medium fires and the highest in case of fast fires.

8.6. Conclusion

Overall it can be concluded that given the values of RTI of sprinklers, ceiling heights, distance between detectors, actuation temperature of detectors, and fire load in a space, it can be predicted (within the assumptions of the model) by using DETACT [6] what is the minimum heat release rate required to actuate a detector, how much time will be taken by detectors to actuate and what may be the heat release rates at actuation.

The results obtained from DETACT clearly demonstrate the importance of sprinkler's or heat detector's locations on activation time and the minimum heat release rate required for activation. It is possible that these two parameters may render the sprinkler system or heat detectors ineffective. For example;

- In the case of assembly buildings where high ceilings are expected, there may be fires that would cause a lot of damages before the sprinkler system activates. For example a sprinkler located at a height of 10m will activate when a fast fire reaches 2.8 MW (Table 8.8).
- Large values of r (distance of detector from the fire axis) may also result in a situation where a fire causes damage prior to activation of the sprinkler system (Tables 8.11 to 8.13).

Chapter 9

9. Summary and Conclusions

An analysis of the Ontario's fire incident data for the eight year period (1995-2002) has been done to evaluate the fire problem in the province of Ontario, and to find out the operational reliability of active fire protection systems including smoke alarms, heat detectors and automatic sprinklers in various occupancies.

Results of the study show that there has been a trend of decreasing numbers of fire incidents, civilian deaths and civilian injuries, whereas property damage has shown a rising trend, probably on account of inflation. The maximum percentage of fire incidents, civilian injuries, civilian deaths, and property damage are primarily concentrated in residential occupancies, whereas industrial fires are observed to incur the most dollar loss.

The majority of fires in Ontario originate in cooking areas or kitchens whereas fires originating from living areas have resulted in the majority of deaths.

In residential occupancies the majority of fires take place due to misuse of ignition source/equipment (electrical failure stands second) and in most other occupancies electrical failure is the main cause. Among the known causes of fire, arson is the cause of the largest number of deaths.

Regarding basement fires, more than ninety percent of these occur in residential occupancies and about 2/3 of them take place in single family homes. It was further observed that either ignition of electrical wiring insulation or ignition of distribution equipment resulted in the largest number of basement fires.

For residential dwellings which include single family homes, semi-detached houses, and townhouses or row houses, asphyxia (CO, HCN) is the root cause of deaths. Townhouses/row houses show the highest death rates whereas detached dwellings show the highest rates of property damage. In the case of semi-detached dwellings as well as townhouses/row houses the chances of fatalities occurring at a floor above the area of fire origin are multifold (3 to 4 times higher, probably rising smoke is the cause behind) as compared to either the room of origin of fire or the floor of fire origin (other room).

Analysis of the data showed that in a large number of fire incidents of various occupancies, the origins of fire or causes of fire could not be determined especially for fires with high rates of deaths, injuries and property damage. The reason for this is that for these fires destruction is so large, that makes it impossible to identify the cause and origin.

The current study reveals that sprinklers are generally more effective than other fire protection devices in controlling fire spread and reducing fire deaths, injuries and property damage. Fire incidents with no fire protection at all, have generally shown higher rates of deaths, injuries and property damage. At times, the clear cut advantage of providing fire protection systems in comparison to those having no protection at all could not be seen due to the low number of fire incidents causing deaths and injuries in case of the installations with no fire protection.

Mean operational reliability estimates for smoke detectors, heat detectors and sprinkler systems coupled with 95 percent confidence limits for various occupancies, have been computed. In general the operational reliability values in the area of origin are higher than those beyond the area of origin. Furthermore the reliability value on the fire floor is higher than that on a different floor. The computed mean reliability values of devices in the compartment of fire origin for all occupancies combined are: battery operated smoke alarms 55.7% (upper limit 57% and lower limit 54.4%), hard wired smoke alarms 83.1% (upper limit 84% and lower limit 82.2%), smoke detectors connected to fire alarm system 88.8% (upper limit 89.7% and lower limit 87.9%), heat detectors 61.4% (upper limit 62.9% and lower limit 59.9%), and sprinklers 70.1% (upper limit 71.3% and lower limit 68.9%). The reliability values indicated by earlier studies are generally higher than the values obtained in the current study because the earlier studies eliminated small fires from their analysis while in the present study small fires were not eliminated.

The computer program DETACT [6] used for evaluating the changes in actuation time of sprinklers or heat detectors under various scenarios showed that:

- The faster fires cause lower actuation times and higher heat release rates. The HRR and Actuation Time, both increase with increase in RTI values for all the fires.
- The higher the ceiling above the fuel, the higher the HRR required for detector activation and thus the longer the actuation time.
- As the distance of the detector from the axis of fire increases, higher HRR is required to activate heat detectors thereby increasing the time for detector actuation.
- As the actuation temperature of the detector increases, higher HRR will be required for heating the detector so that it reaches its actuation temperature, and thus the detector actuation time increases.

Chapter 10

10. Recommendations for future work

In the current study, mean operational reliability associated with 95% confidence interval estimates has been computed and tabulated for each of the occupancies for smoke alarms (battery operated/ hard wired/ hard wired connected to fire alarm system), heat detectors and sprinklers. These estimates have been prepared based upon the eight year (1995-2002) fire incident data received from the office of the Ontario Fire Marshal. It would be good to collect fire incident data from other Canadian provinces. Similar reliability estimates can be prepared and their weighted average taken for the purpose of obtaining more accurate operational reliability values for each of the above fire protection systems.

To look at the Province of Ontario data again to see what happens with all fires that do not cause operation of sprinklers.

- If the property damage was low presumably the fires were too small to cause operation of sprinklers and they can be removed from the current reliability assessment. The reviewer could check this conclusion against the OFM classification of each fire.
- It the property damage was large, then they should have operated the sprinkler system and this would be definite evidence of "lack of reliability". The reviewer could also check this conclusion against the OFM classification of each fire.

Fire incident data from the USA may also be analyzed in a similar fashion and 95% confidence interval reliability estimates prepared so as to compare with the Canadian results.

The present study indicates mean failures of sprinklers in various occupancies. It may be helpful to review the fire loss data to determine whether there are deficiencies in NFPA 13.

To determine the number of different types of residential units in Ontario to obtain fire rates per residential unit.

To take another look at the current DETACT work and simply list the minimum HRR required to cause activation for all scenarios {RTI, T (activation), height of ceiling and radial distance}.

Fires attended by local fire departments are reported to the provincial authorities using standard incident report forms. The office of the Fire Marshal or Fire Commissioner in each province collects and analyses information on all fires which occur in the province. It is felt that more fields of information need to be added to the standard incident report forms used in Canada. The probable additions are as follows:

1. Details of on site material or products, materials contributing most to the flame spread, and whether the fire spread was limited to the room of origin, or floor or building.
2. Additional information like:
   - Was the system operational?
   - Was the design suitable for the hazard?
   - What was the state of maintenance?

3. Details of the fire protection device in use e.g. combination of ionization and photoelectric detectors, residential sprinklers etc. may be added to the list to evaluate the effectiveness of specific devices.
4. Due to high percentage of undetermined reasons of non operation of fire protection devices, efforts may be made for increasing the list of reasons of non operation. This may help in realistic evaluation and taking action for improvement in the presently used detection or suppression devices.

In addition to the above, specific efforts are required to ensure that all fires, whether small or big or controlled by sprinklers etc. are reported. These will help evaluating the actual reliability of the fire protection systems installed.

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Appendix I

List of Occupancies

1. Assembly Occupancies

Production/Viewing performing arts

101	Theatre—Motion Picture
102	Theatre—Concert Hall, Live
103	T.V. Studio
104	Opera House

Museum/Art gallery/Auditorium

111	Museum
112	Art Gallery
113	Library
114	Auditorium
115	Lecture Hall

Recreation/sports facility

121	Bowling Alley, Billiard Centre
122	Dance Studio
123	Community/Exhibition/Dance Hall
124	Sports/Country/Social/Yacht Club
125	Gymnasium
126	Non Residential Club

Education facility

131	School—Pre-Elementary
132	School—Elementary
133	School—Secondary Junior High (Gr. 7 & 8)
134	School—Secondary/Senior High (Gr. 9+)
135	School—Technical, Industrial Trade
136	School—Business, Commerce, Secretarial
137	School—Post Secondary (University)
138	School—Post Secondary (College)

Transportation facility

141	Airport, Heliport
142	Bus Terminal
143	Railway Station

144	Subway Station
145	Marine Terminal
Other assembly	
151	Restaurants (occupant load greater than 30 persons consuming food and drink)
152	Bar, Tavern, Night Club
153	Church, Other Similar Place of Worship
154	Funeral Facility
155	Legislative Facility/Building
156	Court Facility
157	Day Care Centre
Arenas/Swimming pools	
161	Arena
162	Ice Rink
163	Indoor Swimming Facility
Participating/Viewing open air facilities	
171	Theatre Drive-In
172	Stadium
173	Exhibition, Fair Stand, Amusement Park Structure
174	Bleacher, Grandstand, Reviewing Stand
Other assembly	
199	Other Assembly

2. Institutional Occupancies

Persons under restraint	
201	Jail, Prison, Penitentiary
202	Reformatory (with detention quarters)
203	Adult Detention Camp (minimum
204	Police Station (with detention quarters)
205	Young Offender Detention Facility
206	Psychiatric Hospital (with detention quarters)
Persons under supervisory care	
211	Psychiatric Hospital (without detention quarters)
212	Public/Private Hospital
213	Sanatorium (without detention quarters)
214	Home for the Aged
215	Nursing Home
216	Convalescent Home

217	Infirmary
218	Hospice
219	Children Custodial Home
220	Orphanage
221	Reformatory (without detention quarters) Other institutional
Other Institutional	
299	Other Institutional

3. Residential

Detached/semi/attached residential	
301	Detached Dwelling
302	Semi-Detached Dwelling
303	Attached Dwelling (e.g. row house, townhouse, etc.)
Rooming/group/retirement home	
311	Rooming/Boarding/Lodging House
312	Group Home
313	Retirement Home
Multi-unit dwelling	
321	Multi-Unit Dwelling—2 to 6 Units
322	Multi-Unit Dwelling—7 to 12 Units
323	Multi-Unit Dwelling—Over 12 Units
Dual purpose dwelling residential/business/apt	
331	Apartment, Flat, Tenement with Business
332	Detached Dwelling with Business
333	Semi-Detached Dwelling with Business
334	Attached Dwelling with Business
335	Detached Dwelling—Accessory Apartment (above grade)
336	Detached Dwelling—Accessory Apartment (below grade)
337	Semi-Detached Dwelling—Accessory Apartment (above grade)
338	Semi-Detached Dwelling—Accessory Apartment (below grade)
339	Attached Dwelling—Accessory Apartment (above grade)
340	Attached Dwelling—Accessory Apartment (below grade)
Mobile home/dwelling	
341	Motor Home, Camper, Trailer
342	Mobile Home

343	Tent
344	Houseboat
Hotel/Motel/Lodge	
351	Hotel, Inn, Lodge—Not Licensed for Alcoholic Beverages
352	Hotel, Inn, Lodge—Licensed for Alcoholic Beverages
353	Motel, Motor Hotel—Not Licensed for Alcoholic Beverages
354	Motel, Motor Hotel—Licensed for Alcoholic Beverages
Other residential	
361	School/College Dormitory (detached from education facility)
362	Nurses Residence (detached from hospital)
363	Military Barrack
364	Bunkhouse, Workers Barrack
365	Detached Garage
366	Residential Club
367	Hostel
368	Residential Camp
369	Convent, Monastery
399	Other Residential

4. Business/personal services Occupancies

Business or personal services	
401	Bank
402	Post Office
403	Barber Shop, Hairdresser, Beauty Salon
404	Laundry, Dry Cleaner (includes self-service)
405	General Business Office
406	Police Station (without detention quarters)
407	Dental/Medical Office
408	Animal Hospital
409	Radio Station
410	Small Tool/Appliance Rental/Service Establishment
411	Fire Station
Other Business/personal services	
499	Other Business or Personal Services

5. Mercantile

Food/beverage sales

501	Restaurant (occupant load of 30 or fewer persons consuming food/drink)
502	Supermarket, Grocery Store
503	Specialty Food Store (e.g. butcher, delicatessen, etc.)
504	Convenience/Variety Store
505	Liquor/Wine/Beer Store
506	Market—Outdoors (flowers, fruit, vegetable sales)
507	Market—Indoors (flowers, fruit, vegetable sales)

Department/catalogue/mail outlet

511	Department Store
512	Catalogue/Mail Order Outlet

Specialty stores

521	Clothing Store
522	Fabric Store
523	Furniture/Appliance Store
524	Paint/Wallpaper Store
525	Hardware Store
526	Building Supply Store
527	Lumber Yard
528	Garden Supply
529	Book/Stationary/Art Supply Store
530	Pharmacy
531	Florist
532	Hobby Shop, Sporting Goods
533	Pet Shop
534	Video Rental Shop

Other mercantile

599	Other Mercantile

6. Industrial Occupancies

Vehicle sales/service

601	Motor Vehicle Sales
602	Service Station
603	Motor Vehicle Repair Garage
604	Motor Vehicle Parts, Accessory Sales
605	Car Wash

676	Appliances, Appliance Parts
606	Watercraft Sales
607	Marina, Marine Service Station
609	Other Vehicle Sales/Service
Utilities	
611	Hydro Generating Plant
612	Hydro Distribution Facility
613	Gas Processing Plant
614	Gas Distribution Facility
615	Water Works
616	Water Distribution Facility
617	Sanitary Services (includes plant)
618	Flammable Liquid Distribution Facility
619	Other Utilities
Mfg/process Chem/Petro/Paint/Plastic	
621	Petroleum Products
622	Chemicals
623	Plastics
624	Paint, Varnishes, Lacquers
625	Drugs, Cosmetics, Pharmaceutical
626	Rubber Goods
627	Asphalt Products
628	Coal Products
629	Other Chemical/Petroleum/Paint/Plastic Products
Mfg/process Agr/Food/Bev/Tobac products	
631	Meat/Poultry/Fish Products
632	Dairy Goods, Produce
633	Grain Products, Bakery Goods
634	Alcoholic Beverages
635	Soft Drinks
636	Tobacco Products
637	Vegetable/Animal Oil Products
638	Sugar Refining, Sugar Products
639	Other Agr/Food/Beverage/Tabacco products
Mfg/process textiles/cloth/leather products	
641	Textile Manufacturing (e.g. preparing fibres, spinning, weaving, etc.)
642	Tannery

643	Footwear Manufacturing
644	Wearing Apparel Manufacturing
645	Dry Cleaning Plant
649	Other Textiles, Clothing, Leather Goods
Mfg/process Wood/Furn/Paper/print products	
651	Pulp/Paper Processing
652	Primary Processing (e.g. sawmill, plywood manufacturer, etc.
653	Secondary Processing (e.g. finished goods, furniture, etc.)
654	Printing, Publishing (e.g. newspapers, magazines, books, etc
655	Job Printing (e.g. forms, greeting cards, etc.)
659	Other Wood, Furniture, Paper Products, Printing
Mfg/process vehicles parts	
661	Road Vehicles, Parts
662	Rail Vehicles, Parts
663	Watercraft, Parts
664	Aircraft, Parts
665	Specialty Vehicles, Parts
669	Other Vehicles, Parts
Mfg/process other metal/elect/misc products	
671	Primary Metal Processing (e.g. refining, melting, production of ingots, etc.)
672	Secondary Metal Processing (e.g. rolling, drawing, polishing, galvanizing, etc)
673	Precision Goods/Instruments (e.g. surgical instruments, cameras, clocks, etc)
674	Precious Metals, Jewellery
675	Sporting Goods, Toys
676	Appliances, Appliance Parts
679	Other Metal/Electrical/Miscellaneous products
Storage Chemical/Petrol/Paint/Plastic products	
681	Petroleum Products
682	Chemicals
683	Plastics
684	Paint, Varnishes, Lacquers
685	Drugs, Cosmetics, Pharmaceutical
686	Rubber Goods
687	Asphalt Products

688	Coal Products
689	Medical Supplies—Cold Storage
690	Tank, Tank Farm—Flammable or Combustible liquids/gases
691	Tank, Tank Farm—Other Liquids
692	Tank, Tank Farm—Empty
699	Other Chemical/Petroleum/Paint/Plastic Products
Storage Agr/Food/Bev/Tobacco products	
701	Meat/Poultry/Fish Products
702	Dairy Goods, Produce
703	Grain Products, Bakery Goods
704	Alcoholic Beverages
705	Soft Drinks
706	Tobacco Products
707	Vegetable/Animal Oil Products
708	Sugar Refining, Sugar Products
709	Cold Storage—Processed Food
710	Cold Storage—Beverages
711	Tank, Tank Farm—Agricultural Products
712	Tank, Tank Farm—Processed Food, Beverages
713	Elevator—Seed, Bean, Grain, etc.
714	Elevator—Other Goods
715	Elevator—Empty
719	Other Agricultural Products, Food, Beverages, Tobacco, etc.
Storage Textile/cloth/leather products	
721	Textiles
722	Footwear
723	Wearing Apparel
724	Dry Cleaning Plant
725	Furs—Cold Storage
729	Other Textile Goods
Storage Wood/Furn/Paper/print products	
731	Pulp, Paper
732	Primary Products (e.g. plywood, banded lumber, etc.)
733	Secondary Products (e.g. finished
734	Printing, Publishing
735	Job Printing (e.g. forms, greeting cards, etc.)

739	Other Wood, Furniture, Paper Products, Printing
Storage vehicles, parts	
741	Road Vehicles, Parts
742	Rail Vehicles, Parts
743	Watercraft, Parts
744	Aircraft, Parts
745	Specialty Vehicles, Parts
749	Other Vehicles, Parts
Storage Metal/Elect/miscellaneous	
751	Primary Metal Products (e.g. ingots, bars, etc.)
752	Secondary Metal Products
753	Precision Goods/Instruments
754	Precious Metals/Jewellery
755	Sporting Goods/Toys
756	Appliances, Appliance Parts
759	Other Metal/Electrical/Miscellaneous Products
Other Industrial	
791	Recycling Facility
792	Waste Transfer Station
793	Laboratory
794	Aircraft Hangar
799	Other Industrial

7. Miscellaneous Structures/Properties (not classified by O.B.C.)

Mine/Well	
801	Mine
802	Petroleum/Natural Gas Well
Transportation facility	
811	Chair Lift, Cable Car, Ski Lift
812	Bridge, Overpass, Trestle, Tunnel, Underpass
Communications facility	
821	Radio Transmission Site, Microwave Tower
822	Telephone Exchange
823	Weather Station, Lighthouse
Open (outdoor) storage	
831	Agricultural Products
832	Processed Food Beverages
833	Flammable/Combustible Liquids, Gases

	834	Chemicals, Plastics, Rubber Products
	835	Textiles, Fibres, Clothing
	836	Metal Products, Machinery, Appliances
	837	Vehicles or Vehicle Parts
	838	General Goods
Miscellaneous structure		
	841	Mailbox
	842	Fence
	843	Shed, Children's Playhouse
	844	Privy
	845	Telephone Booth
	846	Hydro/Telephone Pole
	847	Toll Station, Weather/Bus Shelter
	848	Trash/Rubbish Container
	849	Tarpot
	850	Parking Lot Kiosk
	851	Newspaper Kiosk
	852	Clothing Drop Box, etc.
	853	Gazebo
	854	Sauna—Outdoors
Miscellaneous property		
	861	Open Land (e.g. light ground cover, bush, grass, etc.)
	862	Forest, Standing Timber
	863	Tree, Hedge
	864	Dump, Land Fill Site
	865	Barn, Fowl/Animal Shelter
	866	Silo, Storage Facility
	867	Crops
	868	Greenhouse
Other Miscellaneous property		
	899	Other Miscellaneous Structure/Property

Appendix II

List of Codes for fire protection devices, their location, operation, and reasons for in-operation

01	Smoke Alarm (battery operated)
02	Smoke Alarm (hard wired)
03	Smoke Alarm—Interconnected (battery operated)
04	Smoke Alarm—Interconnected (hard wired)
05	Smoke Detector (connected to fire alarm system)
06	Heat Detector
07	Flame Detector
08	Sprinkler
09	Pull Station
10	Standpipe
11	Fire Extinguisher
12	Other Fixed Extinguishing Unit
97	Other
98	Undetermined
99	None

Device Location

01	In Area of Origin
02	Beyond Area of Origin—Same Floor
03	Beyond Area of Origin—Different Floor
97	Other
98	Undetermined
99	Not Applicable

Device Operation

01	Alarm Operated
02	Suppression Operated
03	Alarm and Suppression Operated
04	Nothing Operated
97	Other

98 Undetermined
99 Not Applicable

Reason for Inoperation

01 Tampered With (vandalism)
02 Power Not Connected (e.g. no battery, hydro cut off, etc.)
03 Power Failure (e.g. dead battery, hydro failure, etc.)
04 Improper Installation
05 Remote from Fire
06 Separated from Fire (e.g. wall, etc.)
07 Unit Failure (mechanical or electrical failure)
08 Extinguishing Agent Supply Impaired
09 Operation Not Intended
97 Other
98 Undetermined
99 Not Applicable