Validation of Methodologies to Determine Fire Load for Use in Structural Fire Protection

Final Report

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THE FIRE PROTECTION RESEARCH FOUNDATION
Research in support of the NFPA mission

FIRE RESEARCH

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FOREWORD

The uncertainty of fire loads as input data for calculating structural fire performance is a critical concern in the field of structural fire protection. Accurate values are needed for this input criteria to better predict the performance of structures in fire. NFPA 557 is a newly proposed draft standard to provide methods and values for use in the determination of design basis fire loads. The objective of this research project was to validate the fire load survey methodology proposed in the NFPA 557 draft standard and to develop guidance on means to calibrate the results of fire load data surveys developed using various other methodologies.

The content, opinions and conclusions contained in this report are solely those of the author.

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Final Report

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Abstract

In performance based codes, design fires are determined using engineering calculations and tools that include both computer models and experiments to demonstrate acceptable performance. In many of these calculations or tests, fires that are representative of those expected in buildings are used to evaluate building performance. These fires are known as design fires. An important input parameter that affects the design fire is the total available combustible content known as fire load (MJ), often expressed as energy density per unit floor area, Q'' (MJ/m^2). Fire loads are often determined by conducting surveys of the representative building type. The following survey methods have been identified: weighing, inventory, combination of weighing and inventory, questionnaire, and web-site review. Although, the method of data collection has been recognized to have a significant impact on survey results, this impact has not been explicitly quantified. This study seeks to establish a structured approach to validate fire load survey methodologies proposed in the NFPA (draft) Standard 557 and to enhance and develop guidance on means to calibrate the results of fire load data surveys developed using various other methodologies. The study conducted a sensitivity analysis of the key survey methodologies based on available literature and survey of office buildings. A total of 103 offices in five office buildings were surveyed. The percentage difference in fire load density values (MJ/m^2) predicted from different survey method ranged between 1% and 50%. This difference can be attributed to the uncertainties associated with each survey method. The combination method (inventory and weighing) was considered the best survey methodology since it combines best practices from both methods and hence minimizes the degree of uncertainty and error.

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1. Introduction

1.1 Background

The use of engineered fire protection designs for buildings is becoming more acceptable in many countries with the introduction of objective and performance-based codes. Performance-based designs must consider how the building and its fire protection systems perform in the event of a fire. Building performance is evaluated following a fire hazard analysis procedure, which requires the identification of possible fire scenarios that may occur in the building, and the appropriate design fires that should be considered. These designs are done using engineering calculations and tools that include both computer models and experiments to demonstrate acceptable performance. In many of these calculations or tests, fires that are representative of those expected in buildings are used to evaluate building performance. These fires are known as design fires.

The increasing use of engineered solutions results in the need to identify, characterize and quantify design fires for various buildings. The burning characteristics (ingnition, heat release, and flame temperature) of design fires depend on the type, amount, and arrangement of combustible materials (known as fire load), geometry and available ventilation in the room of fire origin, and the ignition source. The type and arrangement of combustibles affect the growth characteristics, while the total amount of fuel and ventilation characteristics in the compartment of fire origin govern the intensity and duration of the fire.

The total fire load is the total heat energy (MJ) that can be released through complete combustion. It is often expressed as energy density per unit floor area, Q'' (MJ/m^2), to enable extrapolation to compartments of different sizes.

The total fire load in a compartment is calculated using the following equation:

$$Q = \sum k_i \, m_i \, h_{ci} \qquad \textit{Equation 1}$$

Where, Q = total fire load in a compartment (MJ), k_i = proportion of content or building component i that can burn, m_i = mass of items i (kg), and h_{ci} = calorific value of item i (MJ/kg).

It must be noted that, in some surveys, the fire load is expressed in terms of load per unit bounding surface area of compartment. The fire load is determined by surveying a representative sample of the buildings of interest and listing the compartments' dimensions, fixed and content combustibles and their pertinent characteristics. Fire loads usually consist of fixed fire loads and contents fire load. Several fire load surveys in the past have used different survey methodologies, including: the inventory, weighing, a combination of inventory and weighing, use of questionnaires and web based photographs of real estate sites. Three basic methods can be used to estimate the combustible energy content of a particular compartment. These are:

- direct measurement of mass, with conversion based on the net heat of combustion;
- direct measurement of volume (with conversion based on a combination of density and net heat of combustion); and
- energy release measurement by calorimetry of an item sufficiently similar to the fuel package.

The first two methods are the most common in the literature. Therefore, the survey conducted in this study also considers the use of these two methods.

1.2 Project Objectives

The method of data collection has been recognized to have a significant impact on survey results; however this impact has not been explicitly quantified. NFPA (draft) Standard 557 recommends that fire load surveys are conducted by using the weighing method or the inventory method. The objective of this research is to establish a structured approach to validate the fire load survey methodology proposed in the NFPA (draft) Standard 557 and to enhance and develop guidance on means to correlate the results from fire load data surveys developed using various other methodologies. To achieve these objectives, a literature review of the various fire load survey methodologies has been conducted. The report further presents a detailed evaluation and sensitivity analysis of the various survey methodologies.

1.3 Organization of Report

The report is organized into five chapters. Chapter 1 gives a general background and objective of the study. Chapter 2 evaluates different fire load survey methods based on a review of literature. Chapter 3 describes the survey plan and the data collection process. Chapter 4 presents an analysis of the fire load data collected during the survey and compares the results of fire load and fire load densities of different survey methods. Chapter 5 presents conclusions and recommendations made from the study.

2. Literature Review

2.1 Evaluation of Fire Load Survey Methodologies

Several fire load survey methodologies (techniques) have been identified from the literature review[1-18], which include: inventory, weighing, combination of inventory and weighing, questionnaires, and website review method. Discussion of these methodologies have been presented in the sections below.

2.1.1 Inventory Method

The NFPA (draft) Standard 557[1], guidance on fuel load surveys (special facility and occupancy based) defines the inventory method as the determination of the mass of an item based on its measured volume and corresponding density. The method requires the physical entry of a building by an expert to list content and characteristics of all combustible items within the compartment. In the past, surveyors have used measured dimensions (physical characteristics of items) to obtain the mass of the item being surveyed. Mass of the items can therefore be calculated using known densities of the corresponding material (NFPA Standard 557, draft) or by estimations based on pre-weighed items data [2,3]. Combustible energy of the compartment contents is then calculated based on the net heat of combustion of the fuel package

Culver [2] developed an inventory survey method employing the collection of visual data, i.e., observable physical characteristics of the various content items, from which weights were obtained. The concept involved the assumption that a relationship existed between the visual characteristics (measured dimensions) of items and their weight. This relationship can be viewed as a transfer function or formula for weight expressed in terms of physical characteristics. Masses of items were developed based on transfer functions.

It must be noted that masses of items were not calculation using measured volume and corresponding material density as specified by the NFPA (draft) Standard 557. Weights of items used to develop the transfer functions were from pre-weighed items and manufacturer's catalogues. Twenty three office buildings across the United States were surveyed. The following information was gathered for each item: type of item (desk, table and etc.), the construction material (wood, metal and etc.), and the measured dimension (length, width and height). For irregular shaped items and irregular pile of papers, approximate dimensions were recorded. Transfer functions were used for the survey but no direct weighing was done. The survey classified weights as movable contents (furniture, equipments and other combustible contents) and interior finish (combustible finish material for walls ceilings and floors). The fire loads presented were obtained by converting the weights of surveyed items to equivalent weights of combustible having a calorific value of 18.5MJ/kg (8000Btu/lb).

Issen [3] conducted a fire load survey of a residential compartment using a method similar to Culver's. Both Issen and Culver used transfer functions which assume that items being surveyed are presumed to be of standard materials and sizes. According to Issen [3], although no industry-wide standards existed, the market place and available technology during the period of the survey produced furniture types that appeared to be consistent in their weight characteristics. Similar to Culver, combustibles stored in enclosed cabinets (combustibles and non-combustibles) or shelves were not reduced by any factors (derating factors) for fire resistance. Fire loads were calculated based on the heat of combustion of wood (18.5MJ/kg).

Kumar [4] also conducted a fire load survey using the inventory method. The approach for the survey was similar to the method Culver used. The aim of the survey was to update existing fire load survey data to reflect conditions that prevailed at that time of the survey in 1993. Kumar's survey was conducted on 8 office buildings in Kanpur, India, and may not be comparable to fire loads in the United States because of differences in building occupancy characteristics. However, the purpose of this review is the type of methodology used and therefore the study is relevant. Similar to Culver [2] and Issen [3], no derating factors were used for enclosed combustibles such as combustibles in cabinets. Derating factors are usually used to reduce the weights of combustibles that are stored in cabinets. This is because the combustibles stored in the cabinets would not burn as efficiently as items that are not. According to Kumar, the justification of not using derating factors is that cabinets may be left opened during the event of a fire. Kumar observed that fire load intensities reported may be reduced by approximately 10% on using the derating factors. Fire loads were computed by multiplying the masses of different items by their specific calorific values. The total energy content of the room was then divided by the floor area to get the fire load per unit area corresponding to that room.

Korpela et al [5] developed a method of fire load survey similar to Culver's method. Korpela determined weights of items based on the physical characteristics (dimensions) of the item and pre-weighed item tables. The study surveyed 1,500 office rooms, open plan offices, archives, libraries and conference rooms. The method was to help make the fire load survey quicker and easier as compared to earlier surveys which were time consuming and labour intensive. The method was based on the assumption that most office furniture is of standard size and form. First, an inventory list was created from accurately weighing different categories of fire loads from an initial visit to two buildings. The inventory consisted of 10 different tables each consisting of a single category of items such as tables, shelves, chairs, computers, displays, etc. Typical dimensions of each of these items were given. The second step was to determine the fire load of the items within a given compartment by taking some dimensions of items and matching them to the relevant inventory list. However, all non standard items had to be estimated by the surveyor. It must be noted that Korpela did not use any transfer functions. Items were matched by comparing physical characteristics of items within the compartment to pre-weighed items.

Several drawbacks of the inventory method discussed in the literature above have been identified. First, the use of derating factors has not been clearly defined. As a result of this, different surveys have used different factors to reduce combustibles stored in enclosures. Others have also considered the fire load as the total combustible content without the use of derating factors for enclosed combustibles. The difference in survey results of the use of these factors have been found to be in the range of 10% [4]. The use of incorrect approximations for miscellaneous and irregular shaped objects can significantly affect the survey results. Furthermore, the use of transfer functions which presume that items are standardized in terms of size and material can also significantly affect survey results. These functions only represent mean values of furniture or items in that category. The lack of standardization in the industry especially for domestic furniture also has an impact on the use of these functions. Incorrect identification and matching of these functions (pre-weighed items) to similar items in compartments being surveyed can also affect the quality of survey results. Finally, in estimating fire load, Issen used the heat release rate of wood to convert masses of items into energy units. This simplification does not effectively account for the contribution of other items (plastics, liquid fuels and etc) to the total amount of energy released. In occupancies where plastics and liquids form a significant part of combustible contents, the use of the heat release rate of wood for all items will significantly affect the fire load. Culver also converted the weights of surveyed items to equivalent weights of combustibles having a calorific value of 18.5MJ/kg. This value was based on the heat of combustion of wood and may not be true for other materials, e.g. plastics and liquid fuels.

2.1.3 Direct Weighing Method

This method also requires physical entry into a building by a surveyor to document contents and characteristics of all items within the compartment. However, unlike the inventory method, the combustible masses of items within the compartment are obtained by direct weighing.

Ingberg [6] conducted an extensive fire load survey using the direct weighing method. The report presented fire loads for different occupancies including; apartments and residences, hospitals, schools, mercantile establishment and manufacturing establishments. In commercial establishments, the survey was limited to selling areas and small storage areas frequented by clerks, and did not include workshops and offices associated with the selling areas. Combustible loads per floor area of the whole department were determined by weighing the combustible contents in a representative area of the department. However, little detail was given in the report as to how other occupancies were surveyed. Combustible contents in this report refer to movable, floor coverings and exposed wood work other than on the floor. Fuel load was presented per floor area of the compartment.

Baldwin et al [7] also conducted a fire load survey of two office buildings using the direct weighing method. The survey used detailed plans to describe the layout of the furniture and room, and provided a list of the types and weight of individual items of furniture. The reported fire load data did not include fixed combustibles on walls and partitions. Fuel load was presented as the total weights of combustibles per floor area (kg/m^2).

Caro [8] surveyed six office buildings using the direct weighing method. Two different direct weighing methods were used. In the first method, all combustible contents within the compartment were taken from their operational location and weighed. In the second, the weights of office contents when packaged for remodelling purposes were determined. The fuel load was calculated for only the combustible contents and does not include all metal contents. Derating factors were used to decrease enclosed combustible items. The fuel load estimates for each office were separated into the following categories: paper/books, computer equipment, furniture, partitions and miscellaneous. This was done to group items of similar material composition. Fuel load was calculated as the ratio of the total equivalent weight of the fuel commodities to the floor area, (lb/sq.ft).

The use of the direct weighing method may not be as common as the inventory method; however in most cases, it is used with the inventory method. The major drawback of the weighing method is the difficulty in accounting for fixed combustibles. Directly weighing fixed combustibles may be impractical. As a result of this difficulty, fixed combustibles are often not included in fire load calculations or assumed based on the surveyor's discretion. Another drawback of the direct weighing method is how to determine the weight of combustible materials in items having both combustible and non-combustible materials. Metals can form a significant portion of the mass of such items, e.g. padded metal chair, metal racks with wooden shelves etc. Measuring the mass of combustibles of such items becomes difficult. Also, the use of the direct weighing survey method is likely to disrupt business activities and invade privacy. This may be controlled by planning the survey during out of office hours and may not directly affect the quality of survey results. However, if certain areas are inaccessible to the survey team due to ongoing business activities or privacy concerns, the fire loads cannot be determined. As discussed above, the method used by Caro is not likely to disrupt business but the risk of error may be high since package contents may not accurately reveal the material characteristics of the item. This is because items within the compartment were packaged and concealed in boxes which do not permit a thorough investigation (material documentation) of the item being surveyed. The weighing method may also affect the survey time adversely. Directly weighing all items within a compartment may require a significant amount of labour. Lifting of items to weigh may require more than a single surveyor and heavy items may require more people. The method requires a larger work force and special weighing devices.

2.1.4 Combination Method (Inventory and Weighing)

This method combines the use of the direct weighing method and the inventory method, the latter of which, may include inventory of pre-weighed items and calculation of mass based on direct measurement of volume and corresponding material densities.

One of the earliest fire load surveys that employed the use of both the inventory method and the direct weighing method is reported in BMS Report 92 [10]. The survey covered different types of building occupancies, including residential, educational, offices, hospitals and warehouses. Weights were obtained by weighing furniture and other contents that could easily be weighed. Fire loads of combustible floors, as well as, fixed combustible and heavy furniture were determined from thickness and area. Doors, windows, frames and trims were included at half their total weight; however no explanation as to this consideration was given in the report. Contents of metal lockers, filing cabinets etc were also included as its total weight without any reduction in weight (no derating factors were used). Contents of closets in residential apartments were averaged with those of the adjoining room or hall. In schools, desks were assumed to be empty and surveys did not include weights of clothing (e.g. outdoor jackets or gym kit) stored by pupils. Fuel load was presented as weight (pounds) of all combustible items per floor area (square foot), which was assumed to be uniformly distributed. Similar to Culver, weights of items, other than wood, were modified to give the equivalent weight of a material having a calorific value of 18.5MJ/kg.

Green [11] also used a combination of the direct weighing and inventory methods to conduct a fire load survey of a hospital. The study described combustible contents by their nature, weight, thickness or surface area. For combustibles that could not be easily weighed, dimensions were measured, volumes were calculated and then weights of combustibles were calculated by using an assumed density of 600kg/m^3. The study assumed that all combustibles had the same calorific value as wood. Fire loads were estimated based on the calorific value of wood.

Barnett [12] conducted a pilot fire load survey using a combined method of both inventoried data and direct weighing. This survey was not intended to give precise fire load results but was only intended to determine the order of magnitude of likely results for each type of building and to set a basic framework for future survey. The survey was conducted in one building of each of the following building categories: hospitals, offices, shops and factories. The survey was divided into two main stages. First, combustibles were divided into fixed and movable fire loads. Fixed fire loads included combustibles in or on the walls, floors and ceiling including power and telephone cables, plastic light fittings, telephones, doors and frames. The second stage was to record weights of combustible contents and to compute volumes from measured dimensions of both fixed and combustible contents that cannot be weighed. In order to obtain fire load densities from inventoried data, a gross calorific value of wood of 20MJ/kg (wood at oven dry conditions) was used.

Yii (2000) [13] conducted a fire load survey using both methods to investigate the effects of surface area and thickness on fire loads. The survey was conducted in six sample university rooms, four samples of postgraduate offices, one sample of motel (kitchen and bedroom) and from several bedrooms in flats. In order to facilitate the data collection a fire load data entry sheet was prepared. Fuel loads were classified into fixed fire loads and movable fire loads. Fixed items such as skirting boards and wall switches were ignored. This was due to the difficulty in assuming the exposed surface area to the fire. Fuel loads were also divided into different types of materials such as wood, plastic and etc. The mass and dimensions were the two most important parameters that were measured. For combustible objects that were too large, the volume was measured and mass obtained by multiplying the volume with the density. Another parameter that was considered in the study was the surface area of the fuel exposed to the fire.

Zalok [14] used the direct weighing method, inventory of pre-weighed common items and calculation of mass based on measured volume and corresponding density. 167 commercial stores were surveyed. Zalok noted that combinations of these methods facilitated the survey process. All questionnaires that were needed to be completed by the store owners or individuals were conducted in-person by the surveyor. This helped to ensure a high quality of survey data and consistencies in data. In order to collect data in a systematic and consistent order a survey form was developed and used for all buildings surveyed. The survey also followed a similar procedure for all compartments. First, the name, address, type of establishment and date of the investigation were noted. This was followed by recording dimensions of the store, types of walls, floors and ceiling lining material as fixed fire loads on the survey form. Finally, classification of all combustible contents in store was recorded. Masses of items that could easily be weighed were measured and their material composition noted. Percentages of each type of material were also determined for items composed of more than one material. Volumes of items that could not be weighed were determined and the mass was calculated from the product of the material density and the measured volume. Items such as carpets and lining material were determined in a similar manner. Masses of items surveyed were converted into energy units using the calorific value of the items. The total fire load for each compartment was then calculated.

Either the inventory or direct weighing method, if used alone, has several drawbacks that may impede the progress of the survey and also adversely affect survey results. This has resulted in the use of both methods for a number of surveys in the past [9-13]. According to Culver [2], the inventory method (mass obtained from inventory of pre-weighed items) gives about 10% degree of error as compared to the direct weighing method and uncertainties between different surveyors can be in the range of 15-20%. Culver attributed this to the fact that the inventory method requires some estimation by the surveyor (e.g. miscellaneous items and irregular piles of paper). The direct weighing method may reduce the degree of error associated with the inventory method. However, it is also not practical to use the direct weighing method for every item within the compartment. For instance, weights of built-in shelving or fixed furniture units may have to be determined by measuring their volume and using the density of the material to calculate their mass. In addition, for items that are made up of different material types, the percentage of each item have to be determined and quantified using the inventory method (mass based on measured volume and corresponding density). Thus, a survey method that combines the best features of the direct weighing and the inventory method should be advantageous. Items that can easily be weighed such as toys and books are directly weighed while inventorying is used for all items that cannot be easily weighed such as bulky furniture and fixed combustibles.

The use of the two methods in combination may still involve some amount of approximations. From the review of literature, the use of the combined method utilizes table of pre-weighed items in order to facilitate the survey process [5,14]. Identifying similar items within the compartment on the catalogue also involves some surveyor discretion. This is critical because no industrial standardization of furniture exists. Therefore, pre-weighed items can only be assumed to have similar characteristics to items within the compartment. Moreover; problems with privacy and disruption of business may impede the effectiveness of the method. The combination method which usually requires walk-down surveys may also involve an appreciable amount of time, especially when the extent of survey is large. Finally, the method of fire load calculation can affect the fire load data obtained from the survey. Barnett [12] used a gross calorific value of wood of 20MJ/kg (wood at oven dry conditions). This may produce conservative fire load results as compared to surveys that used 18.5MJ/kg. Green [11] also assumed that all combustibles had the same calorific value as wood. This assumption may not hold for occupancies where majority of the combustible are liquids, plastics or upholstery. This is because these materials may have different burning characteristics than wood.

2.1.5 The Questionnaire Method

The Questionnaire method involves the distribution of questionnaires, usually with an explanatory note to occupants of a particular building use type. The method basically relies on indirect measurements through tabular look ups and furniture selection tables to compute fire loads. Fire loads are then estimated based on the calorific value of items sufficiently similar to the fuel package.

Kose et al [16] surveyed 216 single-family dwellings using the questionnaire approach. The questionnaires were sent to the occupants with a list of standard furniture and goods commonly found in dwellings. An explanatory sheet with figures of furniture was also added to the questionnaire. Additionally, occupants were required to do measurements of some items within the compartment not included in the figures shown on questionnaires. Clothing which can be a significant source of fire load in dwelling was not sufficiently accounted for in the survey. Fire load was presented as the total weights of all combustibles per floor area, kg/ m^2.

Bwayla [17] also conducted a survey of 74 single-family residences using the questionnaire approach. The survey utilized a web based questionnaire which was distributed through the internet, mainly to employees at the National Research Council of Canada. Similar to Kose et al.[16], questionnaires had a pre-determined list of household items which are commonly found in the living rooms. The web based questionnaire only allowed participants to choose quantity, size, materials and other pertinent attributes. The questionnaire did not make any provision for occupants to provide physical measurements of items within the compartment; nor were illustrations provided for the residents to identify furniture items easily. This means that configuration and sizes of items within the compartment are largely based on assumptions. The questionnaire also made provision for occupants to fill in type and size of the house, number of exits, number of windows in a specific room. Fire load was then calculated using highest values of weight and heat of combustion found for each grouping of furniture.

The use of the questionnaire method has several drawbacks that can significantly affect the fire load. A closer look at the Kose's questionnaire indicates that items such as bookshelves, wardrobes and drawers only had inputs for width, depth and height. This implies such combustibles are to be considered as one complete block neglecting gaps and empty spaces within. Fire load data obtained from questionnaires are usually qualitative. Information received from the questionnaires cannot be easily verified. Independent verification (i.e. the issue of inputting wrong measurements by residents in the case of Kose's method and the issue of inability to provide accurate furniture characteristics by residents) are some of the critical issues to be considered. Inability to verify data from questionnaires may have a greater degree of uncertainty as compared to the use of the inventory and the direct weighing method.

2.1.6 Real Estate Website Review

This method involves a review of real estate websites by an expert to determine fire loads based on architectural drawings and photographs. Weights of the combustible content of a particular compartment is developed using visible information from the photographs. Fire loads are estimated based on the calorific value of items sufficiently similar to the fuel package.

Bwayla et al. [18] conducted a fire load survey using information from a real estate web site. The scope of this study was limited to a local real estate website only. The survey used pictures and dimensions of spaces (likely from original floor plans). The method also used weights of furniture items through a survey of shops.

This method also has limitations to its effective use. Photographs provided only a limited view of the compartment which makes it very difficult to fully document the entire fire load within that compartment. Photographs also show tidy and ideal setting with no clutter conditions [18]. This therefore does not represent the real situation. In addition, the weight of all items within the compartment was based on estimates and assumptions. These assumptions may result in some degree of error. The advantage of this method is that it does not require the physical presence of the surveyor in the compartments being surveyed. The method is therefore not likely to disrupt business or invade privacy.

2.1.7 Summary

The NFPA Standard 557 proposes that a fire load survey must be conducted by either the weighing or the inventory method or a combination of both. The literature review presented in this report has identified other methods of fire load survey such as: the use of questionnaires (directly distributed to occupants or web-based) and the review of real estate websites. The use of these survey methods has been found to have some degree of error and uncertainty which can significantly affect the quality of the fire load survey results or the effective use of that particular method. Table 2-1 provides a summary of these findings.

The inventory method is able to account for both fixed and content fire loads in a compartment. However, the literature review identified the following issues:

- The issue whether to use derating factors has not been explicitly addressed in earlier fire load surveys.
- The use of the surveyor's discretion for approximating mass of miscellaneous and irregular shaped objects can have a significant impact on the quality of the survey results.
- The lack of standardization in the industry especially for domestic furniture, hence the use of transfer functions which presumes that items are standardized in terms of size and material may not be valid.
- Finally, incorrect identification and matching these functions (pre-weighed items) to similar items in compartments being surveyed can also affect the quality of survey results.

Table 2-1 Summary Table

Method	Inventory	Direct Weighing	Questionnaire	Website Review
Derating factors (combustibles in drawers and cabinet)	Not clearly defined	Not clearly defined	NA	NA
Miscellaneous and irregular shaped objects	Based on estimations and assumptions	Precise values from weights of items	NA	NA
Transfer functions (standardization in furniture items)	Can be verified by measuring dimensions	Based on estimations and assumptions	Based on estimations and assumptions	Based on estimations and assumptions
Accounting for Fixed Combustibles	Precise values from measured dimensions	Based on estimations and assumptions	NA	Dependent on design drawings availability
Time needed for survey	Medium	Long	Relatively short	Short
Verification of survey results by surveyor	Yes	Yes	No	No
Privacy concerns and disruption of business	Yes	Yes	No	No

The weighing method has been found to result in the most accurate values for fire loads. However, it also has shortfalls that must be addressed.

- The use of this method cannot effectively account for fixed combustibles within a compartment because of the difficulty in weighing these items.
- It is difficult to determine the exact weight of combustibles by directly weighing items that are made up of non-combustibles and combustibles.
- Issues such as: labour force available for the survey, use of special weighing apparatus, business disruption and privacy concerns must be carefully considered before using this method for any survey.

The ‘questionnaire’ and the ‘web site review’ methods are able to deal effectively with the issues of privacy concerns and disruption to business. In addition, both methods can be used for surveys that involve a very large sample size. However, these shortfalls have been identified:

- There are often difficulties in verifying information received from these methods (refer to Table 2-1).
- Fire loads are largely based on assumptions (website review).
- Information from the use of these methods is largely qualitative.

3. Fire Load Survey

3.1 General

Fire loads and their pertinent characteristics represent an important input in the determination of design fires in a performance-based fire protection design. Knowledge of the types of material that comprises the fire load within a compartment helps in the prediction of fire growth. The total fire load will help to calculate heat release rate of a particular fuel package in a fire scenario. As discussed in previous sections, it is recognized that the method of data collection has a significant impact on the survey results; this impact has not been explicitly quantified.

This section discusses the pilot fire load survey conducted for this research to explore the effects of varying key surveying methods on survey results.

3.2 Surveyed Buildings

Fire load surveys were conducted in five (5) different office buildings in Ottawa, Ontario (National Capital – Canada) and Quebec (Gatineau) from November 2010 to April 2011. The office buildings included private and federal government buildings. A total of 103 office rooms were surveyed (Table 3- 1).

Table 3- 1 Sample Size of Rooms Surveyed

Rooms	**Number of Samples**
Enclosed offices	27
Open offices (Cubicle)	76
Total	103

3.3 Survey Methodology

Several survey methodologies have been identified in the literature [1-18]. Traditionally, surveys have been conducted by physically entering a building and listing the contents and their pertinent characteristics. According to the NFPA (Draft) Standard 557, determining fire loads in a building requires measuring the mass of all combustibles and determining their calorific values. It further states that the mass of an item in a compartment can be determined by weighing (weighing method), or determining its volume and identifying its density (inventory method). The inventory weighing method should be used for heavy items that cannot be weighed, such as heavy furniture and built-in shelves. In most cases, a combination of the weighing and inventory method is used, in which some common items could be weighed, and the surveyor notes their inventory. The NFPA (Draft) Standard 557 proposes the use of either the weighing method or inventory method, or a combination of the two. These methods have been used in this research to explore its effects on the survey results.

The data collection survey methods used in this study is defined as follows:

- Weighing Method – mass obtained from direct weighing and estimations based on pre-weighed item table
- Inventory Method – mass obtained from direct measurement of volume with subsequent conversion based on corresponding density
- Combination Method – mass obtained from the use of the two methods described above.
- Questionnaire method – mass obtained from tabular look-ups based on hand delivered questionnaires

Fire Loads have been calculated based on conversion of mass into energy units (MJ) using the calorific value (heat release) of the corresponding material. To simplify the fire load estimations, the current survey made the following assumptions:

- combustible materials are uniformly distributed throughout the building
- all combustible material (with the exception of combustibles stored in enclosures) in the fire compartment would undergo total combustion

3.4 Survey Plan

The survey was conducted in stages:

1. Preliminary visits were made to the buildings and a reconnaissance survey was conducted in selected rooms by random sampling of the compartments. This was done for the surveyors to be familiar with the fire loads expected and to update survey forms, questionnaires and furniture catalogue information. This helps the final survey to become more focused and less time consuming.
2. Survey questionnaires were prepared and sent to selected office occupants to document fire loads within their compartments without any direct supervision by a surveyor.
3. After the questionnaire method, a survey of fire loads was conducted using the weighing method. A table of pre-weighed furniture was used in situations where very large items of furniture could not be weighed. The catalogue was prepared from manufacturers' catalogues, visits to shops and direct contact with manufacturers through the internet. The necessary approximations were made in situations where office furniture did not directly match catalogue weights.
4. The fire load survey was conducted in the same compartments using the inventory method and finally a combination of the inventory and weighing methods was used.

3.5 Data Collection and Fire Load Calculations

Survey forms were developed to facilitate the collection of data in an organized manner. Three different forms were developed as summarized in Appendices 1, 2 and 3. To ensure consistency in data collection and comparison of results among methods, the three survey forms had similar sections. Each form had 6 sections as follows:

Section 1: office, building and survey information,

Section 2: type of your office – closed or open plan,

Section 3: dimension and geometry of office space,

Section 4: number of openings and dimensions,

Section 5: fixed fire loads (floor, wall, and ceiling finish) and

Section 6: Content fire loads.

The survey forms were designed to make the survey focused and less time consuming.

3.5.1 Weighing Method

The weighing method calculated the fire load based on measured weights of combustibles and the corresponding calorific value of the materials. A table of different furniture dimensions and weights was prepared and used in cases where very large items of furniture could not be weighed. The necessary approximations were made in situation where furniture items within the compartment did not match pre-weighed furniture items. Items (e.g. chairs and small tables) that could be weighed within the compartment were weighed. Other items such as computer monitors, keyboard, telephone, rubbish bins, paper binders and books of different dimensions were directly weighed.

The fire load is calculated using the calorific value (h_c) of different materials to convert measured weights into energy units (MJ). Fire load is presented in energy units per floor area (MJ/m^2), commonly referred to as Fire load density. The calorific values (Heat of combustion) for different materials are presented in Appendix A. For accurate results, materials were grouped under cellulosic (paper and wood), plastics and textiles. Table 3-**2** shows the caloric values used in this research. Combustibles stored in enclosures were derated, (see Appendix D).

Table 3- 2 Heat Release (MJ/kg) of Different Materials

Material	**Minimum(HR) - MJ/kg**	**Average(HR) - MJ/kg**	**Maximum(HR) - MJ/kg**
Paper	13[19,20]	16.3[4]	21[19]
Wood	17[19]	18.5[19]	20.0[19]
Plastic	43[19]	43.5[19]	44[19]
Textile	17[19]	19[19]	21[19]

The use of pre-weighed tabulated tables minimized the time used in surveying each compartment. In addition, the use of these tables reduced the amount of interruptions and disruption to business often associated with the direct weighing method. This is because weighing items such as office desks and other heavy items require special weighing equipments and a large team. The pre-weighed tabulated items had dimensions in addition to the weights. The dimensions were used to accurately match pre-weighed items to items within the compartment. These dimensions aided in approximation of weights where compartment items vary the tabulated data. This approach helps to reduce the level of uncertainty and degree of error that may have been associated with different surveyor's approximation bias.

It has been discussed in the literature review that the weighing method has several drawbacks. This includes how to account for the weights of items with more than one material composition, e.g. a chair with metallic legs and padded seats. To account for these items, pre-weighed similar items were split apart with each combustible component weighed. Additionally, the percentage of each combustible item to the total weight was noted.

3.5.2 Inventory Method

The inventory method calculated fire load based on the measured volume of items. Weights of items were obtained by multiplying the measured volume of combustibles by its density. This method did not use pre-weighed items and no direct measurement of mass was done.

Similar to the direct weighing method, items were classified under cellulosic material (paper, cardboard and wood), plastics (includes foam based material), and textiles (includes carpets and clothing). Table 3- 3 shows the density of different materials used in this research. Fire loads were calculated from the masses of the items and their corresponding calorific value. Calorific Values of items were the same as used for the weighing method, Table 3- 2. Similar to the weighing method, combustibles stored in enclosures were derated, (see Appendix D).

As discussed in previous sections, accounting for irregular or complex shaped items are usually difficult with the use of the inventory method. Appropriate assumptions were made in cases where the volume of irregular shaped objects could not be easily measured. The volume of about 95% of all items within compartments could be measured.

Therefore, inability to account for irregular shaped objects did not have a significant impact on the fire load densities calculated.

Table 3- 3 Density of Different Materials

Material	Density	Reference
Paper	450kg/m^3 or *0.5kg/m^2	Estimated 14
Wood	Minimum – 140kg/m^3 Average – 450kg/m^3 Maximum – 640kg/m^3	24 13 24
Plastic	Polystyrene – 1050kg/m^3 Polypropylene –905kg/m^3	24 24
Textile	Nylon carpet with synthetic backing – 2.4kg/m^2 Other textile carpet – 1kg/m^2	25 14

* Paper with thickness not more than 1mm

3.5.3 Combination Method (Inventory and Weighing)

This method used data from direct weighing method and inventory method. Weights of items were obtained from:

- directly weighing items,
- pre-weighed item tables and
- measured dimensions with subsequent conversion into weights through the use of the item's material densities.

Fire load was calculated by the product of item weights and their corresponding calorific values. Similar to the two methods discussed above, items within the compartment were grouped into: Cellulosic, plastics and textile. Calorific values have been presented in Table 3- 2.Items stored in enclosures (e.g. cabinets) were 'derated', Appendix D.

3.5.4 Questionnaire Method

Fire load survey questionnaires were prepared and delivered by hand to occupants of selected offices. This method used tabular look-ups where office occupants select and identify the combustible items within their compartment using a set of item tables. The participants completed questionnaires without direct supervision. Each questionnaire was accompanied by a description of how to complete the form. Unlike Kose's[16] method, this current method did not require participants to directly measure or weigh items. However, participants were required to estimate room dimensions and other combustible items that could not be tabulated. It must be noted that, other methods such as 'web-based questionnaires and 'web-reviews' may share similar approach ('piece count' and 'tabular look-ups') to the hand delivered questionnaire method used in this study. The scope of the study was limited to hand delivered questionnaires.

An experienced surveyor using the filled questionnaire forms and an inventory of pre-weighed items data sheets later determined weights of items within each compartment. Fire load density was calculated by converting calculated weights into energy units (MJ/m^2) using the corresponding material calorific values.

Participation by building occupants in this method was very poorly. About 60% of the people contacted for participation in the questionnaire survey refused. Another 30% did not return the questionnaire that was sent to them. Furthermore, security concerns were a major problem during questionnaire distribution. Therefore, the survey was discontinued. As a result of this, the initial office building for the survey had to be changed. Another drawback to the questionnaire method was inaccurate and unreliable compartment dimensions estimated by the few participants who participated.

4. Data Analysis

Data collected from the survey have been analyzed to determine the percentage differences between fire loads calculated from the different methods. Traditionally, fire load values using the direct weighing method would have been considered as the bench mark. This is because it gives direct measurements of combustible weights with least uncertainty in fire load predictions. However, it is very difficult in practice to use directly weighing for every item within a compartment, especially with very large or fixed furniture items. As a result of this difficulty, the weighing method discussed in chapter 3 estimated the weights of heavy and fixed items based on knowledge of pre-weighed items. These approximations are likely to increase the degree of uncertainty associated with the traditional direct weighing method. As a result of this, the Combination method which combines best practices from both the inventory and the weighing method were considered as the bench mark. This is because the combination method reduces the amount of approximations associated with the singular use of either the weighing or inventory method.

There is currently no available general theory for fire load distribution [5]. Therefore, the fire load and fire load density obtained from the different survey methods have been plotted and discussed in different ways.

4.1 Statistical Analysis of Survey Results

Fire load density calculated from three different survey methods (Weighing, Inventory, and Combination) has been statistically analyzed. According to the literature [19], fire load density is often considered to be lognormally distributed. This means that, the logarithm of the fire load density is expected to be normally distributed. The probability density function of lognormal distribution is given by:

$$\boldsymbol{f(q)} = \frac{\mathbf{1}}{\boldsymbol{q\sigma\sqrt{2\pi}}}\boldsymbol{e}^{-\frac{1}{2}\left(\frac{\boldsymbol{lnq-\mu}}{\boldsymbol{\sigma}}\right)} \qquad \textit{Equation 2}$$

Where, $\mu =$ mean, $\sigma =$ standard deviation, for the domain $0 \leq q < +\infty, and\ \sigma > 0, \mu > 0$.

Other theoretical cumulative distributions were plotted and goodness of fit was used to estimate the plausibility of success using the Easy Fit© statistical distribution software.

4.1.1 Inventory Method

Lognormal and Type I largest extreme value distribution (Gumbel) distribution fitted quite well to the observed results, but the 'weibul distribution' showed the best fit using the Kolnogorov Smirnov test,

Figure 4-1.

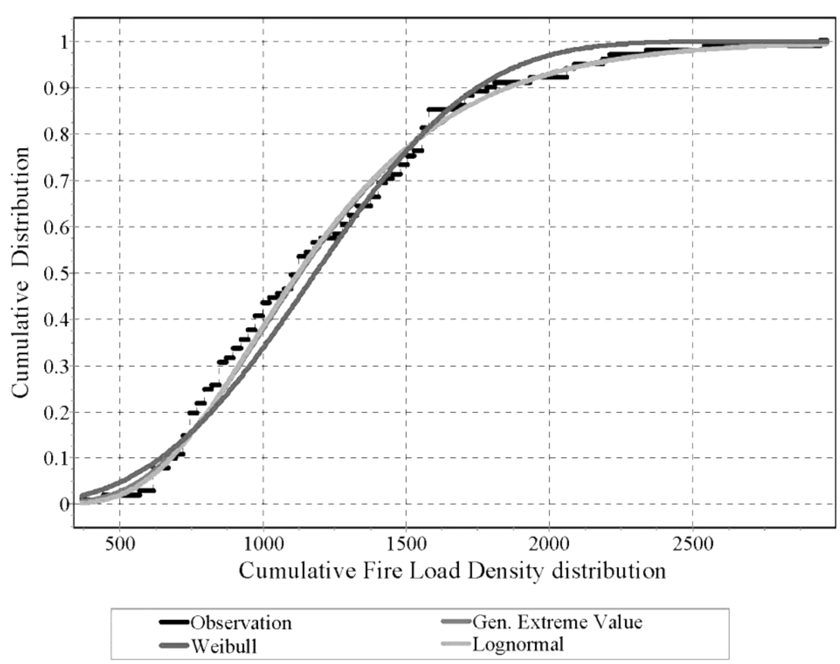

Figure 4-1 Cumulative Fire Load Density Showing Best Fit Curves (Inventory Method)

The probability density function of 'weibull distribution' is given by:

$$f(q) = \frac{q}{\beta}\left(\frac{q}{\beta}\right)^{\alpha-1} exp\left(-\left(\frac{q}{\beta}\right)^{\alpha}\right) \qquad \textit{Equation 3}$$

Where, the domain $0 \leq q < +\infty$

Table 4-1 presents the 80th, 90th, 95th percentile (centile), mean, and standard deviation of the fire load density from the inventory method. The inventory method predicted higher fire load densities as compared to values from the weighing or the combination method. The method may also have higher uncertainties in room with high combustible contents.

Table 4-1 Fire Load Density (Inventory Method)

Description	**Fire Load Density (MJ/m^2)**
80th centile	1,572
90th centile	1,806
95th centile	2090
Mean	852
Standard Deviation	484

The 80th, 90th, and 95th centile was calculated using the Microsoft Excel Software (2007 Edition). Excel uses the following equation to return the pth percentile of values in a range.

$$(n+1)p = i + f \qquad \textit{Equation 4}$$

Where, n = number of observed sample, p = percentile value divided by 100, i = integer part of $(n+1)p$.

4.1.2 Weighing Method

Unlike the inventory method fire load density, the Type I largest extreme value distribution (Gumbel) distribution presented the best fit, followed by Weibull distribution. Lognormal distribution also fitted quite well to the observed results. Figure **4-2** shows a comparison of three best fit cumulative distribution function curves.

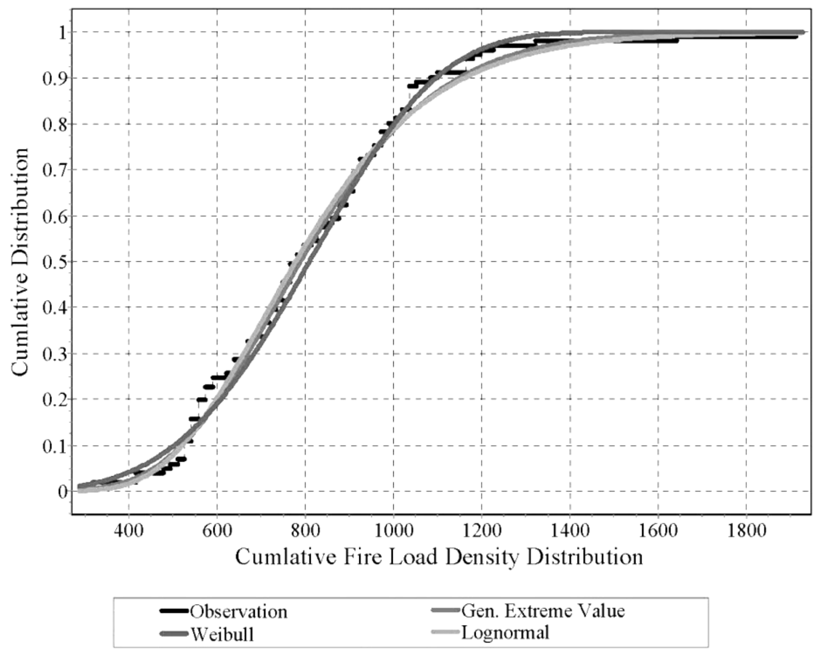

Figure 4-2 Cumulative Fire Load Density Showing Best Fit Curves (Weighing Method)

The probability density function of Type I largest extreme value distribution (Gumbel) is given by

$$f(q) = \frac{1}{\beta} e^{-\frac{q-\mu}{\beta}} e^{-e-\frac{q-\mu}{\beta}} \qquad \textit{Equation 5}$$

Where, the domain $0 < q < +\infty$

The weighing method predicted 80th, 90th, 95th centile, and mean fire load densities which were significantly lower than the inventory method, Table 4-2. However, the weighing method had a high standard deviation which indicates that the fire load densities are spread out over a large range of values.

Table 4-2 Fire Load Density (Weighing Method)

Description	Fire Load Density (MJ/m^2)
80^{th} centile	870
90^{th} centile	995
95^{th} centile	1066
Mean	530
Standard Deviation	484

4.1.3 Combination Method (Inventory and Weighing)

Similar to the weighing method, the Type I largest extreme value distribution (Gumbel) distribution presented the best fit, followed by weibull distribution and the lognormal, Figure 4-3. The calculation of the probability density function has been presented in previous sections.

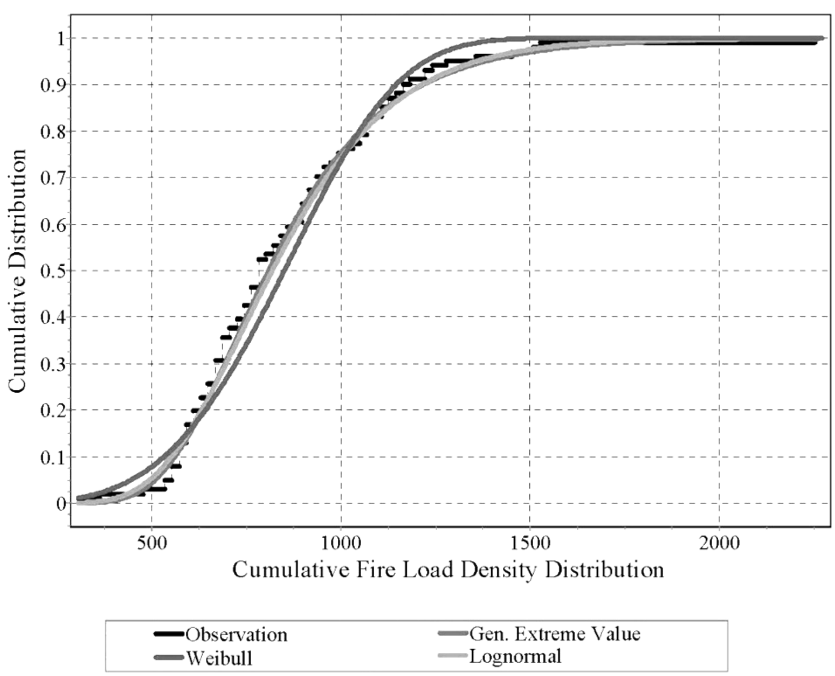

Figure 4-3 Cumulative Fire Load Density Showing Best Fit Curves (Combination Method)

Table 4-3 presents the 80th, 90th, 95th centile, and mean of the fire load density from the combination method. These values were higher than the predictions of the weighing method and lower than the inventory method. However, the standard deviation was lower than the weighing method and the inventory method. This indicates that the fire load density of the combination method tend to be close to the mean as compared to the other methods.

Table 4-3 Fire Load Density (Combination Method)

Description	**Fire Load Density (MJ/m^2)**
80th centile	1077
90th centile	1182
95th centile	1282
Mean	557
Standard Deviation	286

4.1.4 Questionnaire Method

As a result of the small sample size, data from the questionnaire method has been analysed differently. Fire load density of the five different offices has been presented and compared to values from other methods in Table 4-4.

Table 4-4: Fire Load Density (MJ/m^2), Questionnaire Method Versus Other Methods

Office	**Questionnaire Method Fire Load (MJ/m^2)**	**Combination Method Fire Load (MJ/m^2)**	**Weighing Method Fire Load (MJ/m^2)**	**Inventory Method Fire Load (MJ/m^2)**
1	851	792	838	861

2	867	867	648	748
3	746	813	901	1305
4	953	1025	926	1725
5	1330	683	758	1133

The questionnaire method predicted values quite close to the combination method. Table 4-5 provides the comparison between the fire loads computed from the questionnaire method to values computed using the combination of weighing and Inventory method. The percentage difference varied from -8% to 50%, with an average of 20% and 95th centile value of 48.6%.

Table 4-5 Comparison of Fire Load Density Results Between the Questionnaire Method and the Combination of Weighing and Inventory Method.

Office	Fire Load (MJ/m^2) Questionnaire Method	Fire Load (MJ/m^2) Combination Method	Difference (MJ/m^2)	Percentage Difference (%)
1	851	792	59	6.9
2	867	867	0	0
3	746	813	-63	-8.4
4	953	1025	-72	-7.5
5	1330	683	647	48.6

Note: Values presented for the questionnaire method represent 5 sample offices, hence, must be use with caution

Table 4-6 provides comparison between the floor areas of the questionnaire method and the combination method. Floor areas of the questionnaire method were calculated from dimensions of room estimated by the occupants.

Table 4-6 Comparison of Floor Area (Estimated and measured)

Office Number	Floor Area (m^2) Questionnaire Method	Floor Area (m^2) Combination (I. & W.) Method	Difference (m^2)	Difference (%)
1	14	10.9	3.1	28
2	14	12.3	1.7	14
3	13.9	10.9	3	28
4	11.1	12	- 0.9	- 0.1
5	7.4	11	- 3.6	- 33

Note: Values presented for the questionnaire method represent 5 sample offices, hence, must be used with caution. I & W refers to Inventory and Weighing method

The estimated floor area differed from the measured floor area in the range of -33% to 28%, with a mean of 15%. It was observed that all the surveyed offices had simple geometric shapes (rectangular). The range of variability in the percentage difference may be wider in occupancies with complex geometric floor plans. As a result of this, fire load densities calculated using the questionnaire method may become misleading. Uncertainties may be reduced by verification based on: i) architectural drawings or ii) previous surveyed data of similar occupancies.

4.2 Comparison of Fire Load Data among Various Methodologies

Fire load densities of all the 103 offices surveyed have been compared in Table 4-7. The inventory method predicted higher fire load densities in most cases, followed by the combination method, while the weighing method predicted the lowest fire load density. This trend has been shown in Figure 4-4.

Table 4-7 Comparison of Fire Load Density

	Sample size	**Inventory Method (MJ/m^2)**	**Weighing Method (MJ/m^2)**	**Combination Method (MJ/m^2)**
Mean	103	852	530	557
80th centile	103	1572	871	1077
90th centile	103	1805	996	1182
95th centile	103	2090	1188	1282
Standard Deviation	103	484	257	286

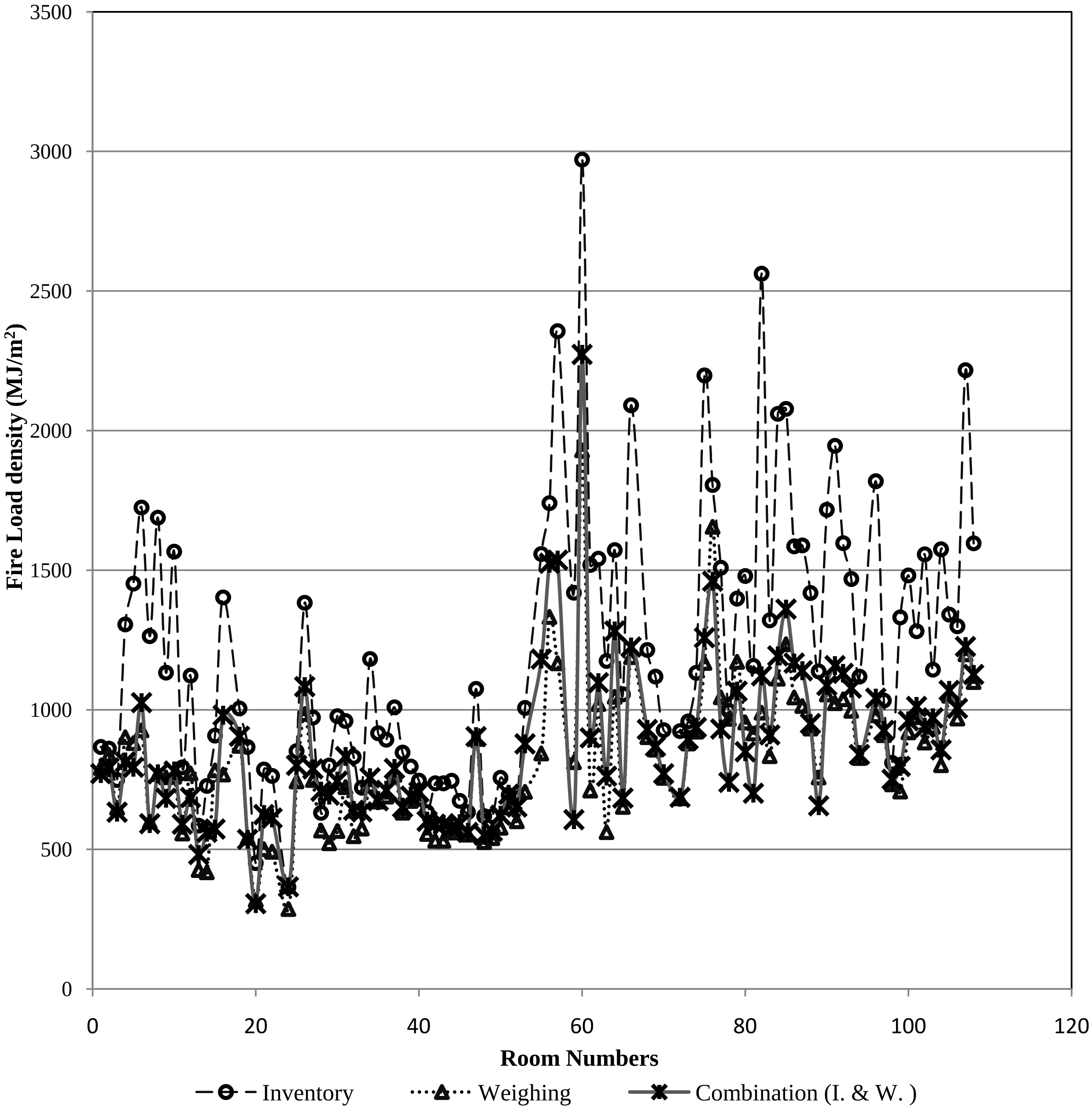

Figure 4-4 Comparison of Fire Load Density Among Different Methods

4.2.1 Comparison of Fire Load Density Based on Inventory, Weighing and Combination Method

Data reduction was carried out to further analyze the fire load density distribution. This was done to understand the fire load distribution in specific room types. This section compares fire load densities based on room type: enclosed offices and cubicle offices.

4.2.2 Mean, 95th Percentile, and Standard Deviation

Table 4-8 shows comparison of Mean and 95th centile values for both inventory and weighing method. The inventory method predicted higher mean and 95th centile values. Weighing method predicted the lowest values, whereas the combination method predicted values in-between the inventory and weighing method.

Table 4-8 Comparison of Mean, 95th centile and Standard Deviation Fire Load Densities (MJ/m^2) of Three Fire Load Survey Methods

Room	**Sample size**	**Mean (MJ/m^2)**			**95th centile (MJ/m^2)**			**Standard Deviation(MJ/m^2)**		
		Inventory Method	Weighing Method	Combination Method	Inventory Method	Weighing Method	Combination Method	Inventory Method	Weighing Method	Combination Method
Enclosed Offices (95th centile Floor Area=25m^2)	27	905	758	685	1664	922	1016	368	193	189
Cubicle offices (95th centile Floor Area=11m^2)	76	1165	850	873	2202	1207	1385	505	261	290
Percentage Difference	-	22	11	22	24	23	26	-	-	-

Cubicle offices had higher fire loads densities (MJ/m^2) as compared to enclosed offices. The percentage difference had an average of 25%. The differences in fire load densities between cubicle offices and enclosed offices may be attributed to 1) the total combustible content (MJ) and 2) total floor area. It is worth noting that the total combustible content

(MJ) of closed offices was higher than cubicle offices (Table 4-9). The total combustible content did not contribute significantly to the higher fire load density values in cubicle offices. On the other hand, enclosed offices had larger floor areas as compared to cubicle offices. The 95th centile floor area of enclosed offices and cubicle offices was 25m^2 and 11m^2 respectively. Larger floor areas (enclosed offices) resulted in lower fire load densities whereas lower floor areas (cubicle offices) resulted in higher fire load densities. Similar observations have been reported in previous literature [14].

Table 4-9 Comparison of Mean, 95th centile and Standard Deviation Fire Load Densities (MJ) of Three Fire Load Survey Methods

Room	Sample size	Mean (MJ)			95th centile (MJ)			Standard Deviation(MJ)		
		Inventory Method	Weighing Method	Combination Method	Inventory Method	Weighing Method	Combination Method	Inventory Method	Weighing Method	Combination Method
Enclosed Offices	27	14972	9800	10044	20665	13355	15666	4395	2496	2912
Cubicle Offices	76	7939	5577	5692	12519	8096	8822	2656	1430	1522

4.2.3 Percentage Difference between Inventory and Weighing Method

The difference between the 95th centile of fire load density of the weighing and inventory method was found to be about 45%. The differences between fire load density of the inventory method and the weighing method may be attributed to the use of material densities to convert measured volume to masses when using the inventory method and approximations associated with the use of each method, Table 4-10. The type of office (cubicle or enclosed office) had no significant impact on the percentage difference between the methods.

Table 4-10 Comparison of 95th centile Fire Load Density of Inventory and Weighing Method

Room	Sample size	Inventory Method	Weighing Method		
		95th centile (MJ/m^2)	95th centile (MJ/m^2)	Difference (MJ/m^2)	Difference (%)
Enclosed Offices`	27	1664	922	742	44
Cubicle Offices	76	2202	1207	995	45

Note: Percentage Difference = ((IM - WM)/IM) X 100.

Culver [2] also reported difference between mean room loads from the use of inventory (use of transfer functions based on pre-weighed items) and weighing method. The difference between the values of the two methods varied from about 0.1% - 30% with an average of 10%.

It must be noted that Culver compared mean values of total room loads (i.e. combustible and non-combustible) from 14 sample offices. The inventory method developed by culver was also different from the method used in this study. The current study calculated weights based on density and physical characteristics (volume) of items whereas Culver calculated weights based on transfer functions and mean values of pre-weighed items.

4.2.4 Percentage Difference between Inventory and Combination Method

The difference between the fire load density of the combination method and inventory method was found to be about 38%, Table 4-11.

Table 4-11: Comparison of 95th centile Fire Load Density of the Combination Method and the Inventory Method

Room	Sample size	Inventory Method	Combination Method		
		95th centile (MJ/m^2)	95th centile (MJ/m^2)	Difference (MJ/m^2)	Difference (%)
Enclosed Offices	27	1664	1017	648	38
Cubicle Offices	76	2202	1385	817	37

Note: Percentage Difference = ((IM - CM)/IM) X 100.

Uncertainties in fire load density values of the inventory method may be attributed to: i) accounting for irregular shaped objects and ii) the use of combustible densities to convert measured volume into weights. High level of uncertainty may arise in occupancies where majority of the combustible content have irregular geometric configuration. In this study, irregular shaped items formed less than 5% of the total combustible content. Hence, uncertainties with the inventory method may not be attributed to this. It must be noted that, despite the small contribution of irregular shaped items, the combination method was effective by the use of weighing method for such items. On the other hand, densities of combustible materials were grouped into cellulosic (paper and wood), plastics, and textiles. This was due to the difficulty in being able to correctly identify specific material type to match its density. This is likely to increase fire load values using the inventory method. The combination method also uses the inventory method, however, it must be noted that the inventory was used for fixed and heavy furniture items. These items form less than 30% of the total combustibles. This therefore reduces the level of uncertainty associated with material densities in using the inventory method as compared to the combination method.

4.2.5 Percentage Difference between Combination and Weighing Method

Overall, the combination method predicted fire load densities very close to the weighing method. Despite this, the difference between the fire load density of the weighing and combination method was found to vary between 9% - 13%, with a mean percentage difference of 10%, Table 4-12.

Table 4-12 Comparison of 95th centile Fire Load Density of the Combination Method and the Weighing Method

Room	**Sample size**	**Weighing Method**	**Combination Method**		
		95th centile (MJ/m^2)	95th centile (MJ/m^2)	Difference (MJ/m^2)	Difference (%)
Enclosed Offices	14	922	1017	- 94	- 9.3
Cubicle Offices	26	1207	1385	- 178	- 12.9

Note: Percentage Difference = ((WM - CM)/WM) X 100

5. Summary and Recommendations

There are uncertainties associated with the use of each fire load survey method. The direct weighing method has uncertainties when estimating weights of heavy and fixed items. Estimations are often based on knowledge of pre-weighed items. Uncertainties in fire load density values of the inventory method may be attributed to accounting for irregular shaped objects, and the use of combustible densities to convert measured volume into weights. The questionnaire method may also have uncertainties in combustible content and floor areas estimated by occupants without direct supervision of an expert. As a result of these short falls in each method, the Combination method which combines best practices from both the inventory and the weighing method have been considered as the most appropriate fire load survey method. The combination method reduces uncertainties associated with the singular use of either the weighing or inventory method.

The pilot fire load survey was conducted in 103 office rooms in five different office buildings within the cities of Ottawa and Quebec between November 2010 and April 2011. The study explored the effects of varying key surveying methods on the survey results. Fire load and fire load densities were compared from different survey methods: inventory, weighing, combination, and questionnaire methods. Table 5-1 summarizes the percentage difference between the fire load densities calculated from the four survey methods.

Table 5-1 Summary of Differences (%) between 95th centile Fire Load Density

Room Type	Sample Size	Difference (%) of 95th centile Fire load Density		
		IM & WM	IM & CM	WM & CM
Enclosed Offices	14	44	38	- 9.3
Cubicle	76	45	37	- 12.9
Average (Total Rooms)	103	44.5	37.5	-11

IM – inventory method, WM – Weighing Method, CM – Combination Method, QM – Questionnaire Method.

As mention earlier, the combination method has been considered to provide better fire load density values as compared to the other methods. The combination method predicted fire load densities that are higher than weighing and lower than inventory methods. Based on the results discussed in Chapter 4, the following recommendations have been made.

The use of the combination method should consider direct weighing for items that can be easily weighed, and use of inventory method for fixed combustibles and heavy furniture items. Inventory method could be done either by calculation of mass based on measured volume or through the use of catalogue (physical characteristics of items and their corresponding weights).

The study used derating factors to reduce combustible items stored in enclosures (such as cabinets). During the survey, about 50% of metal cabinets in offices were opened. Based on this observation, the study recommends the consideration of combustibles stored within cabinets using derating factors listed in Appendix D.

Additionally, for better results, a surveyor must be careful with the appropriate density to be used when converting measured volume into weights. This study also presents the densities of different materials that could be used in future studies, Table 3- 3.

Similarly, calorific values must also be used with care. A list of different materials and their calorific value has been provided in Appendix A. For accuracy, the study classified combustibles into cellulosic (paper and wood), plastics and textiles.

Cubicle offices had fire load densities (MJ/m^2) greater than enclosed offices. However, combustible content (MJ) of cubicle offices was found to be less than that of enclosed offices. Fire load density decreased with increasing floor area. Larger floor areas (enclosed offices) resulted in lower fire load densities whereas lower floor areas (cubicle offices) resulted in higher fire load densities.

Lack of participation was the major challenge encountered in the hand delivered questionnaire method. Future surveys should consider the use of several modes of questionnaire administration such as the use of the internet, phone interviews and by post. The focus should be to minimize threat to security and privacy as much as possible.

Finally, the study results also showed that the floor area estimated by participants varied from -33% to 28% as compared to the floor area calculated from actual measured dimensions. The mean difference was about 15%. Therefore, the study suggests that one should be cautious when using the questionnaire method due to uncertainty caused by participants. To overcome this problem, it is recommended that an experienced surveyor should validate the questionnaire results before performing any analyses.

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Appendix A

Table A. 1 Calorific value of Wood/ Cellulosic Material

WOOD/CELLULOSICS	MJ/kg	REF
Beech	18.7	26
Birch	18.7	26
Celluloid	17-20	20
Cellulose	15-18	20
Cellulose triacetate	17.6	20, 27
Corrugated Box	16.0	23, 30
Cotton	15.6 - 20	27
Douglas Fir	16.4 - 19.6	27, 20, 37
Leaves, hardwood	19.3	26, 35
Lignite	24.8	27
Maple	17.8	27
Newsprint	18.4	26
Paper (average)	16.3	27
Paper, Cardboard	13-21	4
Particle Board (chipboard and hardboard)	17-18	20
Pine Wood	19.1	20
Red Oak	17.1 - 18.7	34
Spruce	20.4	26, 35
Straw	15-16	26
White pine	17.8	20
Wood	17-20	26
Wool	20.5-26	4, 27, 20

Table A. 2 Calorific Value of Different Products and Composites

PRODUCTS/COMPOSITES	MJ/kg	REF
3 Seater Couch (41.8 kg)	18.6	33
Chair T (NFR-PU Foam)	27	32
Clothes	17-21	4, 20
Candle	46.2	29
Kitchen Refuse	8 to 21	20
Leather	18.6 - 20	4
Linoleum	19-21	20
Cloth soaked with IPA	30.4	29
Rubber tire	31-33	20
Silk	17-21	20
Single Chair (21.4kg)	21.4	33
TV Cabinet G (FR-HIPS)	20	32
TV Cabinet H (NFR-HIPS)	23	32
Wardrobes	14.2-18.8	26

Table A. 3 Calorific Values of Different Plastics

PLASTIC	MJ/kg	TYPICAL PRODUCTS (36)	REF
Acrylonitrile-Butadiene-Styrene (ABS)	34-40	Appliances, business machines, containers and lids, fishing tackle boxes, luggage, pipe, power tool housing, sanitary ware, shoes, telephones, toys,	20
Acrilan Fiber	31.8		37, 36
Acrylic	25.9, 27-29	Carpet fibres, glazing, lighting panels, sanitary ware, wall panels,	28, 20
Epoxy	28.8, 33-34		20, 35
Isobutene	20.1		23, 30
Melamine resin	16-19		20
Nylon	23.2 - 33.1	Carpet fibres, clothing, upholstery, wire insulation	28, 30, 37, 36
Polycarbonate	28-30	Glazing, lighting panels, milk bottles, power tool housing,	30, 20
Polyethylene (PE)	43.3 - 51.1	Containers and lids, conduit, grocery bags, house wares, milk bottles, pails, pipe, toys, trash bags, tumblers, wastebaskets, wire insulation	28, 27 - 20, 34, 35
Polyethylene terephthalate (PET)	22.0		30, 23, 35
Phenolformaldehyde	27-30		20
Pure Hydrocarbon Plastics (PE, PP, PS)	40		34
Plastic (average)	22.1		4
Polymethylmethacrylate (PMMA)	25.0		23, 30, 35
Polyacrylonitrile	30.8		23, 30, 35
Polybutadiene	42.8		23, 30, 35
Polyester	23.2 - 32.5	Clothing, power tool housing, soft drink bottles,	28, 20, 37, 36
Polyisobutylene	43.7	Pipes	30, 23, 35
Polyisocyanurate foam	22-26		20
Polyoxymethylene	15.4		30, 23, 35
Polypropylene	42 - 51.1	carpet fibres, containers and lids, conduit, house wares, luggage, pails, upholstery	28, 30, 20, 36

Table A. 4 Calorific Values of Different Plastics continued

PLASTIC	MJ/kg	TYPICAL PRODUCTS	REF
Polystyrene	39.2 - 44.1	Appliances, ceiling tile, containers and lids, lighting panels, house wares,	28, 30, 20, 35
Polyurethane	22-37.2		28, 20
Polyurethane foam	23-28	Shoes, seat cushions	20
Polyvinylidene chloride	9.0		30, 23
Polyvinylidene fluoride	13.3		30, 23
Polytetrafluoroethylene (PTFE)	5 - 6.2	Non stick coating	20, 35
Polyvinylchloride (PVC)	16.4 - 22.1	Clothing, containers and lids, conduit, floor tile, garden hose, gutters, house siding, house wares, lighting panels, phonograph records, pipe, sanitary ware, shoes, shower curtain, toys, upholstery, wall covering, wastebaskets, weather stripping, windows, wire insulation	28, 30, 20, 37, 35
PVC w/ 25%Cl	31.6		35
PVC w/ 36% Cl	26.3		35
PVC w/ 48% Cl	20.6		35
Polychloroprene	25.3		35
Rayon	16.3 - 17		15, 17
Rubber	39.5		4
Rubber foam	34-40		20
Rubber isoprene	44-45		20
Tedlar (PVF)	13.3		35
Teflon (PFA)	5		35
Ureaformaldehyde	14-15		20
Ureaformaldehyde foam	12 to 15		20

Appendix B

Fire Load Survey Form

Building Name …………………………..Building Age: ……………………………….
Address: …………………………………Survey Date: …………………………………
No of Floors: ……………………………Surveyor: …………………………………....

1.1 Occupancy type

Closed: ……….. Cubicle: ……… Assembly Area…………. Storage Area…………….

1.2 Office Dimension

Shape	*Dimension*		*Total Area*
	L1:	W1:	
	L2:	W2:	
	L3:	W3:	
	L4:	W4:	

1.3 Opening Dimension

window	*Width*	*Height*	*Sill Height*	*Area*
W1				
W2				
W3				

Door	*Width*	*Height*	*Area*
D1			
D2			
D3			

1.4 Fixed Fire Load

item	*Quantity*	*Length*	*Width*	*Thickness*	*Material*	*Mass*	*comment*
Walls							
Ceiling							
Floors							
Doors							
Door (frames)							
Windows							
Window(frames)							
Book Shelves							
cabinet							
Others							

1.5 Movable Fire Load

Item	*Quantity*	*Length*	*Width*	*Thickness*	*Material*	*Mass*	*comment*

1.6 Other items

Item	*Yes/No*	*Qty*	*Type*	*material*	*Mass*	*Comments*
Computer (Display & CPU)						
Printer						
Refrigerators						
Coffee Makers						

Appendix C

Fire Load Survey Questionnaire

How to complete the Questionnaire

The questionnaire is divided into six sections. Please read carefully and follow each step as required. If you need further assistance in filling the Questionnaire, you can contact James on jeduful@connect.carleton.ca (Phone: (613)252-6781)

Section 1

Provide the basic information that pertain to your office

Section 2

Select the type of your office

Section 3

Provide a schematic sketch of the shape of the office. Give the dimensions of your office space. (Can be estimated)

Section 4

Part A: Fill this part only if you have a window in your office. If applicable fill in the window dimensions (Can be estimated)

Parts B: Fill in the number of doors to your office. If it is a standard door size (3' X 6'-8''), simply indicate in the space provided without written the estimated dimensions.

Section 5

Indicate the floor, wall, and ceiling finish (e.g. floor – wood, woollen carpet, linoleum, Wall - Gypsum plaster, wood paneling, plastics etc; Ceiling – wood, gypsum plaster, plastic)

Section 6

Part A: from the furniture catalogue attached, indicate the type and number of item unit in your office. If similar but different, indicate and write comment on how it varies.

Part B: From the furniture catalogue attached, indicate the type of desk in your office. Write comments where applicable. If it is made up of a material that does not burn (non-combustible) indicate in your comment.

Part C: Follow the same procedure as above. Indicate a percentage of fill for combustible items (e.g. papers, books, plastic etc.) stored in shelve, from '100% representing shelve filled to capacity with no loose gaps' to '0% representing an empty shelve'.

Part D: Follow the same procedure as indicated in Part C above

Part E: Indicate in the options and spaces provided all other combustibles that have not been covered above. Example include, paper bins, stacks of papers and files that are not stored on shelves or cabinets, combustible television stands and etc.

Fire Load Survey Questionnaire Form

Section 1

Building Name (XXX) Survey Date: …………………………………
Office Number ……………………………

Section 2

Occupancy type: Enclosed: ………….
Cubicle: …………...

Section 3

Office Dimension (Can be estimated)

In the spaces provided below provide a schematic sketch of the office outline (shape) and give estimated dimensions of the space or the floor area.

Shape	*Dimension*		*Comment*
	Length		
	Width		
	Height		

Section 4

Opening Dimension (Can be estimated)

A. Number of windows……………….(0 means No windows)

window	*Width*	*Height*	*Comments*
W1			
W2			

B. Number of Doors……..Standard door…………..…Material……………………

Door	*Width*	*Height*	*Comments*
D1			
D2			

Section 5

Fixed Fire Load

Floor Finish……………………………….. (e.g. – woollen carpet, wood, linoleum, plastic)
Wall Finish…………..……………………………..(e.g. – gypsum plaster, wood, plastic)
Ceiling Finish…………………………………...(e.g. – gypsum plaster, wood, plastic)
Comments (Additional description).…………………………………………………..................
……………………………………………………………………………………………
……………………………………………………………………………………………

Section 6

Movable Fire Load

A. Seats

In the spaces below select which seats falls within your category (Refer to attached Furniture Catalogue)

A. Main Chair………Number of Chair…….Comment……………………………….
B. Visitors Chair…...Number of Chair ……..Comments……………………………..
C. Sofa……………...Number of Sofa………Comments……………………………..

B. Desks

Select and indicate below from the attached catalogue the desk type in the office
Catalogue Desk No.………………Material………………… (e.g. wood, plastic etc)
Contents of drawers: Materials…………………………... (e.g. paper, folders, books etc)
Percentage of fill………… (e.g. 100%-completely full, 0%-empty)
Comment……………………………………………………………………………..

C. Book Shelve

Select and indicate below from the attached catalogue the book shelve type in the office
Catalogue Book Shelve No ………… Material………………………. (e.g. wood, plastic)
Content of Shelve: Materials (items) ………………………….……………………
…………………………………………………………… (e.g. paper, folders, books etc)
Percentage of Fill……………………….. e.g. 100%-completely full, 0%-empty)

D. File Cabinets

Select and indicate below from the attached catalogue the File cabinet type in the office (Select only if combustible, if not fill in details for content only
Catalogue Book Shelve No ……………… Material…………………. (e.g. wood, plastic)
Contents of Cabinets: Materials………………………………... (e.g. paper, folders, books etc)
Percentage of fill………… (e.g. 100%-completely full, 0%-empty)
Comment……………………………………………………………………………

E. Other Items

Item	Yes/No	Qty	Type	material	Comments
Computer (Display & CPU)					
Printer					
Refrigerators					
Coffee Makers					

Item	Yes/No	Qty	Type	material	Comments

General Comments…………………………………………………...

Appendix D

Derating Factors

Table A. 5 Derating Factors

Container	Material	Derating Factors
Desk, cabinet	Wood	1.0
	Metal	0.1
	Plastic	1.0
Shelve	Wood	1.0
	Metal	0.75
	Plastic	1.0
Misc-Item	Non-Combustible	0.75

Note: Derating factors were based on values used in Caro's [8] report