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Fire Severities for Structural Fire Engineering Design

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Preface

This report details research into the fire loads that are applicable to office type occupancies in New Zealand, as well as identifying a methodology for carrying out fire load surveys that can be applied to other occupancies.

Acknowledgements

The fire load surveys carried out as part of this research project are based on preliminary work carried out by Macdonald Barnett Partners Ltd. Their valuable discussions and guidance are gratefully acknowledged.

The help rendered by Mr. Joop de Ruiter of BRANZ in carrying out the surveys is also gratefully acknowledged.

Readership

This report is intended for fire protection engineers, researchers and code writers.

FIRE SEVERITIES FOR STRUCTURAL FIRE ENGINEERING DESIGN

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KEYWORDS

Building Fires, Fire Load, Building Contents, Fire Resistance, Fire Ratings, Structural Engineering.

ABSTRACT

Traditional fire safety design of buildings has been based on the concept of a "fire resistance rating" (FRR). The FRR of part of a building is the period of time for which it does not collapse or spread fire, and is determined in a standard fire resistance test. The required FRR of a construction is specified in building codes and depends on building height, amount of combustible fire load present and other factors. A standard fire test may not always be representative of an actual fire in a building. There are alternative methods of estimating what the real gas "time-temperature" exposure is more likely to be, based on the principles of energy and mass conservation. In the prediction of fire severity using these methods many designers in New Zealand rely greatly on fire load data from Europe and the United States. A survey of the fire loads in several New Zealand insurance offices has been carried out for comparison with data from overseas. Recommendations have been made in this report, based on the findings from this survey. A methodology for carrying out fire load surveys that can be applied to other types of occupancy has also been identified.

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Definitions

FHC	Fire Hazard Category: The number (graded 1 to 4 in order of increasing severity) used to classify purpose groups or activities having a similar hazard and where fully developed fires are likely to have similar impact on the structural stability of the building.
Firecell	Any space, including a group of contiguous spaces, on the same or different levels within a building, which is enclosed by any combination of fire separations, external walls, roofs and floors.
Fire Intensity	The rate of release of calorific energy in Watts, determined either theoretically or empirically, as applicable.
Fire Load	The sum of the net calorific values (at ambient moisture content, measured in MJ) of that fuel in a firecell which can reasonably be expected to burn, including furnishings, built-in and removable materials, and building elements.
FLED	Fire Load Energy Density: The total fire load divided by the firecell floor area. In this calculation, the floor area includes circulation and service spaces, but excludes exitways and protected shafts.
A_v	Total area available for ventilation
A_f	Total floor area
A_t	Total bounding surface area including window openings

1. INTRODUCTION

Fire is one of the major causes of loss of life and property in buildings. In New Zealand, traditional fire safety design of buildings has been based on the concept of a "fire resistance rating" (FRR). The FRR of part of a building is the length of time for which it does not collapse or permit spread of fire, and is determined in a standard fire resistance test eg AS 1530 Part 4 (SAA, 1990). The intensity and duration of fire in buildings varies greatly, depending on the amount and surface area of the combustible material present and the available ventilation. Thus, the standard fire test where the fuel and ventilation are controlled may not be representative of an actual fire in a building.

Fire engineering analytical design methods have been developed and applied overseas, particularly in Sweden and Japan. The various fire engineering design approaches and methodologies have been reviewed by Wade (1991). These methods are aimed at making more reliable estimates of the structural performance of building structures under fire conditions. The process requires knowledge about the following:

- how the fire develops (ie how hot and for how long?)
- how the structure responds (does it collapse?).

Knowledge about the fire enables the time-temperature conditions in a space to be estimated. This will depend on factors such as the size and geometry of the space, how much ventilation is available, the combustion properties of the burning materials and thermal properties of the room surfaces.

Methods for predicting the fire time-temperature conditions have been proposed by researchers in Japan (Kawagoe and Sekine, 1963; and Kawagoe, 1967) and Sweden (Odeen, 1963 and Pettersson, 1984). In predicting the fire performance, two critical parameters are the fire load and the ventilation characteristics of the firecell.

Fire load: (Refer definitions on page iv) Fire load density varies greatly with building occupancies. If other factors remain constant, larger fire loads lead to more severe fires in terms of duration. The peak temperatures reached by such fires are governed by the availability of air (ventilation) and the rate of combustion. Thus, an accurate prediction of the possible fire load in a firecell will assist the designer to better estimate the likely fire severity and thus provide adequate and cost-effective fire protection.

Ventilation: Heat is produced during the combustion of the firecell contents and other combustible construction. The buoyant hot gases rise and are replaced by cold air drawn in through openings. In most cases the hot gases escape through openings in the upper parts of the enclosure while the cooler replacement air is drawn in through low-level openings. The extent of airflow into the firecell will determine whether the fire is fuel controlled or ventilation controlled. Thus the ventilation available to a fire is dependent on aspects such as the height and width of openings, the height of openings above the floor and whether the vents are open or closed.

Both the fire load and ventilation openings can be expected to vary greatly between various regions of the world due to variations in the culture, climatic conditions and the nature of construction material. Thus the applicability of the work carried out overseas to New Zealand conditions needs to be examined. The purpose of this report is to:

1. Review the methods used in determining fire severity;

2. Develop a procedure/methodology for conducting a fire load survey and analysis of the results;
3. Collect fire load data for life insurance offices in New Zealand; and to review and compare the results with available overseas fire load data.

This report outlines the work carried out in surveying the fire loads and ventilation characteristics for insurance offices in Wellington. Based on the findings, practical design "time-temperature" curves have been developed.

2. BACKGROUND

2.1 Fire Severity

Fire in any firecell may be divided into three phases: the growth phase, the fully developed phase and the decay phase, as shown in Figure 1. During the growth phase, heat and gas concentrations in the firecell increase as more and more of the fire load becomes involved, until the fire reaches a fully developed stage. Generally, at this stage, if the temperature in the firecell is sufficiently high sudden ignition of the gases and materials in all parts of the firecell will occur (flashover) and the whole firecell will be fully engulfed in flames. Although it may be unlikely in very large firecells that the whole firecell is simultaneously engulfed in fire, post-flashover conditions can occur in parts of the firecell. Nevertheless, the greatest risk to the structure and structural elements depends on the total heat input, ie peak temperatures and duration of heating. Risk of structural failure can also be expected during the decay phase. The study of fire severity is therefore focused on post-flashover conditions, where structural failure may be imminent.

Figure 2 shows the various steps in fire engineering design as described by Pettersson et al (1976) and Pettersson (1984). The starting point in any design must be an assessment of the likely course of a fire that a firecell may be exposed to in its lifetime. Based on the fire severity, the time-temperature field for the structure may be predicted and its structural response determined. If adequate, the structure may be constructed as designed, otherwise changes to the various structural parameters will have to be made to prevent collapse (Wade, 1991).

Figure 1 : Typical Time-Temperature Curve for Natural Fires in Enclosed Firecells

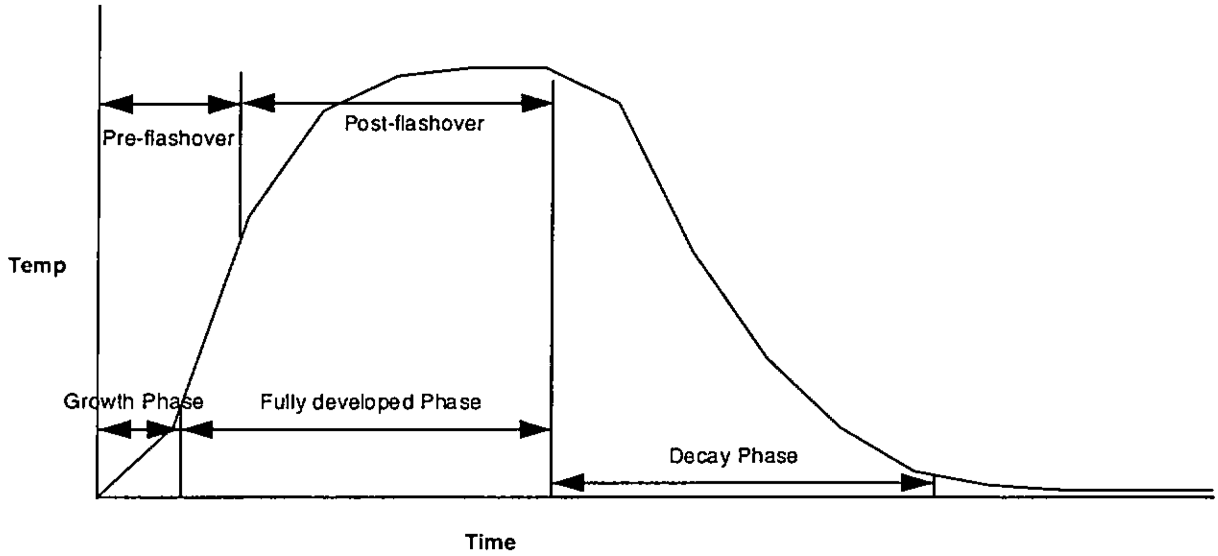
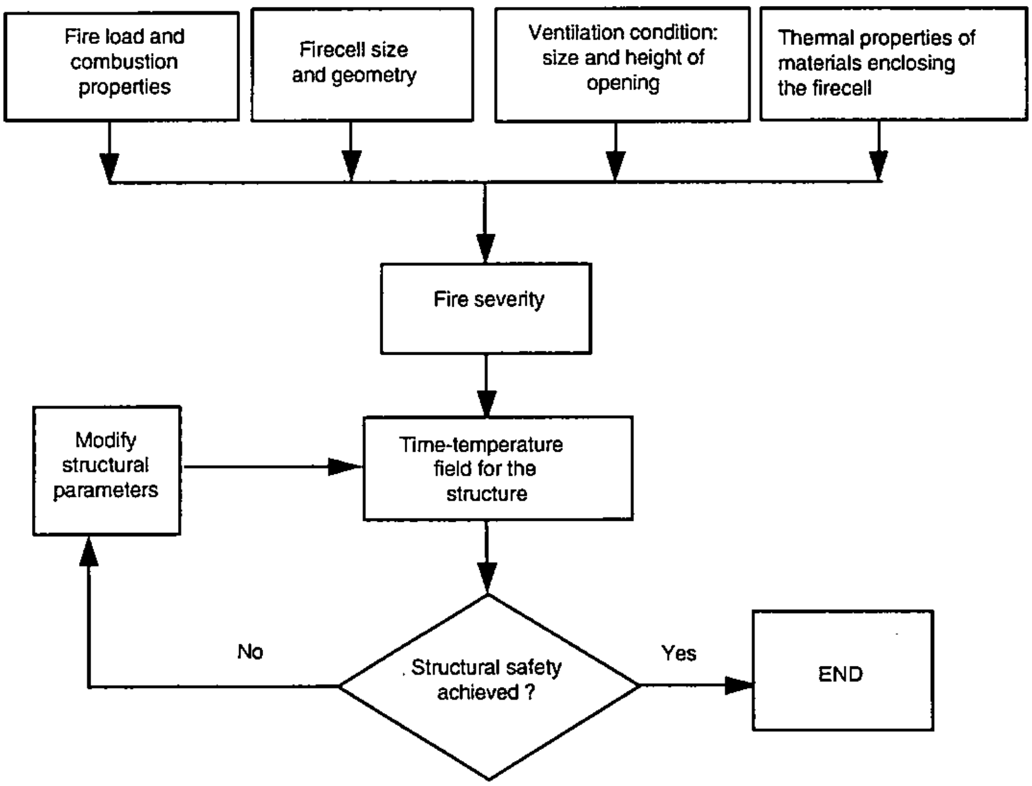


Figure 2 : Simplified Flow Chart Showing the Steps in Fire Engineering Design



2.2 Methods for the Prediction of Fire Severity in Firecells

Fire exposure is estimated by carrying out heat and mass balance calculations. Time-temperature curves for different fire loads have been developed from solving the heat balance equations for enclosed spaces (Kawagoe (1967), Pettersson et al (1976), Lie (1988)). Fires may be either fuel controlled or ventilation controlled depending on the quantity of fuel and air supply available. Kawagoe and Sekine (1963) identified the significance of the fire load density, ventilation to the firecell and the thermal properties of the structure in the heat balance of enclosed spaces. Lie's (1988, 1992) simplification of the expressions developed by Kawagoe and Sekine (1963), Odeen (1963) and Kawagoe (1967) has made them more useable. The prediction methods developed from these studies are based on small firecells.

Odeen's (1963) examination of the heat balance in a firecell for a fully developed fire led to the formulation of the following expression:

$$Q_F + Q_A - Q_G + Q_W + Q_E + Q_R = 0 \qquad \text{Equation 1}$$

where:

Q_F = heat produced by combustion
Q_A = heat content of the incoming air
Q_G = heat used in raising ambient gas temperature
Q_W = heat transfer to walls, floors and ceilings
Q_E = heat content of exhaust gases
Q_R = heat loss by radiation from the windows

2.2.1 Equivalent Time of Fire Exposure

This concept was presented as a way of relating a compartment fire exposure to the fire severity according to standard fires (ECCS, 1985). The equivalent time of fire exposure is defined as the duration of heating in a standard fire that would give the same critical effect on a structural element exposed to the severity of post-flashover compartment fires. Although this method was first formulated for use with protected structural steel elements, it is also applicable to other building materials. The simplified expression (BSI, 1992) is:

$$t_e = k_b \cdot w_f \cdot e_f \qquad \text{Equation 2}$$

where:

t_e = equivalent time of fire exposure
k_b = conversion factor as shown in Table 1 below
w_f = ventilation factor represented by Equation 2a below
e_f = design fire load density (MJ/m^2 of floor area) based on total fire loads (movable + fixed)

The conversion factor, k_b is related to the thermal properties of the enclosure (thermal inertia $\lambda\rho c$), where λ = thermal conductivity (W/mK), ρ = density (kg/m^3), c = specific heat (J/kg K).

Table 1 : Conversion Factor k_b

$\sqrt{(\lambda\rho c)}$ ($J/m^2 s^{1/2} K$)	k_b
$\sqrt{(\lambda\rho c)}$ >2500	0.04
720 < $\sqrt{(\lambda\rho c)}$ < 2500	0.055
$\sqrt{(\lambda\rho c)}$ <720	0.07

The ventilation factor w_f is given by:

$$w_f = \left[\frac{6.0}{H}\right]^{0.3} \left[0.62 + \frac{90\,(0.4 - \alpha_v)^4}{1 + b_v\alpha_h}\right] > 0.5 \qquad \text{Equation 2a}$$

where:

$$\alpha_v = \frac{A_v}{A_f} \qquad 0.05 \leq \alpha_v \leq 0.25$$

$$\alpha_h = \frac{A_h}{A_f} \qquad \alpha_h \leq 0.20$$

$$b_v = 12.5\,(1 + 10\alpha_v - \alpha_v^{\,2}) \geq 10.0$$

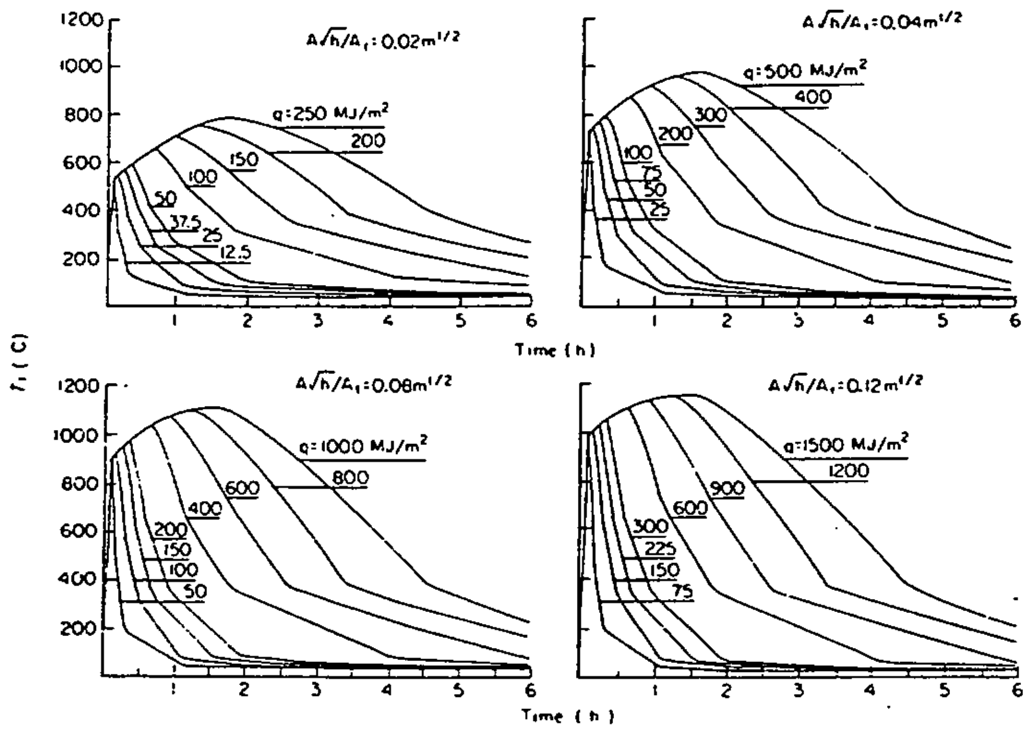
H = height of the compartment
A_v = total area available for ventilation (in walls)
A_h = total area available for ventilation (in roof)
A_f = total floor area

Design fire loads based on the total fire load available in the firecell are used in this approach.

2.2.2 The Swedish Time Temperature Curves

The fire severity predictions of Swedish (Pettersson, 1984) work are also based on solving the heat and mass balances for the firecell. The gas time-temperature curves shown in Figure 3 represent the fire severity in a fully developed compartment fire as a function of fire load density (based on the total mass of combustible material) and the ventilation available for combustion. These design curves are based on the assumption that the bounding material is similar to that of brick or concrete (Pettersson, 1984). They are applicable to typical firecell sizes that would be encountered in the design of dwellings, offices, schools, hospitals, hotels and libraries. It is expected that these design curves may not be suitable for use with large firecells and may provide an inadequate description of the real fire exposure.

Figure 3 : Swedish Temperature-Time Curves For a Fully Developed Compartment Fire



2.2.3 Lie's Time-Temperature Curves

To use Lie's expression the fire must be ventilation controlled. Experiments conducted by Harmathy (1972) indicated that fires in firecells with large fire loads (between 800 and 2000 MJ/m^2) were mainly ventilation controlled. Lie (1992) proposed that time-temperature curves developed on the basis that the fire will be ventilation controlled, have their merits in that ventilation controlled fires are more intense (Harmathy and Mehaffey, 1983). The curves developed on this assumption provide (in the absence of other established methods) a conservative estimate of temperatures for situations where the fire may actually be fuel controlled. Based on this approach, the heat produced by combustion may be directly related to the opening factor, K_o.

$$K_o = \frac{\Sigma(A_i\sqrt{H_i})}{A_T} \qquad \text{Equation 3}$$

where:

A_T	=	total bounding surface (wall, floors and ceiling including openings)
A_i	=	the area of the *i* th opening in the enclosure
H_i	=	the corresponding height of the *i* th opening

Kawagoe (1963), in determining the heat release for cellulosic-based products, showed that the rate of burning **R** for small firecells, estimated theoretically, could be confirmed using experimental methods.

$$R = 5.5 \times (A_i\sqrt{H_i}) \quad \text{kg / min} \qquad \text{Equation 4}$$

or

$$R = 330 \times (A_i \sqrt{H_i}) \quad kg/hr$$ Equation 5

hence τ, the duration of the fire can be expressed as:

$$\tau = \frac{EA_T}{R} = \frac{EA_T}{330 \times (A_i \sqrt{H_i})}$$ Equation 6

or

$$\tau = \frac{E}{330\ K_o}$$ Equation 7

where E = fire load per m^2 of bounding surface.

To simplify the use of Kawagoe's (1967) expression, Lie (1992) selected two sets of material properties as representative of the bounding material:

- one with thermal properties similar to those of high heat capacity and conductivity (or heavy material such as concrete and brick with densities of approximately 1600 kg/m^3);
- another representing materials with low heat capacity and conductivity (or light materials such as lightweight concrete and plasterboard with densities of less than 1600 kg/m^3).

Thus, for given thermal properties of the material bounding the enclosure the heat balance as in Equation 1 may be solved for the temperature as a function of the opening factor. This method was used to calculate the gas time-temperature curves for various values of opening factors (Lie, 1988) as follows:

$$T = 250 (10 \times K_o)^{0.1/K_o^{0.3}} e^{-K_o^2 t} [3 (1 - e^{-0.6t}) - (1 - e^{3t}) + 4(1 - e^{-12t}) + C \sqrt{600/K_o}$$ Equation 8

where

T = gas temperature (°C)

K_o = opening factor ($m^{1/2}$)

t = time from start of fire (hr)

C = 1 for light materials (density $<$ 1600 kg / m^3),
0 for heavy materials (density $\geq$ 1600 kg / m^3)

This expression is valid only for $t \leq [\frac{0.08}{K_o} + 1]$,

for $t > [\frac{0.08}{K_o} + 1]$ then $t = [\frac{0.08}{K_o} + 1]$.

This expression is again only valid for $0.01 \leq K_o \leq 0.15$,
if $K_o > 0.15$, then $K_o = 0.15$

The various methods of predicting decay of the fire (in terms of temperature drop with time) proposed by Kawagoe (1958), Magnusson and Thelandersson (1970), and Harmathy (1972) are in good agreement in showing that the decay rate is greatly influenced by the duration of the fully developed stage of the fire. Longer duration of the fully developed stage leads to slower decay rates. Although Lie's (1988) description of the decay process which takes this into account is a conservative approach, the heating effect is unchanged. The decay phase of Lie's (1988) time-temperature curve assumes that decay occurs at a constant rate until it reaches room temperature. The level of fire protection provided, which is based on fully developed conditions, is not affected as a result of this adaptation. The decay phase of Lie's (1988) time-temperature curve is given by:

$$T = -600\left(\frac{t}{\tau} - 1\right) + T_\tau \qquad \text{Equation 9}$$

where

T_τ = the gas temperature at which decay begins.

$T = 20°\,C$ if $T < 20°\,C$

Thus for $\tau \geq t$,

$$T = [250\,(10 \times F)^{0.1/F^{0.3}}\, e^{-K_{o2}\tau}[\,3\,(1 - e^{-0.6\tau}) - (1 - e^{3\tau}) + 4(1 - e^{-12\tau}) + C\sqrt{600/K_o}\;] - 600\left(\frac{t}{\tau} - 1\right) \qquad \text{Equation 10}$$

Time-temperature curves based on Lie's expression are shown in Figures 4 and 5. The advantage of Lie's method, is that it can be easily adapted for spreadsheet use by designers who may not have access to more sophisticated computer programs.

Figure 4 : Time-Temperature Curves for Ventilation Controlled Fires (for fire load of 800 MJ/m^2)

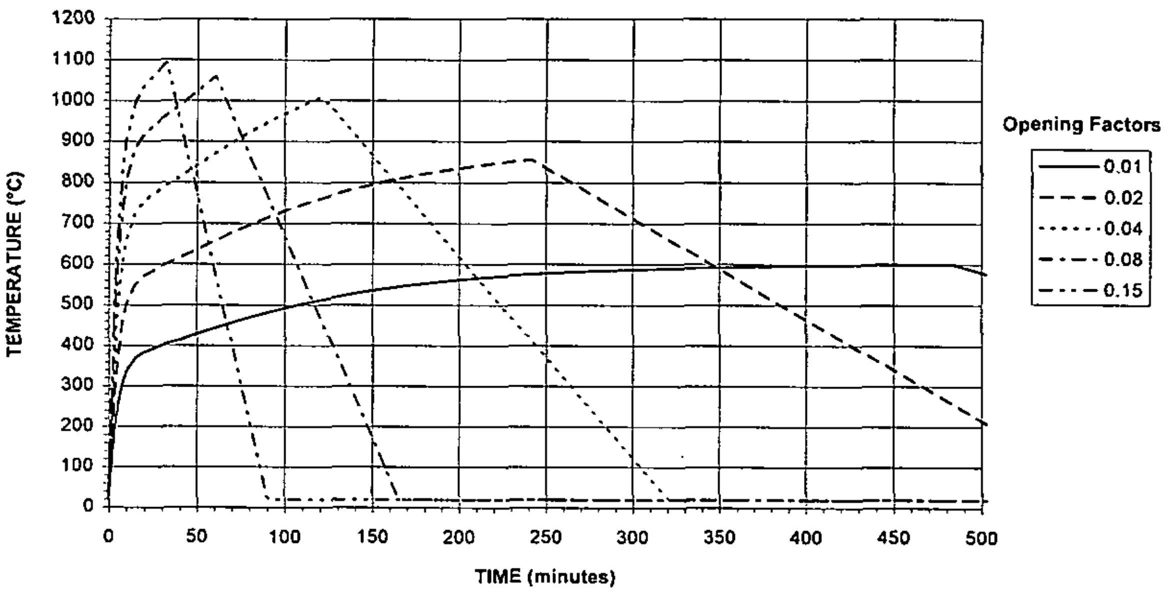
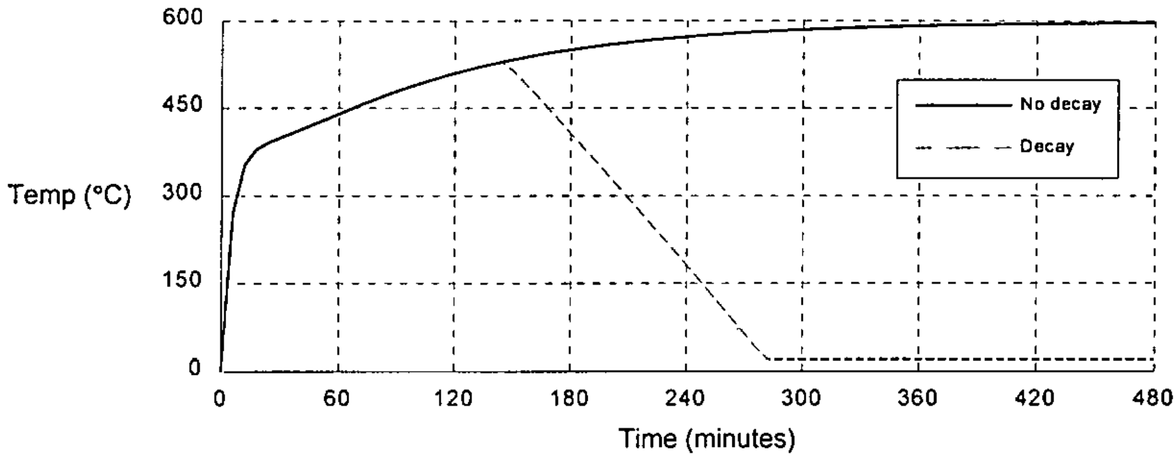


Figure 5 : Comparison Between Time-Temperature Curves With and Without Decay Phase



2.2.4 Limitations

Size of fire cell: The time-temperature relations used in the three approaches above, based on the solution of heat and mass balances, are applicable to fire compartments of a size representative of residential-type buildings, ordinary offices, schools, hospitals, hotels and libraries (Pettersson, 1984). These methods may not provide satisfactory descriptions of real fire exposure for firecells with very large volumes, such as industrial and sports complexes. All three approaches use unit fire loads based on the total (fixed and movable) fire loads. Data available internationally is generally based on average movable (variable) fire loads. The use of only movable load values in the above approaches could lead to serious underestimation of the design fire loads.

2.3 Fire Loads

Dead and live loads within a building may comprise combustible materials that constitute its fire load. In the absence of better data, designers in New Zealand in the past have relied greatly on European fire load information for use in the fire safety design of local buildings. It has not been established whether the fire loads in similar occupancies in Europe reflect accurately the fire loads that may be expected in New Zealand today.

2.3.1 European Fire Load Survey Methodology Applied to New Zealand

A small number of fire load surveys have been carried out in New Zealand by Barnett (1984) as a preliminary study. Barnett's (1984) fire load surveys were conducted for one sample from each of the following occupancies:

- Office
- Hospital
- Warehouse
- Hostel

The fire load surveys carried out in New Zealand as part of this project followed Barnett's (1984) survey procedures.

In estimating fire loads in buildings, the likelihood of the building components and contents participating in the fire must first be assessed. In this regard, the combustion properties of the fire load and their form and location play a critical role. Thus fire loads are categorised on the basis of whether they are fixed (permanent) or movable (variable). It is also important to establish whether the fire loads are in a protected or unprotected state.

2.3.2 Estimation of Fire Loads

The following assumptions are made for the estimation of fire loads:

- All combustible material in a firecell would be involved in the fire;
- Combustible materials are uniformly distributed throughout the building;
- Total combustion of all combustible material in the firecell will occur during the fire;
- Rate of burning of non-cellulosics will be the same as for cellulosics and can be directly evaluated on a wood-equivalent basis.

Based on these assumptions, the total fire load may be expressed in one of the three forms described below (Barnett, 1984):

- **Mass:** Fire load measured in terms of mass as represented by Equation 11 has limited use. The use of the mass value directly in calculation will distort results, as the fire load in most cases will be made up of materials with different calorific values.

$$G = [M_1 + M_2 + \ldots\ldots + M_n] \qquad \text{Equation 11}$$

where

G = Total fire load in kg

M_n = mass in kg of the individual combustible material in the firecell.

- **Potential Heat Energy:** This method assesses the fire loads as shown in Equation 12. It gives the closest approximation of the total fire load in a firecell. Fire load is estimated on the basis of the calorific values of the individual materials. The difficulty with using this method is that materials have to be assessed individually. The calorific values of the fire loads commonly found in buildings are given in Appendix A.

$$\begin{aligned} E = [&R_{c1} \times M_1 \times H_{n1} + R_{c2} \times M_2 \times H_{n2} + \ldots\ldots \\ &+ R_{cn} \times M_n \times H_{nn}] \end{aligned} \qquad \text{Equation 12}$$

where:

E = Total fire load in MJ

R_c = Combined combustion coefficient for the materials in the firecell (discussed later in this section)

H_n = net calorific value of each material at its ambient moisture content (MJ / kg).

- **Mass in Wood Equivalent:** Another commonly used method for expressing fire load is the estimation of fire loads in terms of wood equivalent. This method aims at calculating the fire load contribution of each item in terms of its stored heat energy and normalising the total fire load using the calorific value for wood.

$$B = \frac{[R_{c1} \times M_1 \times H_{n1} + R_{c2} \times M_2 \times H_{n2} + ... + R_{cn} \times M_n \times H_{nn}]}{H_w} \quad \text{Equation 13}$$

where:

B = Total fire load in kg

H_w = net calorific value of wood at its ambient moisture content (MJ / kg).

2.3.3 Fixed or Permanent Fire Loads

Fixed fire loads include all built-in combustible material (CIB W14, 1986) such as doors and frames, walls, partitions, linings, finishings and other permanently installed operation devices such as light fittings, airconditioning ducting, telephones and computers. These often form parts of the firecell that are moved very infrequently during their useful life. Conservative estimates of these loads are recommended to account for changes that may be made during future refurbishment work.

2.3.4 Movable or Variable Fire Loads

All fire load which may vary during the life of a building is classed as movable (variable) (CIB W14, 1986). It constitutes items found in buildings such as chairs, tables, filing cabinets, rugs, indoor plants etc. that support combustion. Where a number of variable fire loads with different combustion properties occur which are independent of each other, the improbability of all of them simultaneously attaining high values must be recognised. Allowance is made for incomplete combustion where fuel is protected (eg in a fire-safe cabinet) or is otherwise in a form where it is not expected be consumed 100% in a fire. In such cases a coefficient is applied based on the variability experienced; $c_q = 0.8$ is considered reasonable in the presence of several independent variable fire loads. For instance, in an office space with wooden tables, plastic plants, wooden shelves, paper files and foam-filled chairs, the variable fire load Q_V is given by:

$$Q_v = c_q \times [m_{vi} \times H_{vi} + m_{vj} \times H_{vj} + ...+ m_{vn} \times H_{vn}]$$

Equation 14

where:

E = Total variable load in MJ

m_v = mass of the variable fire load

H_v = calorific value of the combustible material representing the variable fire load.

2.3.5 Protected Fire Loads

All combustible material that is less likely to be involved in the fire due to protection provided (to delay their participation in the fire) is known as protected fire load. Consideration of the effects of protection requires an estimate of the likelihood of the failure of the protection. There is presently no established method of assessing the probabilities but the assessment of the probability of failure must include the following steps:

- estimation of the maximum temperature in the firecell
- assessment of the failure probability of the protecting body at this temperature

Surveys carried out (CIB W14, 1986) on protected fire loads have led to two proposals of a combustion coefficient for protection levels, c_{pi} , based on probability of failure of the protecting body as shown in Table 2. In both cases the relationship between the combustion behaviour and the degree of protection had not been established. Construction of non-combustible protection with failure probabilities of 0.001 or lower will be at huge cost and hence it is unlikely (from the fire load point of view) to be used extensively in a firecell.

Table 2 : Combination Coefficient for Protected Fire Loads Based on the Probability of Failure

Probability of Failure	c_{pi} (a)	c_{pi} (b)
0.100	0.65	0.40
0.010	0.56	0.12
0.001	0.50	0.03

2.3.6 Unprotected Fire load

All fire load that is not protected by non combustible material falls in this sub-category. A conservative estimate will be achieved if it is assumed that all fire loads in the firecell are unprotected (c_{pi} = 1).

3. FIELD SURVEY - RESULTS AND ANALYSIS

3.1 Sample Selection

The primary objective of carrying out fire load surveys in New Zealand was to enable a comparison to be made with fire load values used in Europe. Life office-type occupancies were selected for this study as it was expected that the occupancy load and work activities were relatively similar to those in Europe (CIB W14, 1986). Fire load surveys in 5 life offices in Wellington's central business district were conducted. The following procedures were adapted in the estimation of the fire loads:

1. The first five positive responses from insurance offices, selected at random from the yellow pages of the telephone directory, gave the buildings surveyed.
2. The firecells were selected on the basis of the maximum fire load observed during the preliminary walk through the building.
3. The floor and ventilation areas of the firecell were determined from architectural plans provided by the building owners.
4. Estimation of fire loads was carried out separately as movable and fixed loads (see data collation sheets in Appendix C).

3.1.1 General Observation

All five offices were located in buildings of reinforced concrete frame construction. Except for Sample A3, which had a concrete exterior wall on all sides, all the buildings surveyed had glazed curtain wall exteriors. The fire load distributions in all were generally similar. There was considerable uniformity in the furniture and fittings found on the floor of any one sample. Due to their rectangular layout all offices showed very similar floor area to total bounding surface area ratios. Tables 3 and 4 show the various aspects for the life offices selected.

Table 3 : Ventilation Characteristics of Firecells Surveyed

Items	Office Sample No.				
	A1	**A2**	**A3**	**A4**	**A5**
Floor Area in sq. metres, A_f	477.00	1115.57	1205.00	425.00	776.00
Vent Area in m^2, A_v	124.14	160.40	78.20	66.08	107.60
Total Bounding Surface Area in m^2, A_t	1163	2552	2743	1048	1891
Height of openings in metres, H	1.50	1.60	1.50	1.55	1.45
Opening Factor, K_o	0.13	0.08	0.03	0.08	0.07

Table 4 : Building Type and Aspect Ratio Information for Firecells Surveyed

Office Sample No:	Building Material	$\frac{A_v}{A_f}$	$\frac{A_v}{A_t}$	$\frac{A_f}{A_t}$	Category (Lie's, 1988)
A1	Concrete	0.26	0.106	0.409	Heavy
A2	Concrete	0.144	0.063	0.438	Heavy
A3	Concrete	0.065	0.028	0.438	Heavy
A4	Concrete	0.016	0.063	0.406	Heavy
A5	Concrete	0.14	0.057	0.409	Heavy

3.2 Data Collation

Data was collected under the two main categories: fixed and movable loads.

3.2.1 Fixed Loads

Electrical and Electronic Equipment: This category consisted of items such as telephones, computers, facsimile machines, photocopiers and printers. The weight and shape of one unit of each item was assessed and a per unit energy potential was assigned. This value was then used for every unit of the item encountered in the firecell.

Electrical Wiring: The total fire load contributed by electrical wiring in the firecell was assessed based on the number of electrical fittings, power points and other electrical connections. The straight line distance between the main switchboard and the approximate centre of the firecell was taken as the average length of wiring per connection.

Partitions, Walls and Fixtures: The fire load contributions of partitions were measured on the basis of the volume of combustible material per metre run. The fixtures on walls were assessed for the volume of combustible material.

3.2.2 Movable Loads

Furniture: In most cases there was great uniformity in the type of furniture found in the firecell. The initial unit was weighed and this value was then used for every unit of the item encountered in the firecell.

Contents: The contents of tables, desks, shelves, filing cabinets, cupboards, etc. were weighed initially using scales. Where similarity was encountered the weights were assigned proportionately.

The data collation sheets used in the survey are found in Appendix C. The calorific value used for each item is based on Table 10 (CIB W14, 1986) in Appendix B.

3.3 Statistical Analysis of Data

The summary of the potential heat energy (in MJ) values of the fire load (total and average) encountered in the sample offices is shown in Table 5. Figures 6, 7 and 8 represent the normal distribution (Box et al, 1978), based on the mean and standard deviation values for the sample range. Table 6 shows the resulting statistical values for the fixed, movable and total fire load results.

For (well-defined) occupancies with little variation in furniture and contents such as schools, offices, hotels etc. where the coefficient of variation (C.O.V) is between 30 and 50 %, the CIB W14 (1986) method for estimating the 80 and 90 percentile values for the fire load in the building based on the mean is given as:

- 80 percentile value for fire load = (1.25 to 1.50) × mean fire load
- 90 percentile value for fire load = (1.35 to 1.65) × mean fire load

Table 5 : Fire Loads in Life Offices in Wellington City (Survey Figures)

	Office Sample									
Items	**A1**		**A2**		**A3**		**A4**		**A5**	
Floor Area (m^2)	477		1116		1205		425		776	
Fire Loads:	Total (MJ)	Ave. (MJ/m^2)	Total (MJ)	Ave. (MJ/m^2)	Total (MJ)	Ave. (MJ/m^2)	Total (MJ)	Ave. (MJ/m^2)	Total (MJ)	Ave. (MJ/m^2)
Fixed Load	63318	133	115029	103	132778	110	47477	112	244587	315
Movable Load										
a. Contents	74529	156	190523	171	586337	487	212870	501	168574	217
b. Furniture	136379	268	169576	152	421615	350	75229	177	105806	137
Average Movable		442		323		837		678		354
Total Fire Load	274226	575	475128	426	1141677	947	335576	790	519636	670

Figure 6 : Normal Distribution for Fixed Fire Load in Life Offices

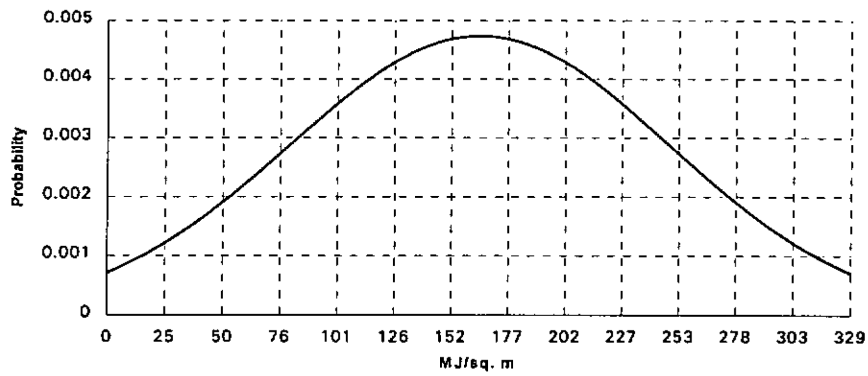


Figure 7 : Normal Distribution for Movable Fire Load in Life Offices

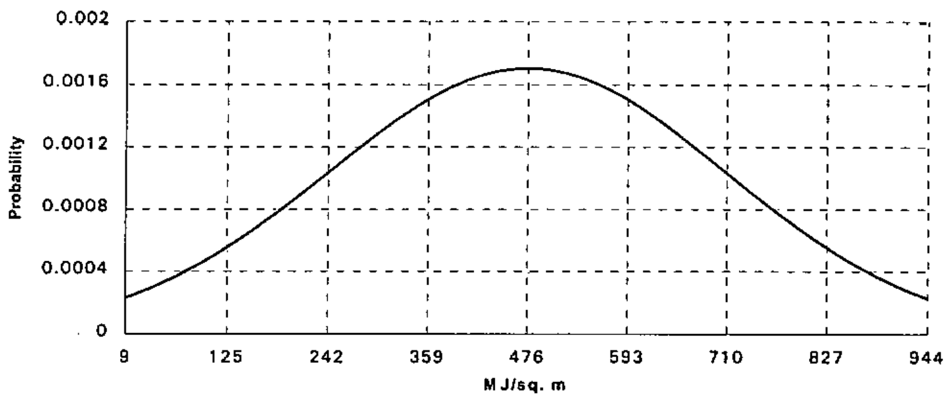


Figure 8 : Normal Distribution for Total Fire Load in Life Offices

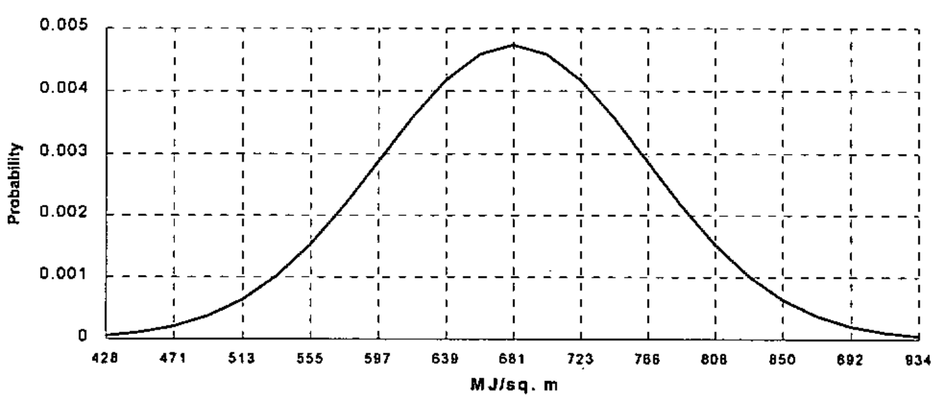


Table 6 : Results of the Normal Distribution of Fire Loads in New Zealand Life Offices

Item	Statistical Value					
	Fixed Load		Movable Load		Total	
	MJ/m^2	kg/m^2	MJ/m^2	kg/m^2	MJ/m^2	kg/m^2
Mean, $\overline{x}$	164.22	9.12	476.26	26.45	681.34	37.85
Standard deviation, s	84.26	4.70	233.83	12.99	226.52	12.58
90 percentile value (1.39 $\overline{x}$)					947.00	52.60
80 percentile value (1.28 $\overline{x}$)	210.20	11.67	609.61	33.86	871.61	48.44
Coefficient of variation ([$\overline{x}$ / s] × 100)	51%		49%		33%	

Table 7 : Comparison of New Zealand Life Office Data With Data for Offices From CIB W14 Study

Item	Statistical Values in MJ/m^2					
	New Zealand	Swedish	US	Swiss	Dutch	French
Mean, $\overline{x}$	476	411	555	750	410	330
Standard deviation, s	233	334	625	-	330	400
Coefficient of variation ([$\bar{x}$ / s] × 100)%	49	81	112	-	80	121

The values achieved for the various categories in the survey shown in Table 6 compare very well with the CIB W14 (1986) guidelines. The measured c.o.v. is 33% and the 80 and 90 percentile values are 1.28 and 1.39 times the mean total fire load respectively. Table 7 shows the comparison of the mean movable fire loads and c.o.v for office type occupancies in the various countries with the results obtained for New Zealand. Because the sample size for the New Zealand study is small, the small c.o.v. must be taken only as a representative figure. As a representative figure the small c.o.v. confirms the similar layouts of the offices and distribution of the fire loads. The observed difference in the average values may be partly attributed to the natural national differences. Difference in the assessment methods used would also contribute to the variations observed.

Table A1 of NZBC Approved Document C4/AS1 Fire Safety Annex (BIA, 1992) recommends that for a FLED range between 500 - 1000 the design value (or the 80 percentile value of FLED) be taken as 800 MJ/m² and is categorised under FHC (Fire Hazard Category) 2. The measured 80 percentile value for total fire loads shows 9% variation from the recommended design value (BIA, 1992). This is a good comparison but is only applicable to FLED values whose mean and standard deviation are as shown in Table 6. Average FLED values closer to the maximum value of the category (in this case closer to 1000 MJ/m² for FHC 2) may be expected to be much greater than the recommended design values in C4/AS1 Fire Safety Annex.

The general arrangement and distribution of fire loads in a firecell has a significant influence on the amount of fire load that will become involved in the combustion process. Thus, to take this aspect into account and to make a closer approximation of design values, the design FLED may be based on the following expression:

Design value for fire load = $F_d \times K_d \times$ mean fire load

F_d = Factor for the distribution characteristics of fire loads.

K_d = Factors applied to the mean fire load to obtain the 80 and 90 percentile values to be used in design

The value for F_d and K_d are given in Table 8 below.

Table 8 : F_d and K_d Values for Fire Loads (CIB W14, 1986)

Precision of Design Value	Fire Load Distribution Factors		K_d Values
	Uniform Distribution (F_d)	Non-Uniform Distribution (F_d)	
90 percentile	1.00	1.20	1.35 - 1.65
80 percentile	1.00	1.15	1.25 - 1.50

3.4 Engineering Analysis of Data

To illustrate the usefulness of the fire load data collected, the fire load values were input into Lie's time-temperature expression. The result for the various samples is shown in Figure 9. Comparisons of the maximum temperatures and the time at which they occurred from the plots with values from the Swedish plots are given in Table 9. The maximum temperatures show good comparison within 15%. Lie's shorter times for the maximum temperature implies a shorter growth phase.

The pinched time-temperature curves are observed for all samples except sample A3. Both Lie's (1988) and Pettersson et al's (1976) curves show quicker fire growth and shorter fire duration for fire in firecells with larger opening factors. This feature results from the assumption that all openings covered over with glazing are available for ventilation. Sample A3 has a concrete exterior wall with windows, unlike the other samples which have glazed curtain wall exteriors. This is illustrated in Figure 10 where the fire loads for sample A3 are plotted against various ventilation factors.

The 80 percentile values of the fire loads have been used to develop time-temperature curves as shown in Figure 10. The curves demonstrate that for very low opening factors the fire would be ventilation controlled and cooler. Thus, using low opening factors in the design of buildings will affect the duration of fire, and therefore the design of structural members in that building.

Figure 9 : Lie (1988) Time-Temperature Curves for Average Fire Load Values for Samples A1-A5

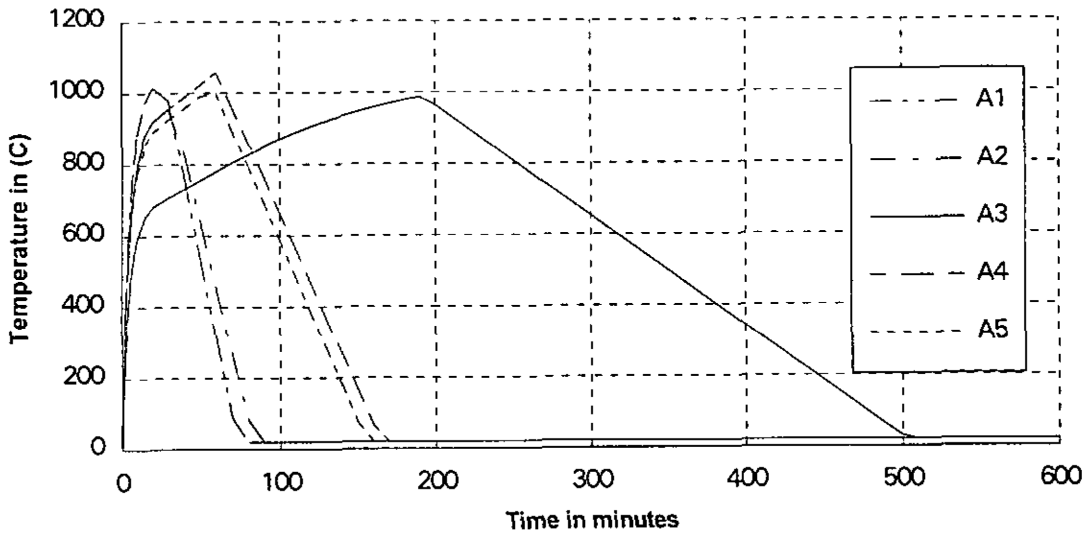


Figure 10 : Lie's Time-Temperature Curves for Sample A3 (Assuming Various Opening Factors)

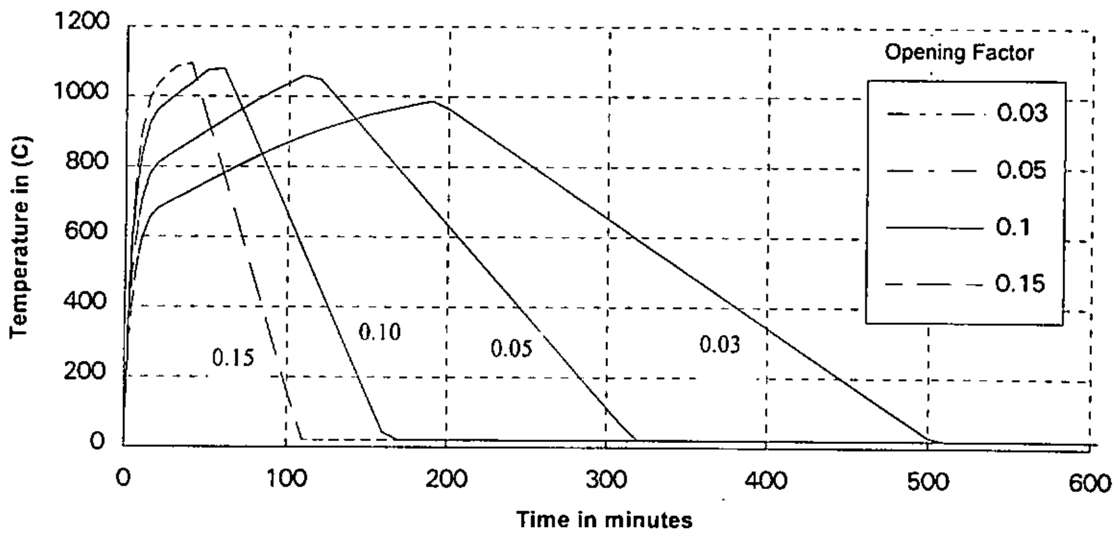


Table 9 : Comparison of the Time-Temperature Results from Lie's Plot with the Swedish Curves

Sample Nos.	Maximum temp in ^{o}C		Time of Occurrence in hrs	
	Lie (1988)	Pettersson (1984)	Lie (1988)	Pettersson (1984)
A1*	1020	1130	0.30	0.70
A2	920	1050	0.40	0.65
A3*	980	1030	2.01	2.40
A4	1060	1135	0.70	1.20
A5*	1005	1080	0.65	0.80

* The Swedish values (Pettersson) are obtained by interpolation of the time-temperature curves

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Sampling: The survey method has proven to be an effective means of determining the total fire load in buildings. In comparing the results with results available internationally, attention must be paid by the user to the influence of:

- × the natural national differences and assessment methods to the variation in fire loads, and
- × the smallness of the sample size for the survey carried out in New Zealand.

Time-temperature curves: An accurate prediction of the time-temperature curve is critical in the use of design for structural safety. The floor area to the total bounding surface area ratio for each of the offices surveyed represents a large firecell scenario. Thus the time-temperature predictions in this report, based on energy and mass conservation for small firecells, although only representative, are conservative figures. The stability and approximations of Lie's time-temperature curves using the fire loads from the survey have been compared with results from the Swedish plots. Good comparisons were observed.

Fire loads: The fire load estimates for life offices in New Zealand compare reasonably well with those from other countries. The significant difference is in the degree of variation between offices. The variation experienced in New Zealand is considerably less than that in other nations (due to the small sample).

Two aspects of concern were encountered during the course of this study with respect to the use of the European values for fire loads (CIB W14, 1986) in New Zealand:

- The values from Table A1.3.13 (CIB W14, 1986) are based on average variable loads only. The concern is that these values are being used in calculations where total fire loads are required i.e. the fixed fire load should be included as well.

- From the comparison of the average variable load for business offices from Table A1.3.13 with the average variable fire loads for life offices in New Zealand, it is believed that there could be an over-estimation of fire loads if the values from Table A1.3.13 are used for design of office buildings in New Zealand.

4.2 Recommendations

On the basis of the findings of this study a recommendation is made for additional fire load surveys to be conducted to achieve the following:

- × to update the generally obsolete overseas data;
- × for comparison of the results for other occupancies with the CIB W14 data (CIB W14, 1986) to establish if there is a trend in the variation in the fire loads encountered when compared with international results;
- × to establish the fire loads for occupancies specific to New Zealand, such as storage of agricultural commodities, which are not available internationally.

5. REFERENCES

Babrauskas, V. 1979. COMPF2 : A Program for Calculating Post-Flashover Fire Temperatures. Centre for Fire Research, National Engineering Laboratory. National Bureau of Standards. Washington D.C.

Barnett, C.R. 1984. Pilot Fire Load Survey carried out for the New Zealand Fire Protection Association. MacDonald Barnett Partners, Auckland.

Barnett, C.R., Buchanan, A.H. and Butcher, G.W. 1987. Seminar on the Draft Design Code. Department of Continuing Education. University of Canterbury.

Box, G.E.P., Hunter, W.G., and Hunter J.S. 1978. Statistics for Experimenters. An Introduction to Design, Data Analysis and Model Building. John Wiley and Sons. USA.

British Standards Institution (BSI). 1992. Eurocode 1 : Part 10 Actions on Structures Exposed to Fire : Part 10A General Principles and Nominal Thermal Actions. London.

Building Industry Authority (BIA). 1992. Approved Document C4/AS1 Fire Safety Annex. Published by Standards New Zealand, Wellington.

CIB W14. 1986. Design Guide - Structural Fire Safety. Report of CIB W14 Workshop. Fire Safety Journal Vol 10, No. 2. pp 77-137.

European Convention for Constructional Steelwork (ECCS). 1985. Design Manual on the European Recommendations for the Fire Safety of Steel Structures. No 35, First Edition. Brussels.

Harmathy, T.Z. 1972. A New Look at Compartment Fires. Part 1 and Part 2. Fire Technology.

Harmathy, T.Z. and Mehaffey, J.R. 1983. Post-flashover Compartment Fires. Review Paper. Fire and Materials, Vol 7, No. 2.

Kawagoe, K. 1967. Estimation of Fire Temperature-Time Curves in Rooms. Research Report No. 29. Building Research Institute, Ministry of Construction, Tokyo. Japan.

Kawagoe, K. and Sekine, T. 1963. Estimation of Fire Temperature-Time Curves in Rooms. B.R.I. Occasional Report No. 11. Building Research Institute, Ministry of Construction, Tokyo. Japan.

Lie, T.T. 1972. Fire and Buildings. Applied Science Publishers Limited. London.

Lie, T.T. 1988. Fire Temperature Relations. In the SFPE Handbook of Fire Protection Engineering. National Fire Protection Association. U.S.A.

Lie, T.T. 1992 (editor). Structural Fire Protection. ASCE Manuals and Reports on Engineering Practice No. 78. Prepared by the Committee of Fire Protection, Structural Division, American Society of Civil Engineers. New York. USA.

Odeen K. 1963. Theoretical Study of Fire Characteristics in Enclosed Spaces. Bulletin 10, Division of Building Construction, Royal Institute of Technology. Stockholm, Sweden.

Pettersson, O. 1984. Requirements of Fire Resistance Based on Actual Fires (Swedish Approach). Division of Building Fire Safety and Technology. Lund Institute of Technology. Lund. Sweden.

Pettersson, O., Magnusson S., Thor, J. 1976. Fire Engineering Design of Steel Structures. Division of Structural Mechanics and Concrete Construction. Lund University of Technology. Lund. Sweden.

Standards Australia (SA). 1990. AS 1530 Part 4: Fire Resistance Tests of Elements of Building Construction.

Wade, C.A. 1991. Fire Engineering Design of Reinforced and Prestressed Concrete Elements. Building Research Association of New Zealand. BRANZ Study Report No. 33. Judgeford, New Zealand.

APPENDIX A

Fixed Fire Loads from CIB W14 (1986)

Type of Occupancies	Fabrication (MJ/m2)	Storage
Academy	300	
Accumulator forwarding	800	
Accumulator mfg	400	800
Acetylene cylinder storage	700	
Acid plant	80	
Adhesive mfg	1000	3400
Administration	800	
Adsorbent plant for combustible vapours	>1700	
Aircraft hangar	200	
Airplane factory	200	
Aluminium mfg	40	
Aluminium processing	200	
Ammunition mfg	Spez	
Animal food preparing, mfg	2000	3300
Antique shop	700	
Apparatus forwarding	700	
Apparatus mfg	400	
Apparatus repair	600	
Apparatus testing	200	
Arms mfg	*300*	
Arms sales	300	
Artificial flower mfg	300	200
Artificial leather mfg	1000	1700
Artificial leather processing	300	
Artificial silk mfg	300	1100
Artificial silk processing	210	
Artificial stone mfg	40	
Asylum	400	
Authority office	800	
Awning mfg	300	1000
Bag mfg (jute, paper, plastic)	500	
Bakery	200	
Bakery, sales	300	
Ball bearing mfg	*200*	
Bandage mfg	400	
Bank, counters	300	
Bank, offices	800	
Barrel mfg, wood	1000	800
Basement, dwellings	900	
Basketwear mfg	300	200
Bed sheeting production	500	1000
Bedding plant	600	
Bedding shop	500	
Beer mfg (brewery)	80	
Beverage mfg, non alcoholic	80	
Bicycle assembly	200	400
Biscuit factories	200	
Biscuit mfg	200	
Bitumen preparation	800	3400
Blind mfg, venetian	800	300
Blueprinting firm	400	
Boarding school	300	
Boat mfg	600	
Boiler house	200	
Bookbinding	1000	
Bookstore	1000	
Box mfg	1000	600
Brick plant, burning	40	
Brick plant, clay preparation	40	

Type of Occupancies	Fabrication (MJ/m2)	Storage
Brick plant, drying kiln with wooden grates	1000	
Brick plant, drying room with metal grates	40	
Brick plant, drying room with wooden grates	400	
Brick plant, pressing	200	
Briquette factories	1600	
Broom mfg	700	400
Brush mfg	700	800
Butter mfg	700	4000
Cabinet making (without woodyard)	600	
Cable mfg	300	600
Cafe		400
Camera mfg	300	
Candle mfg	1300	22400
Candy mfg	400	1500
Candy packing	800	
Candy shop	400	
Cane products mfg	400	200
Canteen	300	
Car accessory sales	300	
Car assembly plant	300	
Car body repairing	150	
Car paint shop	500	
Car seat cover shop	*700*	
Cardboard box mfg	800	2500
Cardboard mfg	300	4200
Cardboard products mfg	800	2500
Carpenter shed	700	
Carpet dyeing	500	
Carpet mfg	600	1700
Carpet store	800	
Cartwright's shop	500	
Cast iron foundry	400	800
Celluloid mfg	800	3400
Cement mfg	1000	
Cement plant	40	
Cement products mfg	80	
Cheese factory	120	
Cheese mfg (in boxes)	170	
Cheese store	100	
Chemical plants (rough average)	300	1000
Chemist's shop	1000	
Children's home	400	
China mfg	200	
Chipboard finishing	800	
Chipboard pressing	100	
Chocolate factory, intermediate storage	*6000*	
Chocolate factory, packing	500	
Chocolate factory, tumbling treatment	1000	
Chocolate factory, all other specialities	500	
Church	*200*	
Cider mfg (without crate storage)	200	
Cigarette plant	300	
Cinema	300	
Clay, preparing	50	
Cloakroom, metal wardrobe	80	
Cloakroom, wooden wardrobe	400	
Cloth mfg	400	
Clothing plant	500	
Clothing store	600	
Coal bunker	2500	

Type of Occupancies	Fabrication (MJ/m2)	Storage
Coal cellar		10500
Cocoa processing	800	
Coffee-extract mfg	300	
Coffee roasting	400	
Cold storage	2000	
Composing room	400	
Concrete products mfg	100	
Condiment mfg	50	
Congress hall	600	
Contractors		500
Cooking-stove mfg	600	
Coopering	600	
Cordage plant	300	600
Cordage store	500	
Cork products mfg	500	800
Cosmetics mfg	300	500
Cotton mills	1200	
Cotton wool mfg	300	
Cover mfg	500	
Cutlery mfg (household)	200	
Cutting-up shop, leather, artificial leather	300	
Cutting-up shop, textiles	500	
Cutting-up shop, wood	700	
Dairy	200	
Data processing	400	
Decoration studio	1200	2000
Dental surgeons laboratory	300	
Dentist's office	200	
Department store	400	
Distilling plant, combustible materials	200	
Distilling plant, incombustible materials	50	
Doctor's office	200	
Door mfg, wood	800	1800
Dressing, textiles	200	
Dressing, paper	700	
Dressmaking shop	300	
Dry-cell battery	400	600
Dry cleaning	300	
Dyeing plant	500	
Edible fat forwarding	900	
Edible fat mfg	1000	18900
Electric appliance mfg	400	
Electric appliance repair	500	
Electric motor mfg	300	
Electrical repair shop	600	
Electrical supply storage H < 3 m	1200	
Electro Industry	600	
Electronic device mfg	400	
Electronic device repair	500	
Embroidery	300	
Etching plant glass/metal	200	
Exhibition hall, cars including decoration	200	
Exhibition hall, furniture including decoration	500	
Exhibition hall, machines including decoration	80	
Exhibition of paintings including decoration	200	
Explosive Industry	4000	

Type of Occupancies	Fabrication (MJ/m2)	Storage
Fertiliser mfg	200	200
Filling plant/barrels		
liquid filled and/or barrels incombustible	<200	
liquid filled and/or barrels combustible:		
Risk Class I	>3400	
Risk Class II	>3400	
Risk Class III	>3400	
Risk Class IV	>3400	
Risk Class V	>1700	
(if higher, take into consideration combustibility of barrels)		
Filling plant, small casks		
liquid filled and casks	<200	
incombustible liquid filled and/or casks combustible:		
Risk Class I	<500	
Risk Class II	<500	
Risk Class III	<500	
Risk Class IV	<500	
Risk Class V	<500	
(if higher, take into consideration combustibility of casks)		
Finishing plant, paper	500	
Finishing plant, textile	300	
Fire works mfg	Spez	2000
Flat		300
Floor covering mfg	500	6000
Floor covering store	1000	
Flooring plaster mfg	600	
Flour products	800	
Flower sales	80	
Fluorescent tube mfg	300	
Foamed plastics fabrication	3000	2500
Foamed plastics processing	600	800
Food forwarding	1000	
Food store	700	
Forge		80
Forwarding, appliances partly made of plastic	700	
Forwarding, beverage	300	
Forwarding, cardboard goods	600	
Forwarding, food	1000	
Forwarding, furniture	600	
Forwarding, glassware	700	
Forwarding, plastic products	1000	
Forwarding, printed matters	1700	
Forwarding, textiles	600	
Forwarding, tinware	200	
Forwarding, varnish, polish	1300	
Forwarding, woodware small)	600	
Foundry (metal)	40	
Fur, sewing	400	
Fur store	200	
Furniture exhibition	500	
Furniture mfg (wood)	600	
Furniture polishing	500	
Furniture store	400	
Furrier	500	
Galvanic station	200	
Gambling place	150	

Type of Occupancies	Fabrication (MJ/m2)	Storage
Glass blowing plant	*200*	
Glass factory	100	
Glass mfg	100	
Glass painting	300	
Glass processing	200	
Glassware mfg	200	
Glassware store	200	
Glazier's workshop	700	
Gold plating (of metals)	800	3400
Goldsmith's workshop	200	
Grainmill, without storage	400	13000
Gravestone carving	50	
Graphic workshop	1000	
Greengrocer's shop	200	
Hairdressing shop	300	
Hardening plant	400	
Hardware mfg	200	
Hardware store	300	
Hat mfg	500	
Hat store	500	
Heating equipment room, wood or coal firing	300	
Heat sealing of plastics	800	
High-rise office building	800	
Homes	500	
Homes for aged	400	
Hosiery mfg	300	1000
Hospital	300	
Hotel	300	
Household appliance, mfg	300	200
Household appliance, sales	300	
Ice cream (including packaging)	100	
Incandescent lamp plant	40	
Injection moulded parts mfg (metal)	80	
Injection moulded parts mfg (plastic)	500	
Institution building	500	
Ironing	500	
Jewellery mfg	200	
Jewellery shop	300	
Joinery	700	
Joiners (machine room)	500	
Joiners (workbench)	700	
Jute, weaving	400	1300
Laboratory, bacteriological	200	
Laboratory, chemical	500	
Laboratory, electric, electronic	200	
Laboratory, metallurgical	200	
Laboratory, physics	200	
Lacquer forwarding	1000	
Lacquer mfg	500	2500
Large metal constructions	80	
Lathe shop	600	
Laundry	200	
Leather goods sales	700	
Leather product mfg	500	
Leather, tanning, dressing, etc	400	
Library	2000	2000
Lingerie mfg	400	
Liqueur mfg	400	
Liquor mfg	400	800
Liquor store	700	
Loading ramp including goods (rough average)	800	
Lumber room for miscellaneous goods	500	
Machinery mfg	200	
Match plant	300	800
Mattress mfg	500	500
Meat shop	50	
Mechanical workshop	200	
Metal goods mfg	200	
Metal grinding	80	
Metal working (general)	200	
Milk, condensed, evaporated, mfg	200	9000
Milk, powdered, mfg	200	10500
Milling work, metal	200	
Mirror mfg	100	
Motion-picture studio	300	
Motor cycle assembly	300	
Museum	300	
Musical instruction sales	281	
News-stand	1300	
Nitrocellulose mfg	Spez	1100
Nuclear research	2100	
Nursery school	300	
Office, business	800	
Office, engineering	600	
Office furniture	700	
Office, machinery mfg	300	
Office machine sales	300	
Oilcloth mfg	700	1300
Oilcloth processing	700	2100
Optical instrument mfg	200	200
Packing, food	800	
Packing, incombustible goods	400	
Packing material Industry	1600	3000
Packing, printed matters	1700	
Packing, textiles	600	
Packing, all other combustible goods	600	
Paint and varnish, mfg	4200	
Paint and varnish, mixing plant	2000	
Paint and varnish shop	1000	
Paint shop (cards, machines, etc)	200	
Paint shop (furniture etc)	400	
Paper mfg	*200*	10000
Paper processing	800	1100
Parking building	200	
Parquetry mfg	2000	1200
Perambulator mfg	300	800
Perambulator shop	300	
Perfume sale	500	
Pharmaceuticals, packing	300	800
Pharmaceutical mfg	300	800
Pharmacy (including storage)	800	

Type of Occupancies	Fabrication (MJ/m2)	Storage
Photographic laboratory	100	
Photographic store	300	
Photographic studio	300	
Picture frame mfg	300	
Plaster product mfg	80	
Plastic floor tile mfg	800	
Plastic mfg	2000	5900
Plastic processing	600	
Plastic products fabrication	600	
Plumber's workshop	100	
Plywood mfg	800	2900
Polish mfg	1700	
Post office	400	
Potato, flaked, mfg	200	
Pottery plant	200	
Power station	600	
Precious stone, cutting etc	80	
Precision instrument mfg		
containing plastic parts	200	
without plastic parts	100	
Precision mechanics plant	200	
Pressing, metal	100	
Pressing, plastics, leather etc	400	
Preparation briquette production		
Printing, composing room	300	
Printing ink mfg	700	3000
Printing, machine hall	400	
Printing office	1000	
Radio and TV mfg	400	
Radio and TV sales	500	
Radio studio	300	
Railway car mfg	200	
Railway station	800	
Railway workshop	800	
Record player mfg	300	200
Record repository, documents see also storage	4200	
Refrigerator mfg	1000	300
Relay mfg	400	
Repair shop, general	400	
Restaurant	300	
Retouching department	300	
Rubber goods mfg	600	5000
Rubber goods store	800	
Rubber processing	600	5000
Saddlery mfg	300	
Safe mfg	80	
Salad oil forwarding	900	
Salad oil mfg	1000	18900
Sawmill (without woodyard)	400	
Scale mfg	400	
School	300	
Scrap recovery	800	
Seedstore	600	
Sewing machine mfg	300	
Sewing machine store	300	
Sheet mfg	100	
Shoe factory, forwarding	600	
Shoe factory, mfg	500	

Type of Occupancies	Fabrication (MJ/m2)	Storage
Shoe polish mfg	800	2100
Shoe repair with manufacture	700	
Shoe store	500	
Shutter mfg	1000	
Silk spinning (natural silk)	300	
Silk weaving (natural silk)	300	
Silverwares	400	
Ski mfg	400	1700
Slaughter house	40	
Soap mfg	200	4200
Soda mfg	40	
Soldering	300	
Solvent distillation	200	
Spinning mill excluding garneting	300	
Sporting goods store	800	
Spray painting, metal goods	300	
Spray painting, wood products	500	
Stationery store	700	
Steel furniture mfg	300	
Stereotype plate mfg	200	
Stone masonry	40	
Storeroom (workshop storerooms etc)	1200	
Synthetic fibre mfg	400	
Synthetic fibre processing	400	
Synthetic resin mfg	3400	
Tar coated paper mfg	1700	
Tar preparation	800	
Telephone apparatus mfg	400	200
Telephone exchange	80	
Telephone exchange mfg	100	
Test room, electrical appliances	200	
Test room, machinery	100	
Test room, textiles	300	
Theatre	300	
Tin can mfg	100	
Tinned goods mfg	40	
Tinware mfg	120	
Tire mfg	700	1800
Tobacco products mfg	200	2100
Tobacco shop	500	
Tool mfg	200	
Toy mfg (combustible)	100	
Toy mfg (incombustible)	200	
Toy store	500	
Tractor mfg	300	
Transformer mfg	300	
Transformer winding	600	
Travel agency	400	
Turnery (wood working)	500	
Turning section	200	
TV studio	300	
Twisting shop	250	
Umbrella mfg	300	400
Umbrella store	300	
Underground garage, private	>200	
Underground garage, public	<200	
Upholstering plant	500	

Type of Occupancies	Fabrication (MJ/m2)	Storage
Vacation home	500	
Varnishing, appliances	80	
Varnishing, paper	80	
Vegetable, dehydrating	1000	400
Vehicle mfg, assembly	400	
Veneering	500	2900
Veneer mfg	800	4200
Vinegar mfg	80	100
Vulcanising plant (without storage)	1000	
Waffle mfg	300	1700
Warping department	250	
Washing agent mfg	300	200
Washing machine mfg	300	40
Watch assembling	300	40
Watch mechanism mfg	40	
Watch repair shop	300	
Watch sales	300	
Water closets	~ 0	
Wax products forwarding	2100	
Wax products mfg	1300	2100
Weaving mill (without carpets)	300	
Welding shop (metal)	80	
Winding room	400	
Winding, textile fibres	600	
Window glass mfg	700	
Window mfg (wood)	800	
Wine cellar	20	
Wine merchant's shop	200	
Wire drawing	80	
Wire factory	800	
Wood carving	700	
Wood drying plant	800	
Wood grinding	200	
Wood pattern-making shop	600	
Wood preserving plant	3000	
Youth hostel	300	

APPENDIX B

Net Calorific Value H_u of Combustible Materials (MJ/kg) from Barnett (1984)

Solids	MJ/kg
Anthracite	31-36
Asphalt	40-42
Bitumen	41-43
Cellulose	15-18
Charcoal	34-35
Clothes	17-21
Coal, Coke	28-34
Cork	26-31
Cotton	16-20
Grain	16-18
Grease	40-42
Kitchen refuse	8-21
Leather	18-20
Linoleum	19-21
Paper, Cardboard	13-21
Paraffin wax	46-47
Plastics	
ABS	34-40
Acrylic	27-29
Celluloid	17-20
Epoxy	33-34
Melamine resin	16-19
Phenolformaldehyde	27-30
Polyester	30-31
Polyester, fibre reinforced	20-22
Polyethylene	43-44
Polystyrene	39-40
Petroleum	40-42
Polyisocyanurate foam	22-26
Polycarbonate	28-30
Polypropylene	42-43
Polytetraflouroethylene	5.0
Polyurethane	22-24
Polyurethane foam	23-28
Polyvinylchloride	16-17

Ureaformaldehyde	14-15
Ureaformaldehyde foam	12-15
Foam rubber	34-40
Rubber (isoprene)	44-45
Rubber tire	31-33
Silk	17-21
Straw	15-16
Wood	17-20
Wool	21-26
Particleboard (chipboard and hardboard)	17-18

Liquids	**MJ/kg**
Gasoline	43-44
Diesel oil	40-42
Linseed oil	38-40
Methanol	19-20
Paraffin oil	40-42
Spirits	26-28
Tar	37-39
Benzene	40.1
Benzyl alcohol	32.9
Ethyl alcohol	26.9
Isopropyl alcohol	31.4

Gases	**MJ/kg**
Acetylene	48.2
Butane	45.7
Carbon monoxide	10.1
Hydrogen	119.7
Propane	45.8
Methane	50.0
Ethanol	26.8

APPENDIX C

BRANZ FIRE LOAD SURVEY	A : BASIC DESCRIPTION OF CONSTRUCTION
Sample No.	Sample Group
Date of Survey	Location

Framework	
Floors	
Walls	
Ceilings	
Roof	
Doors and Windows	
Covering Floors : Walls : Ceilings :	
Electrical Equipment	
Miscellaneous	

BRANZ FIRE LOAD SURVEY	B : DRAWING SHEET
Sample No.	Sample Group
Date of Survey	Location

BRANZ FIRE LOAD SURVEY	C : CALCULATION SHEET
Sample No.	Sample Group
Date of Survey	Location

BRANZ FIRE LOAD SURVEY	D : FIXED FIRE LOAD SHEET
Sample No.	Sample Group
Date of Survey	Location

No.	Designation and description of Fixed Fire Load	Type	Qty	Unit	Cal. Value in MJ	
					U/rate	Total
	Total Gross Heat Load for ________ m^2					MJ
	Unit Fixed Fire Load, b1 = ________					MJ

P = Plastic S = Sheepwool W = Wood

BRANZ FIRE LOAD SURVEY — E: MOVABLE FIRE LOAD SHEET

Sample No. Sample Group

Date of Survey Location

No	Designation and description of Fixed Fire Load	Type	Plan A m^2	Vol V m^3	Wt W kg	Furniture				Contents			
						Q	Units	Unit/MJ	Tot MJ	Q	Units	Unit/MJ	Tot MJ

Total Gross Heat Load for ________ m^2 — MJ — MJ

Unit Movable Fire Load — MJ/m^2 — MJ/m^2

P = Plastic S = Sheepwool W = Wood WM = Wood - metal furniture

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