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A Review of The Building Separation Requirements of the New Zealand Building Code Acceptable Solutions

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A REVIEW OF THE BUILDING SEPARATION REQUIREMENTS OF THE NEW ZEALAND BUILDING CODE ACCEPTABLE SOLUTIONS

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ABSTRACT

This report investigates the parameters that influence the boundary separation tables of the present New Zealand Building Code Acceptable Solutions. From an extensive literature review of theoretical and experimental research papers, revisions are proposed to some of the parameters such as emitted radiation flame projection; limiting distance and piloted ignition flux. Using these revised parameters new boundary separation tables are presented and compared to the existing tables. The new tables result in larger boundary separation (but similar separations between buildings) and potential areas for future research are suggested.

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CHAPTER 1: INTRODUCTION

1.1 PREAMBLE

This project sets out to review the design parameters used for the building separation requirements of the present New Zealand Building Code Acceptable Solutions and compares them with those used by other countries and with the results of scientific research and experiments in each of the relevant areas.

The effects of changing the various parameters based on the research results is evaluated using the radiation module of the FIRECALC computer programme (CSIRO 1993) and suggested changes to the Acceptable Solutions are presented.

1.2 LEGISLATIVE BACKGROUND

Prior to 1992, the fire design aspects of building construction in New Zealand were governed by NZS 1900:Chapter 5:" Fire Resisting Construction and Means of Egress" (SANZ 1988). This Standard was a prescriptive code that set out strict requirements for fire design based on the use of a proposed building and the form of construction to be used. The requirements in Chapter 5 were, to some extent, based on empirical standards laid down by interested parties such as insurance companies and in most cases these standards dated back many years.

For some time, the building community in New Zealand had considered that the prescriptive basis of the existing New Zealand Standards, including Chapter 5, led in some cases to overly conservative and hence expensive construction requirements and stifled the use of new and innovative building methods and materials. After a number of years of lobbying, the Building Industry Commission was set up by the New Zealand Government and, on the basis of the work done by that Commission, the Building Act 1991 was enacted in December 1991 (NZ Government 1991). The Act's description of itself was:

> "An Act to consolidate and reform the law relating to building and to provide for better regulation and control of building."

Under Part VI of the Act, Sections 48 to 50 set up the legislative framework for the National Building Code.

In June 1992, the Building Regulations 1992 (NZ Government 1992) were promulgated. The First Schedule of these Regulations was entitled "The Building Code" and set out the performance requirements for all aspects of building construction. The requirements for each aspect were set out in a specific clause with each clause broken down into "Objective", "Functional Requirements" and "Performance". The requirements relating to building separation are included in Clause C3 - Spread of Fire. The particular sections relating to fire spread to other properties are as set out below:

Objective:

C3.1(c) The objective of this provision is to protect adjacent household units and other property from the effects of fire.

Functional Requirement:

C3.2(c) Buildings shall be provided with safeguards against fire spread so that adjacent household units and other property are protected from damage.

Performance:

C3.3.5 External walls and roofs shall have resistance to the spread of fire, appropriate to the fire load within the building and to the proximity of other household units and other property.

As a performance based code, these clauses set out what is to be done, not how to do it. In order that the Territorial Authorities (TAs) (Authorities Having Jurisdiction), designers and builders could have examples of materials, components and construction methods which, if used, would result in compliance with the Building Code, a series of Acceptable Solutions (BIA 1992) were prepared governing each specific clause of the requirements. It should be noted that these Acceptable Solutions are only one method of complying with the requirements of the relevant clauses of the Building Code. Under the requirements of the Building Act the Territorial Authorities are required to accept a design which complies fully with the methods set out in the Acceptable Solutions. The Acceptable Solutions also provide guidelines by which compliance of alternative solutions can be measured.

1.3 ACCEPTABLE SOLUTION C3/AS1 - SPREAD OF FIRE

This Acceptable Solution, together with the associated Appendices A, B and C of the Fire Safety Annex, sets out methods by which the performance requirements of Clause C3 can be achieved. The sections of C3/AS1 and the Appendices that have an influence on the requirements for building separation are as set out below:-

(a) Building Usage and Fire Load

As shown in Figure 1.1 which is extracted from Appendix A of the Annex, the various likely uses of buildings are divided into purpose groups.

Table A1: Purpose groups
Paragraph A2.1

Purpose group	Description of intended use of the building space	Some examples	Fire hazard category
CROWD ACTIVITIES			
CS or CL	For occupied spaces. CS applies to occupant loads up to 100 and CL to occupant loads exceeding 100.	Cinemas when classed as CS, art galleries, auditoria, bowling alleys, churches, clubs (non-residential), community halls, court rooms, dance halls, day care centres, gymnasia, lecture halls, museums, eating places (excluding kitchens), taverns, enclosed grandstands, indoor swimming pools.	1
		Cinemas when classed as CL, schools, colleges and tertiary institutions, libraries (up to 2.4 m high book storage), nightclubs, restaurants and eating places with cooking facilities, (non-residential) theatre stages, opera houses, television studios (with audience).	2
		Libraries (over 2.4 m high book storage).	3
CO	Spaces for viewing open air activities (does not include spaces below a grandstand).	Open grandstands, roofed but unenclosed grandstand, uncovered fixed seating.	1
CM	Spaces for displaying, or selling retail goods, wares or merchandise.	Exhibition halls, retail shops.	2
		Supermarkets or other stores with bulk storage/display over 3.0 m high.	4
SLEEPING ACTIVITIES			
SC	Spaces in which principal users because of age, mental or physical limitations require special care or treatment.	Hospitals, care institutions for the aged, children, people with disabilities.	1
SD	Spaces in which principal users are restrained or liberties are restricted.	Care institutions, for the aged or children, with physical restraint or detention. Hospital with physical restraint, detention quarters in a police station, prison.	1
SA	Spaces providing transient accommodation, or where limited assistance or care is provided for principal users.	Motels, hotels, hostels, boarding houses, clubs, (residential), boarding schools, dormitories, community care institutions.	1
SR	Attached and multi-unit residential dwellings.	Multi-unit dwellings or flats, apartments, and includes household units attached to the same or other purpose groups, such as caretakers' flats, and residential accommodation above a shop.	1
SH	Detached dwellings where people live as a single household or family.	Dwellings, houses, being household units, or suites in purpose group SA, separated from each other by distance. Detached dwellings may include attached self-contained suites such as granny flats when occupied by a member of the same family, and garages whether detached or part of the same building and are primarily for storage of the occupants' vehicles, tools and garden implements.	1

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Figure 1.1: Acceptable Solution Purpose Groups

Table A1: Purpose groups (contd)
Paragraph A2.1

Purpose group	Description of intended use of the building space	Some examples	Fire hazard category
WORKING BUSINESS OR STORAGE ACTIVITIES			
WL	Spaces used for working, business or storage - light fire hazard	Manufacturing, processing or storage of non-combustible materials, or materials having a slow heat release rate, cool stores, covered cattle yards, wineries, grading, storage or packing of horticultural products, wet meat processing.	1
		Banks, hairdressing shops, beauty parlours, personal or professional services, dental offices, laundry (self-service), medical offices, business or other offices, police stations (without detention quarters), radio stations, television studios (no audience), small tool and appliance rental and service, telephone exchanges, dry meat processing.	2
WM	Spaces used for working, business or storage - medium fire hazard.	Manufacturing and processing of combustible materials not otherwise listed, bulk storage up to 3.0 m high.	3
WD	Spaces used for working, business or storage - high fire hazard.	Areas involving sufficient quantities of highly combustible and flammable or explosive materials which because of their inherent characteristics constitute a special fire hazard, including: bulk plants for flammable liquids or gases, bulk storage warehouses for flammable substances, chemical manufacturing or processing plants, distilleries, feed mills, flour mills, lacquer factories, mattress factories, paint and varnish factories rubber processing plants, spray painting operations, waste paper processing plants, plastics manufacturing, bulk storage of combustible materials over 3 m high.	4
INTERMITTENT ACTIVITIES			
IE	Exitways on escape routes.	Protected path, safe path.	1
IA	Spaces for intermittent occupation or providing intermittently used support functions - light fire hazard.	Garages, carports, enclosed corridors, unstaffed kitchens or laundries, lift shafts, locker rooms, linen rooms, open balconies, staircases (within the open path), toilets and amenities, and service rooms incorporating machinery or equipment not using solid-fuel, gas or petroleum products as an energy source.	1
ID	Spaces for intermittent occupation or providing intermittently used support functions - medium fire hazard.	Maintenance workshops and service rooms incorporating machinery or equipment using solid-fuel, gas or petroleum products as an energy source.	3

NOTE:

IE, IA and ID spaces are not considered occupiable areas when determining occupant load.
Service rooms are spaces designed to accommodate any of the following: boiler/plant equipment, furnaces, incinerators, refuse, caretaking/cleaning equipment, airconditioning, heating, plumbing or electrical equipment, pipes, lift/escalator machine rooms, or similar services.

Figure 1.1 (cont'd): Acceptable Solution Purpose Groups

Each of the purpose groups is specified as having a particular fire hazard category. This category is used to classify the likely impact that a fully developed fire in that purpose group would have on the building and its surroundings. The fire hazard categories are defined in terms of the fire load energy density (total fire load divided by the fire cell floor area) as shown in Table 1.1 below. It is noted in the appendix that FLED is only one factor affecting the fire severity in a building.

Other factors that may require consideration include ventilation, surface area to mass ratio of the fuel and the rate of burning of the fuel. In allocating the fire hazard categories to the various purpose groups, some consideration of these other aspects was also taken.

Fire Hazard Category	**Range of FLED (MJ/m^2)**	**Design Value of FLED (MJ/m^2)**
1	0 to 500	400
2	501 - 1000	800
3	1001 - 1500	1200
4	> 1500	Specific design

Table 1.1: Purpose Group Design FLED

(b) Building Separation

Based on the fire hazard categories detailed in Table 1.1, the building separations for various configurations are tabulated in a series of tables given in Appendix C, "Calculation of the Acceptable Unprotected Area in External Walls". A copy of a typical table from Appendix C is given in Figure 1.2.

Table C3: Permitted unprotected areas in unsprinklered buildings
Method 4: Enclosing rectangles

Paragraph C5.2.1

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Width of enclosing rectangle (m)	Minimum acceptable distance (m) between external wall and relevant boundary for fire hazard categories 3 and 4 and purpose groups SC and SD. Figures in brackets are for fire hazard categories 1 and 2 excluding purpose groups SC and SD. (Applies to SH only where more than two floors)								
	Percentage of unprotected area in external wall								
	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %
Enclosing rectangle 3 m high									
3	1.0 (1.0)	1.5 (1.0)	2.0 (1.0)	2.0 (1.5)	2.5 (1.5)	2.5 (1.5)	2.5 (2.0)	3.0 (2.0)	3.0 (2.0)
6	1.5 (1.0)	2.0 (1.0)	2.5 (1.5)	3.0 (2.0)	3.0 (2.0)	3.5 (2.0)	3.5 (2.5)	4.0 (2.5)	4.0 (3.0)
9	1.5 (1.0)	2.5 (1.0)	3.0 (1.5)	3.5 (2.0)	4.0 (2.5)	4.0 (2.5)	4.5 (3.0)	5.0 (3.0)	5.0 (3.5)
12	2.0 (1.0)	2.5 (1.5)	3.0 (2.0)	3.5 (2.0)	4.0 (2.5)	4.5 (3.0)	5.0 (3.0)	5.5 (3.5)	5.5 (3.5)
15	2.0 (1.0)	2.5 (1.5)	3.5 (2.0)	4.0 (2.5)	4.5 (2.5)	5.0 (3.0)	5.5 (3.5)	6.0 (3.5)	6.0 (4.0)
18	2.0 (1.0	2.5 (1.5)	3.5 (2.0)	4.0 (2.5)	5.0 (2.5)	5.0 (3.0)	6.0 (3.5)	6.5 (4.0)	6.5 (4.0)
21	2.0 (1.0)	3.0 (1.5)	3.5 (2.0)	4.5 (2.5)	5.0 (3.0)	5.5 (3.0)	6.0 (3.5)	6.5 (4.0)	7.0 (4.5)
24	2.0 (1.0)	3.0 (1.5)	3.5 (2.0)	4.5 (2.5)	5.0 (3.0)	5.5 (3.5)	6.0 (3.5)	7.0 (4.0)	7.5 (4.5)
27	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	4.5 (2.5)	5.5 (3.0)	6.0 (3.5)	6.5 (4.0)	7.0 (4.0)	7.5 (4.5)
30	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	4.5 (2.5)	5.5 (3.0)	6.0 (3.5)	6.5 (4.0)	7.5 (4.0)	8.0 (4.5)
40	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	5.0 (2.5)	5.5 (3.0)	6.5 (3.5)	7.0 (4.0)	8.0 (4.0)	8.5 (5.0)
50	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	5.0 (2.5)	6.0 (3.0)	6.5 (3.5)	7.5 (4.0)	8.0 (4.0)	9.0 (5.0)
60	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	5.0 (2.5)	6.0 (3.0)	7.0 (3.5)	7.5 (4.0)	8.5 (4.0)	9.5 (5.0)
80	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	5.0 (2.5)	6.0 (3.0)	7.0 (3.5)	8.0 (4.0)	9.0 (4.0)	9.5 (5.0)
no limit	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	5.0 (2.5)	6.0 (3.0)	7.0 (3.5)	8.0 (4.0)	9.0 (4.0)	10.0 (5.0)
Enclosing rectangle 6 m high									
3	1.5 (1.0)	2.0 (1.0)	2.5 (1.5)	3.0 (2.0)	3.0 (2.0)	3.5 (2.0)	3.5 (2.5)	4.0 (2.5)	4.0 (3.0)
6	2.0 (1.0)	3.0 (1.5)	3.5 (2.0)	4.0 (2.5)	4.5 (3.0)	5.0 (3.0)	5.5 (3.5)	5.5 (4.0)	6.0 (4.0)
9	2.5 (1.0)	3.5 (2.0)	4.5 (2.5)	5.0 (3.0)	5.5 (3.5)	6.0 (4.0)	6.0 (4.5)	7.0 (4.5)	7.0 (5.0)
12	3.0 (1.5)	4.0 (2.5)	5.0 (3.0)	5.5 (3.5)	6.5 (4.0)	7.0 (4.5)	7.5 (5.0)	8.0 (5.0)	8.5 (5.5)
15	3.0 (1.5)	4.5 (2.5)	5.5 (3.0)	6.0 (4.0)	7.0 (4.5)	7.5 (5.0)	8.0 (5.5)	9.0 (5.5)	9.0 (6.0)
18	3.5 (1.5)	4.5 (2.5)	5.5 (3.5)	6.5 (4.0)	7.5 (4.5)	8.0 (5.0)	9.0 (5.5)	9.5 (6.0)	10.0 (6.5)
21	3.5 (1.5)	5.0 (2.5)	6.0 (3.5)	7.0 (4.0)	8.0 (5.0)	9.0 (5.5)	9.5 (6.0)	10.0 (6.5)	10.5 (7.0)
24	3.5 (1.5)	5.0 (2.5)	6.0 (3.5)	7.0 (4.5)	8.5 (5.0)	9.5 (5.5)	10.0 (6.0)	10.5 (7.0)	11.0 (7.0)
27	3.5 (1.5)	5.0 (2.5)	6.5 (3.5)	7.5 (4.5)	8.5 (5.0)	9.5 (6.0)	10.5 (6.5)	11.0 (7.0)	12.0 (7.5)
30	3.5 (1.5)	5.0 (2.5)	6.5 (3.5)	8.0 (4.5)	9.0 (5.0)	10.0 (6.0)	11.0 (6.5)	12.0 (7.0)	12.5 (8.0)
40	3.5 (1.5)	5.5 (2.5)	7.0 (3.5)	8.5 (4.5)	10.0 (5.5)	11.0 (6.5)	12.0 (7.0)	13.0 (8.0)	14.0 (8.5)
50	3.5 (1.5)	5.5 (2.5)	7.5 (3.5)	9.0 (4.5)	10.5 (5.5)	11.5 (6.5)	13.0 (7.5)	14.0 (8.0)	15.0 (9.0)
60	3.5 (1.5)	5.5 (2.5)	7.5 (3.5)	9.5 (5.0)	11.0 (5.5)	12.0 (6.5)	13.5 (7.5)	15.0 (8.5)	16.0 (9.5)
80	3.5 (1.5)	6.0 (2.5)	7.5 (3.5)	9.5 (5.0)	11.5 (6.0)	13.0 (7.0)	14.5 (7.5)	16.0 (8.5)	17.5 (9.5)
100	3.5 (1.5)	6.0 (2.5)	8.0 (3.5)	10.0 (5.0)	12.0 (6.0)	13.5 (7.0)	15.0 (8.0)	16.5 (8.5)	18.0 (10.0)
120	3.5 (1:5)	6.0 (2.5)	8.0 (3.5)	10.0 (5.0)	12.0 (6.0)	14.0 (7.0)	15.5 (8.0)	17.0 (8.5)	19.0 (10.0)
no limit	3.5 (1.5)	6.0 (2.5)	8.0 (3.5)	10.0 (5.0)	12.0 (6.0)	14.0 (7.0)	16.0 (8.0)	18.0 (8.5)	19.0 (10.0)

Figure 1.2: Acceptable Solution Building Separations

It is noted in the comments to Appendix C that the methods used to produce the tables are based on BRE Report BR 187: 1991 "External Fire Spread: Building Separation and Boundary Distances" (Read 1991). One difference between the Acceptable Solution separation tables and the BRE report is the inclusion of the care and detention categories of the sleeping purpose groups in the requirements for FHC 3 and 4. As these purpose groups would not have any greater fire load than other residential uses and as the Building Code performance requirement is to protect **other** property, it does not seem logical to require higher boundary separations for these purpose groups. However, as there is a greater life safety risk with these purpose groups, the working group responsible for this area may have considered that it was necessary to include some owner's property protection against fires in adjacent properties by requiring greater separations or larger proportions of external wall fire rating.

(c) Detached Dwellings

It is important to note that the Building Code does not exclude detached dwellings from the requirements to protect other property. However, when the Acceptable Solutions were prepared, a political decision was made that the requirements would not apply to one or two storey detached dwellings (SH Purpose Group). For these buildings the previous requirement to only fire rate external walls which were within 1.0 m of a boundary was allowed to remain. This was in spite of the fact that it was readily acknowledged that with this boundary separation the radiation from a small low cost house fully involved in fire would exceed the limitations set down for other buildings by a factor of at least 3. The reason for this decision was that the Building Code had been vaunted as being the way to reduce costs in the building industry. It was not considered appropriate to impose a major upgrading of requirements, with the attendant increase in costs, in the residential housing area which was the major sector of the industry and the one which affected the public in an immediate and visible manner. The justification for the decision was that the history of fires in residential areas in New Zealand contained few, if any, examples of fire spread to neighbouring houses. In addition, it was considered that in urban areas where the problem may occur, the Fire Service was likely to respond quickly enough to wet down adjacent houses should this prove necessary. The validity of this justification is reviewed later in this chapter.

1.4 DESIGN PARAMETERS USED IN C3/AS1

In order to produce the tables given in Appendix C, the working group responsible for this section of the Acceptable Solutions had to decide on a number of the design parameters which dictated the radiation which was emitted from the subject building and was received on the neighbouring building. These parameters are outlined below and are then reviewed in detail in subsequent chapters.

1.4.1 Emitted Radiation

In a similar manner to the British Regulations (Department of the Environment 1991), two levels of emitted radiation are considered based on the purpose group contained in the building. For Fire Hazard Categories 1 and 2 an emitted radiation of 84 kW/m^2 is used. For the higher fire load energy densities associated with Categories 3 and 4 and for the care and detention categories of sleeping purpose groups, an emitted radiation of 168 kW/m^2 is used.

1.4.2 Flame Projection

No consideration of flame projection is included in the building separation requirements set out in the C3 tables.

1.4.3 Emissivity

On the basis of black body radiation emission, a conservative value of 1.0 is taken for the emissivity of the radiator.

1.4.4 Position of Receiving Building

In order to produce the C3 tables, an assumption was made that the adjacent building would be a mirror image of the building being considered and would therefore be located the same distance on the other side of the relevant boundary as the radiating building. In the definitions of the Acceptable Solutions the relevant boundary is either a property boundary or a notional boundary located between two proposed buildings on the same lot.

1.4.5 Received Radiation

The radiation received on the target building was determined using the configuration factor method described in various heat and mass transfer text books and in the BRE Report BR187 mentioned earlier.

1.4.6 Critical Radiation

To establish the required separation distances a maximum received radiation of 12.6 kW/m^2 on the receiving building was stipulated.

1.4.7 Verification of C3 Table Results

In order to confirm that the separation distances derived from the C3 tables are in fact based on the parameters given above manual calculations of several cases taken from Figure 1.2 are set out in Appendix A and compared with the results of FIRECALC analyses. The results show that if the above assumptions are made, the separation distances given in the C3 tables can be duplicated manually allowing for some rounding to give separations in 0.5 m intervals.

1.5 BOUNDARY SEPARATION REQUIREMENTS OF OTHER COUNTRIES

From a review of the literature that was available and personal communication with overseas researchers, it would appear that most countries have prescriptive requirements regarding boundary separations but the background performance requirements which dictate those separations are generally not publicised or well known. The prescriptive requirements vary in complexity, some being similar to the tables of the NZBC Acceptable Solutions while others are just strict distance limitations.

(a) Britain

In Britain the Building Regulations 1991 are based on the same BR 187 Report which was used to produce the NZBC Acceptable Solutions and the tables are exactly the same. In private communications, Margaret Law (Law 1998) indicated that at present it was not considered necessary to revise the tables as the performance parameters used to produce them were considered to be reasonably satisfactory. She commented that, although the value of 12.6 kW/m^2 was a conservative value for the ignition of timber cladding, the move to PVC external cladding could mean that this value of received radiation was no longer as conservative. She also made the point that in producing the tables it had been assumed that the fire brigade would be available to help protect any exposed within five minutes after callout. This gave some margin of safety since ignition would be expected to occur approximately 10 minutes after the primary fire had become fully developed. In the same communication, Margaret Law advised that in Germany and France there is a blanket five metre minimum spacing between buildings and if any building is closer than this, at least one of the buildings must be fire rated.

(b) Canada

In Canada the National Building Code (NRC 1990) has similar tables to those of the NZBC Acceptable Solutions but the separation distances are somewhat larger. Dr. David Torvi of the National Research Council of Canada (1998) has advised that the received radiation criteria used to produce the tables are the same as the British regulations, but a flame projection distance of 1.2 m has been included and higher emitted radiation values used. These factors were based on the results of full scale fire tests carried out in Canada in 1958 known as the St. Lawrence Burns and reported by Shorter (1960).

As discussed by McGuire (1965), the peak radiation levels that occurred on the leeward side of the buildings during the St. Lawrence Burns were 1680 kW/m^2 for buildings with combustible interior linings and 840 kW/m^2 for ones with non-combustible linings. These values were ten times larger than the values that were expected and were thought to be due to the effect of flames emanating from the windows. In re-examining the results, it was noted that the radiation values did not exceed 20% of the peak values until at least 16 minutes after the start of the fire. It was felt that firefighting would have started by this time, so it was justifiable to use lower radiation values.

To achieve a received radiation limit of 12.6 kW/m^2, it was decided to require configuration factors of 0.07 for normal buildings and 0.035 for buildings expected to burn vigorously. These configuration factors equate to emitted radiation values of 180 kW/m^2 and 360 kW/m^2 respectively.

The Canadian Code also has the stipulation that where fire service intervention cannot be guaranteed within 10 minutes, the separation distances given in the tables must be doubled.

(c) Japan

Although copies of the Japanese regulations could not be obtained, Dr. Kazunori Harada of the Building Research Institute, Japanese Ministry of Construction (1998) advised that the regulations were based on an emitted radiation of 100 kW/m^2 if no detailed information was available, but different values could be used on the basis of established compartment fire models.

The regulations assume an emissivity of 1 for the radiator and do not take into account flame projection. A lower than normal allowable received radiation of 10 kW/m^2 has been adopted because of the prevalence of thin timber external cladding.

In a recent research paper, Harada et al (1998) also suggested that there should be a limit on the accumulated radiated heat flux at certain distances within the adjacent property in order to account for the time dependency of the compartment temperature. The values suggested were 32,000 $(kW/m^2)^2$.min at 0.5 m from the boundary and 2,000 $(kW/m^2)^2$.min at 3.0 m from the boundary.

(d) Australia

The Building Code of Australia 1996 (ABCB 1996) contains tables giving the required boundary separation for various proportions of fire rated walls that are deemed to satisfy the performance requirements of the Code. The verification method by which alternative designs can be checked contains the table shown in Table 1.2.

Location	Heat Flux (kW/m^2)
On boundary	80
1.0 m from boundary	40
3.0 m from boundary	20
6.0 m from boundary	10
Column 1	**Column 2**

Table 1.2 Australian Radiant Heat Limits

The requirement of the code to avoid the spread of fire between buildings on adjoining properties is verified when:-

(i) A burning building will not cause heat flux greater than the values given in Column 2 at locations within the adjacent property set out in Column 1; and

(ii) When located at the distance from the boundary given in Column 1, a building is capable of withstanding the heat flux given in Column 2.

Enquiries have been made with a number of people involved in the writing of the Australian Code, but the reason for the choice of the particular flux values given above and the parameters that were used in establishing the flux cannot be verified.

(e) America

In America there is no single building code that is used throughout the country, but one of the more commonly used documents is the National Building Code (BOCA 1996). This, like the other codes used in America, is a prescriptive code with no performance criteria or verification methods provided. In the BOCA code boundary separations and exterior wall fire ratings are established by the use of two tables.

The first table sets out the required exterior wall fire ratings at set distances from the boundary for various building uses. Depending on the particular use, the table will specify a fire rating of zero once a certain boundary distance is achieved. The second table gives the maximum area of openings allowed in a fire rated wall depending on the distance to the boundary, with the separation being in bands of 1.5 m width. No allowance for building size is included. Again, it has not been possible to establish the criteria on which the tables are based.

One code which does have some flexibility and provides background data is NFPA 80A (NFPA 1993). This code stipulates a maximum received radiation of 12.6 kW/m^2, but allows it to be adjusted to suit the exterior cladding material being considered. The boundary separations are given for three different fire loading conditions as shown in Table 1.3, with the corresponding required configuration factors.

Building Classification	Fire Load per Unit Floor Area	Flame Spread Rating of Interior Lining	Configuration Factor
Light	<34 kg/m^2	0-25	0.14
Moderate	34-73 kg/m^2	26-75	0.07
Severe	>73 kg/m^2	>75	0.035

Table 1.3 Fire Load Classification For NFPA 80A

The separation distances include a flame projection distance of 1.5 m (5 ft). The distances given also contemplate rapid fire service response and the code states that if this cannot be guaranteed, the distances should be increased by a factor of up to 3.

1.6 IS THERE A PROBLEM WITH EXISTING SEPARATION DISTANCES?

The Building Code has been in effect for approximately six years and it is worth reflecting on whether or not the use of the building separations given in the C3 tables has affected the situation regarding spread of fire to adjacent properties.

In the publication "Emergency Incident Statistics" by the New Zealand Fire Service (NZ Fire Service 1998) a wide variety of statistics relating to fires in the period 1993 to 1997 are provided. For spread of fire to adjacent property, which the Fire Service defines as exposure fires, the figures given in Table 1.4 below have been extracted from a larger range of values covering all areas of initial ignition.

Spread of Fire from	Spread of Fire to	1993	1994	1995	1996	1997
Structure	Structure	61	68	70	102	73
Structure	Vehicle	19	27	26	30	26
Structure	Outside*	38	13	6	10	18
Total Structure "Exposure Fires"		118	108	102	142	117
Total Structural Fires		4097	3933	3608	2841	2813

* "Outside" includes outside storage, rubbish, grass, scrub or trees.

Table 1.4: Numbers of Exposures Fires in New Zealand

As can be seen from Table 1.4, although exposure fires are a relatively small proportion (3%-5%) of all structural fires, there have been a significant number of exposure fires during the period covered by the statistics. Unfortunately the Fire Service incident reporting system is not capable of breaking these figures down further to evaluate more detailed information such as the age or type of the buildings involved, the type of damage that occurred nor the cost of remedial work. From discussions with senior fire safety officers in various regions, the general view is that the bulk of the exposure fires relate to residential situations. In addition, the Fire Service's definition of damage includes discoloured or blistered paintwork, distorted PVC guttering and downpipes as well as charred external timber. It should be noted that the received radiation limits used by the Acceptable Solution documents relate to ignition of the target body.

Apart from the figures given above, there are specific areas where various parties have raised concerns.

1.6.1 Residential Situations

Although the Acceptable Solutions did not change the previous requirements relating to boundary separation for detached dwellings, there appear to be more incidents where damage to adjacent houses is occurring. This could be due in part to the increasing pressure on urban land resulting in smaller section sizes and hence smaller separations between houses. As part of the work associated with this project, the author attended a number of house fires at the invitation of the New Zealand Fire Service. In a number of these, adjacent houses had been damaged as the result of the fire even though boundary separations in all cases exceeded the 1.0 m allowed in the Acceptable Solutions.

An example of this was a fire that occurred in a small low cost house in Manurewa, South Auckland. A fire was started in the house as a result of children playing with either matches or a lighter and although all occupants were able to escape safely, the building was extensively damaged by fire as shown in the photograph in Figure 1.3. The Fire Service responded within four minutes to the notification of the fire which they estimate was some 15 minutes after the start of the fire. Upon their arrival the Fire Service commenced attacking the fire as well as wetting down adjacent houses. In spite of this early intervention, damage occurred to two of the adjacent houses as shown in Figures 1.4 and 1.5.

The house involved in the fire was 2.5 m from the adjacent boundary and the smallest boundary separation of a house on another property was 1.5 m, giving a total separation distance of 4 m, twice that allowed by C3/AS1.

Another example was a two storey house under construction in Howick that was destroyed by fire in 1997. The shell of the house was complete and was awaiting a prelining inspection by the TA.

A plumber was brazing an additional connection to a copper pipe in the wall framing and ignited the bitumen impregnated building paper. The fire quickly spread throughout the house and it was almost completely destroyed before the Fire Service could attend. See Figure 1.6. Although the new house was a minimum of 3.5 m from the boundary, radiation from the fire damaged the house on the adjacent property that was 1.5 m from the boundary - a minimum separation of 5 m. The damage consisted of melted PVC downpipes and cracked windows as seen in Figures 1.7 and 1.8.

In a more recent case, a two storey timber house in Devonport, built in the early 1900s, was completely destroyed in a fire. The house had been vacant and had had all of the services disconnected as the developer wished to demolish it, although the Territorial Authority had refused permission as it was a listed building. A fire, of unknown cause, occurred during the night and the Fire Service were alerted by neighbours woken by the noise of breaking windows. The station is located less than a kilometre from the site and the fire trucks were at the scene within three minutes of the alert. By this time the house was fully involved and all the Fire Service could do was attempt to protect adjacent houses, which were in considerable danger. In fact, the cedar weatherboard cladding on an adjacent house ignited just as the Fire Service arrived.

As can be seen in Figures 1.9 to 1.12, the Fire Service were unable to save the house where the fire started but did prevent major damage to the neighbours. The damage that did occur consisted of broken windows, blistered paintwork, melted PVC plumbing and badly charred timber cladding.

The original house was 4.5 m from the boundary and the closest neighbour, being the white house in Figure 1.9, was 2.5 m inside its site.

The much more extensive charring to the house shown in Figure 1.10 was considered to be because of the dark colour of the cedar cladding and the fact that the timber was stained rather than painted. Damage to the white painted neighbouring house is shown in Figures 1.11 and 1.12.

The most remote damage occurred to the house shown in Figure 1.13, which was 31 m away from the fire. The occupants said that at the height of the fire it was too hot for them to stand on the balcony overlooking it. After the fire blistered paintwork, deformed guttering and a cracked window were found on the wall facing the fire, as seen in Figure.1.14.

1.6.2 Commercial and Industrial Situations

Although no statistics are available for exposure fires in these situations, concerns have been expressed by officers of TAs that new buildings designed on the basis of the Acceptable Solutions must be accepted even though there is an existing building on the adjacent property that does not conform to the mirror image assumption for either separation distance or proportion of non fire rated area.

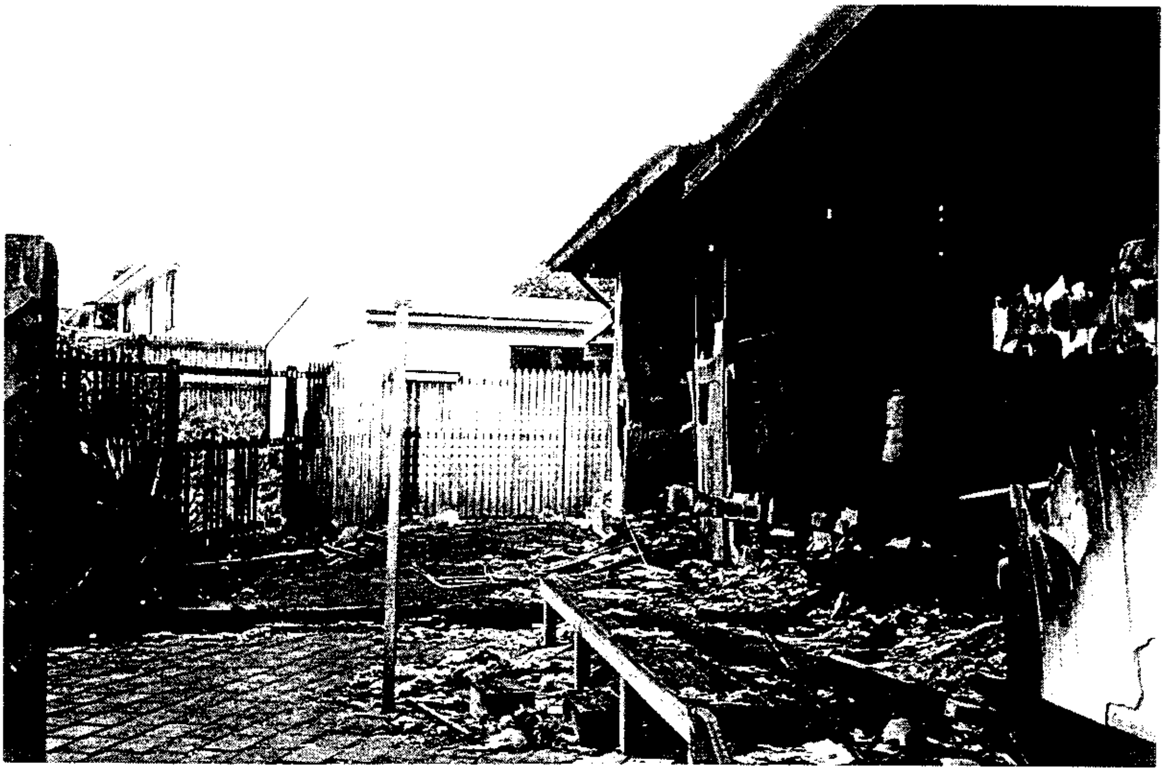


Figure 1.3: Burnt out Manurewa house. Note damage to timber fence.

Figure 1.4: Melted PVC gutter on adjacent house 4m away.

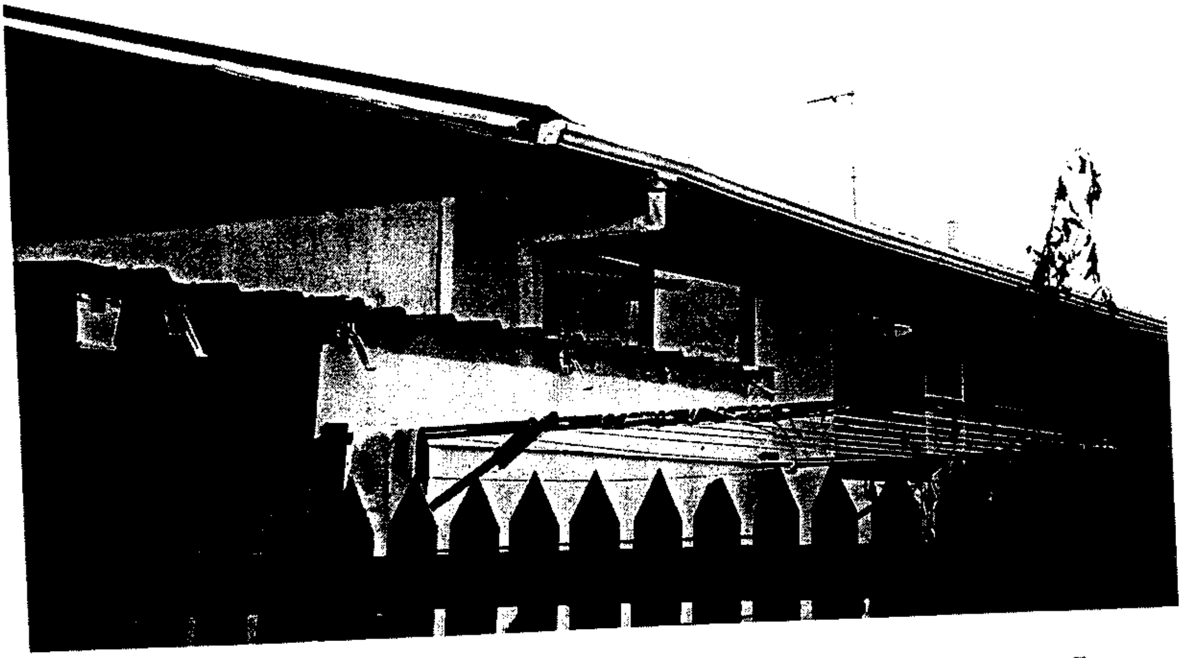


Figure 1.5: Deformed guttering and downpipe 6m away from the fire.

Figure 1.6: Burnt out Howick house.

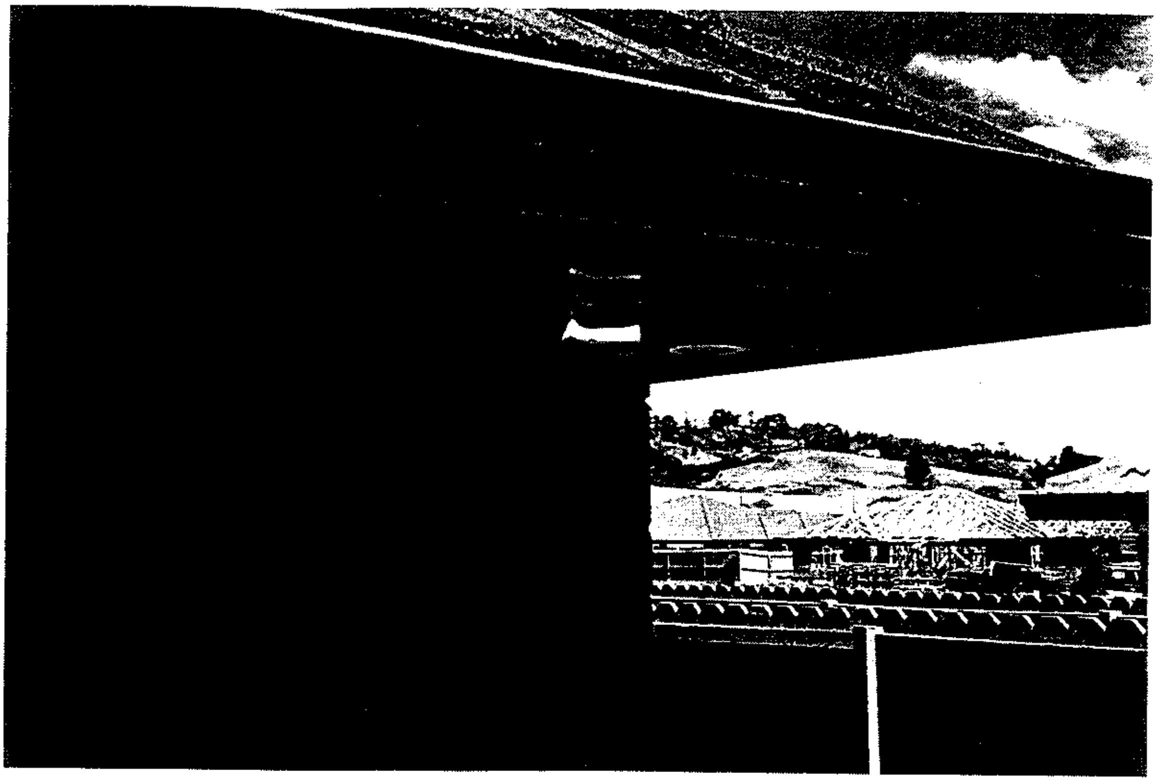


Figure 1.7: Partially melted PVC gutter 5m from Howick fire.

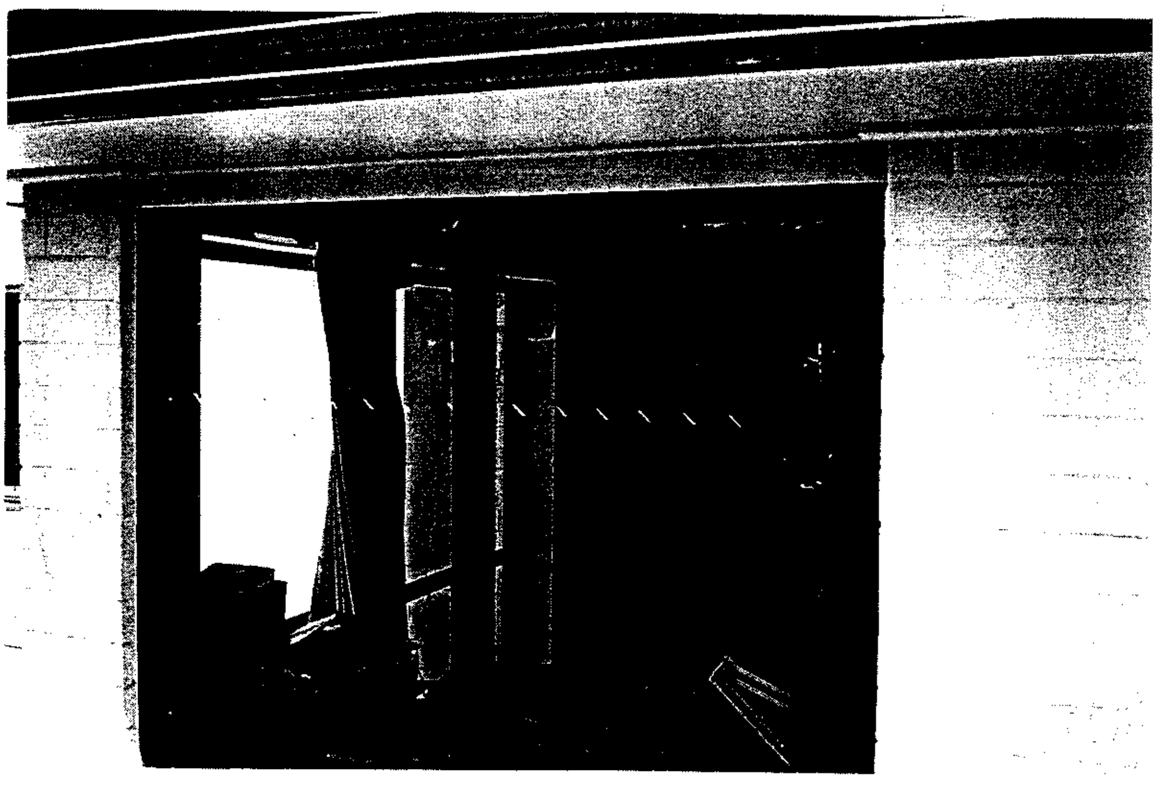


Figure 1.8: Cracked window in house adjacent to Howick fire.

Figure 1.9: Remains of burnt out Devonport house.

Figure 1.10: Extensive charring of neighbouring house. The cedar cladding had started to ignite by the time the Fire Service arrived.

Figure 1.11: Damage to neighbour consisting of broken windows, blistered paintwork and charred timber.

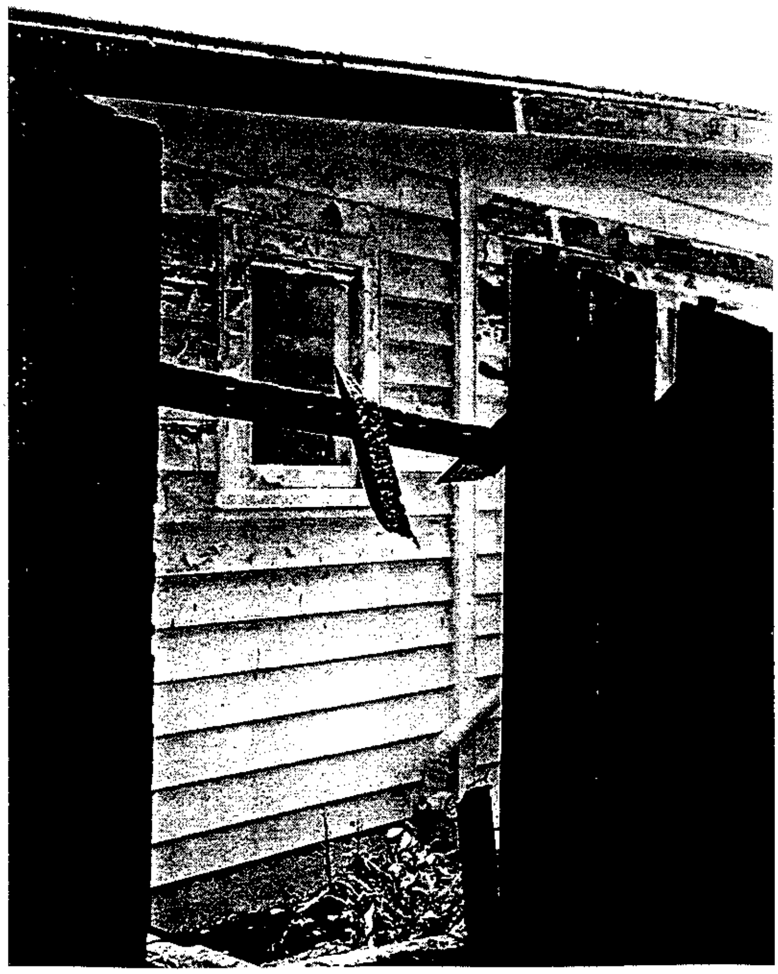


Figure 1.12: Close-up of damage. Note the lack of damage lower down because of the protection from the timber fence.

Figure 1.13: Most remote damage was to the house on the ridge at the rear – 31m from the fire.

Figure 1.14: Blistered paintwork and deformed gutter on remote house.

CHAPTER 2: EMITTED RADIATION

2.1 REVIEW METHOD

In this chapter the basis behind the values of emitted radiation used by the Acceptable Solutions will be explained in detail. Other possible methods of determining emitted radiation based on the work of a number of researchers will be reviewed and their relative advantages/disadvantages will be discussed.

It should be noted that in all cases it is assumed that the radiation is being emitted from openings in a wall of a compartment in which a fire is burning in the post flashover phase of the fire duration curve. See Figure 2.1 below.

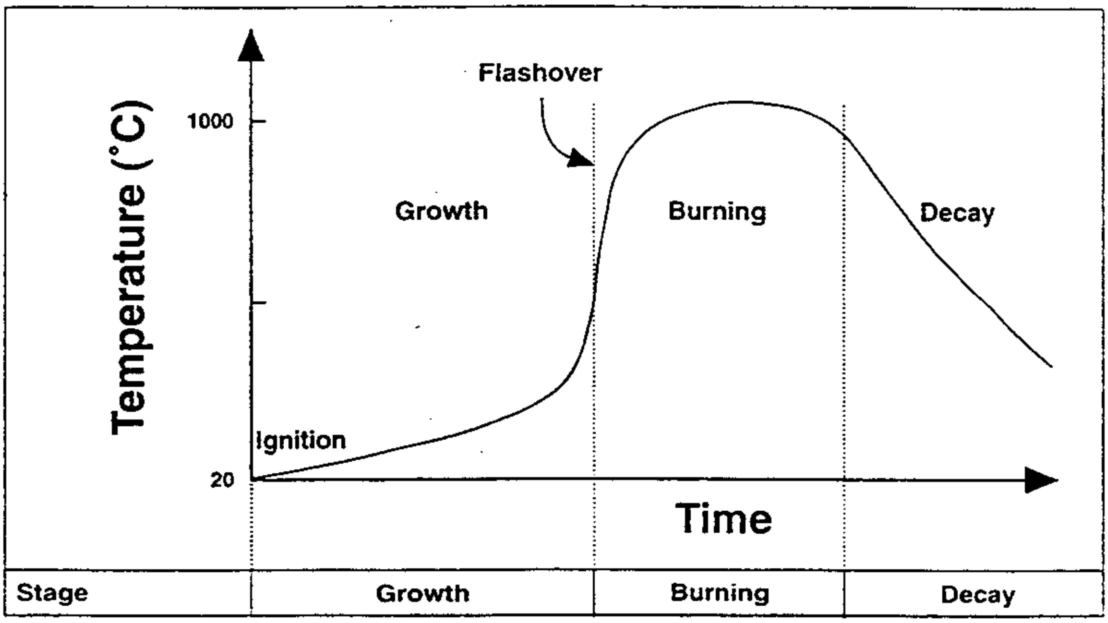


Figure 2.1: Typical Fire Duration Curve

As can be seen from Figure 2.1, the pre flashover growth phase can be an extended period and the compartment temperatures are generally relatively low. Similarly, in the decay phase the compartment temperatures are rapidly reducing from the maximum temperatures achieved during the burning phase and will generally have a much less significant effect.

A number of the more complex methods of determining theoretical time/ temperature curves for compartment fires were produced in order to determine the fire resistance of structural members within or immediately outside the fire compartment. In most case the complexity of the methods has been generated by the need to try to accurately reflect the decay phase of the growth curve. For consideration of the effect of the emitted radiation this area is not as significant and therefore the various complexities involved need not be analysed in detail.

With respect to complexity, it must be borne in mind that the Acceptable Solutions were put in place in order to give people who were not fire engineers a method of achieving the requirements of the New Zealand Building Code. To this end, any method used in the Acceptable Solutions should be reasonably general and simple to apply without the need for extensive computations or theoretical knowledge.

2.2 RADIATION THEORY

In a fire, energy is transferred by three methods - conduction, convection and radiation. In this review it is assumed that the object under consideration is not in contact with the building on fire and therefore will not receive energy by conduction and is also far enough away from the compartment that convection of heat from the hot gases and flames will not occur.

The theory behind heat radiation is given in numerous texts and is defined as the Stefan-Boltzmann Law (Incropera & De Witt, 1990).

$$E_b = \sigma T^4$$

Where E_b = Total emissive power of a black body source

σ = Stefan-Boltzmann constant (5.67×10^{-8} W/m^2.K^4)

T = Hot body temperature in degrees Kelvin

A black body radiator is the ideal emitter in the sense that no surface can emit more radiation than a black body at the same temperature.

For real radiators the concept of emissivity (ϵ) must be incorporated in the formula where the emissivity is the ratio of radiation from the real surface compared to that of a black body.

$$E = \epsilon\sigma T^4$$

E = Emissive power of a real source of temperature T

The effect of the emissivity is discussed in further detail in Chapter 3, but it is generally taken as conservative to assume $\epsilon = 1$. Thus the only variable involved is the temperature of the compartment and as this is raised to the fourth power in the equation any change in T has a significant effect on the emitted radiation.

In considering the radiation from a burning building, the radiator can be taken as either the burning compartment emitting radiation through the unprotected openings such as windows or doors, the radiation from flames projecting out of the unprotected openings or a combination of both. In the following sections the peak compartment temperatures will be considered in detail and the methods proposed by various researchers for evaluating them will be reviewed.

A review of methods of estimating temperatures in compartment fires for the full duration of the fire is given by Walton and Thomas (1995). Reviews of the mathematical model for compartment fires are given by Drysdale (1985) and Quintiere (1995) and it is not proposed to reproduce them in this paper.

2.3 ACCEPTABLE SOLUTIONS METHOD - MARGARET LAW

As noted in Chapter 1, the method used by the Acceptable Solutions to determine building separations is based on BRE Report BR187:1991 "External Fire Spread: Building Separation and Boundary Distances". This report was prepared in support of Approved Document B4 that was part of the Building Regulations for England and Wales (Department of the Environment 1991).

The report is in two parts. Part 1 describes the enclosing rectangle and aggregate notional area methods and these have been copied directly into Appendix C of the Fire Safety Annex of the Acceptable Solutions. The C3 tables of the Fire Safety Annex mentioned earlier, which give the permitted unprotected areas in unsprinklered buildings using the enclosing rectangle method, are a direct copy of Table 1 of this part of BR 187. The report contains some refinements of the method that have not been carried over into the Acceptable Solutions but generally the methods are the same.

Part 2 of the report sets out the basis for the methods described in Part 1 and is a copy of Fire Research Technical Paper No.5 "Heat Radiation from Fires and Building Separations" by Margaret Law (Law 1963). As well as providing the background to Part 1, the paper also describes more sophisticated methods of analysis to provide more accurate answers than those of Part 1. The Law paper describes in detail the reasons for the choice of 12.6 kW/m^2 (0.3 cal $cm^{-2}sec^{-1}$) as the limiting incident radiation and this is looked at in more detail in Chapter 5 of this paper.

The Law paper then details the derivation of the intensity of radiation from compartment fires used to produce the boundary separation tables.

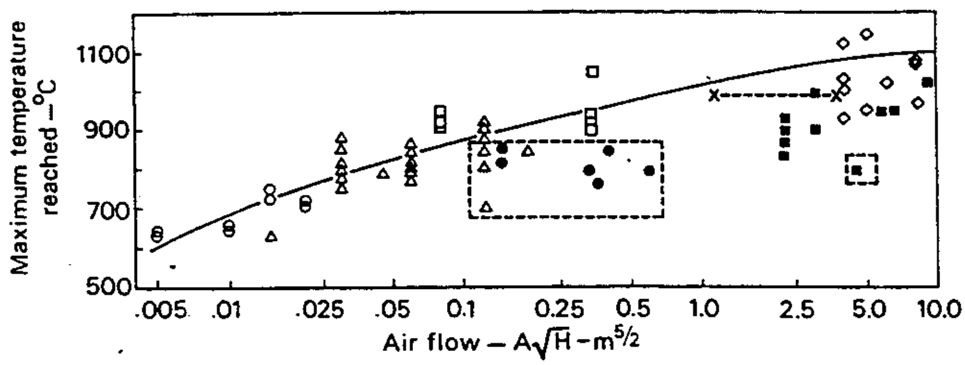
In this section, Law states that although the temperature and hence the radiation from a fire in a compartment varies with time and that the maximum temperatures attained will be dependant on the type and distribution of the fuel and the geometry of the windows and compartment, it is necessary to make considerable simplifications in order to make workable regulations. She states that her report only provides a typical value of intensity that may be expected from fires in a wide variety of buildings and occupancies.

The temperature of a fire depends on the rate of burning within the compartment and the report divides compartment fires into two types:

(a) Those in which the ventilation is restricted and the rate of burning depends on the size of the window. Such fires are considered to be ventilation controlled.

(b) Those in which the window area is comparable to the floor area and therefore the rate of burning depends on the fire load, its surface area and arrangement, not on the window area. Such fires may be said to be fully ventilated or fuel controlled.

For the ventilation controlled fires, Law reviewed the temperatures attained in a number of experiments in England, Sweden and Japan in the middle to late 1950s. For ventilation controlled fires the area of the window opening (A) and its height (H) are important and the value A√H is the most important parameter affecting the rate of burning irrespective of compartment size. Law plotted the maximum temperature achieved in the various experiments against A√H and produced the graph in Figure 2.2.



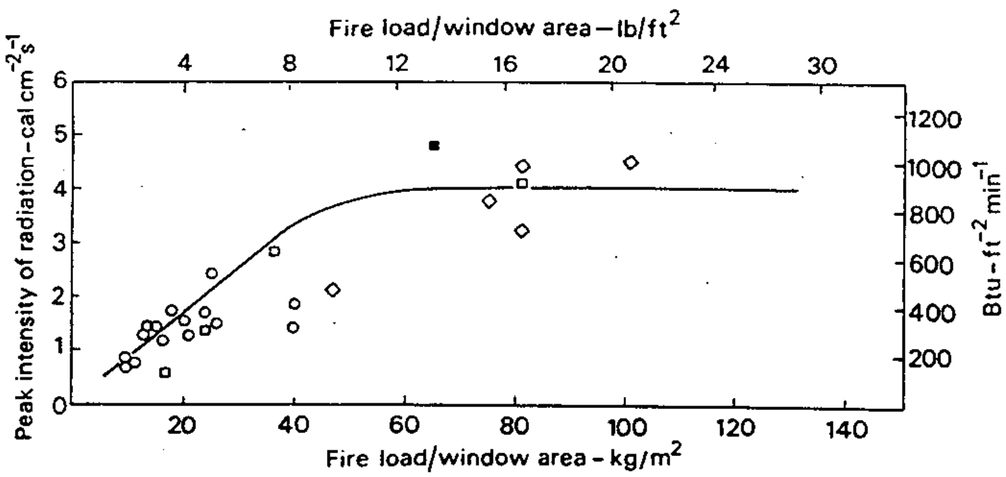
Points within the broken lines are those where the fire load is less than $25kg/m^2$ ($5lb/ft^2$)

	Scale I floor area $0.09m^2$	Scale II floor area $0.49m^2$	Scale III floor area $1m^2$	Large-scale floor area $9m^2$
J.F.R.O. (7) (8) (10)	○	△	□	◇
Swedish test (9)				x-------x
Kawagoe (11) (12)			●	■

Figure 2.2: Maximum Temperature and Air Flow (from Law)

The results of the analysis indicated that there was no marked increase in maximum temperature above an A√H value of 8 $m^{5/2}$ and that the temperatures had a limiting value of less than 1,100°C. For simplicity this was considered to be equivalent to a radiation intensity of 4 cal cm^{-2} sec^{-1} (167.4 kW/m^2). For values of A√H less than 5 $m^{5/2}$ the restricted ventilation begins to have a significant effect on the compartment temperature. This value would correspond to a window size 1.5 m high x 2.7 m wide, so for smaller compartments with restricted window sizes the compartment temperature could be expected to be significantly lower than the limiting value given above. In addition, the results of the experiments indicated that for compartments with low fire loads the fire does not last long enough for the compartment temperatures to reach the limiting value and hence the radiating intensity is significantly less.

For the fuel controlled fires, Law again used experimental values from tests in Japan and England that were done in the late 1950s and early 1960s. For these tests the burning rate was found to be largely independent of A√H and was approximately proportional to the total amount of fuel. The intensity of radiation gave a better correlation with the rate of burning per unit window area. However, for this type of fire, the window area must be comparable to the floor area so the fire load ratios are nominally taken as being the same. The results of the analyses are shown in Figure 2.3. The graph shows that for fire loads greater than 60 kg/m^2 (1,000 MJ/m^2) a radiation intensity of 4 cal cm^{-2} sec^{-1} (167.2 kW/m^2) can be expected. The analyses indicated a number of experiments which had values of fire load per unit floor area of around 25 kg/m^2 had resulted in peak radiation intensities in the order of 2 cal m^{-2} sec^{2} (83.6 kW/m^2). This radiation intensity corresponds to a temperature of about 800°C, which is consistent with the values obtained in Figure 2.3 for the lower fire loads.



	Measured Intensity		Intensity estimated from temperature
	Small scale	3m scale	3m scale
J.F.R.O. (8)(13)(14)(15)(16)	○	□	◇
Kawagoe (11)			■

Figure 2.3: Peak Radiation Intensities vs Fire Load Density

Based on her analysis, Law proposed that for devising regulations on space separation a radiation intensity of 167.2 kW/m^2 (4 cal cm^{-2} sec^{-2}) should be taken for standard occupancies and a lower value of 83.6 kW/m^2 (2 cal cm^{-2} sec^{-1}) be taken for lower fire loads or restricted window sizes. In the Building Regulations for England and Wales, the lower intensity was deemed to come from residential, office and assembly/recreation buildings. For the New Zealand Building Code Acceptable Solutions, these uses corresponded to Fire Hazard Categories 1 and 2 as described in Chapter 1, so a similar stipulation was made.

In further work for the Joint Fire Research Organisation, Law reviewed experimental work in which direct radiation measurements were taken outside a burning compartment (Law 1968). In the experiments the fire load and the window openings were varied and Law's review indicated that fire load and window area and their relationship to each other had a highly significant effect on the intensity of emitted radiation. The graphical analysis of the experimental results indicated a direct relationship between the intensity of radiation and the rate of burning/window area. A comparison of the maximum compartment temperature and the maximum intensity of radiation showed that the assumption of a black body radiator in accordance with the Stefan Boltzmann Law was valid. Law concluded that the results verified that the values used as a basis for the Building Regulations were safe, possibly even a little conservative.

The values mentioned above together with the value of 12.6 kW/m^2 as a critical received radiation (looked at in more detail in Chapter 5 of this paper) have been used as the basis of boundary separation requirements in many countries for the last 30 years. In this time, there have been very few incidences where buildings constructed in accordance with this method have caused significant damage to adjacent buildings. However, with the rise in the use of performance based codes, there has been a move to relook at the matter to see if the approach is overly conservative and hence if any savings can be made in construction costs.

In later work, Margaret Law produced expressions for the maximum compartment temperatures that may be expected for fires in compartments of various sizes with a variety of fire load densities. The work was mainly aimed at determining the fire resistance of structural members within the compartment and is detailed in a Constrado publication "Fire Safety of Bare External Structural Steel" (Law and O'Brien 1981). An extensive analysis of experimental results indicated that it was possible to estimate the maximum fire temperature in a compartment from considerations of fire load, ventilation and compartment dimensions.

The temperature of the fire within the compartment is given by:

$$T_f - T_a = 6000 \frac{(1 - e^{-0.10\eta})}{\eta^{1/2}} (1 - e^{-0.05\psi})$$

where T_f	= maximum fire temperature °K
T_a	= ambient air temperature
A_F	= floor area m^2
A_T	= total enclosure area - window area m^2
A_W	= window area m^2
q	= fire load density kg/m^2
L	= fire load = $A_{F.Q}$
η	= $A_T/(A_W H^{½})$
ψ	= $L/(A_W A_T)^{½}$

Figure 2.4 below shows the compartment temperatures resulting from the above formula for various values of ψ.

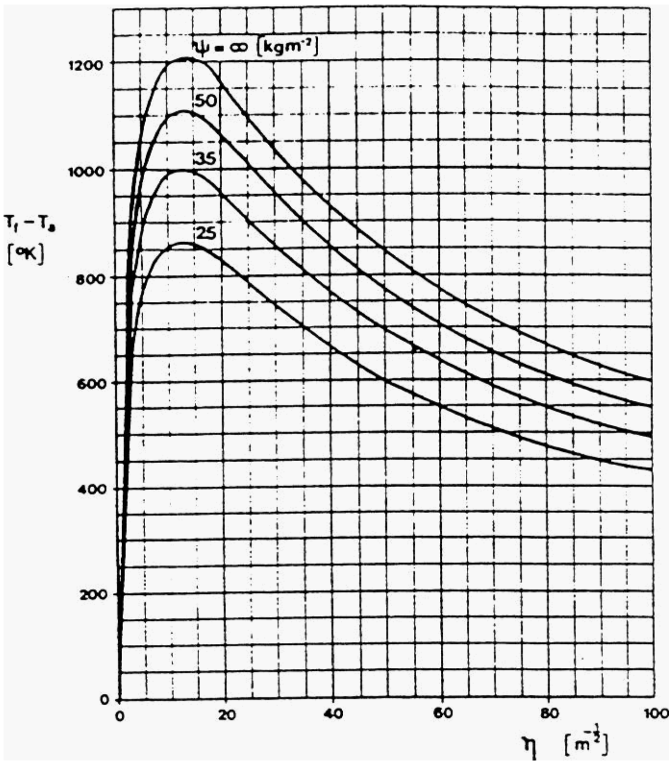


Figure 2.4 Compartment Temperatures

The disadvantage of this method is that it requires some degree of computation and also does not take account of effect of different linings within the compartment and only gives one value for the compartment temperature.

2.4 STANDARD FIRE CURVES

In order to determine the fire performance of building elements, most countries rely on full scale fire resistance tests carried out in large furnaces. In order to have standard fire resistance tests that are readily reproducible, standard time temperature curves have been developed which the furnace heating pattern must adhere to. The most common fire test time temperature curves are **ASTM** E l19 and ISO 834. Most national building codes quote one or other of these specifications in their criteria for establishing fire resistance.

The ISO 834 curve is defined by the equation:-

$$T = 345 \log_{10} (8t + 1) + T_0$$

where t = time (min)

T_0 = ambient temperature (°C).

The ASTM E119 curve was defined by a series of discrete points. For the sake of convenience, a number of equations which approximate the ASTM E119 curve have been produced and one by Lie (1995) is:-

$$T = 750[1 - \exp(-3.79553\sqrt{t})] + 170.41\sqrt{t} + T_0$$

where t = time in hours.

Table 2.1 shows the values of the ASTM E119 curve and ISO 834 for a number of points.

Time (min)	ASTM E119 Temperature (°C)	ISO 834 Temperature (°C)
0	20	20
5	538	576
10	704	678
30	843	842
60	927	945
120	1010	1049
240	1093	1153
480	1260	1257

Table 2.1: ASTM E119 and ISO 834 Fire Temperature Values

The values are shown graphically in Figure 2.5, which indicates that both methods produce similar time temperature curves as would be expected.

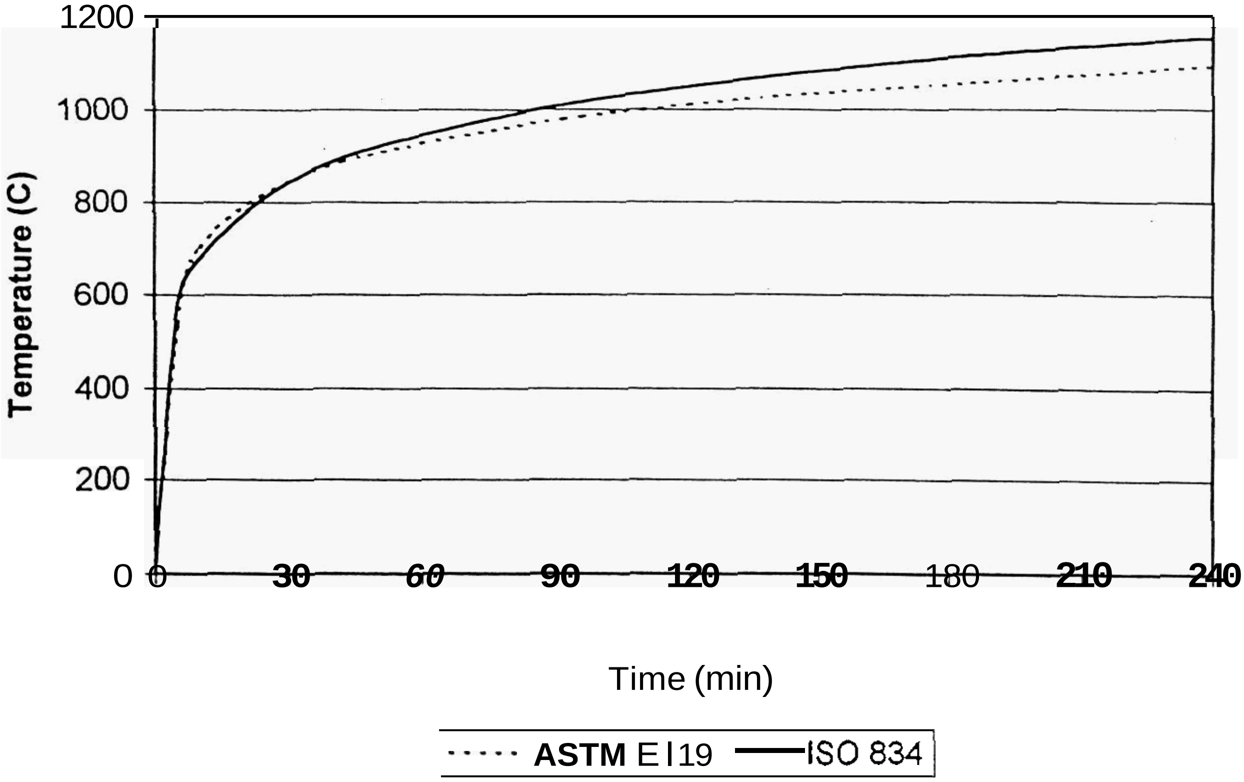


Figure 2.5: Standard Furnace Time Temperature Curves

It has been argued that if fire resistance ratings of structural elements in real fires can be determined by standard fire tests, it is logical to use the same fire tests as the basis for building separation requirements. Barnett (1988) proposed that for a simple method of determining building separations, the standard ISO 834 furnace time temperature curve could be used to approximate the temperature in a compartment and hence predict the radiation that would be emitted through any unprotected openings. In his paper, Barnett illustrates that the emitted radiation values used in the British and Canadian regulations are similar to the radiation values that would result from the temperatures from the ISO 834 fire for 30 minutes and 120 minutes. This is shown on Figure 2.6.

The standard furnace fire test curves are artificial constructs and bear little relationship to the time temperature curves resulting from real fires or from large scale fire tests in that both the initial slow growth and the decay phase are not included. However, both of these regions have substantially lower temperatures than the fully involved phase and hence have much less influence on the radiation being emitted from the compartment.

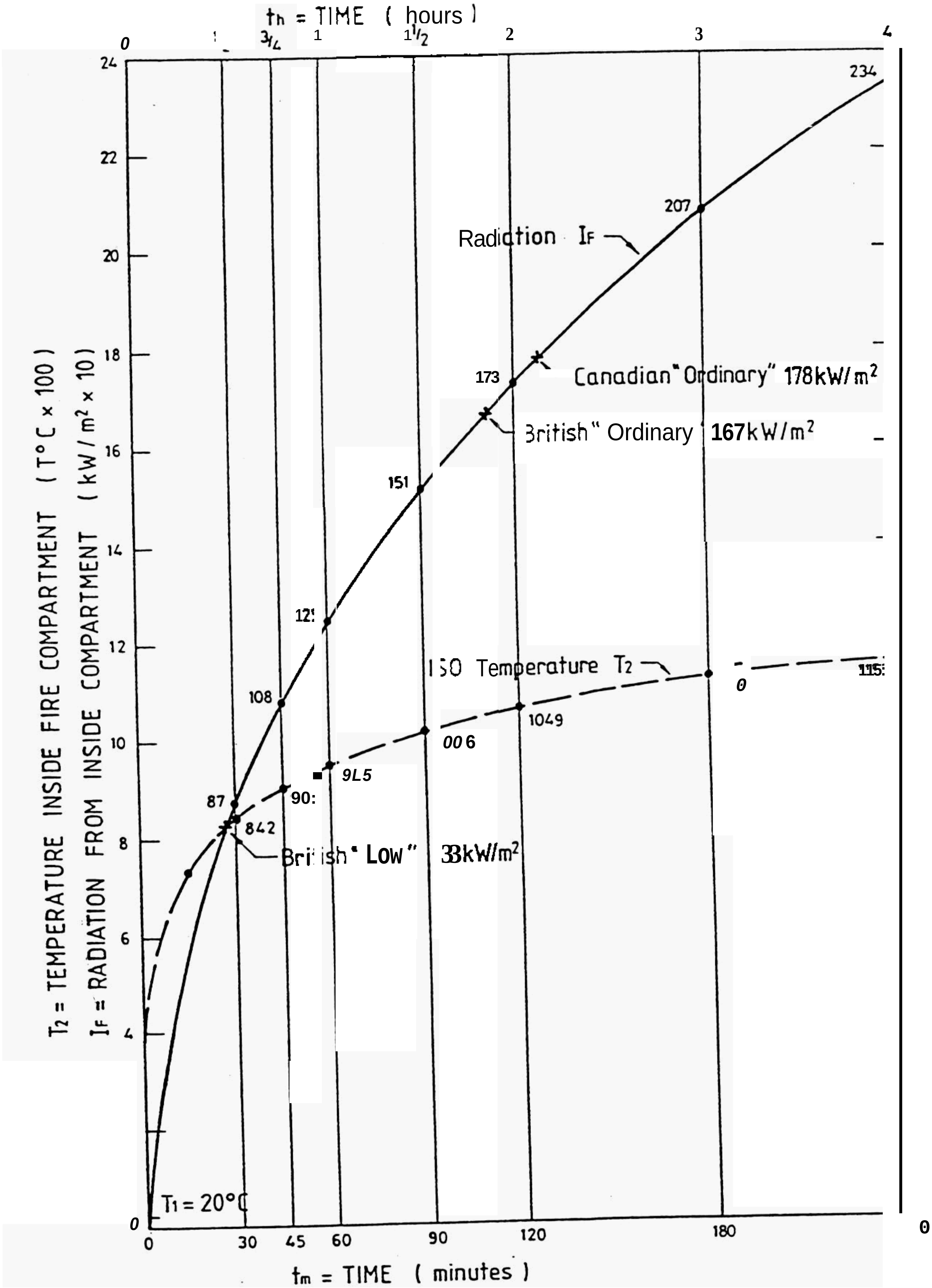


Figure 2.6: Values for ISO Temperature and Corresponding Radiation versus Time for a Fire Compartment

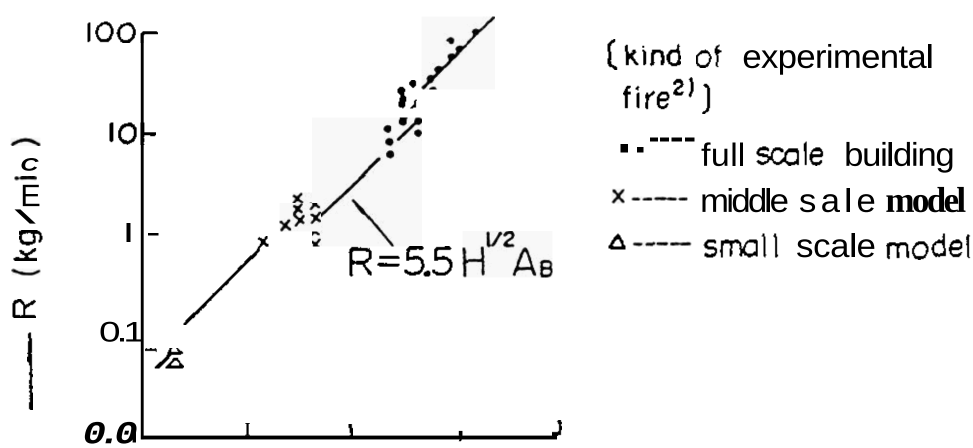
2.5 THEORETICAL AND EXPERIMENTAL WORK BY KAWAGOE

One of the earliest researchers into the behaviour of fully developed compartment fires was Dr Kunio Kawagoe of the Building Research Institute of Japan. Over a number of years Kawagoe and fellow researchers conducted experiments into the parameters affecting compartment temperatures and published a number of definitive papers on the subject (Kawagoe 1958, Kawagoe and Sekine 1963, Kawagoe and Sekine 1964, Kawagoe 1967, Kawagoe 1971).

Based on theoretical analysis of the flow of gases in and out of a burning compartment with a single opening, Kawagoe postulated that the rate of burning in the compartment followed the relationship:-

$$\dot{m} = 5.5\, A_w H^{1/2} \text{ kg/min}$$

where m = the rate of combustion
A_w = area of opening (m^2)
H = height of opening (m)



Based on a simplified analysis of the heat balance in a burning compartment backed up by experimental results, Kawagoe's early work showed that the temperature in a compartment was dependent on the thermal conductivity of the compartment walls as well as a factor he called the "Opening Factor" which was defined as:-

Opening factor $= A_w H^{1/2} / A_T$

where A_T = total internal surface area of the compartment

From a survey of a large number of Japanese buildings, the typical fire loads for various types of residential and commercial buildings were determined. The fire loads were given on an equivalent weight of wood per m^2 of floor area. Using a calorific value of wood of approximately 18 MJ/kg and based on experimental results which gave a combustion ratio of 0.6, Kawagoe took the wood equivalent as being 10.8 MJ/kg (2575 kcal/kg).

The values obtained from the survey varied from 20 to 600 kg/m^2 but for ease of analysis, Kawagoe took only two fire loads, 50 kg/m^2 for a normal fire and 100 kg/m^2 for a large fire. These are approximately 500 MJ/m^2 and 1000 MJ/m^2 respectively.

From the same survey, Kawagoe classified the buildings into nine groups based on their opening factors and calculated the theoretical fire duration times for the two fire loads. The classifications used are given in Table 2.2 below and the resulting time temperature curves taken from the 1963 paper are given in Figure 2.8.

Class	Opening Factor	Fire Duration - ne, T (min)	
		For 100 kg/m^2	For 50 kg/m^2
A	0.034	154	77
B	0.05	118	59
C	0.07	92	46
D	0.09	84	42
E	0.10	64	32
F	0.12	48	24
G	0.16	42	21
H	0.206	41	20
I	0.23	35	18

Table 2.2: Classification of Buildings by Opening Factor (Kawagoe)

It is on this early work by Kawagoe that most of the later work by other researchers throughout the world was based.

In further work Kawagoe re-examined the heat balance equation in more detail and allowed for more of the physical factors that affected the compartment temperatures.

These were the:-

Floor factor **F,** $= A_f/A_T$

Where **A,** = floor area
A_T = total internal surface area

Temperature factor $F_0 = A_w H^{½}/A_T$
(opening factor)

Fire duration factor $F_d = F_f/F_0$

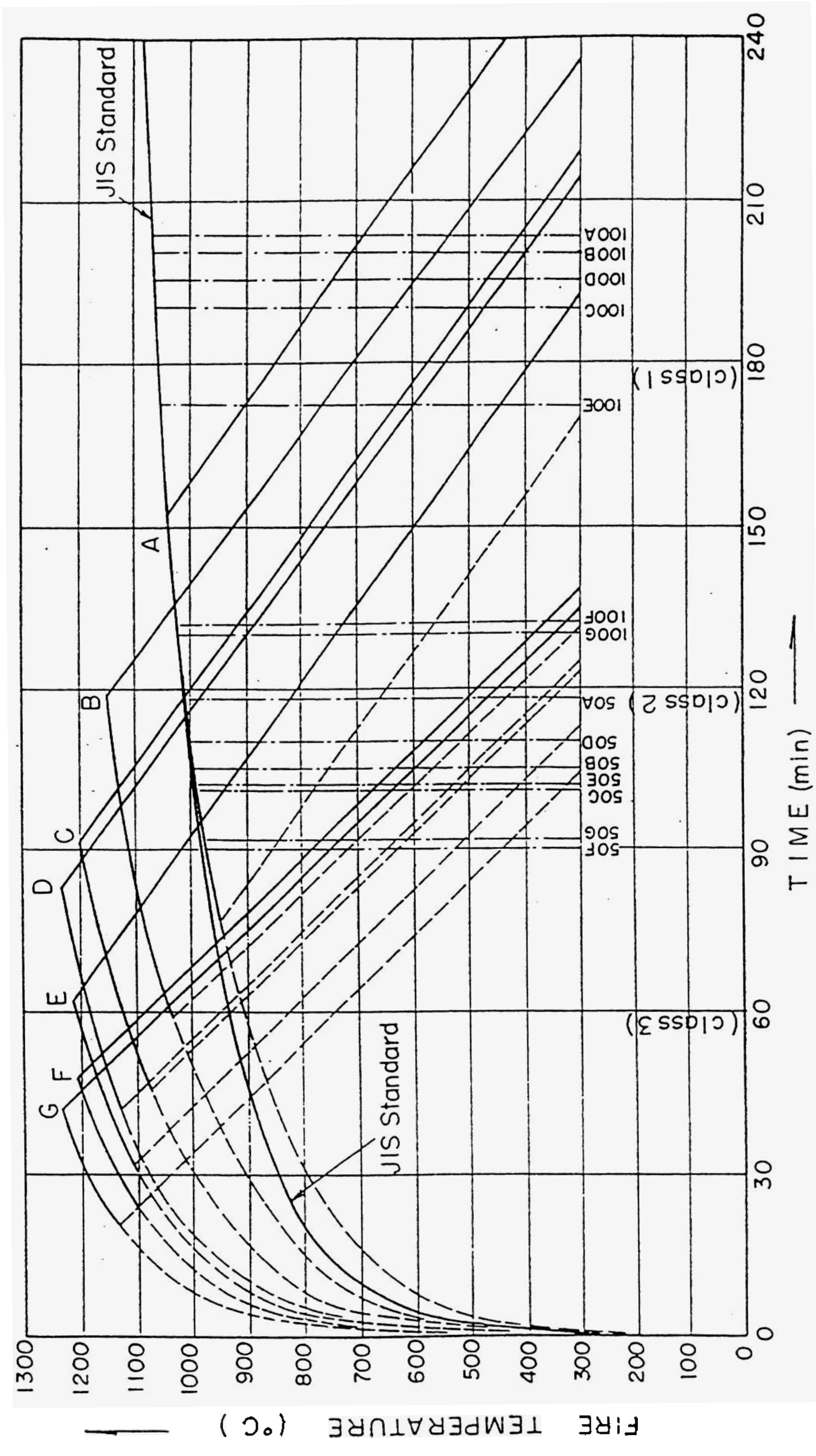


Figure 2.8: Kawagoe's Estimated Fire Temperature Curves

Fig. 8 Nomogram for the estimation of fire temperature time curve and equivalent standard test time

(where λ = 1.0 Kcal/mh°C, C= 0.3 Kcal/kg°C, ρ = 2400 Kg/m^3, W = 5%, wall thickness 15 cm)

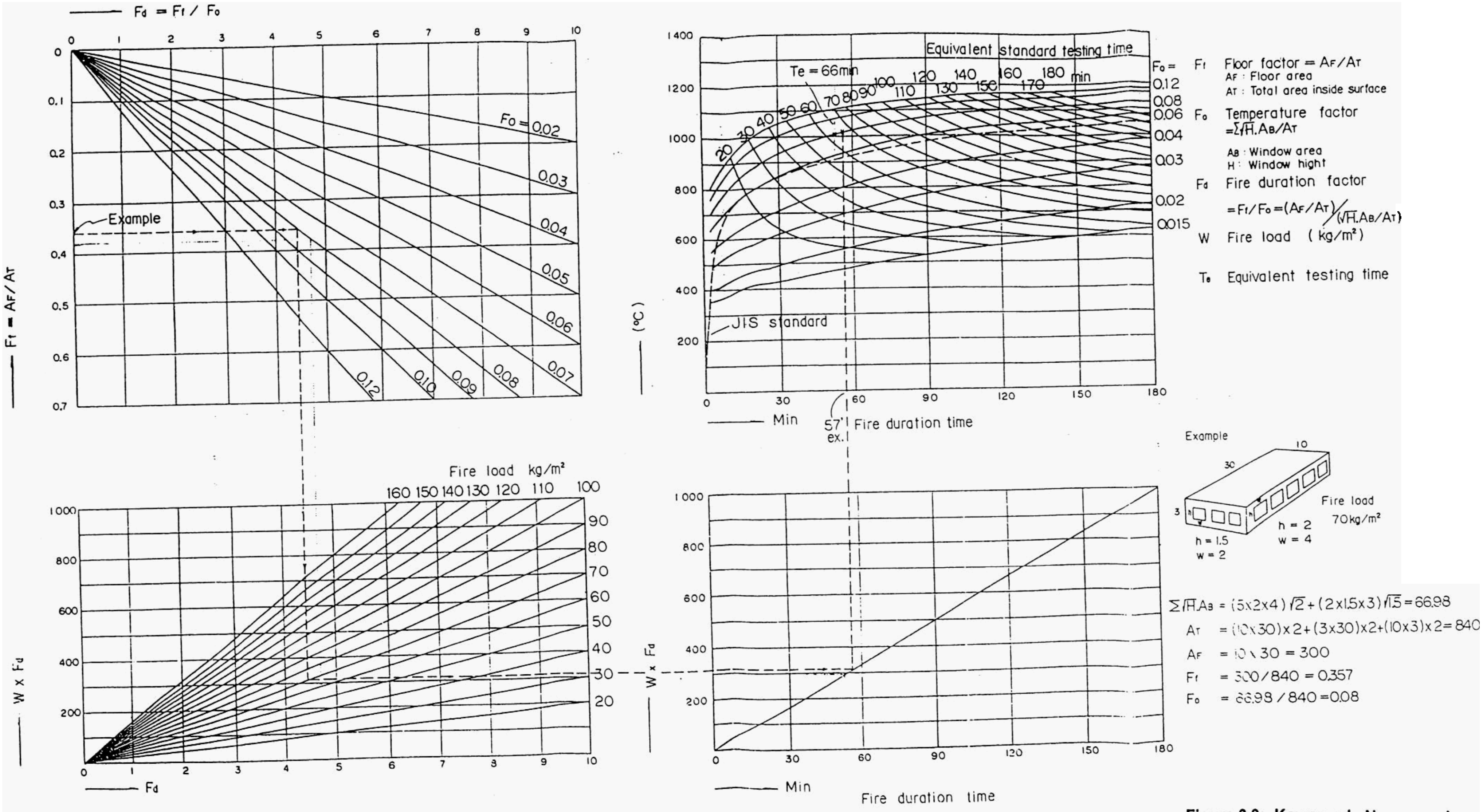


Figure 2.9: Kawagoe's Nomograph for Compartment Temperatures

Based on this more refined analysis and more experimental work, a series of nornographs were produced which could be used to determine the compartment temperature of a particular building based on the physical configuration, the fire load and the thermal conductivity of the enclosure. A typical nomograph is shown in Figure ***2.9,*** which is taken from Kawagoe's 1967 paper.

Although Kawagoe's work is now somewhat dated, the approach would still be generally applicable. However, a considerable amount of rework would be necessary to produce nomographs for New Zealand conditions and it is considered that these forms of nornographs would **be** too complicated to be used in a generally simple acceptable solution.

2.6 SWEDISH FIRE CURVES

The main problem with the early work in determining compartment temperatures was that little account was taken of the effect of different compartment geometries, fire loads or the thermal properties of compartment boundaries. In addition, the rate of decay of the fire was rarely considered although this could have a significant effect on the fire resistance of the structural elements in the compartment.

In 1970, a paper published in Sweden (Magnusson and Thelandersson, 1970) outlining a method which took most of these factors into account. Based on a comprehensive study of the results of wood fuel fires in compartments and building on the **work** of Kawagoe, a computer model was set up to solve the energy balance equation. The model assumed:-

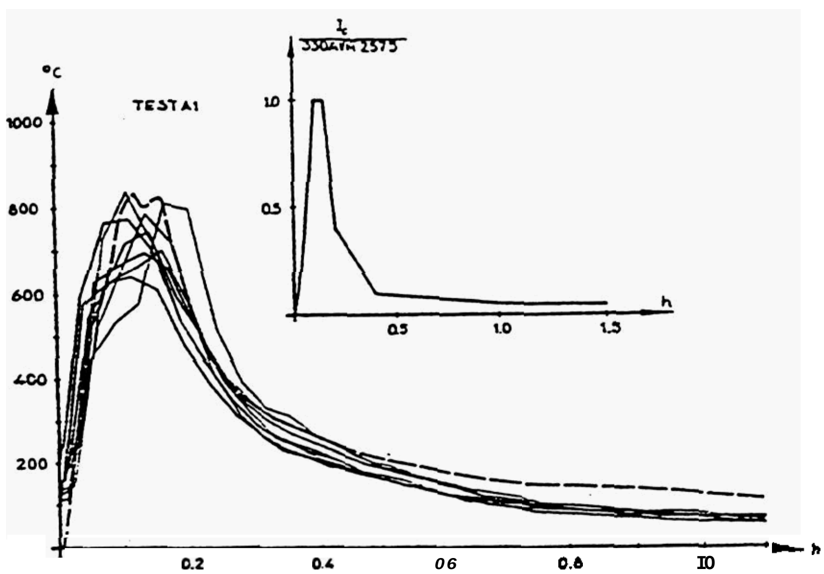
(a) complete combustion took place within the compartment;

(b) the temperature was uniform throughout the compartment;

(c) all internal surfaces had the same heat transfer coefficient;

(d) heat flow to and through the compartment boundaries was one dimensional and the boundaries could be assumed to be "infinite slabs"

One of the factors which has a significant effect on the shape of the time temperature curve is the energy release rate of the fuel as a function of time. The size and length of burning of a fire depends on the fuel, the ventilation and the thermal properties of the compartment. Magnusson and Thelandersson determined that the only way to establish the shape of the energy release rate curve was by analysing experimental data to establish a suitable relationship for a best fit curve. Using the results of about 30 full scale fire tests, energy release rate curves were determined for use as one of the main input values for the computer model. A graph of a typical test result is shown in Figure 2.10 with the smaller graph being the energy release rate and the larger showing the agreement between the calculated (dashed line) and experimental (solid line) temperatures.



Test A1
Percentages of the total bounding surface area:
Concrete, 20 cm in thickness, 34.8 per cent.
Lightweight concrete, 12.5 cm in thickness. 42.2 per cent.
Concrete, 3 cm in thickness + lightweight concrete, 10 cm in thickness, 18.3 per cent
Window area 4.7 per cent.
Opening factor 0.06 $m^{1/2}$ (t > 0.1 h).
Duration of the fire 0.17 h.
Fire load 15.1 Mcal · m^{-2} of bounding surface area.

Figure 2.10: Swedish Experimental Time Temperature Curves

By carrying out extensive calculations, Magnusson and Thelandersson were able to produce time temperature curves for the complete combustion process allowing for a wide range of fuel loads, ventilation factor, total compartment surface area and boundary thermal properties. To simplify the results, the fire load and ventilation factor ($A\sqrt{H}$) were divided by the total internal surface area of the compartment. Charts were then produced for seven types of fire compartments that had varying boundary materials. Figure 2.11 is taken from the paper and gives typical time temperature charts for a Type A enclosure. Note that t is the duration in hours of the flaming phase of the combustion process and q is the fire load density in $Mcal/m^2$. The configuration of the boundary materials of the seven types of compartments analysed in the paper is given in Table 2.3.

Compartment Type	Boundary Structure
Type A	200 mm of a material whose thermal properties correspond to average values for concrete, brick and lightweight concrete. (Standard compartment)
Type B	200 mm of concrete
Type C	200 mm of lightweight concrete
Type D	50% concrete 50% lightweight concrete
Type E	50% lightweight concrete 33% concrete 17% 13 mm plasterboard (internal) plus 100 mm mineral wool plus 200 mm brick (external)
Type F	80% 2 mm uninsulated steel 20% 200 mm concrete
Type G	20% 200 mm concrete 80% 2 x 13 mm plasterboard (internal) plus 100 mm air gap plus 2 x 13 mm plasterboard (external)

Table 2.3: Compartment Types for Swedish Curves

A4

Time Graphs of Temperature of Combustion Gases. Type A Enclosed Space.

Opening Factor $A\cdot\sqrt{H}/A_t = 0.06\ m^{1/2}$

T	0.1	0.2	0.3	0.5	0.75	1.0	1.5	2.0
q	9.0	18.0	27.0	45.0	67.5	90.0	135.0	180.0
Time h	T	e m	p	e	r a	t	u	r e
0.05	575	575	575	575	575	575	575	575
0.10	858	858	858	858	704	704	704	704
0.15	493	861	861	861	784	784	784	784
0.20	404	802	879	879	882	882	882	882
0.25	296	679	898	898	889	889	889	890
0.30	175	538	838	914	908	908	908	908
0.35	174	490	761	928	923	923	923	923
0.40	166	430	669	942	936	936	937	937
0.45	159	369	572	954	949	949	949	949
0.50	151	303	532	877	961	961	961	961
0.60	136	277	433	762	982	982	982	982
0.65	128	262	402	694	992	992	992	992
0.70	120	247	326	620	939	1001	1001	1001
0.80	104	215	300	574	872	1018	1018	1018
0.90	89	185	272	520	795	954	1032	1032
1.00	71	152	243	466	705	909	1044	1044
1.10	51	116	213	409	637	858	1054	1054
1.20	48	80	184	343	593	803	1064	1064
1.30	45	76	155	327	550	742	1029	1072
1.40	43	72	123	303	505	675	1013	1080
1.50	41	68	89	281	460	640	996	1087
1.60	40	65	86	259	413	603	966	1093
1.70	38	62	81	236	364	567	935	1062
1.80	37	59	78	213	348	529	902	1049
1.90	36	56	74	191	332	491	866	1036
2.00	35	54	71	169	317	452	830	1022
2.20	33	50	66	121	289	371	756	984
2.40	32	47	61	93	263	340	683	943
2.60	31	44	57	85	236	310	605	900
2.80	30	42	54	79	210	283	524	854
3.00	29	40	51	74	185	257	440	805
3.20		39	48	70	159	230	381	756
3.40		37	46	67	131	204	355	705
3.60		36	44	63	103	178	331	652
3.80		35	42	60	86	152	308	597
4.00		34	41	57	81	123	288	541
4.20		33	40	55	77	95	269	483
4.40		32	38	53	73	90	249	423
4.60		31	37	51	70	85	230	377
4.80		31	36	49	67	81	211	348
5.00		30	35	47	64	77	193	319
5.20			35	46	62	74	174	292
5.40			34	44	59	71	155	265
5.60			33	43	57	69	135	238
5.80			32	42	55	66	114	210
6.00			32	41	54	64	94	185

A5

Time Graphs of Temperature of Combustion Gases. Type A Enclosed Space.

Opening Factor $A\cdot\sqrt{H}/A_t = 0.08\ m^{1/2}$

T	0.1	0.2	0.3	0.5	0.75	1.0	1.5	2.0
q	12.0	24.0	36.0	60.0	90.0	120.0	180.0	240.0
Time h	T	e m	p	e	r a	t	u	r e
0.05	622	622	622	622	622	622	622	622
0.10	935	935	935	935	766	766	766	767
0.15	532	937	937	937	853	853	853	853
0.20	432	869	955	955	959	959	959	959
0.25	314	734	973	973	965	965	965	965
0.30	181	575	903	987	981	981	981	982
0.35	180	521	818	1001	995	995	995	995
0.40	171	454	720	1013	1008	1008	1008	1008
0.45	163	386	611	1024	1020	1020	1020	1020
0.50	155	314	561	937	1031	1031	1031	1031
0.60	139	285	454	807	1050	1050	1050	1050
0.65	131	269	396	732	1058	1058	1058	1058
0.70	122	253	336	651	996	1066	1066	1066
0.80	106	219	306	598	920	1081	1081	1081
0.90	89	186	275	539	833	1005	1092	1092
1.00	70	151	245	479	735	953	1102	1102
1.10	47	113	214	417	659	897	1111	1111
1.20	44	73	183	352	612	836	1119	1119
1.30	42	70	151	328	564	769	1077	1126
1.40	40	66	117	304	516	695	1058	1132
1.50	39	62	81	281	466	657	1038	1138
1.60	37	59	78	257	415	618	1004	1143
1.70	36	56	74	234	363	577	969	1105
1.80	35	53	71	210	347	537	932	1090
1.90	34	51	68	187	331	496	893	1074
2.00	33	49	65	163	316	454	853	1058
2.20	31	46	59	112	287	368	774	1016
2.40	30	43	55	83	260	337	695	971
2.60	29	40	51	77	233	307	611	923
2.80	28	38	48	71	206	279	524	873
3.00	27	37	45	67	180	252	434	820
3.20		35	43	62	153	224	373	769
3.40		34	41	59	124	198	347	714
3.60		33	40	55	94	171	323	656
3.80		32	38	53	77	143	302	599
4.00		31	37	50	72	113	282	539
4.20			36	48	68	84	262	478
4.40			35	46	65	79	242	415
4.60			34	45	62	75	222	365
4.80			33	43	59	71	203	338
5.00			32	42	56	68	185	309
5.20				40	54	65	166	282
5.40				39	52	62	146	254
5.60				38	50	60	125	227
5.80				37	48	57	104	199
6.00				36	47	55	82	172

Figure 2.11: Swedish Time Temperature Charts

A series of graphs was produced from the charts to enable compartment temperatures to be determined quickly based on the fuel load, ventilation and compartment types.

Magnusson and Thelandersson's work was reviewed by Pettersson (1971) and later extended by Pettersson et al (1976) to produce an engineering method to design steel structures. The charts and graphs in the later publication were based on the earlier work, but were in the more widely accepted metric units and hence now have more overall acceptability. Figure 2.12 gives typical graphs for Type A compartments taken from Drysdale (1985).

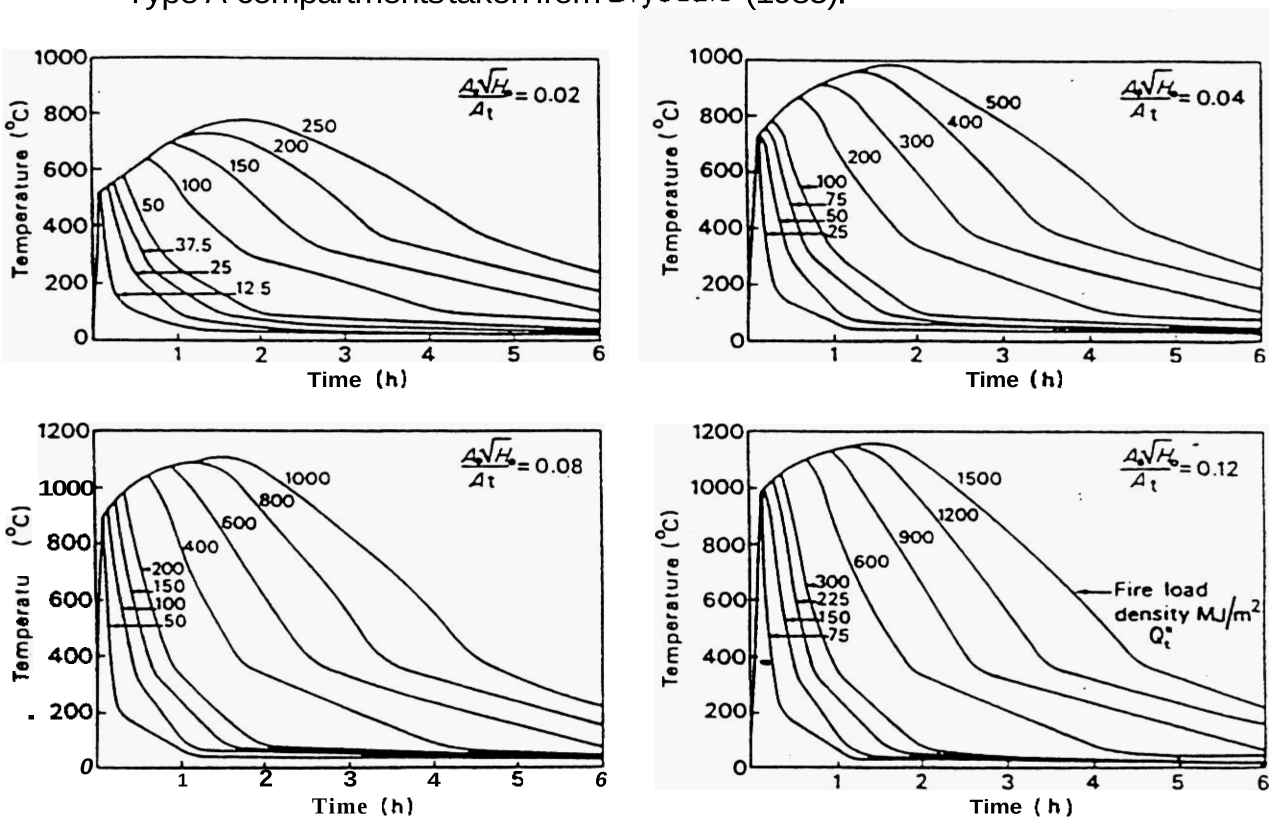


Figure 2.12: Typical Swedish Time Temperature Curves

Thus the Swedish fire curves give a set of realistic time temperature curves for compartment fires as a function of the fire load, the ventilation of the compartment and the thermal properties of the compartment boundaries. The curves rapidly gained acceptance and have been widely used within the fire engineering profession, either in their original state or as modified by subsequent researchers. However, although suitable for specific fire engineering design by experienced practitioners, the curves would appear to be somewhat complicated for inclusion in the Acceptable Solutions. In addition, although they may give accurate compartment temperatures, the user would then be required to undertake further calculations to establish the radiation for each specific case and this would be an unwanted complication for the majority of the users of the Acceptable Solutions.

2.7 SIMPLIFIED MATHEMATICAL EXPRESSION FOR COMPARTMENT TEMPERATURE BY LIE

In a paper presented in Fire Technology magazine, Lie (1974) reviewed the factors influencing the time temperature curve and noted that a number of the factors were very difficult to predict but had a substantial effect on the temperatures produced in a burning compartment. He proposed that it was not necessary to know exactly what the temperatures were at any point in time but rather to be able to find a fire curve for the building which, with reasonably probability, would not be exceeded. He further proposed that the most probable type of fire for most compartments would be ventilation controlled and as this was usually the most severe, this was the only type of fire that need be analysed.

In order to derive his analytical expressions, Lie used the work of Kawagoe and Sekine discussed in Section 2.5 to produce time temperature curves by solving the heat balance equation. In his solution, he used the same factor to allow for the ventilation conditions, ie:

$$F = \frac{AH^{1/2}}{A_T}$$

He found that the thermal properties of the boundary materials did not have a great influence on the curves unless there was a large variation in the properties. He proposed that only two types of boundary conditions need be considered:-

(a) Heavy materials such as concrete, brick, etc. with a density greater than 1600 kg/m³

(b) Light materials such as lightweight concrete, plasterboard, etc. with a density of less than 1600 kg/m^3.

Figure 2.13 shows the time temperature curves for a heavy wall compartment for various opening factors.

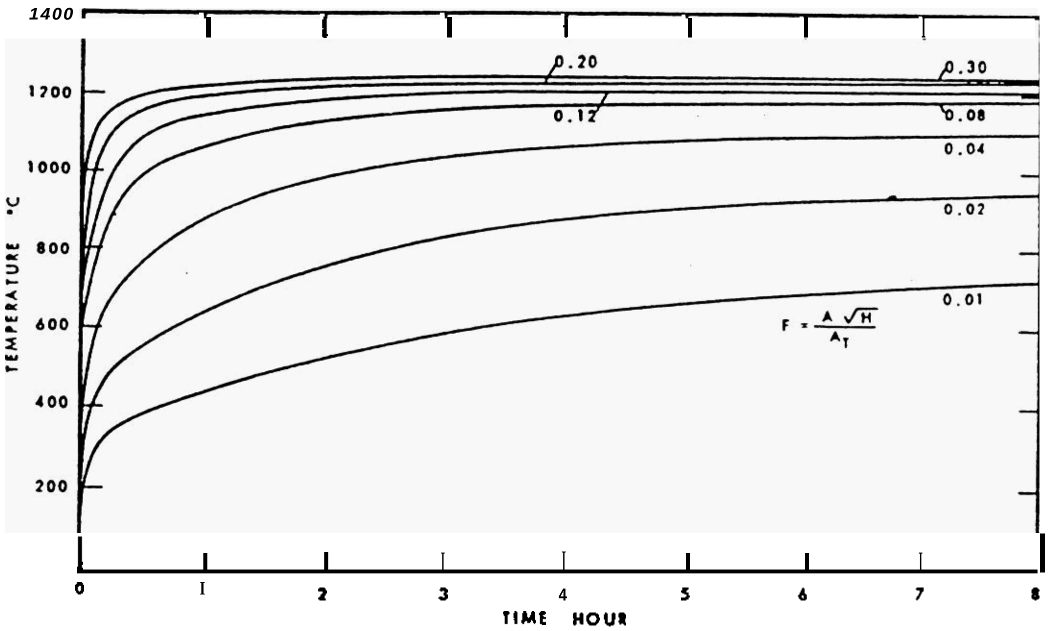


Figure 2.13: Lie's lime Temperature Curves for Heavy Walled Compartment based on Heat Balance

By analysing the curves, Lie was able to derive a mathematical expression that reasonably described them. That expression was:

$$T = 250\,(1 \quad e^{-} \left[3\,(1 - e^{-0.6t}) - (1 - e^{-3t}) + 4(1 - e^{-12t})\right] + C \quad 0$$

Where T = fire temperature (°C)
t = time (hrs)
C = constant based on boundary materials.
C = 0 for heavy material ($P \geq$ 1600 kg/m^3) and
C = 1 for light materials ($P \leq$ 1600 kg/m^3)

Figure 2.14 shows the comparison of the curves produced by the analytical expression with those derived from the solution of the heat balance equation for lightweight boundary materials.

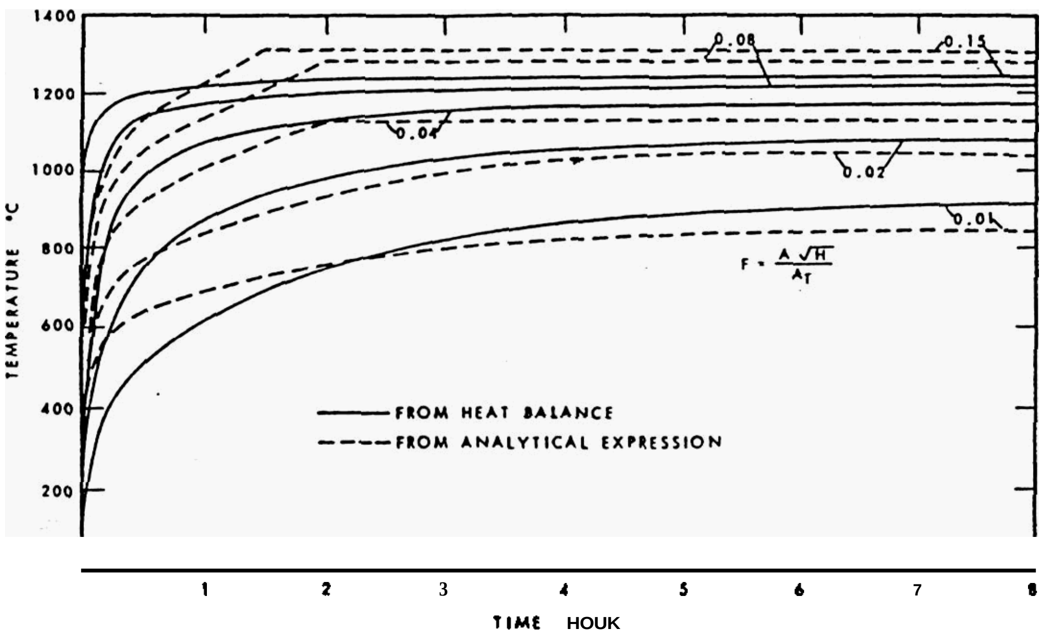


Figure 2.14 Comparison of Time Temperature for Light Walled Compartment obtained from Heat Balance and Mathematical Expression

Although the expression produced curves that tended asymptotically to a maximum temperature after a long duration, all fires will start to decay once the fuel is consumed. Based on Kawagoe's rate of burning expression:

$$R = 330AH^{½}$$

Where **R** = rate of burning in kilograms/hour

Lie showed that the length of the burning phase of a fire was given by:

$$t = \frac{Q}{330F}$$

Where Q is the fire load per unit area of total internal compartment surface (kg/m^2)

After the time *t*, the time temperature curve starts to decrease and Lie derived an expression for the typical decay rates. A typical resultant graph of the time temperature curve is shown in Figure 2.15 for a compartment with heavy boundary materials and an opening factor of 0.05.

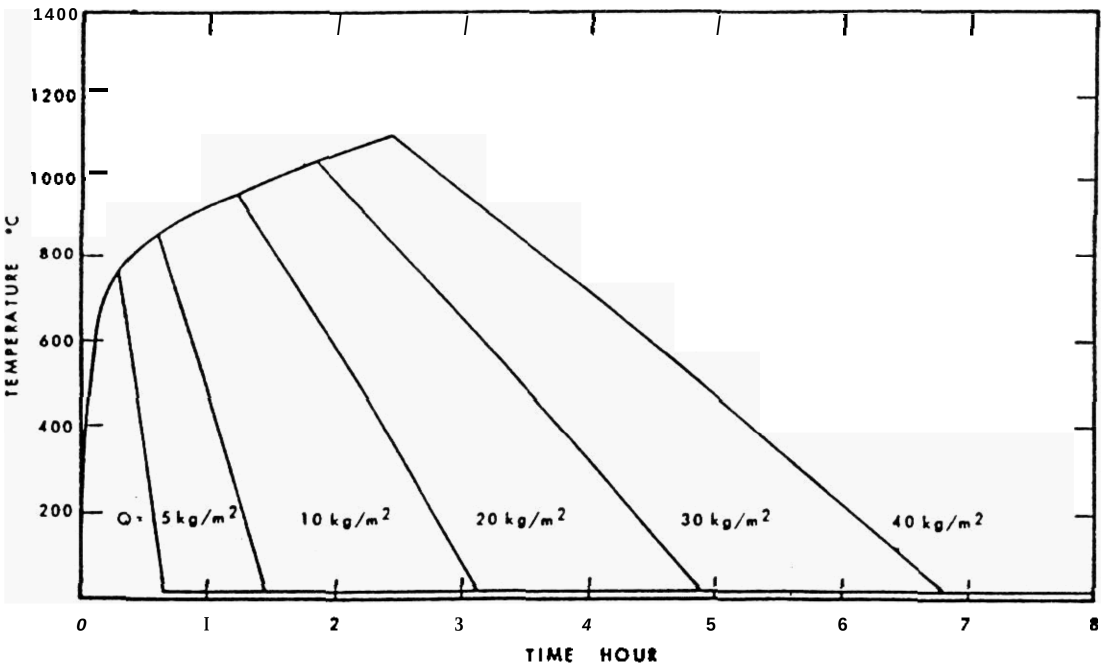


Figure 2.15: Characteristic Temperature Curves from Lie

By comparing his expression with the results of numerous experiments, Lie was able to confirm that it produced curves that were reasonably conservative. A typical comparison with experimental results is shown in Figure 2.16.

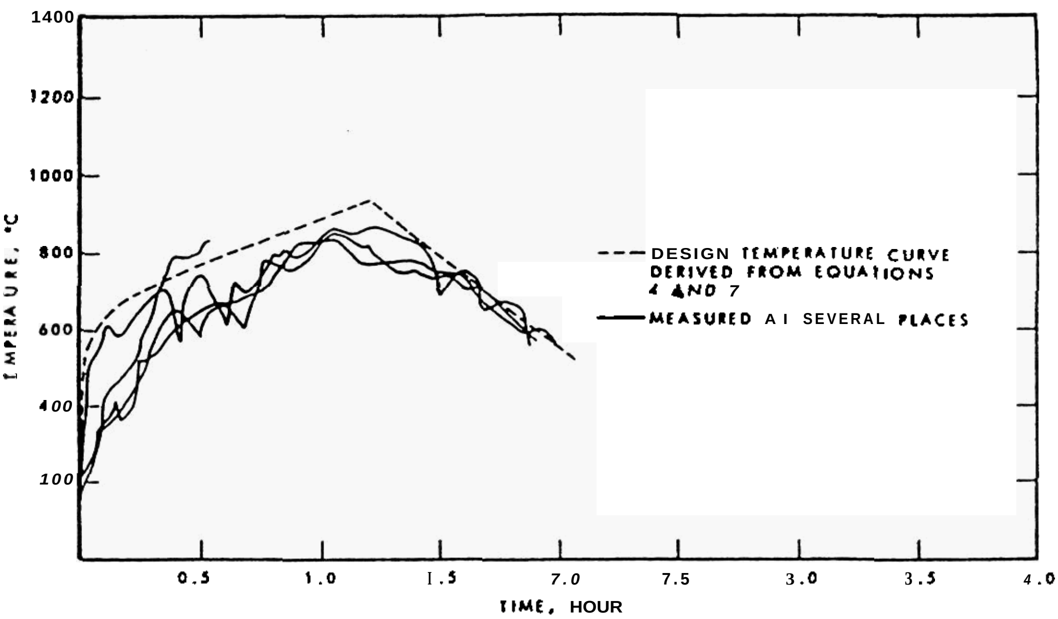


Figure 2.16: Comparison of Experimental and Analytical Time Temperature Curves

Although it is relatively simple to produce curves from the Lie expression using a spreadsheet, the complications mentioned in earlier sections still apply and therefore rule out the method for use in a simple Acceptable Solution.

2.8 BABRAUSKAS'S APPROXIMATE METHOD FOR PREDICTING COMPARTMENT TEMPERATURES

After undertaking detailed theoretical analysis and experimental verification of the post flashover compartment temperatures Babrauskas (1978) developed a computer programme, COMPF2, to calculate the characteristics of a single compartment fire with ventilation through a single opening (1979). This computer model will be reviewed later in this chapter. After this work, Babrauskas wanted to provide a simple calculation method that produced results that fairly accurately agreed with the compartment temperatures predicted by detailed numerical analysis using computer methods.

From his earlier review of the theory, Babrauskas determined that the compartment fire temperature was principally influenced by the following variables:

(a) Fuel release rate
(b) Ventilation opening size and shape
(c) Room wall and ceiling thermal properties
(d) Combustion efficiency
(e) Heat of combustion of the fuel
(9 Effective emissivity of the fire gases

By selecting suitable approximate expressions to account for the above variables, Babrauskas then curve-fitted these expressions to results produced by COMPF2. The expression Babrauskas produced (1981) was:

$$T, = T_a + (1725 - T_a)\,.\theta_1.\theta_2.\theta_3.\theta_4.\theta_5$$

Where: T_f is the fire temperature

T_a is the ambient temperature ("C)

θ_{1-5} are efficiency factors as detailed below

θ_1 Burning Rate Stoichiometry

This variable accounts for the heat release rate for the fuel and Babrauskas produced various expressions for general fuel types, wood cribs and pool fires. The expression compares the actual burning rate with the burning rate at stoichiometry where just sufficient air is provided to fully bum the fuel without residual fuel or air remaining. A dimensionless variable ϕ known as the equivalence ratio is defined as:

$$\phi = \frac{Q}{Q_{st}}$$

where Q = the actual heat release rate

and Q_{st} = the stoichiometric heat release rate.

For general conditions:

$$Q_{st} = 1500 A\sqrt{H}$$

$$\text{so } \phi = \frac{Q}{1500 AJH}$$

Where A = area of opening

H = height of opening

For situations where there is excess air, the burning is said to be fuel lean and ϕ is less than 1. In these situations,

$$\theta_1 = 10 + 0.51 \ln\phi$$

Where there is excess fuel, known as fuel rich, ϕ is greater than 1 and

$$e_, = 1.0 - 0.05 (\ln\phi)^{5/3}$$

A graph for determining θ_1 is given in Figure 2.17

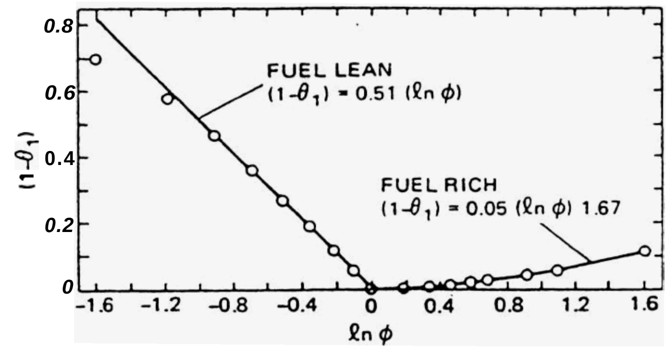


Figure 2.17 Effect of Equivalence Ratio (SFPE)

θ_2 Wall Steady State Losses

This factor accounts for important variables involving the compartment surface properties: area A_T (m^2), thickness L (m), density ρ (kg/m^3), thermal conductivity k (kW/m.K), and heat capacity C_p (kJ/kg.K).

This factor is given as: $\theta_2 = 1.0 - 0.94 \exp\left[-54\left(\frac{A\sqrt{H}}{A_T}\right)^{2/3}\left(\frac{L}{k}\right)^{1/3}\right]$

and this is shown in Figure 2.18.

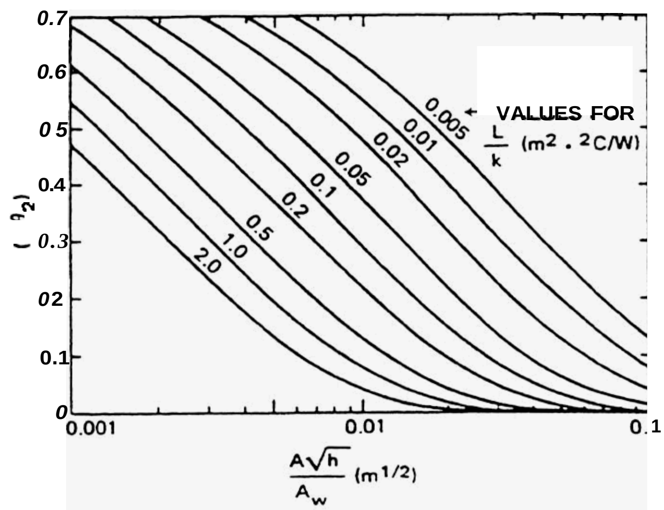


Figure 2.18 Effect of Wall Steady State Losses (SFPE)

8, Wall Transient Losses

If a transient temperature is required, the steady state value given above must be modified by a factor which is based on the Fourier number and from curve fitting was derived as:

$$\theta_3 = 1.0 - 0.92 \exp\left[-150 \left(\frac{A\sqrt{H}}{A_T}\right)^{0.6} \left(\frac{t}{k\rho c_p}\right)^{0.4}\right]$$

This expression is shown in Figure 2.19.

Note that if steady state conditions are required $\theta_3 = 1.0$.

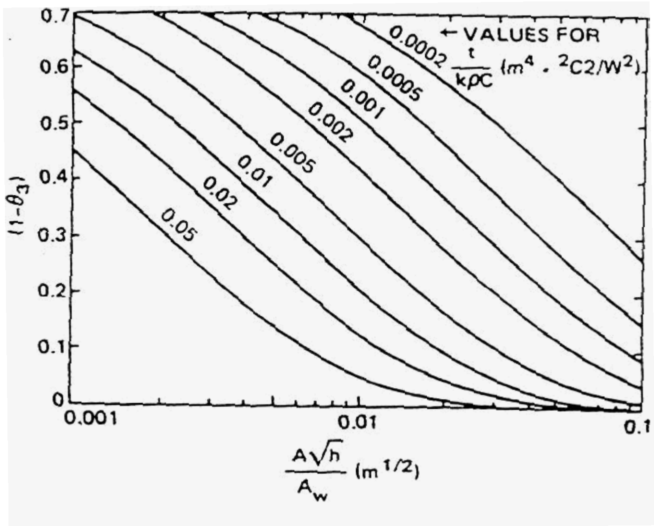
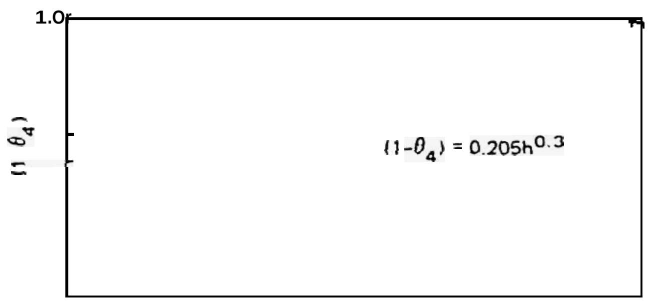


Figure 2.19 Effect of Wall Transient Losses (SFPE)

θ_4 Opening Height Effects

$H^{-0.3}$



θ_5 Combustion Efficiency

In evaluating the heat balance equation, a fire compartment is generally considered as well stirred reactor. However, in actual fires. this is not the case and there is always some degree of non mixing which reduces the compartment temperature. A maximum combustion efficiency b_p can be used to reflect the degree of non mixing. No actual experimental values for b_p have been determined, but agreement with the measured temperatures in real fires can generally be obtained with values of b_p in the range of 0.5 to 0.9. The effect of variation in b_p is given by:

$$\theta_5 = 1.0 + 0.5 \ln b_p$$

as shown in Figure 2.21.

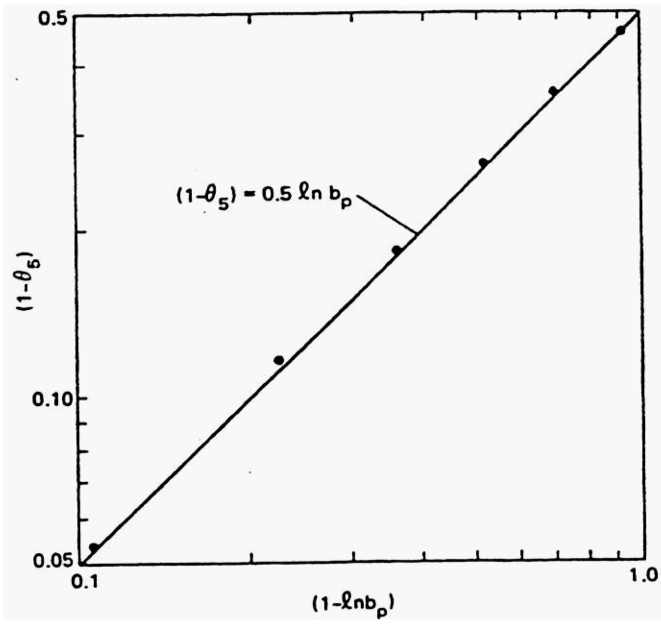


Figure 2.21 Effect of Combustion Efficiency **(SFPE)**

After extensive comparisons with the results obtained from COMPF2, Babrauskas found that there was good correlation with the results for both ventilation limited and fuel rate limited fires. The results of the approximate method generally agree within 3% of the COMPF2 values. Figure 2.22 shows the comparison between the approximate method and the COMPF2 results for a wood crib fire in a 200 m^2 compartment with a 2 m x 2.5 m wide opening in one wall.

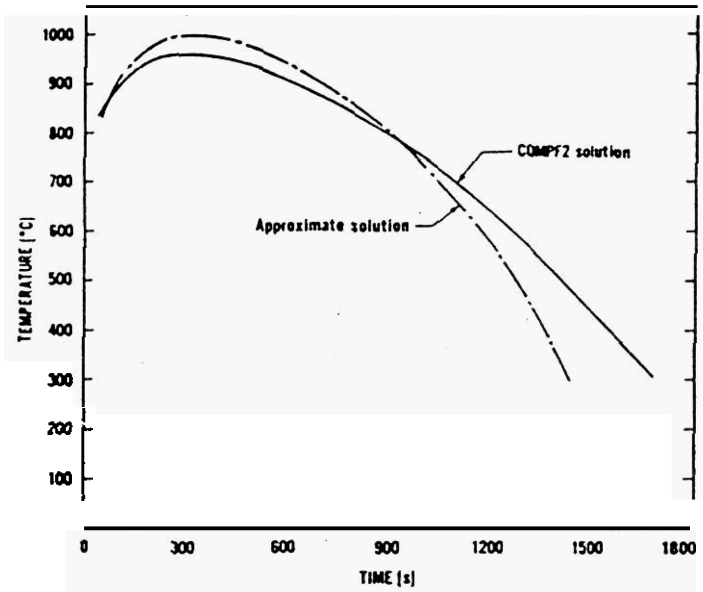


Figure 2.22 Comparison of COMPFZ and Approximate Method

Thus, by using the series of graphs given in Figures 2.17 to 2.21, it is relatively simple to produce a compartment fire temperature that would be sufficiently accurate for use in the radiation calculations. However, the method still requires a significant degree of engineering knowledge and experience to determine the various parameters needed in establishing the factors. Therefore, although the method is relatively simple and probably advantageous for fire engineering professionals, it is not suitable for a generalised method necessary for the Acceptable Solutions.

2 9 EUROCODE PARAMETRIC FIRE

As part of the move to have common European standards, as required by the European Commission, the European Committee for Standardisation (CEN) produced Eurocode 1 Par! 2-2 "Actions on Structures exposed to Fire" (EC1 1995). The document provides a formula for calculating a fire time/temperature curve that was considered to be more in line with the behaviour of real fires in buildings. The formula takes into account the main parameters that were considered to influence the growth and development of fires, ie. fire load, opening (ventilation) factor, area of the enclosure and thermal properties of the enclosure boundaries. As indicated by Buchanan (1998), the formula was an attempt to approximate the Swedish curves discussed in Section 2.6 earlier.

The EC1 method divides the fire development into two phases, a heating phase and a decay phase. The time temperature curve for the heating phase is given by:-

$$T_g = 1325\,(1-0.324e^{-0.2t^*} - 0.204e^{-1.7t^*} - 0.472e^{-19t^*})$$

where t^* is the modified time given by:-

$$t^* = t\,(F_v/0.04)^2.(1160/\sqrt{(k\rho c)})^2$$

F_v is the opening factor given by:-

$$F_v = A_v\sqrt{H}/A_t.$$

The heating phase continues for a time t_d given by:

$$t_d = .00013q_t\,(F_v/0.04)^2.(1160/\sqrt{(k\rho c)})^2.\left(\frac{1}{F_v}\right)$$

where k = thermal conductivity of the compartment's boundaries
c = the specific heat of the compartment boundaries
ρ = the density of the compartment boundaries
q_t = the fire load per unit area of the total area of the enclosure.

The dewy phase of the curves is taken as linear and is based on the duration of the heating phase. Typical graphs produced by the Eurocode formula are given in Figure 2.23.

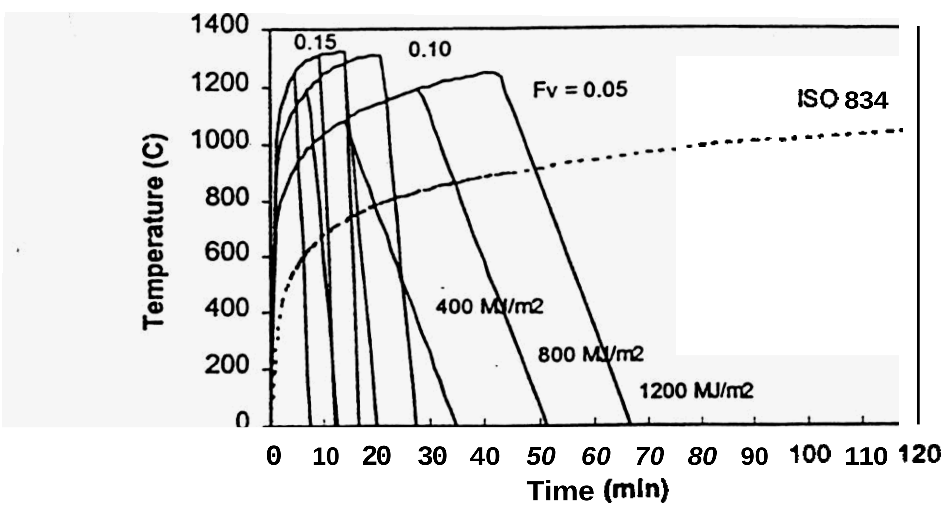


Figure 2.23 Typical Time Temperature Curves for Eurocode Parametric Fires

Although the EC1 formula has a sound scientific basis, its validation was with experimental test fires performed in small compartments. There has been some debate on the validity of the linear short term decay phase with respect to real fires. Comparing the time temperature curves predicted by EC1 with the experimental test results for large scale compartment fires, Clifton (1996), for tests carried out by **BHP** in Australia, and Wang (1996), for tests carried out at Cardington, both showed that the decay phase of real large scale fires was generally much more extended than that predicted by EC1. Figure 2.24 shows a typical result given in Wang's paper for the Cardington tests.

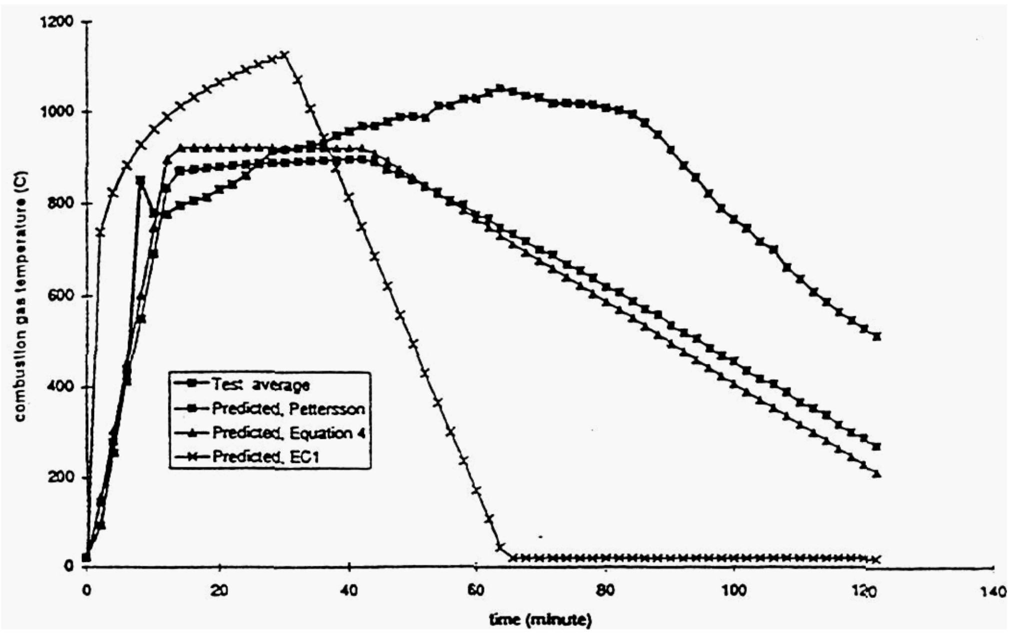


Figure 2.24 Comparison of EC1 Fire Curve with Experimental Results

Although the shape of the decay phase is important when considering the fire resistance of structural elements in a compartment, for calculating the maximum compartment temperature for radiation effects these refinements are not necessary.

Although the EC1 formula can be readily calculated using spreadsheets, it is far too complicated to be used in an Acceptable Solution. A possible alternative based on the EC1 would be the nomogram proposed by Franssen (1996) shown in Figure 2.25. Although this nomogram takes out some of the complications of the formula, there is still a substantial degree of calculation and knowledge required. For this reason, it is not considered applicable to an Acceptable Solutions type of approach.

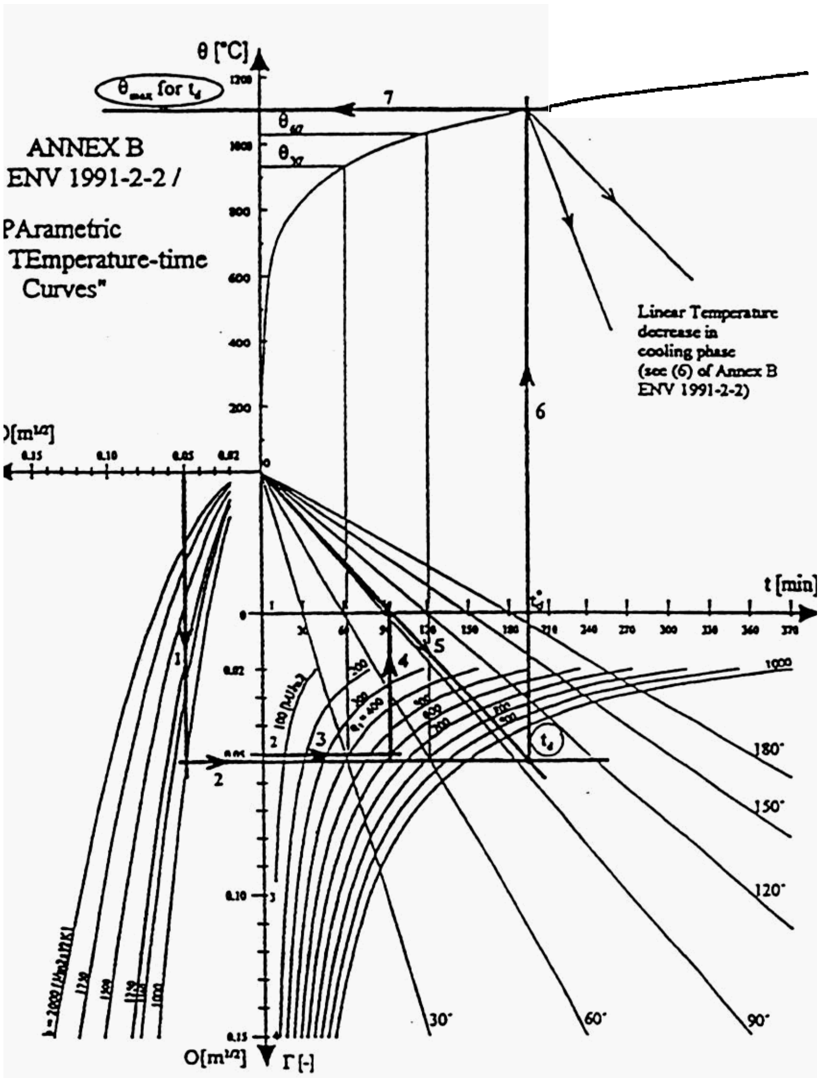


Figure 2.25 Nomogram for EC1

2.10 BARNETT'S BFD CURVES

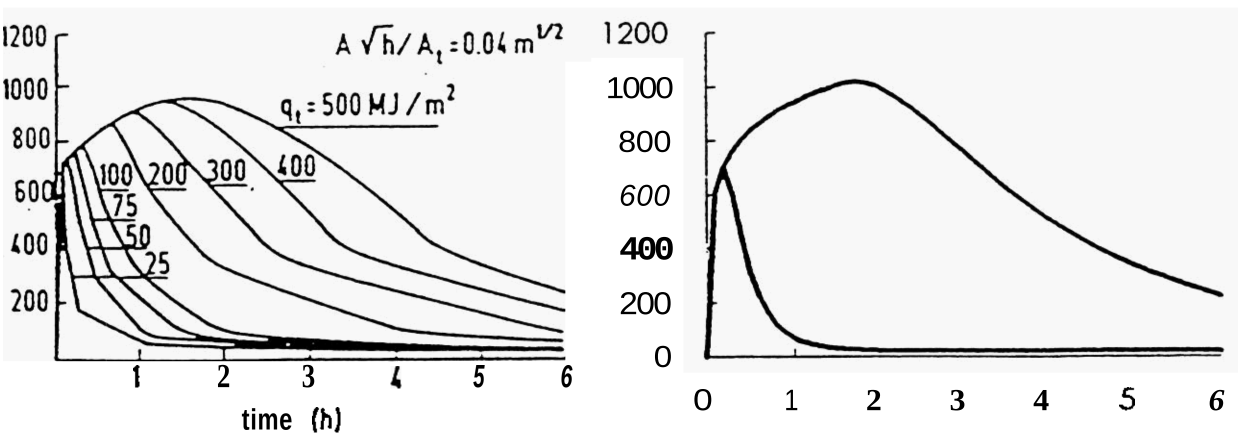
In a presentation at the 1996 IPENZ Conference, Bamett proposed the use of a design time temperature curve which he termed a "BFD curve" (Bamett, 1996). The curve is based on the formula:

$$T_2 = T_3 . e\left(\frac{(\log t - \log t_p)^2}{f}\right) + T_1$$

where T_1 = the ambient temperature °C
T_2 = the temperature at any time t °C
T_3 = the maximum temperature generated °C
t = time from start of fire (min)
t_p = time at which T_3 is reached (min)
f = growth factor f_g, or the decay factor f_d

The method was principally designed to be used to determine the fire resistance **of** structural members in a compartment fire.

The presentation was based on an earlier paper by Bamett **(1995)** which described the preliminary theories behind the BFD curves and showed that by judicious choice of the various parameters of the equation, other design curves such as the Swedish curves or the ISO curve could be generated. For example, Figure 2.26 shows the Swedish (Building Type **A** curves) compared to the BFD curves modelling the 50 and 500 MJ/m^2 fire loads.



Swedish **Curves** BFD Curves.

Figure 2.26 Comparison of Swedish Curves and BFD Curves

In addition to design curves. BFD curves can also be used to model the results of experimental test fires. As an example, Bamett used the results reported by Kirby **(1994)** to model the large scale wood crib fire tests carried out at Cardington. An example of this modelling is shown in Figure 2.27 with the markers being the test results and the solid line the BFD curve.

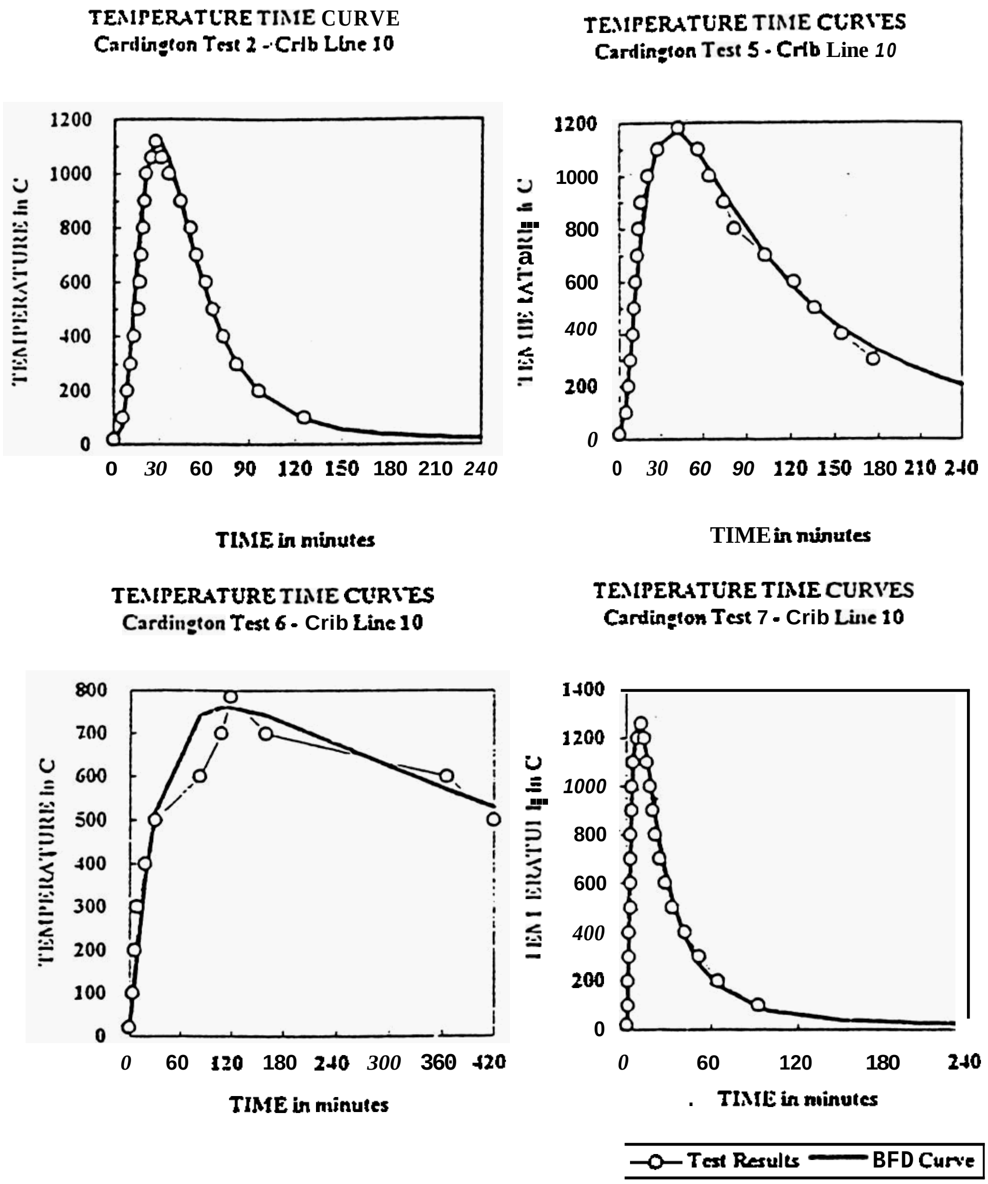


Figure 2.27 Comparison of Experimental Results with BFD Curves

A sample of some of the parameters that Bamett has derived for various design and experimental fires are given Table 2.4.

Time Temperature Curve	BFD Parameter			
	T_a	t_p	f_g	f_d
ISO 834	1400	9700	-65	-
Swedish Curve - Growth	1575	37000	-80	-
500 MJ/M^2 Decay	1018	105	-	-29
Cardington Test 2	1100	29	-0.8	-0.8
Cardington Test 5	1160	39	-1.6	-1.6
Car Test	590	13	-1.0	-1.0

Table 2.4 BFD Parameten for **Fire Curves**

Although the BFD curve method proposed by Barnett appears as though it may be a valuable design tool for fire engineers in the future, the theory has still to be defined and the method is not suited for simplified use as required for an Acceptable Solution.

2.11 COMPUTER MODELLING OF COMPARTMENT FIRES

Computer modelling of compartment fires is a specialised field and completely outside the realms of an Acceptable Solution. However, for the sake of completeness several of the computer models readily available are briefly described.

Although computer programmes were used for calculating post flashover fire temperatures by Kawagoe (1967) and Magnusson and Thelandersson (1970), as described in earlier sections of this chapter, the most enduring and widely accepted of the early computer programmes is COMPF2 by Babrauskas (1979). A detailed review of COMPF2 has been carried out by Wade (1995) and the programme has been used by researchers in New Zealand such as Thomas (1995). Figure 2.28 shows a graph of the type of fire time temperature curves generated by COMPF2.

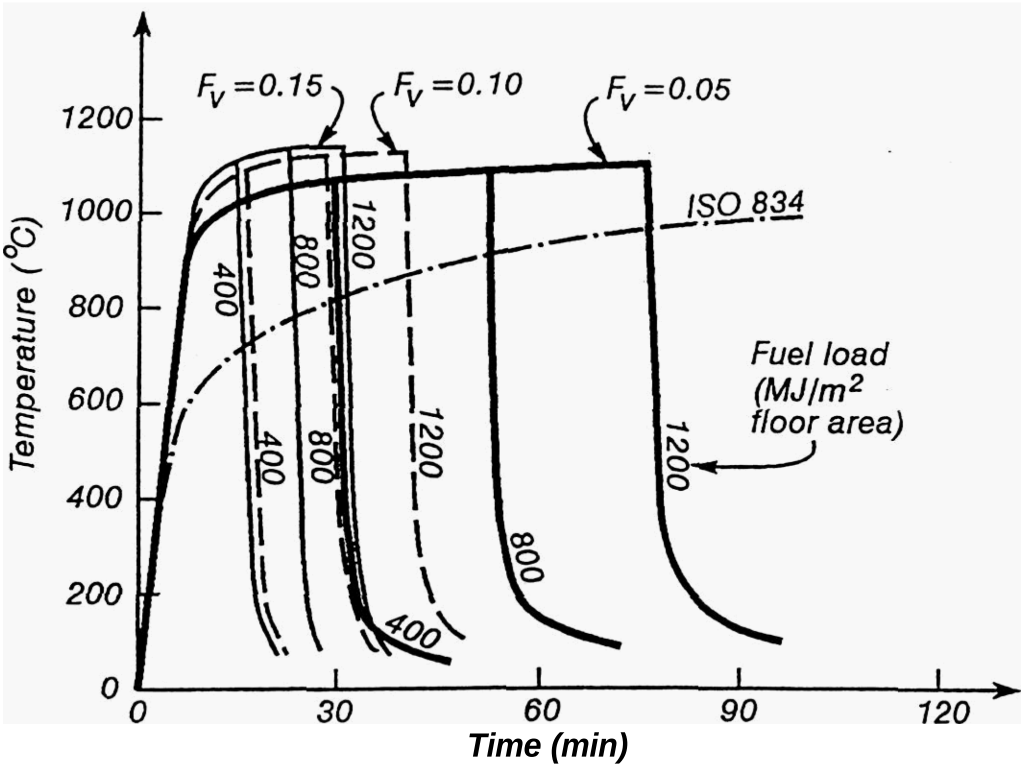


Figure 2.28 Time Temperature Curves obtained from COMPF2

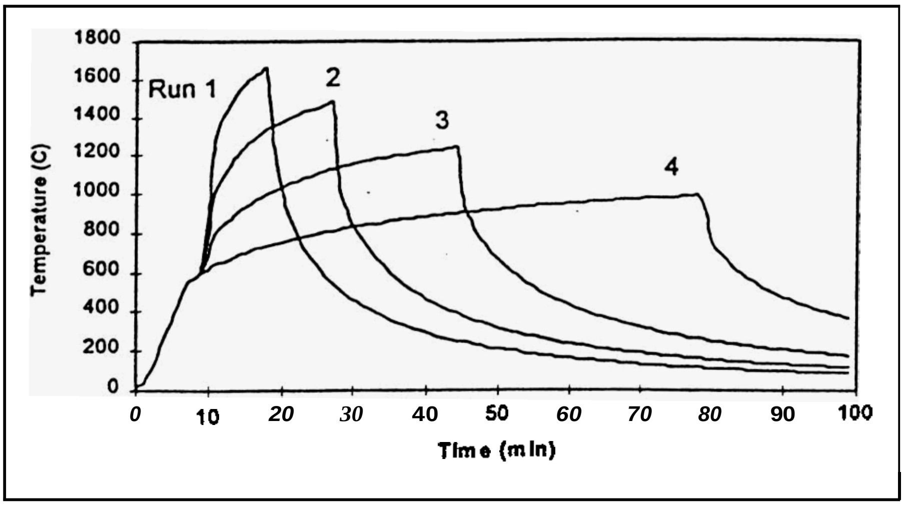
A master's research project is presently underway by Feasey (1998) to determine a methodology for using COMPF2 for typical New Zealand conditions.

Of the more recent computer programmes in general distribution, the most frequently used are FPEtool, CFAST and FASTLite. The earliest of these programmes is FPEtool, which contains a fire modelling module called "FIRE SIMULATOR which is described in the NIST manual by Deal (1993). Considerable testing was done by a number of researchers such as Nelson and Deal (1991) to verify that analysis using FPEtool provided reasonable approximations to experimental test data. Based on the testing it was considered that a reasonable level of confidence could be placed on the model, at least for one room configurations.

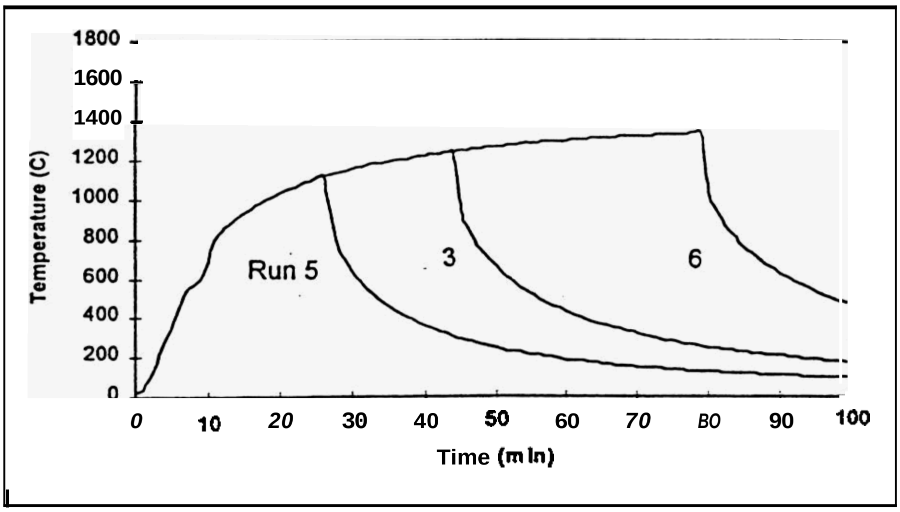
CFAST is a more refined model that allows for a number of parameters not available in FIRE SIMULATOR such as interconnected rooms, ceiling vents and fans. The use of CFAST if described in the manual by Peacock (1997). Again, numbers of researchers have carried out experimental verification tests of CFAST. In work by Dembsey (1995) it was found that CFAST tended to predict hotter compartment temperatures than were achieved in the experiments, but as this was a conservative result it was considered satisfactory.

Because of the good agreement with test results CFAST has been used in conjunction with other programmes to predict the fire resistance of different building elements rather than undertaking full scale testing. Lin (1997) reports on analysis undertaken to predict the thermal and structural performance of timber framed walls exposed to simulated office fires.

Although CFAST is a more robust model than FIRE SIMULATOR, it is substantially more complicated to use and in an attempt to provide a more user friendly tool NIST produced FASTLite which has a range of applications similar to FPEtool but which has a fire growth model that is a simplified version of the CFAST zone model. The user manual for FASTLite was provided for NIST by Portier (1996). A paper by Buchanan (1998) describes in detail the way in which FASTLite may be used to model post flashover fires. Figure 2.29 shows the time temperature curves produced by FASTLite for a compartment with a constant window size and a varying fuel load and vice versa. Buchanan compares the output from various FASTLite runs with the time temperature curves produced in the Swedish curves and using COMPF2, and concludes that the temperatures produced by FASTLite are higher than those of the other methods. At the conclusion of his paper, Buchanan makes a number of recommendations for suggested improvements to the FASTLite programme to enable additional flexibility of input, improved modelling of the fire temperature curve and remedying of a number of software bugs.



Time temperature curves for ventilation controlled burning, with constant fuel load and Varying Window size.



Time temperature curves for ventilation controlled burning, with constant Window size and varying fuel load.

Figure 2.29 FASTLITE Generated Fire Curves

2.12 RECOMMENDED METHOD OF DETERMINING EMITTED RADIATION FOR THE ACCEPTABLE SOLUTIONS

The majority of the methods for establishing compartment temperatures reviewed in this chapter and in the extensive background research carried out for this report are not considered suitable for use as the basis for radiation calculations for an Acceptable Solution for boundary separation. Although the methods are very valuable and can be used to great benefit by experienced professionals for specific circumstances, they are generally aimed towards providing information for establishing fire resistance of structural members. The reasons for rejecting the various methods are one or more of the following:

- Requires extensive computation
- Requires detailed fire engineering knowledge to choose correct values for variables
- Requires compartment variables to be specified to a greater extent than is practical for a building that may vary in the future

Any method to be used for an Acceptable Solution must be capable of being quickly and easily used by people who have no fire engineering knowledge or training and who do not wish to be involved in the intricacies of extensive mathematical computations. From the review carried out for this report and from several years of practice, it is considered that the present Acceptable Solution method in which prescribed radiation values (or compartment temperatures) are used is probably the most suitable for a generalised, easily used solution. However, it is considered that the present method using only two gradations of radiation is too coarse and the values used are not generally consistent with results obtained from more rigorous analyses.

It is proposed that four values of emitted radiation be used based on the fire hazard categories defined in the present Acceptable Solutions and described in Section 1.3 of this report.

Appendix B of this report compares the compartment temperatures obtained using a number of the methods described in this chapter for a typical moderate sized room with a range of fire loads. It is acknowledged that this is for a specific configuration but the results show a spread of values with the highest being approximately 20% higher than the lowest value in each case. The values obtained using the standard ISO curve approach described in section 2.4 were generally midway in the range of results.

As has been indicated earlier, the standard fire curves are used to define the time temperature curves to be produced in furnaces to test the fire resistance of building materials and elements. The concept was first introduced in 1916 and the values used were based on temperatures obtained in early ad hoc testing carried out using wood fires (Drysdale). The standard fire curves are generally not consistent with the time temperature curves obtained from actual compartment fire tests. However their use in defining a temperature to be used to establish an emitted radiation values has several advantages:-

(a) The concept of standard fire curves is already accepted.

(b) The standard fire curves are already defined and values can readily be obtained from simple equations.

(c) The fire resistance of external walls is already considered in the Acceptable Solutions and the approach has been readily accepted by users.

(d) The values obtained using the method are not inconsistent with the results of more rigorous theoretical analyses based on experimental results.

Based on the above, it is considered that using the temperatures obtained from the ISO 834 standard fire curve to generate emitted radiation values is an acceptable compromise to the various methods that have been reviewed.

Using the design values of FLED for each of the Fire Hazard Categories the fire resistance ratings for typical compartments were obtained from Table 1 of C3/AS1, and with some degree of rounding of the values, the typical ratings are 30 min, 60 min, 90 min and 120 min for FHC 1 to 4 respectively.

Using an ambient temperature of 20°C the resulting ISO curve temperatures were determined and from these, emitted radiation values calculated. The figures are given in Table 2.5 below together with the rounded proposed radiation values to be used in the Acceptable Solution.

Fire Hazard Category	Fire Resistance Rating (mm)	ISO Curve Temperature (°C)	Exact Radiation (kw/m²)	Proposed Radiation Values
1	30	842	87.2	85
2	60	945	125	125
3	90	1006	151	150
4	120	1049	173	175

Table 2.5 Proposed Emitted Radiation Values

CHAPTER 3: HEAT RADIATION TRANSFER

Once the radiation intensity being emitted by the fire compartment has been established, it is necessary to consider how that radiation is transferred to the target building. A considerable number of factors are involved which can either increase or decrease the effect of the radiation and these will be considered in this chapter.

3.1 FLAME PROJECTION

As was stated in Chapter 2, this report deals with fires that have flashed over and are in the fully developed burning phase of the fire curve. In this situation, it is usual for flames and hot gases to be emanating from any openings which do not have fire rated closures over them. As can be readily observed from both fire tests and actual fires, the height of these flames above the window and the horizontal distance that they project out from the face of the wall can be quite considerable. The NZBC Acceptable Solutions, like the regulations of most other countries apart from Canada, do not allow for the effect of flame projection and the purpose of this section is to see whether this is valid.

In his paper reviewing spread of fire from compartments, Quintiere (1979) cites experiments done in 1958 by the National Research Council of Canada where a number of full scale fire tests were carried out on buildings in the town of Aultsville (Shorter 1960). These tests are often referred to as the St. Lawrence Bums. In these tests, the radiation measured outside the burning buildings was considerably higher than the figure calculated from the compartment temperature and the window opening. Although there were other factors involved, one of the principal reasons for the higher values was considered to be the large flames projecting from the windows and the burning of the exterior cladding above the windows.

In later work, Law (1968) carried out full scale fire tests to specifically investigate radiation from fires in a compartment. Radiometers were placed outside the opening in the fire compartment with one of the radiometers being shielded from any flames projecting above the height of the window. A number of tests were carried out using varying fire loads and window areas and the results were used to review a number of the factors influencing radiation from a burning building. The tests showed that for the large opening, which was about half of the wall area, the difference between the total radiation measured and that coming from the window alone was not significant except at high fire loads. For the tests with the opening being a quarter of the wall area, the flame radiation became more significant with the difference in the maximum radiation values being 25% of the total radiation. However, the effect of the fire load and the window size on the radiation measured outside the building was much more significant than that of the flames. From a statistical analysis of the results Law concluded:-

> "The extra radiation from flames outside the openings was not large enough to warrant altering the recommended separation distances on which present building regulations have been based."

Figure 3.1 shows the total radiation and window only radiation for the various tests.

In later work in association with Thomas (1974), Law again looked at the effect of flame projection but this time on external structural steelwork located outside the opening of a burning building. In this paper, they reviewed the work on flame projections done by Yokoi (1960), Webster and Raftery (1959) and Seigel (1969). This work had shown that the width/height ratio of openings had an important effect on the flame trajectory. With wide windows the flame does not project far from the wall and clings to any wall above, while with the narrow openings the projection is further as it is easier for air to enter between the wall and the flames when the flame front is narrow. Using empirical correlations of the data produced by the earlier researchers, Law and Thomas derived an approximate formula for the height of a flame above a window as:-

$$z = 18.6\left(\frac{R}{W}\right)^{2/3} - H$$

where **R** is the rate **of** burning (kg/sec)
H is the height of the window
W is the width of the window

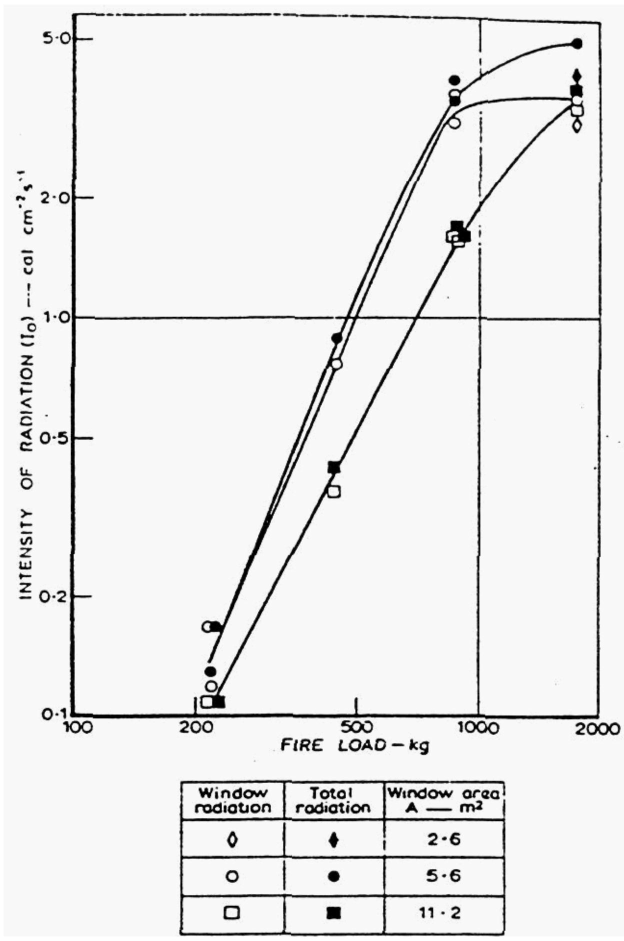


Figure 3.1: Radiation from Windows and Flames from Law's Tests

It was noted in the Law and Thomas paper, that the above formula for flame height tended to give larger values than those found in experimental work. For a later paper in conjunction with OBrien (1981), the correlation was revised ***to:-***

$$z + H = 12.8\left(\frac{R}{W}\right)^{2/3}$$

which seemed to better agreement with the experimental results. In this later paper Law and OBrien also provided correlations for calculating the flame projection out from the face of a wall for situations where there is a wall above the window:-

for H < 1.25 W (most situations)

P = ⅔H

for H > 1.25 W

$$P = 0.312H^{1.54}W^{-0.54} + \frac{H}{3}$$

(Note that in many texts the last term, $\frac{H}{3}$ is usually neglected.)

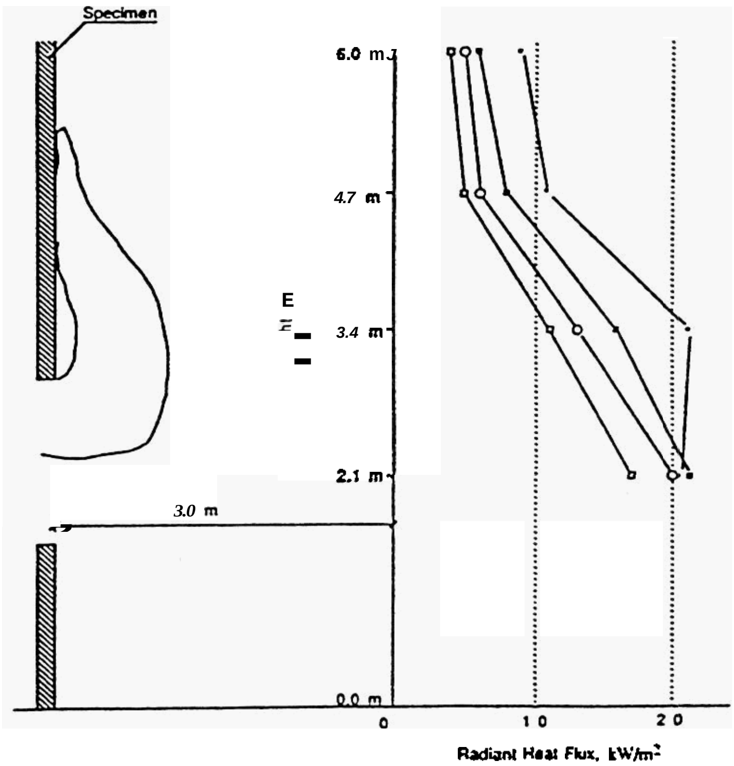
As in the previous paper, the emphasis in this paper was to determine the effect of flame projections on steel members outside the opening. It was not considered that flame projections need be included in boundary separation considerations for a number of reasons. These were:-

(a) Separation distances are based on the areas of unrated wall rather than only windows. Although the glass windows may break and allow flames to project out of the opening, the non fire rated sections of wall will withstand the effect of the fire for some time before allowing flames through.

(b) Separation calculations are usually based on a maximum intensity radiating from the entire unrated area for the full length of time, which tends to produce an overestimate of the radiation flux reaching the neighbour.

Based on the results of the St.Lawrence Bums, Canada is one of the few countries which incorporates a flame projection distance in its standard charts for building boundary separations. Following a research programme for the National Research Council of Canada, Yung and Oleszkiewicz (1988) reported on the results of full scale fire testing for fire spread by exterior walls.

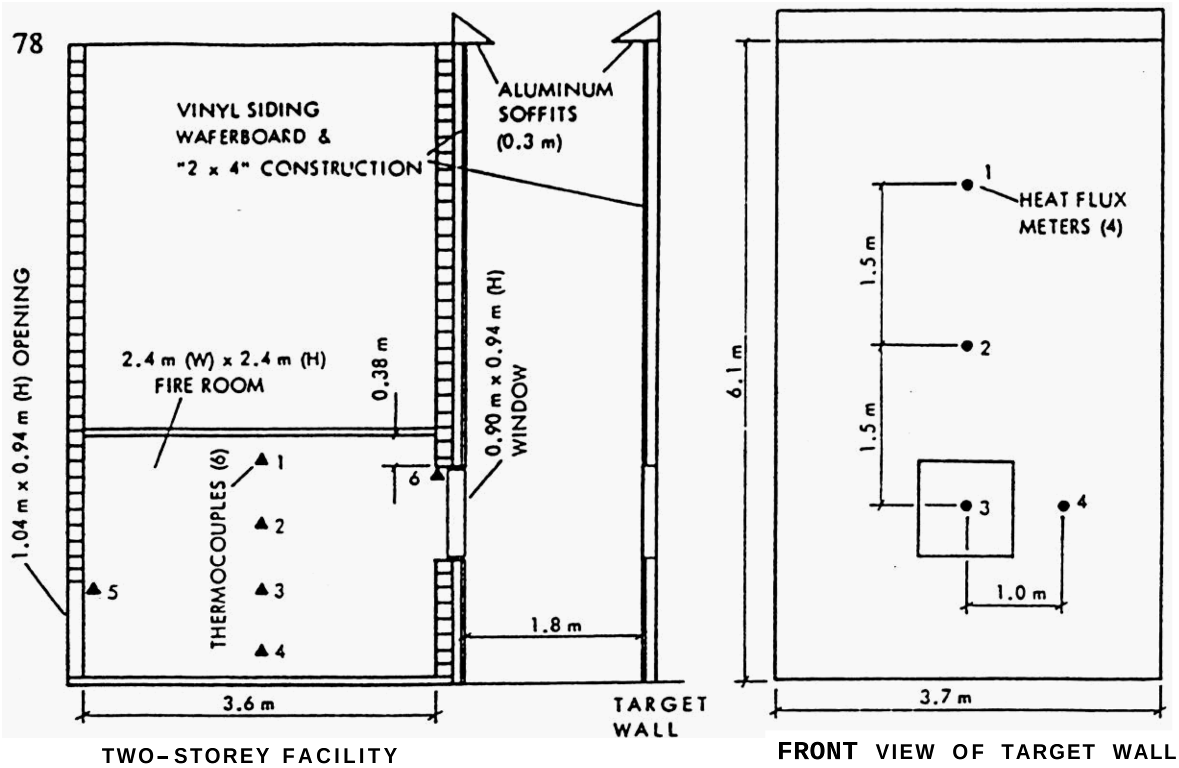
The first full scale test was to determine the effect of combustible claddings above an opening through which flames were projecting. The radiometers were placed on an adjacent wall three metres from the opening at various positions above the opening. Different types of cladding material were used above the flaming opening and the results of the tests are shown in Figure 3.2. As expected, the radiation from the flames decreased with the height above the opening and increased with the combustibility of the wall cladding of the emitting building



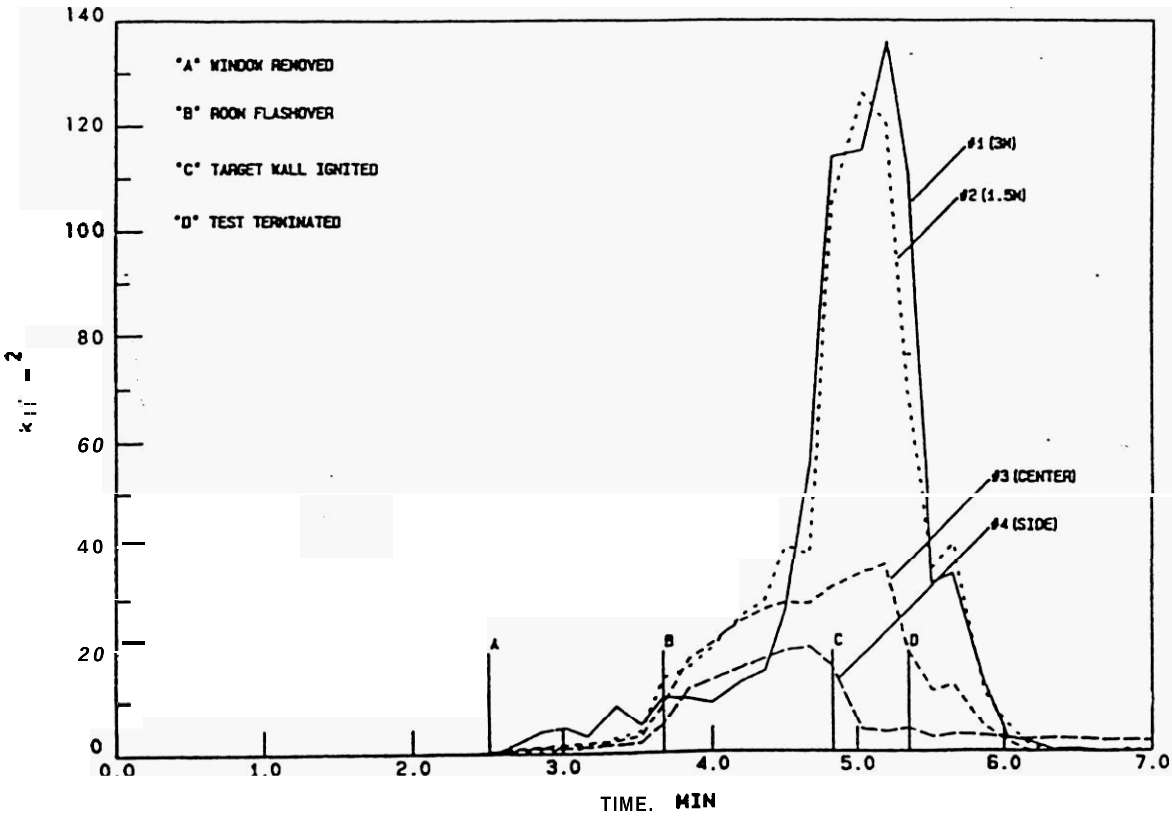
Maximum radiant heat flux recorded by radiometers on target mast, full-scale tests: □ Marinite, O gypsum sheathing, ■ assembly showing limited flame spread, • assembly showing flame spread to the top of the wall

Figure **3.2:** Radiation from Flames

The paper also reports on a full scale fire test conducted to assess the fire spread potential to a neighbouring building located 1.8 m away from a flaming opening, with both buildings having combustible cladding. The test set up and results are shown in Figure 3.3.



Full-scale *fire* spread test setup



Heat flux at target wall

Figure 3.3: Canadian Radiation Testing for Flaming Opening

The fire was started with the window glass in place. At 2.5 minutes the glass was manually removed after it had cracked. This is Point A on the graph. Prior to this time, the radiation flux on the target wall was insignificant. At Point B flashover occurred and flames and hot gases started issuing from the opening. The facade above the window ignited and at **4** minutes 40 seconds the flux readings on the target wall were 29 kW/m^2 at the opening, 38 kW/m^2 at 1.5 m above the centre of the opening and 55 kW/m^2 at 3.0 m above the centre. These figures are all well above the normally accepted heat flux for non piloted ignition of combustible cladding of 25 kW/m^2 and shortly thereafter the target wall ignited. This is Point C on the graph. At this point, the fire room temperature was relatively uniform at about 1000°C. If the results of the experiment are compared to a FIRECALC analysis based on the experimental configuration and assuming radiation coming only from the window, the maximum radiation directly opposite at a distance of 1.8 m would be **11** kW/m^2 compared with the 30 kW/m^2 obtained in the test. This intensity of radiation would be achieved if it was assumed the window was located one metre away from the target wall. **To** check the effect of the flame projection, the same test was carried out with **a** fire window over the opening and the maximum radiation on the target wall was only 5 kW/m^2. This agrees well with the FIRECALC analysis, assuming 50% attenuation through the fire window glazing.

In a paper presented to the second international symposium **of** the International Association **of** Fire Safety Science Barnett **(1**988), proposed that if specific flame projection and flame temperature calculations were not carried out an additional **two** metres should be added to the required building separation ***to*** allow for the effect of external flaming. However, from the example analysis given in Appendix C of this report, it can been seen that the effect **of** external flames for a typical sized window would be to increase the separation by only 0.32 m. Although larger flame projections from tall narrow windows and from larger overall radiators may occur, the figure of **two** metres proposed by Barnett would appear to be overly conservative. ***An*** increase of 1.2 m in the building separation, as used in the Canadian Code would appear to be more applicable, but for ease of calculation and as the present Acceptable Solutions do not include any allowance at all, projections of 1.0 m are proposed for Fire Hazard Categories 3 and 4 and 0.5 m Fire Hazard Categories 1 and 2. The large projection for the higher categories is because the higher fire loads will result in ventilation controlled burning with significant external flaming.

3.2 EMISSIVITY

Methods for calculating the emissivity of flames projecting from a burning compartment are described in Appendix C. However when considering the radiation coming from the openings of a burning compartment, all of the researchers included in the reference list advocate the use of an emissivity equal to 1.0. This was particularly noted in the work done by Law for Fire Research Technical Paper No.20 (1968), in which she states that the compartment should be assumed to be a black body when determining the radiation being emitted through any openings. In the literature review undertaken as part of this project, no references could be found to justify a value for the emissivity of less than 1.0.

3.3 CONFIGURATION FACTORS

The intensity of radiation received on a surface remote from the emitter can be found by using an appropriate "configuration factor", which takes into account the shape of the emitter, the shape of the receiver and the geometrical relationship between the *two*. Values of configuration factors are given in most heat transfer texts, such as Incropera and de Witt (1970) or Howell (1982). In essence the configuration factor is the factor by which the value of emitted radiation is multiplied by in order to achieve the maximum received radiation. For the values used in the Acceptable Solutions, a configuration factor of 0.075 is used for the higher intensity fire and a factor of 0.15 is used for the lower value of emitted radiation.

The boundary separation tables of the Acceptable Solutions, like those of most other countries, assume that the receiver is located opposite the centre of a rectangular emitter. The configuration factor for this situation is given as part of the analysis of the C3 tables outlined in Appendix A of this report. For situations where the entire facade of the rectangle is assumed to be on fire, the configuration factor method is accurate and relatively straightfoiward. However, when there are number of openings in a fire rated wall the configuration factor method must be applied with care. As set out in the original paper by Law (1963), configuration factors for walls with regularly spaced openings can be based on the proportion of the area of the unrated openings compared to the overall wall area. However, if a wall has an uneven distribution of openings or widely spaced openings, the effect of increases or decreases in the proportion of unrated area to overall wall area must included. In the early work to produce spatial separation tables using the overall configuration factor method such as that by McGuire (1965), a considerable amount of manual computation was required to produce the tables and consider any local variations. With this amount of manual computation came the inherent risks of errors. To allow more rapid calculation of spatial separation and consideration of the effects of non uniform openings, Williams-Leir (1966 and 1970) proposed various approximations that gave relatively close agreement to the exact calculations using the configuration factor method. However with the advent of easily accessible computers and spreadsheet programmes, the drudgery of hand calculations has been eliminated and the effect of local concentrations of openings can be rapidly assessed, as shown in the spreadsheet included in Appendix A.

Based on the above, it is considered appropriate to continue to use the configuration factor method assuming a rectangular radiator as used in the Acceptable Solutions, but with the proviso that the effects of a non uniform distribution of openings must be considered.

3.4 WIND

In the C3 tables of the Acceptable Solutions the effect of wind on flame projections is not taken into account and this is the case for the spatial separation tables used in most other countries. As reported by McGuire (1965) the St.Lawrence Bums, which were the basis for the Canadian regulations, indicated that wind direction and speed had a significant effect on the radiation received outside the building. The experiments were carried out in windy conditions with wind speeds of up to 22 km/hr. It was found that the radiation levels on the leeward of a building were, in general, much greater than those on the windward side. In spite of this, the Canadian regulations do not include the effects of wind in the derivation of their tables.

The effect of wind is difficult to generalise. If the building has a through draught, flames projecting out of the openings on the leeward side will be longer but possibly cooler. For wind parallel to the wall, the flames will be deflected along the wall thereby reducing the forward projection and again causing cooling.

Law (1968) reported on small scale tests in which air was blown into 0.5 m^3 compartments containing burning wood cribs. It was concluded from the model tests that burning rates would differ by less than 70% for wind speeds of up 29 km/hr. Law concluded that the large volumes of received radiation recorded in the St.Lawrence Bums may have been the result of through draughts in the Canadian buildings which typically had fewer internal walls. To support this conclusion, she reported on full scale house fire tests carried out in 1949 where there was a marked increase in flames out of the leeward windows once the internal partitions had collapsed. This did not occur until very late in the fire tests.

Although high winds may promote spread of fire by transporting flaming brands for some distance from the original fire, this aspect of fire spread is not considered as part of this report. Because of the difficulty in generalising the effects of wind on flame projection, flame temperature and compartment temperature, it is not considered that the potential effects need be included in standard tables designed for generalised use throughout the country. The allowance of 0.5 m and 1.0 m for flame projection proposed in Section 3.1 above would cater for the effect of wind to some extent. Although the flame projection may get greater once internal partitions have collapsed and a through draught develops, this is likely to occur very late in the fire at which time the Fire Service should have intervened in most urban situations.

3.5 TRANSMISSIVITY

Transmissivity is also known as absorption and is normally given a value between 0 and 1. It represents the partial attenuation of the radiation energy by absorption while travelling between the source and the receiver. The absorption can take place in the atmosphere, water spray or in building materials such as glass. Although there are methods for calculating the transmissivity through all of these media, this would come under realms of specific fire engineering design and is beyond the scope of the Acceptable Solutions.

It should be noted that atmospheric absorption increases with increasing relative humidity of the air. Under normal circumstances, there is a less than 10% decrease in received radiation for separation distances up to 20 m and therefore it is normal practice to assume a value of 1.0 for transmissivity.

3.6 FIRE SERVICE INTERVENTION

As described in Section 1.5, the majority of overseas codes reviewed derived their required separation distances on the basis that the fire service would attend within a short period (under 10 minutes) and begin wetting down adjacent buildings that might be at risk. This is also true of the Acceptable Solutions, although it is not stated anywhere in the document.

As the vast majority of cases where radiant ignition of adjacent property may occur will be in urban built up areas, it can be expected that the New Zealand Fire Service will be in attendance within 10 minutes. Therefore it would appear reasonable to continue to allow for this in establishing revised separation distances.

CHAPTER 4: SPECIFICATION OF CRITICAL SEPARATION DISTANCES

4.1 MIRROR IMAGE CONCEPT

The Building Code Acceptable Solutions, like most other countries, specify boundary separation distances in the tables. This is on the basis that the boundary distance is half the separation distance at which the received radiation would be 12.6 kW/m^2. This is known as the "mirror image" concept. The supposition is that two similar buildings, one the mirror image of the other, are placed equidistant either side of the property boundary such that the distance between them is the correct separation to limit the received radiation on either to 12.6 kW/m^2.

However, in practice, when a new building is being designed the position and nature of any potentially exposed neighbouring building may not be known. If a neighbouring building does exist, it is most unlikely that it will be mirror image of the proposed building and has the same boundary separation. There is always the possibility that any existing building may be demolished and a building with totally different radiation characteristics and boundary separation may be constructed. In these circumstances, it is not considered appropriate that the actions of a neighbour should require an owner to upgrade his own building.

In Law's original paper (1963) on which the British and hence the New Zealand separation tables are based, she discussed the problem and admits that for dissimilar buildings the mirror image concept may result in received radiation intensities greater than the limiting criteria.

4.2 EXAMPLE OF MIRROR IMAGE CONCEPT RESULTING IN A DANGEROUS SITUATION

As an example of the problems that may occur, consider the situation shown in Figure 4.1.

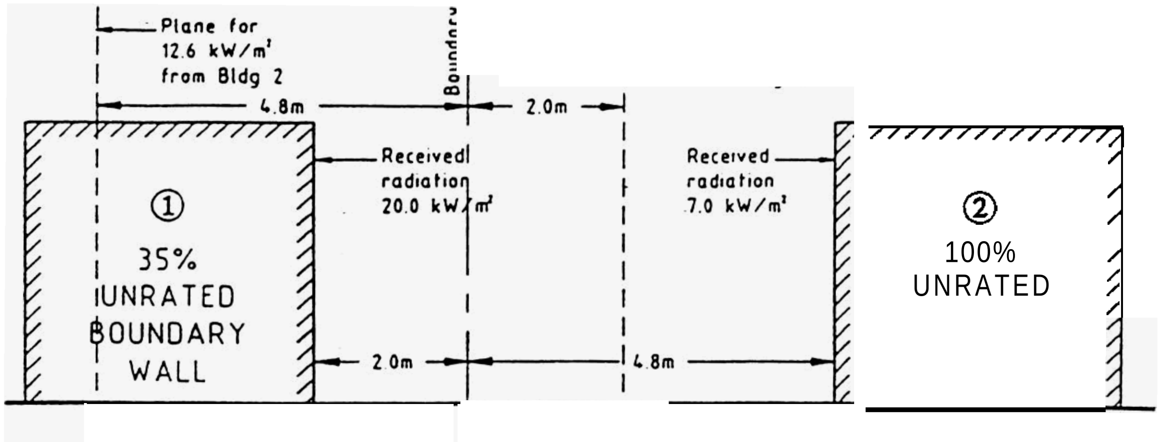


Figure 4.1: Mirror Image Concept

Building 1 is erected initially and is 4 m high by 15m long. The wall adjacent to the boundary is predominantly of concrete blocks but selected panels, uniformly distributed along the length, are of timber framing with cedar shingles. These unrated areas amount to 35% of the wall area. From the spreadsheet analysis given in Appendix D a boundary separation of 2 m would be required to comply with the Acceptable Solutions. Subsequently, a building is built on the neighbouring property of similar size but, in this case, the wall facing the boundary is completely unrated. In order to comply with the mirror image concept, this building must be located 4.8 m from the property boundary. The final configuration results in a total separation between the two buildings of 6.8m. From the FIRECALC analysis given in Appendix D, it can be seen that if Building 1 is on fire the radiation received on Building 2 is only 7.0 kW/m². However, if Building 2 bums, the incident radiation on Building 1 is 20.0 kW/m², which is substantially more than the limiting value of 12.6 kW/m² assumed by the Acceptable Solutions.

In her paper, Law suggests that the only way to ensure that all possible situations are made safe is to limit the radiation at the boundary to 12.6kW/m². Law rejects this idea as being overly conservative and likely to result in either large amounts of wasted land or much higher building costs to provide fire rated walls. In a private communication, Law (1998) advised that the mirror image concept was adopted because under the British regulatory system the design of a building on one lot could not be legally made dependent on the location of a building on another property. In practice it had been found that the mirror image concept generally followed the "swings and roundabouts" principle.

4.3 LIMITING DISTANCE CONCEPT

In spite of the wide use of the mirror image concept, the example above illustrates that it is relatively easy to produce situations where the received radiation on a building is substantially higher than the accepted limits and the difference would have been substantially more if the buildings were of different sizes as well as different configurations. In most countries, the building regulations stipulate a minimum boundary separation below which boundary walls are not permitted to have unrated openings and the claddings are to be incombustible. In New Zealand this limiting distance is 1.0 m. If any building is constructed on an adjacent property closer than this distance to the common boundary. it can be assumed that the wall will have a fire resistance rating of at least 30 minutes and will be rated from both sides. As such, it can be taken that these walls would withstand a much higher incident radiation than the present critical values used in determining the separation tables. However, at distances greater than 1.0 m, parts or all of the boundary wall may be non fire rated and have a combustible cladding. As the owner of one property has no right impose limitations on the manner or form of construction on a neighbouring property (provided such building complies with the Building Code) there is no way of determining where non fire rated openings may occur. Therefore it would appear logical to take this limiting distance of 1.0 m as being the point at which the limiting incident radiation must not be exceeded.

If this approach is used for the example quoted in Appendix D of two buildings 4 m high by 15 m long, Building 1 with a boundary separation of 2.0 m would be allowed to have only 28% of the wall face area unrated while the adjacent

Building 2 located 4.8 m from the boundary could only have 52% of its wall area unrated. This is illustrated in Figure 4.2. (Note that no allowance has been made for flame projection in this example.) Conversely, if the amounts of unrated wall area were to remain the same as the first example, the boundary separation distances would have to increase to 3.0 m and 8.6 m respectively. In all cases the incident radiation on the faces of both buildings is less than'the critical value.

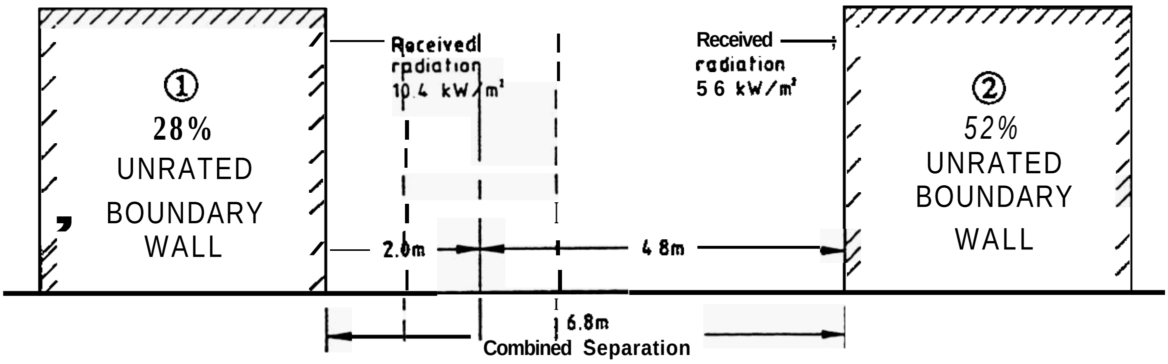


Figure 4.2 Limiting Distance Concept

4.4 RECOMMENDED CHANGE

As stated by Law, the mirror image method has not led to a significant number of failures in the past on the basis that neighbouring buildings are as likely to be built outside the critical distance as inside it. However, in the modem market where commercial pressures require as much building as possible for the least cost, it is far more likely that buildings will be constructed as close as possible to boundaries with the minimum possible fire ratings. It is considered that on the basis of sound fire engineering principles the limiting distance concept should be adopted based on the 1.0 m boundary separation limitation for unrated openings used in the present Building Code Acceptable Solutions, even though this may result in increased boundary distances or decreases in allowable proportions of non rated wall area. If this proves to be a major economic disadvantage, a possible increase in the 1.0 m limitation to say 1.5 m could be considered.

CHAPTER 5: CRITICAL RECEIVED RADIATION

5.1 WHAT IS DAMAGE?

The functional requirements of Clause 3.2.1 of the New Zealand Building Code requires that:

> "Buildings shall be provided with safeguards against fire spread so that:
>
> "......... adjacent household units and other property are protected from damage."

However, "damage" is not defined anywhere in the Building Code. As can be seen in the photographs given in Section 1.6.1 of this report, damage can range from blistered paintwork, cracked windows and melted PVC downpipes up to charred and ignited exterior cladding.

The New Zealand Building Code Acceptable Solutions consider critical radiation to be that which would cause piloted ignition of timber. Piloted ignition is used as it is generally considered that although flaming brands are unlikely to ignite an adjacent wall directly, it is very likely that small burning embers will occur which will ignite the combustible volatiles that are driven off heated cladding materials. Most other countries use the same criterion. The rationale behind this would appear to be that if ignition of the exterior of an adjacent building occurs it could lead to partial or total loss of this building and potentially increase the risk of fire spread to further buildings because of the increased fire size. The life safety of the occupants of the adjacent buildings could also be compromised.

Minor damage such as blistered paint, minor charring, cracked windows and melted guttering can be relatively easily and cheaply repaired. Major charring and potential ignition of cladding could lead to substantial repair costs if the adjacent building becomes fully involved and also there may be an increased risk of loss of life if occupants of a neighbouring building are not given adequate warning.

One potential risk that has been suggested as a design criterion is the ignition of curtaining or other material on the inside of a window in the adjacent building. It is not considered that this is a limiting case. If the glass of a window remains in place the material can only catch fire through spontaneous ignition as no embers will be present to act as an initiator. Generally spontaneous ignition occurs at much higher values of received radiation - usually in excess of 20 kW/m^2. Under normal circumstances it is unlikely that the glass in a window of an adjacent building will fall out even if the pane has been cracked due to the effect of an adjacent fire. This would seem to be borne out by observations of actual fires by the author, even though this is admittedly only a small sample.

Based on the above, it is considered that prevention of piloted ignition of the exterior cladding should still be regarded as the criterion for preventing damage of adjacent buildings.

5.2 IGNITION DUE TO RADIANT HEATING

The processes involved in the heating of solids by radiant energy are numerous and complex To derive expressions for the rise in surface temperature it is necessary to consider reradiation from the heated surface, conduction through the solid, radiation from the rear face and convective cooling from both faces. The theory of the process is covered in detail by Drysdale (1985) and by Kanury (1995) and it is not proposed to reproduce this analysis here. It is sufficient to say that with major simplifying assumptions being made, it is possible to produce one dimensional mathematical solutions for the rise of temperate of a surface due to radiant heating. Both Drysdale and Kanury stress that, because of the simplifications made, great care is required in applying any of the mathematical expressions. Because of the complexities involved, a great deal of research has gone into establishing critical radiant heat fluxes for various materials by conducting laboratory tests.

The tests generally consist of subjecting a sample of material to a constant heat flux from a radiant heater and establishing the time and/or temperature at which ignition of the material takes place. In considering the ignition, two situations must be considered - piloted ignition and spontaneous ignition. For piloted ignition the test involves the introduction of a spark close to the surface of the material to ignite the combustible gases that are being driven *off* from the material by the elevated temperature. For spontaneous ignition, the combustion gases may ignite spontaneously if the gas/air mixture reaches a sufficiently high temperature. This requires a much higher heat flux than piloted ignition. In real life, the only time when spontaneous ignition could be guaranteed is if the heated material is behind a barrier that will not allow burning embers close to the material. For example this could be a curtain inside a window. The most likely situation that could occur when considering fire spread between buildings is the piloted ignition *of* a combustible wall cladding and this is the design criterion that is invariably used.

5.3 EXTERNAL CLADDINGS TO BE CONSIDERED

In New Zealand at the present time, there are a considerable number of variations in possible external claddings. These include timber, **PVC,** fibrous cement panels, masonry and plaster over either fibrous cement or rigid polystyrene. Apart from the timber and **PVC** the other products are either non combustible **or** require exposure to a very high radiant heat flux for a prolonged period before piloted ignition will take place.

The Building Research Association *of* New Zealand has carried out tests on typical exterior cladding materials to determine the relative performance in regard to flame spread up the exterior of a building. The results of the tests and a proposed revised method of classifying the claddings has been reported by Wade (1995) and Cowles and Wade **(1998).** The testing involved exposing samples of the various claddings to a radiant flux of 50 kW/m^2 for **15** minutes with a sparker present in a cone calorimeter and measuring the time to ignition, peak heat release rate and total heat released. The results for time to ignition are shown in Table 5.1.

Generic Description		
Exterior Insulation and Finish System	Insulclad	77
Fibre-cement board	Hardiflex Brown	86
Fibrecement board	Hardiplank Brown	82
Metal sheet	Nu-Wall	98
Plaster	Multiplast Insulcote	130
Plaster	Duraplast	84
PVC	Superclad	28
Timber	Pine Brown Acrylic	15
Timber	Shadowclad	18
Hardboard WB	Weathertex Brown	23
Fibre-cement board	Hardiflex White	134
	Hardiplank White	66
	Pine White Acrylic	15
	Weathertex White	65

Table 5.1: Time to Ignition for 50 kW/m^2 Radiant Flux

As can be seen, only the PVC had an ignition time close to the various timber products. Testing by the manufacturers indicates that the ignition point of PVC is in the order of 480°C compared to the 350°C quoted by Drysdale for piloted ignition of wood. The one failing of the PVC is that it will distort at a very low temperature of around 50°C. However, based on the damage criterion proposed in Section 5.1, this distortion would not be regarded as a design criterion for specifying building separations.

Thus it is considered that the piloted ignition of timber should continue to be regarded as the design criterion for specifying building separations.

5.4 IGNITION OF TIMBER CLADDING

In the paper by Law (1963) on which the British regulations and hence the Acceptable Solutions are based, she states that piloted ignition of oven dried wood only occurs with intensities above 12.6 kW/m^2 for heating times in the order of ten minutes or more. She states that in practice exterior timber will always contain some moisture which will have the effect of raising the minimum intensity at which piloted ignition will occur. In addition, painted timber will also require a higher ignition intensity. She states that the figure of 12.6 kW/m^2 "errs on the side *of* safety".

In later work with Simms (1977). Law carried out experiments to specifically investigate the effects of moisture content on the radiant ignition of timber. **A** large number of experiments were carried out using **a** range of timber species, sizes and moisture contents. The effects of moisture content on both piloted and spontaneous ignition were investigated. The results of some of the experiments relating *to* piloted ignition are shown in Table 5.2.

Wood	Density kg/m^3	Thickness mm	Moisture Content %	Range of intensities kW/m^2	Range of ignition Times (sec)
Oak	660	13	Dry 20 40	15.9-20.9 23 24.7-27.2	415-140 605 635-530
	800	19	Dry 20 40	15.9-16.7 20.9-23.0 17.1-18.8	1260-1115 1020-630 2580-2020
Columbian Pine	460	13	Dry 20 40	19.2-20.9 22.6-23.0 26.3-29.3	430-160 460-500 310-140
	770	19	Dry 20 40	16.3-16.7 18.0-18.8 16.3-17.1	2130-1440 1940-1770 3540-2230
European Whitewood	460	13	Dry 20 40	18.8-20.9 21.7-25.1 23.8-25.1	240-180 610-370 550-260
		19	Dry 20 40	15.5-16.3 16.7-21.7 17.6-20.9	2380-1520 1800-300 1520-530

Table 5.2: Result of Experiments investigating the Effect of Moisture Content on Radiant Piloted Ignition (Law *and* Simms)

The results were converted into a graphical form showing how the minimum radiant intensities vaned with moisture content as shown in Figure 5.1.

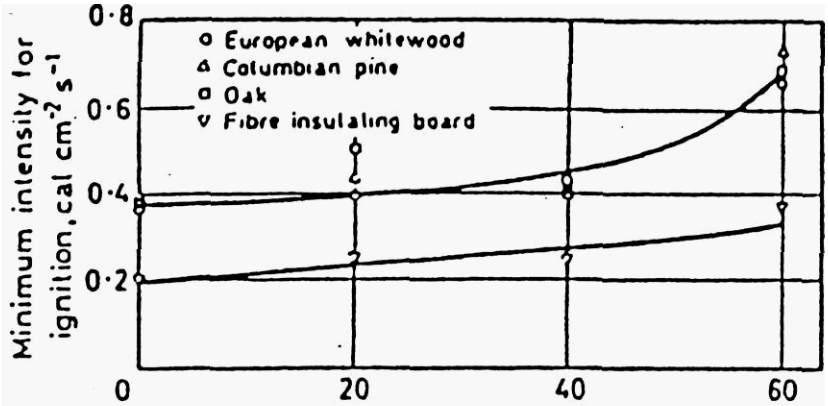
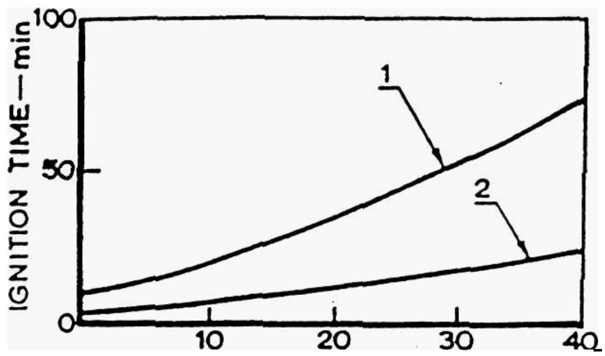


Figure 5.1: Minimum Intensity of Radiation for Piloted Ignition

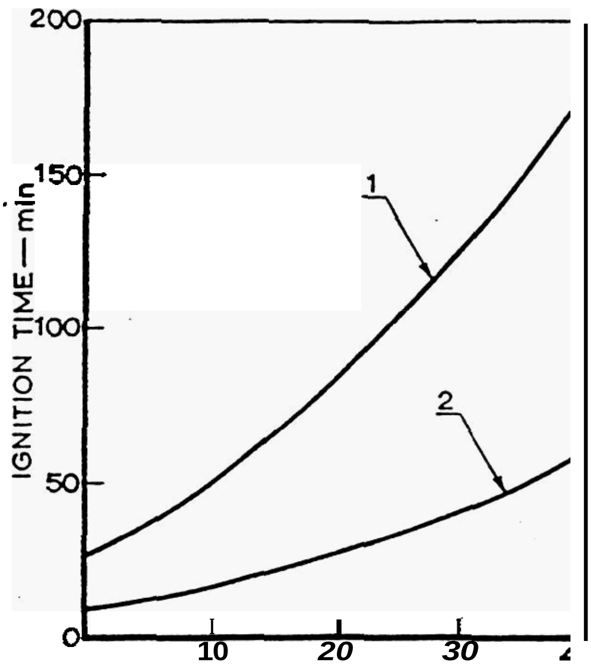
The experiments showed that the effect of moisture in timber was to increase the ignition time, the total ignition energy and the minimum intensity for both spontaneous and piloted ignition. The report noted that based on the extensive testing done, the lowest value at which piloted ignition of dry timber was likely to occur was 14.6 kW/m^2. At the lowest likely moisture content of 10% for external timber, ten minutes of exposure to a flux of 16.7 kW/m^2 would be required before piloted ignition took place. Thus the conclusions of the report stated that there was an "amply safe margin" in the choice of 12.6 kW/m^2 as the maximum acceptable level of received radiation for the Building Regulations.

In her later Fire Research Technical Paper No.20, Law (1968) presented the results in a different graphical form as shown in Figure 5.2.

In this paper Law states that for a typical moisture content of 15%, timber with a density of 800 kg/m^2 would take about 65 minutes to ignite under a constant heat flux of 15.9 kW/m^2 and 27 minutes for a flux of 18.4 kW/m^2. She pointed out that the peak constant flux is not likely to occur until at least 10 minutes after the start of a fire.



(a) Density of dry wood 0·5 g/cm³



(b) Density of dry wood 0·8 g/cm³

1. Incidant intansity 0.38 cal $cm^{-2}s^{-1}$
2. Incidant intensity 0·44 cal $cm^{-2}s^{-1}$

Figure 5.2: Relationship between Ignition Time and Moisture Content for Timber

The effect of various environmental conditions on the ignition of timber has been investigated by a number of researchers. Atreya has carried out experiments on many aspect of the problem and in conjunction with Abu-Zaid (1991) investigated the effects of moisture content, wind speed and O_2 concentration on piloted ignition. Following earlier work (1985) which showed that piloted ignition parameters were not affected by the sample orientation, ie. vertical or horizontal, numerous tests were carried out on horizontal samples of Douglas Fir subjected to radiant heat. The tests showed that the moisture content had a significant effect on the piloted ignition of timber with the ignition time increasing with higher moisture content and the surface temperature and ignition flux also being higher. In the testing, the minimum heat flux at which piloted ignition occurred, even for dry timber, was 17.5 kW/m^2, as seen in Figure 5.3

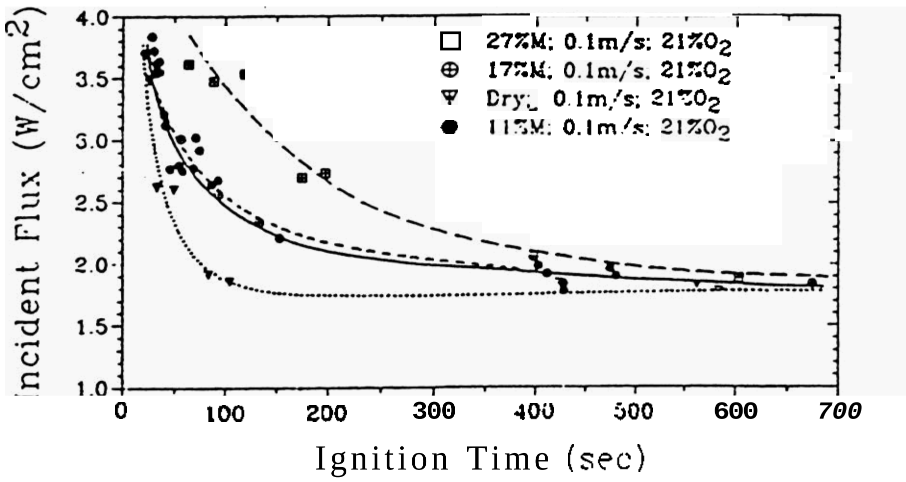


Figure 5.3: **Effect** of Moisture Content on Ignition (Atreya)

The paper points out that at low incident heat fluxes the curves for the different moisture contents tend towards the same asymptote. This is because the timber heats slowly and the moisture is driven off prior to ignition. This drying out absorbs some of the heat energy which would normally go into heating of the timber and hence the time to ignition is significantly increased.

By correlating the results of similar work for a variety of timber species, Janssens (1991) derived a simplified thermal model for piloted ignition. Cone calorimeter tests were used to establish the parameters in the formula:-

$$q = q_{cr}\left[1+0.73\left(\frac{k\rho c}{h_{ig}^2 t_{ig}}\right)^{0.547}\right]$$

For oven dry timber, the parameters shown in Table 5.3 were established.

Species	T_{ig}(°C)	q''_{cr}(kW.m^{-2})	h_{ig}(W.m^{-2}.K^{-1})	kρc(kJ^2.m^{-4}.K^{-2}.s)
Western Red Cedar	354	13.3	34.9	0.087
Redwood	364	14.0	35.9	0.141
Radiata Pine	349	12.9	34.6	0.156
Douglas Fir	350	13.0	34.6	0.158
Victorian Ash	31[illegible]	10.4	31.5	0.260
Blackbutt	300	9.7	30.6	0.393

Table 5.3: Parameters for Janssens Thermal Model

In a PhD thesis, Janssens **(1991)** extended the earlier **work** to investigate the effect of moisture content on his model. He concluded that the ignition temperature (T_{ig}) increases by about **2°C for** every 1% increase in ***moisture*** content. For Radiata Pine the parameters that were derived are shown in Table 5.4.

Moisture Content (%)	T_{ig} (°C)	h_{ig} (W/m^2-K)	q_{cr} (kW/m^2)	kρc (kJ^2-s/m^4-k^2)
0	349	36.6	13.7	0.156
5	359	37.4	14.4	0.198
10	369	38.2	15.2	0.240
15	379	39.1	16.0	0.281
20	389	40.0	16.8	0.323

Table 5.4: Parameters for Radiata Pine for Varying Moisture Content

Using these parameters in the formula derived earlier, it is possible to calculate the heat **flux** for a range of ignition times. The results are **shown** in Figure **5.4.**

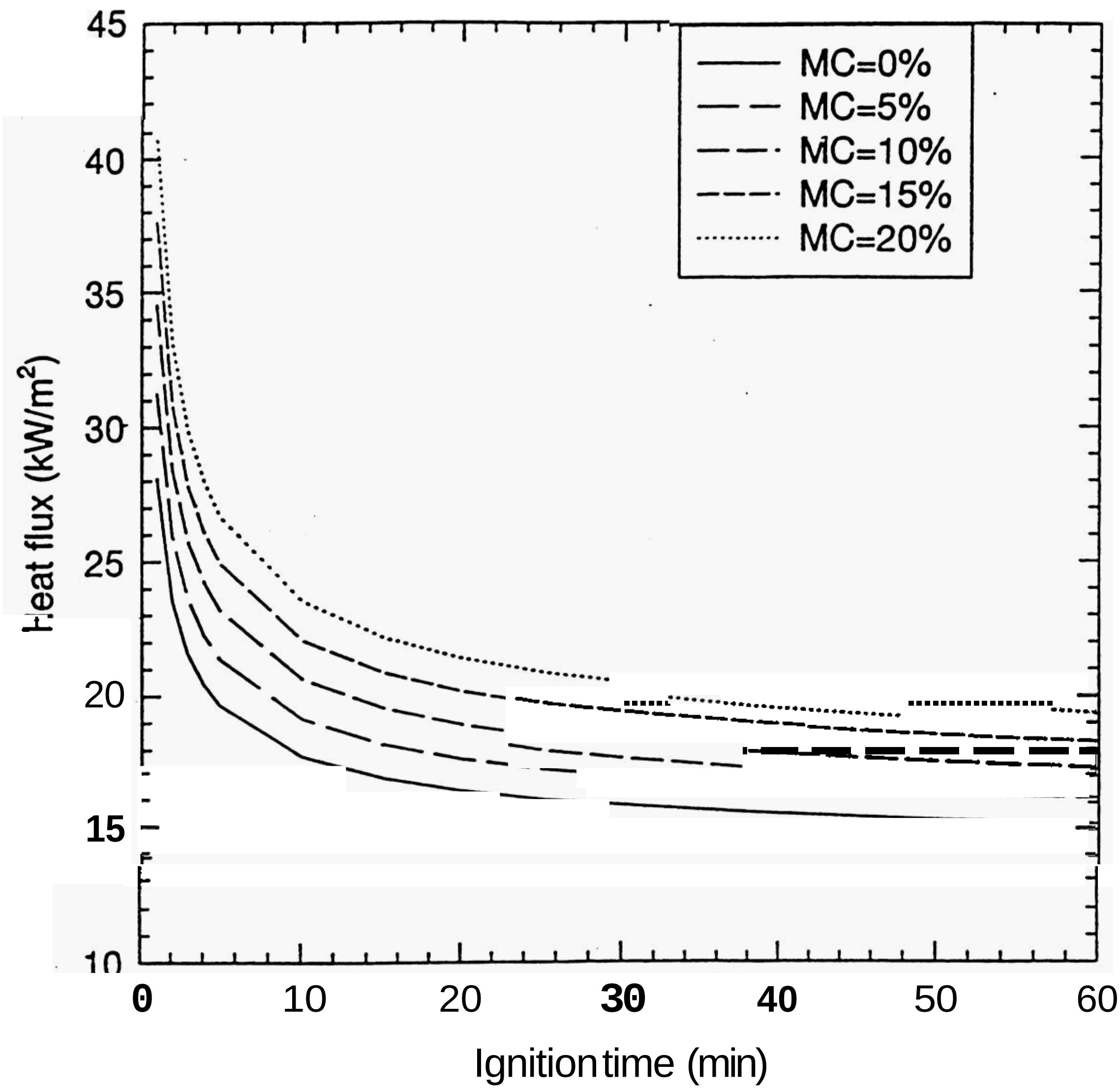


Figure 5.4 Piloted Ignition of Radiata Pine (Janssens)

From this graph it can be seen that the minimum heat flux that may be expected to cause piloted ignition for dry timber is in the order of 15 kW/m^2 and for pine with a 15% moisture content a minimum flux of 18 kW/m^2 may be expected for the durations we are concerned with.

In recent communications (Janssens (1999) confirmed that his work showed that the critical heat flux is directly related to the ignition temperature and hence increases with moisture content. He pointed out that using surface temperature as a criterion for ignition is an engineering approximation as, in reality, ignition is dependent on the mass flux of the volatiles being driven off the timber. The mass flux must be sufficient to create a flammable moisture in the gas phase and this is referred to as the critical mass flux. Moisture being driven from the timber dilutes the combustible volatiles and a higher mass flux is required for ignition, hence higher surface temperature and critical flux values.

The critical flux is determined on the basis of an extrapolation for an infinite exposure time when, in reality, exposure times rarely exceed an hour and are often less than 20 minutes. On this basis Janssens agreed that using a higher critical flux to account for moisture content was justified.

In more recent work in Australia, Moghtaderi et al (1997) derived a slightly different correlation based on cone calorimeter tests on samples of Radiata Pine and three native Australian wood species. Their expression was:

$$q'' = \left[\left(\frac{\pi}{4} k\rho c\right)^{1/2} \theta_{ig}\right] t_{ig}^{-1/2}$$

The power factors used are not too different to that of Janssens and as may be expected, the graph of their experimental results shown in Figure 5.5 is a similar shape to that of Janssens' correlation shown in Figure 5.4.

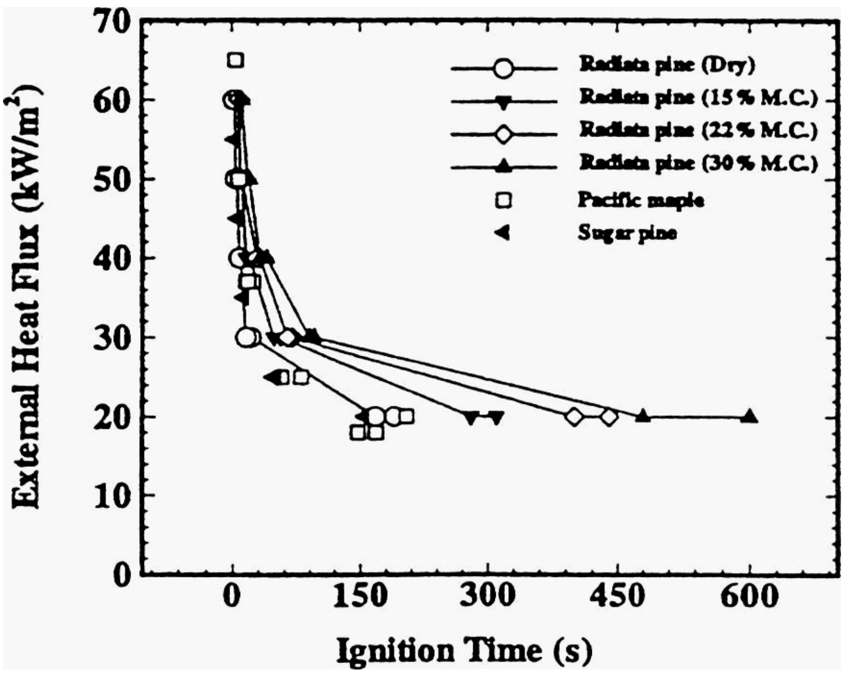


Figure 5.5: Heat Flux and Ignition Times for Varying Moisture Content

5.5 PROPOSED NEW CRITICAL RADIATION LIMITS

Based on the work by the various researchers reviewed in Section 5.4, it is clear that the present received radiation limit of 12.6 kW/m^2 is conservative. Even allowing for only a low moisture content it would appear that a value of 16 kW/m^2 could be justified for the longer duration, higher intensity fires of Fire Hazard Categories 3 and 4. For the shorter fires of Fire Hazard Categories 1 and 2 the peak emitted radiation is lower and the exposure time is less, so it is considered that a critical received radiation limit of 17 kW/m^2 would be applicable to these.

Prolonged exposure to the proposed levels of radiation will eventually cause piloted ignition but the ignition time will be extended. For both situations the limits do not allow for the time dependent nature of the radiation from a real fire, which would tend to increase the time to ignition even further.

At the radiation limits proposed the time to ignition for real situations will be significantly longer than the standard Fire Service response time so there will be additional safeguards against piloted ignition of neighbouring buildings.

CHAPTER 6: CONCLUSIONS

6.1 REQUIREMENTS FOR CHANGE

As detailed in Chapter 1, the boundary separations of the present Acceptable Solutions are similar to the prescriptive requirements of a number of overseas countries. To date there have been only a few instances, generally of a minor nature, where a building tire has caused damage to adjacent buildings. However with the present emphasis on more closely packed urbanisation and owners' wishes for maximum window area in external walls and maximum site coverage, it is considered that there is a probability of increased risk in the future.

As the New Zealand Building Code is a performance based code it is considered that boundary separation requirements should be based on sound fire engineering principles and current research. This is especially true when specific tire engineering designs are proposed as alternatives to the Acceptable Solutions, but the Acceptable Solutions are not to the same level of rigorousness. Based on the research detailed in the preceding chapters, it is apparent that there is scope to modify the parameters used to produce the boundary separation tables of the present Acceptable Solutions.

6.2 EMITTED RADIATION

From the review in Chapter 2 of alternative methods of establishing emitted radiation it is concluded that, as is done in the present Acceptable Solutions, specifying the radiation values to be used is the most appropriate method. However, the present two levels of emitted radiation are considered too coarse and it is proposed that four levels be used corresponding to the four fire hazard categories used in the present Acceptable Solutions.

6.3 RADIATION TRANSFER

In Chapter 3 the various parameters affecting heat radiation transfer between buildings are reviewed and in most instances the existing parameters are considered to be acceptable. The exception is the inclusion of flame projection in the separation distances. A number of the research papers reviewed indicate that flame projection out of openings can have a significant effect of the level of radiation received on an adjacent building. It is considered that some allowance for the effect of flame projection should be included in any revised boundary separation tables.

It is significant to note that most of the overseas codes specifically state that the separation distances are based on the assumption that there will be Fire Service intervention within a short period, usually under 10 minutes. If this intervention cannot be guaranteed, the overseas codes require the separation distances to be doubled, or in some cases tripled. This requirement for Fire Service intervention is not stated in the present Acceptable Solutions although it is implicit in the values that have been determined.

6.4 BUILDING SEPARATIONS

The boundary separations of the present Acceptable Solutions, like those of most other countries, are based on a mirror image concept where it is assumed that any receiving building is a mirror image of the building being designed. Chapter 4 gives examples of how this approach can easily lead to unsafe conditions. However, as the Acceptable Solutions specify a boundary distance within which a neighbouring building must be fire rated, design to this "limiting distance" would maintain safe conditions in all cases.

6.5 RECEIVED RADIATION

Chapter 5 discusses the type of damage to be considered in the design criteria and the external claddings that may be critical.

It is concluded that the criteria used in the present tables, ie. piloted ignition of external timber cladding, should continue to be used as the critical design case. However it is considered that the present value of 12.6 kW/m^2 is conservative and can be increased.

CHAPTER 7: RECOMMENDATIONS

7.1 GENERAL

Based on the conclusions outlined in Chapter 6 it is proposed that revised boundary separation tables be prepared incorporating the alterations to the design parameters detailed in the following sections.

7.2 EMITTED RADIATION LEVELS

As discussed in Section 2.12, it is proposed that four levels of emitted radiation be incorporated in the new separation tables. The values proposed are based on the required fire resistance ratings of the typical compartments in each of the fire hazard categories and are determined from the temperatures obtained from the ISO 834 standard fire curve for each fire duration. The proposed values are 85 kW/m^2, 125 kW/m^2, 150 kW/m^2 and 175 kW/m^2 for Fire Hazard Categories 1 to 4 respectively.

7.3 FLAME PROJECTION

Based on experimental results, a number of overseas codes include an allowance of between 1.2 m and 1.5 m for flame projection. However as there have not been significant problems in New Zealand to date and because of the varying effect of flames, it is proposed that smaller allowances be used in the amended tables. For Fire Hazard Categories 1 and 2 a flame project of 0.5 m is proposed while for Fire Hazard Categories 3 and 4 the allowance is increased to 1.0 m.

7.4 FIRE SERVICE INTERVENTION

Any new boundary separation tables should continue to be based on the premise that the Fire Service will attend the fire within a relatively short period, say under 10 minutes, and being wetting down any neighbouring building that is at risk.

However this assumption should be explicitly stated in the notes of the tables with the rider that if this is not possible to guarantee, the separation distances given must be doubled.

7.5 BUILDING SEPARATIONS

In order to ensure that critical radiation limits are not exceed as a result of dissimilar faces on adjacent buildings or differences in construction timing, it is proposed that the "limiting distance" concept be incorporated in the tables. As the Acceptable Solutions specify a 1.0 m boundary distance within which a neighbouring building must be fire rated, it is proposed that this "limiting distance" be used to establish the minimum building separations and hence the required boundary separation for the building being designed. This proposal is probably the most significant of all of the suggested changes in this report as it can substantially increase the required boundary separation.

7.6 VALUES FOR CRITICAL RADIATION

As discussed in Chapter 5 a number of overseas researchers have concluded that the critical radiation value for piloted ignition of timber is increased by the present of moisture in the timber.

Based on this overseas research, received radiation values of 17 kW/m^2 for Fire Hazard Categories 1 and 2 and 16 kW/m^2 for Fire Hazard Categories 3 and 4 are recommended.

7.7 PROPOSED SEPARATION TABLES

The proposed design parameters on which the separation tables are to be based are given in Table 7.1, together with the existing parameters.

Case	Emitted Radiation (kW/m^2)	Flame Projection (m)	Limiting Radiation (kW/m^2)	Limiting Distance (m)
Old moderate	a4	0	12.6	Mirror image
Old high	168	0	12.6	Mirror image
New FHC1	85	0.5	17.0	1.0
New FHC2	125	0.5	17.0	1.0
New FHC3	150	1.0	16.0	1.0
New FHC4	175	1.0	16.0	1.0

Table 7.1: Boundary Separation Parameters

Using these parameters, the example buildings considered in Appendix A for 100% unrated walls are reanalysed in Appendix E and the change in separation requirements are given in Table 7.2

Fire Hazard Category	Wall Size	Present Boundary Separation (m)	New Boundary Separation (m)	Present Building Separation (m)	New Building Separation (m)
1	3 x 12	3.65	5.5	7.3	6.5
2	3 x 40	4.75	9.9	9.5	10.9
3	6 x 12	8.30	13.6	16.6	14.6
4	6 x 30	12.40	22.0	24.8	23.0

Table 7.2: Example Boundary and Building Separations

As illustrated in the table, the new boundary separations are significantly greater than under the existing Acceptable Solutions. However, the last two columns of the table compare the actual building separations that are assumed in the two approaches. In the mirror image method of the present tables the building separation is twice the boundary separation. For the limiting distance approach the building separation is the boundary separation plus the limiting distance of 1.0 m used in the present Acceptable Solutions. As can be seen, the building separations are comparable and in three of the four examples the new ones are in fact less than under the present system. With the proposed tables all situations will be safe, whereas the mirror image approach can result in situations where the limiting radiation is exceeded to a significant degree.

To check the general effect of the revised parameters new separation tables for the Fire Hazard Categories have been produced and are given in Appendix E. Using these tables and tables for the existing parameters also given in Appendix E, the separation requirements for unrated 3 m high walls of various lengths have been determined and are given in Table 7.3 and illustrated in Figure 7.1.

Wall Length (m)	Existing FHC1 and 2	Existing FHC3 and 4	New FHC1	New FHC2	New FHC3	New FHC4
2	1.75	2.5	2.5	3.0	4.0	4.5
4	2.50	3.5	3.5	4.5	6.0	7.0
6	3.00	4.5	4.5	5.5	7.0	8.0
8	3.50	5.0	5.5	6.5	8.0	9.0
10	3.50	6.0	5.5	7.5	9.0	10.0
12	4.00	6.0	5.5	7.5	10.0	12.0
14	4.00	7.0	6.5	8.5	10.0	12.0
16	4.50	7.0	6.5	8.5	12.0	12.0
18	4.50	7.0	6.5	8.5	12.0	12.0
20	4.50	7.0	6.5	9.5	12.0	14.0

Table 7.3: Boundary Separations for 3 m High Unrated Walls

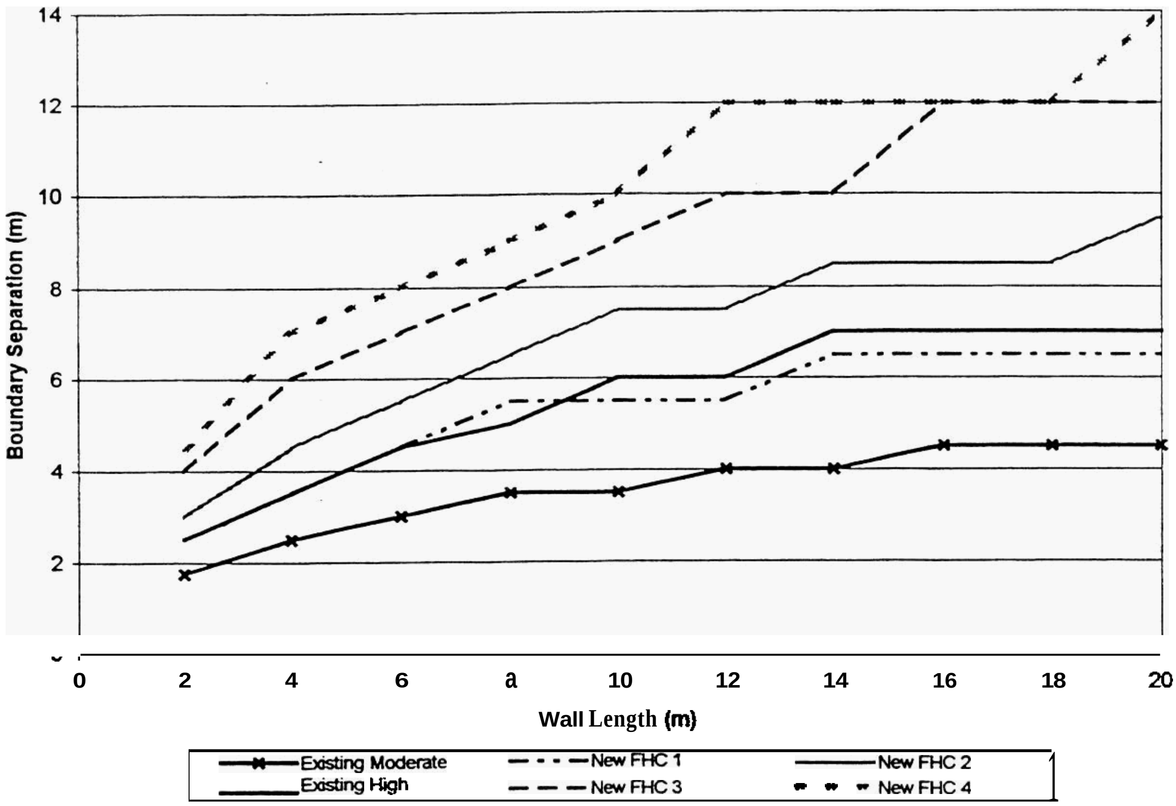


Figure 7.1: Comparison of Boundary Separations using Existing and Proposed Tables

7.8 POTENTIAL AREAS FOR FURTHER CONSIDERATION OR RESEARCH

As can be seen from Figure 1, the new separation requirements are a significant increase over those of the existing solutions. This is likely to cause significant resistance to any changes to the existing values, but all of the proposed parameters have been chosen for valid reasons and are based on verified published research material.

However, there is scope for additional research in some areas which may lead to a reduction in the separation requirements established in this report. These areas for possible future research are:-

(a) Emissivity

By reviewing the radiation emitted from actual building fires, it may be possible to justify an overall design value for emissivity of <1.0.

(b) Flame Projection

From either experimental or more extensive literature research the nominal, but still significant, values assumed in this report could be either verified or discounted.

(c) Limiting Distance

The limiting distance of 1.0 m of the present Acceptable Solutions has the most significant impact on the new tables. A review of the construction cost savings resulting from an increase in this distance to 1.5 m or even 2.0 m compared to the increased costs for building within the limiting distance may indicate that an increase is justified. As well, consideration of differing conditions for residential properties compared with commercial or industrial buildings may be fruitful.

(d) Fire Service intervention

As has been stated, the separation tables assume that there will be intervention to protect adjacent properties within 10 minutes. Although the effect is not enumerated, it is included as a de facto safety factor. If such an assumption is made de facto and due allowance is made in cases where it cannot be complied with, it may be overly conservative to design for emitted radiation values resulting from 90 minutes and 120 minute tires. From a review of Fire Service operations and statistics of past fires it may be possible to place an upper limit on the emitted radiation in areas where Fire Service intervention can be guaranteed.

(e) Critical Radiation

A detailed experimental study into the values of critical radiation for piloted ignition of typical **New** Zealand timber cladding materials at relevant moisture contents may indicate possible modifications to the values proposed in this report.

(f) Radiation from Growing Fires

The research results reviewed for this report were all based on tests carried out on radiators emitting a fixed level of heat flux. For actual fires the emitted radiation will increase as the fire grows and hence the time to reach the critical radiation will be longer. In addition the effects of convective cooling and conduction into the wall framing will increase the time taken **for** piloted ignition to occur.

Experimental testing of typical wall construction under transient heating rather than fixed radiation on a small sample of timber may prove that longer periods of exposure can be justified.

When considering the recommendations of this report it must be borne in mind that in addition to pure engineering considerations any significant changes to the present tables will have considerable political and cost/benefit implications. However sound the engineering involved it may be overruled by either politicians or accountants.

REFERENCES:

Atreya A, Carpentier C and Harkleroad M, 1985	"Effect of Sample Orientation on Piloted Ignition and Flame Spread". Fire Safety Science Proceedings of the 1st International Symposium. (pp.97-109)
Atreya A and Abu-Zaid M, 1991	"Effect of Environmental Variables on Piloted Ignition". Fire Safety Science Proceedings of the 3rd International Symposium. (pp.177-186)
Australian Building Codes Board, 1996	"Building Code of Australia", 1996
Babrauskas V, 1979	"A Program for Calculating Post-Flashover Fire Temperatures" NBS TN 991, Washington
Babrauskas V, 1981	"A Closed-Form Approximation for Post-Flashover Compartment Fire Temperatures", Fire Safety Journal Vol.4, 1981
Babrauskas V and Williamson R B, 1978	"Post-Flashover Compartment Fires; Basis of a Theoretical Model". Fire and Materials Vol.2, 1978
Barnett C R. 1988	"Fire Separation between External Walls of Buildings". Fire Safety Science. Proceedings of the 2nd International Symposium. (pp.841-850)
Barnett C R, 1995	"BFD Curve -Theory", unpublished
Barnett C R, 1996	"Design Fires for Structural Engineers". Proceedings of 1997 IPENZ Conference. (pp.289-295)
BIA 1992	"New Zealand Building Code Handbook and Approved Documents". Building Industry Authority

BOCA, 1996	"National Building Code", 1996
Buchanan A H (editor), 1994	"Fire Engineering Design Guide". Centre for Advanced Engineering, University of Canterbury
Buchanan A H, 1998	"Modelling Post-Flashover Fires with FASTLite" Journal of Fire Protection Engineering Vol.9, No.3.
Buchanan A H, 1998	"Performance Based Structural Design for Fire". SFPE Conference on Performance Based Codes, Maui Hawaii 1998.
Clifton C. 1996	"Fire Models for Large Fire cells" HERA Report R 4-83
Cowles G and Wade C, 1998	"Flame Spread Classification Method for Exterior Wall claddings". BRANZ Conference Paper No 48 (1998)
CSIRO, 1993	"FIRECALC Version 2.3 Users Manual". CSIRO Division of Building Construction and Engineering
Deal S, 1993	'Technical Reference Guide for FPEF001 Version 3.2". NISTR 5486 National Institute of Standards and Technology
Dembsey N, Pagni P and Williamson R, 1995	"Compartment Fire Experiments: Comparison with Models". Fire Safety Journal No 25
Department of the Environment (UK) 1991	'The Building Regulations 1991, Section B4"
Drysdale D D, 1985	"An Introduction to Fire Dynamics". John Wiley & Sons

ECI 1995	"Eurocode 1 - Basis of design and actions on structures. Part 2-2: Actions on structures -Actions on structures exposed to fire". ENV 1991-2-2: 1995. European Committee for Standardisation, Brussells
Feasey R, 1998	'Post Flashover Design Fires" Research Project for M E degree University of Canterbury
Franssen J M et al, 1996	"Connection between Parametric Temperature or Time Curves and Equivalent time of fire exposure". International Association for Bridge and Structural Engineering Colloquium, Delft
Harada K, 1998	Personal Communication
Harada K et al, 1998	"A Pilot Case Study of a Performance-Based Fire Safety Design Method to a Multi-Tenant Office Building" Fire Science Technology Vol 18 No 1
Howell J R, 1982	"A Catalogue of Radiation Configuration Factors"
Incropera and de Witt, 1990	"Fundamentals of Heat and Mass Transfer, 3rd Edition"
Janssens M, 1991	"A Thermal Model for Piloted Ignition of Wood including Variable Thermophysical Properties". Fire Safety Science Proceedings of the 3rd International Symposium. (pp. 167-176)
Janssens M, 1991	"Fundamental thermophysical characteristics of wood and their role in enclosure fire growth". PhD thesis University of Ghent, Belgium
Janssens M, 1999	Personal communication.

Kanury A, 1995	"Flaming Ignition of Solid Fuels". SFPE Handbook 2nd Edition Chapter 2-13
Kawagoe, 1958	"Fire Behaviour in Rooms", Report No.27, Building Research Institute, Tokyo
Kawagoe K and Sekine T, 1963	"Estimation of Fire Temperature - Time Curve in Rooms". BRI Report No.11 Building Research Institute, Tokyo
Kawagoe K and Sekine T, 1964	"Estimation of Fire Temperature - Time Curve in Rooms 2nd Report". BRI Report No 17 Building Research institute, Tokyo
Kawagoe K, 1967	"Estimation of Fire Temperature - Time Curve in Rooms 3" Report". BRI Research Paper No 29 Building Research Institute, Tokyo
Kawagoe K, 1971	'Charts for Estimating the Equivalent Fire Duration on the Standard Temperature - time Curve". BRI Research Paper No 45 Building Research Institute, Tokyo
Kirby B R et al, 1994	"Natural Fires in Large Scale Compartments". British Steel Technical, Fire Research Station Collaborative Report
Law M, 1963	"Heat Radiation from Fires and Building Separation". Fire Research Technical Paper No.5, Joint Fire Research Organization
Law M. 1968	"Radiation from Fires in a Compartment", Fire Research Technical Paper No.20, Ministry of Technology and Fire Offices Committee

Law M, 1981	"Notes on the External Fire Exposure Measured at Lehrte". Fire Safety Journal Vol.4 1981. (pp.243-246)
Law M and O'Brien T, 1981	"Fire Safety of Bare External Structural Steel". Constrado
Law M, 1998	Personal Communication
Lie T T, 1974	"Characteristic Temperature Curves for Various Fire Severities". Fire Technology Vol.10 No.4
Lie T T, 1979	"Calculating Resistance to Fire:. CBD-204 National Research Council of Canada
Lie T T, 1995	"Fire Temperature - Time Relations". SFPE Handbook 2nd Edition Chapter 4-8
Lin E and Mehaffey J, 1997	"Modelling the Fire Resistance of Wood-Frame Office Buildings" Journal of Fire Sciences Vol 15
Magnusson S and Thelandersson S, 1970	"Temperature - Time Curves of Complete Process of fire Development: Theoretical Study of Wood Fuel Fires in Enclosed Spaces". Acta Polytechnica Scandinavica. Civil Engineering and Building Construction Series No 65
McGuire J H, 1965	"Fire and the Spatial Separation of Buildings" Fire Technology **Vol 1 No 4 1965**
McGuire J and Williams-Leir G, 1981	"Spread of Fire between Buildings". CBD-216 National Research Council of Canada

Moghtaderi B, Novozhilov V, Fletcher D F and Ken J H, 1997	"A New Correlation for Bench-scale Piloted Ignition Data of Wood". Fire Safety Journal No.20 1997
National Research Council of Canada, 1990	"National Building Code of Canada" 1990
Nelson H, Deal S, 1991	"Comparing Compartment Fires with Compartment Fire Models". IAFSS Proceedings of the Third International Symposium
New Zealand Fire Service, 1998	"Emergency Incident Statistics 1993-1997"
New Zealand Government, 1991	'The Building Act 1991", Department of Internal Affairs
New Zealand Government, 1992	'The Building Regulations 1992", Department of Internal Affairs
NFPA 1993	'National Fire Code 80A: Protection of Buildings from Exterior Fire Exposures" National Fire Protection Association
Peacock R et al, 1997	"A User's Guide for FAST 3.0: Engineering Tools for Estimating Fire Growth and Smoke Transport". NIST Special Publication
Pettersson O, Magnusson SE and Thor J, 1976	"Fire Engineering Design of Structures", Swedish Institute of Steel Construction Publication No 50
Portier R, Peacock R and Reneke P, 1996	"FASTLite: Engineering Tools for Estimating Fire Growth and Smoke Transport". NIST Special Publication 899
Quintiere. 1979	"The Spread of Fire from a Compartment - A Review". Design of Buildings for Fire Safety ASTM

	STP 685
Quintiere, 1995	"Compartment Fire Modelling", SFPE Handbook 2nd Edition Chapter 3 - 5
Read, R E, 1991 (Editor)	"External Fire Spread: Building Separation and Boundary Distances". Building Research Establishment Report BR **187**
Seigel L, 1969	"The projection of flames from burning buildings". Fire Technology Vol 5 1969
SFPE. 1995	'The SFPE Handbook **of** Fire Protection Engineering". 2nd Edition, Society of Fire Protection Engineers
Shorter ***G* W,** McGuire **J** H, Hutcheon N B and Legget **R** F, 1960	'The St Lawrence Burns" NFPA Quarterly Vol 53 NO 4
Simms D and Law M, 1967	"The Ignition of Wet and Dry Wood by Radiation". Combustion and Flame **Vol II** No 5
Standards Association of New Zealand, 1988	"NZS 1900 Chapter 5: Fire Resisting Construction and Means of Egress"
Thomas ***G* C** et al, 1995	"Light Timber Framed Walls Exposed to Compartment Fires". Journal of Fire Protection Engineering Vol 7, No 1
Thomas P **H** and Law M, 1974	"The Projection of Flames from Buildings on Fire". Fire Prevention Science and Technology No.10 (pp.19-26)
Tien C L, Lee **K Y** and Stretton **AJ,** 1995	"Radiation Heat Transfer" SFPE Handbook 2nd Edition Chapter 1 - 4

Torvi D, 1998	Personal Communication
Wade C. 1995	"Post-Flashover Fire Models - A Review". FPE 520 Term Paper Centre for Fire Safety Studies Worcester Polytechnic Institute
Wade C, 1995	"Fire Performance of External Wall Claddings Under a Performance Based Building Code". Fire and Materials Vol 19
Walton W D and Thomas P H 1995	"Estimating Temperatures in Compartment Fires" SFPE Handbook 2nd Edition Chapter 3 - 6
Wang Y, Cooke G and Moore D, 1996	"Large Compartment Fire Tests at Cardington and the Assessment of Eurocode 1" International Association for Bridge and Structural Engineering Colloquium, Delft
Webster C and Raftery M, 1959	"The burning of tires in rooms". Joint Fire Research Organisation Fire Research Note 401
Williams-Leir G. 1966	"Approximations for Spatial Separation". Fire Technology Vol 2 No 2
Williams-Leir G, 1970	"Another Approximation for Spatial Separation". Fire Technology Vol 6 No 3
Yokoi S, 1960	"Study on the prevention of fire spread caused by hot upward current". Japanese Building Research Institute Report No 34
Yung D and Oleszkiewicz, 1988	"Fire Spread via Exterior Walls of Buildings". Proceedings of the 4th Conference on Building Science and Technology, Toronto 1988

Appendix A

Verification of Boundary Separation Tables of the Acceptable Solutions

APPENDIX A

VERIFICATION OF BOUNDARY SEPARATION TABLES OF THE ACCEPTABLE SOLUTIONS

Using the design parameters given in Section 1.4, the required boundary separations for four typical wall elevations are determined from the C3 tables, manually using Margaret Law's method and from a purpose designed spreadsheet. The values of the incident radiation on a mirror image building is then checked using FIRECALC.

The four examples are:-

(a) Single storey Childcare Centre with a 100% unrated wall 3 m high by 12 m long - Fire Hazard Category 1.

(b) Single storey classroom block with an unrated side wall 3 m high by 40 m long - Fire Hazard Category 2.

(c) Unrated end wall 6 m high by 12 m long of a factory with Fire Hazard Category 3.

(d) Unrated side wall 6 m high by 12 m long of a vehicle tyre retailer - Fire Hazard Category 4.

1.0 From Appendix C of the Acceptable Solutions:-

(a) Enclosing rectangle 3 m x 12 m FHC = 1–boundary separation = 3.5 m
(b) Enclosing rectangle 3 m x 40 m FHC = 2–boundary separation = 5.0 m
(c) Enclosing rectangle 6 m x 12 m FHC = 3–boundary separation = 8.5 m
(d) Enclosing rectangle 6 m x 30 m FHC = 4–boundary separation = 12.5 m

2.0 The emitted radiation values used in the tables would mean that (a) and (b) are assumed *to* have a radiation intensity of 84 kW/m^2, while (c) and (d) would have 168 kW/m^2. Based on the formula $I = \epsilon\sigma T^4$ with ϵ = 1.0 the compartment temperatures relating *to* these intensities would be 830°C and 1039°C.

Using the configuration factor method detailed in the Fire Engineering Design Guide (Buchanan 1994) the radiation received on a mirror image building conforming *to* the boundary separations given above would be determined from:-

$I_R = \phi\varepsilon\sigma\,[(273 + T_e)^4 - (273 + T_r)^4]$

ϕ is the configuration factor

ε is the emissivity = 1.0

T_e is the temperature of the emitter **("C)**

T_r is the temperature of the receiver **("C)**

For a receiver located a distance **R** away from a rectangular emitter:

$$\phi = \frac{1}{90}\left[\frac{x}{\sqrt{1+x^2}}\tan^{-1}\left(\frac{y}{\sqrt{1+x^2}}\right) + \frac{y}{\sqrt{1+y^2}}\tan^{-1}\left(\frac{x}{\sqrt{1+y^2}}\right)\right]$$

Where x = H/(2R)

y = W/(2R)

H = height of the enclosing rectangle (m)

W = width of the enclosing rectangle (m)

R = distance between the emitter and receiver (m) (twice the boundary separation for **a** mirror image situation)

(a) H = 3 m W = 12 m R = 7 m I_e = 84 kW/m²

x = 3/14 = 0.2143

y = 12/14 = 0.8571

→ ϕ = 0.1599

→ I_R = 13.43 kW/m²

(b) H = 3 m W = 40 m R = 10 m I_e = 84 kW/m²

x = 3/20 = 0.15

y = 40/20 = 2.0

$\Rightarrow \phi = 0.1423$

$- \; I = 11.95 \text{ kW/m}^2$

(c) $H = 6$ m $W = 12$ m $R = 17$ m $I_e = 168 \text{ kW/m}^2$

$x = 6/34 = 0.1765$

$y = 12/34 = 0.3529$

$\rightarrow \phi = 0.0719$

$\Rightarrow I = 12.09 \text{ kW/m}^2$

(d) $H = 6$ m $W = 30$ m $R = 25$ m $I_e = 168 \text{ kW/m}^2$

$x = 6/50 = 0.12$

$y = 30/50 = 0.60$

$\rightarrow \phi = 0.0743$

$\rightarrow I_R = 12.49 \text{ kW/m}^2$

3.0 A spreadsheet has been prepared which is based on the C3 tables of the Acceptable Solutions, but which enables various parameters such as firecell temperature, emissivity, flame projection and limiting radiation to be adjusted. The exact size of the boundary wall can be entered together with the actual separation distance in order to find the proportion of fire rating required for the wall.

The **test** examples were checked using this spreadsheet, as shown on the following pages, and the required separations to achieve an incident radiation of 12.6 kW/m^2 are as shown below..

(a) Enclosing rectangle 3 m x 12 m

$I_e = \mathbf{84\ kW/m^2}$ Required boundary separation = 3.65 m

(b) Enclosing rectangle 3 m x 40 m

$I_e = 84 \text{ kW/m}^2$ Required boundary separation = 4.75 m

(c) Enclosing rectangle 6 m x 12 m

I_e = 168 kW/m^2 Required boundary separation = 8.3 m

(d) Enclosing rectangle 6 m x 30

I_e = 168 kW/m^2 Required boundary separation = 12.45 m

4.0 In order to confirm these figures, the specific radiation calculations on the following pages were undertaken using the radiation module of FIRECALC. As can be seen, the analyses confirm that the separations given by the spreadsheet result in the incident radiation being 12.6 kW/m^2 as required. Note that the initial calculation in each case is to confirm the temperature required by FIRECALC to produce an emitted radiation of 84 kW/m^2 and 168 kW/m^2.

5.0 Table A.I below gives the comparison of the boundary separation obtained from the Acceptable Solutions with the separations obtained by specific design. As can be seen, both the spreadsheet and FIRECALC confirm that the parameters given in Chapter 1 will indeed produce the values of the C3 Tables of the Acceptable Solution.

Enclosing Rectangle	Fire Hazard Category	C3 Tables Boundary Separation (m)	Specific Design Boundary Separation (m)
3x12	1	3.5	3.66
3x40	2	5.0	4.76
6x12	3	8.5	6.31
6x30	4	12.5	12.44

Table A.I: Boundary Separations from **Acceptable** Solution **Tables** and **Specific** Design

26-Jan-99

NZBC Fire Safety Annex. Appendix C. Table C3 - Mirror Image concept
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION: C3 Table Verification

Limiting Radiation = 12.6 kW/m^2

		Exact Distance																										
Radiation Distance		7.3	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance (Radiation + Projection)	= S m	7.3	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Boundary Distance	=0.5S m	3.65	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17

Rectangle Size			Permitted unprotected area %												
H	W	Ae													
m	m	m^2													
3	12	36	100	18	21	25	30	35	41	47	53	60	76	94	100

26-Jan-99 NZBC Fire Safety Annex. Appendix C. Table C3 - Mirror Image concept

Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION:	C3 Table Verification

Fire Hazard Category	FHC = 2	Emissivity = 1	Limiting Radiation = 12.6 kW/m^2	Flame Projection Distance	P = 0 m

		Exact Distance																										
Radiation Distance		9.5	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance (Radiation + Projection)	= S m	9.5	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Boundary Distance	=0.5S m	4.75	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17

Permitted unprotected area %

Rectangle Size H m	W m	Ae m^2															
3	40	120	100	18	21	25	29	34	38	43	48	53	63	73	83	94	100

A6

26-Jan-99 *NZBC Fire Safety Annex. Appendix C. Table C3 - Mirror Image concept*
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION: C3 Table Verification

Fire Hazard Category FHC = 3 | Emissivity = 1 | Limiting Radiation = 12.6 kW/m^2 | Flame Projection Distance

		Exact Distance										
Radiation Distance		16.6	1	1.5	2	2.5	3	3.5	4	4.5	5	6
Separation Distance (Radiation + Projection)	= S m	16.6	1	1.5	2	2.5	3	3.5	4	4.5	5	6
Boundary Distance	=0.5S m	8.3	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3
Rectangle Size H W Ae (m m m^2): 6 12 72		100	8	8	9	10	11	12	14	15	17	21

Permitted unprotected area %

Radiation Distance	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance (Radiation + Projection)	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Boundary Distance	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17
Rectangle Size H W Ae (m m m^2): 6 12 72	25	30	36	42	57	74	93	100								

26-Jan-99 *NZBC Fire Safety Annex. Appendix C. Table C3 - Mirror Image concept*
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION:	C3 Table Verification

Fire Hazard Category	FHC =	4	Emissivity	=	1	Flame Projection Distance	P =	0 m
			Limiting Radiation	=	12.6 kW/m^2			

		Exact Distance																									
Radiation Distance		24.8	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance (Radiation + Projection)	= S m	24.8	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Boundary Distance	=0.5S m	12.4	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17

Rectangle Size			Permitted unprotected area %																	
H	W	Ae																		
m	m	m^2																		
6	30	180	100	8	8	9	10	11	12	13	14	15	17	20	22	[illegible]	[illegible]	[illegible]	[illegible]	

FIRECALC, v.2.3, update 31 October 1994

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RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature **830.** °C

Distance	Offset		Size of source		Opening
X	Yx	Zx	Y	Z	%
0	**0**	**0**	**12**	**3**	**100**

Maximum radiation flow:
84.015 kW/m²
Orientation:
Θ = 90.0°
ϕ = 0.0°

Radiation at emitter for low tire load

FIRECALC, v.2.3, update 31 October 1994
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RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 830. °C

Distance	Offset		Size of source		Opening
X	Yx	Zx	Y	Z	%
7.32	0	0	12	3	100

Maximum radiation flow:
12.593 kW/m²
Orientation:
Θ = 90.00
ϕ = 0.00

Radiation from Building (a) at specific design separation

FIRECALC, v.2.3, update 31 October 1994

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RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 830. °C

Distance	Offset		Size of source		Opening
X	Yx	Zx	Y	Z	%
9.52	0	0	**40**	3	**100**

Maximum radiation flow:
12.604 kW/m²
Orientation:
Θ = 90.0°
ϕ = 0.0°

Radiation from Building (b) at specific design separation

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RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 1039 °C

Distance	Offset		Size of source		Opening
X	Yx	zx	Y	Z	%
0	0	0	12	6	100

Maximum radiation flow:
168.106 kW/m^2
Orientation:
$\Theta = 90.0°$
$\phi = 0.00$

Radiation from emitter for high fire load

RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 1039 °C

Distance	Offset		Size of source		Opening
X	Yx	Zx	Y	Z	%
16.62	0	0	12	6	100

Maximum radiation flow:
12.601 kW/m²
Orientation:
Θ = 90.00
φ = 0.0°

Radiation from Building (c) at specific design separation

FIRECALC, v.2.3, update 31 October 1994

RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 1039 °C

Distance	Offset		Size of source		Opening
X	Yx	Zx	Y	Z	%
24.88	0	0	30	6	100

Maximum radiation flow:
12.596 kW/m²
Orientation:
Θ = 90.00
ϕ = 0.0°

Radiation from Building (d) at specific design separation

Appendix B

Comparison of Methods to Determine Compartment Temperature

APPENDIX B

COMPARISON OF METHODS TO DETERMINE COMPARTMENT TEMPERATURE

To compare the temperatures obtained using the various methods outlined in Chapter 2, the following compartment will be analysed for a range of fire loads.

Compartment:	4 m wide x 6 m long x 2.5 m high with fire rated ceiling
Ventilation:	One window 2.4 m long x 1.2 m high at 800 mm from floor
Interior Lining:	Equivalent to timber framed wall with 16 mm Fyreline
Fire Load 1:	Studio apartment at 400 MJ/m^2 of floor area
Fire Load 2:	Professional office at 800 MJ/m^2 of floor area
Fire Load 3:	File room at 1200 MJ/m^2 of floor area
Fire Load **4:**	Bond store for duty free shop at 2000 MJ/m^2 of floor area

A_F = 24 m^2

A, = 2 x 24 + 2 x (4 + 6) x 2.5 = 98 m^2

A, = 2.88 m^2

JH = 1.095 $m^{½}$

$A_W\sqrt{H}$ = 3.155 $m^{5/2}$

A_h/A_F = 0.0

A_W/A_F = 0.12

1.0 ACCEPTABLE SOLUTIONS

Fire Loads 1 and 2 correspond to Fire Hazard Categories 1 and 2 and therefore the emitted radiation is 84 kW/m^2. The Compartment temperature for this radiation would be 830°C. Fire Loads 3 and 4 are Fire Hazard Categories 3 and 4 and therefore the emitted radiation is taken as 168 kW/m^2. This corresponds to a compartment temperature of 1039°C.

2.0 LAW'S TEMPERATURE EQUATION

$$T, - T_a = 6000 \left(\frac{1-e^{-0.1\eta}}{\eta^{½}}\right) . (1-e^{-0.05\psi})$$

Taking h_c for wood = 16 MJ/kg, the fire loads are:-

FL1 = 25 kg/m^2

FL2 = 50 kg/m^2

FL3 = 75 kg/m^2

FL4 = 125 kg/m^2

A_t = 98 - 2.9 = 95.1 m^2

L1 = 25 x 24 = 600 kg

L2 = 1200 kg

L3 = 1800 kg

L4 = 3000 kg

η = $A_t/(A_W\sqrt{H})$ = 95.113.155 = 30.1

ψ_1 = 600/(2.88 x 95.1)'' = 36.25

ψ_2 = 72.5

ψ_3 = 108.75

ψ_4 = 181.25

for FL1 $T_f - T_a = 6000 \left(\frac{1-e^{-3.01}}{J30.1}\right) . (1-e^{-1.81})$

= 870°C

$\Rightarrow T_{f1}$ = 890°C

for FL2 $T_f - T_a$ = 1039.7 $(1-e^{-3.62})$

= 1012°C

$\rightarrow T_{f2}$ = 1032°C

for FL3 $T_f - T_a$ = 1039.7 $(1-e^{-5.43})$

= 1035°C

$\Rightarrow T_{f3}$ = 1055°C

for FL4 $\quad T_f - T_a = 1039.7\,(1-e^{-9.06})$

$= 1039.6$

$\Rightarrow T_{f4} \quad = 1059.6°C$

3.0 STANDARD FIRE CURVES

Formulae are given in the Fire Engineering Design Guide to establish the required fire rating of external walls. These formulae are empirical expressions from Eurocode 1 to establish the equivalent fire severity t_e (min) where

$$t_e = e_f\, k_c\, w_f$$

where e_f is the fire load (MJ/m^2 floor area)

k_c **is** the insulation factor given by Table B-1

w_f is the ventilation factor as given below

$\sqrt{\lambda\rho c}$**(J/m^{2}Ks$^{0.5}$)**	**Typical** Construction	**k_c (min m$^{2.3}$/MJ)**
<720	Insulating material	0.080
720 to *2500*	Concrete or plasterboard	*0.055*
>2500	Thin steel	0.045

λ = thermal conductivity W/m **K**
ρ = density kg/m^3
c = specific heat Jlkg **K**

Table **B.I:** Insulation Factor **k_c**

The ventilation factor w_f is given by:

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

where α_v $\quad = A_v/A \quad$ $0.05 \le \alpha_v \le 0.25$

$\alpha_h \quad = A_h/A_f \quad$ $\alpha_h \le 0.20$

$b_v \quad = 12.5\,(1 + 10\,\alpha_v - \alpha_v^2)$

A_f is the floor area of the firecell (m^2)

A_v is the area of vertical window and door openings (m^2)
A_h is the area of horizontal openings in the roof (m^2) and
H is the height of the firecell (m)

These expressions have been put into a computer spread sheet and for each of the fire load examples the attached output gives the required fire ratings as

for FL1	S = 34 min
for FL2	S = 67 min
for FL3	S = 101 min
for FL4	S = 168 min

∴ from ISO 834 equation

T_{f1} = 860°C
T_{f2} = 962°C
T_{f3} = 1023°C
T_{f4} = 1099°C

4.0 KAWAGOE'S NOMOGRAPH

For a plasterboard wall take λ = 0.5 kcal/mh°C

$A_w\sqrt{H}$ = 3.144 $m^{5/2}$
A_T = 98 m^2
A_F = 24 m^2
Fr = A_F/A_T = 0.245
FO = $A_w\sqrt{H}/A_T$ = 0.032

Taking the equivalent calorific value of wood as 10.78 MJ/kg in accordance with Kawagoe's paper the equivalent weights of wood are:-

FL1 = 400110.78 = 37.1 kg
FL2 = 74.2 kg

26-Jan-99

Table *1* of *C3/AS1*
with variations for height and ***kb***

Fire Engineering

LOCATION | Appendix B example for FHC 1

S Rating Based On: te = **ef.kb.wf** **(min)**

Notes on Input:
ef = Fire load from FHC (MJ/m^2)
kb = Insulation factor (C3/AS1 uses 0.067)
OR Use 0.080 for insulating material
Use 0.055 for plaster board or concrete
Use 0.045 for thin steel
wf= ventilation factor based on Ah/Af & Av/Af
(see Eurocode 1993 formula in Sec 6.4
of Fire Engineering Design Guide)

Firecell Height (m)	2.500					
kb	0.055					
FLED (MJ/m^2)	400					
	Ah/Af					
Av/Af	bv	0	0.05	0.1	0.15	0.2
0.05	18.719	56	38	31	28	26
0.06	19.955	52	35	29	26	25
0.07	21.189	48	33	28	25	24
0.08	22.420	45	30	26	24	23
0.09	23.649	42	29	25	23	22
0.10	24.875	39	27	24	22	21
0.11	26.099	36	26	23	21	21
0.12	27.320	34	24	22	21	20
0.13	28.539	31	23	21	20	20
0.14	29.755	30	22	21	20	19
0.15	30.969	28	22	20	20	19
0.16	32.180	26	21	20	19	19
0.17	33.389	25	20	19	19	19
0.18	34.595	24	20	19	19	18
0.19	35.799	23	20	19	19	18
0.20	37.000	22	19	19	18	18
0.21	38.199	21	19	18	18	18
0.22	39.395	20	19	18	18	18
0.23	40.589	20	18	18	18	18
0.24	41.780	19	18	18	18	18
0.25	42.969	19	18	18	18	18

Filename. *Firechart* xls

26-Jan-99

Table 1 of C3/AS1
with variations for height and kb

Fire Engineering

LOCATION Appendix B example for FHC 2 1

S Rating **Based** On: te = ef.kb.wf (min)

Notes on Input:

ef = Fire **load** from FHC (MJ/m^2)
kb = Insulation factor (C3/AS1 uses 0.067)
OR Use 0.080 for insulating material
Use 0.055 for plaster board or concrete
Use 0.045 for thin steel
wf= ventilation factor based on Ah/Af & Av/Af
(see Eumcode 1993 formula in Sec 6.4
of Fire Engineering Design Guide)

Firecell Height (m)	2.500					
kb	0.055					
FLED (MJ/m^2)	800					
	Ah/Af					
Av/Af	bv	0	0.05	0.1	0.15	0.2
0.05	18.719	113	75	62	56	52
0.06	19.955	104	70	58	53	49
0.07	21.189	97	65	55	50	47
0.08	22.420	89	61	52	48	45
0.09	23.649	83	57	50	46	44
0.10	24.875	77	54	47	44	42
0.11	26.099	72	51	46	43	41
0.12	27.320	67	49	44	42	40
0.13	28.539	63	47	43	41	40
0.14	29.755	59	45	41	40	39
0.15	30.969	56	43	40	39	38
0.16	32.180	53	42	40	38	38
0.17	33.389	50	41	39	38	37
0.18	34.595	48	40	38	37	37
0.19	35.799	45	39	38	37	37
0.20	37.000	44	38	37	37	36
0.21	38.199	42	38	37	36	36
0.22	39.395	41	37	37	36	36
0.23	40.589	40	37	36	36	36
0.24	41.780	39	37	36	36	36
0.25	42.969	38	36	36	36	36

Filename: Firechart.xls

26-Jan-99

Table 1 of C3/AS1
with variations for height and kb | ***Fire Engineering***

LOCATION	Appendix B example for FHC 3

S Rating Based On: te = ef.kb.wf (min)

Notes on Input:
ef = Fire load from FHC (MJ/m^2)
kb = Insulation factor (C3/AS1 uses 0.067)
OR Use 0.080 for insulating material
Use 0.055 for plaster board or concrete
Use 0.045 for thin steel
wf = ventilation factor based on Ah/Af & Av/Af
(see Eurocode 1993 formula in Sec 6.4
of Fire Engineering Design Guide)

Firecell Height (m)	2.500					
kb	0.055					
FLED (MJ/m^2)	1200					
		Ah/Af				
Av/Af	bv	0	0.05	0.1	0.15	0.2
0.05	18.719	169	113	94	84	78
0.06	19.955	156	105	88	79	74
0.07	21.189	145	98	83	75	71
0.08	22.420	134	91	78	72	68
0.09	23.649	125	86	74	69	66
0.10	24.875	116	81	71	66	64
0.11	26.099	108	77	68	64	62
0.12	27.320	101	73	66	63	61
0.13	28.539	94	70	64	61	59
0.14	29.755	89	67	62	60	58
0.15	30.969	83	65	61	59	57
0.16	32.180	79	63	59	50	57
0.17	33.389	75	61	58	57	56
0.18	34.595	71	60	57	56	55
0.19	35.799	68	59	56	56	55
0.20	37.000	66	58	56	55	55
0.21	38.199	63	57	55	55	54
0.22	39.395	61	56	55	54	54
0.23	40.589	60	55	54	54	54
0.24	41.780	58	55	54	54	54
0.25	42.969	57	54	54	54	54

Filename: Firechart.xls

26-Jan-99

Table 1of *C3/AS1* Fire Engineering
with variations for height and *kb*

LOCATION	Appendix B example for FHC 4 -

S Rating Based On: te = ef.kb.wf (min)

Notes on Input:
ef = Fire load from FHC (MJ/m^2)
kb = Insulation factor (C3/AS1 uses 0.067)
OR Use 0.080 for insulating material
Use 0.055 for plaster board or concrete
Use 0.045 for thin steel
wf = ventilation factor based on Ah/Af & Av/Af
(see Eurocode 1993 formula in Sec 6.4
of Fire Engineering Design Guide)

Firecell Height (m)	2.500					
kb	0.055					
FLED (MJ/m^2)	2000					
		Ah/Af				
Av/Af	bv	0	0.05	0.1	0.15	0.2
0.05	18.719	282	188	156	139	129
0.06	19.955	261	175	146	132	123
0.07	21.189	241	163	138	125	118
0.08	22.420	224	152	130	120	113
0.09	23.649	208	143	124	115	109
0.10	24.875	193	135	119	111	106
0.11	26.099	180	128	114	107	103
0.12	27.320	168	122	110	104	101
0.13	28.539	157	117	106	102	99
0.14	29.755	148	112	103	99	97
0.15	30.969	139	108	101	98	96
0.16	32.180	131	105	99	96	94
0.17	33.389	125	102	97	95	93
0.18	34.595	119	100	95	94	92
0.19	35.799	114	98	94	93	92
0.20	37.000	109	96	93	92	91
0.21	38.199	105	94	92	91	91
0.22	39.395	102	93	91	91	90
0.23	40.589	99	92	91	90	90
0.24	41.780	97	91	90	90	90
0.25	42.969	95	91	90	90	89

Filename: Firechart.xls

FL3 = 111.3 kg
FL4 = 185.5kg

From Kawagoe's nomograph (1967) for A = 0.5 given on the following sheet:

T I = 885°C
T_2 = 990°C
T3 = 1055°C
T4 = the fire load of 185kg is *off* the scale of the nomograph but the line for F_o = 0.03 appears to be tending asymptotically to 1100°C.

5.0 SWEDISH CURVES

From the types of enclosures defined in the Swedish Curves the closest to this example is the Type G which has 20% of the surface as concrete and 80% **as** timber framing clad on both faces with 2 layers of 13 mm plasterboard.

Opening factor = 0.032

FL I = 400 x 24/98 = 98 MJ/m^2 = 23.4 Mcal.m^{-2}
FL2 = 46.8 Mcal.m^{-2}
FL3 = 70.2 Mcal.m^{-2}
FL4 = 117 Mcal.m^{-2}

For FL1 from Graph G2 for opening factor = 0.02 T = 800°C
from Graph G3 for opening factor = 0.04 T = 900°C

∴ Take T_{f1} = 850°C

For FL2 from Graph G2 T = 880°C
from Graph G3 T = 970°C

∴ Take T_{f2} = 925°C

Fig. 9 Nomogram for the estimation of fire temperature time curve and equivalent standard test time

(where λ = 0.5 Kcal/mh°C, C = 0.3 Kcal/kg°C ρ = 2400 kg/m^3, W = 5%, wall thickness 15 cm)

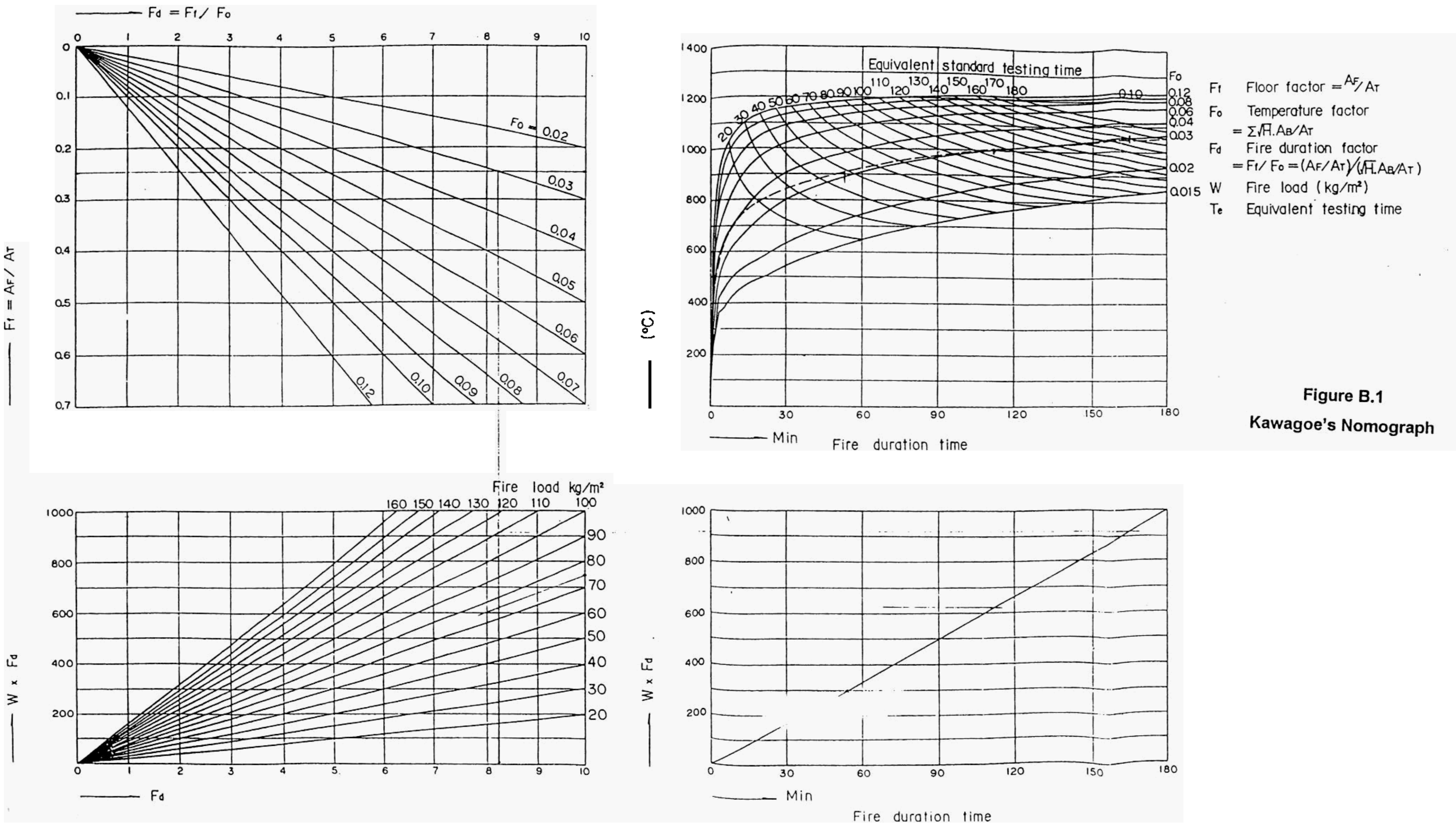

Figure B.1

Kawagoe's Nomograph

For FL3 from Graph G2 T estimated at 920°C (FL3 larger than graphed values)

From Graph G3 T = 990°C

∵ Take T_{f3} = 955°C

For FL4 from graph G2 T estimated at 950°C (FL4 larger than graphed value)

From Graph G3 T = 1010°C

∵ Take T_{f4} = 980°C

6.0 LIE'S SIMPLIFIED EXPRESSION

$$F = \frac{A_w H^{1/2}}{A_T} = 0.0322$$

Taking the heat release of 1 kg of wood as 2575 kcal (10.78 MJ) the fire loads in kg of wood for total enclosure area are:

Q_1 = 400 x 24198110.78 = 9.09 kg/m²

Q_2 = 18.17 kg/m²

Q_3 = 27.26 kg/m²

Q_4 = 45.44 kg/m²

Using the expression of burning duration of

$$T = \frac{Q}{330F}$$

the peak temperatures will occur at:

$$t_1 = \frac{9.09}{330 \times 0.0322} = 0.855 \text{ hr}$$

t_2 = 1.71 hr

t_3 = 2.57 hr

t_4 = 4.28 hr

Lie's expression is valid for:

$0.01 \leq F < 0.15$ (OK as F = ,0322)

and $t \leq \frac{0.08}{F} + 1$

ie. $t \leq \frac{.08}{.0322} + 1$

≤ 3.48 hr

$\Rightarrow$ use the $t_4 = 3.48$ hr.

$\therefore$ using Lie's expression:

$T_{f1} = 915°C$
$T_{f2} = 1032°C$
$T_{f3} = 1109°C$
$T_{f4} = 1157°C$

7.0 EUROCODE PARAMETRIC FIRE

To convert FLED *to* fire load/total enclosure area:

FL1 $= 400 \times 24/98 = 98$ MJ/m^2
FL2 $= 195.9$ MJ/m^2
FL3 $= 293.9$ MJ/m^2
FL4 $= 489.8$ MJ/m^2

$F_v = A_w H^{1/2}/A_T = 0.0322$

For gypsum wallboard take:

$k = 0.48$ W/mK
$\rho = 800$ kg/m^3
$c = 840$ J/kgK

$\sqrt{(k\rho c)} = 567$. The EC1 places a minimum limit on this factor of 1000 so this will be used.

$$\therefore \text{ duration of burning } t_{d1} = .00013 \times 98.\left(\frac{.0322}{.04}\right)^2 \cdot \left(\frac{1160}{1000}\right)^2 \cdot \frac{1}{.0322}$$

$$= 0.00352 \times 98$$

$$= 0.35 \text{ hr}$$

$$t_{d2} = 0.69 \text{ hr}$$

$$t_{d3} = 1.03 \text{ hr}$$

$$t_{d4} = 1.72 \text{ hr}$$

$$\Rightarrow \quad t^*_1 = .35 \times \left(\frac{.0322}{.04}\right)^2 \cdot \left(\frac{1160}{1000}\right)^2$$

$$= .35 \times 0.87$$

$$= 0.31 \text{ hr}$$

$$t^*_2 = 0.60 \text{ hr}$$

$$t^*_3 = 0.90 \text{ hr}$$

$$t^*_4 = 1.5 \text{ hrs}$$

Using the EC1 parametric formula:

$$T_{g1} = 760°C$$

$$T_{g2} = 847°C$$

$$T_{g3} = 908°C$$

$$T_{g4} = 985°C$$

8.0 COMPARISON OF RESULTS

The results of the various analyses are summarised in Table 6.2 below. As can be seen there is a spread of values for each case with the EC1 parametric curve generally being the lowest and the values using Lie's expression being the highest - generally around 20% higher than the EC1 values. The compartment temperatures obtained from using the standard ISO fire curve approach are generally midway in the range of values for each example. The relationship of the various methods can be seen more clearly in Figure 8.2.

Method	Compartment Temperatures ("C)			
	FL1 400 MJ/m²	FL2 800 MJ/m²	FL3 1200 MJ/m²	FL4 2000 MJ/m²
Acceptable Solutions	830	830	1039	1039
Law	890	1032	1055	1060
Standard Fire Curve	860	962	1023	1099
Kawagoe	885	990	1055	1100
Swedish Curves	850	925	955	980
Lie	915	1032	1109	1157
EC1 Parametric Curve	760	847	908	985

Table 6.2: Compartment Temperatures from Alternative Methods

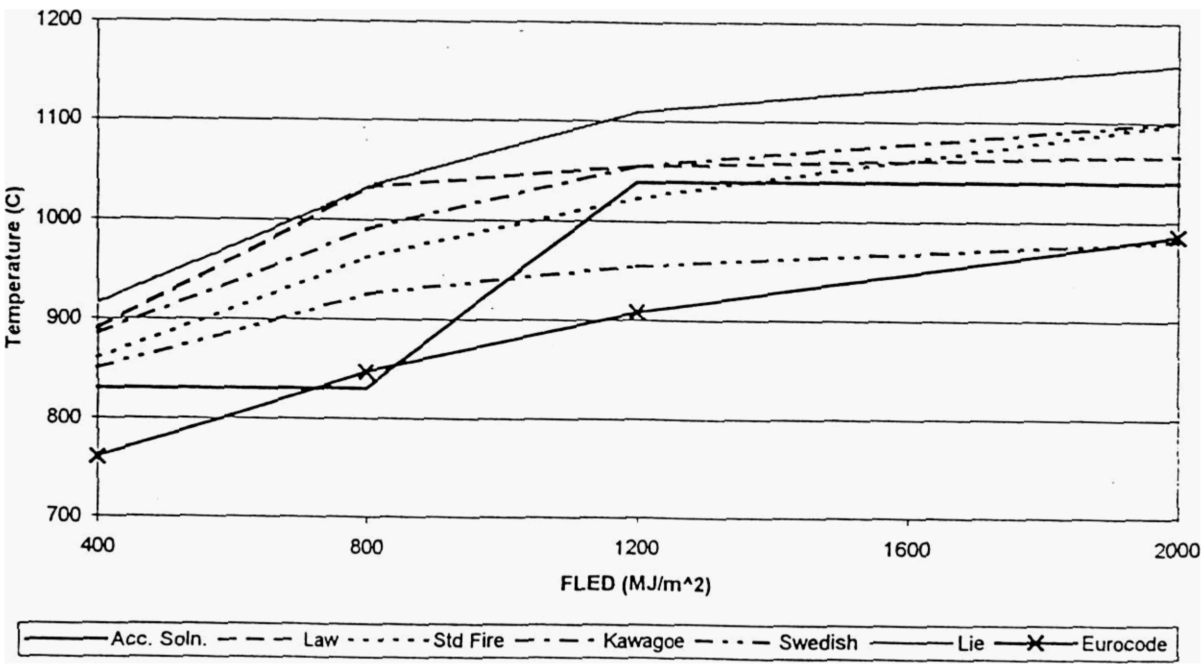

Figure B.2: Comparison of Compartment Temperatures

Appendix C

flame Projection Calculations

APPENDIX C

FLAME PROJECTION CALCULATIONS

Using the same compartment as in Appendix B, the external flame height and projection are calculated using the formulae proposed by Law and O'Brien (1981) as given in the Fire Engineering Design Guide (Buchanan 1994).

$Z =$ $\quad 12.8\ (R\ /\ W)^{2/3} - h$

$R =$ $\quad 0.09\ A_w\ \sqrt{(h)}$

$=$ $\quad 0.09 \times 2.4 \times 1.2 \times \sqrt{(1.2)}$

$=$ $\quad 0.284$ kg/sec

$Z =$ $\quad 12.8 \times (.284\ 12.4)^{2/3} - 1.2$

$=$ $\quad 1.9$ m above top of window

As $h < 1.25W$

Projection of flame front = $2h / 3$ = 800 mm

Projection to centre of flame = $h / 3$ = 400 mm

The Fire Engineering Design Guide proposes that the radiation from an external flame can be determined by assuming a flame temperature of 600 °C and a flame emissivity of 0.5. Therefore for a flame 1.9 m high x 2.4 m wide, the radiation at a distance of 2.4 m would be 3.28 kW/ m^2 as shown on the attached radiation analysis on C4.

Law and O'Brien state that the emissivity is related to the flame thickness λ(m) by:

$\varepsilon =$ $\quad 1 - e^{-0.3\lambda}$

and the flame temperature T_f at a distance **X** along the centre of the flame is given by:

$T_f =$ $\quad 520\ /\ [1-0.027(XW/R)] + T_{ambient}$

The applicability of this equation was confirmed by full-scale testing at Lehtre reported by Law (1981). Therefore at the flame tip T_f = 540 °C and at the top of the window.

T_f = 520 / [1-0.027(1.9x2.4/.284)] +20
= 938 °C

As radiation is proportional to T^4 take

T_{fav}= $(540^4+938^4 / 2)^{.25}$
= 809 °C

ε = $1 - e^{-0.3x.8}$
= 0.21

Therefore for the same flame front given above, the radiation at 2.4 m would be 3.25 kW/ m^2 as shown on C5 which is very similar to the previous result. The SFPE Handbook (Tien 1995) and Drysdale indicate that the emissivity of luminous flames can be calculated from $\varepsilon = 1 - e^{-KL}$.

Where K = effective emission coefficient
L = mean beam length

Some values of **K** given by Drysdale are:

Material	**K (m^{-1})**
Diesel Oil	0.43
PMMA	**0.5**
Polystyrene	1.2
Wood Cribs (1)	**0.8**
Wood Cribs (2)	0.51
Furniture	1.13

Table C.l Emission Coefficients

Values for L based on the formula L = CL, are given in Figure C-1 taken from Chapter 1 – 4 of the SFPE Handbook. Taking the flame as the front face of a 1.9 m cube and a value of 0.8 for K as a representative figure:

$\varepsilon = 1 - e^{-.66 \times .9 \times .8}$ = 0.38

Drysdale makes the point that flames that have a high emissivity generally contain large quantities of soot particles which provide a heat loss mechanism and hence the flames are cooler. Because of the difficulties in accurately assessing external flame temperatures Drysdale states that black body behaviour, ie $\varepsilon = 1.0$ is commonly assumed as a conservative approach.

However for this analysis the simple method proposed in FEDG will be used.

Assuming a compartment temperature of 842 °C the effect of the external flames is analysed using the FIRECALC radiation module as shown on pages C6 - C10. From these calculations the maximum radiation at a distance of 2.4 m from the wall for just the window emission is 11.6 kW/ m^2. If the effect of the flames are included the radiation increases to 14.67 kW/ m^2, ie a 26% increase [Note that this is similar to values reported by Law). The same effect can be obtained if the window is assumed to be 0.32 m closer to the receiver.

Geometry of Gas Body	Radiating lo	Geometric Mean Beam Length L_0	Correction Factor C
SPHERE	Entire surface	0.66D	0.97
CYLINDER H=0.5D	Plane end surface	0.48 D	0.90
	Concave surface	0.52 D	0.88
	Entire surface	0.50 D	0.90
CYLINDER H=D	Center of base	0.77 D	0.92
	Entire surface	0.66 D	0.90
CYLINDER H=2D	Plana end surface	0.73 D	0.82
	Concave surface	0.82D	0.93
	Entire surface	0.80 D	0.91
SEMI-INFINITE CYLINDER H→∞	Center of base	1.00 D	0.90
	Entire base	0.81 D	0.80
INFINITE SLAB	surface element	2.00 D	0.90
	Both bounding planes	2.00 D	0.90
CUBE D x D x D	Single face	0.66D	0.90
BLOCK D x D x 4D	1 x 4 face	0.90D	0.91
	1 x 1 face	0.86 D	0.83
	Entire surface	0.09D	0.91

Figure C.l: Mean Beam Length for Various Gas Body Shapes

FIRECALC, v.2.3, update 31 October 1994
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RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 600 °C

Distance	Offset		Size of source		Opening
X	Yx	ZX	Y	Z	%
2.4	**0**	**0**	2.4	**1.9**	**50**

Maximum radiation flow:
3.277 kW/m²
Orientation:
Θ = 90.0°
ϕ = **0.00**

Flame Radiation from FEDG

FIRECALC, v.2.3, update 31 October 1994

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RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 809 °C

Distance	Offset		Size of source		Opening
X	Yx	ZX	Y	Z	%
2.4	0	0	2.4	1.9	21

Maximum radiation flow:
3.241 kW/m^2
Orientation:
$\Theta = 90.0°$
$\phi = 0.0°$

Flame Radiation from Law & O'Brien

FIRECALC, v.2.3, update 31 October 1994

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RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 842 °C

Distance	Offset		Size of source		Opening
X	Yx	ZX	Y	Z	%
2.4	0	0	2.4	1.2	100

Maximum radiation flow:
11.608 kW/m^2
Orientation:
$\Theta = 90.0°$
$\phi = 0.00$

Radiation from Window Only

FIRECALC, v.2.3, update 31 October 1994

RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 600 °C

Distance	Offset		Size of source		Opening
X	Yx	Zx	Y	Z	%
1.6	0	0	2.4	1.9	50

Maximum radiation flow:
5.86 kW/m^2
Orientation:
Θ = 90.00
ϕ = 0.0°

Radiation from Flame Front at 2.4m from Wall

RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 842 °C

Distance	Offset		Size of source		Opening
X	Yx	ZX	Y	Z	%
1.6	0	0	2.4	1.9	18.8

Maximum radiation flow:
5.862 kW/m^2
Orientation:
$\Theta = 90.0°$
$\phi = 0.0°$

Equivalent Radiation for Flame *at* Compartment Temperature

RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 842 °C

Distance	Offset		Size of source		Opening
X	Yx	ZX	Y	Z	%
1.6	0	−1.16	2.4	1.9	18.8
2.4	0	0.4	2.4	1.2	100

Maximum radiation flow:
14.669 kW/m^2
Orientation:
Θ = 91.00
ϕ = 0.00

Combined Radiation from Window & Flame

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RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 842 °C

Distance	Offset		Size of source		Opening
X	Yx	ZX	Y	Z	%
2.08	0	0	2.4	1.2	100

Maximum radiation flow:
14.664 kW/m²
Orientation:
Θ = 90.00
ϕ = **0.00**

Equivalent Radiation from Window at Reduced Separation

Appendix D

Comparison of Mirror Image and Limiting Distance Concepts for Boundary Separation

APPENDIX D

COMPARISON OF MIRROR IMAGE AND LIMITING DISTANCE CONCEPTS FOR BOUNDARY SEPARATION

As an example, consider two buildings of similar size, 4 m high x 15 m long, built on adjacent properties. Building 1 is constructed first and has 35% of the boundary wall area unrated. Using the mirror image concept as calculated on page D3, the required boundary separation is 2.0 metres. Building 2 is then constructed but has a 100% unrated boundary wall and therefore from page D4 requires a boundary separation of 4.8 metres. This results in a total building separation of *6.8* metres as illustrated in Figure D.1.

From the **FIRECALC** analyses given on pages D5 and D6, it can be seen that:

- If Building 1 burns, the radiation on building 2 is 7.0 kW/ m^2 **OK**
- If Building 2 burns, the radiation on building 1 is 20.0 kW/ m^2 **NG**

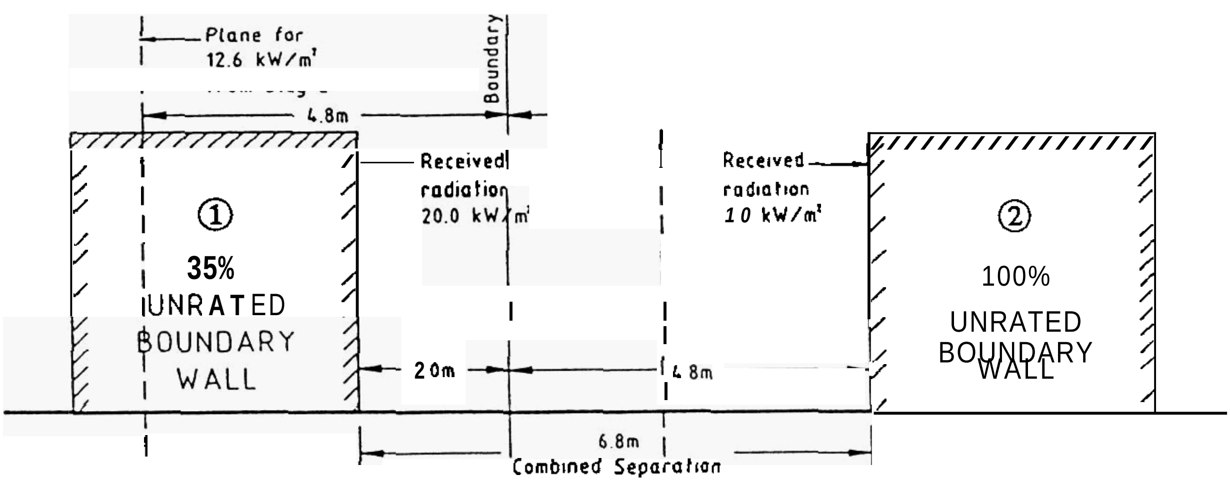

Figure D.1 Boundary Separations and Resultant Radiation
For Mirror Image Concept

For the limiting distance concept, with a limiting distance of 1.0 m, the same boundary separations as above would require the proportions of unrated wall area to decrease to 28% and 52% as shown on pages D7 and D8. Alternatively, the boundary separations of the buildings must increase to 3m and 8.6m, as calculated on pages D9 and D10, if the original proportions of unrated wall area are used. However, in either situation, the radiation intensity at 1 m inside the adjacent properties is limited to 12.6 kW/ m^2 so the situation is safe irrespective of which building is constructed first or which building catches fire. This is illustrated in Figure D.2. The resultant radiation intensities on each building from a fire in the other are given on pages D11 and D12, and are significantly reduced from the mirror image concept.

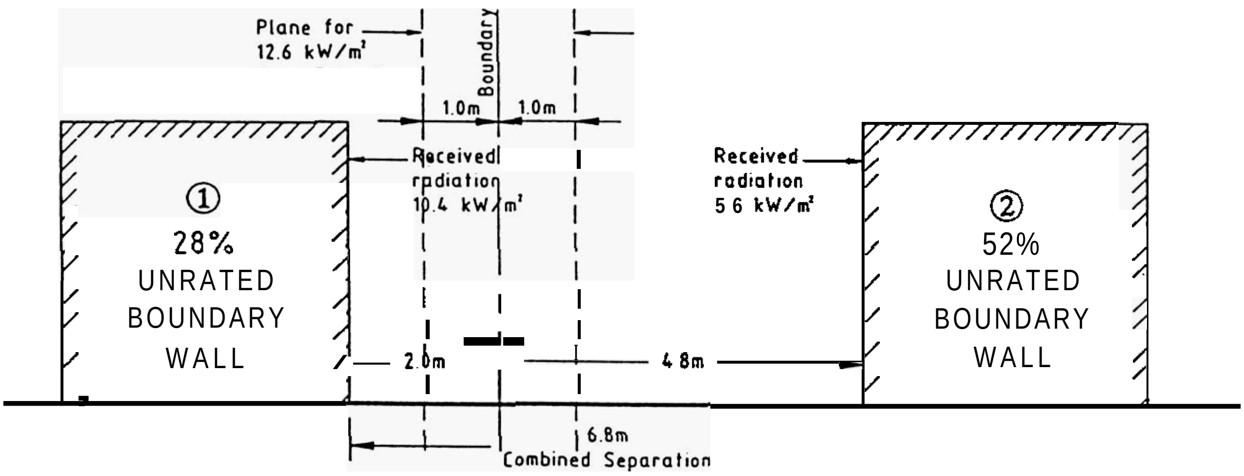

Figure D.2 Proportions of Unrated Wall Area and Resultant Radiation for Limiting Distance Concept

26-Jan-99 NZBC Fire Safety Annex. Appendix C. Table C3 - Mirror Image concept
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION: Boundary separation distance for building 1

[illegible] Limiting Radiation = 12.6 kW/m^2

		Exact Distance																										
Radiation Distance		4	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance (Radiation + Projection)	= S m	4	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
[illegible]	=0.5S m	2	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17

Rectangle Size			Permitted unprotected area %														
H	W	Ae															
4	15	60	35	17	19	21	24	28	31	35	40	44	54	65	78	92	100

D3

26-Jan-99 NZBC Fire Safety Annex. Appendix C. Table C3 - Mirror Image concept

Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION:	Boundary separation distance for building 2

Limiting Radiation = 12.6 kW/m^2

		Exact Distance																										
Radiation Distance		9.6	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance (Radiation + Projection)	= S m	9.6	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Boundary Distance	=0.5S m	4.8	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17

Rectangle Size				Permitted unprotected area %														
H	W	Ae																
m	m	m^2																
4	15	60	100	17	19	21	24	28	31	35	40	44	54	65	78	92	100	

D4

RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 830. °C

Distance	Offset		Size of source		Opening
X	Yx	ZX	Y	Z	%
6.8	0	0	15	4	35

Maximum radiation flow:
7.003 kW/m²
Orientation:
$\Theta = 90.0°$
$\phi = 0.00$

Radiation *on* Building.2 from Building 1 Fire
(Mirror Image Concept)

RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 830. °C

Distance	Offset		Size of source		Opening
X	Yx	Zx	Y	Z	%
6.8	**0**	**0**	**15**	**4**	**100**

Maximum radiation flow:
20.008 kW/m^2
Orientation:
Θ = 90.00
ϕ = **0.00**

Radiation on Building 1 from Building 2 Fire

(Mirror Image Concept)

Proposed Boundary Separation Tables - Limiting Distance Concept
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

LOCATION:	Boundary separation distance for building 1

Limiting Radiation = 12.6 kW/m^2 | Limiting Distance

		Exact Distance																								
Radiation Distance		3	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance	= S m	3	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
(Radiation + Projection)		2	0	0.5	1	1.5	2	2.5	3	3.5	4	5	6	7	8	9	11	13	15	17	19	21	23	25	27	29	31	33

Rectangle Size

H	W	Ae														
4	15	60	28	17	19	21	24	28	31	35	40	44	54	[illegible]	[illegible]	[illegible]	[illegible]

07

26-Jan-99 *Proposed Boundary Separation Tables - Limiting Distance Concept*
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings Fire Engineering

LOCATION: Boundary separation distance for building 2

Limiting Radiation = 12.6 kW/m^2 | Limiting Distance

		Exact Distance																										
Radiation Distance		5.8	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance (Radiation + Projection)	= S m	5.8	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
		4.8	0	0.5	1	1.5	2	2.5	3	3.5	4	5	6	7	8	9	11	13	15	17	19	21	23	25	27	29	31	33

Rectangle Size			Permitted unprotected area %													
H	W	Ae														
m	m	m^2														
15	20	52	17	19	21	24	28	31	35	40	44	54	65	76	92	100

26-Jan-99

Proposed Boundary Separation Tables - Limiting Distance Concept
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION: Boundary separation distance for building 1

Fire Hazard Category	FHC =	2	Emissivity = 1	Flame Projection Distance	P =	0 m
			Limiting Radiation = 12.6 kW/m^2	Limiting Distance	Lx =	1 m

		Exact Distance																										
Radiation Distance		4	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance (Radiation + Projection)	= S m	4	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
[illegible]	= S - Lx =	3	0	0.5	1	1.5	2	2.5	3	3.5	4	5	6	7	8	9	11	13	15	17	19	21	23	25	27	29	31	33

Rectangle Size H	W	Ae	Permitted unprotected area														
4	15	60	35	17	19	21	24	28	31	35	40	44	54	65	78	92	100

Filename: Lxunpro.xls

26-Jan-99 *Proposed Boundary Separation Tables - Limiting Distance Concept*
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION:	Boundary separation distance for building 2

Fire Hazard Category	FHC	=	2	Emissivity	=	1	Flame Projection Distance	P	=	0 m
				Limiting Radiation	=	12.6 kW/m^2	Limiting Distance	Lx	=	1 m

		Exact Distance																										
Radiation Distance		9.6	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance	= S m	9.6	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
(Radiation + Projection)																												
Boundary Distance	= S - Lx m	8.6	0	0.5	1	1.5	2	2.5	3	3.5	4	5	6	7	8	9	11	13	15	17	19	21	23	25	27	29	31	33

Permitted unprotected area %

Rectangle Size																	
H	W	Ae															
m	m	m^2															
4	15	60	100	17	19	21	24	28	31	35	40	44	54	65	78	92	100

D10

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RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 830. °C

Distance	Offset		Size of source		Opening
X	Yx	Zx	Y	Z	%
6.8	0	0	15	4	28

Maximum radiation flow:
5.602 kW/m²
Orientation:
Θ = 90.00
φ = 0.0°

Radiation on Building 2 from Building 1 Fire
(Limiting Distance Concept)

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RADIATION
at a given point
from a system of fire sources

(all the dimensions are in meters)

X-sources:
Radiation temperature 830. °C

Distance	Offset		Size of source		Opening
X	YX	ZX	Y	Z	%
6.8	**0**	**0**	**15**	**4**	**52**

Maximum radiation flow:
10.404 kW/m²
Orientation:
Θ = 90.00
ϕ = **0.00**

Radiation on Building 1 from Building 2 Fire
(Limiting Distance Concept)

Appendix E

Boundary Separations using the Proposed Modified Parameters

APPENDIX E

BOUNDARY SEPARATIONS USING THE PROPOSED MODIFIED PARAMETERS

Using the modified parameters detailed in Chapter 6 and the limiting distance concept, the examples used in Appendix A are reanalysed on the following pages. The original and new boundary separations of the examples to allow unrated boundary walls are shown in Table E.1.

Fire Hazard Category	Enclosing Rectangle	Original Separation (m)	New Separation (m)
1	3 x 12	3.65	5.5
2	3 x 40	4.75	9.9
3	6 x 12	8.30	13.6
4	6 x 30	12.40	22.0

TABLE E.1: COMPARISON OF BOUNDARY SEPARATIONS

Tables E.2 to E.5 give the modified boundary separation tables for each of the fire hazard categories whilst Tables E.6 and E.7 are based on the original C3 tables, and are provided for comparison.

26-Jan-99

Proposed Boundary Separation Tables - Limiting Distance Concept
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION:	FHC 1 example using proposed revised C3 tables

Fire Hazard Category	FHC = 1	Emissivity	= 1	Flame Projection Distance	P = 0.5 m
		Limiting Radiation	= 17 kW/m^2	Limiting Distance	Lx = 1 m

		Exact Distance																										
Radiation Distance		6	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance	= S m	6.5	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6.5	7.5	8.5	9.5	10.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	28.5	30.5	32.5	34.5
(Radiation + Projection) Boundary Distance	= S - Lx m	5.5	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5.5	6.5	7.5	8.5	9.5	11.5	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5

Rectangle Size

Permitted unprotected area %

H m	W m	Ae m^2																												
3	12	36	100	24	29	34	40	47	54	62	71	80	100																	

26-Jan-99 *Proposed Boundary Separation Tables - Limiting Distance Concept*
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION: FHC 2 example using proposed revised C3 tables

Fire Hazard Category	FHC = 2	Emissivity	= 1	Flame Projection Distance	P =	0.5 m
		[illegible]	= 17 kW/m^2	Limiting Distance	Lx =	1 m

		Exact Distance																											
		10.4	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Radiation Distance Separation Distance (Radiation + Projection)	≡ S m	10.9	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6.5	7.5	8.5	9.5	10.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	28.5	30.5	32.5	34.5
		[illegible]	[illegible]	1	1.5	2	2.5	3	3.5	4	4.5	5.5	6.5	7.5	8.5	9.5	11.5	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5

Permitted unprotected area %

Rectangle Size																	
H	W	Ae															
3	40	120	100	16	19	23	26	30	35	39	43	48	57	66	78	[illegible]	[illegible]

26-Jan-99 *Proposed Boundary Separation Tables - Limiting Distance Concept*
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION: FHC 3 example using proposed revised C3 tables

Fire Hazard Category FHC = 3 | Emissivity Limiting Radiation = 16 kW/m^2 | Limiting Distance Lx = 1 m

		Exact Distance																										
Radiation Distance		13.6	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance (Radiation + Projection)	= S m	14.6	2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11	13	15	17	19	21	23	25	27	29	31	33	35
Boundary Distance	= S - Lx m	13.6	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34

Rectangle Size H m	W m	Ae m^2	Permitted unprotected area %																
6	12	72	100	11	12	13	14	16	18	20	22	24	30	36	43	51	60	81	100

E5

26-Jan-99 *Proposed Boundary Separation Tables - Limiting Distance Concept*
Allowable Proportions of Unrated Wall Area in Unsprinklered Buildings

Fire Engineering

LOCATION:	FHC 4 example using proposed revised C3 tables

Firecell Temperature Tf = 1053 C

Limiting Radiation = 16 kW/m^2
Emitted Radiation = 175.0 kW/m^2

Limiting Distance Lx = 1 m

		Exact Distance																										
Radiation Distance		22	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34
Separation Distance	= S m	23	2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11	13	15	17	19	21	23	25	27	29	31	33	35
(Radiation + Projection)																												
Boundary Distance	= S - Lx m	22	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34

Rectangle Size — Permitted unprotected area %

H (m)	W (m)	Ae (m^2)																											
6	30	180	100	10	10	11	12	13	14	15	17	18	21	24	27	31	35	43	52	62	74	86	100						

Table E.2: Proposed Separation Tables for FHC 1

Fire Hazard Category	FHC = 1	Emissivity = 1	Flame Projection Distance	P = 0.5 m
		Limiting Radiation = 17 kW/m^2	Limiting Distance	Lx = 1 m
Firecell Temperature	Tf = 835 C	Emitted Radiation = 85.0 kW/m^2		

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m			1.5	2	2.5	3	3.5	4	4.5	5	5.5	6.5	7.5	8.5	9.5	10.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	28.5	30.5	32.5	34.5	36.5	38.5	40.5
(Radiation + Projection) Boundary Distance = S-Lx m			0.5	1	1.5	2	2.5	3	3.5	4	4.5	5.5	6.5	7.5	8.5	9.5	11.5	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5	35.5	37.5	39.5
1	1	1	83	100																											
1	2	2	55	96	100																										
1	3	3	49	78	100																										
1	4	4	47	71	100																										
1	5	5	46	68	94	100																									
1	6	6	45	66	90	100																									
1	8	8	45	65	86	100																									
1	10	10	45	64	84	100																									
1	12	12	45	64	84	100																									
1	14	14	45	63	83	100																									
1	16	16	45	63	83	100																									
1	18	18	45	63	83	100																									
1	20	20	45	63	83	100																									
1	30	30	45	63	83	100																									
1	40	40	45	63	82	100																									
1	50	50	45	63	82	100																									
1	60	60	45	63	82	100																									
1	80	80	45	63	82	100																									
1	100	100	45	63	82	100																									
2	1	2	55	96	100																										
2	2	4	36	56	83	100																									
2	3	6	31	45	64	88	100																								
2	4	8	30	41	55	74	96	100																							
2	5	10	29	39	51	66	84	100																							
2	6	12	29	38	49	62	78	96	100																						
2	8	16	29	37	47	58	71	85	100																						
2	10	20	28	36	46	56	68	80	94	100																					
2	12	24	28	36	45	55	66	77	90	100																					
2	14	28	28	36	45	55	65	76	87	100	100																				
2	16	32	28	36	45	55	65	75	86	98	100																				
2	18	36	28	36	45	54	64	74	85	96	100																				
2	20	40	28	36	45	54	64	74	84	95	100																				
2	30	60	28	36	45	54	63	73	83	93	100																				
2	40	80	28	36	45	54	63	73	83	93	100																				
2	50	100	28	36	45	54	63	73	83	92	100																				
2	60	120	28	36	45	54	63	73	83	92	100																				
2	80	160	28	36	45	54	63	73	82	92	100																				
2	100	200	28	36	45	54	63	73	82	92	100																				

Table E.2: Proposed Separation Tables for FHC 1 (cont'd)

Limiting Radiation = 17 kW/m^2 | Limiting Distance Lx

BOUNDARY SEPARATION TABLES USING LIMITING DISTANCE CONCEPT

Permitted unprotected area %

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			1.5	2	2.5	3	3.5	4	4.5	5	5.5	6.5	7.5	8.5	9.5	10.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	28.5	30.5	32.5	34.5	36.5	38.5	40.5
Boundary Distance = S-Lx m			0.5	1	1.5	2	2.5	3	3.5	4	4.5	5.5	6.5	7.5	8.5	9.5	11.5	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5	35.5	37.5	39.5
Rectangle Size H m	W m	Ae m^2																													
3	1	3	49	78	100																										
3	2	6	31	45	64	88	100																								
3	3	9	27	36	48	64	83	100																							
3	4	12	26	32	42	54	68	86	100																						
3	5	15	25	31	39	48	60	74	90	100																					
3	6	18	25	30	37	45	55	67	81	96	100																				
3	8	24	24	29	35	42	50	60	70	82	95	100																			
3	10	30	24	29	34	41	48	56	65	75	85	100																			
3	12	36	24	29	34	40	47	54	62	71	80	100																			
3	14	42	24	28	34	40	46	53	61	69	77	96	100																		
3	16	48	24	28	34	39	46	52	59	67	75	92	100																		
3	18	54	24	28	34	39	45	52	59	66	74	90	100																		
3	20	60	24	28	33	39	45	52	58	65	73	88	100																		
3	30	90	24	28	33	39	45	51	57	64	71	84	99	100																	
3	40	120	24	28	33	39	45	51	57	64	70	83	97	100																	
3	50	150	24	28	33	39	45	51	57	63	70	83	98	100																	
3	60	180	24	28	33	39	45	51	57	63	70	83	96	100																	
3	80	240	24	28	33	39	45	51	57	63	70	83	96	100																	
3	100	300	24	28	33	39	45	51	57	63	70	82	96	100																	
4	1	4	47	71	100																										
4	2	8	30	41	55	74	98	100																							
4	3	12	26	32	42	54	68	86	100																						
4	4	16	24	29	36	45	56	69	83	100																					
4	5	20	23	27	33	40	49	59	71	85	100	100																			
4	6	24	23	27	31	38	45	54	64	75	88	100																			
4	8	32	23	26	30	35	41	48	55	64	74	98	100																		
4	10	40	23	25	29	34	39	45	51	58	66	84	100																		
4	12	48	22	25	29	33	38	43	49	55	62	78	96	100																	
4	14	56	22	25	29	33	37	42	48	53	60	74	89	100																	
4	16	64	22	25	29	32	37	42	47	52	58	71	85	100																	
4	18	72	22	25	28	32	37	41	46	51	57	69	82	97	100																
4	20	80	22	25	28	32	36	41	46	51	56	68	80	94	100																
4	30	120	22	25	28	32	36	41	45	50	55	65	75	87	98	100															
4	40	160	22	25	28	32	36	40	45	49	54	64	74	84	95	100															
4	50	200	22	25	28	32	36	40	45	49	54	64	73	83	94	100															
4	60	240	22	25	28	32	36	40	45	49	54	63	73	83	93	100															
4	80	320	22	25	28	32	36	40	45	49	54	63	73	83	93	100															
4	100	400	22	25	28	32	36	40	45	49	54	63	73	83	92	100															

Table E.2: Proposed Separation Tables for FHC 1 (cont'd)

Limiting Radiation = 17 kW/m^2 | Limiting Distance Lx = 1 m

BOUNDARY SEPARATION TABLES USING LIMITING DISTANCE CONCEPT

Permitted unprotected area %

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m			1.5	2	2.5	3	3.5	4	4.5	5	5.5	6.5	7.5	8.5	9.5	10.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	28.5	30.5	32.5	34.5	36.5	38.5	40.5
(Radiation + Projection)																															
Boundary Distance = S-Lx m			0.5	1	1.5	2	2.5	3	3.5	4	4.5	5.5	6.5	7.5	8.5	9.5	11.5	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5	35.5	37.5	39.5
Rectangle Size																															
H m	W m	Ae m^2																													
5	1	5	46	68	94	100																									
5	2	10	29	39	51	68	84	100																							
5	3	15	25	31	39	48	60	74	90	100																					
5	4	20	23	27	33	40	49	59	71	85	100	100																			
5	5	25	23	26	30	36	43	51	61	72	83	100																			
5	6	30	22	25	29	34	39	46	54	63	73	96	100																		
5	8	40	22	24	27	31	36	41	47	54	62	79	100	100																	
5	10	50	22	24	26	30	34	38	43	49	55	70	88	100																	
5	12	60	22	24	26	29	33	37	41	46	52	64	78	94	100																
5	14	70	22	23	26	29	32	36	40	45	50	61	73	87	100																
5	16	80	22	23	26	29	32	36	40	44	48	58	70	82	96	100															
5	18	90	22	23	26	29	32	35	39	43	47	57	67	79	92	100															
5	20	100	22	23	26	29	32	35	39	43	47	56	66	76	88	100															
5	30	150	22	23	26	28	31	35	38	42	45	53	62	71	80	90	100														
5	40	200	22	23	26	28	31	34	38	41	45	53	60	69	77	86	100														
5	50	250	22	23	26	28	31	34	38	41	45	52	60	68	76	84	100														
5	60	300	22	23	26	28	31	34	38	41	45	52	60	68	76	84	100														
5	80	400	22	23	26	28	31	34	38	41	45	52	60	67	75	83	99	100													
5	100	500	22	23	26	28	31	34	38	41	45	52	60	67	75	83	99	100													
6	1	6	45	66	90	100																									
6	2	12	29	38	49	62	78	96	100																						
6	3	18	25	30	37	45	55	67	81	96	100																				
6	4	24	23	27	31	38	45	54	64	75	88	100																			
6	5	30	22	25	29	34	39	46	54	63	73	96	100																		
6	6	36	22	24	27	31	36	42	48	56	64	83	100																		
6	8	48	21	23	26	29	32	37	42	48	54	68	86	100																	
6	10	60	21	23	25	28	31	34	39	43	48	60	74	90	100																
6	12	72	21	23	25	27	30	33	37	41	45	55	67	81	96	100															
6	14	84	21	23	24	27	29	32	36	39	43	52	63	74	87	100															
6	16	96	21	22	24	26	29	32	35	38	42	50	60	70	82	95	100														
6	18	108	21	22	24	26	29	32	35	38	41	49	58	67	78	89	100														
6	20	120	21	22	24	26	29	31	34	37	41	48	56	65	75	85	100														
6	30	180	21	22	24	26	28	31	34	36	39	46	53	60	68	76	94	100													
6	40	240	21	22	24	26	28	31	33	36	39	45	52	58	65	73	88	100													
6	50	300	21	22	24	26	28	31	33	36	39	45	51	58	64	71	86	100													
6	60	360	21	22	24	26	28	31	33	36	39	45	51	57	64	71	84	99	100												
6	80	480	21	22	24	26	28	31	33	36	39	45	51	57	64	70	83	97	100												
6	100	600	21	22	24	26	28	31	33	36	39	45	51	57	63	70	83	96	100												

Table E.2: Proposed Separation Tables for FHC 1 (cont'd)

Fire Hazard Category FHC = 1	Emissivity = 1	Flame Projection Distance P = 0.5 m
Firecell Temperature Tf = 835 C	Limiting Radiation = 17 kW/m^2	Limiting Distance Lx = 1 m
	Emitted Radiation = 85.0 kW/m^2	

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			1.5	2	2.5	3	3.5	4	4.5	5	5.5	6.5	7.5	8.5	9.5	10.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	28.5	30.5	32.5	34.5	36.5	38.5	40.5
Boundary Distance = S-Lx m			0.5	1	1.5	2	2.5	3	3.5	4	4.5	5.5	6.5	7.5	8.5	9.5	11.5	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5	35.5	37.5	39.5
Rectangle Size			Permitted unprotected area %																												
H m	W m	Ae m^2																													
7	1	7	45	65	87	100																									
7	2	14	29	37	48	60	74	89	100																						
7	3	21	24	29	36	43	52	63	74	87	100																				
7	4	28	23	26	30	38	43	50	59	69	79	100																			
7	5	35	22	24	28	32	37	43	50	58	66	86	100																		
7	6	42	22	24	26	30	34	39	45	51	58	75	94	100																	
7	8	56	21	23	25	27	30	34	38	43	49	61	76	93	100																
7	10	70	21	22	24	26	29	32	35	39	44	54	68	79	94	100															
7	12	84	21	22	24	26	28	31	34	37	41	49	59	71	84	98	100														
7	14	98	21	22	23	25	27	30	33	36	39	47	55	65	77	89	100														
7	16	112	21	22	23	25	27	29	32	35	38	45	53	62	72	83	100														
7	18	126	21	22	23	25	27	29	32	34	37	44	51	59	68	78	100														
7	20	140	21	22	23	25	27	29	31	34	37	43	50	57	65	75	95	100													
7	30	210	21	22	23	25	26	28	31	33	35	41	48	53	59	66	81	99	100												
7	40	280	21	22	23	25	26	28	30	33	35	40	45	51	57	63	78	91	100												
7	50	350	21	22	23	25	26	28	30	33	35	40	45	51	56	62	74	87	100												
7	60	420	21	22	23	25	26	28	30	33	35	40	45	50	56	61	73	85	98	100	100										
7	80	560	21	22	23	25	26	28	30	33	35	40	45	50	55	61	72	84	96	100	100										
7	100	700	21	22	23	25	26	28	30	33	35	40	45	50	55	61	72	83	95	100	100										
8	1	8	45	65	86	100																									
8	2	16	29	37	47	58	71	85	100																						
8	3	24	24	29	35	42	50	60	70	82	95	100																			
8	4	32	23	26	30	35	41	48	55	64	74	96	100																		
8	5	40	22	24	27	31	36	41	47	54	62	79	100	100																	
8	6	48	21	23	26	29	32	37	42	48	54	68	86	100																	
8	8	64	21	22	24	26	29	32	36	40	45	56	69	83	100																
8	10	80	21	22	23	25	27	30	33	37	40	49	59	71	85	100	100														
8	12	96	21	22	23	25	27	29	31	34	38	45	54	64	75	88	100														
8	14	112	21	22	23	24	26	28	30	33	36	43	50	59	69	79	100														
8	16	128	21	22	23	24	26	28	30	32	35	41	48	55	64	74	96	100													
8	18	144	21	21	23	24	26	27	29	32	34	40	46	53	61	69	89	100													
8	20	160	21	21	23	24	25	27	29	31	34	39	45	51	58	66	84	100													
8	30	240	21	21	22	24	25	27	29	31	33	37	42	47	53	59	72	87	100												
8	40	320	21	21	22	24	25	27	28	30	32	36	41	46	51	56	68	80	94	100	100										
8	50	400	21	21	22	24	25	27	28	30	32	36	41	45	50	55	66	77	89	100	100										
8	60	480	21	21	22	24	25	27	28	30	32	36	41	45	50	55	65	75	87	98	100										
8	80	640	21	21	22	24	25	27	28	30	32	36	40	45	49	54	64	74	84	95	100										
8	100	800	21	21	22	24	25	27	28	30	32	36	40	45	49	54	64	73	83	94	100										

BOUNDARY SEPARATION TABLES USING LIMITING DISTANCE CONCEPT

Table E.3: Proposed Separation Tables for FHC 2

Fire Hazard Category FHC = 2
Firecell Temperature Tf = 946.5 C
Emissivity = 1
Limiting Radiation = 17 kW/m^2
Emitted Radiation = 125.0 kW/m^2
Flame Projection Distance P = 0.5 m
Limiting Distance Lx = 1 m

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m			1.5	2	2.5	3	3.5	4	4.5	5	5.5	6.5	7.5	8.5	9.5	10.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	28.5	30.5	32.5	34.5	36.5	38.5	40.5
(Radiation + Projection) Boundary Distance = S-Lx m			0.5	1	1.5	2	2.5	3	3.5	4	4.5	5.5	6.5	7.5	8.5	9.5	11.5	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5	35.5	37.5	39.5
H	W	Ae																													
1	1	1	57	100																											
1	2	2	38	65	100																										
1	3	3	33	53	79	100																									
1	4	4	32	48	69	94	100																								
1	5	5	31	46	64	85	100																								
1	6	6	31	45	61	80	100																								
1	8	8	31	44	59	75	92	100																							
1	10	10	31	43	57	72	88	100																							
1	12	12	30	43	57	71	86	100																							
1	14	14	30	43	57	71	85	100																							
1	16	16	30	43	56	70	84	99	100																						
1	18	18	30	43	56	70	84	98	100																						
1	20	20	30	43	56	70	84	98	100																						
1	30	30	30	43	56	69	83	97	100																						
1	40	40	30	43	56	69	83	96	100																						
1	50	50	30	43	56	69	83	96	100																						
1	60	60	30	43	56	69	83	96	100																						
1	80	80	30	43	56	69	83	96	100																						
2	1	2	38	65	100																										
2	2	4	25	38	57	81	100																								
2	3	6	21	31	43	60	79	100																							
2	4	8	20	28	38	50	65	83	100																						
2	5	10	20	26	35	45	57	72	88	100																					
2	6	12	20	26	33	42	53	65	79	94	100																				
2	8	16	19	25	32	40	48	58	69	81	94	100																			
2	10	20	19	25	31	38	46	55	64	74	85	100																			
2	12	24	19	25	31	38	45	53	61	70	80	100																			
2	14	28	19	25	31	37	44	52	60	68	77	96	100																		
2	16	32	19	25	31	37	44	51	59	66	75	92	100																		
2	18	36	19	25	31	37	44	51	58	65	73	90	100																		
2	20	40	19	25	31	37	43	50	57	65	72	88	100																		
2	30	60	19	25	30	37	43	50	57	63	70	85	100	100																	
2	40	80	19	25	30	37	43	50	56	63	70	84	98	100																	
2	50	100	19	25	30	37	43	50	56	63	70	83	97	100																	
2	60	120	19	25	30	37	43	50	56	63	69	83	97	100																	
2	80	160	19	25	30	37	43	50	56	63	69	83	96	100																	
[illegible]	[illegible]	[illegible]	19	25	30	37	43	50	56	63	69	83	96	100																	

Table E.3: Proposed Separation Tables for FHC 2 (cont'd)

Fire Hazard Category	FHC = 2	Emissivity	= 1	Flame Projection Distance	P = 0.5 m
Firecell Temperature	Tf = 946.5 C	Limiting Radiation	= 17 kW/m^2	Limiting Distance	Lx = 1 m
		Emitted Radiation	= 125.0 kW/m^2		

Radiation Distance	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6.5	7.5	8.5	9.5	10.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	28.5	30.5	32.5	34.5	36.5	38.5	40.5
Boundary Distance = S-Lx m	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5.5	6.5	7.5	8.5	9.5	11.5	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5	35.5	37.5	39.5

BOUNDARY SEPARATION TABLES USING LIMITING DISTANCE CONCEPT

Rectangle Size / Permitted unprotected area %

H m	W m	Ae m^2	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
3	1	3	33	53	79	100																									
3	2	6	21	31	43	60	79	100																							
3	3	9	19	25	33	44	57	72	90	100																					
3	4	12	17	22	29	37	47	58	72	87	100																				
3	5	15	17	21	26	33	41	50	61	73	87	100																			
3	6	18	17	20	25	31	38	46	55	65	76	100																			
3	8	24	17	20	24	29	34	41	48	56	64	84	100																		
3	10	30	16	20	23	28	33	38	44	51	58	75	94	100																	
3	12	36	16	19	23	27	32	37	42	48	55	69	85	100																	
3	14	42	16	19	23	27	31	36	41	47	52	65	80	96	100																
3	16	48	16	19	23	27	31	36	40	46	51	63	76	90	100																
3	18	54	16	19	23	27	31	35	40	45	50	61	73	87	100																
3	20	60	16	19	23	27	31	35	40	44	49	60	71	84	97	100															
3	30	90	16	19	23	26	31	35	39	43	48	57	67	78	88	100	100														
3	40	120	16	19	23	26	30	35	39	43	48	57	66	76	85	96	100														
3	50	150	16	19	23	26	30	35	39	43	47	56	65	75	84	94	100														
3	60	180	16	19	23	26	30	35	39	43	47	56	65	74	84	93	100														
3	80	240	16	19	23	26	30	35	39	43	47	56	65	74	83	92	100														
3	100	300	16	19	23	26	30	35	39	43	47	56	65	74	83	92	100														
4	1	4	32	48	69	94	100																								
4	2	8	20	28	38	50	65	83	100																						
4	3	12	17	22	29	37	47	58	72	87	100																				
4	4	16	16	20	25	31	38	47	57	68	81	100																			
4	5	20	16	19	23	27	33	40	49	58	68	91	100																		
4	6	24	16	18	21	26	31	37	43	51	60	79	100																		
4	8	32	15	18	20	24	28	32	38	44	50	65	83	100																	
4	10	40	15	17	20	23	26	30	35	40	45	57	72	88	100																
4	12	48	15	17	20	22	26	29	33	38	42	53	65	79	94	100															
4	14	56	15	17	19	22	25	29	32	36	41	50	61	73	86	100															
4	16	64	15	17	19	22	25	28	32	36	40	48	58	69	81	94	100														
4	18	72	15	17	19	22	25	28	31	35	39	47	56	66	77	89	100														
4	20	80	15	17	19	22	25	28	31	35	38	46	55	64	74	85	100														
4	30	120	15	17	19	22	25	28	31	34	37	44	51	59	67	76	94	100													
4	40	160	15	17	19	22	25	27	31	34	37	43	50	57	65	72	88	100													
4	50	200	15	17	19	22	25	27	30	34	37	43	50	57	64	71	86	100													
4	60	240	15	17	19	22	25	27	30	34	37	43	50	57	63	70	85	100	100												
4	80	320	15	17	19	22	25	27	30	34	37	43	50	56	63	70	84	98	100												
4	100	400	15	17	19	22	25	27	30	34	37	43	50	56	63	70	83	97	100												

Table E3: Proposed Separation Tables for FHC 2 (cont'd)

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			1.5	2	2.5	3	3.5	4	4.5	5	5.5	6.5	7.5	8.5	9.5	10.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	28.5	30.5	32.5	34.5	36.5	38.5	40.5
Boundary Distance = S-Lx m			0.5	1	1.5	2	2.5	3	3.5	4	4.5	5.5	6.5	7.5	8.5	9.5	11.5	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5	35.5	37.5	39.5
Rectangle Size			Permitted unprotected area %														BOUNDARY SEPARATION TABLES USING LIMITING DISTANCE CONCEPT														
H m	W m	Ae m^2																											
5	1	5	31	46	64	85	00																						
5	2	10	20	26	35	45	57	72	88	100																			
5	3	15	17	21	26	38	11	50	61	73	87	100																	
5	4	20	16	19	23	27	33	40	49	58	68	91	100																
5	5	25	15	18	21	25	29	35	41	49	57	76	98	100															
5	6	30	15	17	20	23	27	32	37	43	50	66	84	100															
5	8	40	15	16	18	21	24	28	32	37	42	54	68	84	100														
5	10	50	15	16	18	20	23	26	30	33	38	47	59	72	88	100													
5	12	60	15	16	18	20	22	25	28	32	35	44	53	64	77	90	100												
5	14	70	15	16	18	20	22	25	27	31	34	41	50	59	70	82	100												
5	16	80	15	16	18	20	22	24	27	30	33	40	47	56	66	76	100												
5	18	90	15	16	18	19	22	24	27	29	32	39	46	54	62	72	94	100											
5	20	100	15	16	18	19	22	24	26	29	32	38	45	52	60	69	89	100											
5	30	150	15	16	17	19	21	24	26	28	31	36	42	48	54	61	76	92	100										
5	40	200	15	16	17	19	21	23	26	28	31	36	41	47	52	59	71	85	100										
5	50	250	15	16	17	19	21	23	26	28	31	36	41	46	52	57	69	82	95	100	100								
5	60	300	15	16	17	19	21	23	26	28	30	35	41	46	51	57	68	80	93	100	100								
5	80	400	15	16	17	19	21	23	26	28	30	35	41	46	51	56	67	79	90	100	100								
5	100	500	15	16	17	19	[illegible]	[illegible]	[illegible]	28	30	35	40	46	51	56	67	78	89	100	100								
6	1	6	31	45	61	80	100																						
6	2	12	20	26	33	42	53	65	79	94	100																		
6	3	18	17	20	25	31	38	46	55	65	76	100																	
6	4	24	16	18	21	26	31	37	43	51	60	79	100																
6	5	30	15	17	20	23	27	32	37	43	50	66	84	100															
6	6	36	15	16	19	21	25	28	33	38	44	57	72	90	100														
6	8	48	15	16	17	20	22	25	29	32	37	47	58	72	87	100													
6	10	60	14	16	17	19	21	23	26	29	33	41	50	61	73	87	100												
6	12	72	14	15	17	18	20	23	25	28	31	38	46	55	65	76	100												
6	14	84	14	15	17	18	20	22	24	27	30	36	43	51	60	69	92	100											
6	16	96	14	15	17	18	20	22	24	26	29	34	41	48	56	64	84	100											
6	18	108	14	15	16	18	20	21	24	26	28	33	39	46	53	61	79	100	100										
6	20	120	14	15	16	18	20	21	23	25	28	33	38	44	51	58	75	94	100										
6	30	180	14	15	16	18	19	21	23	25	27	31	36	41	46	52	64	78	93	100	100								
6	40	240	14	15	16	18	19	21	23	25	27	31	35	40	44	49	60	71	84	97	100								
6	50	300	14	15	16	18	19	21	23	25	27	31	35	39	44	48	58	69	80	92	100								
6	60	360	14	15	16	18	19	21	23	25	26	31	35	39	43	48	57	67	78	88	100	100							
6	80	480	14	15	16	18	19	21	23	25	26	30	35	39	43	48	57	66	76	85	96	100							
6	100	600	14	15	16	18	19	21	23	25	26	30	35	39	43	47	56	65	75	84	94	100							

Table E.3: Proposed Separation Tables for FHC 2 (cont'd)

Fire Hazard Category FHC = 2
Firecell Temperature Tf = 946.5 C
Emissivity = 1
Limiting Radiation = 17 kW/m^2
Emitted Radiation = 125.0 kW/m^2
Flame Projection Distance P = 0.5 m
Limiting Distance Lx = 1 m

BOUNDARY SEPARATION TABLES USING LIMITING DISTANCE CONCEPT

Permitted unprotected area %

Rectangle Size H m	W m	Ae m^2																													
Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m			1.5	2	2.5	3	3.5	4	4.5	5	5.5	6.5	7.5	8.5	9.5	10.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	28.5	30.5	32.5	34.5	36.5	38.5	40.5
(Radiation + Projection) Boundary Distance = S-Lx m			0.5	1	1.5	2	2.5	3	3.5	4	4.5	5.5	6.5	7.5	8.5	9.5	11.5	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5	35.5	37.5	39.5
7	1	7	31	44	60	77	96	100																							
7	2	14	19	25	32	41	50	61	73	86	100																				
7	3	21	17	20	24	30	36	43	51	60	69	92	100																		
7	4	28	15	18	21	24	29	34	40	47	54	71	91	100																	
7	5	35	15	17	19	22	25	29	34	39	45	59	75	93	100																
7	6	42	15	16	18	20	23	26	30	35	40	51	64	79	97	100															
7	8	56	14	15	17	19	21	23	26	29	33	42	52	63	76	91	100														
7	10	70	14	15	16	18	20	22	24	27	30	37	45	54	64	76	100														
7	12	84	14	15	16	17	19	21	23	25	28	34	40	48	57	67	89	100													
7	14	98	14	15	16	17	19	20	22	24	27	32	38	44	52	61	80	100													
7	16	112	14	15	16	17	18	20	22	24	26	30	36	42	49	56	73	93	100												
7	18	126	14	15	16	17	18	20	21	23	25	30	35	40	46	53	68	86	100												
7	20	140	14	15	16	17	18	20	21	23	25	29	34	39	44	51	65	81	100	100	100										
7	30	210	14	15	16	17	18	19	21	22	24	28	32	36	40	45	55	67	80	95	100										
7	40	280	14	15	16	17	18	19	21	22	24	27	31	35	39	43	52	62	72	84	97	100									
7	50	350	14	15	16	17	18	19	21	22	24	27	31	34	38	42	50	59	69	79	90	100									
7	60	420	14	15	16	17	18	19	21	22	24	27	31	34	38	42	50	58	67	78	88	98	100								
7	80	560	14	15	16	17	18	19	21	22	24	27	30	34	38	41	49	57	65	74	82	91	100								
[illegible]	[illegible]	[illegible]	14	15	16	17	18	19	21	22	24	27	30	34	38	41	49	57	64	73	81	89	98	100							
8	1	8	31	44	59	75	92	100																							
8	2	16	19	25	32	40	48	58	69	81	94	100																			
8	3	24	17	20	24	29	34	41	48	56	64	84	100																		
8	4	32	15	18	20	24	28	32	38	44	50	65	83	100																	
8	5	40	15	16	18	21	24	28	32	37	42	54	68	84	100																
8	6	48	15	16	17	20	22	25	29	32	37	47	58	72	87	100															
8	8	64	14	15	16	18	20	22	25	27	31	38	47	57	68	81	100														
8	10	80	14	15	16	17	19	20	23	25	27	33	40	49	58	68	91	100													
8	12	96	14	15	16	17	18	20	21	23	26	31	37	43	51	60	79	100													
8	14	112	14	15	15	17	18	19	21	23	24	29	34	40	47	54	71	91	100												
8	16	128	14	15	15	16	18	19	20	22	24	28	32	38	44	50	65	83	100												
8	18	144	14	15	15	16	17	19	20	22	23	27	31	36	41	47	61	78	94	100	100										
8	20	160	14	15	15	16	17	18	20	21	23	26	30	35	40	45	57	72	88	100	100										
8	30	240	14	15	15	16	17	18	19	21	22	25	29	32	36	40	49	59	71	83	97	100									
8	40	320	14	15	15	16	17	18	19	21	22	25	28	31	35	38	46	55	64	74	85	97	100								
8	50	400	14	15	15	16	17	18	19	21	22	25	28	31	34	38	45	52	61	69	79	89	100	100							
8	60	480	14	15	15	16	17	18	19	21	22	25	28	31	34	37	44	51	59	67	76	85	94	100							
8	80	640	14	15	15	16	17	18	19	20	22	25	27	31	34	37	43	50	57	65	72	80	88	97	100						
8	100	800	14	15	15	16	17	18	19	20	22	25	27	30	34	37	43	50	57	64	71	78	86	94	100						

Table E.4: Proposed Separation Tables for FHC 3

Limiting Radiation | Limiting Distance

Radiation Distance	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m	2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
(Radiation + Projection) Boundary Distance = S-Lx m	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40

Rectangle Size / Permitted unprotected area %

H m	W m	Ae m^2	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10
1	1	1	45	87	100											
1	2	2	30	51	81	100										
1	3	3	26	42	62	87	100									
1	4	4	25	38	54	74	97	100								
1	5	5	24	36	50	67	86	100								
1	6	6	24	35	48	63	79	99	100							
1	8	8	24	34	46	59	73	88	100							
1	10	10	24	34	45	57	69	83	98	100						
1	12	12	24	34	45	56	68	80	94	100						
1	14	14	24	34	44	55	67	79	91	100						
1	16	16	24	34	44	55	66	78	90	100						
1	18	18	24	34	44	55	66	77	89	100						
1	20	20	24	34	44	55	66	77	88	100	100					
1	30	30	24	34	44	55	65	76	87	98	100					
1	40	40	24	34	44	54	65	76	86	97	100					
1	50	50	24	34	44	54	65	76	86	97	100					
1	60	60	24	34	44	54	65	75	86	97	100					
1	80	80	24	34	44	54	65	75	86	97	100					
1	100	100	24	34	44	54	65	75	86	97	100					
2	1	2	30	51	81	100										
2	2	4	19	30	45	63	87	100								
2	3	6	17	24	34	47	62	80	100							
2	4	8	16	22	30	39	51	65	81	98	100					
2	5	10	16	21	27	35	45	56	69	83	99	100				
2	6	12	15	20	26	33	42	51	62	74	87	100				
2	8	16	15	20	25	31	38	45	54	63	74	97	100			
2	10	20	15	19	24	30	36	43	50	58	67	86	100			
2	12	24	15	19	24	30	35	41	48	55	63	79	99	100		
2	14	28	15	19	24	29	35	41	47	53	60	75	92	100		
2	16	32	15	19	24	29	34	40	46	52	59	73	88	100		
2	18	36	15	19	24	29	34	40	45	51	57	71	85	100		
2	20	40	15	19	24	29	34	39	45	51	57	69	83	98	100	
2	30	60	15	19	24	29	34	39	44	50	55	66	78	90	100	
2	40	80	15	19	24	29	34	39	44	49	55	66	77	88	100	100
2	50	100	15	19	24	29	34	39	44	49	55	65	76	87	98	100
2	60	120	15	19	24	29	34	39	44	49	55	65	76	87	98	100
2	80	160	15	19	24	29	34	39	44	49	54	65	76	86	97	100
2	100	200	15	19	24	29	34	39	44	49	54	65	76	86	97	100

Table E.4: Proposed Separation Tables for FHC 3 (cont'd)

Fire Hazard Category	FHC = 3	Emissivity	= 1	Flame Projection Distance	P = 1 m
		Limiting Radiation	= 16 kW/m^2	Limiting Distance	Lx = 1 m
Firecell Temperature	Tf = 1003 C	Emitted Radiation	= 150.0 kW/m^2		

BOUNDARY SEPARATION TABLES USING LIMITING DISTANCE CONCEPT

Permitted unprotected area %

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m			2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
(Radiation + Projection) Boundary Distance = S-Lx m			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Rectangle Size																															
H m	W m	Ae m^2																													
3	1	3	26	42	62	87	100																								
3	2	6	17	24	34	47	62	80	100																						
3	3	9	15	19	26	34	45	57	71	87	100																				
3	4	12	14	17	22	29	36	46	56	68	81	100																			
3	5	15	13	16	21	26	32	40	48	58	68	93	100																		
3	6	18	13	16	20	24	30	36	43	51	60	81	100																		
3	8	24	13	15	19	22	27	32	37	44	51	66	85	100																	
3	10	30	13	15	18	22	26	30	35	40	46	59	73	91	100																
3	12	36	13	15	18	21	25	29	33	38	43	54	67	81	97	100															
3	14	42	13	15	18	21	25	28	32	37	41	51	62	75	89	100															
3	16	48	13	15	18	21	24	28	32	36	40	49	59	71	84	97	100														
3	18	54	13	15	18	21	24	28	31	35	39	48	57	68	79	92	100														
3	20	60	13	15	18	21	24	28	31	35	39	47	56	66	76	88	100														
3	30	90	13	15	18	21	24	27	31	34	38	45	53	61	69	78	98	100													
3	40	120	13	15	18	21	24	27	30	34	37	44	52	59	67	75	92	100													
3	50	150	13	15	18	21	24	27	30	34	37	44	51	59	66	74	89	100													
3	60	180	13	15	18	21	24	27	30	34	37	44	51	58	66	73	88	100													
3	80	240	13	15	18	21	24	27	30	34	37	44	51	58	65	72	87	100													
3	100	300	13	15	18	21	24	27	30	34	37	44	51	58	65	72	86	100													
4	1	4	25	38	54	74	97	100																							
4	2	8	16	22	30	39	51	65	81	98	100																				
4	3	12	14	17	22	29	36	46	56	68	81	100																			
4	4	16	13	16	19	24	30	37	45	53	63	87	100																		
4	5	20	12	15	18	22	26	32	38	45	53	72	93	100																	
4	6	24	12	14	17	20	24	29	34	40	47	62	80	100																	
4	8	32	12	14	16	19	22	25	30	34	39	51	65	81	98	100															
4	10	40	12	14	16	18	21	24	27	31	35	45	56	69	83	99	100														
4	12	48	12	13	15	18	20	23	26	30	33	42	51	62	74	87	100														
4	14	56	12	13	15	17	20	23	25	29	32	39	48	57	68	79	100														
4	16	64	12	13	15	17	20	22	25	28	31	38	45	54	63	74	97	100													
4	18	72	12	13	15	17	20	22	25	27	30	37	44	52	60	70	91	100													
4	20	80	12	13	15	17	19	22	24	27	30	36	43	50	58	67	86	100													
4	30	120	12	13	15	17	19	22	24	27	29	35	40	46	53	59	74	90	100												
4	40	160	12	13	15	17	19	22	24	26	29	34	39	45	51	57	69	83	98	100	100										
4	50	200	12	13	15	17	19	22	24	26	29	34	39	45	50	56	67	80	93	100	100										
4	60	240	12	13	15	17	19	22	24	26	29	34	39	44	50	55	66	78	90	100	100										
4	80	320	12	13	15	17	19	22	24	26	29	34	39	44	49	55	66	77	88	100	100										
4	100	400	12	13	15	17	19	22	24	26	29	34	39	44	49	55	65	76	87	98	100										

Table E.4: Proposed Separation Tables for FHC 3 (cont'd)

Fire Hazard Category	FHC =	3	Emissivity	=	1		Flame Projection Distance	P	=	1	m
			Limiting Radiation	=	16 kW/m^2		Limiting Distance	Lx	=	1	m
Firecell Temperature	Tf =	1003 C	Emitted Radiation	=	150.0 kW/m^2						

Permitted unprotected area %

BOUNDARY SEPARATION TABLES USING LIMITING DISTANCE CONCEPT

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
Boundary Distance = S-Lx m			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Rectangle Size																															
H m	W m	Ae m^2																													
5	1	5	24	36	50	67	86	100																							
5	2	10	16	21	27	35	45	56	69	83	99	100																			
5	3	15	13	16	21	26	32	40	48	58	68	93	100																		
5	4	20	12	15	18	22	26	32	38	45	53	72	93	100																	
5	5	25	12	14	16	19	23	27	32	38	45	59	77	97	100																
5	6	30	12	13	15	18	21	25	29	34	39	51	66	83	100																
5	8	40	12	13	15	17	19	22	25	29	33	42	53	66	80	96	100														
5	10	50	12	13	14	16	18	20	23	26	30	37	46	56	68	81	100														
5	12	60	12	13	14	16	18	20	22	25	28	34	42	50	60	71	96	100													
5	14	70	12	13	14	15	17	19	22	24	27	32	39	47	55	64	86	100													
5	16	80	12	13	14	15	17	19	21	23	26	31	37	44	51	60	79	100													
5	18	90	12	12	14	15	17	19	21	23	25	30	36	42	49	56	73	93	100												
5	20	100	12	12	14	15	17	19	21	23	25	30	35	41	47	54	69	87	100												
5	30	150	11	12	14	15	17	18	20	22	24	28	33	38	43	48	59	72	87	100	100										
5	40	200	11	12	14	15	17	18	20	22	24	28	32	37	41	46	56	67	79	91	100										
5	50	250	11	12	14	15	17	18	20	22	24	28	32	36	41	45	54	64	75	86	98	100									
5	60	300	11	12	14	15	17	18	20	22	24	28	32	36	40	45	54	63	73	83	94	100									
5	80	400	11	12	14	15	17	18	20	22	24	28	32	36	40	44	53	62	71	80	90	100	100								
5	100	500	11	12	14	15	17	18	20	22	24	28	32	36	40	44	53	61	70	79	88	97	100								
6	1	6	24	35	48	63	79	99	100																						
6	2	12	15	20	26	33	42	51	62	74	87	100																			
6	3	18	13	16	20	24	30	36	43	51	60	81	100																		
6	4	24	12	14	17	20	24	29	34	40	47	62	80	100																	
6	5	30	12	13	15	18	21	25	29	34	39	51	66	83	100																
6	6	36	12	13	15	17	19	22	26	30	34	45	57	71	87	100															
6	8	48	11	12	14	15	17	20	22	25	29	36	46	56	68	81	100														
6	10	60	11	12	13	15	16	18	21	23	26	32	40	48	58	68	93	100													
6	12	72	11	12	13	14	16	18	20	22	24	30	36	43	51	60	81	100													
6	14	84	11	12	13	14	16	17	19	21	23	28	33	40	47	54	72	93	100												
6	16	96	11	12	13	14	15	17	19	21	22	27	32	37	44	51	66	85	100												
6	18	108	11	12	13	14	15	17	18	20	22	26	31	36	42	48	62	78	97	100	100										
6	20	120	11	12	13	14	15	17	18	20	22	26	30	35	40	46	59	73	91	100	100										
6	30	180	11	12	13	14	15	17	18	19	21	24	28	32	36	40	50	61	73	86	100										
6	40	240	11	12	13	14	15	16	18	19	21	24	28	31	35	39	47	56	66	76	88	100									
6	50	300	11	12	13	14	15	16	18	19	21	24	27	31	34	38	46	54	63	72	82	92	100								
6	60	360	11	12	13	14	15	16	18	19	21	24	27	31	34	38	45	53	61	69	78	88	98	100							
6	80	480	11	12	13	14	15	16	18	19	21	24	27	30	34	37	44	52	59	67	75	83	92	100							
6	100	600	11	12	13	14	15	16	18	19	21	24	27	30	34	37	44	51	59	66	74	81	89	97							

Table E.4: Proposed Separation Tables for FHC 3 (cont'd)

Fire Hazard Category FHC = 3

Firecell Temperature Tf = 1003 C

Emissivity = 1

Limiting Radiation = 16 kW/m^2

Emitted Radiation = 150.0 kW/m^2

Flame Projection Distance P = 1 m

Limiting Distance Lx = 1 m

Permitted unprotected area %

Rectangle Size H (m)	W (m)	Ae (m^2)	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
7	1	7	24	35	47	60	75	92	100																						
7	2	14	15	20	25	32	39	48	57	68	79	100																			
7	3	21	13	16	19	23	28	33	40	47	54	72	93	100																	
7	4	28	12	14	16	19	23	27	31	37	42	56	71	89	100																
7	5	35	12	13	15	17	20	23	27	31	35	46	59	73	89	100															
7	6	42	12	13	14	16	18	21	24	27	31	40	50	62	78	91	100														
7	8	56	11	12	13	15	16	18	21	23	26	33	40	49	60	71	97	100													
7	10	70	11	12	13	14	15	17	19	21	23	29	35	42	50	60	81	100													
7	12	84	11	12	13	14	15	16	18	20	22	26	32	38	45	52	70	91	100												
7	14	98	11	12	12	13	15	16	17	19	21	25	30	35	41	47	63	81	100												
7	16	112	11	12	12	13	14	16	17	19	20	24	28	33	38	44	57	73	91	100	100										
7	18	126	11	12	12	13	14	16	17	18	20	23	27	31	36	42	54	68	84	100	100										
7	20	140	11	12	12	13	14	15	17	18	20	23	26	30	35	40	51	64	78	95	100										
7	30	210	11	12	12	13	14	15	16	18	19	22	25	28	32	35	43	53	63	74	87	100									
7	40	280	11	12	12	13	14	15	16	17	19	21	24	27	30	34	41	48	57	66	76	86	98	100							
7	50	350	11	12	12	13	14	15	16	17	19	21	24	27	30	33	40	47	54	62	70	79	89	99	100						
7	60	420	11	12	12	13	14	15	16	17	19	21	24	27	30	33	39	46	52	60	67	75	84	93	100						
7	80	560	11	12	12	13	14	15	16	17	19	21	24	27	30	33	39	45	51	58	65	72	79	87	95	100					
7	100	700	11	12	12	13	14	15	16	17	19	21	24	27	30	32	38	44	51	57	63	70	77	84	91	98	100				
8	1	8	24	34	46	59	73	88	100																						
8	2	16	15	20	25	31	38	45	54	63	74	97	100																		
8	3	24	13	15	19	22	27	32	37	44	51	66	85	100																	
8	4	32	12	14	16	19	22	25	30	34	39	51	65	81	98	100															
8	5	40	12	13	15	17	19	22	25	29	33	42	53	66	80	96	100														
8	6	48	11	12	14	15	17	20	22	25	29	36	46	56	68	81	100														
8	8	64	11	12	13	14	16	17	19	22	24	30	37	45	53	63	87	100													
8	10	80	11	12	12	13	15	16	18	20	22	26	32	38	45	53	72	93	100												
8	12	96	11	12	12	13	14	15	17	18	20	24	29	34	40	47	62	80	100												
8	14	112	11	12	12	13	14	15	16	18	19	23	27	31	37	42	56	71	89	100	100										
8	16	128	11	11	12	13	14	15	16	17	19	22	25	30	34	39	51	65	81	98	100										
8	18	144	11	11	12	13	14	15	16	17	18	21	25	28	32	37	48	60	74	90	100										
8	20	160	11	11	12	13	14	15	16	17	18	21	24	27	31	35	45	56	69	83	99	100									
8	30	240	11	11	12	13	13	14	15	16	17	20	22	25	28	31	38	46	55	65	76	88	100								
8	40	320	11	11	12	13	13	14	15	16	17	19	22	24	27	30	36	43	50	58	67	76	86	97	100						
8	50	400	11	11	12	13	13	14	15	16	17	19	22	24	27	29	35	41	48	54	62	70	78	87	97	100					
8	60	480	11	11	12	13	13	14	15	16	17	19	22	24	27	29	35	40	46	53	59	66	74	82	90	99	100				
8	80	640	11	11	12	13	13	14	15	16	17	19	22	24	26	29	34	39	45	51	57	63	69	76	83	90	98	100			
8	100	800	11	11	12	13	13	14	15	16	17	19	22	24	26	29	34	39	45	50	56	61	67	73	80	86	93	100	100		

Filename Lxareas xls

Table E.5: Proposed Separation Tables for FHC 4

Fire Hazard Category FHC 4 | Limiting Radiation = 16 kW/m^2 | Limiting Distance Lx = 1 m

BOUNDARY SEPARATION TABLES USING LIMITING DISTANCE CONCEPT

Permitted unprotected area %

Rectangle Size H (m)	W (m)	Ae (m^2)	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
Boundary Distance = S-Lx m			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
1	1	1	38	74	100																										
1	2	2	25	44	69	100																									
1	3	3	22	36	53	75	100																								
1	4	4	21	32	46	63	83	100																							
1	5	5	21	31	43	57	74	93	100																						
1	6	6	21	30	41	54	68	85	100																						
1	8	8	21	30	39	50	62	75	90	100																					
1	10	10	21	29	39	49	59	71	84	97	100																				
1	12	12	20	29	38	48	58	69	80	92	100																				
1	14	14	20	29	38	47	57	67	78	89	100																				
1	16	16	20	29	38	47	57	67	77	88	99	100																			
1	18	18	20	29	38	47	56	66	76	86	97	100																			
1	20	20	20	29	38	47	56	66	75	85	96	100																			
1	30	30	20	29	38	47	56	65	74	84	93	100																			
1	40	40	20	29	38	47	56	65	74	83	92	100																			
1	50	50	20	29	38	47	56	65	74	83	92	100																			
1	60	60	20	29	38	47	56	65	74	83	92	100																			
1	80	80	20	29	38	47	56	65	74	83	92	100																			
1	100	100	20	29	38	47	56	65	74	83	92	100																			
2	1	2	25	44	69	100																									
2	2	4	17	26	38	54	74	98	100																						
2	3	6	14	21	29	40	53	69	87	100																					
2	4	8	14	19	25	34	44	58	69	84	100																				
2	5	10	13	18	23	30	39	48	59	71	85	100																			
2	6	12	13	17	22	28	36	44	53	63	75	100																			
2	8	16	13	17	21	27	32	39	46	54	63	83	100																		
2	10	20	13	17	21	26	31	37	43	50	57	74	93	100																	
2	12	24	13	17	21	25	30	35	41	47	54	68	85	100																	
2	14	28	13	17	21	25	30	35	40	46	52	65	79	95	100																
2	16	32	13	17	21	25	30	34	39	45	50	62	75	90	100																
2	18	36	13	17	21	25	29	34	39	44	49	61	73	86	100																
2	20	40	13	17	21	25	29	34	39	44	49	59	71	84	97	100															
2	30	60	13	16	20	25	29	33	38	43	47	57	67	77	88	100	100														
2	40	80	13	16	20	25	29	33	38	42	47	56	66	75	85	96	100														
2	50	100	13	16	20	25	29	33	38	42	47	56	65	75	84	94	100														
2	60	120	13	16	20	25	29	33	38	42	47	56	65	74	84	93	100														
2	80	160	13	16	20	25	29	33	38	42	47	56	65	74	83	92	100														
2	100	200	13	16	20	25	29	33	38	42	47	56	65	74	83	92	100														

Table E.5: Proposed Separation Tables for FHC 4 (cont'd)

Fire Hazard Category	FHC = 4	Emissivity	= 1	Flame Projection Distance	P = 1 m
		Limiting Radiation	= 16 kW/m^2	Limiting Distance	Lx = 1 m
Firecell Temperature	Tf = 1053 C	Emitted Radiation	= 175.0 kW/m^2		

Radiation Distance	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)	2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
Boundary Distance = S-Lx m	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40

Rectangle Size — Permitted unprotected area %

H m	W m	Ae m^2	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
3	1	3	22	36	53	75	100																								
3	2	6	14	21	29	40	53	69	87	100																					
3	3	9	12	17	22	29	38	49	61	74	89	100																			
3	4	12	12	15	19	25	31	39	48	58	70	96	100																		
3	5	15	11	14	18	22	28	34	41	49	58	80	100																		
3	6	18	11	14	17	21	25	31	37	44	51	69	90	100																	
3	8	24	11	13	16	19	23	27	32	37	43	57	73	91	100																
3	10	30	11	13	16	19	22	26	30	34	39	50	63	78	94	100															
3	12	36	11	13	16	18	21	25	28	32	37	46	57	70	83	99	100														
3	14	42	11	13	15	18	21	24	28	31	35	44	53	64	76	90	100														
3	16	48	11	13	15	18	21	24	27	31	34	42	51	61	72	83	100														
3	18	54	11	13	15	18	21	24	27	30	34	41	49	58	68	79	100														
3	20	60	11	13	15	18	21	24	27	30	33	40	48	56	66	75	98	100													
3	30	90	11	13	15	18	21	23	26	29	32	39	45	52	59	67	84	100													
3	40	120	11	13	15	18	20	23	26	29	32	38	44	51	57	64	79	94	100												
3	50	150	11	13	15	18	20	23	26	29	32	38	44	50	57	63	77	91	100												
3	60	180	11	13	15	18	20	23	26	29	32	38	44	50	56	63	75	89	100												
3	80	240	11	13	15	18	20	23	26	29	32	38	44	50	56	62	74	87	100												
3	100	300	11	13	15	18	20	23	26	29	32	38	44	50	56	62	74	87	99	100											
4	1	4	21	32	46	63	83	100																							
4	2	8	14	19	25	34	44	56	69	84	100																				
4	3	12	12	15	19	25	31	39	48	58	70	96	100																		
4	4	16	11	13	17	21	26	31	38	46	54	74	98	100																	
4	5	20	11	13	15	18	22	27	33	39	46	61	80	100																	
4	6	24	11	12	14	17	21	25	29	34	40	53	69	87	100																
4	8	32	10	12	14	16	19	22	25	29	34	44	56	69	84	100															
4	10	40	10	12	13	15	18	20	23	27	30	39	48	59	71	85	100														
4	12	48	10	12	13	15	17	20	22	25	28	36	44	53	63	75	100														
4	14	56	10	12	13	15	17	19	22	24	27	34	41	49	58	68	91	100													
4	16	64	10	11	13	15	17	19	21	24	27	32	39	46	54	63	83	100													
4	18	72	10	11	13	15	17	19	21	24	26	32	38	44	52	60	78	99	100												
4	20	80	10	11	13	15	17	19	21	23	26	31	37	43	50	57	74	93	100												
4	30	120	10	11	13	15	17	19	21	23	25	30	34	40	45	51	63	77	93	100	100										
4	40	160	10	11	13	15	17	18	21	23	25	29	34	39	44	49	59	71	84	97	100										
4	50	200	10	11	13	15	16	18	20	23	25	29	34	38	43	48	58	68	80	92	100										
4	60	240	10	11	13	15	16	18	20	23	25	29	33	38	43	47	57	67	77	88	100	100									
4	80	320	10	11	13	15	16	18	20	23	25	29	33	38	42	47	56	66	75	85	96	100									
4	100	400	10	11	13	15	16	18	20	23	25	29	33	38	42	47	56	65	75	84	94	100									

Table E.5: Proposed Separation Tables for FHC 4 (cont'd)

Fire Hazard Category	FHC = 4	Emissivity = 1	Limiting Radiation = 16 kW/m^2	Flame Projection Distance P = 1 m	Limiting Distance Lx = 1 m

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
Boundary Distance = S-Lx m			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Rectangle Size			Permitted unprotected area %																BOUNDARY SEPARATION TABLES USING LIMITING DISTANCE CONCEPT													
H m	W m	Ae m^2																													
5	1	5	21	31	43	57	74	93	100																						
5	2	10	13	18	23	30	39	48	59	71	85	100																			
5	3	15	11	14	18	22	28	34	41	49	58	80	100																		
5	4	20	11	13	15	18	22	27	33	39	46	61	80	100																	
5	5	25	10	12	14	17	20	23	28	33	38	51	66	83	100																
5	6	30	10	11	13	15	18	21	25	29	34	44	57	71	87	100															
5	8	40	10	11	12	14	16	19	22	25	28	36	46	56	69	82	100														
5	10	50	10	11	12	14	15	18	20	22	25	32	40	48	58	69	94	100													
5	12	60	10	11	12	13	15	17	19	21	24	29	36	43	52	61	82	100													
5	14	70	10	11	12	13	15	17	18	21	23	28	33	40	47	55	73	95	100												
5	16	80	10	11	12	13	15	16	18	20	22	27	32	38	44	51	67	86	100												
5	18	90	10	11	12	13	15	16	18	20	22	26	31	36	42	48	63	80	99	100	100										
5	20	100	10	11	12	13	14	16	18	20	21	25	30	35	40	46	60	75	93	100	100										
5	30	150	10	11	12	13	14	16	17	19	21	24	28	32	37	41	51	62	74	88	100										
5	40	200	10	11	12	13	14	16	17	19	21	24	28	31	35	39	48	57	67	78	90	100									
5	50	250	10	11	12	13	14	16	17	19	21	24	27	31	35	39	47	55	64	74	84	95	100								
5	60	300	10	11	12	13	14	16	17	19	20	24	27	31	35	38	46	54	62	71	80	90	100								
5	80	400	10	11	12	13	14	16	17	19	20	24	27	31	34	38	45	53	61	69	77	85	94	100							
5	100	500	10	11	12	13	14	16	17	19	20	24	27	31	34	38	45	52	60	68	75	83	92	100							
6	1	6	21	30	41	54	68	85	100																						
6	2	12	13	17	22	28	36	44	53	63	75	100																			
6	3	18	11	14	17	21	25	31	37	44	51	69	90	100																	
6	4	24	11	12	14	17	21	25	29	34	40	53	69	87	100																
6	5	30	10	11	13	15	18	21	25	29	34	44	57	71	87	100															
6	6	36	10	11	12	14	17	19	22	26	29	38	49	61	74	89	100														
6	8	48	10	11	12	13	15	17	19	22	25	31	39	48	58	70	96	100													
6	10	60	10	10	11	13	14	16	18	20	22	28	34	41	49	58	80	100													
6	12	72	10	10	11	12	14	15	17	19	21	25	31	37	44	51	69	90	100												
6	14	84	10	10	11	12	13	15	16	18	20	24	29	34	40	47	62	80	100												
6	16	96	10	10	11	12	13	15	16	18	19	23	27	32	37	43	57	73	91	100	100										
6	18	108	10	10	11	12	13	14	16	17	19	22	26	31	36	41	53	67	83	100	100										
6	20	120	10	10	11	12	13	14	16	17	19	22	26	30	34	39	50	63	78	94	100										
6	30	180	10	10	11	12	13	14	15	17	18	21	24	27	31	35	43	52	62	74	86	100									
6	40	240	10	10	11	12	13	14	15	17	18	21	24	27	30	33	40	48	56	66	75	86	98	100							
6	50	300	10	10	11	12	13	14	15	17	18	21	23	26	29	33	39	46	54	62	70	79	89	99	100						
6	60	360	10	10	11	12	13	14	15	17	18	21	23	26	29	32	39	45	52	59	67	75	84	93	100						
6	80	480	10	10	11	12	13	14	15	16	18	20	23	26	29	32	38	44	51	57	64	71	79	86	94	100					
6	100	600	10	10	11	12	13	14	15	16	18	20	23	26	29	32	38	44	50	57	63	70	77	84	91	98	100				

Filename: Lxareas.xls

Table E.5: Proposed Separation Tables for FHC 4 (cont'd)

Fire Hazard Category	FHC = 4	Emissivity = 1	Flame Projection Distance	P = 1 m
		Limiting Radiation = 16 kW/m^2	Limiting Distance	Lx = 1 m
Firecell Temperature	Tf = 1053 C	Emitted Radiation = 175.0 kW/m^2		

BOUNDARY SEPARATION TABLES USING LIMITING DISTANCE CONCEPT

Permitted unprotected area %

Rectangle Size H m	W m	Ae m^2																														
Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
Boundary Distance = S-Lx m			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
7	1	7	21	30	40	52	65	79	95	100																					
7	2	14	13	17	22	27	34	41	49	58	68	91	100																		
7	3	21	11	13	16	20	24	29	34	40	47	62	80	100																	
7	4	28	10	12	14	16	19	23	27	31	36	48	61	77	94	100															
7	5	35	10	11	13	15	17	20	23	26	30	39	50	63	76	92	100														
7	6	42	10	11	12	14	16	18	20	23	27	34	43	53	65	78	100														
7	8	56	10	10	11	12	14	16	18	20	22	28	35	42	51	61	83	100													
7	10	70	10	10	11	12	13	15	16	18	20	25	30	36	43	51	69	91	100												
7	12	84	10	10	11	12	13	14	15	17	19	23	27	32	38	45	60	78	98	100	100										
7	14	98	10	10	11	12	13	14	15	16	18	21	25	30	35	41	54	69	87	100	100										
7	16	112	10	10	11	11	12	13	15	16	17	21	24	28	33	38	49	63	78	96	100										
7	18	126	10	10	11	11	12	13	14	16	17	20	23	27	31	36	46	58	72	88	100										
7	20	140	10	10	11	11	12	13	14	15	17	20	23	26	30	34	44	54	67	81	97	100									
7	30	210	10	10	11	11	12	13	14	15	16	19	21	24	27	30	37	45	54	64	74	86	99	100							
7	40	280	10	10	11	11	12	13	14	15	16	18	21	23	26	29	35	42	49	56	65	74	84	95	100						
7	50	350	10	10	11	11	12	13	14	15	16	18	21	23	26	28	34	40	46	53	60	68	76	85	95	100					
7	60	420	10	10	11	11	12	13	14	15	16	18	21	23	26	28	33	39	45	51	58	65	72	80	88	97	100				
7	80	560	10	10	11	11	12	13	14	15	16	18	20	23	25	28	33	38	44	49	55	61	68	74	81	88	96	100			
7	100	700	10	10	11	11	12	13	14	15	16	18	20	23	25	28	33	38	43	49	54	60	66	72	78	84	91	98	100		
8	1	8	21	30	39	50	62	75	90	100																					
8	2	16	13	17	21	27	32	39	46	54	63	83	100																		
8	3	24	11	13	16	19	23	27	32	37	43	57	73	91	100																
8	4	32	10	12	14	16	19	22	25	29	34	44	56	69	84	100															
8	5	40	10	11	12	14	16	19	22	25	28	36	46	56	69	82	100														
8	6	48	10	11	12	13	15	17	19	22	25	31	39	48	58	70	96	100													
8	8	64	10	10	11	12	13	15	17	18	21	26	31	38	46	54	74	98	100												
8	10	80	10	10	11	12	13	14	15	17	18	22	27	33	39	46	61	80	100												
8	12	96	9	10	11	11	12	13	14	16	17	21	25	29	34	40	53	69	87	100	100										
8	14	112	9	10	10	11	12	13	14	15	16	19	23	27	31	36	48	61	77	94	100										
8	16	128	9	10	10	11	12	13	14	15	16	19	22	25	29	34	44	56	69	84	100										
8	18	144	9	10	10	11	12	13	13	15	16	18	21	24	28	32	41	51	63	77	92	100									
8	20	160	9	10	10	11	12	12	13	14	15	18	20	23	27	30	39	48	59	71	85	100									
8	30	240	9	10	10	11	11	12	13	14	15	17	19	22	24	27	33	40	48	56	65	76	87	99	100						
8	40	320	9	10	10	11	11	12	13	14	15	17	19	21	23	26	31	37	43	50	57	65	74	83	93	100					
8	50	400	9	10	10	11	11	12	13	14	15	17	19	21	23	25	30	35	41	47	53	60	67	75	83	92	100				
8	60	480	9	10	10	11	11	12	13	14	15	17	19	21	23	25	30	34	40	45	51	57	63	70	77	85	93	100			
8	80	640	9	10	10	11	11	12	13	14	15	17	18	21	23	25	29	34	39	44	49	54	59	65	71	77	84	90	97	100	
8	100	800	9	10	10	11	11	12	13	14	15	16	18	20	23	25	29	34	38	43	48	53	58	63	68	74	80	85	92	98	100

Filename: Lxareas.xls

Table E.6: Existing Separation Tables for FHC 1 & 2

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
(Radiation + Projection)																															
Boundary Distance =0.5S m			0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	1	63	100																											
1	2	2	42	72	100																										
1	3	3	37	58	87	100																									
1	4	4	35	53	76	100																									
1	5	5	34	51	70	94	100																								
1	6	6	34	50	67	88	100																								
1	8	8	34	48	65	82	100																								
1	10	10	34	48	63	80	97	100																							
1	12	12	34	48	63	79	95	100																							
1	14	14	34	48	62	78	94	100																							
1	16	16	34	48	62	77	93	100																							
1	18	18	34	48	62	77	93	100																							
1	20	20	34	48	62	77	92	100																							
1	30	30	34	47	62	77	92	100																							
1	40	40	34	47	62	77	91	100																							
1	50	50	34	47	62	77	91	100																							
1	60	60	34	47	62	77	91	100																							
1	80	80	34	47	62	76	91	100																							
1	100	100	34	47	62	76	91	100																							
2	1	2	42	72	100																										
2	2	4	27	42	63	89	100																								
2	3	6	24	34	48	66	87	100																							
2	4	8	22	31	42	55	72	91	100																						
2	5	10	22	29	38	50	63	79	97	100																					
2	6	12	22	28	37	47	58	72	87	100																					
2	8	16	21	28	35	44	53	64	76	89	100																				
2	10	20	21	27	34	42	51	60	70	82	94	100																			
2	12	24	21	27	34	42	50	58	67	77	88	100																			
2	14	28	21	27	34	41	49	57	66	75	85	100																			
2	16	32	21	27	34	41	48	56	65	73	82	100																			
2	18	36	21	27	34	41	48	56	64	72	81	99	100																		
2	20	40	21	27	34	41	48	56	63	71	80	97	100																		
2	30	60	21	27	34	40	48	55	62	70	78	93	100																		
2	40	80	21	27	34	40	48	55	62	69	77	92	100																		
2	50	100	21	27	34	40	47	55	62	69	77	92	100																		
2	60	120	21	27	34	40	47	55	62	69	77	92	100																		
2	80	160	21	27	34	40	47	55	62	69	77	91	100																		
2	100	200	21	27	34	40	47	55	62	69	77	91	100																		

Table E.6: Existing Separation Tables for FHC 1 & 2 (cont'd)

Limiting Radiation = 12.6 kW/m^2

BOUNDARY SEPARATION TABLES USING MIRROR IMAGE CONCEPT

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
(Radiation + Projection) Boundary Distance =0.5S m			0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rectangle Size			Permitted unprotected area %																												
H m	W m	Ae m^2																													
3	1	3	37	58	87	100																									
3	2	6	24	34	48	66	87	100																							
3	3	9	20	27	36	48	63	80	99	100																					
3	4	12	19	24	31	40	51	64	79	96	100																				
3	5	15	19	23	29	36	45	56	68	81	96	100																			
3	6	18	18	22	28	34	42	50	60	72	84	100																			
3	8	24	18	22	26	32	38	45	53	61	71	93	100																		
3	10	30	18	22	26	31	36	42	49	56	64	82	100																		
3	12	36	18	21	25	30	35	41	47	53	60	76	94	100																	
3	14	42	18	21	25	30	35	40	45	51	58	72	88	100																	
3	16	48	18	21	25	30	34	39	45	50	56	69	84	100	100																
3	18	54	18	21	25	29	34	39	44	50	55	67	81	96	100																
3	20	60	18	21	25	29	34	39	44	49	54	66	79	93	100																
3	30	90	18	21	25	29	34	38	43	48	53	63	74	86	97	100															
3	40	120	18	21	25	29	34	38	43	48	53	63	73	83	94	100															
3	50	150	18	21	25	29	34	38	43	48	52	62	72	82	93	100															
3	60	180	18	21	25	29	34	38	43	48	52	62	72	82	92	100															
3	80	240	18	21	25	29	34	38	43	47	52	62	72	82	92	100															
3	100	300	18	21	25	29	34	38	43	47	52	62	72	82	91	100															
4	1	4	35	53	76	100																									
4	2	8	22	31	42	55	72	91	100																						
4	3	12	19	24	31	40	51	64	79	96	100																				
4	4	16	18	22	27	34	42	52	63	75	89	100																			
4	5	20	18	21	25	30	37	45	53	64	75	100																			
4	6	24	17	20	24	28	34	40	48	56	66	87	100																		
4	8	32	17	19	22	26	31	36	42	48	55	72	91	100																	
4	10	40	17	19	22	25	29	34	38	44	50	63	79	97	100																
4	12	48	17	19	22	25	28	32	37	42	47	58	72	87	100																
4	14	56	17	19	21	25	28	32	36	40	45	55	67	80	95	100															
4	16	64	17	19	21	24	28	31	35	39	44	53	64	76	89	100															
4	18	72	17	19	21	24	27	31	35	39	43	52	62	73	85	98	100														
4	20	80	17	19	21	24	27	31	34	38	42	51	60	70	82	94	100														
4	30	120	17	19	21	24	27	30	34	37	41	49	57	65	74	83	100														
4	40	160	17	19	21	24	27	30	34	37	41	48	56	63	71	80	97	100													
4	50	200	17	19	21	24	27	30	34	37	41	48	55	63	70	78	95	100													
4	60	240	17	19	21	24	27	30	34	37	40	48	55	62	70	78	93	100													
4	80	320	17	19	21	24	27	30	34	37	40	48	55	62	69	77	92	100													
4	100	400	17	19	21	24	27	30	34	37	40	47	55	62	69	77	92	100													

Table E.6 : Existing Separation Tables for FHC 1 & 2 (cont'd)

Fire Hazard Category	FHC = 1 & 2	Emissivity	= 1	Flame Projection Distance	P = 0 m
		Limiting Radiation	= 12.6 kW/m^2		
Firecell Temperature	Tf = 831.6 C	Emitted Radiation	= 84.0 kW/m^2		

Permitted unprotected area %

BOUNDARY SEPARATION TABLES USING MIRROR IMAGE CONCEPT

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Boundary Distance =0.5S m			0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rectangle Size																															
H m	W m	Ae m^2																													
5	1	5	34																												
5	2	10	22																												
5	3	15	19																												
5	4	20	18																												
5	5	25	17																												
5	6	30	17																												
5	8	40	16																												
5	10	50	16																												
5	12	60	16																												
5	14	70	16																												
5	16	80	16																												
5	18	90	16																												
5	20	100	16																												
5	30	150	16																												
5	40	200	16																												
5	50	250	16																												
5	60	300	16																												
5	80	400	16																												
5	100	500	16																												
6	1	6	34	50	67	88	100																								
6	2	12	22	28	37	47	58	72	87	100																					
6	3	18	18	22	28	34	42	50	60	72	84	100																			
6	4	24	17	20	24	28	34	40	48	56	66	87	100																		
6	5	30	17	19	22	25	30	35	41	47	55	72	93	100																	
6	6	36	16	18	20	23	27	31	36	42	48	63	80	99	100																
6	8	48	16	17	19	22	24	28	31	36	40	51	64	79	96	100															
6	10	60	16	17	19	21	23	26	29	32	36	45	56	68	81	96	100														
6	12	72	16	17	18	20	22	25	28	31	34	42	50	60	72	84	100														
6	14	84	16	17	18	20	22	24	27	30	33	39	47	56	66	77	100														
6	16	96	16	17	18	20	22	24	26	29	32	38	45	53	61	71	93	100													
6	18	108	16	17	18	20	22	24	26	28	31	37	43	50	58	67	87	100													
6	20	120	16	17	18	20	22	24	26	28	31	36	42	49	56	64	82	100													
6	30	180	16	17	18	20	21	23	25	27	30	34	40	45	51	57	70	86	100												
6	40	240	16	17	18	20	21	23	25	27	29	34	39	44	49	54	66	79	93	100	100										
6	50	300	16	17	18	20	21	23	25	27	29	34	38	43	48	53	64	76	88	100	100										
6	60	360	16	17	18	20	21	23	25	27	29	34	38	43	48	53	63	74	86	97	100										
6	80	480	16	17	18	20	21	23	25	27	29	34	38	43	48	53	63	73	83	94	100										
6	100	600	16	17	18	20	21	23	25	27	29	34	38	43	48	52	62	72	82	93	100										

Table E.6: Existing Separation Tables for FHC 1 & 2 (cont'd)

Fire Hazard Category	FHC = 1 & 2	Emissivity = 1	Flame Projection Distance P = 0 m
		Limiting Radiation = 12.6 kW/m^2	
Firecell Temperature	Tf = 831.6 C	Emitted Radiation = 84.0 kW/m^2	

BOUNDARY SEPARATION TABLES USING MIRROR IMAGE CONCEPT

Permitted unprotected area %

H m	W m	Ae m^2																												
Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Boundary Distance = 0.5S m			0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rectangle Size																															
7	1	7	34	49	66	85	100
7	2	14	21	28	36	45	55	67	80	95	100
7	3	21	18	22	27	33	39	47	56	66	77	100
7	4	28	17	20	23	27	32	38	44	51	60	78	100
7	5	35	16	18	21	24	28	32	38	43	50	65	82	100
7	6	42	16	18	20	22	25	29	33	38	44	58	71	88	100
7	8	56	16	17	19	20	23	26	29	32	37	46	57	70	84	100	100
7	10	70	16	17	18	20	22	24	27	30	33	40	49	59	71	84	100
7	12	84	16	17	18	19	21	23	25	28	31	37	45	53	63	74	98	100
7	14	98	16	16	18	19	21	22	24	27	29	35	42	49	57	67	88	100
7	16	112	16	16	17	19	20	22	24	26	28	34	40	46	54	62	81	100
7	18	126	16	16	17	19	20	22	24	26	28	33	38	44	51	58	75	95	100
7	20	140	16	16	17	19	20	22	23	25	27	32	37	43	49	56	71	89	100
7	30	210	16	16	17	18	20	21	23	25	27	31	35	39	44	50	61	74	88	100	100
7	40	280	16	16	17	18	20	21	23	25	26	30	34	38	43	47	57	68	80	93	100
7	50	350	16	16	17	18	20	21	23	25	26	30	34	38	42	47	56	65	76	87	99	100
7	60	420	16	16	17	18	20	21	23	24	26	30	34	38	42	46	55	64	74	84	95	100
7	80	560	16	16	17	18	20	21	23	24	26	30	34	38	42	46	54	63	72	81	91	100
7	100	700	16	16	17	18	20	21	23	24	26	30	34	37	41	46	54	62	71	80	89	98	100
8	1	8	34	48	65	82	100
8	2	16	21	28	35	44	53	64	76	89	100
8	3	24	18	22	26	32	38	45	53	61	71	93	100
8	4	32	17	19	22	26	31	36	42	48	55	72	91	100
8	5	40	16	18	20	23	27	31	35	40	46	59	75	93	100
8	6	48	16	17	19	22	24	28	31	36	40	51	64	79	96	100
8	8	64	16	17	18	20	22	24	27	30	34	42	52	63	75	89	100
8	10	80	16	16	18	19	21	23	25	27	30	37	45	53	64	75	100
8	12	96	16	16	17	18	20	22	24	26	28	34	40	48	56	66	87	100
8	14	112	16	16	17	18	20	21	23	25	27	32	38	44	51	60	78	100
8	16	128	16	16	17	18	19	21	22	24	26	31	36	42	48	55	72	91	100
8	18	144	15	16	17	18	19	21	22	24	26	30	34	40	46	52	67	84	100
8	20	160	15	16	17	18	19	20	22	24	25	29	34	38	44	50	63	79	97	100	100
8	30	240	15	16	17	18	19	20	21	23	24	28	31	35	40	44	54	65	78	92	100
8	40	320	15	16	17	18	19	20	21	23	24	27	31	34	38	42	51	60	70	82	94	100
8	50	400	15	16	17	18	19	20	21	23	24	27	31	34	38	41	49	58	67	77	87	98	100
8	60	480	15	16	17	18	19	20	21	23	24	27	30	34	37	41	49	57	65	74	83	93	100
8	80	640	15	16	17	18	19	20	21	23	24	27	30	34	37	41	48	56	63	71	80	88	97	100
8	100	800	15	16	17	18	19	20	21	23	24	27	30	34	37	41	48	55	63	70	78	86	95	100

Filename C3areas.xls

Table E.7: Existing Separation Tables for FHC 3 & 4

Fire Hazard Category	FHC = 3 & 4	Emissivity = 1	Flame Projection Distance P = 0 m
Firecell Temperature	Tf = 1040 C	Limiting Radiation = 12.6 kW/m^2	
		Emitted Radiation = 168.0 kW/m^2	

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Radiation Distance	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Boundary Distance =0.5S m	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Rectangle Size

Permitted unprotected area %

BOUNDARY SEPARATION TABLES USING MIRROR IMAGE CONCEPT

H m	W m	Ae m^2	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14
1	1	1	31·	61	100													
1	2	2	21	36	57	83	100											
1	3	3	18	29	43	61	83	100										
1	4	4	18	27	38	52	68	88	100									
1	5	5	17	25	35	47	61	76	94	100								
1	6	6	17	25	34	44	56	69	85	100								
1	8	8	17	24	32	41	51	62	74	87	100							
1	10	10	17	24	32	40	49	58	69	80	92	100						
1	12	12	17	24	31	39	48	56	66	76	87	100						
1	14	14	17	24	31	39	47	55	64	73	83	100						
1	16	16	17	24	31	39	47	55	63	72	81	100						
1	18	18	17	24	31	39	46	54	62	71	80	98	100					
1	20	20	17	24	31	38	46	54	62	70	79	96	100					
1	30	30	17	24	31	38	46	53	61	69	78	92	100					
1	40	40	17	24	31	38	46	53	61	68	76	91	100					
1	50	50	17	24	31	38	46	53	61	68	76	91	100					
1	60	60	17	24	31	38	46	53	61	68	76	91	100					
1	80	80	17	24	31	38	46	53	60	68	75	90	100					
1	100	100	17	24	31	38	46	53	60	68	75	90	100					
2	1	2	21	36	57	83	100											
2	2	4	14	21	31	45	61	80	100									
2	3	6	12	17	24	33	44	56	71	88	100							
2	4	8	11	15	21	28	36	46	57	69	83	100						
2	5	10	11	15	19	25	32	40	48	59	70	96	100					
2	6	12	11	14	18	23	29	36	43	52	61	83	100					
2	8	16	11	14	18	22	27	32	38	45	52	68	88	100				
2	10	20	11	14	17	21	25	30	35	41	47	61	76	94	100			
2	12	24	11	14	17	21	25	29	34	39	44	56	69	85	100			
2	14	28	11	14	17	21	24	28	33	37	42	53	65	78	93	100		
2	16	32	11	14	17	20	24	28	32	37	41	51	62	74	87	100		
2	18	36	11	14	17	20	24	28	32	36	40	50	60	71	83	96	100	
2	20	40	11	14	17	20	24	28	32	36	40	49	58	69	80	92	100	
2	30	60	11	14	17	20	24	27	31	35	39	47	55	64	73	82	100	
2	40	80	11	14	17	20	24	27	31	35	38	46	54	62	70	79	96	100
2	50	100	11	14	17	20	24	27	31	35	38	46	53	61	69	77	94	100
2	60	120	11	14	17	20	24	27	31	35	38	46	53	61	69	76	92	100
2	80	160	11	14	17	20	24	27	31	35	38	46	53	61	68	76	91	100
2	100	200	11	14	17	20	24	27	31	35	38	46	53	61	68	76	91	100

Filename: C3areas.xls

Table E.7: Existing Separation Tables for FHC 3 & 4 (cont'd)

Fire Hazard Category FHC = 3 & 4
Firecell Temperature Tf = 1040 C

Emissivity = 1
Limiting Radiation = 12.6 kW/m^2
Emitted Radiation = 168.0 kW/m^2

Flame Projection Distance P = 0 m

BOUNDARY SEPARATION TABLES USING MIRROR IMAGE CONCEPT

Permitted unprotected area %

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Boundary Distance = 0.5S m			0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rectangle Size H m	W m	Ae m^2																													
3	1	3	18	29	43	61	83	100																							
3	2	6	12	17	24	33	44	56	71	88	100																				
3	3	9	10	14	18	24	31	40	50	61	73	100																			
3	4	12	10	12	16	20	26	32	39	48	57	79	100																		
3	5	15	9	12	14	18	23	28	34	40	48	65	86	100																	
3	6	18	9	11	14	17	21	25	30	36	42	57	74	93	100																
3	8	24	9	11	13	16	19	22	26	31	36	47	59	74	91	100															
3	10	30	9	11	13	15	18	21	24	28	32	41	52	64	77	92	100														
3	12	36	9	11	13	15	18	20	23	27	30	38	47	57	68	81	100														
3	14	42	9	11	13	15	17	20	23	26	29	36	44	53	63	74	99	100													
3	16	48	9	11	13	15	17	20	22	25	28	35	42	50	59	68	91	100													
3	18	54	9	11	13	15	17	19	22	25	28	34	40	48	56	65	85	100													
3	20	60	9	11	13	15	17	19	22	25	27	33	39	46	54	62	80	100													
3	30	90	9	11	13	15	17	19	22	24	26	32	37	43	49	55	69	84	100												
3	40	120	9	11	13	15	17	19	21	24	26	31	36	42	47	53	65	77	91	100	100										
3	50	150	9	11	13	15	17	19	21	24	26	31	36	41	46	52	63	74	87	100	100										
3	60	180	9	11	13	15	17	19	21	24	26	31	36	41	46	51	62	73	84	96	100										
3	80	240	9	11	13	15	17	19	21	24	26	31	36	41	46	51	61	72	82	93	100										
3	100	300	9	11	13	15	17	19	21	24	26	31	36	41	46	51	61	71	81	92	100										
4	1	4	18	27	38	52	68	88	100																						
4	2	8	11	15	21	28	36	46	57	69	83	100																			
4	3	12	10	12	16	20	26	32	39	48	57	79	100																		
4	4	16	9	11	14	17	21	26	31	38	45	61	80	100																	
4	5	20	9	10	12	15	18	22	27	32	37	50	66	83	100																
4	6	24	9	10	12	14	17	20	24	28	33	44	56	71	88	100															
4	8	32	8	10	11	13	15	18	21	24	28	36	46	57	69	83	100														
4	10	40	8	10	11	13	15	17	19	22	25	32	40	48	59	70	96	100													
4	12	48	8	9	11	12	14	16	18	21	23	29	36	43	52	61	83	100													
4	14	56	8	9	11	12	14	16	18	20	22	28	34	40	48	56	75	97	100												
4	16	64	8	9	11	12	14	16	18	20	22	27	32	38	45	52	68	88	100												
4	18	72	8	9	11	12	14	15	17	19	21	26	31	36	42	49	64	81	100												
4	20	80	8	9	11	12	14	15	17	19	21	25	30	35	41	47	61	76	94	100	100										
4	30	120	8	9	11	12	14	15	17	19	20	24	28	33	37	42	52	63	76	90	100										
4	40	160	8	9	11	12	14	15	17	19	20	24	28	32	36	40	49	58	69	80	92	100									
4	50	200	8	9	11	12	14	15	17	19	20	24	28	31	35	39	47	56	65	75	86	97	100								
4	60	240	8	9	11	12	14	15	17	18	20	24	27	31	35	39	47	55	64	73	82	92	100								
4	80	320	8	9	11	12	14	15	17	18	20	24	27	31	35	38	46	54	62	70	79	87	96	100							
4	100	400	8	9	11	12	14	15	17	18	20	24	27	31	35	38	46	53	61	69	77	85	94	100							

Table E.7: Existing Separation Tables for FHC 3 & 4 (cont'd)

Fire Hazard Category	FHC = 3 & 4	Emissivity	= 1	Flame Projection Distance	P = 0 m
		Limiting Radiation	= 12.6 kW/m^2		
Firecell Temperature	Tf = 1040 C	Emitted Radiation	= 168.0 kW/m^2		

Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Boundary Distance =0.5S m			0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Rectangle Size

Permitted unprotected area %

BOUNDARY SEPARATION TABLES USING MIRROR IMAGE CONCEPT

H m	W m	Ae m^2																													
5	1	5	17	25	35	47	61	76	94	100																					
5	2	10	11	15	19	25	32	40	48	59	70	96	100																		
5	3	15	9	12	14	18	23	28	34	40	48	65	86	100																	
5	4	20	9	10	12	15	18	22	27	32	37	50	66	83	100																
5	5	25	8	10	11	14	16	19	23	27	31	42	54	68	84	100															
5	6	30	8	9	11	13	15	17	20	24	27	36	46	58	72	86	100														
5	8	40	8	9	10	12	13	15	18	20	23	30	37	46	56	68	93	100													
5	10	50	8	9	10	11	13	14	16	18	21	26	32	40	48	57	77	100													
5	12	60	8	9	10	11	12	14	16	17	19	24	29	35	42	50	67	88	100												
5	14	70	8	9	10	11	12	14	15	17	19	23	27	33	39	45	60	78	98	100	100										
5	16	80	8	9	10	11	12	13	15	16	18	22	26	31	36	42	55	71	89	100	100										
5	18	90	8	9	10	11	12	13	15	16	18	21	25	30	34	40	52	66	81	99	100										
5	20	100	8	9	10	11	12	13	15	16	18	21	25	29	33	38	49	61	76	92	100										
5	30	150	8	9	10	11	12	13	14	16	17	20	23	26	30	34	42	51	61	72	85	98	100								
5	40	200	8	9	10	11	12	13	14	16	17	20	23	26	29	32	39	47	55	64	74	85	96	100							
5	50	250	8	9	10	11	12	13	14	15	17	20	23	25	29	32	38	45	52	60	69	78	87	97	100						
5	60	300	8	9	10	11	12	13	14	15	17	20	22	25	28	31	38	44	51	58	66	74	82	91	100						
5	80	400	8	9	10	11	12	13	14	15	17	20	22	25	28	31	37	43	50	56	63	70	77	85	93	100					
5	100	500	8	9	10	11	12	13	14	15	17	20	22	25	28	31	37	43	49	55	62	68	75	82	89	96	100				
6	1	6	17	25	34	44	56	69	85	100																					
6	2	12	11	14	18	23	29	36	43	52	61	83	100																		
6	3	18	9	11	14	17	21	25	30	36	42	57	74	93	100																
6	4	24	9	10	12	14	17	20	24	28	33	44	56	71	88	100															
6	5	30	8	9	11	13	15	17	20	24	27	36	46	58	72	86	100														
6	6	36	8	9	10	12	14	16	18	21	24	31	40	50	61	73	100														
6	8	48	8	9	10	11	12	14	16	18	20	26	32	39	48	57	79	100													
6	10	60	8	9	9	10	12	13	14	16	18	23	28	34	40	48	65	86	100												
6	12	72	8	8	9	10	11	12	14	15	17	21	25	30	36	42	57	74	93	100	100										
6	14	84	8	8	9	10	11	12	13	15	16	20	24	28	33	38	51	65	82	100	100										
6	16	96	8	8	9	10	11	12	13	14	16	19	22	26	31	36	47	59	74	91	100										
6	18	108	8	8	9	10	11	12	13	14	15	18	22	25	29	34	43	55	68	83	100	100									
6	20	120	8	8	9	10	11	12	13	14	15	18	21	24	28	32	41	52	64	77	92	100									
6	30	180	8	8	9	10	11	12	13	14	15	17	20	22	25	28	35	43	51	61	71	82	94	100							
6	40	240	8	8	9	10	11	12	13	14	15	17	19	22	25	27	33	39	46	54	62	71	80	90	100						
6	50	300	8	8	9	10	11	12	13	14	15	17	19	22	24	27	32	38	44	50	57	65	73	81	90	100	100				
6	60	360	8	8	9	10	11	12	13	14	15	17	19	22	24	26	32	37	43	49	55	62	69	76	84	92	100				
6	80	480	8	8	9	10	11	12	13	14	15	17	19	21	24	26	31	36	42	47	53	59	65	71	77	84	91	99	100		
6	100	600	8	8	9	10	11	12	13	14	15	17	19	21	24	26	31	36	41	46	52	57	63	69	74	80	87	93	100	100	

Table E.7: Existing Separation Tables for FHC 3 & 4 (cont'd)

Fire Hazard Category	FHC = 3 & 4	Emissivity = 1	Flame Projection Distance P = 0 m
		Limiting Radiation = 12.6 kW/m^2	
Firecell Temperature	Tf = 1040 C	Emitted Radiation = 168.0 kW/m^2	

Permitted unprotected area %

BOUNDARY SEPARATION TABLES USING MIRROR IMAGE CONCEPT

Rectangle Size H m	W m	Ae m^2																													
Radiation Distance			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Separation Distance = S m (Radiation + Projection)			1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Boundary Distance =0.5S m			0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4	4.5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
7	1	7	17	24	33	42	53	65	78	93	100																				
7	2	14	11	14	18	22	28	34	40	48	56	75	97	100																	
7	3	21	9	11	13	16	20	24	28	33	38	51	65	82	100																
7	4	28	9	10	11	14	16	19	22	26	30	39	50	63	77	93	100														
7	5	35	8	9	10	12	14	16	19	22	25	32	41	51	63	76	100														
7	6	42	8	9	10	11	13	15	17	19	22	28	35	44	53	64	89	100													
7	8	56	8	8	9	10	11	13	14	16	18	23	28	35	42	50	68	90	100												
7	10	70	8	8	9	10	11	12	13	15	16	20	25	30	35	42	57	74	94	100	100										
7	12	84	8	8	9	10	10	11	13	14	15	19	22	27	31	37	49	64	81	100	100										
7	14	98	8	8	9	9	10	11	12	13	15	18	21	25	29	33	44	57	71	88	100										
7	16	112	8	8	9	9	10	11	12	13	14	17	20	23	27	31	40	51	64	79	95	100									
7	18	126	8	8	9	9	10	11	12	13	14	16	19	22	26	29	38	48	59	72	86	100									
7	20	140	8	8	9	9	10	11	12	13	14	16	19	21	25	28	36	45	55	67	79	94	100								
7	30	210	8	8	9	9	10	11	12	12	13	15	17	20	22	25	31	37	44	52	61	71	81	93	100						
7	40	280	8	8	9	9	10	11	11	12	13	15	17	19	21	24	29	34	40	46	53	61	69	78	87	97	100				
7	50	350	8	8	9	9	10	11	11	12	13	15	17	19	21	23	28	33	38	43	49	56	63	70	78	86	94	100			
7	60	420	8	8	9	9	10	11	11	12	13	15	17	19	21	23	27	32	37	42	47	53	59	65	72	79	87	94	100		
7	80	560	8	8	9	9	10	11	11	12	13	15	17	19	21	23	27	31	36	41	45	50	56	61	66	72	78	85	91	98	100
7	100	700	8	8	9	9	10	11	11	12	13	15	17	19	21	23	27	31	36	40	45	49	54	59	64	69	74	80	86	92	98
8	1	8	17	24	32	41	51	62	74	87	100																				
8	2	16	11	14	18	22	27	32	38	45	52	68	88	100																	
8	3	24	9	11	13	16	19	22	26	31	36	47	59	74	91	100															
8	4	32	8	10	11	13	15	18	21	24	28	36	46	57	69	83	100														
8	5	40	8	9	10	12	13	15	18	20	23	30	37	46	56	68	93	100													
8	6	48	8	9	10	11	12	14	16	18	20	26	32	39	48	57	79	100													
8	8	64	8	8	9	10	11	12	14	15	17	21	26	31	38	45	61	80	100												
8	10	80	8	8	9	9	10	11	12	14	15	18	22	27	32	37	50	66	83	100	100										
8	12	96	8	8	9	9	10	11	12	13	14	17	20	24	28	33	44	56	71	88	100										
8	14	112	8	8	9	9	10	11	11	12	14	16	19	22	26	30	39	50	63	77	93	100									
8	16	128	8	8	8	9	10	10	11	12	13	15	18	21	24	28	36	46	57	69	83	99	100								
8	18	144	8	8	8	9	10	10	11	12	13	15	17	20	23	26	33	42	52	63	76	90	100								
8	20	160	8	8	8	9	10	10	11	12	13	15	17	19	22	25	32	40	48	59	70	82	96	100							
8	30	240	8	8	8	9	9	10	11	11	12	14	16	18	20	22	27	33	39	46	54	62	71	81	92	100					
8	40	320	8	8	8	9	9	10	11	11	12	14	15	17	19	21	25	30	35	41	47	53	61	68	76	85	94	100			
8	50	400	8	8	8	9	9	10	11	11	12	14	15	17	19	21	25	29	33	38	43	49	55	61	68	75	83	91	99	100	
8	60	480	8	8	8	9	9	10	11	11	12	14	15	17	19	20	24	28	33	37	42	47	52	57	63	69	76	83	90	98	100
8	80	640	8	8	8	9	9	10	11	11	12	14	15	17	19	20	24	28	32	36	40	44	49	53	58	63	69	74	80	86	92
8	100	800	8	8	8	9	9	10	11	11	12	14	15	17	19	20	24	28	31	35	39	43	47	52	56	61	65	70	75	80	86

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