FIRE AND SECURITY
CONSULTING SERVICES
ABN 67 166 244 105

17 McKenna Court
NOOSAVILLE
QUEENSLAND, 4566
AUSTRALIA

Phone: +61 (0)7 5455 5148, Mobile: 0409 399 190, Email: rafoster@bigpond.net.au

COMPUTER FIRE MODELLING & DESIGN TOOLS

Fire and Security Consulting Services (FSCS) is frequently asked about the software and methodology it uses in the Fire Engineering process.

In 1990 when Fire Engineering was in its infancy, Rick Foster was a partner in Eagle Consulting Group in Sydney (see CV). Rick and was one of the first Fire Engineers in Australia to adopt the newly released suite of fire engineering programmes called FireCalc, developed by the CSIRO Division of Building Construction and Engineering.

FireCalc was a suite of programmes each developed to address single fire related events in a compartment fire. They were simple programmes designed to operate effectively on computers with 286 processors.

Since that time, fire related computing has evolved to a mature state where multiple events in multiple compartments can be evaluated.

Quantitative Hazard Analysis

Fire modelling allows a Fire Engineer to carry out a system of “quantitative” analysis in a selected fire scenario. Unlike “qualitative” analysis which relies on expert judgement or comparisons with known or acceptable criteria, quantitative analysis requires measurement of results from various input data using acceptable and verifiable algorithms.

There are many highly interactive factors which need to be considered in performing a quantitative fire hazard analysis. Experimental measurements of the burning behaviour of materials and details of the building in which they burn are needed to define the fire in terms of its release of energy and mass over time (**§).** The transport of this energy and mass through the building is influenced by its geometry, the construction materials used, and the fire protection systems employed. The response of occupants and the consequences of the fire depend on when the occupants are notified, their physical capabilities, the decisions they make, and their susceptibility to the hazards to which they are exposed.

Tools for fire hazard analysis make it possible to evaluate fire performance against a fire safety goal. For example, a goal of fire safety has always been to "keep the fire contained until the people can get out." The problem is that it is very difficult to keep the "smoke" contained. Quantitative hazard analysis allows the determination of the impacts of smoke, such as toxicity, relative to the impact of other hazards of fire for a prescribed building and set of occupants. It determines if the time available for egress is greater than the time required; and if not, why not. Time is the critical factor. Having 3 minutes for safe escape when 10 are needed results in human disaster. But providing 30 minutes of protection when 10 are needed can lead to high costs. A quantitative analysis method can help prevent both types of problems from occurring.

Quantitative hazard analysis techniques have the potential of providing significant cost savings. Alternative protection strategies can be studied within the analysis framework to give the cost-benefit relation for each. In addition, measures are evaluated as a system with their many interactions, including the impact of both structure and contents. Providing these alternatives promotes the design flexibility which reduces redundancies and cost without sacrificing safety. New technology can be evaluated before it is brought into practice, thus reducing the time lag currently required for code acceptance. Thus, quantitative hazard analysis is a powerful complement to existing codes and standards and a useful tool in evaluating improvements to them.

§ ***Reference to the FSCS paper “Developing Design Fires for Alternative Solutions” provides further information on this topic***.

What Is a Computer Fire Model?

A computer fire model is a mathematical representation of burning or other processes associated with fires. Mathematical models range from relatively simple formulae that can be solved analytically to extensive hybrid sets of differential and algebraic equations that must be solved numerically on a computer. Software to accomplish the latter is referred to as a computer fire model.

Computer Modelling provides the facility for fast calculation of specific fire engineering problems from a range of areas. The results of these can then be used as part of an overall engineering solution to a particular design situation.

Computer Modelling is a valuable tool but must be used appropriately by fire engineering professionals who must remain aware of their ultimate responsibility to exercise professional judgement in its use.

Compartment Fires

The most common scenario presented to a Fire Engineer is one of extended travel distances in a large building. Typical large warehouses can be up to 10,000 m^2 in area and it follows from this that travel distances from substantial parts of the building will exceed the prescribed 40m travel distance to an exit.

In these scenarios, the developer has only one Deemed to satisfy (DtS) option, and that is to construct fire escape tunnels within the building so that all parts of the floor area are within 40m of an entrance to the tunnel. This is a costly exercise in both space taken and capital cost with the tunnel requiring emergency lighting and an independent fresh air supply. Such tunnels are also an unnatural method of egress from a building and in many cases occupants may suffer claustrophobia within them.

Accordingly a Fire Engineer is often requested to prepare an Alternative Solution where the tunnels can be deleted by demonstrating that the tenability of conditions within the building during egress is within acceptable limits. This is usually up to 2.1m above floor level for occupants and may be indefinite or of such a time that the Required Safe Egress Time (RSET) is less than the Available Safe Egress Time (ASET) before the conditions become untenable.

Even in large compartments, untenable conditions evolve rapidly and it is usually necessary to provide smoke exhaust fans, smoke venting or sprinkler systems to vent the smoke and/or suppress the fire. Occupant warning by smoke or other detection methods is also required to alert occupants at an earlier stage thus reducing the overall time for egress.

One point that is often forgotten is that on arrival, fire fighters also need to access the fire compartment to effect rescue and/or fire suppression activities. Although fire fighters have protective clothing and breathing apparatus, visibility, temperature and radiant heat flux can impact on their activities. Accordingly a tenability height of 1.5m has been set in the Fire Engineering Guidelines for their activities.

Considering all of the above, a Fire Engineer can model the conditions in a fire compartment by a number of means as follows.

Zone Modelling

A zone model divides each room into two spaces or zones: an upper zone containing the hot gases produced by the fire and a lower zone containing all space beneath the upper zone. The lower zone is a source of air for combustion and is the location of the fire source. During the course of the fire, the upper zone can expand to occupy virtually all of the space in the room.

In a zone model, the upper zone is considered a control volume that receives both mass and energy from the fire and loses energy to the surfaces in contact with the upper zone by conduction and radiation, by radiation to the floor, and by convection or mass movement of gases through openings. Some models evaluate conditions in the lower layer; others assume that the lower layer remains at ambient conditions. Mass is conserved, accounting for mass entering or vented from the control volume.

BranzFire

For compartment fire modelling, FSCS uses the Zone Model BranzFire. It is a multi-compartment two zone model which represents the fire environment generated from single or multiple burning objects within a compartment as two homogenous layers, comprising an upper smoke (hot) layer and a lower ambient layer and predicts various tenability conditions.

BranzFire has the capability to model hot gas flows through doors and vents to adjoining compartments and predict various tenability conditions in those compartments.

For the required analytical results, FSCS commonly computes the following inputs and outputs in order to properly conduct an analysis of the tenability conditions in the compartment being modelled:-

As well as compartment size(s) and materials of construction, input data includes:-

1. Single or multiple fires;
2. Door and ventilation openings with locations and variable opening and closing times;
3. Glazing fracture resulting in additional openings;
4. Smoke detector location and sensitivity;
5. Sprinkler head response time index, location and temperature rating;
6. Design density of sprinkler discharge;
7. Sprinkler suppression or control ;
8. Mechanical (fan) extract or pressurisation;
9. Fan flows and pressures.

Typically the Fire Engineer is required to consider conditions in the lower part of a compartment so as to assess tenability for occupant evacuation and fire fighter entry. Accordingly the following outputs are used although many more are available in respect to both upper and lower layer combustion species and temperatures.

1. Smoke detector and / or sprinkler activation (secs);
2. Hot smoke layer height –(m);
3. Lower layer CO (ppm);
4. Lower layer temperature (^{o}C);
5. Lower layer visibility (metres);
6. Lower layer radiant heat flux at specified height above the floor (kW/m^2).

BranzFire results are presented in and Excel spreadsheet although FSCS presents the results in a series of graphs of each output with all the connected compartments shown on a single graph for ease of understanding as shown in Figure 1 below which shows the layer heights in a multi-compartment warehouse with connected compartments.

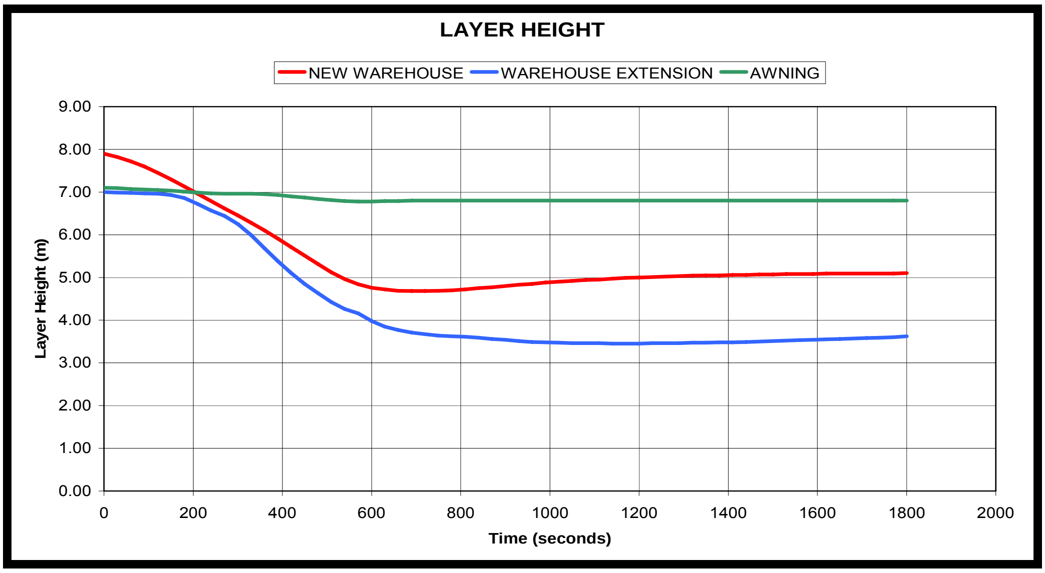


Figure 1

Further information on BRANZFIRE including a download of the User Reference and Technical Reference Guides, can be had from:

http://www.branz.co.nz/cms_display.php?sn=74&st=1

BranzFire is validated for complex large single and multi compartment fires and the Branz Study Report on smoke filling in large spaces using BranzFire (9MB) can be downloaded from http://www.branzfire.com/frst/limitations-on-use/

The Branz Study Report cited above compared results from enclosures ranging from 625m^2 to 5,000m^2 with heights from 6 to 12m with those from CFD. It was found that the BranzFire zone model provided good agreement with CFD (FDS – see below) for compartment areas up to 1,250m^2. It recommended that for larger enclosures up to 5,000m^2, additional simulations and sensitivity analysis should be conducted by subdividing the compartment into “virtual” compartments as shown in Figure 2 below as well as the single zone simulation.

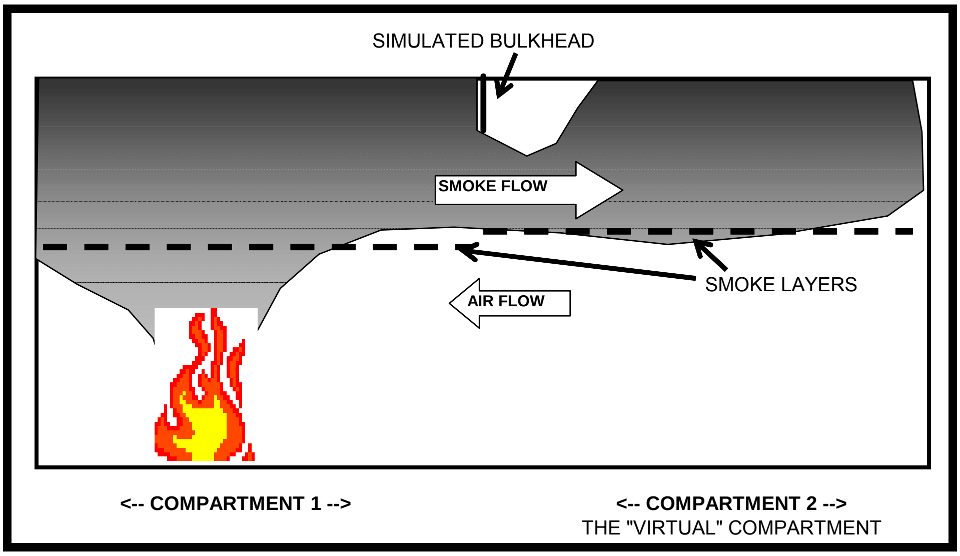


Figure 2 – A Virtual Compartment

Field Modelling

Field models are Computational Fluid Dynamics (CFD) programmes which divide the space being modelled into many small cells to a much higher spatial resolution than a zone model. Typically CFD is noded to generate a large number of small cells, in the order of 0.5m^3, in the compartment. Mass, momentum and energy equations are computed for each cell, and when combined, results in greater accuracy than a zone model. However this accuracy comes at a price because of the time to programme the multiple inputs and the increased computing power required.

The basic laws of mass, momentum, and energy conservation are applied in each cell and balanced with all adjacent cells. The computational modelling is a complex fluid mechanics solution of both turbulent and laminar flow derived from classic fluid dynamics theory.

The governing equations involve a set of three-dimensional, nonlinear partial differential equations expressing conservation of mass, momentum, and energy. Important sub-models related to individual cells address turbulence, radiation, soot, pyrolysis, flame spread, and combustion and provide the same outputs as a zone model.

Approaches to the modelling differ among the various CFD models. CFD models can examine the fire environment in much greater detail than zone models. In general, CFD models are significantly more expensive to obtain and use. Important engineering decisions are required in setting up the problem and interpreting the output produced by the model.

However, the use of CFD models in fire protection problems is increasing. CFD models are particularly well suited for situations where the space is irregular, turbulence is a critical element, or very fine details are sought.

FDS

For compartment fire modelling, FSCS uses the FDS (Fire Dynamics Simulator), which is a CFD fire modelling programme developed by the US Building and Fire Research Laboratory of the National Institute of Standards and Technology.

FDS) is a CFD model of fire-driven fluid flow. FDS solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires.

The partial derivatives of the conservation equations of mass, momentum and energy are approximated as finite differences, and the solution is updated in time on a three-dimensional, rectilinear grid as shown in Figure 3 below. This is the visibility in an 85m x 32m x 12m high compartment at 900 seconds. Notice that instead of a single point of layer height as a zone model predicts, a field model shows different visibility at different parts of the compartment.

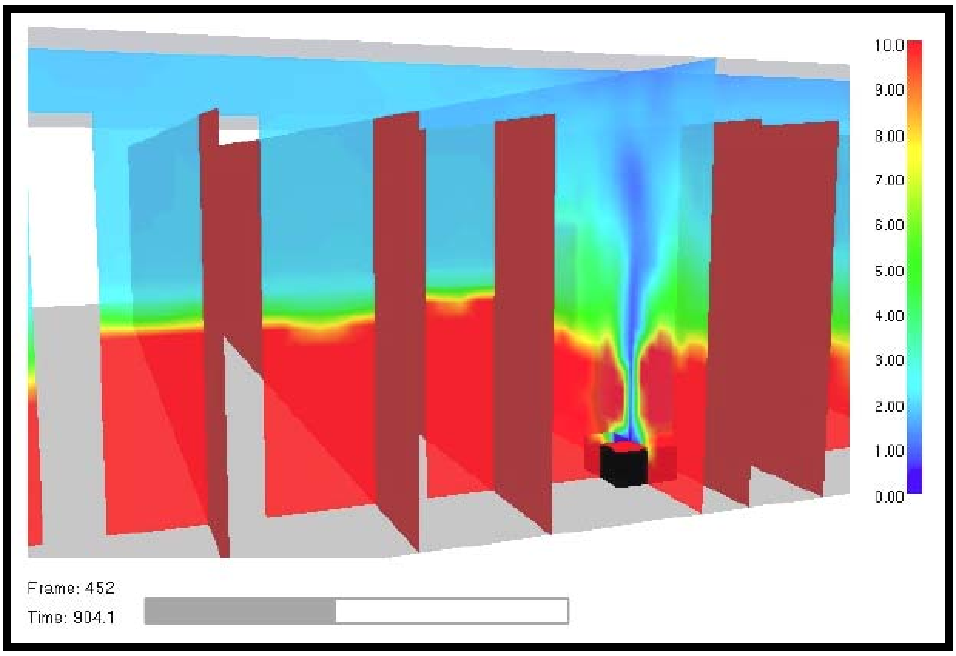


Figure 3 – CFD Visibility

FDS can also show the temperatures (^{o}C) in the compartment as shown in Fig. 4.

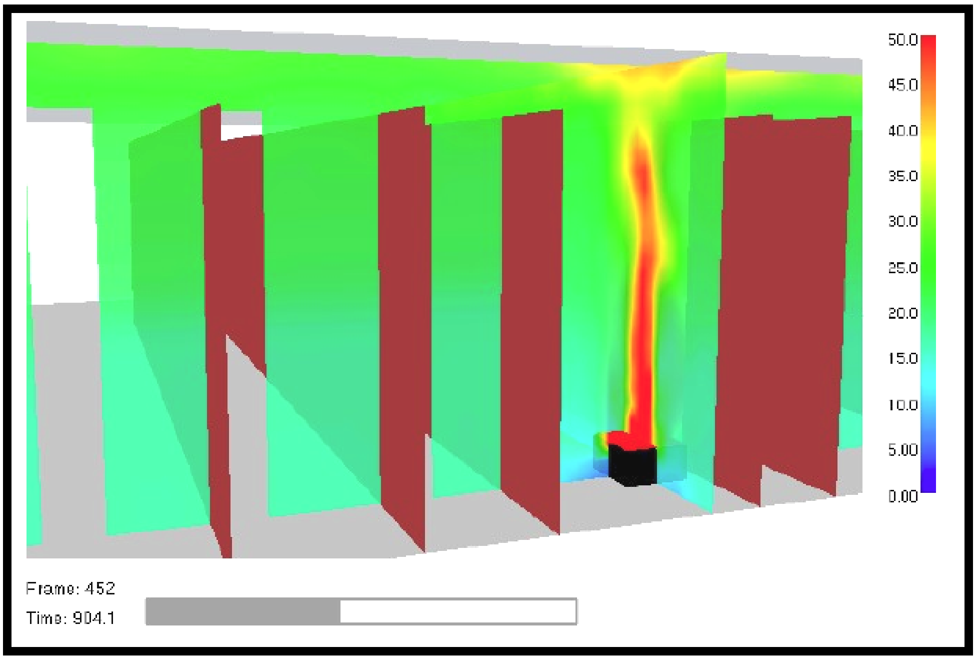


Figure 4 – CFD Temperatures

Summary

Because of the small cell analysis, field models are extremely useful in analysing building structures where smoke and hot gas flows are likely to flow between complex interconnecting openings such as ducting, stairs etc.

Whilst FDS can compute sprinkler control, i.e. where the combustion rate is capped at sprinkler activation, FDS does not provide the accuracy of the effects of sprinkler suppression (**§)** that BranzFire does where the rate of combustion is reduced.

However for simple single or interconnecting compartments, a zone model is the most economical model where repeated computations are required to be executed to develop required ventilation and fire suppression strategies. The Branz Study Report cited above advises that for most compartments, a zone model is adequate because generally it is more conservative than a field model.

The costs associated with field modelling can be five times the cost of zone modelling without, for most simulations, no added benefit in the analysis.

§ ***Reference to the FSCS paper "ESFR Sprinkler Systems" provides further information on this topic***.

Heat Flux Radiation

For radiation calculations, FSCS uses the spreadsheet “Rad Parll Surf.xls” written by I.D Bennetts and K.W.Poh from CSARE VUT – Feb. 2000 (Victoria University of Technology).

This is a simplified version of the CSIRO FireCalc programme “Radiation”, but using only parallel surfaces. The following information is provided with the programme:

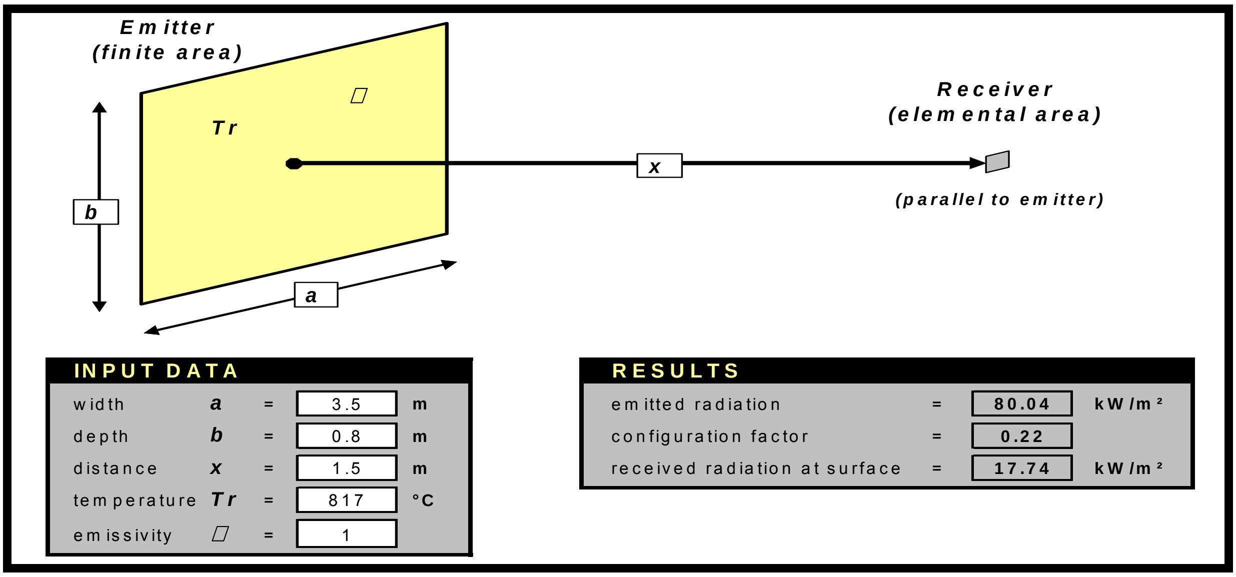
The program computes maximum radiation at a point in the assumption that the fire sources are not dispersed so that the fire sources are not dispersed so that the direction of maximum radiation is significantly aside from the centre of gravity of fire sources. For instance, the case of two fire sources located at an angle more than 90° is not covered by this program. All fire sources are supposed to be of rectangular shape and located in the rectangular planes as shown in the introductory screen. Emissivity of fire sources is assumed to be 1.0, i.e. "temperature of sources" is radiation temperature.

The radiation is computed using the formula: $dQ = \sigma T^4 \cos\alpha \cos\beta / (\pi r^2)\, dF1\, dF2$, *where* σ *is Stefan-Boltzmann's constant,* T *is absolute temperature,* α *and* β *are angles between radius-vector* r *and infinitesimal areas* $dF1$ *of radiation and* $dF2$ *of a receptor located in the origin.*

Temperatures are estimated for the expected fire source and FireCalc advises that temperatures of between 750°C and 1,000°C are appropriate for compartment fires. FireCalc also advises that for petroleum fires a flame temperature of 1,026°C is appropriate.

- For Radiation from the adjacent property this analysis contemplates a maximum heat flux of 80kW/m^2 (From BCA Verification Method CV1) on the boundary which equates to a flame temperature of 817°C.
- For Radiation to the adjacent property this analysis contemplates a flame temperature of 1,000°C within the building in general occupancy areas.

The calculation methodology produces data in the format shown in Figure 5 below.



INPUT DATA

width	*a*	=	3.5	m
depth	*b*	=	0.8	m
distance	*x*	=	1.5	m
temperature	*Tr*	=	817	°C
emissivity	▱	=	1	

RESULTS

emitted radiation	=	80.04	kW/m²
configuration factor	=	0.22	
received radiation at surface	=	17.74	kW/m²

Figure 5 – Typical Heat Flux data

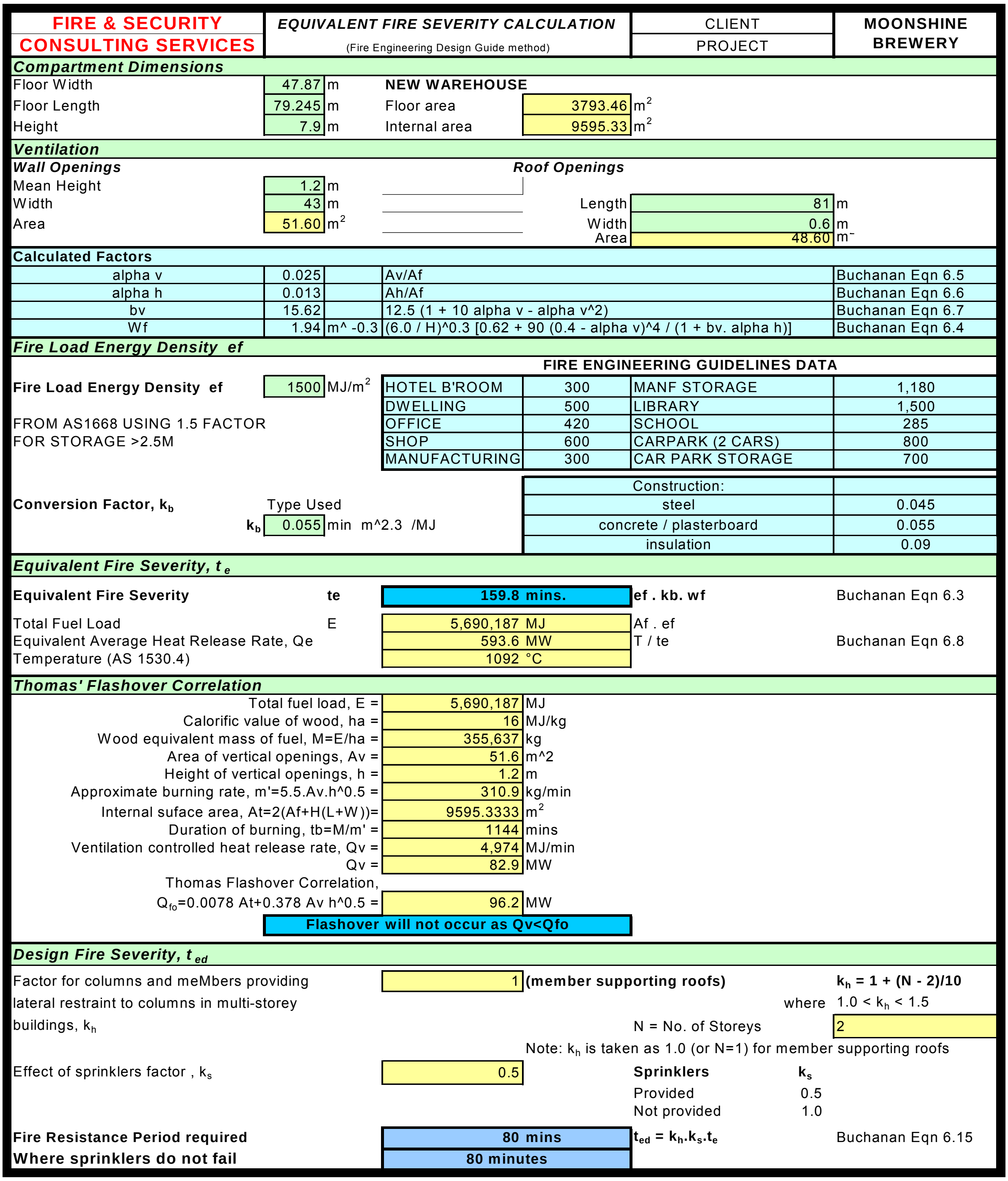
§ ***Reference to the FSCS paper “Heat Flux Calculations and Assessment” provides further information on this topic***.

Equivalent Fire Severity

For the fire severity in compartments FSCS uses a spreadsheet based on fire loads from the International Fire Engineering Guidelines. The method of analysis described by Buchanan, calculates an actual fire time-temperature regime, dependent on room geometry, fire load, and ventilation characteristics. This is then compared to the standard time temperature regime as defined by AS1530.4. Results include:

1. Average Heat Release in MW.
2. Ventilation controlled heat release in MW.
3. HRR at flashover.
4. Time for fire severity in minutes.
5. Fire Resistance period required.

Figure 6 below shows a typical Equivalent Fire Severity calculation for a manufacturing warehouse



FIRE & SECURITY CONSULTING SERVICES	*EQUIVALENT FIRE SEVERITY CALCULATION* (Fire Engineering Design Guide method)	CLIENT PROJECT	MOONSHINE BREWERY

Compartment Dimensions

Floor Width	47.87	m	**NEW WAREHOUSE**		
Floor Length	79.245	m	Floor area	3793.46	m^2
Height	7.9	m	Internal area	9595.33	m^2

Ventilation

Wall Openings			***Roof Openings***		
Mean Height	1.2	m			
Width	43	m	Length	81	m
Area	51.60	m^2	Width	0.6	m
			Area	48.60	m⁻

Calculated Factors

alpha v	0.025		Av/Af	Buchanan Eqn 6.5
alpha h	0.013		Ah/Af	Buchanan Eqn 6.6
bv	15.62		12.5 (1 + 10 alpha v - alpha v^2)	Buchanan Eqn 6.7
Wf	1.94	m^ -0.3	(6.0 / H)^0.3 [0.62 + 90 (0.4 - alpha v)^4 / (1 + bv. alpha h)]	Buchanan Eqn 6.4

Fire Load Energy Density ef

Fire Load Energy Density ef 1500 MJ/m^2

FROM AS1668 USING 1.5 FACTOR
FOR STORAGE >2.5M

FIRE ENGINEERING GUIDELINES DATA

HOTEL B'ROOM	300	MANF STORAGE	1,180
DWELLING	500	LIBRARY	1,500
OFFICE	420	SCHOOL	285
SHOP	600	CARPARK (2 CARS)	800
MANUFACTURING	300	CAR PARK STORAGE	700

Conversion Factor, k_b Type Used

k_b 0.055 min m^2.3 /MJ

Construction:	
steel	0.045
concrete / plasterboard	0.055
insulation	0.09

Equivalent Fire Severity, t_e

Equivalent Fire Severity	**te**	**159.8 mins.**	**ef . kb. wf**	Buchanan Eqn 6.3
Total Fuel Load	E	5,690,187 MJ	Af . ef	
Equivalent Average Heat Release Rate, Qe		593.6 MW	T / te	Buchanan Eqn 6.8
Temperature (AS 1530.4)		1092 °C		

Thomas' Flashover Correlation

Total fuel load, E =	5,690,187	MJ
Calorific value of wood, ha =	16	MJ/kg
Wood equivalent mass of fuel, M=E/ha =	355,637	kg
Area of vertical openings, Av =	51.6	m^2
Height of vertical openings, h =	1.2	m
Approximate burning rate, m'=5.5.Av.h^0.5 =	310.9	kg/min
Internal suface area, At=2(Af+H(L+W))=	9595.3333	m^2
Duration of burning, tb=M/m' =	1144	mins
Ventilation controlled heat release rate, Qv =	4,974	MJ/min
Qv =	82.9	MW
Thomas Flashover Correlation, Q_{fo}=0.0078 At+0.378 Av h^0.5 =	96.2	MW

Flashover will not occur as Qv<Qfo

Design Fire Severity, t_{ed}

Factor for columns and meMbers providing lateral restraint to columns in multi-storey buildings, k_h 1 **(member supporting roofs)** **k_h = 1 + (N - 2)/10**

where 1.0 < k_h < 1.5

N = No. of Storeys 2

Note: k_h is taken as 1.0 (or N=1) for member supporting roofs

Effect of sprinklers factor , k_s 0.5

Sprinklers	**k_s**
Provided	0.5
Not provided	1.0

Fire Resistance Period required	**80 mins**	**t_{ed} = k_h.k_s.t_e**	Buchanan Eqn 6.15
Where sprinklers do not fail	**80 minutes**		

Figure 6 – Typical Equivalent Fire Severity Calculation

HRR from Flammable or Combustible Liquid Fires

To calculate the HRR from flammable or combustible liquid spill fires, FSCS uses the methodology as set out in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-25. This utilises the following equations and data:

$Q = m''\Delta H_{c,eff}(1 - e^{-k\beta D}) A_{dike}$

Where Q = pool fire heat release rate (kW)

m'' = mass burning rate of fuel per unit surface area (kg/m2-sec)

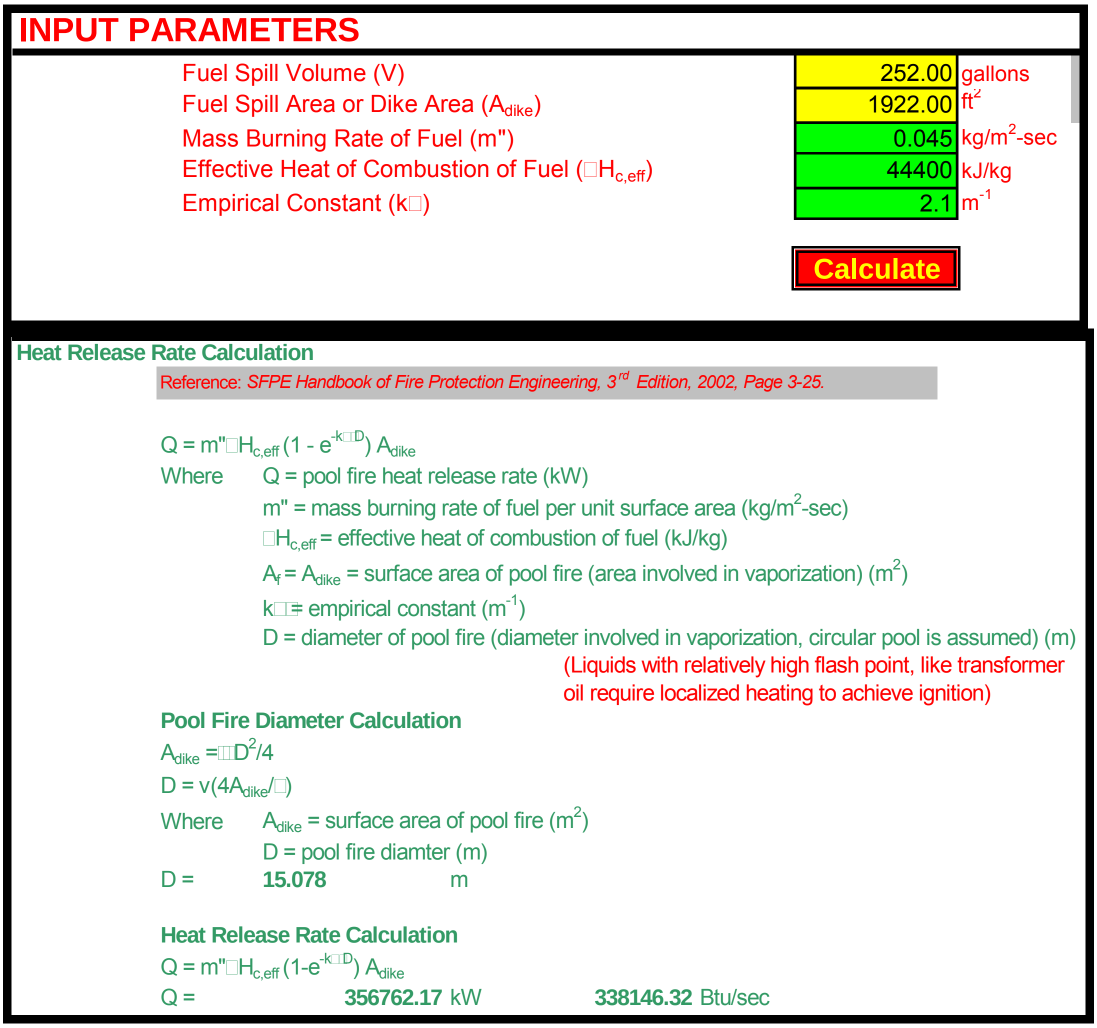
$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m2)

$k\beta$ = empirical constant (m-1)

D = diameter of pool fire (diameter involved in vaporization, circular (m).

Figure 7 below is the HRR calculation of a diesel oil spill from a vehicle in a warehouse. Note that the spreadsheet is based on US imperial units where 1 US gallon is 3.97 litres.



INPUT PARAMETERS

Fuel Spill Volume (V)	252.00	gallons
Fuel Spill Area or Dike Area (A_{dike})	1922.00	ft^2
Mass Burning Rate of Fuel (m")	0.045	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\square H_{c,eff}$)	44400	kJ/kg
Empirical Constant (k□)	2.1	m^{-1}

Heat Release Rate Calculation

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-25.*

$Q = m''\square H_{c,eff}(1 - e^{-k\square D}) A_{dike}$

Where Q = pool fire heat release rate (kW)

m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)

$\square H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

k□□= empirical constant (m^{-1})

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

(Liquids with relatively high flash point, like transformer oil require localized heating to achieve ignition)

Pool Fire Diameter Calculation

$A_{dike} = \square\square D^2/4$

$D = v(4A_{dike}/\square)$

Where A_{dike} = surface area of pool fire (m^2)

D = pool fire diamter (m)

D = **15.078** m

Heat Release Rate Calculation

$Q = m''\square H_{c,eff}(1-e^{-k\square D}) A_{dike}$

Q = **356762.17** kW **338146.32** Btu/sec

Figure 7 – HRR Calculation for Diesel Oil Spill

Rate of Rise Heat Detectors

For heat detector actuation where BranzFire or FDS dos not provide for “rate of rise” detector actuation modelling, FSCS use Detact-T2. This programme written by the US National Bureau of Standards and is distributed by NIST.

Detact-T2 (DETector ACTuation - Time squared) is a program for calculating the actuation time of thermal devices below unconfined ceilings. It can be used to predict the actuation time of fixed temperature and rate of rise heat detectors, and sprinkler heads subject to a user specified fire which grows as the square of time. The programme assumes that the thermal device is located in a relatively large area, that is, only the fire ceiling flow heats the device, and there is no heating from the accumulated hot gases in the room. The required program inputs are the ambient temperature, the response time index (RTI) for the device, the activation and rate of rise temperatures of the device, height of the ceiling above the fuel, the device spacing and the fire growth rate. The program outputs are the time to device activation and the heat release rate at activation. DETACT-T2 was written in BASIC and FORTRAN by D.W. Stroup.

I trust that this Paper clarifies the use of fire modelling in Fire Engineering Reports prepared by FSCS.

Richard A Foster

Dip Mech Eng; Dip Mar Eng; MSFPE; Member IE (Aust) SFS

RPEQ 7753

Fire Safety Engineer

QFRS Accredited Fire Safety Adviser under BFSR 2008

Principal – Fire and Security Consulting Services

FIRE AND SECURITY CONSULTING SERVICES
ABN 67 166 244 105

Rick Foster
RPEQ 7753 M.I.E. Aust. SFS
MSFPE Dip. Mech Eng Dip Mar Eng
PRINCIPAL
17 Mclrenna Court
Noosaville
Queensland 4566
Australia
Phone: +61 (0) 7 5455 5148
Mobile: +61 0409 399 190
Email: rafoster@bigpond.net.au

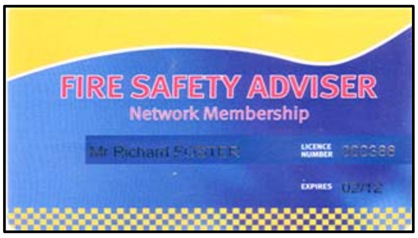
INDUSTRIAL COMMERCIAL
RESIDENTIAL MARINE

FIRE ENGINEERING
FIRE SYSTEMS DESIGN
PROJECT MANAGEMENT
DOCUMENTATION & COST CONTROL
RISK & HAZARD ASSESSMENT
COMPLIANCE INSPECTIONS
REGULATORY RESEARCH & ADVICE
PRODUCT SOURCING
OPERATION & TRAINING MANUALS

Board of
Professional Engineers
Queensland Government

Certificate of Registration as a
Registered Professional Engineer of Queensland

Richard Anthony Foster RPEQ: 7753
Area: Mechanical
Valid: 28 May 2009 to 30 June 2010



FIRE SAFETY ADVISER
Network Membership

Mr Richard FOSTER
LICENCE NUMBER 000388
EXPIRES 02/12