PRESCRIBING THE INPUT FOR THE ASET VERSUS RSET ANALYSIS: IS THIS THE WAY FORWARD FOR PERFORMANCE BASED DESIGN?

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ABSTRACT

The popularity of Performance Based Design (PBD) has continued to increase over the last two decades and many consider PBD provides for cost effective and innovative solutions to fire safety challenges. Fundamental to PBD for life safety, is the principle that the occupants have enough time to exit the building before being overcome by the fire. In fire engineering terms the Available Safe Egress Time (ASET) must exceeding the Required Safe Egress Time (RSET) with an appropriate margin of safety. Currently the necessary input and acceptance criteria are left up to the fire engineer with the approval from the authority having jurisdiction. Unfortunately the conventional guidance is more qualitative rather than quantitative which can lead to varying levels of safety in buildings depending on the values chosen for use in the analysis. This paper describes the necessary input parameters and the appropriate acceptance criteria for ASET versus RSET analysis and discusses some of the available guidance for determining these values. The paper ends with a brief description of the framework that the Department of Building and Housing is proposing for PBD in New Zealand. The framework outlines the design fire scenarios, design fires, premovement times and acceptance criteria that is currently being field tested.

INTRODUCTION

For nearly two decades Performance Based Design (PBD) has been touted as the future of building design for fire safety providing for cost effective and innovative solutions to fire safety challenges. Although PBD continues to grow in popularity and sophistication, Fire Engineering has yet to reach the same level of understanding compared with the more traditional disciplines where PBD is common place. Fire engineering is still a rapidly developing discipline with new methodologies and understanding evolving continuously. For example, it has only been the last five years that CFD modeling has become common practice for complex fire engineering analysis, where a decade ago only universities and research institutions had the necessary computing power. Since 1996 the Society of Fire Protection Engineers has held a biennial international conference on performance based codes and design methods to highlight the latest developments in performance based fire safety research and design.

At the very heart of PBD for life safety is the fundamental principle that the occupants have enough time to exit the building before being overcome by the fire. In fire engineering terms, the Available Safe Egress Time (ASET) must exceed the Required Safe Egress Time (RSET) with an appropriate margin of safety. There are a number of books, guides, and codes on PBD and many countries allow for performance based solutions to design problems. One of the most comprehensive codes that include a performance based option is the National Fire Protection Association Life Safety Code[1] (NFPA101). NFPA101 lays out 8 scenarios that must be used to evaluate a proposed building design. However the scenarios and supporting performance clauses of the code are very qualitative in nature and do not provide quantitative advice about the design fire, acceptance criteria, or methodology but simply outline all of the factors that should be considered by a designer without actually quantifying any of the necessary input parameters or acceptance criteria. This leaves the designer having to develop their own criteria and design input with the approval of the Authority Having Jurisdiction (AHJ). This lack of quantified guidance forces the FPE to turn to the literature and pull together the required input and performance criteria from a number of sources to carry out their analysis.

Under the current approach, without quantified guidance, there is significant variability in the design fire scenarios, design fires and performance criteria. For example in one building the designer evaluates the Fractional Equivalent Dose (FED) at 2 m above the floor yet in another design the Fire Engineer calculates the FED at 1.8 m. In many cases the local AHJ is reluctant to challenge the Fire Engineer's recommendations for the design fire and performance criteria because the AHJ has a lower qualification than the Fire Engineer. This can lead to inconsistent levels of fire safety in buildings of similar occupancy.

This paper outlines the input required to carry out the typical ASET versus RSET analysis. A brief review of the literature is presented for the primary input required for the ASET versus RSET analysis including fire scenarios, design fires, egress parameters and acceptance criteria. The paper will then summarize the ongoing work in New Zealand in which the Department of Building and Housing is developing a framework that will specify the required input for PBD. The framework has been under development for 2 years and is currently being field tested by fire engineering practitioners. Prior to releasing the framework for the trial, an internal evaluation was carried out applying the framework to a number of building designs that complied with the New Zealand compliance documents[2] that are "deemed to satisfy" the performance based code. The results of the internal trial will also be discussed.

FIRE SCENARIOS

Fundamental to any fire safety evaluation process are the design fire scenarios. In the context of this paper, a fire scenario is a qualitative description that characterizes the key events of a potential fire. A design fire scenario is a description of a specific fire scenario that can be used in a fire safety engineering analysis. Typically the design fire scenario as used in deterministic analysis may simply dictate particular performance requirements such as the allowable surface spread of flame in exitways. There are an infinite number of potential fire scenarios and it is common for the fire engineer to reduce the fire scenarios to a manageable amount and use deterministic methods to evaluate the consequences of the scenario in the proposed building against the performance criteria.

There are a number of references which discuss the various aspects of choosing fire scenarios[3, 4]. The International Standards Organization technical committee 92 developed ISO/TS16733 *Fire safety engineering – Selection of design fire scenarios and design fires*[5] which outlines a 10 step comprehensive procedure which includes an event tree to help reduce the number of design scenarios to a manageable level. The 10 steps are:

1. **Location of fire** – Select fire locations that produce the most challenging fire scenarios.
2. **Type of fire** – Identify the most likely types for fire scenarios and most likely high consequence fire scenarios based on fire incident statistics.
3. **Potential fire hazards** – identify other critical high consequence scenarios for consideration.
4. **Systems impacting on fire -** Identify the building and fire safety systems that are likely to have a significant impact on the fire or development of untenable conditions.
5. **Occupant response** – Identify occupant characteristics and response features that are likely to have a significant impact on the course of the fire scenarios.
6. **Event tree** – Develop event tree that represents the possible factors that have been identified as significant.
7. **Consider probability** – Estimate the probability of occurrence of each state using the available reliability data and engineering judgment when data is not available.

8. **Consideration of consequence –** Estimate the consequences of each scenario using engineering judgment.
9. **Risk ranking –** Rank the scenarios in order of relative risk.
10. **Final selection and documentation –** Select the highest-ranked fire scenario for quantitative analysis.

The National Fire Protection Association (NFPA) has taken a different approach to developing fire scenarios for use as a performance based option in their Life Safety Code®[1] and Building Construction and Safety Code®[6]. In each of these codes the NFPA has identified 8 scenarios that must be analyzed and compared to the performance criteria. The 8 required scenarios include:

1. Occupancy specific fire representative of a typical fire for the occupancy.
2. An ultra-fast developing fire in the primary means of egress, with interior doors open at the start of the fire.
3. A fire that starts in a normally unoccupied room, potentially endangering a large number of occupants in a large room or other area.
4. A fire that originates in a concealed wall or ceiling space adjacent to a large occupied room.
5. A slowly developing fire, shielded fire protection systems, in close proximity to a high occupancy area.
6. Most severe fire resulting from the largest possible fuel load characteristics of the normal operation of the building.
7. Outside exposure fire
8. Fire originating in ordinary combustibles in a room or area with each passive and active fire protection system independently rendered ineffective.

Additional scenarios may also be specified by the design team or authority having jurisdiction. According to the NFPA, additional scenarios should be considered and suggest that as a minimum the following three types of scenarios be considered:

1. High-frequency, low-consequence scenarios
2. Low-frequency, high-consequence scenarios
3. Special problems scenarios

The additional scenarios are intended to take into account the unique characteristics of the building.

Although the NFPA and ISO/TC92 documents give very detailed discussion for developing the fire scenarios, they do not specify the design fires that are required to carry out the fire safety evaluations for a building. Thus it is left to the fire engineer to come up with the design fire required.

DESIGN FIRE CHARACTERISTICS

Each of the design fire scenarios are qualitative in nature and require a quantitative design fire for use in a fire safety assessment. A design fire is intended to represent a credible worse case scenario that will challenge the fire protection features of the building. Although simple in concept this definition can be hard to interpret when attempting to quantify the design fire especially in low ceiling spaces where occupants are expected to be sleeping. Typically the design fire is described in terms of the heat release rate from the fire. Indeed, the heat release rate history is considered the single most important variable in describing a fire hazard.[7] However, the design fire may also include an estimate of the size of the fire, the species being produced, and the smoke production rate. Unfortunately it is not possible to derive the design fire from first principles and can be quite difficult to quantify in practice. The detail required for a design fire is dependent on the issue being investigated and what questions the engineer is trying to answer. For example it is not much use to have a design fire that includes the decay phase if the engineer is trying to predict the activation of a sprinkler head. Likewise, the growth phase makes little difference if the engineer is trying to model the fire resistance of a structural member after four hours of fire exposure. Thus the nature of the design fire depends on the issues the fire engineer is resolving. Figure 1shows the idealized fire growth rate highlighting the four phases of conventional fire development and the transition of flashover.

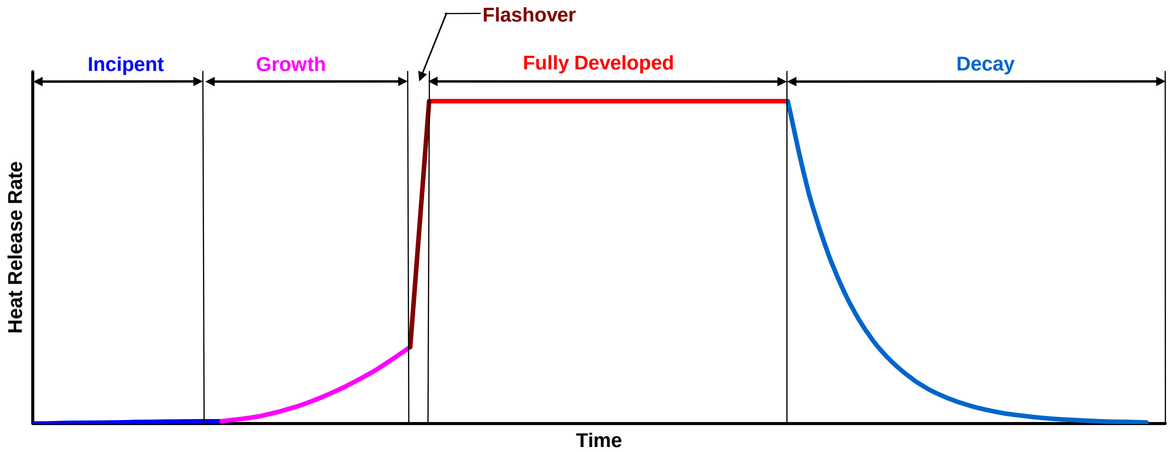

Figure 1 Idealized heat release rate history highlighting the 4 phases of conventional fire development and flashover.

The **Incipient Phase** of a fire can last from a few seconds to days depending on the initial fuel involved, ambient conditions, ignition source, etc. In the case of a flammable liquid spill the incipient phase is effectively nonexistent. If it is a self- heating to ignition, the incipient phase can last for hours if not days. In some cases the fire may not grow beyond the incipient phase, consider a cigarette which smolders on a wool fabric covered chair may never ignite the flammable padding beneath the fabric. There are far too many variables to allow for reliable modeling of the incipient phase of a fire. Indeed, for the furniture calorimeter test a gas burner is used simulate a wastepaper basket to eliminate the impact of incipient phase on the early growth phase.

The **Growth Phase** is considered to begin when the radiation feedback from the flame governs the burning rate. Assuming the compartment is vented, the growth rate is primarily governed by the fuel properties and orientation. During the growth phase the fire spread across the fuels surfaces, increasing the burning area and corresponding heat release rate. The heat release rate is assumed to be independent of the fire enclosure and governed more by the flame spread rate. Compartment enhancement due to the accumulation of hot gases is considered small until the fire nears flashover.

Modeling the actual growth rate is extremely difficult and remains an area of active research. It is dependent on many factors which are not only a function of the burning object but are also stochastic in nature such as size and location of the ignition source, orientation of the object, proximity to other object, proximity to boundaries, proximity to openings, etc. Not withstanding these limitations, the engineer must rely on judgment when choosing a growth rate. It is true that most fires occurring during the life of a building will be quite minor and are likely to go unreported; it is the reasonable worst case fire and not the most likely fire that must be used for design.

There are several approaches to estimating the growth rate for a particular design fire. The most popular is the t-squared fire growth rate. Originally developed in the 1970's for predicting fire detector activation, the t-squared fire gained popularity when it was included in the appendix of NFPA72[8]. In NFPA72 there are three categories for fire growth slow, medium, and fast. These definitions are simply determined by the time required for the fire to reach 1055 kW (1000 BTU/s). A slow fire is defined as taking 600 or more seconds to 1055 kW. A medium fire takes more than 150 seconds and less than 300 seconds and fast fire takes less than 150 seconds to reach 1055 kW. Over time the definition for t-squared fire has evolved to include an "ultra fast" fire as well. The common definition for the growth times are shown below:

$$\dot{q} = \alpha t^2 \tag{1}$$

where:

$\dot{q}$ - heat release rate (kW)
α - growth constant (kW/s^2)
t - time from effective ignition (s)

Classification	**Growth time** (Time to 1055kW) (s)	α (kW/s^2)
Slow	600	0.00293
Medium	300	0.0117
Fast	150	0.0469
Ultra	75	0.188

The t squared fire growth can be thought of in terms of a burning object with a constant heat release rate per unit area in which the fire is spreading in a circular pattern at a constant flame speed. Obviously more representative fuel geometries may or may not produce a t-squared fire growth. However, the implicit assumption in many cases is that the t-squared approximation is close enough to make reasonable design decisions[9]. It should be noted that the t-squared growth rate has been adopted well beyond the original intent in some cases for fires as large as 30 MW. Such application has been questioned in the literature.[10]

Flashover occurs when the radiation from the upper layer is so intense that all of the combustible surfaces in the compartment ignite. Flashover can be thought of as a transition from a small object oriented fire to full room involvement. This transition typically occurs over a short time span measured in seconds. Figure 2 is a plot of the heat release rate and upper layer temperature versus time for an ISO 9705 scale compartment with wood cribs and Medium Density Fiberboard wall linings. Flashover occurs in the cross hatched region of the curve. From an experimental point of view flashover is considered to occur when the upper layer temperature reaches 500-600°C, as seen in Figure 2. The increase in radiation from the upper layer not only ignites all of the combustibles in the room but also enhances the heat release rate of all the burning objects. From a design point of view, flashover should be modeled as a linear transition from a growing fire to a fully developed fire over a very short period of time.

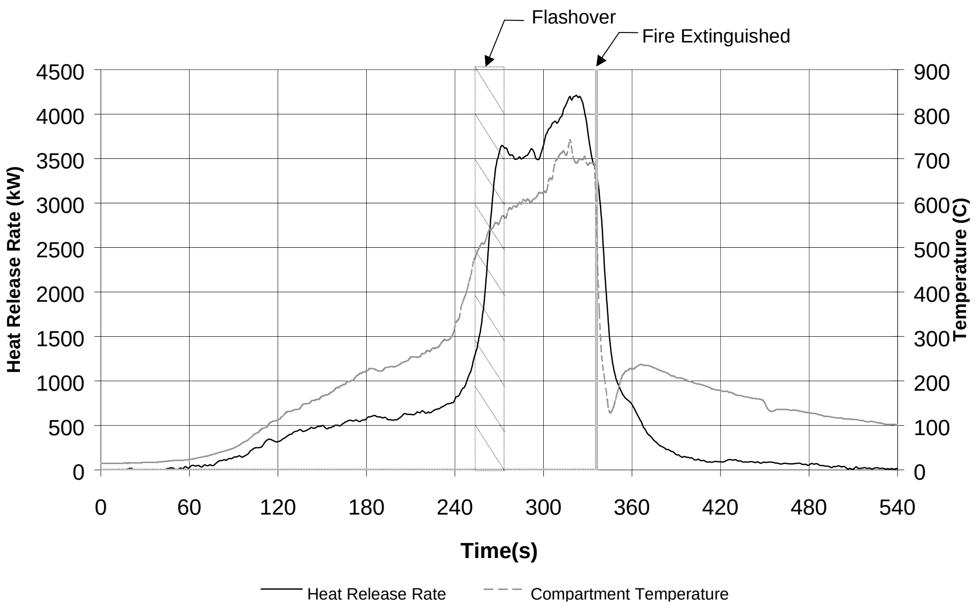

Figure 2 - Heat Release Rate History and upper layer temperature from an ISO sized compartment fire showing the rapid increase in the heat release rate as the upper layer temperature rises above 500 to 600ºC.

In the **Post Flashover/Fully Developed** phase of the fire all of the combustible objects in the compartment are burning and the heat release rate is either limited by the fuel surface area or the available air supply. Typically it is the available air supply that governs the post flashover phase except in the cases of very large openings or low combustible surface areas. The mass of air that flows into an opening can be estimated using the well know A square root H correlation first identified by Kawagoe when reducing post flashover fire data in 1958[11].

$$\dot{m}_{air} = 0.5 A_O \sqrt{H_O} \tag{2}$$

where:

$\dot{m}_{air}$ - mass flow rate of air into the compartment (kg/s)
A_O - area of the opening (m^2)
H_O - height of the opening (m)

The heat release rate within the compartment can then be estimated using the assumption that most fuels release a constant amount of energy per unit mass of air consumed, that is 3.0 MJ/kg_{air}. Thus turning Equation 2 into a heat release rate equation:

$$\dot{q}_{inside} = 1.5 A_O \sqrt{H_O} \tag{3}$$

where:

$\dot{q}_{inside}$ - heat release rate inside the compartment (MW)

It should be reiterated that this is the energy that is released inside the compartment. In many cases the burning objects actually release more fuel than can be consumed within the compartment, i.e. the fire is ventilation limited which can fuel very long flames out of the opening[12].

The **Decay Phase** occurs when the fire has consumed much of the available fuel and the heat release rate starts to diminish. During the Decay phase the fire will typically transition from ventilation controlled to surface area controlled. This is primarily of interest when determining the required fire resistance of structural elements. This phase of the design fire curve is the least studied and least understood. In most cases fire fighting intervention prevents or at least interferes with the fires' decay.

PERFORMANCE CRITERIA

The performance criteria can be as challenging as the design fire scenarios and design fires themselves. The appropriate performance criteria are dependent on the particular fire scenario and the portion of the design being evaluated. For building to building fire spread the performance criteria could be an allowable radiative heat flux or surface temperature on the adjacent building or boundary, for structural performance it could be a prescribed time in a specific standard fire test, for surface finish it could be a performance in a standard flame spread test. Quantifying the performance is much more challenging when predicting the impact of the fire on the occupants. The fires impact on life safety is commonly broken down into four categories; thermal effects, narcotic gas effects, irritant gas effect and visibility. The most comprehensive review on the hazard to occupants from the fire gases is given by Purser in *The SFPE Handook of Fire Protection Engineering*[13]. In this section, Purser gives a compendium of the available literature on the hazards that smoke poses to humans and provides the engineering tools necessary to allow the designer to estimate the hazard that the smoke may have on egressing occupants. The assessment is usually in the form of the Fractional Effective Dose (FED) which is defined as the ratio of the exposure dose to the exposure dose necessary to produce incapacitation. The FED can be defined for asphyxiant toxicants, irritant gases, or radiative and convective heat exposure. For information on calculating the hazard for occupants posed by the smoke and heat the reader is directed to references 13, 14 &15.

Ultimately the performance criteria must be selected for life safety. Although an FED of 1 is considered to be the point at which a person might be expected to be incapacitated, it is considered prudent, for two primary reasons, to use a value less than one for "conservatism". Firstly, the uncertainty in calculations is high because of the limited amount of data available for comparison. The data used to develop the relationships are based on both human and animal research. To further refine the results, additional experiments would be necessary but exposing humans to dangerous toxic species is considered unethical and is not expected to ever be available. The second reason is that the data used was for young healthy adult humans and animals which represent the least vulnerable population. Certain subpopulations such as elderly and the young are expected to be more vulnerable to the effects of fire and must be considered in design. Thus documents such as Published Document 7947-6:2004[16] recommend the use of the FED<0.3 as the acceptance criteria and visibility of 10 m. In cases where the occupants are considered to be a vulnerable subpopulation the FED may be set even lower.

REQUIRED SAFE EGRESS TIME (RSET)

The Required Safe Egress Time (RSET) can be defined as the time from ignition of a fire until the time when the occupants reach a place of safety[16]. The RSET is a function of four time based values:

> **Δt_{det} - detection time:** time from ignition to detection by an automatic system or time for occupants to detect the fire's cues.
>
> **Δt_{alarm} – alarm time**: time from detection to a general alarm.
>
> **Δt_{pre} – pre-movement time**: time from alarm to time when occupants start to egress the building. This time includes two components: time for the occupant to recognize the alarm and time for the occupant to respond to the alarm and start evacuation.

Δt_{travel} **–travel time**: time it takes for the occupants to travel from their location in the building to a safe place. This commonly comprises two parts, the walking time and the flow time. The walking time is based on the speed that the occupants are expected to walk when egressing. The flow time is the time it takes for the occupants to flow through the exit which includes flows through a doorway or down stairs. This can also include the time an occupant is in a queue waiting to evacuate a space.

Premovement Times

For a detailed description on how to determine the values listed above the reader is directed to references 15-17. In an RSET analysis the detection time is calculated using a deterministic model to estimate the time a detection device will activate. Originally this was carried out using the program DETACT which estimated the detection time based on the ceiling jet temperature and velocity and the Response Time Index (RTI) of the detection device. However as our understanding of detection theory has improved so have the models for predicting the detection time. The reader should consult reference 18 for more detail on detection theory. The alarm time and premovement times should be agreed upon as part of the Fire Engineering Brief (FEB) process before calculating the RSET. Proulx has carried out a number of studies quantifying the evacuation times from both trial evacuations and actual fires that are summarized in reference19. Unfortunately researchers in the area of human behavior are reluctant to suggest numbers for the premovement times due to the limited research in this area. However, the PD7974-6:2004[16] does address the premovement times for occupants and gives guidance for estimating the premovement times. The suggested times are based on: occupancy classification, alert status of the occupants (awake or asleep), familiarity with the building, level of management, and type of alarm signal.

Table 1shows the recommended values for the premovement time suggested in PD7974-6:2004. The following descriptions help to explain the codes in the first column of

Table 1:

Management Level
M1- occupants (staff and residents) should be trained to a high level of fire safety management
M2- similar to M1 but lower staff ratio and floor wardens not always present
M3-basic management with minimum fire safety management

Alarm Level
A1-automatic detection throughout the building activating an immediate general alarm to all occupants
A2-automatic detection throughout the building providing a prealarm to management or security with a manually activated general alarm
A3-local automatic detection and alarm only near location of the fire or no automatic detection with manually activated general alarm

Building complexity
B1- simple rectangular single story building with one or few enclosures and simple layout
B2-simple multi-enclosure (usually multi-story) building and simple internal layout
B3-large complex building internal layout and enclosures involve often large and complex spaces such that occupants may have wayfinding difficulties.

Columns 2 and 3 in Table 1 give the time from alarm to the movement of the first few occupants and the distribution times for the populations of occupants to start their evacuation. For additional details regarding the values given in Table 1 the reader should consult PD7974-6:2004[16]. The premovement times shown in Table 1 demonstrate the wide range of values that might be expected in a building. Clearly the biggest influence is the level of management within the building. For example, in Table 1, for office buildings the values range from 0.5 to >15 minutes for first occupants to start moving based on the quality of the management. The alarm type dependence is less significant than management but is a major factor when only a manual alarm is available. For complex building a fixed amount of time is added to the premovement times ranging from 0.2 to 1.0 minutes.

SCENARIO CATEGORY AND MODIFIER	**First occupants** $\Delta t_{pre\ (1st\ percentile)}$ (Minutes)	**Occupant distribution** $\Delta t_{pre\ (99th\ percentile)}$ [a] (Minutes)
A: Awake and Familiar (office or industrial)		
M1 B1 – B2 A1 – A2	0.5	1.0
M2 B1 – B2 A1 – A2	1	2
M3 B1 – B2 A1 – A3	*>15*	*>15*
For B3, add 0.5 for wayfinding		
M1 would normally require voice alarm/PA if unfamiliar visitors likely to be present		
B: Aawake and Unfamiliar (shop, restaurant, circulation space)		
M1 B1 A1 – A2	0.5	2
M2 B1 A1 – A2	1.0	3
M3 B1 A1 – A3	*>15*	*>15*
For B2 (Cinema, theater) add 0.2 for wayfinding. For B3 add 1.0 for wayfinding		
M1 would normally require voice alarm/PA		
Asleep		
Ci: Sleeping and Familiar (e.g. dwellings – individual occupancy)	*5*	*5*
M2 B1 A1	*10*	*>20*
M3 B1 A3		
For other units in block assume one hour		
Cii: Managed Occupancy (e.g. serviced apartments, halls of residence)	*10*	*20*
M1 B2 A1 – A2	*15*	*25*
M2 B2 A1 – A2	*>20*	*>20*
M3 B2 A1 – A3		
Ciii: Sleeping and Unfamiliar (e.g. hotel, boarding house)	*15*	*15*
M1 B2 A1 – A2	*20*	*20*
M2 B2 A1 – A2	*>20*	*>20*
M3 B2 A1 – A3		
For B3 add 1.0 for wayfinding		
M1 would normally require voice alarm/PA		
D: Medical Care.		
Awake and Unfamiliar (e.g. day centre, clinic, surgery, dentist)		
M1 B1 A1 – A2	0.5	2
M2 B1 A1 – A2	1.0	3
M3 B1 A1 – A3	*>15*	*>15*
For B2 add 1.0 for wayfinding. For B3 add 1.0 for wayfinding		
M1 would normally require voice alarm/PA		
Sleeping and Unfamiliar (e.g. hospital ward, nursing home, old peoples' home)		
M1 B2 A1 – A2		
M2 B2 A1 – A2	5 [b]	10 [b]
M3 B2 A1 – A3	10 [b]	20 [b]
For B3 add 1.0 for wayfinding	*>10* [b]	*>20* [b]
M1 would normally require voice alarm/PA		
E: Transportation. Awake and Unfamiliar (e.g. railway, bus station or airport)		
M1 B3 A1 – A2	1.5	4
M2 B3 A1 – A2	2.0	5
M3 B3 A1 – A3	*>15*	*>15*
M1 and M2 would normally require voice alarm/PA		
a. Total pre-movement time = $\Delta t_{pre\ (1st\ percentile)} + \Delta t_{pre\ (99th\ percentile)}$. Figures with greater levels of uncertainty are italicized.		
b. These times depend upon the presence of sufficient staff to assist evacuation of handicapped occupants.		

Table 1 Suggested premovement times from PD7974-6:2004.

A CASE STUDY IN DEFINING THE INPUT FOR ASET VERSUS RSET ANALYSIS

Since August 2006 the New Zealand Department of Building and Housing (DBH) has been developing a new methodology to demonstrate compliance with the Fire Safety requirements of the New Zealand Building Code (NZBC) specifically the C clauses. This work was identified as necessary after a comprehensive review of the existing building code. One of the key outcomes of the review was that the public feels that the existing code provides an acceptable level of safety. The New Zealand Building Code will maintain its performance basis for fire safety but inputs for performance-based designs will be predetermined. This approach still permits flexibility and innovation in design, but ensures consistency between designs for very similar uses. This provides a mechanism for the regulator to exercise control over the level of fire safety that must be achieved in buildings, without having to go through a formal process to calculate expected fire losses on a building-by-building basis. These inputs are analogous to wind, earthquake, snow loads etc given in a loadings code for structural design. At the time of this paper (October 2009) the framework is being field tested with a number of practicing engineers that will conclude in December 2009. The design fire scenarios, design fires, premovement times, and acceptance criteria are briefly discussed below as an example of where this author believes future of PBD should lead.

Design Fire Scenarios

Ten fire scenarios are proposed for the use in the new framework loosely based on those in NFPA 5000[6], with some modification and in one case (fire spread to neighbouring property and fire service operations) has been expanded. Other scenarios for external vertical fire spread and interior surface finishes have also been added to specifically address fire scenarios currently dealt with in the existing prescriptive compliance documents referred to as C/AS1[2]. All ten scenarios are presented here for completeness although only four of the scenarios are applicable for ASET versus RESET analysis.

Table 2 summarizes the design fire scenarios being proposed in the framework. Column 1 gives the scenario number for ease of identification, Column 2 gives a description of the scenario, Column 3 describes the performance objectives for each scenario, Column 4 defines the design event that must be used in the analysis, and Column 5 describes the methodology expected to demonstrate that the scenario has been addressed. Details about the design fires and performance criteria are described in the following sections.

#	*Description*	*Performance Objective*	*Design Event*	*Expected Methodology*
1	These fires are intended to represent a credible worse case scenario that will challenge the fire protection features of the building.	Provide a tenable environment for occupants in the event of fire while they egress to a safe place.	Design fires are characterized with t-squared rate of heat release, peak rate of heat release, and fire load energy density (FLED). Design values for yields are specified for CO, CO2 and soot/smoke. The design fires are intended to represent 'free-burning' fires but they may be modified during an analysis to account for building ventilation and fire suppression effects on the fire.	Calculations of the fire environment in the escape routes that will be evaluated using the tenability criteria.
2	Fire is located near the primary escape route or exit that prevents occupants from leaving the building by that route. Fire originating within an exitway may be the result of a deliberately lit fire or be accidental. Fire originating within an escape route in the open path will be considered to be a severe fire applicable to the particular building use as described in Scenario 1.	Provide a viable escape route from the building for occupants in the event of fire, i.e. provide at least 2 exits of equal size	Fire blocking exit in open or safe path. Fire characteristics don't matter since fire is assumed to physically block the exit.	Provide alternative escape routes that are tenable or design single escape routes so that no more than 50 people are served (for open paths) or 150 people (vertical safe paths). Analysis not required. This scenario applies to individual rooms in the open path, and to corridors and stairs that are part of an exitway. Escape routes serving less than 50 persons will be permitted to have a single exit.
3	A fire starting in an unoccupied space may grow to a significant size undetected and spread to other areas where the greatest number of occupants.	Maintain tenable conditions on escape routes until the occupants have evacuated. Protect against fire spread that could compromise the retreat of fire-fighters.	Use fire characteristics from scenario 1 for the applicable occupancy.	Include fire separations or fire suppression to confine the fire to room of origin Include automatic detection to provide early warning of the fire in the unoccupied space Carry out tenability analysis of escape routes if fire is able to spread into the occupied space
4	A fire that starts in a concealed space could develop undetected and spread to endanger a large number of occupants in another room.	Maintain tenable conditions on escape routes until the occupants have evacuated. Protect against fire spread that could compromise the retreat of firefighters.	Currently unable to identify a suitable quantitative description of the design event, and would expect that traditional solutions would apply – i.e containment, detection or suppression.	Fire separations or suppression to confine fire to concealed space Automatic detection to provide early warning Tenability analysis with fire spreading into the occupied space

#	*Description*	*Performance Objective*	*Design Event*	*Expected Methodology*
5	A slow smouldering fire that causes a threat to sleeping occupants.	Maintain tenable conditions on escape routes until the occupants have evacuated.	Refer to fire characteristics for a smouldering fire.	Provide automatic smoke detection in sleeping rooms and no further analysis is required.
6	A large fire within a building may spread to neighbouring buildings as a result of heat transfer (predominantly by radiation through openings in external walls). To reduce the probability of fire spread between neighbouring properties, measures to limit the radiation flux received by the neighbouring building are required.	1. External walls shall be designed to limit the radiation received on the neighbouring property to: a. no more than 30 kW/m² on the relevant boundary; and b. no more than 16 kW/m² at 1m beyond the relevant boundary. 2. External walls of buildings, if located 1m or closer to a relevant boundary, and when subjected to a radiant flux of 30 kW/m² shall: • not ignite in 30 min. (PG III, IV) • not ignite in 15 min. (PG I, II)	Emitted Radiation flux from unprotected areas in external walls (assuming no intervention) shall be taken as: 88 kW/m² for FHC = 1 108 kW/m² for FHC = 2 152 kW/m² for FHC = 3 or 4	• C/AS1 tabulated data for boundary distances are acceptable, • Unprotected areas can be calculated using the given emitted and received radiation levels, boundaries distances and configuration factors. • Fire tests of external cladding systems using the cone calorimeter apparatus (ISO 5660) or similar are needed to demonstrate that performance measure 2 above is met.
7	A fire source adjacent to an external wall such as a fire plume emerging from a window opening, or a fire source in close contact with the façade that could ignite and spread fire vertically. There are two parts to this scenario: 1. External vertical fire spread via the façade materials 2. Window fire plumes spreading fire vertically through higher openings	• Prevent fire spread to other property and spaces where people sleep (in the same building) and maintain tenable conditions on escape routes until the occupants have evacuated. • Protect against external vertical fire spread that could compromise the safety of fire-fighters working in or around the building.	For 7A • Radiant flux of 50 kW/m² impinging on the façade for 15 minutes (for PG II and PG III) • Radiant flux of 90 kW/m² impinging on the façade for 15 minutes (for PGIV) For 7B • Window plume projecting from opening in external wall, with characteristics determined from design fire for Scenario 1.	1. Follow existing C/AS1 and use: a. Large or medium-scale ‘façade type’ fire tests (eg NFPA 285, ISO 13785, VCT) b. Small-scale testing using ISO 5660 or AS/NZS 3837 (cone calorimeter) for homogeneous materials. 2. Use non-combustible materials. 3. Validated flame spread models could be used for some materials. 4. Construction features such as ‘aprons’ and/or ‘spandrels’ or ‘sprinklers’ could be used to meet performance measure 3 above. Window plume characteristics/geometry may be derived from Scenario 1 design fires.
8	A flaming fire source located in a wall-corner junction that ignites room surface lining materials and which then subsequently leads to untenable conditions on an escape route.	• Tenable conditions on escape routes shall be maintained while occupants evacuate. • Protect against rapid fire spread that could compromise the retreat of firefighters.	Fire source of output 100 kW in contact with a wall-corner element for 10 minutes followed by 300 kW for 10 minutes in accordance with ISO 9705.	1. ISO 9705 room corner fire 2. ISO 5660 cone calorimeter test at 50 kW/m² (e.g. correlated to a full-scale result) 3. Use non-combustible materials to AS 1530.1. 4. Use calculations from validated flame spread models (if available for the material and configuration of interest)

#	*Description*	*Performance Objective*	*Design Event*	*Expected Methodology*
9	Mitigation of risk on the fireground on the part of the officer requires the ability to predict both fire and building behaviour. What compromises this ability is the occurrence of events that are sudden, unexpected or disproportionate to the change that caused them. It is the broad predictability of the building behaviour and the fire environment that is encapsulated in the concept of 'reasonable expectations' of firefighters to be safe.	In order that the officer in charge may make a risk-informed judgement about how to tackle firefighting and rescue operations • Information must be available to the crew on arrival to enable them to rapidly size-up the situation • Access to all floors of the building must provide firefighter protection i. firefighting water must be available in the vicinity of the fire	Firefighter tenability must be established for large (>1500m^2) FHC 4 buildings, where fire growth rate is very rapid, or for unsprinklered building layouts where the distance from the safe path access to any point on a floor exceeds 75m. The firefighting design fire is 50MW, unless the fire is sprinkler, ventilation or fuel limited at some lower value by the time the fire service arrives.	**1. Features that facilitate rapid size-up of the situation** • Hazardous substance signage • Fire detection system • Panel location and information • Firefighter control of building fire safety systems • Limitation of fire size by sprinklers or firecell size **2. Features that facilitate safe access for rescue and firefighting** • Firefighter access around building • Sprinklers in buildings higher than fire service ladder appliances • Access through tall buildings • Protected from structural collapse 3. **Features that facilitate adequate firefighting water** • External hydrants plus fire appliance access to building • Internal risers, hydrants and hosereels • Sprinklers
10	The robustness of the design will be tested by considering the design fire with each key fire safety system rendered ineffective in turn.	Provide a tenable environment for occupants in the event of fire while they escape to a safe place.	Design event is the same as scenario 1 above.	Calculations of the fire environment in the escape routes that will be evaluated with one of the key fire safety systems rendered ineffective. Only the FED narcotic criterion is to be met.

Table 2 – Design Fire Scenarios for the Conceptual Framework being field tested in New Zealand.

Design Fires

Quantifying the design fire is one of the most challenging requirements for PBD. Resolving the issue of defining the design fire has resulted in some reflection on the existing compliance documents which have been considered to provide a societal accepted level of safety. Indeed if the design fires required for use in PBD are significantly more severe than the inherent fires within the compliance documents[2], than there is a disincentive for PBD that would suppress innovation in building design. Thus choosing an appropriately rigorous design fire to provide an acceptable level of safety without being too onerous to stifle PBD required a great deal of effort. Ultimately the following design fire was chosen (the few exceptional cases are discussed below):

- For all buildings except for the buildings explicitly discussed below, the fire is assumed to grow as a fast t^2 fire up to flashover and is then limited by the available ventilation assuming all windows are broken out.
- For sprinklered buildings the fire is assumed to be controlled, i.e. constant heat release rate, after the sprinkler activates based on RTI and activation temperature.
- Species yield for soot (Y_{soot}) is equal to 0.07 kg/kg_{fuel}.
- Species yield for carbon monoxide (Y_{CO}) is equal to 0.04 kg/kg_{fuel}.
- Net Heat of Combustion (ΔH_C) 20 MJ/kg
- Radiative fraction from fire 0.35

Exceptions to the fast t^2 fire

Building use	Fire Growth rate ($\dot{q}$)	Species
Carparks	$0.0117t^2$	Y_{soot}=0.07 Y_{CO}=0.04 ΔH_C= 20 MJ/kg
Rack Storage Group 1(Polystyrene chip in single wall cardboard cartons)	$0.0088t^3$ H	Y_{soot}=0.07 Y_{CO}=0.04 ΔH_C= 20 MJ/kg
Rack Storage Group 2 (FMRC Standard Plastic commodity, upholstery cushions)	$0.0025\ t^3$ H	Y_{soot}=0.07 Y_{CO}=0.04 ΔH_C= 17 MJ/kg
Rack Storage Group 3 (FMRC Class II Double triwall cardboard cartons)	$0.00068t^3$ H	Y_{soot}=0.07 Y_{CO}=0.04 ΔH_C= 15 MJ/kg

Performance Criteria

The performance criteria have been taken primarily from PD7974-6:2004[16]. These values are consistent with the values found in the literature. Two exceptions are applied to the criteria, first is the relaxed values allowed for sprinklered buildings. In New Zealand sprinkler systems have a rigorous inspection and maintenance regime that helps to ensure that the system will function as designed when required. In addition the current level of modeling does not adequately take into account the positive effect sprinklers can have so the relaxation of the performance criteria is necessary to promote the use of sprinklers. The second relaxation is that the performance criteria are not assessed within the household unit of origin.

Two performance criteria are suggested; the simple criteria are used when the smoke layer is not expected to impact the egressing occupants and greatly simplifies the analysis. The second more detailed criteria are used whenever the occupants are expected to have to egress through the smoke.

Occupant life safety - simple criteria

The simple criteria are used when the smoke layer is not allowed to reach the occupants.

1. minimum clear smoke layer height of 2.5 m
2. maximum upper layer temperature of 200ºC

Obviously, this method will not be suitable for spaces with low ceilings or where a distinct layer interface cannot be determined.

Occupant life safety - detailed criteria

The detailed criteria are applied when the occupants are assumed to be egressing through the smoke. Three criteria, all must be achieved. Calculations should be in accordance with ISO/TS 13571[20]. FEDs and visibility may be determined at a height of **2.0 m** above floor level using upper/lower layer properties as applicable, or else can be based on upper layer properties alone.

1. Fractional Effective Dose (FED) for narcotic (toxic) gases. This accounts for the cumulative effects of CO, O2 depletion and CO2 effects on respiration rate.
   FED ≤ 0.3 (suitable for most general occupancies)
2. Fractional Effective Dose (FED) for radiant and convective heat. This accounts for cumulative exposure to skin to radiant heat (2nd degree burns) and to convective heat from air.
   FED ≤ 0.3 (suitable for most general occupancies)
3. Visibility
   Visibility not less than 5 m, for rooms/spaces ≤ 100 m²
   Visibility not less than 10 m, for rooms/spaces > 100 m²
4. Sprinklered buildings (System must be installed according to NZS4541[21] or NZS4515[22])
   Visibility criteria does not apply
   FED thermal does not apply
   FED Narcotic < 0.3
5. Within household unit of fire origin analysis tenability criteria is not assessed.

Premovement Times

In New Zealand, there exist the evacuation regulations which require most commercial buildings open to the public to have an approved evacuation scheme. As a result there is a widespread culture of evacuating a building when the fire alarm sounds. Therefore shorter times then are typically found in the literature have been suggested:

Description of building use	Premovement Time (s)
Buildings where the occupants are considered awake alert and familiar with the building. Such as offices, warehouse not open to the public, etc	
Fire Cell of Origin	30
Remote from the Fire Cell of Origin	60
Buildings where the occupants are considered awake, alert and unfamiliar with the building. Such as retail shops, exhibition space, restaurants,	
Fire Cell of Origin (Standard Alarm Signal)	60
Remote from the Fire Cell of Origin (Standard Alarm Signal)	120
Fire Cell of Origin (Voice Alarm Signal)	30
Remote from the Fire Cell of Origin (Voice Alarm Signal)	60
Buildings where the occupants are considered sleeping and familiar with the building. Such as Sleeping Residential	
Fire Cell of Origin (Standard Alarm Signal)	60
Remote from the Fire Cell of Origin (Standard Alarm Signal)	300

Buildings where the occupants are considered sleeping and unfamiliar with the building. Such as Sleeping Accommodation	
Fire Cell of Origin	60
Remote from the Fire Cell of Origin (Standard Alarm Signal)	600
Remote from the Fire Cell of Origin (Voice Alarm Signal)	300
Buildings where the occupants are considered awake and under the care of trained staff and unfamiliar with the building. Such as day care, dental office, clinic	
Fire Cell of Origin (independent of alarm signal)	60
Remote from the Fire Cell of Origin (independent of alarm signal)	120
Buildings where the occupants are considered to be asleep, under the care of trained staff. Such as hospitals and rest homes. (PG3 & PG4)	
Room of Origin (independent of alarm signal)	180
Fire Cell of Origin	300
Remote from the Fire Cell of Origin (independent of alarm signal)	1800
Spaces which have only focused activities such cinemas, theatres, stadiums, etc	
Evacuation starts when fire reaches 500 kW or 60s after detection which ever is first.	0

Table 3 - Premovement times for proposed in the New Zealand Performance Based Design Framework

SUMMARY

Performance based design can provide for cost effective and innovative solutions to fire safety challenges. However, allowing the designer to specify the design fire scenarios, design fires, premovement times, and acceptance criteria can result in inconsistent levels of safety in building designs and can make it difficult for the AHJ. Unfortunately the literature is primarily focused on qualitative guidance and is reluctant to give quantitative guidance for use in PBD. Thus it is up to the regulating authority to specify the input values and acceptance criteria for PBD.   The specified input should include the design fire scenarios, design fires, premovement times, and acceptance criteria which address society's tolerable risk to life safety from fire.

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