IMPORTANT DESIGN FACTORS FOR REGULATING PERFORMANCE-BASED FIRE SAFETY ENGINEERING DESIGN OF BUILDINGS IN AUSTRALIA

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ABSTRACT

The practice of performance-based fire safety engineering design (PBFSED) has been active in Australia over the last ten years. PBFSED activities have also existed in the UK, Japan and New Zealand and are starting to increase in other countries such as the United States, Canada, Singapore and Hong Kong/China. Despite the growth and expansion, there is still a relatively strong reticence expressed against PBFSED solutions, particularly from regulatory personnel where they have the responsibility of appraising the designs. In the current practice of PBFSED, significant variations in the final solution can occur even for similar buildings. This can lead to an unacceptable increase in the number of unsafe outcomes for buildings designed using a PBFSED approach. The variation in the design outcomes has previously been identified to be largely attributed to a lack of consistency in the determination of the input design parameters, methodologies and assumptions in the design processes, compared to other established engineering disciplines such as structural design. Although this is not a newly recognised issue, there has been little improvement accomplished in this area to date. Meanwhile, fire safety engineers continue to make their own judgement of what they believe constitute the best design parameters for assessing fire safety, and buildings continue to be designed in very much an ad-hoc approach in terms of achieving an adequate level of safety in the design. This paper looks at the practice of PBFSED in Australia, and identifies the important design parameters that can be used to form a preliminary framework for regulating performance-based fire safety engineering design of buildings in Australia. Whilst the experience in based in Australia, it is believed that the applicability is not limited to Australia.

KEYWORDS: Consistency, Design, Fire engineering, Framework

INTRODUCTION

The practice of performance-based fire safety engineering design (PBFSED) for developing alternative building solutions to comply with the *Performance Requirements* of the building code has been active in Australia for the last ten years. PBFSED activities have also existed in the UK, Japan and New Zealand and are starting to increase in other countries such as the United States, Canada, Singapore and Hong Kong/China, where codes have recently been introduced or are in the process of being reformed to incorporate PBFSED.

Despite the growth and expansion in this practice and the developing interest in this relatively new engineering discipline, there is still a relatively high level of reticence expressed towards the practice of PBFSED, particularly amongst regulatory or certifying authorities who have the responsibility of appraising these designs. This view has largely grown out of the lack of a proper means of appraising a PBFSED proposal. Unlike more conventional disciplines, there are no formal checks and balances against which to assess the validity of the PBFSED. It may be possible that the adequacy of the design is almost entirely reliant upon the judgement and capacity of the engineer.

Variations in the PBFSED solutions have previously been identified to be largely attributed to the lack of consistency in the determination of the input design parameters, methodologies and assumptions in the design processes[3], compared to other established engineering disciplines, such as, structural design. As a result, significant deviations in the final design solutions can occur even for similar buildings, and this may lead to an unacceptable increase in the number of potentially unsafe outcomes for buildings designed using a PBFSED approach.

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Concerns have also been raised as to the adequacy in the development of fire safety engineering as a discipline. Is our current knowledge in and approach to fire safety engineering and building design sufficient to undertake a fire engineering assessment and recommend a building solution that would be considered to meet the objectives of the building code, which is intended to represent community expectations? Are the alternative building solutions sufficiently robust and not less safe than the prescriptive provisions? Are we producing less costly design solutions at the expense of safety due to our inability to assess them accurately?

In Australia, the regulatory process for building approval is to demonstrate compliance with the *Performance Requirements* of the Building Code of Australia[1] (BCA). The conventional approach of gaining building approval is to comply with the prescriptive-based *Deemed-to-Satisfy* (*DtS*) *Provisions* of the BCA. Alternatively, compliance can also be achieved by a performance based route using PBFSED in the determination of an *Alternative* (Building) *Solution* that satisfies the *Performance Requirements* of the BCA. It is an alternative to the *DtS Provisions* of the BCA, and is usually undertaken to incorporate design options that are not permissible or impractical to implement under the *DtS Provisions*.

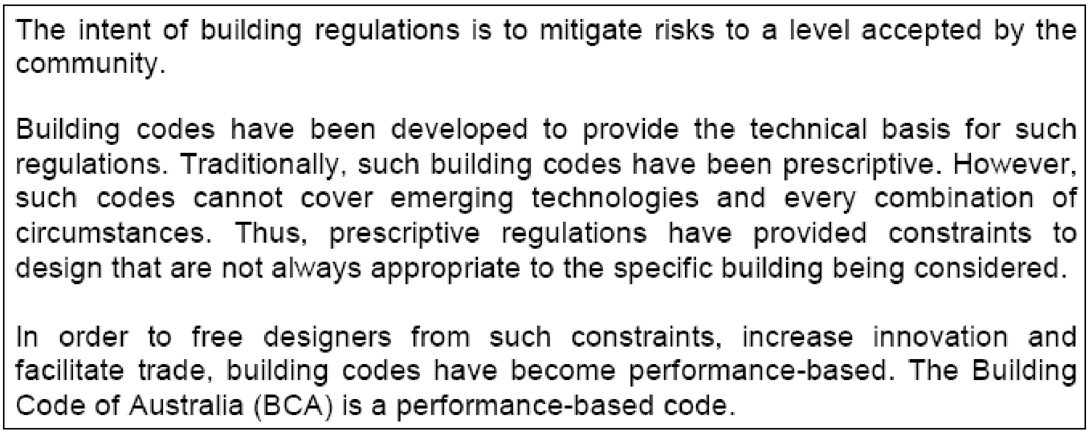
This paper discusses the qualitative nature of the *Performance Requirements* of the BCA and the design approach that the PBFSED profession has converged towards in terms of demonstrating compliance with the relevant *Performance Requirements*. A design framework is recommended which outlines a range of important design parameters that requires regulatory guidance as part of the design processes towards achieving design consistency towards achieving the minimum acceptable levels of safety.

THE PERFORMANCE BASED DESIGN PROCESS

The fire engineering design process in Australia is built around the performance based clauses of the BCA that was initially introduced into the code in the 1996 edition. In order to understand the limitations of the design processes in a performance based format, the structure of the performance clauses of the BCA that enables fire engineering solutions is firstly described.

Structure of the Performance Based BCA

The move to a performance format in the context of PBFSED is succinctly portrayed in the Fire Engineering Guidelines[2] as follows (Fig. 1):



The intent of building regulations is to mitigate risks to a level accepted by the community.

Building codes have been developed to provide the technical basis for such regulations. Traditionally, such building codes have been prescriptive. However, such codes cannot cover emerging technologies and every combination of circumstances. Thus, prescriptive regulations have provided constraints to design that are not always appropriate to the specific building being considered.

In order to free designers from such constraints, increase innovation and facilitate trade, building codes have become performance-based. The Building Code of Australia (BCA) is a performance-based code.

FIGURE 1. Extract from the Fire Engineering Guidelines[2]

The performance based design concept has generally been well accepted because it provides an engineering based alternative in lieu of prescriptive solutions as explained in the above extract.

However, the performance based alternative is a significant departure from the traditional *DtS Provisions*, both in terms of means of appraisal and the lack of prescriptive requirements. The *DtS Provisions* and the *Performance Requirement* clauses are virtually at opposite ends of the spectrum in terms of design clarity. These points are discussed below:

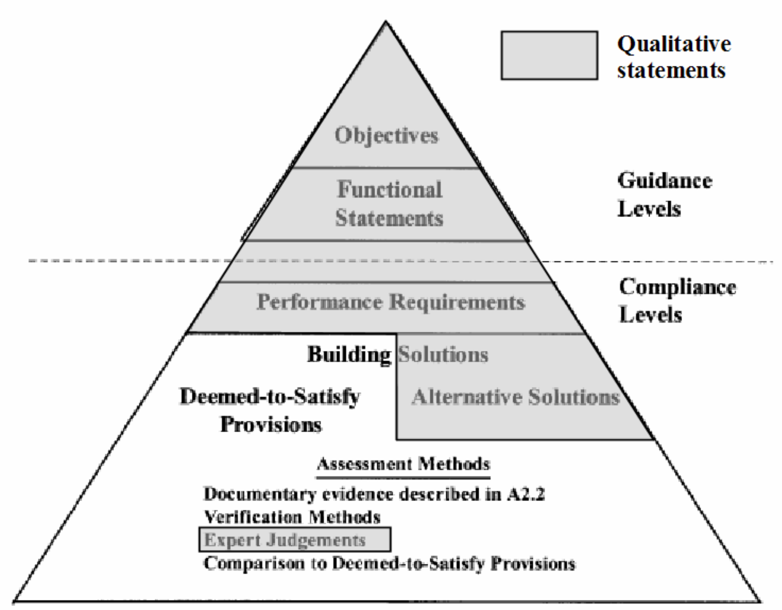


FIGURE 2. BCA Structure[1]

Fig. 2 shows the hierarchical structure of the BCA in four parts:

Objectives – Set out what the community expects of a building.

Functional Statements – Describe how it is proposed that the building will be designed and constructed to meet those community expectations.

Performance Requirements – Requirements which state the level of performance which a *Building Solution* must meet.

Building Solutions – Solutions which comply with the *Performance Requirements*

The structure in Fig. 2 clearly illustrates the demarcation between Guidance Levels and Compliance Levels. According to the BCA, the *Objectives* and *Functional Statements* are only informative aids included to assist in interpreting the content and intent of the *Performance Requirements* and the *Deemed-to-Satisfy Provisions*. The *Objectives*, *Functional Statements* and *Performance Requirements* are essentially qualitative statements.

At the Compliance Level, the top of the hierarchy is the *Performance Requirements*. These requirements have been developed to meet both the BCA *Objectives* and *Functional Statements*. The *Performance Requirements* are the only BCA hierarchy levels where compliance is compulsory under building control legislation. The *Deemed-to-Satisfy Provisions* are prescriptive requirements, and prior to the code becoming performance-based, complying with the *Performance Requirements* is an entirely objective process.

The mechanism to comply with the BCA through a performance based route is shown in Table 1, illustrating the corresponding clauses involved in determining a compliant *Building Solution*. The PBFSED equivalent of a *Building Solution* is referred to as the *Alternative Solution.*

TABLE 1. The BCA Compliance mechanism via a performance-based approach

Clause	**Requirements**
A0.4 Compliance with the BCA	*Building Solution* will comply with the BCA if it satisfies the *Performance Requirements*.
A0.5 Meeting the *Performance Requirements*	Compliance with the *Performance Requirements* can only be achieved by— (a) complying with the *Deemed-to-Satisfy Provisions*; or (b) formulating an *Alternative Solution* which— (i) complies with the *Performance Requirements*; or (ii) is shown to be at least equivalent to the *Deemed-to-Satisfy Provisions*; or (c) a combination of (a) and (b).
A0.8 *Alternative Solutions*	(a) An *Alternative Solution* must be assessed according to one or more of the *Assessment Methods*. (b) An *Alternative Solution* will only comply with the BCA if the *Assessment Methods* used to determine compliance with the *Performance Requirements* have been satisfied. (c) The *Performance Requirements* relevant to an *Alternative Solution* must be determined in accordance with A0.10.
A0.9 Assessment Methods	The following *Assessment Methods*, or any combination of them, can be used to determine that a *Building Solution* complies with the *Performance Requirements*: (a) Evidence to support that the use of a material, form of construction or design meets a *Performance Requirement* or a *Deemed-to-Satisfy Provision* as described in A2.2. (b) *Verification Methods* such as— (i) the *Verification Methods* in the BCA; or (ii) such other *Verification Methods* as the appropriate authority accepts for determining compliance with the *Performance Requirements.* (c) Comparison with the *Deemed-to-Satisfy Provisions*. (d) *Expert Judgement*

The compliance processes are illustrated in the flow diagram shown in Fig. 3. The main performance route, which is highlighted in grey, relies primarily on the use of *Expert Judgement*. The BCA defines *Expert Judgement* as follows:

Expert Judgement means the judgement of an expert who has the qualifications and experience to determine whether a *Building Solution* complies with the *Performance Requirements*.

The BCA requires that in cases where an *Alternative Solution* has been proposed, the documentation that needs to be retained includes

details of any *Expert Judgement* relied upon including the extent to which the judgement was relied upon and the qualifications and experience of the expert;

Hence the validity of the *Expert Judgement* is reliant on the 'qualifications and experience of the expert'. Accordingly, the design assumptions are also reliant on the level of qualifications and experience of the expert. Fire safety engineers will therefore be left to put together a solution in whatever way their experiences have taught them. What you end up with is a diverse range of inputs, assumptions and a collection of different styles, approaches and solutions which lack consistency. These are difficult to assess, compare and review but more critically, the resulting solutions will have a varied level of safety.

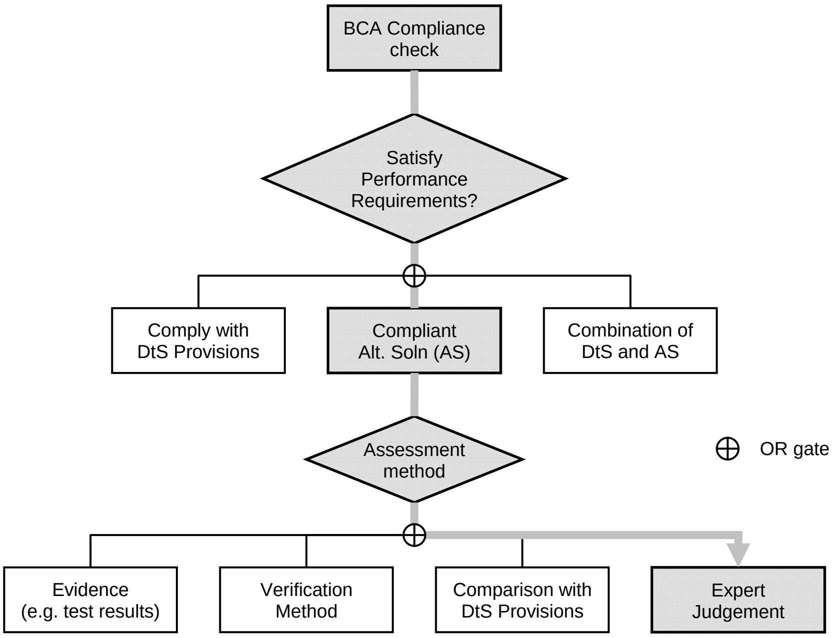
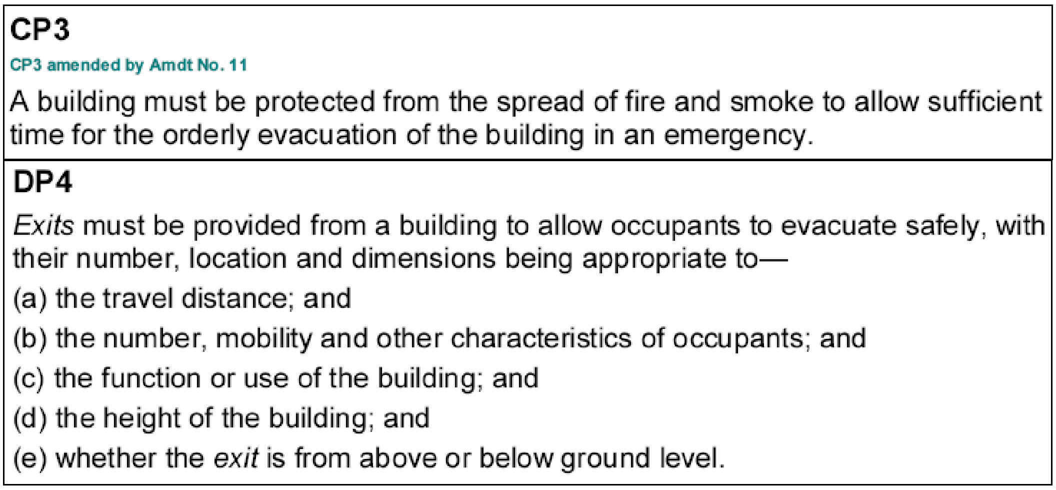


FIGURE 3. BCA Compliance Process – highlighting primary 'performance-based' route[1]

There is a significant qualitative component in the *Expert Judgement* route but it represents the most relied upon means of assessment to demonstrate compliance with the *Performance Requirements*. The other three means of assessment have clearly defined pass/fail criteria. Hence, in the incorporation of a performance-based format, the most significant departure in the BCA is the move away from a prescriptive form of compliance, towards a qualitative measure of demonstrating compliance. The lack of prescriptive means of enforcing design consistency on major aspects of the fire engineering design has lead to significantly varied solution outcomes.

The Performance Requirements

The BCA defines *Performance Requirement* as a requirement which states the level of performance which a *Building Solution* must meet. These requirements are provided in reasonable detail to describe the intent of the code, but they are still largely qualitative expressions. Typical clauses are illustrated below:



CP3

CP3 amended by Amdt No. 11

A building must be protected from the spread of fire and smoke to allow sufficient time for the orderly evacuation of the building in an emergency.

DP4

Exits must be provided from a building to allow occupants to evacuate safely, with their number, location and dimensions being appropriate to—

(a) the travel distance; and

(b) the number, mobility and other characteristics of occupants; and

(c) the function or use of the building; and

(d) the height of the building; and

(e) whether the *exit* is from above or below ground level.

FIGURE 4. Performance requirement clauses in the BCA

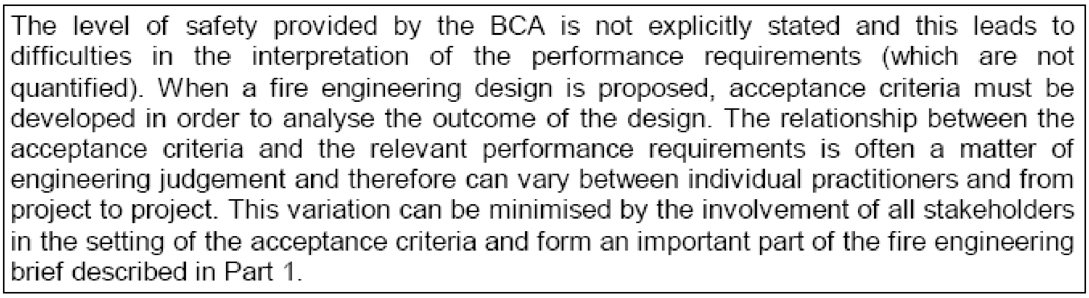
As described previously, the *Performance Requirements* have been developed to meet both the BCA *Objectives* and *Functional Statements*. It is noted in the BCA that the *Objectives* and *Functional Statements* are intended to be used as an aid to the interpretation of the BCA and not for determining compliance with the BCA. The *DtS Provisions* are considered to comply with the *Performance Requirements* and hence meet the *Objectives* and *Functional Statements.* However, this consideration is based entirely on the historical legacy in the manner with which the requirements of the BCA has evolved over time. The DtS Provisions are not directly amenable to calculations and hence the extent to which the *Objectives* and *Functional Statements* have been met has never been adequately quantified. In the case of an *Alternative Solution,* the reliance on *Expert Judgement* in demonstrating compliance with the *Performance Requirements* is even more difficult to ascertain without a clearly defined acceptable benchmark comparison.

The results of an engineering analysis are nearly always a quantifiable outcome – e.g. gas temperature and visibility output. Engineering analysis is therefore directly amenable to a quantitative assessment. To assess the performance of a proposed solution for compliance therefore simply requires a quantitative comparison against minimum accepted criteria levels. As with other building codes and standards, these are not provided in the BCA. A disjoint therefore occurs in the performance compliance assessment process, i.e. how are *Alternative Solutions* shown to comply with the *Performance Requirements*?

The Alternative Solution

The design approach and methodologies for undertaking a fire engineering analysis is documented in the International Fire Engineering Guidelines[2] (IFEG). The IFEG recognises that fire engineering lacks the necessary array of validated tools and data necessary to produce a mandatory document or code. It relies upon the extensive use of *engineering judgement* to analyze the output of fire engineering evaluations and to demonstrate an understanding of the fire engineering process and what constitutes an acceptable fire engineering evaluation. The IFEG process also relies upon the establishment of acceptance criteria by the engineer, again involving *engineering judgement*, against which to assess the outcome of the design. In other words, *engineering judgement* is almost entirely relied upon in the IFEG to assess compliance against the *Performance Requirements.*

Of interest is the acknowledgement in the IFEG that design outcomes are subject to variation depending upon the acceptance criteria and the interpretation of the *Performance Requirements*, as shown in Fig. 5. The IFEG relies on the minimisation of this variation by the involvement of stakeholders in the determination of the acceptance criteria. Is this an adequate reliance?



The level of safety provided by the BCA is not explicitly stated and this leads to difficulties in the interpretation of the performance requirements (which are not quantified). When a fire engineering design is proposed, acceptance criteria must be developed in order to analyse the outcome of the design. The relationship between the acceptance criteria and the relevant performance requirements is often a matter of engineering judgement and therefore can vary between individual practitioners and from project to project. This variation can be minimised by the involvement of all stakeholders in the setting of the acceptance criteria and form an important part of the fire engineering brief described in Part 1.

FIGURE 5. Excerpt from the International Fire Engineering Guidelines[2] (IFEG)

The assessment against an agreed set of acceptance criteria is often used in fire engineering solutions for assessing the performance of *Alternative Solutions.* The acceptance criteria are largely defined in terms of the tenability criteria limits to occupants who may be potentially exposed to the effects of fire. In simple terms, if the occupants can be shown to escape the effects of fire with an acceptable margin, the solution is considered to have met the relevant *Performance Requirements*. Since the tenability limits of occupants do not vary greatly, the range of acceptance criteria is relatively consistent.

A minimal set of acceptance criteria for tenability limits may be
- Smoke temperature above 2.1m < 185°C (2.5kW/m² radiation limit)
- Smoke temperature below 2.1m < 60°C
- Visibility in smoke below 2.1m > 10m

These cover the requirements for safety against the exposure and ability to safely negotiate the egress path to a place of safety. Hence, the proposed limits in the acceptance criteria can generally be considered to results in limits that are relatively consistent.

The fire engineering analytical process typically involves assessing the fire development, smoke spread and occupant evacuation and the outcome is assessed by incorporating an ASET/RSET timeline comparison based on the tenability limits specified in the acceptance criteria. The ASET/RSET acronyms are defined as follows:

ASET = Available Safe Egress Time (time to untenable conditions)
RSET = Required Safe Egress Time (time to evacuate building)

The ASET is determined from the time the effects of fire reach the tenability limits prescribed in the acceptance criteria. The RSET is determined from an analysis of the time taken by occupants to evacuate the building due to the effect of fire. Hence, the assessment of the acceptance criteria is ultimately made on a *relative* basis that occupants can safely evacuate from a building before being becoming exposed to untenable conditions from the effects of fire, ie ASET > RSET. This has been generally considered to indirectly achieve the relevant *Performance Requirements* and therefore the corresponding *Objectives* and *Functional Statements*. The only mandate imposed by the BCA is that the assessment has allowed for the appropriate factors in the relevant Performance Clauses (refer Fig. 4).

Hence the *Alternative Solution* appears to provide an assessment against quantifiable limits that are relatively consistent. However, it does not mean that the design itself results in safety levels that are correspondingly consistent. This is discussed further below.

The Fire-Engineering Analysis

Up to this point, there is generally a consensus on the fire engineering approach towards assessing a design against compliance with the *Performance Requirements* of the code. The issues with the fire engineering process, however, are related to the determination of the ASET and RSET, and the inconsistent (and sometimes lacking) use of safety margin associated with it. The key dependents that may have a significant influence in the determination of these values are listed as shown in Table 2.

TABLE 2. Key dependent variables for ASET/RSET

Parameter	**Dependent variables**
ASET	*Design fire* Fire model Fire suppression mechanisms Smoke control systems Building geometry
RSET	Detection time *Occupant behaviour* Movement time Wayfinding

Note: The most variable or important parameters are shown in italics

Previous assessments of the above design variables have indicated that the determination of the design fire is the key variable for the determination of ASET and occupant behaviour or pre-movement time specifically, for the determination of RSET[3,4,5]. Finally, the consideration of an appropriate safety margin expressed either as a percentage or a factor should be incorporated to account for uncertainties and assumptions in the design, and perhaps to reflect the level of risk associated with the project – e.g. should taller buildings have a higher factor of safety? These are considered to be the three most critical aspects of fire engineering analysis that have a significant influence on the consistency in safety levels in a performance-based solution determined to meet the relevant *Performance Requirements*.

The Design Appraisal

The fire engineering review process in Australia for building approvals is currently determined by the Relevant Building Surveyor, as to whether the proposed design requires an independent review. This is of a similar process to the SFPE Guidelines[6] which states that the peer review process is initiated by the stakeholder.

The Singapore Civil Defence Force is currently the only regulatory authority that mandates an independent peer review process as part of a fire engineering design approval process. Considering the current lack of quantitative design details in the current suite of fire engineering codes and guidelines, it would be sensible that a form of review process be set in place to provide some level of assurance that the design approach provides a demonstrable measure of complying with the objectives of the code. A means of design review is practiced in other established engineering discipline, such as structural design. If the determination of the dominant variables discussed previously is more consistently defined, the requirement for an independent review is likely to be less onerous. All designs may benefit even from a minimal review, as a measure of quality control. However, there are associated issues for a truly independent review.

A more rigorous approach is to develop a technical standard that incorporates the above issues discussed in delivering consistency in design but still allows innovation and design flexibility in the design process. The need for such a standard is considered essential to achieving design consistency in the PBFSED practice. A preliminary framework for such a purpose is proposed based on the three most important factors affecting design consistency discussed previously.

PRELIMINARY FIRE ENGINEERING FRAMEWORK

The following are major if not critical aspects of fire engineering design that are currently being utilised in fire engineering practice but lack proper guidance for a quantitative evaluation. They are aspects which have been raised and discussed and noted as important considerations in various forums and publications but there are presently no technical standards available to date that mandate some form of minimum requirements for its use in design. The following sections provide a brief overview of these aspects in relation to typical fire engineering design practice (but excludes more comprehensive evaluation approaches such as risk assessment) and provide quantitative recommendations as a starting point for establishing minimum requirements. Although it is recognised that each of these design aspects require a more thorough study to achieve conclusive recommendations, they are provided on the simple premise that crude practical recommendations are better than none being available.

TABLE 3. Important design aspects requiring quantitative recommendations

Design aspect	Issue	Potential solution
Design fires	Wide range of approaches and assumptions made to determine design fires.	Provide specifications for design fire in a technical standard
Pre-movement time	Pre-movement times can vary significantly, generally lack consistency with different building occupancies	Provide specifications for occupant pre-movement times in a technical standard
Redundancy/Safety Factor	Wide range of approach adopted, particular in relation to the use/reliance of sprinklers. Also safety factors in egress calculations vary significantly between projects.	Introduce safety factors appropriate to the level of risk and consequence.

Each of the above design aspects are discussed below.

Design Fire

Design fires have a significant impact on the design outcome of performance-based solutions[7]. However, it is one of the most difficult design parameter to quantify accurately. If design fires are clearly specified in a technical standard, it will provide a significant level of design consistency in PBFSED solutions. Without such a structured framework in determining design fires, PBFSED is akin to allowing structural engineers to design a building without a loading code! The basis of a recommendation is discussed below.

Measurements of heat release rates from full-scale fire tests often exhibit a significant variation as shown in Fig. 6

FIGURE 6. As shown in the figure, there is a major difficulty with trying to quantify a fire in a consistent manner.

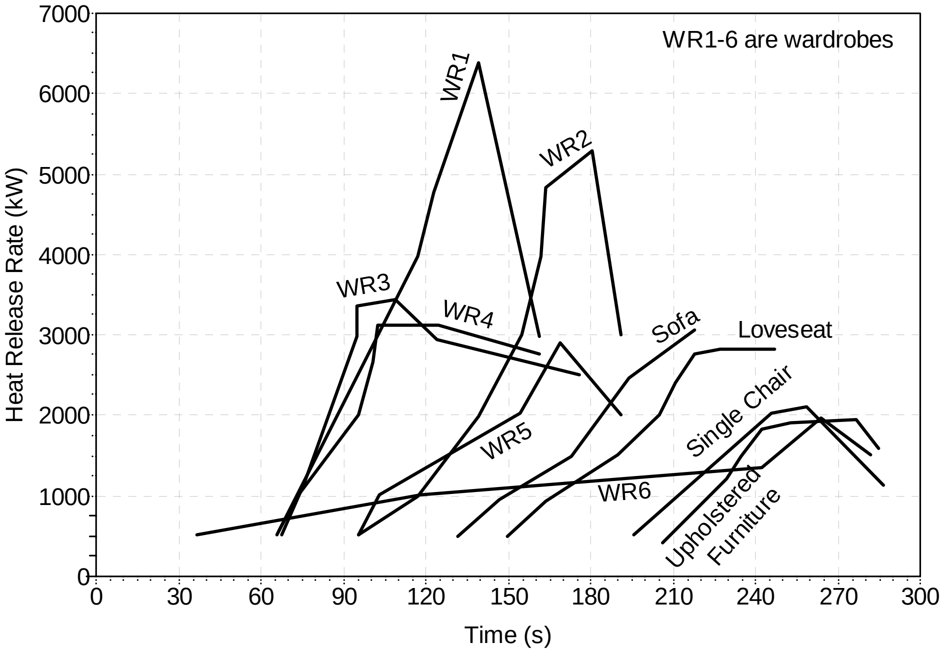


FIGURE 6. Heat release rates of furniture items[8]

However, when the same set of curves are adjusted along the time axis such that their main growth regions are approximately aligned, the growth regions appear to correspond to either the rapid or ultra-fast t² fire as shown in Fig. 7. It is therefore feasible to recommend standard growth curves to initial fires depending based upon simple descriptors of the fire load and fire scenario.

Guidance on the peaks, duration and subsequent delay portions of the design fire will also require a quantification process such that similar design fire outcomes can be expected for similar characterisation of the fire scenarios.

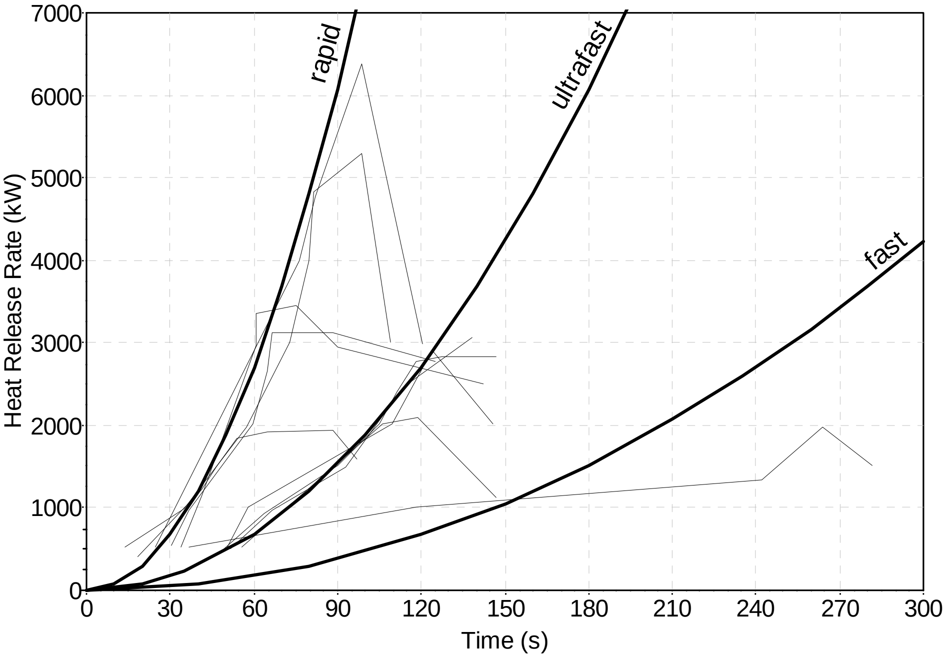


FIGURE 7. Heat release curves with shifted time axis

Pre-movement Time

Studies of human behaviour have shown that there is a wide range of response times to the effects of fires[5]. As with design fires, human behavioural responses also have a high level of difficulty to predict accurately. As a start, pre-movement times should be determined in a more methodical manner through a design framework or a technical standard to provide durations that engineers can pick from a in a more consistent manner appropriate to the building configuration, function and use, as opposed to just left to the expert judgement of the engineer.

There are two main factors affecting the prediction of pre-movement times: the alertness of the occupant and the detail of information communicated to the occupant. The former may be generally categorised by the type of building occupancy whilst the latter is simply the form of warning communication provided. This is reflected in the pre-movement times recommended in the BSI (1994) code. Based on those recommendations, four categories of occupancies differentiating pre-movement times can be derived as shown in Table 4.

TABLE 4. Pre-movement times in secs (based on BSI, 1994)

#	Category	Occupancy	Directive PA	Non-Directive PA	Alarm
1	Alert and mobile occupancies	offices, underground stations	60	180	240
2	Mixed occupancies	shops, complexes, sports stadia and other public places	120	180	300
3	Occupancies of long term accommodation	Hotels, residential and nursing homes	120	240	360
4	Occupancies requiring intensive care and treatment	hospitals	180	300	480

Nursing homes and hospitals are managed by staff that may be considered to be alert and mobile. Their associated delays in pre-movement times are due mainly to the time required to prepare and organise the patients for evacuation.

It is important to note that published pre-movement times are representative times for the general population in the building that are remote from the fire, ie they are not in direct contact, sight or smell of the fire and rely on warning systems to advice them of the fire. Hence, the pre-movement times of occupants that are in close proximity to the fire can be expected to be less that the overall times. For example, it is unlikely that an alert occupant located in the same enclosure as the fire will take longer than a minute to respond. In addition, there is also usually an associated range of times with these data that may be significant and vary with the activity and alertness of each individual.

Safety Factors

These need not be overly complex. It can be as simple as a Factor of Safety (FoS) in the ASET > REST rule, i.e. ASET = FoS × RSET or a margin of safety, MoS = ASET-RSET. The FoS can be refined to reflect the level of risk and consequence of potential fires in the building under consideration. A simple relation may be derived based on the proposed Type of Construction prescribed in the BCA. The Type of Construction is a measure of the fire-resisting construction of the building, ranging from Type A, the most fire-resistant to Type C the least fire-resistant. Determination of the Type of Construction is based on the rise in storeys (effectively the number of floors above ground) and the class of building (effectively discriminating between residential and commercial). This is shown in Table 5. Hence the safety factor should be increasing when going from Type C to Type A.

TABLE 5. Type of Construction (BCA[1])

Rise in storeys	Residential	Commercial
4 or more	A	A
3	A	B
2	B	C
1	C	C

Whilst there are persuasive arguments in many published literature on this subject to incorporate safety factors in the design, there is still no mandate to provide a minimum measure of safety margin in current fire engineering design codes or guidelines. This will simply leave many design solutions to be considered ‘adequate’ as long as ASET is no less than RSET notwithstanding the fact that the variations in some of the design assumptions leading to the determination of these values can be at least 20% and as high as a few hundred percent. To avoid this, safety factors should be determined by prescriptive means and not based on engineering judgement.

It is important to note that the extent of safety factor should also depend upon the level of conservatism that may already have been allowed for in the major constituents of the assessment terms, eg pre-movement times in RSET. Many designs are currently evaluated by directly comparing ASET and RSET, ie using a safety factor =1. Hence safety factors in the order of 1.2, 1.5 and up to 2 for Types C, B and A respectively may be generally appropriate to reflect some equivalency with the measure of relative risk associated with the DtS Provisions of the BCA.

CONCLUSIONS

An overview of the performance-based fire safety engineering design process in Australia is outlined. Various weaknesses in the design framework for performance-based fire safety engineering were identified, particularly in terms of demonstrating the achievement of compliance with the *Performance Requirements* of the BCA. From a regulatory perspective, these were determined to be largely attributed to the departure of the BCA to allow compliance to be achieved in a qualitative manner. From a design perspective, the contributing factors were the lack of a structured means to provide consistent outcomes in the quantification of critical design variables that had a significant impact on the level of safety in the design.

The critical design variables were considered to be the determination of the design fire and the appropriate selection of pre-movement times, although there were a number of other variables that are also important. Additional measures to assure adequate levels of safety in performance-based design solutions were the use of appropriate safety factors and implementation of an appropriate and efficient review process. The determination of a more prescriptive means of establishing important design variables such as design fires, pre-movement times and safety factors would significantly improve the consistency in the level of safety using performance-based fire safety engineering design, without necessarily limiting the benefits of innovation and design flexibility. It is envisaged that a properly written technical standard would be required to provide the protocols necessary to achieve the level of design consistency within the framework for a performance based design approach for fire engineering.

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