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Using Risk as a Basis for Establishing Tolerable Performance: An Approach for Building Regulation

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Abstract

For engineers and designers, the performance environment promises greater opportunities to apply analytical tools and methods to design safe, cost effective, and aesthetically pleasing buildings. For regulators and enforcement officials, performance-based approaches are often met with scepticism and concern, as the desired performance is not always well defined and agreed, the perceived certainty associated with compliance with prescriptive design requirements is no longer be assured, and there is concern that the data, tools and methods – necessary to assure that performance-based designed buildings achieve the levels of performance and risk deemed tolerable to society – are lacking. To address some of these critical issues, a risk-informed performance-based approach is being explored for establishing tolerable levels of building performance, with the aim to better connect tolerable risk, performance expectations, and associated design criteria. Use of risk-informed performance-based approaches being considered in Australia, New Zealand and the United States are discussed.

1. Introduction

Performance- (functional-, objective-) based building codes have been in use since 1985 with the publication of The Building Regulations 1985 in England and Wales (DOE, 1985). At present, more than a dozen countries are working in a performance-based building regulatory environment, with several others in the process of developing performance-based building codes (Meacham et al., 2005).

For many of the early players in the performance regulatory environment, work on second-generation performance-based codes and design processes are underway. As part of the development of second generation performance-based building codes, the idea of using risk as a basis of identifying tolerable building performance has been proposed (e.g., Meacham, 2000; 2001; 2004; 2004a; 2005; Meacham et al., 2005). Building on concepts discussed and developed in the seismic engineering community (e.g., Hamburger, 1995; SEAOC, 1995) and fire protection engineering community (e.g., Meacham, 1998; 2000) some of the concepts have already been incorporated into performance-based building codes in the United States (ICC, 2001; 2003).

A significant reason that one has building codes is to provide for the design and construction of buildings that provide an acceptable level of shelter and safety from natural hazards (heat, cold, rain, snow, high winds, earthquakes) and technological hazards (fire, fuels used for heating or cooking, glazing, etc.). With knowledge of what 'society' finds acceptable in terms of minimum requirements for shelter and safety, one can establish associated performance requirements for the design and construction of buildings.

For example, it is probably not acceptable for any roof to fail in a 5 kph wind. However, in a cyclone-prone area, it might be accepted that roofs for some structures may fail in 100 kph winds, such as for an out-building or shed, yet a roof on a single family home should remain in place. Likewise, one the very rare occasion where a 200 kph wind may occur, one might expect some damage even to the roof of a single family home, but not to a hospital, which will be expected to be open to treat injuries that may come from the exceedingly high winds. By following a process such as this, one can identify the tolerable risk levels (in this case establishing a return period from the probability of wind speed exceeding a threshold level) and establish quantifiable performance measures (e.g., no roof damage for a single family home for 1:100 year winds, slight damage tolerable for 1:200 year winds, significant damage tolerable for 1:1000 year winds). By stating the return periods and damage levels in the building code, engineers can design appropriate roofs to meet the performance expectations.

Many countries, including Australia, Canada, Japan, New Zealand, and the United States are already using risk-informed criteria, such as return periods and damage associated with sustained or peak wind speed for defining the required performance of buildings or structural components. The same approach is used for seismic events, flooding and snowfall, and can be readily used for most natural hazard events. At present, the approach is being evaluated for potential application to technological events, specifically fire. Given the growing use of risk-informed criteria in various aspects of building design, the question has been raised: why not expand the concept and create risk-informed performance-based building codes? The Australian Building Codes Board (ABCB) and the Department of Building and Housing (DBH) in New Zealand have in fact started down this path, and are using concepts embodied in the ICC Performance Code (ICCPC) and resident in the performance-based hierarchy of the Inter-jurisdictional Regulatory Collaboration Committee (IRCC).

2. IRCC Hierarchy

For performance-based regulations and design methods to be effective, there must be a logical and transparent relationship between top level societal and policy level goals, and the bottom level specification solutions, or performance verification methods. Until now, many performance-based building regulations have followed the five-tiered hierarchy first suggested by the Nordic Committee on Building Regulations in 1976 (NKB, 1976; 1978). In recent years, however, it has become apparent that more detail is required to describe the levels of performance – and in many cases risk – that a category of buildings is intended to achieve over a wide range of hazard events. It has also been recognized that more detail is also needed to better describe the criteria or measures against which successful performance will be evaluated (e.g., Meacham, 1999; 2004a). As a result, an eight-tiered performance-based hierarchy has been developed by the author, in collaboration with the members of the Inter-jurisdictional Regulatory Collaboration Committee (www.ircc.gov.au). The NKB and IRCC hierarchies are illustrated in Figure 1.

The fundamental difference between the IRCC performance hierarchy and the NKB hierarchy is the inclusion of tiers for *performance or risk group*, *performance or risk level,* and *performance or risk criteria* (measures) within the IRCC model. These tiers were added to the hierarchy to illustrate how factors such as levels of tolerable building performance or risk, and importance of a building category to the community, are reflected in goals, functional requirements, and operative (performance) requirements. With these added tiers, the IRCC hierarchy is also better able to illustrate how test methods and standards, evaluation methods, design guides, and other verification methods can be used to demonstrate compliance. The IRCC hierarchy can be viewed as “top-down” or “bottom-up,” meaning that one can go from an overarching goal to the specific requirements necessary to achieve that goal (top-down), or start with a specific requirement and understand the goal(s) it supports.

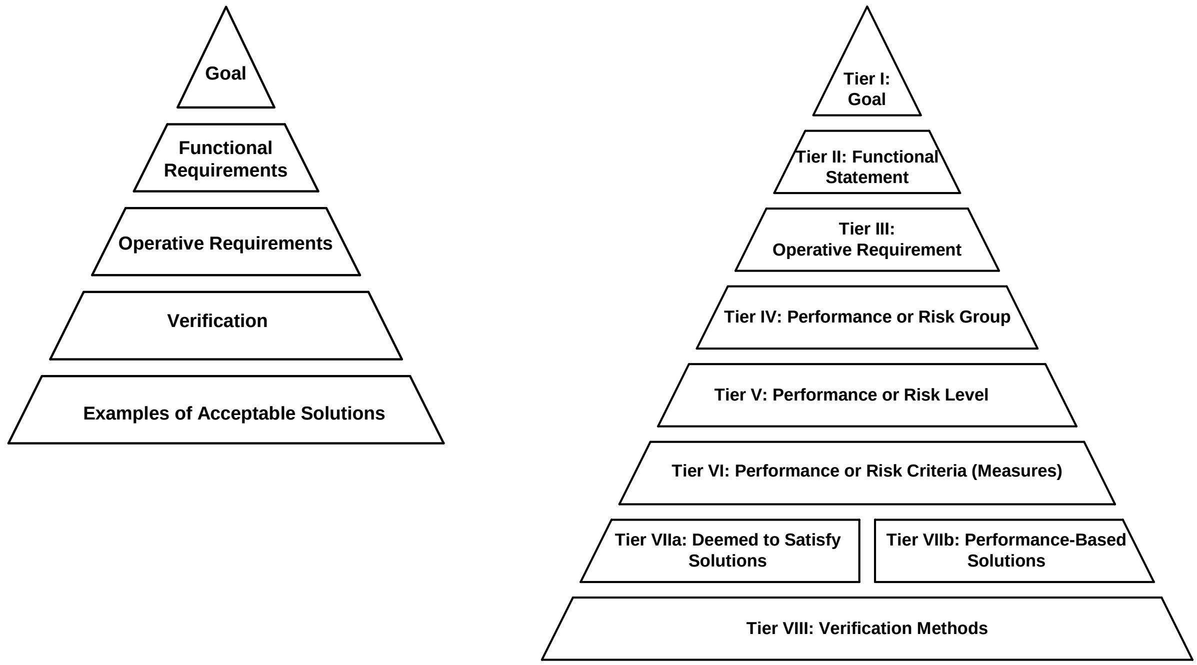


Figure 1. NKB Hierarchy (NKB, 1976) and Eight-Tier IRCC Performance-Based Building Regulatory System Hierarchy (IRCC, 2000).

Societal and policy level goals, and to some extent each of the lower levels, embody value statements regarding acceptable performance of buildings in terms of health, safety, welfare, amenity, mission and/or other goals for buildings of various uses. *This means that acceptable performance – and acceptable risk – should not necessarily be driven solely by the current state of scientific and engineering knowledge, but also by what society deems to be acceptable or tolerable*. In the case of government occupancies, goals may also be driven by such factors as terrorism mitigation and national security, which may result in higher levels of required performance for specific structures or for certain categories of structures.

Once goals for acceptable (tolerable) levels of performance and risk have been established, and related functional and operative requirements have been developed, scientists and engineers can translate these goals and functional and operative requirements into criteria for design and design assessment. This translation occurs predominantly between Tiers III and VIII: Operative (Performance) Requirements and Verification Methods. As part of establishing goals and functional and operative requirements, it is helpful to consider whether and how different classes of buildings may be expected to perform under a variety of normal and emergency conditions (thus resulting in categorization into different performance groups with differing performance levels). Once the categorization is complete, *and* a building or a building element can be described in terms of how it performs under normal and emergency conditions with respect to appropriate load effects, *and* methods are available to evaluate and to verify this performance, a design solution that complies with the regulation can be engineered.

3. Characterizing Risk

An essential step in the risk-informed performance-based approach is to characterize the risk and performance expectations of the facilities to be regulated. Risk characterization is a process that provides a framework for, and the integration of, various aspects of risk, including identification, assessment, communication and analysis. It is the product of an analytic-deliberative decision-making process, wherein there is an appropriate mix of scientific information (from "traditional" risk assessment) and input from interested and affected parties throughout (Stern and Fineberg, 1996).

Risk characterization is a decision-driven activity, directed toward informing choices and solving problems. Since coping with a risk situation requires a broad understanding of the relevant losses, harms, or consequences to the interested or affected parties, significant interaction is required (see Figure 2). It is very important, therefore, that the process have an appropriately diverse participation or representation of the spectrum of interested and affected parties, of decision-makers, and of specialists in appropriate areas of science, engineering and risk analysis at each step. The more widespread the participation, and the broader the scope of factors considered at the outset, the less likely it will be that major factors are overlooked. For example, a singularly-focused view of risk may inadvertently miss important considerations, such as technical, social, economic, value, perceptual or ethical impacts. As a result, the problem may be formulated improperly, either technically, socially or in some other manner, and the resulting analysis may omit key parameters. In addition, if not all interested or affected parties are involved in the process, they may disagree with anything from the problem statement to the measure of risk selected. Sensitive populations may be left out, socio-economic factors may be ignored, or cultural sensitivities may be unknown.

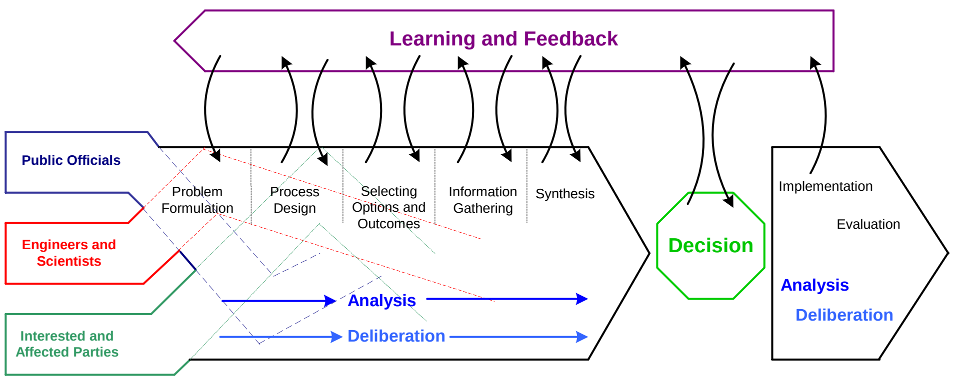


Figure 2. Representation of Risk Characterization Process (adapted from(Stern and Fineberg, 1996)).

The success of the risk characterization process depends critically on systematic analysis that is appropriate to the problem, responds to the needs of the interested and affected parties, and treats uncertainties of importance to the decision problem in a comprehensible way. Success also depends on deliberations that formulate the decision problem, guide analysis to improve decision participants' understanding, seek the meaning of analytic findings and uncertainties, and improve the ability of interested and affected parties to participate effectively in the risk decision process. In other words, good risk characterization requires a well-defined problem that those involved agree with, a sound scientific base, the proper use of analytical techniques with proper consideration of uncertainties and unknowns, and sufficient discussion and deliberation so that everyone understands all of the issues. The process will likely require several iterations, as new information and data become available, and as participants gain better understanding and raise more issues. It needs to be an interactive process, and not one where one group dominates the deliberations and/or analysis and forces a solution.

One of the most important factors in risk characterization is to ensure that adequate scientific and technical information is available to support the decision. This function occurs primarily in step one of the diagnosis stage: diagnose the kind of risk and state of knowledge. To help focus this effort, various diagnostic questions should be asked about the hazards and the risks, including (Stern and Fineberg, 1996):

- Who is exposed?
- Which groups are exposed?
- What is posing the risk?
- What is the nature of the harm?
- What qualities of the hazard might affect judgments about the risk?
- Where is the hazard experience?
- Where and how do hazards overlap?
- How adequate are the databases on the risks?
- How much scientific consensus exists about how to analyze the risks?
- How much scientific consensus is there likely to be about risk estimates?
- How much consensus is there among the affected parties about the nature of the risk?
- Are there omissions from the analysis that are important for decisions?

4. Risk Characterization and the Development of the ICCPC

The risk characterization process outlined above can be used in the development of performance-based building regulations. This has been done in the United States in the development of the *ICC Performance Code for Buildings and Facilities* (Meacham, 2000; 2004; ICC, 2001; 2003). Key objectives were to explore how risk could serve as a metric for defining acceptable building performance, and to incorporate the results into the building code. As a first step, the building code objectives were reviewed, and input was solicited from stakeholders relative to those occupant, building, and community risk factors that should be considered (Meacham, 2000; 2000a). The above list of diagnostic questions served as the basis for this step. As a result of this effort, the following hazard, occupant, building, and community risk factors were identified:

The key hazard factors:

- The nature of the hazard,
- Whether the hazard is likely to originate internal or external to the structure, and
- How the hazard may impact the occupants, the structure, and/or the contents.

The key risk factors:

- The number of persons normally occupying, visiting, employed in, or otherwise using the building, structure, or portion of the building or structure.
- The length of time the building is normally occupied by people.
- Whether people normally sleep in the building.
- Whether the building occupants and other users are expected to be familiar with the building layout and means of egress.
- Whether a significant percentage of the building occupants are, or are expected to be, members of vulnerable population groups.
- Whether the building occupants and other users have familial or dependent relationships.

In addition to these above, the issue of importance of a building to a community was also considered. This was important to understand why a community may deem a building, or class of buildings, to be important to community welfare. The considered factors were:

- The service the building provides (e.g., a safety function, such as a police or fire station, or a hospital),
- The service the building provides in an emergency (e.g., an emergency shelter, hospital, communications facility, or power generating station),
- The building's social importance (e.g., a historic structure, a church or meeting place), or

- The hazard the building poses to the community, not just its occupants (e.g., chemical manufacturing facilities or nuclear power generating facilities).

A detailed discussion of the risk characterization process undertaken as part of the development of the ICCPC is detailed elsewhere (e.g., Meacham, 2004). In brief, the outcomes included:
- A set of use group descriptions, modified to incorporate occupant risk factors and importance factors,
- A framework, based on SEAOC efforts of the late 1990s, which lays out performance groups, hazard events, and levels of tolerable impacts, and
- A model for use in incorporating risk concepts into performance-based building regulation.

Conceptually, the matrix of performance groups, hazard events, and levels of tolerable impacts, as illustrated below, is the central feature.

		INCREASING LEVEL OF BUILDING PERFORMANCE →→→→→→→→→ → →→→→→→→ **PERFORMANCE GROUPS**			
		PG I	**PG II**	**PG III**	**PG IV**
MAGNITUDE OF EVENT INCREASING MAGNITUDE OF EVENT ↑↑↑↑↑↑↑	VERY LARGE (Very Rare)	SEVERE	SEVERE	HIGH	MODERATE
	LARGE (Rare)	SEVERE	HIGH	MODERATE	MILD
	MEDIUM (Less Frequent)	HIGH	MODERATE	MILD	MILD
	SMALL (Frequent)	MODERATE	MILD	MILD	MILD

Figure 3. Maximum tolerable impact based on performance groups and design event magnitudes

In brief, buildings with common risk characteristics, importance factors and expected performance are categorized by performance groups. For any given event magnitude, such as LARGE, the expected impact on the facility changes by performance group (PG): *SEVERE* impact for PG I (low risk to life / importance), *HIGH* for PG II, *MODERATE* for PG III, and *MILD* for PG IV (important buildings). Seismic engineers in the USA and New Zealand, among others, will be familiar with this approach.

5. Use of Risk to Inform Building Regulation in Australia and New Zealand

Although promulgated before the ICCPC was published, performance-based building codes in New Zealand (1992) and Australia (1996) lacked quantified performance levels and performance criteria, and there was no clear linkage to societal expectations in terms of risk mitigation or building performance. Over the course of several year, building performance problems arose within each country, and various studies undertaken in response to those problems highlighted the need to better quantify performance and to better clarify the basis for the performance requirements (e.g., Campbell Report, 2002; Hunn Reports, 2002; Productivity Commission Report; 2004). This led to efforts in each country to identify means by which to quantify building performance, and in each country, risk was identified as a primary factor.

5.1. New Zealand Situation

Although New Zealand was one of the first countries to promulgate a performance-based building code in 1992, the code had few quantitative performance criteria – most criteria decisions were left to engineers. Although many reference standards and guidelines had criteria for engineers, their use was not guaranteed because it was not required. Over time, numerous issues were raised, including consistency in performance delivered in the built environment. In the early 2000s, the situation became more complicated as a large number of buildings were beginning to have moisture-related failures.

In brief, moisture was entering the building from a variety of sources, primarily around windows with improper flashing, and was not being removed, either due to the tightness of the buildings or the lack of heat to evaporate the moisture. In total, the "leaky building syndrome" resulted in damage to as many as 18,000 homes and numerous multi-unit buildings (Hunn Reports, 2002; May, 2003; Ministry of Economic Development, 2003). Although the failure can be tied, in large part, to problems with certification of alternative building methods and with third-party certification of buildings, the entire building regulatory system was challenged. As a result, the Building Industry Authority, which had responsibility for the Building Code, was abolished, and a new government department, the Department of Building and Housing (DBH) was established. One of the first charges for the DBH was an entire review of the building code. DBH in turn had an aim to better quantify performance.

As part of the DBH efforts to better quantify performance, there was a desire to consider risk as a basis for performance quantification. DBH funded a study in this area (Meacham, 2006), which identified the following (note: the study was to look overall at risk as a basis of performance with a focus on fire):

- It is possible to establish risk-based criteria, in terms of annual expected risk to life (or other measures). This is done in various countries, such as the UK (HSE) and the Netherlands. Depending on political will, stakeholder agreement on data, and time to conduct analysis, level(s) of acceptable fire risk can be established.
- The concept of performance levels (importance levels) for fire is suggested. It is further suggested that these follow the seismic importance levels. Certain values may need to be adjusted (such as occupant population numbers), but the concept is useful in identifying the performance expectations for buildings.
- A key difference between the seismic / structural approach and fire is that currently the system lacks a good set of representative fire loads (either strictly deterministic, probabilistic, or in combination). Some potential approaches to codifying design fire loads are suggested, but it will require research and development to actually quantify any such design fire loads before they should be adopted into the Code.
- At the specific performance requirement level, it is possible to develop specific criteria in terms of such factors as temperature, radiant heat flux, species concentrations, and the like. It is even possible to create distributions around values, if one accepts subjective approaches to probability quantification.
- Although criteria can be quantified, the selection of detailed criteria is very closely coupled with verification methods (and data availability). As such, it is not recommended to place specific criteria in the Code without simultaneously defining the related verification methods. (Also, fixing criteria could in some cases limit innovation.)

It was recommended that a potential way to address the desire to have some criteria in the Code, and maintain flexibility, is to set 'high-level' risk targets in the Code, and place criteria and verification methods in 'compulsory compliance documents.'

Based on the above effort, DBH staff established working groups to investigate application of the risk-informed performance-based approach to the Building Code of New Zealand. A recent DBH internal discussion report suggests that the risk-informed performance framework has provided a very good basis for developing rational design for structure and fire, and provides guidance for other areas as well (DBH, 2007). These concepts will be open to public comment in a May 2007 consultation paper.

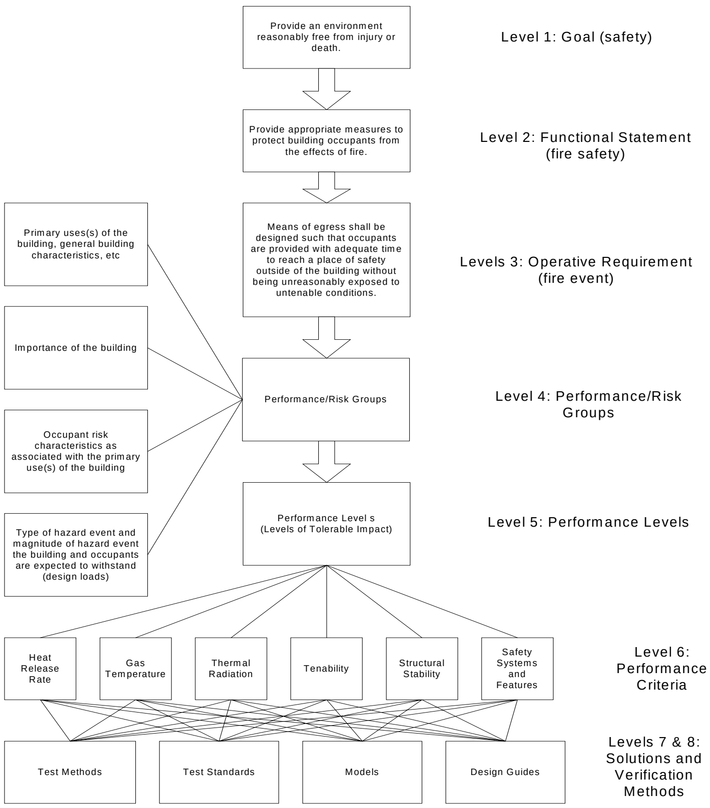
- For Structure, the work shows that the probability of demand exceeding capacity, and therefore the risk of "failure" can be related to the consequences of failure (tolerable impacts). Estimates of demand and capacity, incorporating estimates of variability and uncertainty, can be included in the rational design basis and can form a rational and robust basis for future loading and materials design methods (usually New Zealand or other national Standards).
- For Fire, the framework provides for design scenarios and performance criteria to be specified, to provide assurance about the probability that capacity exceeds demand.
- The process seems to have applicability in other areas as well, including Indoor Air Quality and Safety in Use.

5.2. Australian Situation

The 1996 version of the Building Code of Australia (BCA) was promulgated as a performance-based code. As with the New Zealand Building Code of 1992, there were few performance criteria in the BCA 1996. Following on issues raised in New Zealand with 'leaky buildings' and quantification of performance, as well as the 2002 Campbell report on Quality in Buildings, which identified some quality problems in buildings, and the 2004 Productivity Commission review and report on Reform of Building Regulation, it was decided that performance should be better quantified in the BCA. As a result, a protocol for quantifying performance in the BCA was developed (Meacham, 2005a), and ABCB staff has been using the protocol, internally developed performance assessment sheets, and a well-defined process to identify performance requirements and performance measures. Some of the key components of the protocol, as related to risk, include:

- Wherever appropriate, risk should be a driver for establishing high level performance requirements. (A primary aim of building regulation is to provide adequate safety to building occupants: establishing building performance at levels of risk that are socially tolerable is a defensible approach.)
  a. Risk means different things to different people, so a clear and common understanding should be sought. For the purpose of this protocol, risk is a function of an unwanted event, the likelihood of event occurrence, and the potential consequences should the event occur. An analytic-deliberative process is recommended for characterizing risk for use in regulation.
  b. Events of concern should be clearly defined.
  c. Intolerable consequences (inverse of required performance) should be clearly articulated (can be qualitative). Where certain parameters cannot be used for political or other reasons (e.g., number of deaths per event), a suitable surrogate should be selected (one must be able to directly correlate the surrogate to the actual parameter of concern).
  d. Values for likelihood (frequency, probability) must be quantifiable – this can be accomplished from existing objective data, new data, subjective estimates, or other accepted methods. To the extent possible, target values or distributions should be used, and can be in the form of chance (1:1000), return period, probability of exceedence, or other recognized format.
  e. Acknowledgement of uncertainty and variability should be made in the quantification process. Likewise, uncertainty, variability, reliability and efficacy should be addressed in verification methods and DTS.

A flowchart of the quantification process is provided in Figure 4b below, shown in parallel with an alternate representation of the IRCC hierarchy (Meacham, 2004a), which more clearly shows linkages between risk, performance group, and criteria. Although not depicted in the BCA quantification flowchart, the aim is to use it to develop a code structure similar in form to that in the ICCPC. Performance in various BCA provisions has been quantified following this approach with good success.



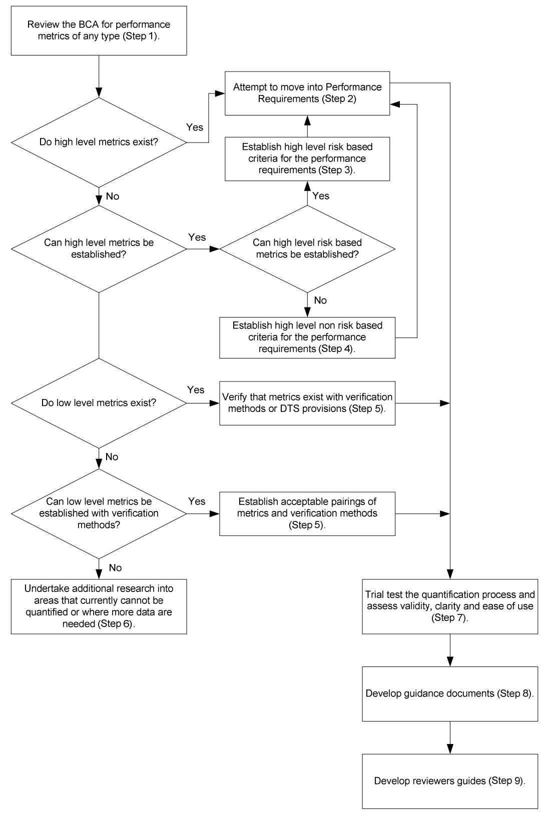


Figure 4a. IRCC Hierarchy with Linkages Figure (left) 4b. Draft Quantification Process for the BCA

Conclusions

The concept of using risk information – particularly the levels of tolerable risk – to inform performance levels in building regulation is gain traction in several countries. Building on concepts outlined by the seismic engineering community in the US in the 1990s, and developed further by the International Code Council and others through the early 2000s, countries such as Australia and New Zealand are proceeding with efforts to quantify performance in their building codes based on tolerable risk levels. A fundamental basis of each of these efforts is the analytic-deliberative risk characterization process which brings analytic risk and engineering data together with stakeholder deliberations to jointly agree risk and performance levels and criteria. Keys to success include providing a thorough yet transparent decision framework, adequate data and analysis tools, and good stakeholder communication.

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