Journal of Risk Research

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713685794

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First published on: 21 April 2010

To cite this Article Meacham, Brian J.(2010) 'Risk-informed performance-based approach to building regulation', Journal of Risk Research,, First published on: 21 April 2010 (iFirst)

To link to this Article: DOI: 10.1080/13669871003703260

URL: http://dx.doi.org/10.1080/13669871003703260

Journal of Risk Research
2010, 1–17, iFirst Article

Risk-informed performance-based approach to building regulation

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(*Received 31 December 2009; final version received 10 February 2010*)

Performance-based building codes are being developed and promulgated around the world. Concurrently, performance-based analysis and design approaches are being used in a number of disciplines, including structural, mechanical, and fire protection engineering. The performance-based building regulatory and design environment promises great opportunities for engineers and designers to innovate and to apply analytical tools and methods to design safe, efficient, cost-effective, and aesthetically pleasing buildings. However, for regulators and enforcement officials, performance-based approaches are often met with skepticism 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 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 these concerns, risk-informed performance-based approaches are being explored, with the aim to better identify and connect tolerable levels of risk, performance expectations, and design criteria for different aspects of building design. Risk-informed performance-based approaches being considered in Australia, New Zealand, and the USA are discussed.

Keywords: risk-informed; performance-based; building regulation

Introduction

Performance-based building regulations, also variously referred to as function-based or objective-based building standards, codes, or regulations, began to be implemented in the early 1980s. Since then, more than a dozen countries have developed performance-based building regulations, and for many of the early players in the performance regulatory environment, work on second-generation performance-based codes and design processes are underway, advancing the scope to address emerging issues, pressures, and threats to the built environment (Meacham et al. 2005; Meacham 2010).

As part of the development of second-generation performance-based building regulations, using the concept of identifying 'tolerable levels of risk' as a basis for identifying 'tolerable levels of building performance' has become one of the common objectives (e.g., Meacham 2001, 2004a, 2004c, 2005b, 2007a, 2007b, 2008; Meacham et al. 2005). On the surface, the use of risk to establish tolerable performance makes sense: with knowledge of what society finds tolerable with respect to factors such as

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ISSN 1366-9877 print/ISSN 1466-4461 online

DOI: 10.1080/13669871003703260
http://www.informaworld.com

'safety' and 'energy and environmental impacts', associated performance requirements for the design and construction of buildings can be developed.

For example, many people would not find it tolerable for the roof of any building to fail in a 10 kph wind. However, in a cyclone-prone area, it might be tolerable for some roofs to fail in 100 kph winds, such as those on out-buildings or sheds, yet it is expected that a roof on a single-family home should remain in place. Likewise, on the very rare occasion where a 200 kph wind may occur, some damage could be expected, and therefore tolerated, for the roof of a single-family home, but damage to the roof of a hospital, which will be expected to be open to treat injuries that may come from the exceedingly high winds, would not be tolerated. By following a process such as this, one can identify 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, the USA and the 27 Member States of the European Union, are already using risk-informed criteria in some aspects of building regulations and standards, such as reflected in 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 Inter-jurisdictional Regulatory Collaboration Committee (IRCC), a group comprising lead building regulatory agencies of more than 13 countries (see www.irccbuildingregulations.org), has been exploring this for a number of years and has proposed a structure for how risk concepts might be more explicitly reflected within performance-based building regulations (Meacham et al. 2005). Many of the concepts in the IRCC approach were contemplated by the International Code Council (ICC) in the USA during the drafting of their model building code, the *ICC Performance Code (ICCPC) for Buildings and Facilities* (ICC 2001; Meacham 2001). Since then, the Australian Building Codes Board (ABCB) and the Department of Building and Housing (DBH) in New Zealand have considered the concepts embodied in these approaches and have explored these and other approaches to better linking 'tolerable risk' to 'tolerable performance' in their respective building codes.

In setting the stage for the following discussion, it is worth noting that the concept of 'risk tolerance' is used to reflect the fact that risks associated with building performance are tolerated more so than accepted with respect to the building regulatory environment. Acceptance, for example, implies that one has all of the pertinent information on which to base a decision, that one understands the information, and that one is free to choose whether they want to accept or reject the risk (Kasperson and Kasperson 1983). With respect to building safety performance, building occupants may not know what level of risk mitigation is being provided and for what hazards, so they are not actively thinking about and identifying, assessing, and accepting the broad range of safety-related risks in a building. Rather, they may simply expect that the building regulations provide for some minimum level of safety, and therefore tolerate the levels of risk imposed upon them.

With respect to the discussion above, for example, most people would not know at what wind speed their roof might fail, or at what ground motion cracks might appear in their foundation, but expect their building to perform reasonably well under a wide range of events. This is particularly true for public buildings (e.g., anything from offices, to concert halls to retail stores), where there is rarely any individual risk assessment associated with the use of a building for work, recreation, or other purposes. The result is that those responsible for the regulation and its enforcement must make judgments regarding the nature of the risks and about acceptable distribution of risks across various populations. This requires value judgments and consideration of various ethical issues which enter into the decision-making process, including valuing consequences, paternalism versus autonomy, equity considerations, and a responsible decision process (Kasperson and Kasperson 1983).

It is also important to note that the term ‘risk-informed’ is used to reflect the concept that quantitative risk data are but one component of a tolerable risk decision and not the sole basis of the decision. In some regulations, quantitative risk values are used as the basis for establishing tolerable risk levels. Such approaches can work reasonably well when there is a well-defined problem, adequate data, and well-defined means of assessment and verification (e.g., a safety system performance level might be set based on a statistically derived failure rate as measured following a specific procedure). This is defined here as ‘risk-based’ regulation. By contrast, a ‘risk-informed’ approach assumes quantitative risk criteria to be one component of the regulatory decision-making process, which must be balanced with societal costs and benefits, equity issues, cultural and political systems, and other influences on the regulatory environment to help inform decisions about building performance targets.

Lastly, the term ‘performance-based’ is used to reflect a focus on the intended function or outcome of a regulatory requirement rather than on how that function or outcome is to be achieved, which is described as ‘prescriptive’ or ‘descriptive’. For example, a performance-based objective for building fire safety design might be to ‘provide occupants not intimate with the fire materials burning with adequate time to safely evacuate a building prior to being exposed to untenable conditions’. In a prescriptive environment, this might be addressed through a set of prescribed factors, such as maximum travel distances, minimum widths of exits, and fire resistance ratings for walls. In the former, it is required for building designers to demonstrate how the building performs to meet that objective for a wide range of fire scenarios and occupant characteristics. In the latter, one simply constructs the building, with no assessment of expected performance given the types of fires and occupants expected in the building (see Meacham (2004a) for more discussion on this difference).

IRCC hierarchy

Until recently, the basic structure behind many of the performance-based building regulations currently in use has followed the five-tiered hierarchy first suggested by the Nordic Committee on Building Regulations in 1976 (NKB 1976, 1978). In the NKB hierarchy (Figure 1), regulatory provisions are based on a set of broad goals (essential interests of society), functional requirements (qualitative statements related to the desired function of buildings or specific building elements), and operative requirements (quantitative requirements, often stated in terms of performance criteria or

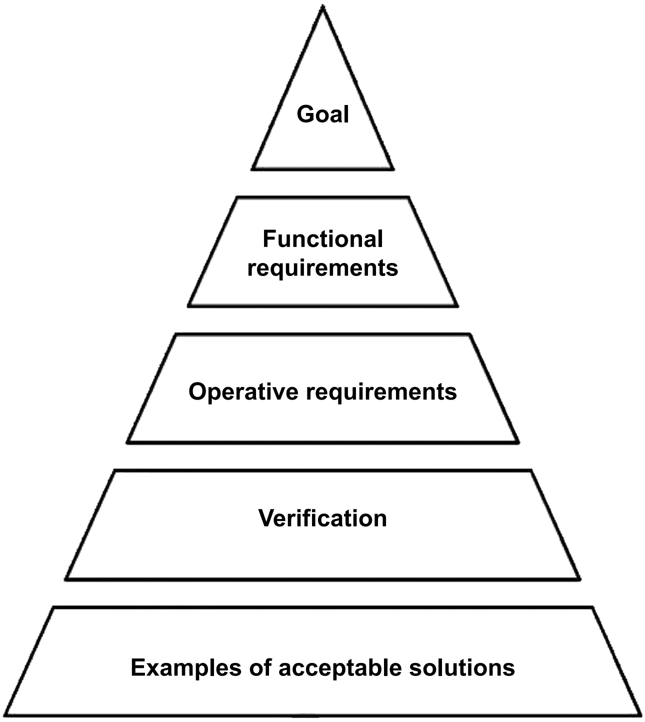


Figure 1. NKB hierarchy (Meacham 2008).

expanded functional descriptions). Instead of prescribing a single set of design specifications for regulatory compliance, which is the norm in prescriptive-based building regulation, the NKB hierarchy provides for two options: acceptable solutions, which provide a set of readily implementable solutions which have been deemed to comply with the functional and operative requirements (much like the old prescriptive design specification), or demonstration of compliance through the application of verification methods, such as engineering analyses, test methods, measurements, or simulations, which provide flexibility in the design and approval process. Many jurisdictions have found the NKB hierarchy to be attractive because it places the focus on what is expected from the building (e.g., provide appropriate measures to protect building occupants from the negative effects of unwanted fire), and allows for a variety of means to demonstrate compliance, rather than providing a single set of prescribed solutions (e.g., maximum travel distance to an exit, minimum fire resistance rating, etc.).

However, since the introduction of the NKB model, it has been recognized that for performance-based regulations and design methods to be effective, there must be a logical and transparent relationship between top-level societal goals and the bottom-level verification methods and acceptable solutions. In recent years, it has become apparent that in order to assure that solutions meet the upper-level goals and objectives, more detail is required to describe the levels of performance – and in many cases the levels of risk – which a category of buildings is intended to achieve over a wide range of hazard events. It has also been recognized that more detail is needed to better describe the criteria or measures against which successful performance will be evaluated. As a result, an eight-tiered performance-based hierarchy has been developed (Meacham

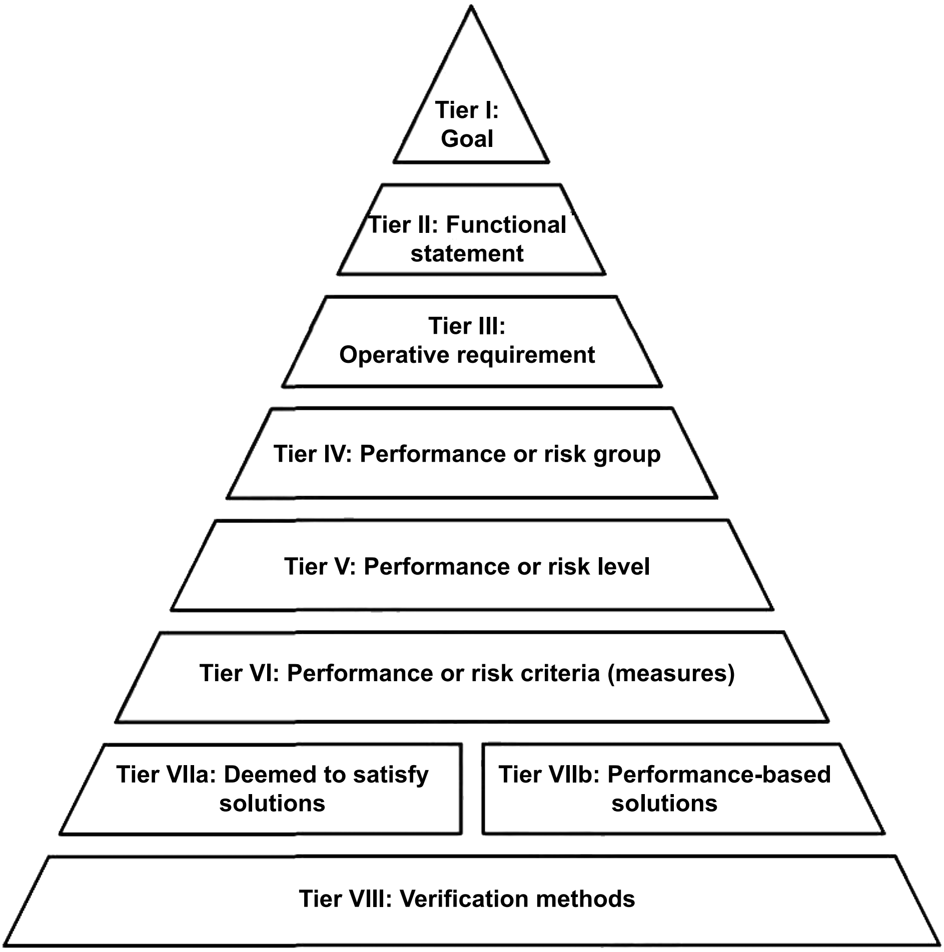


Figure 2. Eight-tier IRCC performance-based building regulatory system hierarchy (Meacham 2008).

1999, 2004a, 2010). The NKB and IRCC hierarchies are illustrated in Figures 2 and 3, respectively, with Figure 3 including some example language for a goal (safety from natural and technological hazards), a functional statement (provide measures to protect occupants from fire), and an operative requirement (design means of egress to allow occupants adequate time to reach a place of safety in the event of fire).

The fundamental difference between the IRCC performance hierarchy and the NKB model 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 (see discussion under the ICCPC below for more detailed descriptions of these terms). 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.

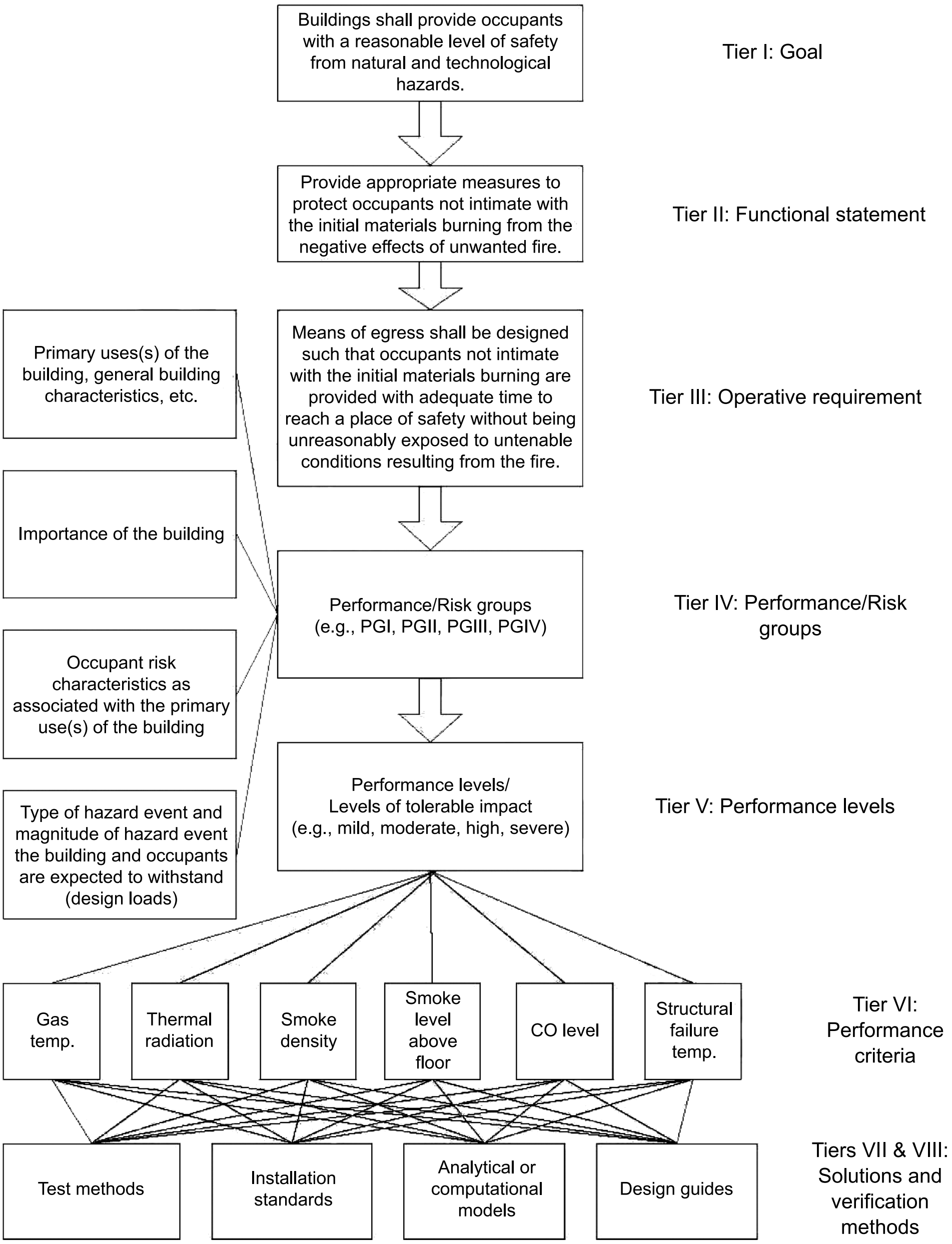


Figure 3. IRCC hierarchy with linkages (adapted from Meacham 2008).

The inclusion of the risk and performance levels into the IRCC hierarchy is seen as critical to a risk-informed performance-based approach since societal and policy level goals (Tier I), and to some extent each of the lower tiers, embody value statements regarding tolerable performance of buildings in terms of meeting risk-related expectations for issues deemed important to society, which traditionally have included such factors as occupant health and safety, and in some countries property protection. In the case of government or mission-critical facilities, goals may also be driven by such factors as resistance to extreme events, which may result in higher levels of required performance for specific structures or for certain categories of structures. Likewise, with global warming concerns, sustainability and resource efficiency goals may become more explicit in building regulations, driving expected building functionality and performance under a wider range of conditions than was anticipated in the past. Each of these areas has clear (albeit not clearly defined) risk–benefit–cost relationships.

As part of establishing goals, and perhaps more importantly the functional and operative requirements that sit below the goals, it is helpful to consider whether and how different classes of buildings may be expected to perform under a variety of normal and emergency (extreme) conditions. This helps the categorization of building uses into performance groups with common risk and performance expectations (Tiers IV and V). Once this is done, scientists and engineers can translate the functional and operative requirements into criteria for design and design assessment (Tier VI), which in turn can be linked to 'acceptable solutions' (deemed-to-satisfy, DTS, or performance-based) and to the methods of verification needed to demonstrate compliance (Tiers VII and VIII). In addition to showing the hierarchical relationship between the tiers, Figure 3 also illustrates that a wide range of performance criteria and methods of verification may be needed to demonstrate compliance with any single goal (see Meacham (1999, 2004a) for more discussion on these interactions).

Characterizing risk

In order to develop an integrally linked hierarchical construct such as envisioned in the IRCC hierarchy, which links concepts of tolerable risk to tolerable levels of building performance, a well-defined and transparent process is needed. It has been suggested (e.g., Meacham 2001, 2004a, 2004b, 2004c) that the risk characterization process outlined by the US National Research Council (Stern and Fineberg 1996) is appropriate. As presented, the risk characterization process provides a framework for 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. It 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 4). 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.

When applied to regulatory development, the risk characterization process will likely require several iterations, as new information and data become available and as participants gain better understanding and raise more issues. 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 the first step 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):

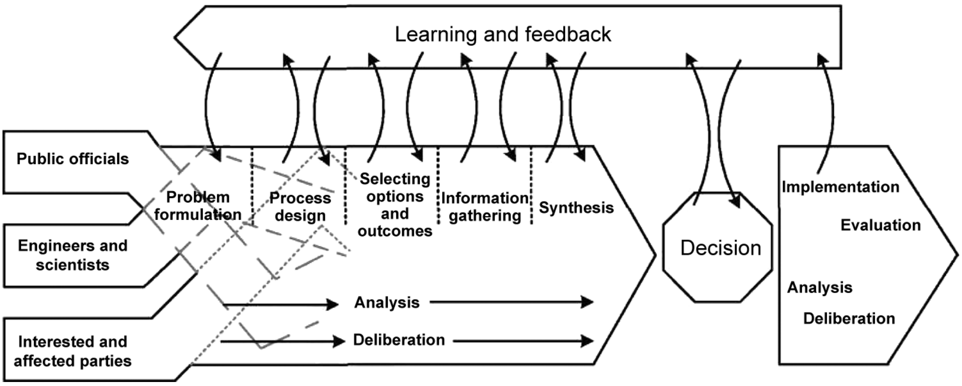


Figure 4. Representation of risk characterization process (adapted from Meacham 2008).

- 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?

Risk characterization in building regulation

Risk characterization can be a useful tool in the development of performance-based building regulations. This has been described in some detail in the literature (e.g., see Meacham 2001, 2003, 2004a, 2004b, 2004c). The application of the risk characterization process to building regulation development can occur at different levels of detail depending on the needs of the regulation. The outcome results in risk information which informs the regulation development.

In the USA, a formal risk characterization process was used in the development of the *ICC Performance Code (ICCPC) for Buildings and Facilities* (ICC 2001, 2003; Meacham 2000, 2004c), which built upon concepts discussed and developed in the seismic engineering community (e.g., Hamburger, Court, and Soulages 1995; SEAOC 1995), and borrowed heavily from the regulatory structures in place in New Zealand and Australia.

In New Zealand and Australia, regulatory agencies have been looking at how risk characterization can be applied in the development of ‘second-generation’ performance-based building regulations. When originally published, the performance-based building codes in New Zealand and Australia 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 years, however, building performance issues 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 Report 2002a, 2002b; Productivity Commission 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.

The use of risk to inform building regulation in the USA: the ICCPC

Key objectives in the application of the risk characterization process in the development of the ICCPC were to explore how risk could serve as a metric for defining acceptable building safety 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 2001, 2004b). 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:

Key hazard factors:

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

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:

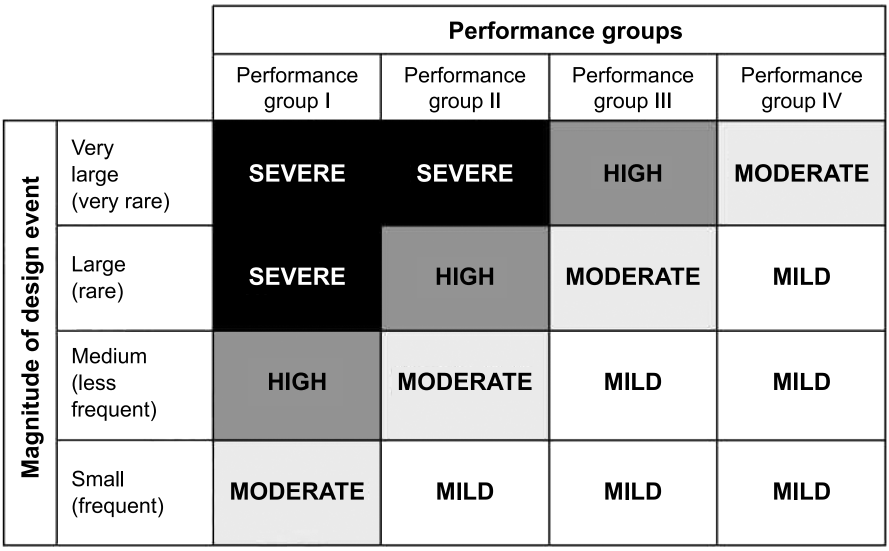
- The service the building provides (e.g., a safety function, such as a police or fire station, or a hospital)
- The service the building provides in an emergency (e.g., an emergency shelter, hospital, communications facility, or power generating station)
- The building's social importance (e.g., a historic structure, a church, or meeting place)
- 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 provided elsewhere (e.g., Meacham 2004c). 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 in Figure 5, is the central feature.

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.



		Performance groups			
		Performance group I	Performance group II	Performance group III	Performance group IV
Magnitude of design 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 5. Maximum tolerable impact based on performance groups and design event magnitudes (Meacham 2008).

The use of risk to inform building regulation in New Zealand

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 being left to engineers. Although many reference standards and guidelines had criteria for the 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 (see Hunn Report 2002a, 2002b; May 2003).

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 Report 2002a, 2002b; 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. The 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. To help DBH better understand how this could be accomplished, they looked to the IRCC hierarchy, risk characterization literature, and other countries' experience with the use of risk in building regulations. Initial investigation showed that various approaches could be used, from developing probabilistic risk criteria to utilizing more of a risk matrix approach. Focusing first on fire and natural hazards, it was noted that (Meacham 2006):

- 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 in the UK (Health and Safety Executive) and in the Netherlands. Depending on political will, stakeholder agreement on data, and time to conduct analysis, level(s) of tolerable risk can be established.
- However, a risk-informed performance-based approach, which defines performance levels (importance levels) for fire, seismic, and other hazards, may be easier to implement, since the building community is already familiar with the concept for seismic provisions. With this in mind, it is suggested that the approach follows seismic importance levels (understanding that certain values may need to be adjusted, such as occupant population numbers) since the concept has been accepted in specifying building performance targets.
- In developing the new approach, it should be recognized that a key difference between the approach for seismic loading and the approach that needs to be developed for fire is that there is not currently a good set of representative fire loads (either strictly deterministic, probabilistic, or in combination), and research and development is needed to quantify design fire loads before they can be adopted into the regulations.
- At the specific performance requirement level, it is possible to develop specific criteria for fire performance in terms of factors such 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 in cases where objective data are lacking.
- Although criteria for fire performance 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

regulations without simultaneously defining the related verification methods, following in part the approach adopted in the Building Standards Law (BSL) of Japan (BSL 2004).

Following this initial effort, DBH established working groups to investigate application of the risk-informed performance-based approach to the Building Code of New Zealand, with application of risk characterization and the risk-informed performance framework envisioned in the IRCC hierarchy resulting in recommended changes that have a stronger basis in linking tolerable risk and expected performance of buildings, particularly in the area of fire safety (for a report on the building code review, see http://www.dbh.govt.nz/bcl-building-code-review). Recommendations include incorporating Performance Groups and defining fire loads (scenarios) and performance criteria, in line with the approach for seismic design and all in relation to tolerable levels of risk. The approach envisioned for fire performance issues has been presented for consideration in international forums (e.g., Wade et al. 2007) and the most recent iteration is currently being field-tested (DBH 2009). Additional deliberation was conducted through public consultation and working group processes.

The use of risk to inform building regulation in Australia

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 some of the issues raised in New Zealand with 'leaky buildings' and the desire to have better quantification of performance, as well as the Campbell Report (2002) on quality in buildings, which identified some quality problems in buildings, and the Australian Productivity Commission (2004) review and report on reform of building regulation, it was decided that performance should be better quantified in the BCA, and where possible, and appropriate, risk should be used as a primary metric. As a result of this decision, a protocol for quantifying performance in the BCA was developed (Meacham 2005a). Some of the key components of the protocol, as related to risk, include:

(1) Review the BCA and identify existing quantified metrics, noting their form and format, what level they are at, and whether there are associated verification methods or DTS solutions.
(2) Where high-level metrics exist (e.g., risk-based, percentages, etc.), at whatever level, seek to raise them into the performance requirements, and seek opportunities to expand the concept to other regulated areas. Where they do not exist, but there is an opportunity to establish them, do so.
(3) 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 (Stern and Fineberg 1996) 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 exceedance, or other recognized format.
   (e) Acknowledgment 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.

(4) Where risk is not appropriate as a driver for establishing high-level performance requirements, other broad metrics, such as percentage (increase or reduction), distributions, or similar metric, should be considered.
   (a) A sustainability performance requirement, for example, may be in the form of reducing construction waste by 5% per year from 2004 levels until a 50% reduction has been achieved. Likewise, a water conservation performance requirement may be in the form of reducing water consumption in Class 2 buildings by 20% of the 2004 usage within five years.
   (b) An accessibility performance requirement, for example, may be to design buildings to allow unrestricted access of the 90th percentile of wheelchair dimensions available in 2004 to all habitable spaces.

(5) Where high-level metrics are not feasible (achievable) at this time, seek to establish verification method/DTS and metric pairs.
   (a) Where detailed metrics exist, without specific verification methods or DTS, aim to develop verification methods or DTS to correlate with the metrics.
   (b) Where verification methods or DTS exist, without specific metrics, aim to develop metrics to correlate with the verification methods or DTS.

(6) Where no clear option for metrification exists, and the performance is still required, seek to add additional guidance for assessing the performance and designing to comply with performance, and institute research projects aim at developing quantifiable metrics for the performance requirement.

(7) Upon completion of the initial quantification process, trial test the resulting performance requirements, verification methods, and DTS using case studies to assess and validate the clarity, effectiveness, and appropriateness of the metrics. Should changes be necessary, cycle back through the process as appropriate.

(8) Upon validation of the performance metrics and gaining acceptance of the revised performance requirements, develop guidance documents, training material, and related support mechanisms to assist in the transition into use.

(9) To assist review authorities, develop review guidance documents.

A flowchart of the quantification process is provided in Figure 6 (Meacham 2005a). Performance in various BCA provisions has been quantified by ABCB staff following this approach with good success. In the context of the analytic-deliberative framework, the protocol facilitated identification of relevant data and, where needed, the conduct of targeted research activities. Deliberation with stakeholders ranged from discussion within ABCB technical committees to public consultation on proposed changes to the BCA. The bringing together of analytical data and stakeholders with diverse concerns in a well-structured and transparent process facilitated changes related to risk-informed performance criteria quantification that all involved could understand and agree to.

Related activities

Given their interest in advancing a risk-informed performance-based approach to building regulation, the IRCC held a workshop in 2006 to explore the use of risk in regulation (Meacham 2007b). The workshop included presentations from experts in risk and regulatory issues from outside the building regulatory environment, with discussion focusing on challenges faced in quantifying and presenting risk within regulations, and how the building regulatory community might take advantage of lessons learned from other regulated areas, including chemical process safety and nuclear power facilities (Meacham 2007b). The discussion was wide-ranging, and some key concepts which may impact the future of performance-based building regulation were agreed:

- A performance-based approach is characterized and recognized by the occurrence of five defined attributes: (1) a framework exists or can be developed to show that performance, as indicated by identified parameters, will serve to accomplish desired goals and objectives; (2) measurable, calculable, or constructable parameters to monitor acceptable performance exist or can be developed; (3) objective criteria to assess performance exist or can be developed; (4) margins of performance exist such that if performance criteria are not met, an immediate safety concern will not result; and (5) flexibility in meeting the established performance criteria exists or can be developed.
- Performance-based design can work effectively when expectations/outcomes are defined in terms of decision variables; specific damage measures are defined to measure these outcomes; and damage measures and performance outcomes are assessed based on evaluation of specific engineering demand parameters for events of defined magnitude.
- A performance-based framework should closely link loss objectives, performance metrics, and design approaches with probabilistic representations of hazards and expected losses. Such linking of risk and performance clarifies stakeholder expectations and engineering analysis, and opens the door for benefit–cost analysis and other mechanisms to be introduced to help decision-making, which in many cases, results in design strategies that go beyond current code requirements.

Overall, the outcomes of the workshop provided additional support for the concepts embodied in the IRCC hierarchy and the evolution of performance-based building regulations to a risk-informed performance-based format.

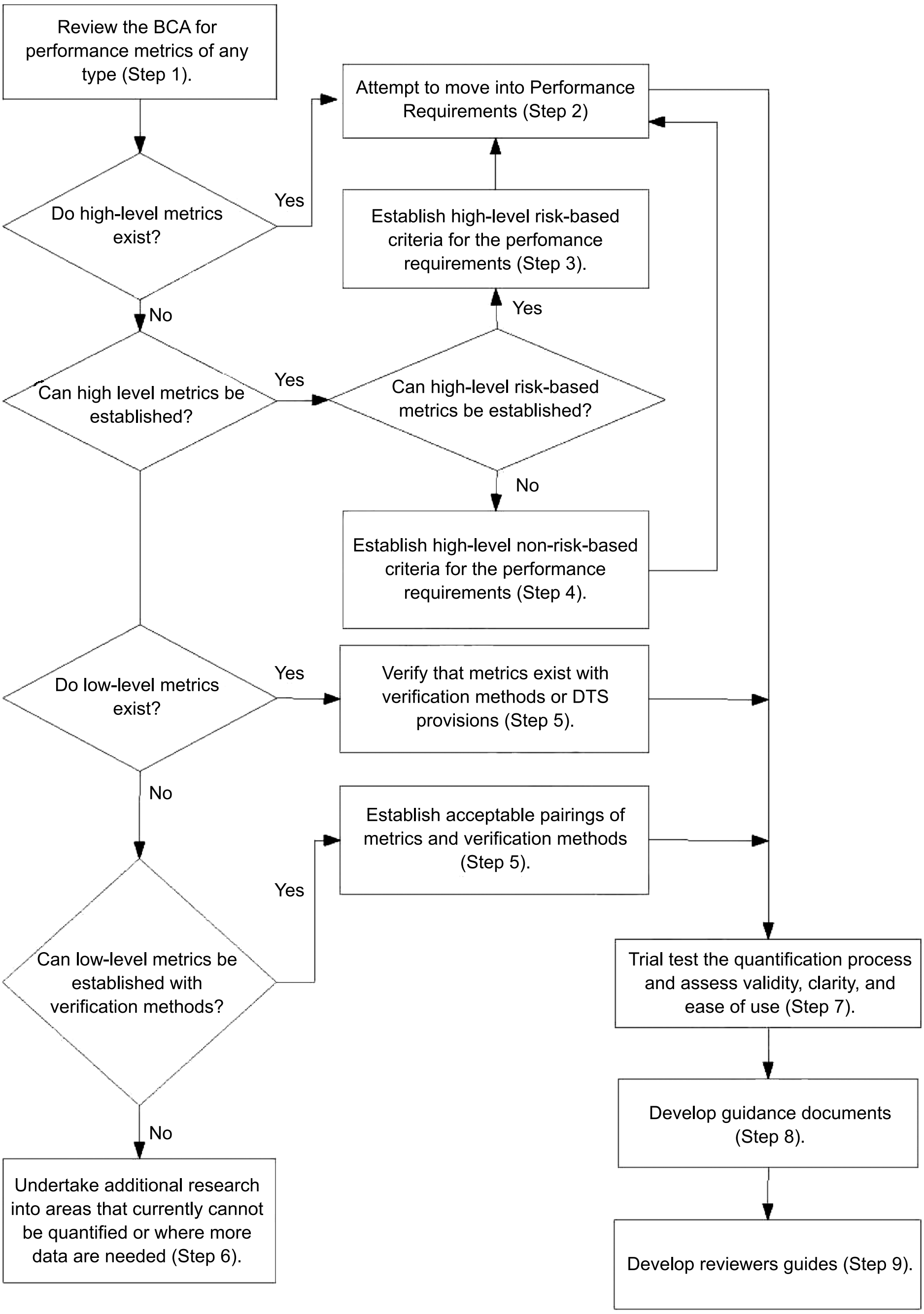


Figure 6. Quantification process for the BCA (Meacham 2008).

Conclusions

The concept of using risk information – particularly the levels of tolerable risk – to inform performance levels in building regulation is gaining traction in several countries. Building on concepts outlined by the seismic engineering community in the USA in the 1990s, and developed further by the ICC 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 analytical 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.

Acknowledgments

The author graciously acknowledges members of the IRCC for their support in the development and testing of many of the concepts outlined in this paper and for examples of how the transition to risk-informed performance-based building regulations is proceeding. This paper draws heavily from a paper published in the Proceedings of the Seventh International Conference on Performance-Based Codes and Fire Safety Design Methods, with text and images reproduced with permission of the Society of Fire Protection Engineers, for which the author is greatly appreciative.

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