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The New Zealand Building Code became mandatory in January 1993 and has requirements for building durability that apply across the whole Building Code. Over many years of testing and assessing the durability of building materials and systems, BRANZ has acquired a substantial knowledge and skill base in this area. In many cases, durability verification methods were based on 'first principles', since previous assessments were not available. This paper outlines the durability requirements of the NZBC, and the processes involved in providing evidence of durability. The general results and implications after seven years of a durability building code will also be discussed. The role of standards and their relationship to local conditions as a basis for 'Acceptable Solutions' or 'Deemed to Satisfy' provisions in a performance-based code is also examined. Brief descriptions of relevant examples of products and building systems, which have been appraised, are included.

1. Introduction

New Zealand is a country that is diverse in both geographical and climatic conditions and has a population of 3.6 million people [1]. The country is situated between 34ºS and 48ºS latitude and the South Island is subjected to Antarctic winds while the tip of the North Island is sub-tropical. New Zealand is exposed to high winds with coastal regions subjected to severe corrosion, and has earthquake zones and geothermal regions that provide a challenging environment for manufacturers, designers and regulators.

Prior to July 1992, residential and commercial building in New Zealand was carried out under prescriptive building regulations that were set by each local authority. Prescriptive regulations specify how buildings must be built, not what level of performance they must achieve. The clear advantage of prescriptive type regulations is that they are self contained, inclusive, and relatively easily enforced. A major drawback attributed to prescriptive systems is that they make it difficult introduce innovative new practices and materials.

New Zealand moved away from this type of regulation in 1992 with the optional introduction of the New Zealand Building Code (NZBC) [2]. This code is *performance-based* and has health and safety as its primary goals although some consideration is also given to protection of adjoining property and energy conservation. A performance-based building code sets out what must be achieved, not how it must be achieved. The NZBC has required performance levels in 35 areas, which must be achieved in order for a building consent to be issued. These areas include structural design, weatherproofing, energy efficiency, plumbing and durability.

Prior to the start of construction of any building in New Zealand, a building consent must be obtained from the local territorial authority. Before issuing the consent, the authority must have reasonable grounds to believe that the building if built as planned would meet the NZBC. While the NZBC allows for innovation, it was recognised that many buildings would be constructed along traditional lines and the added expense of proving compliance with the Code in these cases was a burden. To assist with this process 'Approved Documents' were also published with the NZBC. These include 'Verification Methods' and 'Acceptable Solutions'. These documents set out methodologies that allow builders and designers to show approving bodies that they have met the performance requirements of the NZBC. The acceptable solution are mostly based on traditional building standards that have proved to be satisfactory.

New Zealand and Australia have closer economic relationship (CER) agreements in place and these ties are becoming more substantial, especially through the harmonization of standards. New Zealand and Australia do not have the same building codes but the NZBC and the Building Code of Australia (BCA96) [3] are both performance-based codes with similar structures, with the Australian having been developed in part from the New Zealand code. They are both structured with objectives, functional requirements and performance requirements, but there is a significant difference between the performance requirements. The NZBC has a separate section for durability, which specifies minimum durability in years, for various components/systems of the building. BCA96 has no specific section on durability, however durability provisions are implied within the performance requirements of the specific parts of the Building Code, and sometimes implied or specifically stated in the 'deemed to satisfy' acceptable construction practice/manuals.

2. Performance Based Building Codes, an International Perspective

A prescriptive building code requires a code to be tailored specifically for local environmental conditions and to take into account local building materials, building practices and social customs. This makes it difficult for agreement to be reached on standardisation between countries where these conditions differ widely. In contrast, a performance-based code can embody local considerations in the higher-level performance clauses and allow joint development of standards to verify performance. Regulations or building codes, which are based on performance assessment, make international harmonisation of regulations easier and facilitate innovation [4].

International trade, for some nations, has been restricted through the use of 'de facto' trade barriers, such as standards and specification requirements. For the European Community (EC), the removal of the technical barriers to trade was implemented in 1957 and in 1980 for GATT. The current World Trade Organisation agreement (WTO) [4] notes that 'Wherever appropriate, parties shall specify technical regulations and standards in terms of performance rather than design or descriptive characteristics' (clause 2.4), in an attempt to reduce the impact of trade barriers. Even under these agreements, implementation has not progressed rapidly. This has been overcome, with some degree of success, by not harmonising every aspect of a product's property and performance, instead the requirements were focussed on the health and safety aspects and used the country of origin's requirements to specify the other product features and performances [5]. The current approach, which is winning international approval, is the production of mutually accepted product conformity and fitness certificates issued by an accredited national organisation, such as members of World Federation of Technical Assessment Organisations (WFTAO).

Performance-based building codes offer the opportunity for superior building quality. This is because the end-user of the product, through the designer, can specify from a larger range of approved materials, building systems, or innovative approaches with fewer restrictions. This type of specification increases the owners' and final users' assessment of the *quality* of the construction, because of reduced design compromises. (Where *quality*, in this case uses the BS4778: 1971 [6] definition, as the 'totality of features and characteristics of a product or service that bear upon its ability to satisfy a given need' [3]).

Ultimately, performance-based building codes allow architects and designers greater choice between traditional and innovative products by reducing technical impediments, as long as the performance requirements are clearly quantified.

3. Durability and Performance-Based Building Codes

The durability clause in the NZBC differs from the other thirty-four NZBC clauses, in that it contains specific default minimum service lives for buildings and their components. The durability provisions apply to any part of a building, which is fulfilling another code requirement (eg. structural stability), but do not cover aesthetic considerations [2,7].

The inclusion of the B2 'Durability' clause has caused considerable debate. In an ideal market economy, the customer would define their requirements and a contract would be negotiated on this basis with the supplier. As long as minimum health and safety requirements were met, the longevity of a building or its components would be a customer choice. Given that the Building Act [8], which introduced the NZBC, requires that owners must ensure that their buildings comply with the NZBC over their lifetime, it could be argued that specific durability provisions are unnecessary and, as is discussed later, difficult to operate. In practice, the market is poorly educated about materials performance and building serviceability. Ownership of houses also changes approximately every seven years, and subsequent owners are unlikely to be aware of decisions made by the first owner that may trade durability for lower costs, so minimum lifetime requirements for building elements are required.

The NZBC B2 'Durability' clause sets minimum lifetimes for building elements that are serving specific NZBC functions. The periods specified are 5 and 15 years, or the intended life of the building but not more than 50 years with normal maintenance included in these periods. The periods are based on the function of the element and the degree of difficulty in access and repair to the element. Structural elements, including structural fixings and bracing materials, have a 50-year requirement. Items that are very difficult to access or replace, or where deterioration could not be detected during scheduled maintenance, also have a 50-year requirement. Building elements, which are easy to access and replace have a 5-year requirement and a 15-year requirement covers the remaining elements. Table 1 lists select examples from the NZBC.

It is important to note that alternative building lifetimes can be specified at the building consent stage. For example, with some agricultural buildings a 15-year life may be appropriate. In these cases, the building would be subject to a demolition order after the 15-year period unless appropriate reports were provided to show that it would continue to meet NZBC requirements. With other structures, such as hospitals or bridges, a 100-year or more service life might be specified. In these cases, this becomes a matter of specification and contract between the client and the design/construction companies.

The 5-, 15- and 50-year periods are effectively an implied warranty by the material and components suppliers and the owner is required to ensure that the building still complies with the NZBC when these periods are exceeded.

Table 1: Selected examples of nominated building elements required to have 5, 15 and 50-year durabilities [2]

	Examples of durability required under NZBC B2.3.1		
Element	**5 Years**	**15 Years**	**50 Years**
Acoustic elements	Easy to access and replace	Behind non-structural claddings or linings	Integral with structural elements
Building paper and roofing underlay		Exposed to view and easy to access or replace	Access would require removal of masonry or concrete walls, clay or concrete roof tiles, or structural elements
Cladding		Non-structural cladding	Structural cladding (including bracing elements)
Damp-proof membranes (DPM and vapour barriers)		DPMs in easy to access subfloor spaces, vapour barriers behind non structural linings	Inaccessible tanking, DPMs under concrete floor slabs, vapour barriers behind structural linings
Doors	Internal doors and frames all hardware	External doors and frames	
Electrical work	Exposed fittings, and surface run wiring, wiring in easy to access ducts	Wiring behind lightweight linings, complex conduit runs in concrete or blockwork walls and floors	Wiring buried in or under concrete slabs, wiring behind structural linings without ducts
Flooring (sheet/strip material)	Flooring laid independent of bottom plates		Flooring laid under loadbearing bottom plates, flooring as a bracing diaphragm
Framing	Easy to access non-structural partitions eg non-loadbearing partitions		Structural framing (including bracing elements)
Insulation	Exposed to view eg under a raised pole house floor	Behind non-structural claddings and linings, and in roof spaces	Hidden behind masonry or concrete walls, or structural elements, or in skillion roofs
Interior wall linings	Easy to access linings		Structural linings
Plumbing	Exposed piping, fittings and valves	Piping, fittings and valves behind wall linings or in skillion roofs having no maintenance provision	Piping, fittings and valves buried in or under concrete slabs or in masonry cavity walls and not ducted or provided with access maintenance access

This ultimately means designers/architects must seriously consider the durability of the material in the specific location (environment) for the required lifetime, and what maintenance would be required to ensure such durability is obtainable. The most significant factors in durability are the climatic factors such as rainfall, relative humidity, temperature, orientation/ exposure to sunlight, local wind patterns, and pollution of air and water [9]. Geographical aspects such as proximity to the sea, sheltering from prevailing winds, elevation above sea level, and design issues of microclimates in and around the structure are also important.

NZBC Clause B2 assumes normal maintenance is necessary to meet the specified lifetime for building components. If no maintenance is specified in the technical literature provided by a manufacturer, then the user could expect a product to be durable without maintenance, which is nonsense in most situations. Maintenance requirements reduce the possibility of premature failure and increase life expectancy and include washing surfaces to remove dirt and contaminant build-up, painting, replacing sealants and high wearing parts such as washers. It is important to note that some materials such as steel bolts, reinforcement, brick ties, etc., may be incorporated into the building and effectively no maintenance is possible.

4. Impact of Performance-Based Building Codes

Some societies in the developed world are now questioning the impact of urbanisation, building aesthetics and visual pollution. Furthermore, the environmental impact of material usage and the ever increasing pressure to use recycled or recyclable materials, e.g. ISO 14000 ‘Environmental Management Systems’ [10], will in the future affect the decisions made at the design stage of buildings. The implementation of performance-based building code promotes innovation and can accommodate changing societal needs and desires.

An unexpected outcome to performance-based building codes has been a reduction in the common building practice of materials substitution. The process where the architect designs and specifies materials and subsequently the builder substitutes another product has significantly reduced. In New Zealand, for example, it was common for substitution of items such as screws, nails, nail plates and anchors, building papers, corrugated galvanised or zincalume steel products, timber, particleboard and paints [11]. The substitution of products, which ‘looked the same’, can have serious effects since they may not have identical performance or durability in all situations. For example, if the substitution occurred in a part of a system which provided structural integrity or fire safety, the results could be collapse or loss of life in a fire. Another example is a wall bracing system used in specific design for seismic and wind resistance. The properties of the lining material, fasteners, and framing material all play an important role in establishing the bracing resistance. Substitution of any of these components in thickness or shape/design could produce unforeseen changes in the system performance, which in turn affects durability. An option for substitution exists when a product is specified through a product standard.

5. Testing and Durability Verification of Building Materials at BRANZ

As previously mentioned, the NZBC B2 includes a Verification Method (VM1) and an Acceptable Solution (AS1). B2 VM1 provides three methods of verification of durability performance; history of use, laboratory testing and assessment of the performance of similar products. The most common method of assessing durability of a product, particularly at the time of NZBC implementation, used the past performance of products and systems. VM1 provides guidance on what issues are important in this process but does not provide a prescriptive methodology. Issues raised include:

- length of service
- environment of use
- intensity of use
- compatibility with adjacent materials
- limitations in performance
- degree of degradation and
- changes in formulation.

This method cannot be applied to new products but valuable information can be obtained if the new product is similar to an existing product that has been successfully used for a similar application for the same climatic conditions. This is an acceptable approach if the mechanisms involved in material degradation for various climatic conditions are understood, which in turn allows confident predictions of long-term durability. To assist with predicting durability of components, environmental studies can be carried out to identify areas where higher rates of degradation occur. The presence of airborne pollutants such as sea salt, sulphur dioxide, oxides of nitrogen, hydrogen sulphide, particulate of carbon, high UV exposure, severe temperature ranges or high humidity can all or individually cause degradation. The results of these studies can be used to determine and map regions of common ranges of degradation rates for specific materials. An example of this is the AS/NZS 2312 [9], which identifies environmental corrosivity zones in New Zealand. These standards are based on substantial research and historical data.

Where the product is new and no ready comparison is available, then a regime of performance testing is prescribed. The most reliable option is exposure in the intended end-use environment (i.e. marine, rural, industrial). However, in-service history studies usually require long timeframes that pose major problems when new products are introduced to the market. Accelerated or laboratory testing provides results in a shorter time frame, which makes them a popular choice with manufacturers. There is a wide range of accelerated tests available. An example is the weatherometer, a commonly used accelerated testing device for determining polymer durability. This equipment provides ultraviolet light (UV) at high intensities using UV sources such as xenon arc while varying temperature and humidity. For material testing, the application of environmental variables is important since it is common for interactions between these factors to occur [12].

Accelerated laboratory tests, even when carried out to a recognised standard test method, can produce results that do not represent the deterioration occurring in real life building applications. They require an understanding of the mechanisms of degradation and the microenvironments to which the material may be exposed in service [13]. NBZC B2 recognises this and gives general guidance on how such tests are to be assessed. Factors such as:

- types of degradation mechanisms likely to be induced by testing
- the degradation mechanisms likely in service
- details of methods of assessment
- variability of results and
- the relevance of the test to the building element under study.

6. Role of Standards

As noted above, standards provide an important support role for a performance-based building code. Verification of performance is required to establish code compliance regardless of whether an acceptable solution or specific performance-based design is used. Many Acceptable Solutions or Deemed to Satisfy documents are based on historical building practices or industry standards that have been developed over time.

With respect to durability, there are large numbers of standards available worldwide which purport to assess some aspect of material durability. These include exposure tests, heat aging, moisture testing, freeze/thaw etc. These tests all assume that the mechanisms responsible for deterioration have been identified and that the test regime is suitable. Historically, uniform testing standards were formalised as test methods/procedures, which include report requirements. The objective is to limit the variation between test facilities and to provide a common ground for comparison of test results. Experience has shown in many round-robin tests for ASTM in America, that uniformity can sometimes be difficult to achieve. Not only is it difficult to achieve consistency in a test method but also the actual standard may have limited applicability. For example, the International Organisation for Standardisation ISO9223 predicts corrosion rate classes for steel and zinc, based on meteorological data, and pollution (SO_2 and chloride levels) [14]. ISO 9223 has been shown to have severe shortcomings in predicting corrosivity levels in a number of regions in the world, including Australia, New Zealand, the Philippines and Russia and the investigations found that “ISO 9223 is in any case a poor predictor of corrosion rates (of zinc especially) in tropical and temperate marine environments” [15].

Ideally, an assessment of durability and any accelerated test should be based on an understanding of the:

- performance requirements in the specific application,
- properties of the material,
- agents likely to cause degradation,
- mechanism(s) of degradation.

These steps apply for each assessment carried out. As discussed previously, NZBC B2 VM1 provides some guidance in this area, but it is limited in scope. Some standards have been developed which instead of prescribing a set-testing regime, give guidance on how to develop test procedures. ASTM E632 [16] is a good example, which sets out a process for devising accelerated test methods. Other standards and documents have been produced which take a wider view than testing and focus on the process of determining service lives for buildings and components. A CIB and RILEM committee (140-TSL/CIB W80) has produced publications [e.g. 17, 18] covering both service life prediction and the gathering of data for use in service life prediction. The British Standards Institution published BS 7543 [19] and the Architectural Institute of Japan a guide [20], both providing guidance on service life planning. Work is currently underway in ISO to produce standards covering the design life of buildings. ISO TC 59 “Building Construction” Subcommittee 14 “Design Life” is working on six draft Standards titled “Buildings – service life planning. ISO 15686 Part 1 “General principles” and part 2 “Service life prediction principles” are nearing final publication. These Standards draw on existing work and provide guidance on how to assess the service life of building components. They are likely to be referenced in future revisions of the Verification Method for NZBC B2 and are a logical inclusion in any performance-based building code that includes durability provisions.

7. Appraisal of Products and Building Systems

BRANZ carries out product appraisals in New Zealand and Australia. Product appraisals are not mandatory but provide Territorial Authorities with independent third party opinions on compliance with the NZBC (or BCA96 if relevant) as well as checks on manufacture and 'buildability'. A third party appraisal is required if a manufacturer is applying for a product accreditation through the Building Industry Authority who administer the NZBC. A BIA Accreditation ensures automatic acceptance throughout New Zealand. Products that BRANZ has appraised range from simple stand alone building components to complete building systems. For each of these Appraisals, an assessment of durability is required. This will be against the NZBC B2 requirements if applicable, and an estimate of serviceable life as well as ultimate will usually be attempted. Most of the products assessed for 50-years durability have had a reasonable history of performance or are products that generically have a long history of use. These include standard structural building materials such as steel, concrete, timber and masonry, and composite products based on adhesives with durable adhesives such as phenol formaldehyde or, for interior use, melamine and urea formaldehyde. Structural adhesive jointed systems have largely been restricted to epoxy and phenol/resorcinol based products. This is mainly due to the difficulty in sourcing adequate durability information and a reluctance by manufacturers and users to embark on extensive test programmes. Items requiring a 15-year durability cover the full range of materials and are based on historical data, environmental data combined with an analysis of degradation mechanisms and accelerated aging. Galvanised steel roofing and accessories are assessed using corrosion rate data reported by BRANZ [21]. Factory-coated galvanised steel in addition would undergo salt spray testing and outdoor exposure as well as an assessment of coating formulation and profile radii [22] Plastic cladding products will be assessed by outdoor exposure and accelerated weathering using a xenon arc to ASTM G26 [23], followed by impact resistance testing. Any durability assessment will involve looking at all available data on the product or system being evaluated. Test reports from overseas laboratories are commonly part of the available data. The usefulness of these reports depends on the approach taken by the testing laboratory in assessing what testing to carry out and the actual methods used. Claims such as "weathered for the equivalent of 20 years in a weatherometer" are of very limited use and a test report complying with an internationally recognised standard is preferred. This enables the results to be interpreted in the context of local conditions.

Product assessments from members of the World Federation of Technical Assessment Organisations such as British Board of Agrément (BBA), Centre Scientifique et Technique du Bătiment (CSTB), or Australian Building Systems Appraisal Council (ABSAC) are also valuable supporting data. As internationalisation of standards proceeds, interpreting test data from overseas will become simpler and provide more useful input into the product appraisal process.

8. Feedback after Seven Years Experience at BRANZ

One of the main criticisms of NZBC B2 Durability by the New Zealand construction industry is the lack of detail in the Approved Documents. Manufacturers' frequently want to assess the durability of a new material or system or may be using a conventional material in a new application. They find the lack of a list of specific test methods, which will give them a durability rating of 5, 15 or 50 years frustrating. The difficulty of including material test methods in an Acceptable Solution or Verification Method that will provide reliable estimates of performance has been discussed earlier in this paper. Materials suppliers have also generally proved reluctant to invest the time and money into establishing reliable service life assessments. With complex building systems, such an assessment could take some years and cost over NZ$100,000. The option most commonly taken is to attempt to establish whether a material's durability is likely to meet the minimum NZBC criteria rather than establish what the actual expected life might be. In many cases, the minimum NZBC criteria are somewhat less than what the market expectation may be (e.g. a wall cladding lasting only 15 years). Despite this, there is no doubt that there has been an improvement in the quality of technical literature provided by manufacturers. This literature is now much more likely to contain information on installation, required maintenance and limitations on use.

The introduction of new innovative building solutions will be enhanced by continued improvement in durability prediction tools that enable better prediction of material durability. An important aspect of this will be the continued development of databases of environmental degradation factors that can be used to provide more accurate input into durability assessments. The use of national climatic data obtained by meteorological observation stations has the potential to supplement localised exposure studies if a relationship between the two can be established. An example of this is corrosion-mapping data gathered in New Zealand over 10 years [24], which has been used to define corrosivity zones. This data has been used in New Zealand Standard NZS 3604 [25] which is also referenced in a NZBC Acceptable Solution B1/AS1 [2]. Research underway aims to establish a relationship between sea salt aerosol properties and wind speed/direction data to enable the corrosivity mapping to be extended without costly and time consuming extensive corrosion surveys. This data will eventually be used in graphical information systems to improve end-user access.

An unresolved issue associated with the NZBC is that it does not state what an acceptable level of risk is. Historically, the level of defects, which can be tolerated in buildings, is set largely by society through codes and standards and tends to be very small. The actual value being a compromise between safety and cost. Engineers are used to including risk in structural calculations and the Approved Documents for NZBC clause B1 Structure cover this aspect. At this stage, very few durability assessment techniques provide a statistically-based service life for use in engineering calculations or for demonstrating compliance where other NZBC clauses are concerned. Work being carried out in a number of countries is attempting to bring engineering concepts such as reliability theory into durability design [26, 27, 28]. This approach requires quantification of agents causing degradation for each material as well as models that can predict degradation under a range of environmental conditions.

9. Summary

Performance-based building codes are the direction favoured in the developed world to enhance trade opportunities and reduce the encumbrance of de facto trade barriers such as prescriptive codes and specifications. With the introduction of internationally accepted testing methods, and registered test facilities, the introduction of new building technology will occur at a faster rate for those countries that have accepted harmonisation of standards.

The acceptance of a performance-based building code with a durability clause, as New Zealand has, provides freedom for designers/architects in selecting materials/subsystems and invites innovation.

With over seven years experience, BRANZ has found that durability prediction for performance-based building codes is not without problems but these are predominantly related to the transition from a prescriptive to a performance-based system, suppliers not providing reliable service life predictions for their products, materials, or subsystems and a shortage of reliable service life prediction methodologies. The verification of the performance of building components to 50 years can be difficult and this requires an approach based on an understanding of the mechanisms of degradation. When these mechanisms are applied with knowledge of the required performance criteria and the quantification of the agents causing degradation, performance can be predicted. With the development of more localised verification models, which will refine international models and standards, more reliable prediction of performance should result.

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