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A Guide to the Performance Expectations of New Zealand Housing Systems

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PERFORMANCE EXPECTATIONS OF NEW ZEALAND HOUSING SYSTEMS

1. INTRODUCTION

The primary objective of this guide is to detail the performance expectations of New Zealand housing systems. The aim is to prescribe quantified values where possible. The expectation is that this guide will provide a rational basis upon which innovative systems can be assessed and compliance with the performance requirements of the New Zealand building control framework verified. The emphasis is on the 'in-service behaviour of building systems' with discussion generally on what agents may be expected to be acting on the system when it is installed into the completed house. Problems and limitations of this holistic approach are discussed and remedies recommended.

In most cases the structural performance criteria stated reflect those attained by buildings built in accordance with the New Zealand light timber framing standard NZS 3604:1990 'Code of Practice for Light Timber Framed Building Not Requiring Specific Design' (SNZ 1990). The guide attempts to highlight issues related to the means of verification of such systems, particularly as they influence prototype testing, one recognised means of performance compliance determination.

The primary focus of this guide is on the structural aspects of system performance. These issues are discussed in detail. Other non-structural performance expectations are also discussed but usually in more general terms. While the specific performances demanded for compliance with the New Zealand Building Code (NZBC 1992) are the primary measure, other market force driven expectations are identified and included where appropriate.

Suggestions as to how the New Zealand industry expects information of this type to be presented is given in Section 6 below. The various, often disparate, needs and expectations of the numerous end-users are identified. They are intended to provide some assistance to those with marketing and publication responsibilities within the industry.

2. SCOPE OF APPLICATION

This guide is intended to be used as the basis for considering the performance of houses which fall within the following scope:

- One or two family dwellings.

- One or two storey detached single occupancy family dwellings, including split-level construction and developed roof space dwelling areas which do not exceed 50% of the ground floor plan area.

- Buildings where the slope of any roof plane is less than 60° to the horizontal.

- The overall maximum building height (from the lowest ground adjacent to the highest point of the roof) shall not exceed 10 m.

- Buildings where the supporting ground has a safe bearing capacity not less than 100 kPa.

3. PERFORMANCE-BASED HOUSING IN NEW ZEALAND

3.1 General

Building owners are naturally conservative when experimenting with new systems. The market expects new systems to be sound economically (both initial cost, in-service costs and secondary costs such as resale effects), to have clearly defined maintenance requirements and overall to have assured sound in-service performance. New systems are expected to perform at least as well, if not better, than their traditional alternatives both at the time of installation and throughout their intended life. The promoter of any such system must accept responsibility to provide evidence that these performance expectations will be met. They must also have a credible long-term presence both with regard to their product and to their ability to provide the necessary ancillary support and maintenance network required for the product or system.

For a building component or system to comply with stated performance criteria, be they mandatory such as those prescribed in the provisions of the New Zealand Building Code (New Zealand Government, 1992) or voluntary such as this guide, there is a requirement to verify that the response of the system is within specified limits when they are subjected to the action of the various agents to which they will be exposed in service. Verification of any such performance can be demonstrated by calculation, by prototype compliance testing (either when installed or within a laboratory) or by expert judgement.

To define 'System Performance' two essential features must be prescribed, namely the agent being applied and response of the system to that agent. The agent may be a physical load such as wind load or occupancy load, or environmental loads such as temperature or moisture. The response of the system to such agents is the change of physical or chemical properties resulting from the application of that agent. 'Acceptable performance' requires limiting the system response to acceptable values when subjected to the action of agents of an intensity of sufficiently remote frequency of occurrence.

Statistically sound data is needed as to the intensity/recurrence relationships of the agent being imposed and the system response to such actions. For structural assessments loads or forces are generally the agents applied. The intensity and distribution of such actions with an appropriate probability of occurrence are prescribed in the New Zealand Loadings Standard, NZS 4203 (SNZ 1992). For non-structural agents such as temperature or sunshine, specific design data may be gained from the National Institute of Water and Atmospherics.

As an example, wall framing elements satisfy the onset of criteria associated with crack development of a sheet lining under face load when they are shown to dependably deflect less than their height/400 when subjected to serviceability design wind pressures. The 'dependable performance' of the resistant system requires several 'typical' samples to be assessed and the resulting deflections to be statistically manipulated to show the results are an acceptable lower bound for the system being assessed. The 'serviceability design wind pressure' is codified within the New Zealand loading standard (SNZ 1992) as that resulting from wind speeds which have a 5 percentile probability of being exceeded in any year at the given location.

The response of the system to the application of the nominated agent can be assessed by calculation (when the appropriate physical properties of the system are known or can be reasonably assessed), by physically testing either the completed system or a laboratory prototype of the system, or by applying expert judgement (often derived from consideration of in-service behaviour of similar systems).

Methods by which compliance of the system to the required performance can be assessed are discussed in Section 4 below.

3.2 New Zealand Building Code Provisions

The performance of building products and systems acceptable for use in New Zealand either fulfil a mandatory function prescribed by the New Zealand Building Code (NZBC) (in which case they must fulfil that function for the design life of the component) or they fulfil some other function which, although not prescribed within the Building Code and is therefore not mandatory, is reasonably expected by the home owner/occupier.

The Building Code provisions which have direct application to housing are listed in Table 1. Functional requirements with specific application to multi-tenancy buildings are marked with *[1] and printed in italics. Code provisions which are peripheral to the building fabric (ie have little or no influence on the elements which form the primary structure and the building envelope) are identified with*[2]. These fall outside the scope of this guide and are not included in the further discussion.

Table 1: Approved Document provision applicable to housing

Clause	Subject	Domestic application
B1	Structure	Adequate stiffness for amenity preservation and strength for stability and collapse avoidance.
B2	Durability	Longevity of required compliant components.
C1	Outbreak of Fire	Chimney and fireplace provisions.
_C2_	_Means of Escape_*[1]*[2]	_Fire escape routes and means of emergency egress for which compliance is usually readily achieved, and applicable to domestic construction._
_C3_	_Spread of Fire_*[1]	_Fire resistance ratings of external boundary walls, and inter- tenancy partitions._
_C4_	_Structural Stability in Fire_*[1]*[2]	_Assurance that structural stability is achieved throughout the duration of the fire._
_D1_	_Access routes_*[1]*[2]	_Disabled Person access and vehicle access provisions._
E2	External Moisture	Preclusion of the ingress of rain and other natural sources of moisture either into the building or the building fabric.
E3	Internal Moisture	Preclusion of spread of internal water (from bathrooms, laundries, kitchens).
F2	Hazardous Building Materials	Provisions for the use of safety glass and glazing panels.
F4	Safety from Falling*[2]	Handrail provisions around steps and balconies.
_F6_	_Emergency Lighting_*[1]*[2]	_Lighting requirements for emergency egress._
G1	Personal Hygiene *[2]	Privacy and sanitary fitting requirements.
G3	Food Preparation *[2]	Requirements for appliances and food preparation areas to ensure food preparation areas are easily cleaned.
G4	Ventilation	Natural and forced ventilation requirements.
G5	Internal Environment *[2]	Temperature controls which apply to old-people's homes and child care centres only.
_G6_	_Sound_*[1]	_Provisions for the control of impact and airborne sound._
G7	Natural Lighting	External window provisions and acceptable reflectance levels. Includes the amenity provisions of awareness of outside environment.
G8	Artificial Lighting *[2]	Required minimum lighting levels.
G9	Electricity *[2]	Provisions & requirements for electrical reticulation and appliances.
G11	Gas Supply *[2]	Reticulation pipe sizes, together with gas meter location requirements.
G12	Water Supply *[2]	Hot & cold water supply and reticulation requirements.
G13	Foul Water *[2]	Waste water disposal requirements.
H1	Energy	Thermal energy efficiency of the building envelope.

Note: *[1] Provisions in italics relate to multi-tenancy residential units
*[2] Provisions which have minimum effect on the fabric of the building

3.3 Structural Performance Provisions

Clause B1 of the NZBC stipulates that elements which are part of the primary structural system of the building (ie providing primary support to the building) are required to:

a) be sufficiently rigid that their deflection is small enough to avoid interfering with the amenity value of the building when subjected to more moderate events, such as may be expected to occur several times during the life of a building (these being serviceability limit state considerations).

b) have the capacity to resist, without rupture, instability or collapse, actions of great intensity which may be expected from very rare, extreme events such as severe earthquakes or extraordinary winds (these being ultimate limit state considerations).

These requirements are required to be satisfied for each action and combination of actions which can reasonably be expected to be applied to the building once or more often during its design life.

The five primary load categories for buildings are nominated within the New Zealand Loading Standard NZS 4203 (SNZ 1992), namely:

a) the dead load of the structure, denoted by the symbol G and representing the self weight of the structure and the permanent portion of any imposed live load;

b) the live or variable load, denoted by the symbol Q and representing the variable load imposed on the building by its occupants and contents;

c) the wind induced forces, represented by the symbol W and resulting from local wind flow acceleration effects as the wind flows around the building;

d) the earthquake induced actions denoted by the symbol E and representing the inertial effects of the building mass as it experiences dynamic ground motion initiated by earthquakes; and

e) loads induced from nature such as ponded rainwater, snow or ice and any lateral pressures resulting from retained soils. These are denoted by the symbol S.

- Gravity induced actions such as dead load and live load are generally easy to understand and are purely the reaction of the mass or object as it is supported by the building. Such actions are applied vertically downwards. Live loads are often classified by the contact area between the body imposing the load and the item resisting that load. These may be concentrated loads (such as those imposed directly from individual people, or from the legs of furniture or storage items), line loads (such as those imposed by upper walls) or uniformly distributed loads (UDL) (commonly assumed when no specific detail on the load pattern is available).

- Wind loads are applied to exposed surfaces of buildings. They result from local acceleration effects as the wind is forced to disperse laterally around bluff objects such as buildings. Generally the wind speed increases with height above the ground since the influence of ground surface drag decreases. The wind pressure varies as the square of the wind speed. The wind forces imposed on buildings are usually very large at corners and openings (typically two to three times above the average pressure). Wherever the wind stream separates from the building face, local suction zones are created. This induced suction can pull claddings from the building face. Both wall claddings and roof sheathings are subjected to these suction effects. Where the building leaks and allows air pressure to build inside, then internal pressure effects also need to be considered. Tables of both the regional wind speeds appropriate for each limit state, and external and internal pressure coefficients are published in NZS 4203 (SNZ 1992). For houses, a wind zone approach has been used within the New Zealand light timber framing standard NZS 3604 (SANZ 1990). The design wind speeds are prescribed in table 2.4 of that standard. The Serviceability and Ultimate Limit State wind pressures are shown in Table 2 below.

Table 2: Design wind pressures for New Zealand wind zones

	Nominal Design Wind Speed (m/sec)	Ultimate Design Wind Speed (m/sec)	Serviceability Design Wind Pressure (kPa)	Ultimate Design Wind Pressure (kPa)
Low	32	35	480	735
Medium	37	40	625	960
High	44	45	790	1215
Very High	50	50	975	1500

(Note: The nominal design wind speeds in column 2 are those printed in NZS 3604:1990 but were prepared from NZS 4203 prior to the inclusion of the ultimate limit state multiplier of 0.93. This has been included and the results rounded to the ultimate design wind speeds given in column 3. The ultimate limit state pressures are calculated from $P=0.6\ V^2$, with the ratio of $(0.75/0.93)^2=0.65$ being applied to the ultimate design wind pressure to determine the serviceability design pressure.)

- Earthquake induced loads are internationally less common. Only in seismically active countries are house designers required to consider earthquake induced loads. Earthquake forces are generated by ground motion induced inertial effects imposed on the building and its contents. Such actions are generally only considered to be applied laterally (ie resulting in translational slip of squat buildings or overturning of tall slender buildings or components). When designing for earthquakes, it is usual to distribute the building and occupancy masses at each floor, and to impose the dynamic motion of the ground and any structurally enhancement to that mass. Whilst this is a convenient tool used for analysis, it is some distance from the random response that actually is imposed on the building during an earthquake attack. Features which significantly influence the dynamic response of buildings during an earthquake attack are:

  1. the geometry of the building itself (ie whether it is regular in plan and vertical stiffness)

  2. the actual in-service elastic and post-elastic lateral stiffness of structural components themselves, together with the influence the non-structural component may have on that lateral stiffness

a) prior to the onset of damage to these components
b) following the onset of non-structural damage.

Thus features such as building geometry and elemental interaction will have a significant influence on the dynamic response of the building during earthquake attack. Thus earthquakes are not only uncommon experiences, they also apply loads which are unique in that they are lateral in direction and cyclic in character. In an attempt to provide security against collapse for such uncommon loading situations, New Zealand practice is to utilise and control the post-elastic response of systems under severe earthquake excitation. Damage is expected under such attacks, but the system is required to be detailed so as to ensure that collapse is prevented. The ability of the structural system to accept and maintain lateral load carrying capability without significant strength loss is known as its 'structural ductility' and is a very important parameter for aseismic design of New Zealand buildings.

- Water induced loads such as snow, ice or ponding effects, together with retained soil pressures have both a vertical gravity induced component (ie their weight) but also a lateral component which prevents them from spreading. Such lateral or retaining actions generally vary with the depth of the retained material. The intensity of this lateral pressure is zero at the free, unretained surface. The intensity of the lateral component depends on the character of the material retained but typically varies from 1 to 0.33 of the vertical load imposed.

Loads from each load case can sometimes be applied individually, or may be applied in combination. Load factors are published in the New Zealand Loading Standard, NZS 4203:1992, for each load and load combination, for consideration of serviceability limit state considerations and for assessing their ultimate capacity. These are reproduced here in Table 3: Load factors for each limit state, for easy reference.

Table 3: Load factors for each limit state

	Serviceability	Ultimate Limit State
Dead load only	G	1.4G
Dead and live load	G&ψQ	1.2G&1.6(ψQ)
Dead and wind	G&W_s	1.2G&W_u↓
Wind suction	W_s	0.9G&W_u↑
Dead and earthquake	G&E_s	1.2G&E_u
Dead and environmental	G&S_s	1.2G&1.2S_u

{Notes: The symbols used in Table 3 represent the following actions

G = Gravity or Permanent Loads

Q = Occupancy or Live Loads

ψ *= Live load duration effect multiplier*

W = Wind Effects

E = Earthquake Effect
S = Snow, water, earth or other environmental actions
Subscript s for serviceability and u for ultimate limit state intensity actions}

3.4 Durability Provisions

Clause B2 'Durability' of the NZBC prescribes the expectations with regards to elemental degradation with age or while in service.

The provisions of this clause apply to all elements which combine to fulfil one or more of the mandatory functional requirements of the Code (refer Table 1). The durability provisions are included in recognition that systems are required to be sufficiently durable to fulfil this function for the duration specified in clause B2.3 (reproduced here as Table 4). Although provision is made to nominate an 'intended building life' less than those specified in clause B2.3, adoption of short life buildings is rare.

Table 4: NZBC Clause B2 Durability performance requirements

B2.3 From the time a code compliance certificate is issued, building elements shall with normal maintenance continue to satisfy the performance of this code for the lesser of the specified intended life of the building, if any or:	
(a)	For the structure, including building elements such as floors and walls which provide structural stability: the life of the building being not less than 50 years
(b)	For services to which access is difficult, and for hidden fixings of the external envelope and attached structures of a building: the life of the building being not less than 50 years
(c)	For other fixings of the building envelope and attached structures, the building envelope, lining supports and other building elements having moderate ease of access but which are difficult to replace: 15 years
(d)	For linings, renewable protective coatings, fittings and other building elements to which there is ready access: 5 years

Examples of elements which require less than the 50 year durability requirements are presented in Table 5.

Table 5: Examples of elements required to have 5 and 15 years durability

5 Years Durability	15 Years Durability
Wall & ceiling linings	Structural suspension systems for ceilings
Floor coverings in wet areas (bathrooms, laundries, etc.)	Internal wall and floor secondary elements (doors, windows, trapdoors, etc.)
Interior and exterior coatings used as protection against moisture	Waterproof linings in showers and around wet areas such as baths and tubs
Exposed electrical and plumbing fittings	Impervious barriers to protect adjoining property
Signs	External envelope (walls/roof cladding and sheathing)

Hot water cylinders	External envelope secondary elements (windows/doors/skylights) Services: high temperature flues

3.5 Fire Control Provisions

Clause C 'Fire' of the NZBC controls **fire related issues** of buildings. It is split into four subclauses. The provisions of Clause C1 'Outbreak of Fire' control combustion at its source, which for housing typically relates to open fires, solid fuel appliances (fire places), their chimneys and their surrounds. The provisions of Clause C2 'Means of Escape', while applicable to detached houses, are usually readily complied with and thus somewhat trivial for this subset. However the provisions of both Clause C2 and Clause C3 'Spread of Fire' are applicable to multi-tenancy housing (where a safe means of escape and fire cell separation is required) and those built near property boundaries (where fire spread is to be inhibited). A guide to applying the fire-related Approved Documents to low-rise buildings has been prepared by BRANZ (BRANZ 1994). It provides a simple path for low-rise building compliance to be attained through the Approved Documents.

Alternative solutions can be developed using a rational fire engineering approach. The mandatory performance requirements of the Code itself must be complied with in these cases. The solutions derived are commonly specific to the particular case and generally less onerous. The input parameters for such a design approach are the fire spread characteristics, with the resistance being determined from the high temperature structural properties (strength and stiffness) of the materials and the flame spread characteristics of the linings present. Suppliers of innovative housing systems to be used within multi-tenancy developments will need to provide this information as input parameters for either compliance path.

3.6 External Moisture Control Provisions

Clause E2 'External Moisture' of the NZBC controls the **ingress of external moisture** (eg rain, snow, humid air) into the building. Such measures may related either to moisture entering either the habitable space or entering the building fabric itself. This part recognises the effective shelter provisions of buildings. The majority of in-service problems and failures of housing systems relate directly to accidental moisture ingress into the building envelope. Dimensional changes (causing cracking, splitting and a further breakdown of the weathering membrane) and the consequential deterioration of elements which are exposed to any such moisture ingress are some of the more common consequences of inadequate moisture control measures. Often the durability provisions of Clause B2 will directly depend on both the external and internal moisture control measures being effective. For new or innovative solutions, demonstration of compliance with these provisions will be important. While there are no prescribed verification methods contained within the Approved Documents as they relate to Clause E2, Acceptable Solution E2/AS1 depicts several solutions which are deemed to satisfy the intended performance requirements of this Clause.

3.7 Internal Moisture Control Provisions

Clause E3 'Internal Moisture' of the NZBC controls the **unacceptable accumulation of moisture** within the building. Such controls are needed to both provide a suitable, healthy internal living environment for the occupants, and to prevent premature deterioration (durability problems) of the building fabric which may result from condensation or other moisture-related problems associated with water introduced within the house. These provisions apply specifically to rooms in the house where either free water is present, or where high humidity is to be expected (ie laundry and bathroom). No Verification Method is prescribed in regards Clause E3 within the Approved Documents to the NZBC. Acceptable Solution E3/AS1 prescribes control measures which prevents the penetration of free flow water to other tenancies within the building by providing impervious coatings to walls and floors in areas where overflow or splashing may occur. Fungal growth is prevented by controlling condensation by prescribing minimum levels of thermal insulation in walls and ceilings and ventilation which requires minimum air changes per hour (being 2 for kitchens, bathrooms and showers and 0.5 for other rooms). While the provision of surfaces that are 'impervious and easily cleaned' is required under other provisions within the Code, Acceptable Solution E3/AS1 provides solutions for both floors and walls which are Deemed to Comply with the Code's intention. Thus floor may be covered with vinyl sheets, ceramic tiles (with waterproof grout) or steel float finish concrete, while walls may be similarly lined or be finished with laminates, high gloss paint or washable wall paper. Such coatings are required to have a five-year durability, after which time they are expected to be either renewed or replaced.

3.8 Hazardous Materials Control Provisions

Clause F2 'Hazardous Building Materials' of the NZBC controls the **use of hazardous materials** in buildings. These provisions may relate to systems which are themselves hazardous (eg where safety glass is required) and also to materials which may release hazardous matter into the building (eg asbestos or phenolic aromatics). The stated objective of ensuring a safe building environment may prevent the use of given materials, or may reduce their use, often by referring to deemed to comply solutions (such as in the case of safety glass the provisions of NZS 4223 'Code of Practice for Glazing in Buildings, Part 3 Human Impact Safety Provisions' (SNZ 1993)).

Clause F4 'Safety from Falling' stipulates the need for protective barriers to **avoid injury from falls**. The provisions of this clause are directed to the providing of handrails and other barriers which do not affect the building fabric and as such are not discussed within this guide.

3.9 Provision of Services

Clause G 'Service' of the NZBC controls the **provision of services** into the building. It is split into 15 Clauses each of which address an aspect of the services present in New Zealand buildings. Several relate to buildings other than houses (refer Table 1) and most address specific provision of services themselves. As such they have only an indirect influence on the building fabric itself and as such are not included in this guide.

Clause G1 ‘Personal Hygiene’ stipulates the requirements for the **provision of sanitary fittings** as a means of safeguarding people from illness caused by infection or contamination and from loss of amenity arising from the absence of appropriate personal hygiene facilities. Requirements as to the number of such fittings and the requirement to ensure an adequate level of privacy and security with regards to personal hygiene are included. The privacy and security provisions of the Acceptable Solutions G1/AS1 require partitions which ensure no direct line of sight between a general public area and any personal hygiene facility (WC, bath, shower, etc.). ‘General Public Areas’ are however not defined, but have been interpreted by the BIA as relating to public spaces. As such they do not apply to household units, but rather to partitions between these units.

Clause G3 ‘Food preparation and prevention of contamination’ stipulates that specific **food storage be provided** and **food preparation areas must have work surfaces which are impervious and easily cleaned** as a means of ensuring food preparation areas are free from contamination.

Clause G4 ‘Ventilation’ stipulates the need for **fresh air circulation** within the building. Minimum requirements for opening windows into habitable spaces are specified within the Acceptable Solution of this clause.

Clause G5 ‘Internal Environment’ stipulates the **low temperature control measures** and the minimum activity space requirement relating specifically to old-peoples homes and early childhood facilities. There are no provisions specifically relating to housing systems.

Clause G6 ‘Airborne and Impact Sound’ of the NZBC stipulates the required **acoustic performance** requirements for buildings. These apply only to multiple occupancy buildings (ie not to single family houses). Acceptable levels of both airborne sound and sound generated by direct impact are specified. Compliance measurements in accordance with ASTM test methods are specified within the acceptable solutions to this Clause.

Clause G7 ‘Natural Lighting’ of the NZBC stipulates the need for **external windows** within rooms, and the desire for occupants to have contact with their outside environment. As such the need to provide windows and penetrations through the external building fabric are affected. The size and frequency of such openings will in some way be controlled by these provisions.

3.10 Energy Efficiency Provisions

Clause H1 ‘Energy Efficiency’ of the NZBC requires a minimum level of thermal performance from the whole building. The Approved Document offers an Acceptable Solution which includes specific thermal resistance requirements for the external building envelope (ie roof, walls and floor). When introduced as an amendment to the Local Government Act in 1978, the thermal resistance requirements were consistent across all New Zealand. The proposed 1996 revision to the Acceptable Solution of the Building Code (still to be incorporated) provides for three climate zones across New Zealand, which when taken in combination result in two zones for houses and buildings less than 300 m^2 floor area and two zones for larger buildings. It is unlikely that these or future changes to Clause H1 will conflict with other performance requirements except in unusual forms, such as skillion or cathedral roofs where framing member depth may need to be increased to facilitate the installation of sufficient insulation.

The current level of thermal performance from conventional timber framed walls is close to being the maximum which can be practically achieved. It is likely that similar constraints will apply to other forms of building.
The majority of construction has provided thermal performance through the inclusion of additional thermal insulants within an enclosed cavity. Construction types that provide external insulation (either inside the building or exposed to the outside climate) may also provide the required thermal resistance, but with differing thermal performance.

4. COMPLIANCE VERIFICATION METHODS

Compliance with either the mandatory Building Code performance requirements or other non-mandatory nominated performance criteria, can be verified by:

1. Rational engineering or scientific calculation (using the accepted actions from applied agents such as loads defined within the NZS 4203:1992 'General Design Requirements and Design Loadings for Buildings' [SNZ 1992] and elemental resistance to these actions using either appropriate material standards or dependable elemental properties derived from laboratory or in-service testing.) As the compliance relates to in-service conditions, composite action and elemental interaction and load sharing should be included in the calculation procedure. Similarly if the system is likely to be affected by aging or deterioration an allowance for any such changes in material properties should be made. Often the engineering models used as the basis for verification will need to be calibrated against in-service or experimental results, particularly when there is a high level of redundancy and load sharing between elements which can reasonably be expected for many housing systems.

2. Assessing the behaviour of full-scale prototype systems using experimental performance evaluation techniques. Experimental evaluation may be either laboratory based or in-service. It may be designed to either address the performance property of the system directly, or the material property required as input into either calculation or expert judgement assessments.

Features which are to be considered in any such experimental assessment include:

- The action applied should represent the most adverse anticipated for the specimen. (Note it is common to impose load to a magnified intensity, the range of which will depend on the number of samples being used as the basis for the assessment).

- The specimen fabrication procedures should be consistent in detail and workmanship with that expected in practice.

- Scale effects should be avoided if practical (hence the desire for full-scale samples with realistic boundary conditions).

- The specimen boundary conditions used to fix the specimen into the test apparatus (edge and end fixity) should not artificially enhance the elemental behaviour.

- The means by which the performance or the material property is to be measured should be clearly prescribed and reported.

- Any pre-conditioning or pre-loading conditions which are applied to the specimen (to represent an in-service history) should be fully prescribed.

- The agent (load, pressure, temperature) should be applied in a realistic manner and in such a way that its application does not influence the element's response to the applied action.

- The loading protocol should be fully described and any special effects, such as the rate of application, considered and reported on.

- Where age-related degradation may occur, reductions shall be applied when calculating the dependable strength of the system. Care must be taken to ensure that the loss of strength or stiffness does not alter the deformation or collapse mechanism observed, thereby changing the basis for the performance assessment.

A fair test of the level of detail required within either the report on an experimental programme or within an approved test procedure is that it should be sufficient to allow a third party to reproduce the results from the information provided.

3. Expert judgement based on experience of both the particular system being considered and of similar systems. Such judgements will often require a combination of experiment, analysis and calculation. Care is needed when adopting experimental results into engineering calculations to ensure the rationale both of the experimental programme and the engineering model are consistent and applicable to the solutions being sought.

   Expert judgement often is based on an assessment of comparative performance between a system being considered and one which is 'Deemed To Comply' either with the mandatory or the end-user requirements. In such cases the performance of the 'Deemed to Comply' system is measured and become the basis of acceptance for the alternative system. While such a approach is legitimate and often the only way of quantifying the intended performance, it should be remembered that the performance requirements of the Building Code itself are the measures against which compliance is required. Thus, while equivalent performance with an acceptable product is one way of demonstrating Code compliance, in-service compliance of the system with the fundamental performance requirements of the Code is the true measure being sought.

5. BUILDING SYSTEMS & SUB-ASSEMBLIES

5.1 General

The specific performance criteria for New Zealand houses are contained within this part of the guide. The part is split into sections as indicated in Table 6.

These sections loosely relate to the progressive stages of construction and are similar to those used within NZS 3604 "Code of Practice for Light Timber Framed Buildings not Requiring Specific Design" (SNZ 1990). While the discussion and performance criteria provided relate to each sub-section, it is the performance of the house as a whole which governs acceptance and attention must be given to the interface between each section. Performance verification must also accurately replicate the in-service boundary conditions and constraints.

For clarity, each section has the following headings:

1. Elements within the sub-system (ie the scope included the section).
2. Functional requirements expected from each sub-system.
3. Structural behaviour considering the action applied, serviceability controls, strength controls and verification measures.
4. Non-structural issues for this sub-system.

Table 6: Identification of housing sub-systems

The System	The System Components & Elements	The Structural Actions Imposed
1. Subfloor Systems	• Piles and bracing elements • Footings and perimeter walls • Supporting bearers	a) Gravity induced load. b) Lateral loading from wind & earthquake effects imposed on the superstructure.
2. Floor Systems	• Floor framing members (including joists and blocking) • Floor sheathing • Concrete slab	c) Gravity induced (self-weight and occupancy induced) as a uniformly distributed load, as a point load and as a transient dynamic load (vibration effects). d) In-plane diaphragm action required to accept and transmit lateral loads induced from wind and/or earthquakes on other parts of the building.
3. Wall Systems	• Non-load bearing partitions; framing (studs, plates, noggings, linings and doors) • Gravity load bearing walls; all the above plus lintels, beams and opening trims • Exterior walls; all the above plus claddings, windows, doors, and long-span beams etc	e) Occupancy impact and abrasion related wear. f) Gravity (self-weight and occupancy related) loads imposed from above by the roof, upper floors and upper walls. g) Distributed face pressures or suction from wind action. h) In-plane (racking) loads arising

	• Bracing panels; wall systems which resist lateral earthquake and wind actions	from receipt of lateral wind & earthquake actions imposed on other parts of the building.
4. Roof Systems	• Roof claddings, battens, rafters & roof framing (or trusses), lateral bracing elements • Ceiling linings, ceiling battens, ceiling runners • Eaves framing, lining and trimmers	i) Gravity (self-weight and construction or maintenance related) loads imposed on the roof cladding. j) Snow and ponded rainwater. k) Distributed face pressures and suction from wind action. l) In-plane (racking) loads from wind & earthquake.

5.2 Subfloor and Footings

5.2.1 Elements within this sub-system

Subfloor and footing assembles include all piles and bracing elements, piers and foundation walls and the associated ribbon plate and bearers upon which floor systems are supported.

5.2.2 Functional requirements

The subfloor and footings are required to satisfy the following functional requirements of the NZBC:

- Clause B1 'Structure' requires that elements within this subset support the superstructure against all anticipated structural actions, primarily gravity induced vertical loads and lateral wind or earthquake induced actions.

- Clause B2 'Durability' considers elements within the subset to be 'structural components in which failure is not readily observed and which is difficult to replace' and as such they are required to sustain their structural integrity throughout the intended life of the building (nominally 50 years unless otherwise specified).

- Clause E2 'External Moisture' stipulates that elements within the subset are arranged so as to avoid passage of natural ground water or airborne moisture through the subfloor into the building. Acceptable Solution E2/AS1 stipulates minimum ventilation requirements and minimum clearances between the floor supports and the ground for elevated timber floors, compliance being deemed to permit adequate subfloor ventilation. Damp-proofing membranes are stipulated for concrete slab-on-ground construction.

- Clause H1 'Energy Efficiency' applies to the provision of energy efficiency ratings for the complete building envelope. Floors form part of that envelope and contribute to attaining the overall energy rating.

5.2.3 Structural behaviour

5.2.3.1 Actions applied

- **Gravity Loads:** The subfloor system accepts the gravity induced loads (self-weight and occupancy loads) from the superstructure. Timber piled or framed subfloor systems receive these actions from direct bearing from the floor joists and bearers. Slabs-on-grade are loaded directly from the bottom plate of the load bearing walls. Such actions are applied vertically. Piled systems accept load from a wide contributing area of floor and concentrate these actions at a relatively few contact points of high bearing pressure. Conversely slab systems tend to be stiffer and spread the imposed loads more evenly over their entire area.

  Gravity induced loads comprise the dead load of a building, denoted by the symbol G, and the live (or occupancy induced) load, denoted by the symbol Q. The dead loads constitute the self-weight of the building and the long-term component of the occupancy load. As such they are considered to be always present. The live load intensity varies with time. Such actions are introduced into the subfloor assembly either as a line load (where a continuous load bearing wall is present above), as a distributed load (where high intensities loads are applied directly to the floor above), or as concentrated loads when supporting posts, poles or beam support props.

- **Lateral Loads:** Lateral loads which are applied to the subfloor system may be generated

  a) by wind effects on the superstructure

  b) from inertia effects resulting from earthquake induced ground motion

  c) from soil or water pressure effects when the subfloor acts as a retaining wall.

- Foundation systems are particularly vulnerable to damage under earthquake attack. In all cases the floor system above the subfloor is generally able to act as a horizontal diaphragm or deep beam, accepting the lateral load from the point of application and transmitting this across all elements within the subfloor system. Variations in lateral stiffness of either the floor diaphragm or the foundations will result in torsional or twisting of the superstructure. These effects should be included when assessing the ability of the system to resist imposed lateral loads.

  Soil and water pressure effects are usually imposed directly at the contact surface of the structure and the adjacent ground. The subfloor assembly may resist these actions either by a simple bending action between footing and floor level, or by cantilever or propped cantilever action. This is where the basement foundation acts as a cantilever and the upper floor as a reaction prop transmitting a portion of the applied lateral load into the floor diaphragm and then throughout the structure.

5.2.3.2 Structural serviceability issues

The serviceability limit state provisions are considered to be breached when the deformation of the subfloor element is such that it worries occupants (typically vertical settlement in excess of 5 mm over a 2.4 m grid). Limits of acceptable settlement greatly depend on the nature and brittleness of the cladding and wall lining systems employed within the superstructure. In brittle cladding systems such as a masonry or masonry veneers, initial cracking has been observed at strains of 0.005 (particularly in sill panels below window openings). Such cracking usually is similar in character to shrinkage cracking and seldom affects the weather resistant requirements of veneer systems. Lateral displacement of subfloor systems for serviceability relate to the onset of damage to service connections under serviceability limit state intensity wind or earthquake (typically 8 mm for modern plastic plumbing and waste fittings).

The foundation system is also required to resist serviceability limit state intensity lateral loads without experiencing excessive transverse deformation. In this context, ‘excessive deformation’ is deemed to be when the global deformation (i.e. that between ground and floor) is greater than 16 mm (when the rupture of service connections may be anticipated). When evaluating the stiffness of such systems, it is reasonable to assume that this global deformation is split evenly between the subfloor structure and deformation within the soil itself.

5.2.3.3 Structural capacity issues

Subfloor elements satisfy the ultimate limit state performance requirements of Clause B1 provided they can sustain combinations of ultimate limit state intensity loads (as specified in NZS 4203 [SNZ 1992]) without instability, rupture or collapse. Lateral instability is considered to be approached when the differential relative displacements between the top and base of the footing exceeds one half its width (in the direction of loading).

Gravity induced loads from dead and occupancy induced live loads are required to be sustained without the dependable strength of the system being exceeded.

Lateral loading from either of these actions is applied infrequently and is generally of short duration. Consequently the presence of severe defects may pass undetected until the advent of one such rare event occurs. The system is required to be capable of resisting lateral loads associated with ultimate limit state conditions without collapse or instability. For the purposes of evaluation, ‘collapse’ may be considered to have occurred when the peak load has dropped by more than 25% or when the deformation is greater than 60 mm (by which time second order overturning effects may be experienced within the foundation system).

5.2.3.4 Verification methods

A method of testing metal plate connectors used to fasten bearers to piles has been published in BRANZ Study Report SR 46 ‘Design strength of various house pile foundation systems’ [Thurston 1993]. The deformation controls used in this method consider both the serviceability limits (±8 mm) and an overall stability limit (±60 mm) for ultimate limit state considerations.

5.2.4 Other NZBC performance issues

- **Durability issues:** The subfloor region is considered by BRANZ to be exposed to natural ground conditions, and an area where component deterioration could continue without being observed for extended periods (ie it is not readily inspected). Since the majority of the components within this region fulfil a structural function, they are required to sustain that function **for 50 years.** The perimeter boundary framing and associated sheathing are exceptions in that they function as non-structural aesthetic elements for which no specific durability requirements apply.

  Key considerations when undertaking a durability assessment of elements within the subfloor are:

  a) whether the element is in **direct contact with the ground** (the embedded piles) or

  b) the extent to which the element is exposed to **high relative humidity** from ground water induced dampness (all elements above ground) and

  c) the degree by which the provision of natural ventilation will expose the element to **airborne contaminates** (geothermal by-products or sea salt, if within say 500 m of the sea, and with conventional ventilation provisions).

All components which fulfil a structural function are required to be sufficiently durable to resist degradation under these conditions for the intended life of the structure.

Experience also indicates that moisture can be drawn upward through timber piles and poles embedded within the ground. Whilst this is usually limited to elevations of less than 450 mm in sawn timber members, round poles have sometimes been observed to be drawing water up to heights of 2 metres. Usually such moisture is contained within the element in ground contact and is thought to be drawn through the cellular structure within the timber itself (ie is seldom transferred in sufficient quantity to affect other members even when in direct contact with the top region of the pile). The galvanised protection of metal components fixed into timber which has been impregnated with a high level of CCA preservative, have been observed to experience premature degradation with the timber preservative salts aggressively attacking the protective zinc coating. Stainless steel or powder-coated galvanised components may be required in such cases.

- **External moisture:** The external moisture requirements of Clause E2 can be met using a damp-proof membrane (DPM) system beneath the concrete slab system together with a damp-proof course material between bottom plate and slab. A minimum ground clearance of 450 mm for an elevated ground floor is generally adequate, provided sufficient ventilation and clearance is provided so as to prevent the ingress of external moisture from the soil beneath. It also provides a convenient crawl space for access beneath to the floor. Lower levels may be acceptable with damp-proof membranes covering the ground and some ventilation maintained.

- **Energy efficiency:** The energy efficiency requirements of Clause H1 include the attainment of a minimum “building performance index” within the Acceptable Solution. This index is calculated with reference to the complete building envelope and improvements to the energy efficiency of the subfloor and floor areas have only a minor effect on the overall index. Some gains can be obtained however by installing a thermal insulation beneath concrete slabs or around the slab perimeter, or by draping insulation foil between floor joists.

5.3 Floor Systems

5.3.1 Elements within this sub-system

The floor system within the context of this guide is considered to include the primary supporting elements (ie free spanning beams, etc.), the floor joists (including blocking, etc.) and the floor sheathing. Floors may either be above the subfloor void (and thus exposed to the subfloor environment, or elevated floors (i.e. fully enclosed within the building).

5.3.2 Functional requirements

The performance requirements stipulated in the NZBC for **Floor Systems** relate to the following:

- The structural provisions of Clause B1 with regards to supporting the building, its contents and its occupants. Floors are often called upon to act as horizontal diaphragms which distribute lateral wind or earthquake loads between vertical shear panels.

- The durability provisions of Clause B2 are to be applied to all functional aspects required by the NZBC in accordance with the guidelines set out in section 3.4 above.
- The ingress of ground water from beneath the floor is to be controlled in accordance with the requirements of Clause E2 (as discussed in section 5.2.4).
- The internal moisture control provisions of Clause E3 (usually addressed by stipulating the provision of a protective membrane such as sheet vinyl or similar as a floor covering to prevent the floor decking from being exposed to internal moisture within wet areas).
- The hazardous building materials provisions of Clause F2 (with the propensity of particleboard floors to release free formaldehyde fumes);
- The safety from falling provisions of Clause F4 apply when changes in floor elevation greater than 1m exist (requiring safety barriers to be installed).
- The Energy Efficiency provisions of Clause H1 relate to the complete building envelope of which flooring systems form a part.

5.3.3 Structural behaviour

5.3.3.1 Actions applied

- **Gravity induced loads:** Floor systems support gravity induced vertical loads by spanning horizontally between supporting beams, frames or walls. Floor systems are almost always dictated by serviceability issues (excessive sag, deflection or liveliness). Strength seldom governs conventional floor systems.

  Floor decks are usually formed from large sheets or interconnected timber planks which extend over several support joists. The thickness of the decking is usually controlled by concentrated loads. The intensity of the concentrated load required to be imposed is prescribed in Table 3.4.1 of Part 3 of NZS 4203 (SNZ 1992). For domestic occupancies the nominal concentrated load intensity is 1.8 kN and the area of contact the actual contact area, but this should not be greater than 300 mm by 300 mm square. Non-load bearing (internal) partitions are supported by flooring systems and may be applied anywhere over the floor area. These walls are generally much stiffer than the floor supporting them. This being so, they may be considered as an equivalent uniformly distributed long-term load. Load bearing walls usually require specific support in the form of blocking or direct bearing. They can thus be ignored when considering the floor deck.

  Floor framing members provide direct support to the deck. They generally span horizontally providing support in flexure. Their spacing is usually dictated by the capability of the deck to sustain its loading without exceeding its serviceability limits or it ultimate capacity. Floor framing members which fail generally exceed acceptable serviceability limits associated with long-term sag, short-term deflection or excessive liveliness. Long-term effects should be considered under a combination of self-weight and long-term live load (typically 40% of the nominal uniformly distributed live load that is 0.4x1.5 kPa = 0.6 kPa). Systems which experience long-term creep effects should include these when the system response is assessed. Short-term deflections should be assessed with the full intensity of concentrated load being applied and any location along the member, and also with the short-term duration live load (usually 60% of the nominal uniformly distributed live load that is 0.6x1.5 kPa = 0.9 kPa). Any creep effect can be ignored when assessing short-term response. Floor vibration or liveliness assessments usually involve assessing the dynamic response of floor systems to transient impulse loads associated with people moving about on the floor, in combination with the presence of the dead load and long-term average live load (typically 20% of the nominal live load or 0.3 kPa). Since the dynamic response of the floor improves as mass is added, it is important that the superimposed live load is not too large. Ultimate limit state compliance is also required to be verified. Enhanced concentrated loads (2.88 kN) are required to be imposed at any location along the framing member. Uniformly distributed load combinations, which are also required to be considered for floor systems, are 1.4 times the dead load, 1.2 times dead load plus 1.6 times the full live load.

- **Wind or earthquake induced lateral loads:** Floor systems can be highly suitable as horizontal diaphragms which are used to spread lateral load from the point of application to vertical shear walls or other vertical shear transmission elements. The floor deck is required to act as the web of a deep beam (thereby accepting and distributing the imposed shear), with the perimeter boundary framing members acting as the chord members (acting as tension and/or compression elements). The lateral loads are imposed at their point of contact with the floor diaphragm. They are transmitted by the diaphragm to the various vertical lateral load transmitting elements (shear walls or braced frames) within the plane of the diaphragm and from there transmitted out of the structure. To be effective, diaphragms must be sufficiently rigid that damage to supported elements is avoided. They must also be sufficiently strong, both themselves, and at their connections to their supporting shear walls, to permit the distribution of the imposed lateral shear.

5.3.3.2 Structural serviceability issues

<u>Gravity induced actions & resistance (self weight & occupancy)</u>

Acceptable structural serviceability criteria for floors are dictated by the nature of the activity being supported by that floor. Consideration as to why the control is required at all is very important and can greatly influence the resulting control. The rationale may range from aesthetic considerations of the floor deck (or ceiling system as indicated in section 5.9 below), to the use and functionality of the floor (how flat must it be to fulfil its intended purpose) to whether sag or short-term deflections are likely to impinge on or cause damage to attached non-structural elements.

Floor Decking: Typical flooring grade particleboard systems used in New Zealand houses have a minimum panel stiffness of 1.7 mm/kN and a minimum in-service ultimate strength of 1.8 kN (when applied through a 20 mm diameter steel probe as specified in AS 1859:1980 [SAA 1980]). The acceptance criteria for sag and deflection for these elements depend on the occupancy use of the floor, and the type and reflective index of the surface finish to be applied. Carpeted floors can sustain deck-sag (ie sag between joists) up to 2 mm without being apparent, while abrupt stepping at sheet joints greater than 0.75 mm can be felt, even through carpet and underlay. Highly polished finishes, whether a directly exposed deck or one with vinyl sheet covering, require much more stringent controls and limits of 0.5 mm deck-sag can be noticed. Liveliness problems associated with the floor deck are unusual since the response frequency of these elements is usually very high.

Floor Framing Members: The member sizes of floor framing elements are usually governed by serviceability issues such as long-term sag, short-term deflection in the along-joist direction, and overall floor liveliness. Acceptability limits for these members depend on the visibility of the sag or deflection and the ability of members supported by the floor to accept such deformations without damage. Clearances between sagging floor members and non-structural elements may also dictate acceptable deflections. Floor framing member deflection limits are discussed and suggested in BRANZ Study Report SR 57 Serviceability Limit State Criteria for New Zealand Building [King 1999]. The limits applicable for domestic floor systems are reproduced as Table 7 below. Within Table 7 ψ_L and ψ_S are the long-term and short-term live load duration factors which are used to modify the nominal live load.

Excessive floor liveliness under repetitive (eg washing machine spin cycles) or transient occupancy loads (eg people moving about) are the most common causes of floor problems and thus the most usual control constraint. These effects result in dynamically active floors which can be disturbing for occupants. Acceptance criteria for any such dynamic effects are complex and highly dependent on both the frequency of the response (both the natural frequency of the floor system and how often the disturbance occurs) and the activity being undertaken by the occupant at the time of excitation. A static deflection check is given in Table 7 (ie 1.5 mm static deflection under a 1 kN point load). This is intended to be a trigger value only which, if exceeded, indicates that a more detailed investigation is merited. Guidance is given in BRANZ Study Report SR 57 [King 1999] as to how such an assessment can be undertaken.

In-plane diaphragm resistance to lateral loads

Acceptable serviceability displacement limits for a diaphragm are dictated by the ability of the elements being supported by the diaphragm to accept 'out-of-plane' distortions without unacceptable distress. When demonstrating compliance, either by calculation or prototype test, the deformation of the diaphragm itself plus that resulting from relaxation of any vertical shear walls should be added to attain the relative movement between the top and bottom of any supported wall elements. For both diaphragms and shear panels, the total deformation can be assessed from the sum of the deformations arising from:

a) the shear deformation of the sheet linings being the web member of the diaphragm

b) the panel rotation resulting from nail slip between the frame and the sheet lining

c) the panel rotation resulting from end restraint relaxation

d) the flexural deformation from the diaphragm acting as a deep beam, and

e) the relaxation being a combination of lateral shear and rotation at the diaphragm supports.

An engineering design method appropriate for such assessment is prescribed in section 5 of NZS 3603 Timber Structure [SNZ 1993]. When new or innovative diaphragm systems are being developed, the shear deformation of the sheet lining being used (as in (a) above), the fastener load/slip characteristics at the sheet-to-fastener interface under both unidirectional (for wind) and full reversal cyclic load (for earthquake) (as in b above) parallel and perpendicular to the joist line, and the degree of relaxation of the end restraint (as in c above) are required as the basis for compliance assessment. Second order effects such as chord beam continuity and the tension/compression splice joint characteristics within any boundary joists, and the load/slip characteristics at the diaphragm reaction points should be included in any such calculations. Full scale prototype testing of domestic diaphragms has become increasingly common as a means of validating specific design and does provide a valuable basis upon which the interaction between the diaphragm elements can be assessed.

Table 7: Suggest serviceability criteria for domestic floor systems

Location	**Aspect**	**Control Issue**	**Load Case**	**Suggested Limit**
Beams where Line-of-sight is along invert	Seen	Sag	G & ψ_LQ	Span/500
Beams where Line-of-sight is across soffit	Seen	Sag	G & ψ_LQ	Span/250
Flooring	Seen	Ripple	G & ψ_LQ	Span/300
Floor Joists/beams	Seen	Sag	G & ψ_LQ	Span/300
Floors (lightly damped eg concrete or steel)	Sensed	Vibration	Qb = 1.0 kN	<1 mm
Floors (more highly damped eg joist & deck)	Sensed	Vibration	Qb = 1.0 kN	<1.5 mm
Floor - sidesway	Sensed	Lateral Sway	Ws	<0.01 g
Flooring (differential slope between joists)	Function	Tilt	G & ψ_SQ	<0.002 Radian
Floors supporting masonry walls	Damage Control	Crack development	G & ψ_SQ	Span/500
Floors supporting plaster lined walls	Damage Control	Cracks in linings	G & ψ_SQ	Span/300

5.3.3.3 Structural capacity issues

Punching shear failures are most likely under imposed concentrated loads. The intensity of point load required to be considered for ultimate limit state assessment of domestic floors is prescribed in NZS 4203 (Table 3.4.1 and clause 2.4.3.3 combine to require a concentrated live load of 1.6x1.8 = 2.88 kN to be imposed for compliance verification).

The dependable strength of both the floor system as a whole and each supporting element within the floor system must exceed the ultimate limit state intensities of combined actions imposed upon the floor for the collapse or instability ultimate limit state requirements of Clause B1 of the NZBC to be satisfied. Decking should be checked for local punching shear under factored concentrated live loads (1.6 x 1.8 kN = 2.88 kN) applied over a 300 x 300 bearing pad. The flexural capacity of the decking should also be assessed under a line loads (intensity 1.6 x nominal uniformly distributed live load x deck support spacing), applied midway between the support points.

5.3.3.4 Verification methods

Verification of compliance with either the serviceability limit state or the ultimate capacity of the floor system can be undertaken by rational engineering design using the stiffness and dependable strength of the system as the basis of any such assessment. Compliance verification by calculation is difficult for floor decks which need to be modelled as plate elements on joists. Prototype testing under both concentrated loads and uniformly distributed loads is more common with the AS 1859:1980 Flat Pressed Particleboard (Standards Australia 1980) (note the later version of this standard does not include strength and stiffness test protocol).

Performance verification by engineering calculation is commonly applied to floors and is valid provided the appropriate material standards are available. Floors are generally simplified to be flexible decks with ribbed joists on rigid supports. Transverse stiffening from either decking or blocking is ignored in such models, even though these effects can significantly influence measured response. Floor support beams are usually designed independently. Such an elemental approach is usually conservative but requires care to ensure that the compound effects, such as combined joist support beam flexibility, are accounted for. Load sharing between elements is an acceptable addition to any such models, provided the level of such sharing can be verified. Floor performance verification by prototype testing is also acceptable. The degree of end rotational restraint and the distribution of stiffness between adjacent joists needs to be carefully considered and incorporated into any such testing. The scope of application of the resulting output needs also to be limited to reflect the test conditions.

The dynamic response of floors is difficult to accurately predict by calculation. The amount of movement which is able to be discerned is usually small at some frequencies. An analytical method of evaluation which limits the unit velocity under an impulse load has been adopted for New Zealand conditions from the floor performance criteria outlined in Eurocode 5 'Timber Design' (EN 5 1992, Ohlsson 1990) and published in BRANZ Study Report 57 (BRANZ 1999). Interim changes have been introduced in the acceptance criteria to be used in New Zealand following testing undertaken at BRANZ wherein obviously lively floors were within the European acceptance criteria (Beattie 1998). Work is continuing in this area.

Verification of diaphragm resistance to lateral loads can be achieved by calculation for diaphragms of regular shapes. Unfortunately within real buildings horizontal floor diaphragms are often irregular in shape and penetrated by stair or other openings. The influence of such irregularities should be assessed and included within any compliance assessment. Stress concentrations as the diaphragm shear flows around openings are recognised as a cause of inadequate diaphragm behaviour and specific provisions to counteract these actions should be included when designing diaphragms.

5.3.4 Other NZBC performance issues

- **Durability Issues:** Upper floor systems generally enjoy the benign environment of being encapsulated within the building envelope and only strength or stiffness loss through ageing and initial exposure during construction need be considered. Floors of wet areas such as bathrooms and laundries are often an exception. The use of vinyls and waterproof wall linings is widespread in such rooms. Leaks and penetrations through these protective surfaces can pass undetected for lengthy periods with degradation occurring as a result. Elevated ground floor systems are generally detailed to be clear of the ground thereby avoiding direct contact with ground moisture. They are however exposed to the subfloor space which is likely to be subjected to seasonal variations in relative humidity (and thus moisture content) and may also be exposed to airborne salts or other contaminates which can be aggressive to flooring components. The potential for loss of strength and/or rigidity under these conditions will need to be verified when assessing the durability of the floor system. Concrete slab-on-ground construction provides separation between the ground and the structure. Adequate cover to reinforcing steel within such slabs must be ensured to avoid rusting of the steel and metal fasteners used within the slab.

- **External Moisture Control:** Only the floors which form part of the external building envelope are affected by the provisions of Clause E2 of the NZBC. Thus suspended floor systems which overhang the external walls or are exposed to the subfloor cavity are required to demonstrate they are able to prevent the passage of external moisture into the structure. This is usually achieved by providing adequate clearance from surfaces which may be become wet periodically and by ensuring adequate ventilation to avoid surface condensation. When slab-on-ground construction is used, a damp proof membrane is commonly installed beneath the slab to prevent ground water being drawn into the living space. Provided such measures are effective, the slab itself is considered to experience the internal living space environment and slab deterioration is considered improbable. The exception is the exposed external perimeter edge of the slab. An acceptable solution prescribes a minimum distance to be maintained between the exposed exterior of the building and its internal environment. A minimum distance of 100 mm is nominated as being sufficient to maintain a thermal gradient which is sufficiently flat that the passage of water by capillary action is unlikely.

- **Sound Insulation of Floors:** Clause G6 of the NZBC requires floors separating tenancies to be of a Sound Transmission Class (STC) of not less than 55 and an Impact Insulation Class (IIC) of not less than 55. Acceptable Solution G6/AS1 stipulates that the performance for airborne sound insulation may be verified using the procedures stipulated in ASTM E336:1997 ‘Method of measurement of airborne sound’ (ASTM 1997), and the field sound transmission class verified using the method described in ASTM E413:1994 ‘Classification of rating sound insulation’ (ASTM 1994). The performance for impact sound insulation may be verified using the procedures detailed in ISO 140:Part VII ‘Field measurement of impact sound insulation of floors’ (ISO 1978), and the field impact insulation class may be verified using the method described in ASTM E989:1994 ‘Classification for determination of impact insulation class’ (ASTM 1994A).

- **Energy Efficiency Rating of Floors:** The energy efficiency rating provisions of Clause H1 of the NZBC impact on the floor system as part of the external building envelope. The use of insulating foil draped between framing members is nominated with the acceptable solution associated with this clause. Although floors, as part of the building envelope, contribute to the thermal resistance requirements of buildings, their contribution is usually quite small and the benefits to be gained by improving floor insulation in the 'energy trade-off' of the building as a whole are likewise limited.

5.4 Walls: General

Walls may be categorised into two generic types based on their construction form namely:

a) **Framed wall systems:** These systems typically comprise vertical framing members or studs, continuous boundary trimmers being the top and bottom plate members which spread and provide fixity for the studs, intermittent blocking between studs (optional) to inhibit stud twisting, and some form of sheathing either side of the framing (either as cladding to protect the structure against the ingress of the elements if external or as linings to resist occupancy induced impact or normal wear and tear if internal).

b) **Integral wall systems**: These systems typically comprise either solid or bonded unitised elements interconnected to form the wall panels. Supplementary linings or weathering claddings can be affixed to the surfaces of the panels.

This guide subdivides the wall section into four parts relating to their function namely a) non-load bearing partitions, b) gravity load bearing walls, c) external walls, and d) bracing panels. Each separately detail the performance expectations of their particular class, although many walls will be required to fulfil multiple roles.

5.5 Walls: Non-Load Bearing Partitions

5.5.1 Elements within this sub-system

Non-load bearing partitions take no part in the primary load bearing function within a building. As such all non-load bearing walls will be internal to the building (since all external walls are exposed to wind induced face loads and are often gravity load bearing walls sustaining mass induced from the roof or upper floors). All elements of such walls, including their substrate and linings together with doors and attached items, are included within the section.

5.5.2 Functional requirements

The performance requirements stipulated within the NZBC for **non-load bearing partitions** relate to the following:

- The durability requirements of Clause B2 apply to surfaces which fulfil any of the mandatory requirements specified by the NZBC.

- The fire provisions of Clause C where the partition is being used as separation between fire compartments in multi-tenancy occupancies.

- Non-load bearing partitions may form part of the internal moisture control provisions Clause E3. Such moisture control measures are 'solution dependent' and other means of attaining the required control are acceptable.

- The hazardous building materials provisions of Clause F2 (with the propensity of particleboard floors to release free formaldehyde fumes).

- The hygiene requirements for surface coatings of wall linings adjacent to food preparation areas of Clause G3 requires these surfaces to be impervious and easily cleaned.

- The airborne sound transmission provisions of Clause G6 apply to inter-tenancy partitions.

- Market forces (ie consumer expectations) require internal partitions to be sufficiently strong and resilient to avoid damage or excessive wear during normal occupancy.

5.5.3 Structural behaviour

5.5.3.1 Structural actions applied

Non-load bearing partitions are used inside the building only. Such partitions are required to sustain the following actions:

a) their own weight, (applied vertically within their own plane)

b) the support of any items which gain support from the partition (eg doors or items of hung furniture) applied at points of contact between the item and the partition

c) differential wind pressures between adjacent spaces within a building applied uniformly over the partition surface

d) accidentally imposed impact loads resulting from people or contents bumping or falling against the partition will often dictate market acceptance of wall rigidity. The height of application of any such impact should be that within which normal contact with the wall is expected (ie between 0.8 and 1.5 m above floor level)

e) abrasion and wear resistance resulting from accidental contact with the surface linings.

5.5.3.2 Structural serviceability issues

- **Partition Self-weight:** The internal partition must be sufficiently robust to be able to support itself. Normally partitions will be supported along their base and are often provided with clearance along their top edge to allow vertical sag in the primary superstructure above.

- **Secondary Element Support:** Many internal partitions are called upon to provide hanging support for items of furniture or fittings. Such items vary widely in mass. Fixings can be either standard fixings or proprietary items. If the latter is to be used, the fixing capacity in both shear and withdrawal should be published.

- **Face Load Rigidity:** Internal partitions should possess sufficient rigidity that they can resist differential wind pressures of half the serviceability design wind pressure applied across the partition (based on positive pressure of +0.2 on one side and a suction of -0.3 on the other), without exceeding a mid-height deflection of wall height/300 within the body of the wall and height/400 at door and window openings (where the wall deflection affects the function of these non-structural elements). Partitions with brittle linings such as ceramic tiles, should be limited to deflections of less than height/500 to avoid tile damage. (Design wind pressures are included in Table 2 above.)

- **Accidental Impact:** Within houses, there is a non-mandatory market expectation that the strength of the partitions will be sufficient to resist impact levels of 60 Joules from a hard-body impact (i.e. a fist, foot or elbow impact) and 80 Joules from soft body impact (i.e. a shoulder or body impact) without experiencing damage which requires repair. Serviceability acceptance criteria differ within the body of the wall (mid-height deflections < height/400) and adjacent to opening (i.e. door/window trim members where mid-height deflection height/600).

- **Wear and abrasion resistance:** Market forces dictate that the surfaces of internal partitions have adequate resistance to abrasion and scuffing. These are non-mandatory consumer driven expectations. They are best assessed by comparison with commonly acceptable equivalent linings.

5.5.3.3 Structural capacity issues

Ultimate limit state considerations seldom control internal partitions, although connections between the partition and at the ceiling or floor can rupture or fail under ultimate pressures and should be checked.

Internal partitions are require to possess sufficient strength that they can sustain 0.5 times the ultimate design wind speed for the site without fracture of the studs or failure of the fixings. The wall lining (and its fixings) should be sufficiently robust to avoid detaching from the studs when subjected to wind suction of 0.3 times the ultimate design wind pressure.

5.5.3.4 Verification methods

The ability of the panel to support its own weight is usually self-obvious once it has been installed. When the internal partition is pre-assembled (i.e. a panelised unit) construction handling and out-of-plane lifting can be difficult to determine by calculation. It is common to allow a 50% increase in the self weight of the panel to allow for impulse loads as any such panel is lifted.

The ability of the panel to support furniture and fittings can be determined by conducting fastener shear and withdrawal tests on the range of fasteners to be permitted for used with the panel under consideration. A means of determining the dependable capacity of such fixings is presented in BRANZ standard structural test method ST 05 (BRANZ 1998). It would be usual to base any such capacity on a sample of at least 10 fasteners of each type tested under the appropriate loading regime (i.e. pull-out or shear).

Verification of adequate wall panel impact resistance is strongly influenced by the energy dissipation mechanisms generated as a result of the impact. As such it is very difficult to assess by calculation. Full scale testing of panels supported within the most rigid frame they are expected to encounter provides a practical alternative and has been found to yield a reasonable assessment of impact resistance. As a guide to the adequacy of a wall system to resist impact a point load of 0.7 kN applied approximately 1.5 m above the adjacent floor may be considered.

5.5.4 Other NZBC performance issues

- **Durability:** All aspects of the panel that are required for the building to comply with all necessary requirements of the Building Code, are required to be sufficiently durable to ensure they fulfil these functions for the periods stated in Clause B2. The background to the duration that they are required to fulfil is indicated in Table 4 and Table 5.

- **Fire Related Issues:** Inter-tenancy walls in multiple tenancy dwellings are required to have a fire resistance rating (FRR) of not less than 30/30/30 minutes for residential units. Other provisions control the type of room lining materials including surface finishes which are required in transient sleeping accommodation (purpose group SA being hotels, motels, hostels, etc.) and sleeping care facilities (purpose group SC being rest homes, hospitals, etc.). In these situations the rate of flame spread across a surface and the rate of smoke development are controlled in an attempt to ensure evacuation of the building is possible during a fire. The purpose group associated with normal residential occupancy of attached units, SR, do not have any requirements for either flame spread or smoke development except in shared exitways. The specific requirements are published in Table 4 of Acceptable Solution C3/AS1.

- **Hazardous Building Materials:** Innovative building solutions may include either structural components or sheathing elements that discharge contaminates which may be detrimental to the health or well being of the building occupants. The use of such materials is prohibited by Clause F4 of the NZBC.

- **Personal Hygiene:** Whilst there are no mandatory requirements for internal non-load-bearing partitions, market forces expect them to be used to fulfil these privacy requirements and thus enclose bathrooms and sanitary facilities. Where partitions are provided, they are expected to satisfy the 'impervious and easily cleaned' requirements, examples of which are stated in Clause 3.0 of Acceptable Solution E3/AS1 relating to watersplash control. Since these are non-mandatory, if installed a five-year durability requirement would apply.

- **Hygienic Food Preparation & Prevention from Contamination:** The Acceptable Solution G3/AS1 requires that wall surfaces adjacent to food preparation areas be easily cleaned and shaped to avoid accumulation of contaminates and to facilitate ease of cleaning. Impervious linings such as stainless steel, decorative high pressure laminates, tiles, or wallboards with painted or applied impervious coatings are nominated as suitable finishes for such areas within houses. These finishes are both accessible and readily replaced and are required to perform their function over a five-year period.

- **Airborne Sound:** Clause G6 requires walls between tenancies to be of a Sound Transmission Class (STC) of not less than 55. Acceptable Solution G6/AS1 stipulates that the performance for airborne sound insulation may be verified using the procedures stipulated in ASTM E336:1990 'Method of measurement of airborne sound', and the field sound transmission class verified using the method described in ASTM E413 ‘Classification of rating sound insulation’. Several acceptable alternatives are provided within G6/AS1 for walls of different materials. These stipulate that reinforced concrete masonry walls are required to be not less than 200 mm thick with all cells filled, reinforced concrete walls to be not less than 150 mm thick and timber-framed walls to have two layers of plasterboard supported on separated double studs with 75 mm of glass fibre insulation within the cavity.

5.6 Walls: Gravity Load Bearing

5.6.1 Elements within this sub-system

Gravity load bearing walls provide support to other elements and the building occupants by sustaining gravity induced loads. All elements within the walls, including lintels and beams which span openings through the walls, are considered in the section. *(Note those walls subjected to face loads or in-plane loads are considered separately in section 5.7 ‘External Walls’ and section 5.8 ‘Bracing Panels’ below.)*

5.6.2 Functional requirements

The performance requirements stipulated in the NZBC for **gravity load bearing walls** relate to the following:

- all of the functional requirements applicable to non-load bearing partitions stipulated in section 5.5.2 above

- the structural provisions of Clause B1 of the NZBC with regards to the support of the loads induced by gravity effects on the supported superstructure

- the durability provisions of Clause B2 of the NZBC as they relate to structural elements (i.e. requiring the intended life to be the lesser of a nominated period or 50 years).

5.6.3 Structural behaviour

5.6.3.1 Actions applied

- Gravity loads arise from mass of the superstructure and occupancy induced live loads. **Gravity load bearing walls** accept these loads through their upper boundary element. Loads are transferred through the bearing points between the wall and superstructure. In the case of a ribbed floor system this is likely to be as a series of regularly spaced reaction points (being either the floor joists or the roof trusses or rafters). Where the upper boundary member is a top-plate spanning between studs, local stiffeners or additional propping members may be used to supplement the flexural capacity of the top plate. The wall linings of framed walls provide an effective means of distributing the imposed loads between the primary structural elements. When the wall panels are continuous between points of support (i.e. not broken by door openings), the deep beam action of the wall panel can effectively distribute imposed gravity loads directly to the support points. In these cases the wall lining sustains the shear transfer within the wall, the plates and the chord actions, and the studs provide local stiffening and bearing points.

  Beams and lintels span openings, providing support as horizontally spanning flexural components. Beams are usually less rigid than the uninterrupted wall panel and require clearance beneath them to avoid clashing with non-structural components (windows or doors), which may fill the opening beneath the beam. The beam reaction is imposed on the framing members on either side of the opening, which may require supplementary framing to sustain these more concentrated loads.

5.6.3.2 Structural serviceability issues

- **The Gravity Load Bearing Walls:** Serviceability limit state compliance of these walls requires that the top boundary element of the wall be sufficiently stiff between points of rigidity (ie stud supports) so as to avoid:

  1. damage to the wall linings or to the adjacent elements such as ceiling or scotia elements. Damage that requires repair should be considered noticeable. Deformation controls should be such that the top boundary element of the wall deflects less than clear span/200 or 3 mm when subjected to uniformly spaced point loads from joists or trusses

  2. settlement of elements supported by load-bearing walls. Variations in top plate alignment greater than 1 mm are likely to result in noticeable ripples across a reflective finished ceiling plane when viewed parallel to the wall line, unless ceiling battens are employed to maintain the true ceiling line. Non-reflective ceiling surface finishes, being more tolerant to these ripple effects, will generally be able to withstand top plate variations of 2 mm without becoming noticed. When load bearing walls provide the propping support for overhanging cantilevered floor joists, longitudinal misalignment of the top boundary element can be greatly amplified at the end of the joists. In such cases misalignment of the boundary member should be limited to not more than 0.5 mm under dead plus long-term live load.

- **Beams and Lintels:** Serviceability limit state compliance requires that the beam (or lintel) does not experience excessive sag when subjected to self-weight and long-term live load (including creep allowances) or when subjected to full live-load (without creep). Quantifying ‘excessive’ is difficult as it will depend on the tolerance that supported elements have to in-plane movement and the degree to which the beam has been successfully isolated from adjacent elements that are sensitive to movement. Typically total beam sag should be limited to less than 1/240 of the beam span/250 and 12 mm to prevent joinery items being jammed by the beam movement. However much tighter controls may be necessary when brittle elements are reliant on the beam for support. Checks should be made to ensure the beam curvature does not exceed that which at which damage to the secondary element is likely to occur.

5.6.3.3 Structural capacity issues

For ultimate limit state compliance, the wall system or lintel is required to resist loads of ultimate intensity without rupture or instability. Both the flexural capacity of the boundary elements (loaded midway between the support studs) and axial stability of the panel itself needs to be assessed.

5.6.3.4 Verification methods

System compliance at each limit state can be verified either **by calculation or prototype testing**. Engineering calculation usually employs simplified models and requires the dependable material properties be known. If the contribution of secondary elements is to be considered when assessing the strength or stiffness of the wall, then testing is likely to be required to justify its contribution.

Prototype testing should be undertaken on full scale specimens which are representative of the in-service wall configuration under consideration. Issues which influence the test configuration are as follows:

- Wall panels are to be of sufficient length to avoid local edge effects (for framed walls this will usually involve at least a 2.4 m length of wall, although elements within the wall, such as an individual stud or a segment of top-plate, may be assessed using prototype testing to provide information to enable computational modelling).

- The load bearing capacity of wall panels is usually controlled by the onset of out-of-plane buckling. Specimens should be provided with a realistic level of lateral restraint against secondary buckling either in full or partial compression. The presence of wall sheathings is usually effective in providing this restraint and can be included in the test configuration. The way in which the load is applied needs to be carefully considered so as to ensure it provides a realistic worst-case degree of eccentricity to the panel.

- The specimen boundary conditions should be carefully considered so as to provide a realistic level of end restraint, particularly when assessing serviceability deflections and load/slip stiffnesses.

- The distribution of loading should realistically reflect the least advantageous configuration for the panel or beam under consideration.

- The intensity of applied load should be amplified by a factor which reflects the level of reliability of the test panel.

- The loading regime should reflect the characteristics of the applied load where practical. Usually slower load rates place greater demands on the specimen, but this assumption should be validated for each generic system.

5.6.4 Other NZBC performance issues

There are no additional non-structural performance criteria for gravity load bearing walls over those discussed in relation to non-load bearing walls (section 5.5.4).

5.7 Walls: External

5.7.1 Elements within this sub-system

External walls form part of the external envelope of the building. As such, in addition to other loads, they are subjected to significant structural face loads and provide the waterproofing and thermal separation between the building interior and the natural environment. Components considered within this section are all elements within external walls, which includes their substrates, claddings, linings and infill elements (such as lintels, doors and windows).

5.7.2 Functional requirements

The performance requirements stipulated in the NZBC for **external wall systems** relate to the following:

- All of the functional requirements applicable to non-load bearing partitions stipulated in section 5.5.2 and to gravity load bearing walls stipulated in section 5.6.2 above may also be applicable to external walls and where this is so should be satisfied.

- The structural provisions of Clause B1 with regards to resistance to face loads induced by wind or earthquake induced ground motion.

- The durability provisions of Clause B2 are to be applied to all functional aspects required by the NZBC in accordance with the guidelines set out in section 3.4 above.

- The fire provisions of Clause C3 'Spread of Fire' have application to external walls built in the vicinity of a common boundary. For detached dwellings the fire resistance rating needs to be considered when the wall is within 1 m of the boundary.

- The ingress of airborne moisture is to be controlled in accordance with the requirements of Clause E2.

- The internal moisture control provisions of Clause E3, usually as it applies to condensation control with the external wall experiencing a high thermal and/or moisture gradient between the building interior and the natural environment outside.

- The airborne sound transmission provisions of Clause G6 apply to external walls which open onto common spaces.

- The energy efficiency provisions of Clause H1 relate to the complete building envelope of which wall and flooring systems form a part.

5.7.3 Structural behaviour

5.7.3.1 Actions applied

- **Wind effects:** Wind speeds and related wind pressures for both serviceability and ultimate limit state considerations are given in Table 2 above. These pressures need to be multiplied by the pressure coefficient, Cp, applicable to each surface of the element.

- External pressure coefficients can be either positive (for face load pressures into the panel surface) or negative (for suction effects away from the panel surface). The maximum positive external pressure, Cpe = 0.7, and requires an additional local pressure coefficient K_l = 1.25 to be applied for local wind pressure effects. Suction effect pressure coefficients apply to the leeward face of the building (Cpe = -0.5 to -

0.3 depending on the roof pitch) and on side walls which are parallel to the direction of the wind (Cpe = -0.65 to -0.5 depending on the distance from the windward leading edge).

The interior walls surfaces are often also subjected to wind face loads. The intensity of these actions depends on the permeability of each surface which encloses the internal space. For framed houses, BRANZ considers that normally two walls will be equally permeable and that the internal pressure should be either -0.3 or +0.2 times the design wind pressure.

The presence of a large opening on one face of any space, whilst the other faces remain relatively impermeable, will result in very high internal pressures (equal to those applicable to the external face itself). In an attempt to avoid abrupt changes of pressures, and in acknowledgment that window and doors have been found to be elements prone to such failures, the 1994 amendment to NZS 4211:1985 (SNZ 1985) requires windows to be designed to resist internal pressures of +0.7 or -0.65 when designing for strength (i.e. ultimate limit state considerations). This was based upon the assumption that flying debris is likely to be present at wind speeds above 42 m/sec. The abrupt change of pressure associated with such failures will be sudden and incremental failures promulgating through the building could result. This is considered undesirable and an additional protection is provided to such elements through the provision of slightly higher pressure coefficients. The wind speeds associated with serviceability limit state considerations are sufficiently low that heavy debris is unlikely to be transported and that correctly designed windows will therefore remain intact.

5.7.3.2 Structural serviceability issues

- Wind Effects: The serviceability limits applicable to external walls relate to deflection control. Acceptable deflection limits depend on the nature and resilience of the claddings, the linings and the fittings used to tolerate out-of-plane deformations. In some cases nature of the cladding will influence the loading pattern applicable to the wall system (ie pressure variations through the depth of the wall may vary across each element within the wall - sheathing, building paper or internal linings).

  Features which should be considered when considering face-load serviceability include the following:

  1. Cracked external claddings do not provide effective weather protection unless specifically detailed. Resistance to water ingress of such systems can be provided by filling and coating, provided they are regularly adequately maintained and their long-term performance can be assured. In such cases a specified building maintenance schedule is needed.

  2. Reflective surfaces, such as glass, reflectively amplify distortions (particularly at night) and can cause anxiety when experiencing mid-height displacements in excess of span/400.

  3. Masonry veneers are stiff, self-supporting elements until they crack, after which they become heavy facade elements which depend on the substrate for

support. Being heavy, they make a significant contribution to the seismic mass of building on which they are used. Cracking is generally initiated by loading normal to the wall plane initiated either by wind or earthquake. The initial crack usually occurs in one of the lower horizontal mortar beds or at a change of section such as between windows. The resulting panel becomes pinned at the crack line and is now fully dependent on the ties connecting the panel to the framing. The presence of any such cracking does not in itself present a problem since the cavity between the outer leaf and the framing will continue to drain the joint thus providing the weather protection intended.

5.7.3.3 Structural capacity issues

External walls are required to withstand ultimate limit state intensity face loading (from wind or earthquake induced ground motion) without breaking or becoming unstable. Frame distortion and associated damage to either the outer facade or the internal lining is to be expected under this intensity of loading. Facades and claddings are to remain attached to the structure.

5.7.3.4 Verification methods

Engineering calculation methods can be applied to verify compliance of the primary structural components under lateral load, provided the dependable strength and stiffness of the materials involved has been quantified. For such calculations it is usual to assume that the differential design wind pressure applies across the full width of the wall. Establishing the performance of the facade and cladding elements by calculation is also possible when fastener characteristics are adequately prescribed for a cladding material and the substrate into which it is attached. The provision of design information of this detail is however rare, and prototype testing of wall specimens with facades attached is common.

Prototype testing of full-scale wall segments under either simulated wind face loads or face loads in combination with axial loads is practical and does provide a means of performance verification. Issues which need to be considered when developing such a test are:

a) The specimen should be representative of the system in-service and should be constructed accordingly. With highly variable elements, such as timber studs, the distribution of strong or stiff elements relative to their neighbours should be considered with the objective of a lower bound condition being sought within the test specimen.

b) The presence of wall linings and/or claddings may be included in the test, although care should be taken as the conditions applied during the test may limit the scope of application of the results from that test (i.e. lower bound conditions should be identified for the intended application and used during the evaluation).

c) The dimensions (length and height) of the specimen to be tested. Square panels are usually a minimum with panels longer than their height preferred.

d) The location of the primary resisting elements (i.e. studs for a framed wall) in relation to the specimen configuration. This will often involve extending the panel face beyond the framing by half the stud spacing either side to ensure all studs within the frame are subjected to equal load.

e) The method of loading should be representative of the panel in service. Thus face loading should be uniformly applied. Axial load, if present, should be imposed in a realistic manner through the top boundary element. Details at the connection point should be carefully considered to ensure no artificial rotational restraint is provided by the provision of that axial load.

f) The effect of repeated loading, included fatigue in some cases, should be considered and applied if appropriate.

g) The loading protocol would normally be required to consider both stiffness under load and the residual deflection of the panel after the load is removed. For New Zealand conditions, the applied pressure intensity should be consistent with the serviceability pressures identified for each wind zone (as indicated in Table 2), corrected by the nett internal and external pressure coefficients appropriate for the given configuration (refer to section 5.7.3.2). These pressures should be applied for a given period (usually one minute) with both the mid-height and plate deflections being monitored, the pressure released to enable the residual deflection to be measured, and the pressure re-applied to the next limiting value.

Prototype testing of walls with openings for windows or doors can be undertaken. In addition to the issues identified above:

a) The effect that the width and location of the opening may have on the performance of the wall system as a whole may need to be investigated.

b) The characteristics of the element within the opening (stiffness and load distribution) should be replicated within the specimen as accurately as practical, although the presence of the element itself within the specimen is usually unnecessary.

c) When openings are included, the framing should be adjusted to represent the presence of additional propping studs and lintels around the opening.

d) The presence of the sill and the behaviour of the framing below window openings is likely to influence the behaviour of the wall around the opening.

5.7.4 Other NZBC performance issues

- **Durability Issues:** The durability provisions of Clause B2 apply to all aspects of performance required to satisfy the health and safety criteria implicit in all the provisions of the NZBC. The 50 year intended life provision of B2 applies to all items whose function is essential to fulfilling the health and safety provisions of the Code and yet they are difficult to inspect and/or maintain (e.g. structural walls, brick veneer ties, precast concrete fixings, cast-in downpipes). The 15 year intended life provision applies to claddings and their fixings provided they are moderately easy to inspect and if necessary to replace (claddings & sidings, stucco fixings, exterior doors, boxed gutters, etc.). Items which are open to easy inspection and are readily replaced are assigned a 5 year intended life (e.g. gutters, metal flues, window hardware etc.)

- **Fire Provisions:** Provisions regarding the spread of fire as prescribed in Acceptable Solution C3/AS1 apply to external walls which are located in close proximity to the boundary. Table C3 of Appendix C4/AS1 prescribes measures required for these walls if they are built closer to any property boundary than the clause minimum distance. When the minimum boundary separation distances are not attained then the fire spread provisions and surface finish requirements of Table 2 of C3/AS1 are applicable

- **External Moisture:** The provisions of Clause E2 apply to all external walls. While there are no prescribed verification methods contained within the Approved Documents as they relate to Clause E2, Acceptable Solution E2/AS1 details various profiles which are deemed to comply with the performance requirements of this section. Cladding systems, including their joints and the joints with other elements (e.g. windows) which form part of the weatherproofing envelope, are required to preclude the ingress of moisture into the building. Methods of testing windows for use in New Zealand houses are published in NZS 4211:1985 (SNZ 1985). This Standard is nominated as an alternative solution in E2/AS1 Clause 3.0.4 but noted as exceeding the intended performance of Clause E2. Amendment 3 to the Standard prescribes pressures for air and water leakage tests which align to the wind zones nominated within the non-specific design standard for light timber framed houses in New Zealand, NZS 3604 (SNZ 1990). The test relates to the window and window frame only with the test specimen being installed in a standard test rig. The performance of that window when installed in actual wall systems is not part of that assessment. Test and evaluation procedures for installed windows or building facades have been published in SA/NZS 4284:1995 'Testing of Building Facades' (SA/SNZ 1995). Although this Standard specifically applies to the facades of multistorey buildings, it could be used as the basis of assessment for houses if required.

- **Internal Moisture:** The provisions of Clause E3 'Internal Moisture' relate to external walls particularly with respect to preventing fungal growth. The high thermal gradient across external walls is likely to result in condensation on internal walls and thus fungal growth unless the dew point at which condensation develops is controlled to occur in a location where the relative humidity of the air is kept low. Acceptable Solution E3/AS1 stipulates minimum insulation ratings for external walls in combination with adequate ventilation. This will provide a suitable level of control to prevent condensation which may lead to fungal growth.

- **Ventilation**: The ventilation provision of Clause G4 relates directly to the external walls and prescribes levels of air movement which are deemed to result in a healthy living environment within the building. Adequate ventilation also plays an important part in ensuring the provisions of E3 'Internal moisture' are met.

- **Natural lighting:** The natural lighting provisions of Clause G7 dictate that each internal room is to have a minimum level of natural lighting provided. This has an influence in the layout of window penetrations through external walls, although these minimum provisions are generally far below those required by the market.

- **Airborne Sound:** The provisions of Clause G6 of the NZBC relating to sound insulation requirements for walls do not differentiate between internal (refer section 5.5.4) and external walls, both of which require a STC rating of not less than 55.

- **Energy Efficiency**: The energy efficiency rating requirements of Clause H1 are directly applicable to external walls, these being part of the building envelope. Such elements are highly influential in the overall thermal efficiency of buildings. Considerable gains are still possible by increasing the thermal resistance ratings of these elements, but the impact on the overall wall construction system (ie wider studs to permit additional cavity insulation) should be considered.

5.8 Walls: Bracing Panels

5.8.1 Elements within this sub-system

Bracing panels are structural shear walls which provide stability to the building when it is subjected to lateral loads induced by wind or earthquake induced ground motion. Bracing panels may be either internal or external walls. All elements of the panel, including their substrate, their sheathings and any additional up-lift rotational restraints are considered within this section.

5.8.2 Functional requirements

The performance requirements stipulated in the NZBC for **bracing panels** relate to the following:

- All of the functional requirements applicable to non-load bearing partitions (section 5.5.2), gravity load bearing panels (section 5.6) and/or external panels (section 5.7) as appropriate.

- The structural provisions of Clause B1 of the NZBC with regards the support of the lateral loads induced by wind or earthquake effects on the supported superstructure.

- The durability provisions of Clause B2 of the NZBC as they relate to structural elements (ie requiring the intended life to be the lesser of a nominated period or 50 years).

5.8.3 Structural behaviour

5.8.3.1 Actions applied

Bracing panels support the superstructure by transmitting lateral loads by in-plane shear. Such lateral loads usually occur as a result of wind load being applied to the outer building envelope, or from the inertial response of the superstructure consequential to earthquake induced ground motion. As **bracing panels** utilise their in-plane shear capacity to fulfil this function, only those panels orientated with their length along the direction of loading are effective.

The actions applied to the bracing panels are significantly influenced by the characteristics of the loads applied. Wind loads are predominantly uni-directional although the turbulence within the wind stream will exert a pulsating effect on the structure. Earthquake induced ground motion is truly dynamic and will result in full load reversal being experienced by the panel. When assessing the dependable resistance of a bracing panel, the displacement protocol applied to the panel should reflect the characteristics of the actions applied.

The shear resistance of bracing panels can be achieved either by the wall itself (as in the case of masonry or panelised walls) or by the composite action of the wall sheathing and its substrate. In each case lateral load is introduced into the panel through its upper boundary perimeter connections and transmitted from the panel through its lower boundary elements. Detailing of all elements within the panel must be sufficient to ensure all likely load paths are of sufficient strength and stiffness to resist the prescribed intensity of design load. The behaviour of bracing panels is strongly influenced by both the effectiveness of composite interaction between elements within the panel and by the behaviour of elements abutting the panel itself. It is therefore difficult to use conventional engineering analysis to predict actual panel resistance. Thus prototype testing of bracing panels is the most common technique by which the resistance of bracing panels is verified. In all such tests, the panel must be fabricated and installed strictly in accordance with the system specification. Since the objective is usually to predict the performance of the panel when it is installed as part of a building, particular care is needed to ensure panels are secured in a way which truly reflects the in-service boundary conditions of the panels, and that the load application is realistic. Supplementary hold-down restraints can be justified for timber framed systems and may be included. Other less traditional systems will need to rationally justify the use of alternative supplementary hold-down devices. The displacement protocol imposed on the panel will often have a marked influence on the apparent resistance of bracing panels and should be selected to reflect the characteristics associated with the load under consideration.

5.8.3.2 Structural serviceability issues

- Bracing panels shall resist serviceability intensity wind or earthquake actions without experiencing distortions which:

  a) Result in damage which requires repair within the bracing panels itself. *(The magnitude of in-plane distortion at which such damage occurs is a function of the elements of the panels themselves and can be assessed through observation during laboratory testing).*

  b) Result in damage which requires repair within adjacent non-structural elements within the same plane as the bracing panel. *(The onset of damage often occurs within door or window lintels or seams with return walls adjacent to the bracing panels. The distortion at which this occurs is usually a function of the material and geometry of the adjacent panel/lintel. For New Zealand wall systems which include paper faced gypsum plasterboard linings the onset of such damage has been observed as occurring at panel distortions of between 6 and 8 mm for panels of 2.4 m height ie height/400 to height/300. Other systems need to be specifically assessed.)*

  c) Results in damage which requires repair within other non-structural elements which are reliant upon the bracing panel for support. *(The tolerance of face loaded panels and infill elements to inter-storey lateral drift will vary widely. The consequences of rotation and possible crack development within such elements should be carefully assessed. Once established, the combined* *relaxation of the wall panels and the supporting horizontal span elements (diaphragms or bond beams) should be used as the basis for determining the acceptable serviceability deformation limit for bracing panels.)*

5.8.3.3 Structural capacity issues

- Bracing panels shall resist ultimate limit state intensity wind and earthquake actions without failure. The ultimate limit state earthquake intensity varies with the ability of the systems to sustain post-elastic distortions (ie their ductility). A structural ductility factor of 4 is assumed within the bracing demand tables published within NZS 3604 (SNZ 1990). The bracing resistance rating is required to be downgraded in accordance with the design coefficients contained in NZS 4203 (SNZ 1992) when the bracing system is assessed as possessing a system ductility factor less than 4. For bracing systems which exhibit a pinched hysteretic post-elastic response (ie degrade to experience low lateral resistance (‘slop’) during their mid-range response, yet are still able to attain appreciable and reliable resistance at their extreme response range), then the classical single degree of freedom bilinear response oscillator model (used as the basis for the derivation of the design earthquake design spectra published within NZS 4203 (SNZ 1992)) is inappropriate. In such cases it is recommended that inelastic time-history analysis be undertaken using elements which correspond to the pinched hysteretic response observed by used as the basis of evaluation.

- The onset of ‘failure’ is considered to have occurred when the system experiences significant (>20%) resistance loss of resistance between successive loading excursions to a nominated displacement.

- The dependable resistance rating for wind effects may be taken as the peak load resisted by the panel (being the average of the positive and negative cycles of all specimens tested within a series). The dependable resistance rating for earthquake effects is assessed as the average residual resistance exhibited by the system following two previous displacement excursions. This may require downgrading when the system ductility cannot be attained.

5.8.3.4 Verification methods

- Engineering calculation have been unable to predict the in service performance of bracing panels beyond their serviceability limit and are generally regarded as inappropriate for use as a performance verification tool.

- Prototype testing of individual wall panels has been widely undertaken both within New Zealand and overseas. The BRANZ P21 method (Cooney, 1979) was amended in 1991 (King, 1991) to incorporate the current limit state design approach used in our Light Timber Framing Standard NZS 3604 (SNZ 1990). BRANZ has undertaken a research study to derive a rational basis for testing and evaluating the wind and earthquake resistance of bracing panels, the results of which are contained in BRANZ Study Report SR 78 (Herbert & King, 1998).

5.8.4 Other NZBC performance issues

Since bracing panels perform a solely structural function, their only non-structural performance requirements relate to their functions as internal partitions (section 5.5), gravity load bearing walls (section 5.6), or external walls (section 5.7) as appropriate.

5.9 Roof Systems

5.9.1 Elements within this sub-system

The roof system is considered to be all elements of the building above the top of the wall; that is the roof cladding and its immediate supports (i.e. the battens), the principle roof structural members (i.e. the rafter or truss system), all lateral bracing above the upper wall plate, the ceiling system (including the ceiling framing, the linings) and the eaves and gables.

5.9.2 Functional requirements

The performance requirements stipulated in the NZBC for **roof systems** relate to the following:

- The structural provisions of Clause B1 with regards to resistance to supporting the self-weight of the building, imposed live loads and forces induced by wind or earthquake induced ground motion.

- The durability provisions of Clause B2 are to be applied to all functional aspects required by the NZBC in accordance with the guidelines set out in section 3.4 above. The primary structural elements are required to perform throughout the intended life of the building. Roof cladding elements, together with fixings and immediate supports which are readily accessible are required to fulfil their function for not less than 15 years. Fixings which are not easily replaced (eg concrete tile fixings) may require a 50-year durability.

- The fire provisions of Clause C3 'Spread of Fire' has application to roof systems to limit vertical fire spread from an adjacent lower roof.

- The ingress of airborne moisture is to be controlled in accordance with the requirements of Clause E2.

- The internal moisture control provisions of Clause E3, usually as they apply to condensation control of roofs;

- The energy efficiency provisions of Clause H1 in terms of the complete building envelope of which roof systems form an important part.

5.9.3 Structural behaviour

5.9.3.1 Actions applied

- **Gravity Loads:** Gravity loads, generated either from the self-weight of the roof system, items installed upon the roof or from temporary loads supported by the roof. All such actions are imposed vertically downwards. For pitched roof elements, this will be inclined to the plane of the roof, an aspect that will need to be considered. For ceiling or attic spaces, which are used for storage, additional support is expected to be provided within the roof space to sustain such loads. Beyond the storage area, and within inaccessible roof spaces, the primary structural elements are required to sustain a concentrated load of 1 kN applied at any point. Ceiling elements are only required to support their self-weight.

The roof system provides support for these loads by spanning between gravity load bearing walls. It is currently common practice that the roof system is constructed from long-span truss elements and that the load bearing walls are located along opposite external walls only. More traditional construction utilised shorter spanning elements and required internal load bearing partitions.

- **Wind Loads:** Wind effects usually dominate the structural considerations of the **roof system.** For most roofs there will be a combination of wind suction (usually along the windward edge of the roof and the leeward side of the roof particularly near the roof ridge line. Positive (downwards pressures) pressures will develop on the windward side of more steeply pitched roofs (ie pitch > 25°). Otherwise most of the roof will be subjected to wind suction and must be anchored against sheet uplift. The pitched and often complex shape of most house roofs results in significant uncertainty as to the actual distribution or intensity of design wind loads appropriate for roofs. This uncertainty should be remembered when preparing mathematical or experimental roof models to replicate wind effects.

  The eaves of buildings are designed to the same pressure as is acting on the wall beneath the eaves. Thus eaves above windward walls are subjected to positive pressure, being 0.7 times the design wind pressure (as stipulated for the wind zone and limit state being considered in Table 2 above). Eaves above side or leeward walls are subjected to wind suction of 0.65 and 0.5 times the design pressures respectively.(*Note the internal wind pressure within the cavity above the eaves is considered to be equally permeable in all directions and thus does not contribute to the nett pressure on the eaves).* Loss or damage to the soffit can have serious consequences in that the roof space may become fully pressurised, with the nett pressure on the roof cladding now including an internal pressure of up to +0.7 times the design pressure (whereas this was previously applied to the ceiling below). The recent advent of flexible vinyl soffits, often slotted into plastic jointer strips and into a grooved facia, need careful consideration to ensure they do not flex too far and disengage from their supporting slots, thereby becoming free from the supporting structure (ie 'failing') well before the rupture strength of the soffit itself is attained.

- **Earthquake loading** on roofs is primarily a function of the self-weight of the roof itself. Heavy roofs, particularly those comprising of individual elements (ie tiles) will generate significant lateral loads during earthquake attack. Such actions can either be down or across the roof slope. The down-slope action is usually within the plane of the rafter or truss and can usually be easily accommodated (provided the element is adequately secured to the its supporting framing so as not to become dislodged and slide from the roof. The across-slope actions usually require some additional measures to ensure the lateral load can be transmitted from its point of development (often towards the roof apex) to the ceiling plane, where it can be collected within the ceiling diaphragm and transmitted to upper-floor bracing walls. Such actions will usually require diagonal braces to extend from apex to ceiling plane, either directly or as sloping props, usually from the ridge to the ceiling or top chord of the bracing wall. Alternatively inclined diagonal bracing elements can achieve the same result by following the underside of the roof itself. Such braces still extend to the roof apex, but usually are fixed to the underside of the truss or rafter system, terminating at the outer wall line. Care must be taken to ensure positive fixity is achieved both at the apex and at the lower connection points. This will normally require use of nail-plate or straps. Seldom can the required tension be developed with simple nailing.

Ceiling systems may be part of the primary structural system when they support the tops of walls against face loading through their behaviour as horizontal diaphragms. In such cases the ceiling plane itself transmits the shear induced within the diaphragm, with the battens and ceiling support framing providing an adequate level of out-of-plane rigidity to prevent the ceiling buckling. The shear is induced into the ceiling through the top-plate to ceiling framing connection and transmitted from the ceiling diaphragm by the connection between the ceiling framing and the bracing wall panels orientated parallel to the direction of loading. (Refer section 5.3 for further discussion on the behaviour of horizontal diaphragms.)

- Other loads imposed by the natural elements on the **roof structure** are induced by snow (in areas of high altitude or within most of the South Island). The free ground snow intensity is typically 0.5 kPa, but this can increase when the roof geometry is such that snow drifts may gather. Water ponding can also occur on roofs which are flat or near flat, or through accidental blockage or malfunction of the normal roof drainage system. Particular attention should be given to ponding effects where internal gutters are present, particularly if natural run off is inhibited by the presence of parapets of other mechanisms.

5.9.3.2 Structural serviceability issues

- **The roof sheathing:** The roof sheathing, together with its fixings and immediate supports, must be able to sustain serviceability limit state wind effects (applied as a uniformly distributed load) or maintain related concentrated loads without the sheathing becoming disengaged (ie water leakage along the seams between sheets) and without the system experiencing any discernible residual deformation when the applied (test) load is removed. The concentrated load of 1.1 kN (representing a foot fall) is applied through a 100 mm diameter rubber bearing pad applied anywhere over the roof surface. For smooth reflective surfaces such as metal roofing, a residual deformation of 1/600 measured over a 300 mm datum is appropriate as a control. Such provisions may be relaxed (or removed entirely) for textured roof claddings, or when the roof is not overlooked and therefore cannot be readily seen. Where the roof has a very low pitch (<5°), permanent deformation from any source may result in a local backfall with localised ponding resulting. For metal roofs, this would affect the durability requirements since ponding on galvanised steel would normally be outside the manufacturers approved scope of use.

- **The ceiling system & its immediate supports:** The ceiling itself is usually required to support only its own weight without undue sag between support points. Some ceiling systems may sag after repeated humidity cycles in which case these effects need to be included in any evaluation. The point at which magnitude where ceiling sag becomes unacceptable is influenced by the texture of the ceiling, the level (and often the direction) of lighting present and the proximity of the ceiling system to the occupants line of sight. Flat ceilings painted with reflective finishes are much less tolerant to undulations. Sag between support points of as little as 0.5 mm (Span/1000) can be noticed within such surfaces, particularly if the ceiling slope is such that the lighting direction can be near parallel with the ceiling plane. Other ceilings, such as textured finishes or suspended ceiling systems, may be acceptable with sag levels of up to 1.5 mm or more between support points (span/400). For ultimate limit state considerations, the ceiling and support battens are only required to sustain their own mass without failure. This is not usually difficult to achieve, although aging effects may be of concern when the ceiling system experiences strength loss or embrittlement either with age or exposure to the light and heat levels present within the house. Where the ceiling is required to act as a horizontal diaphragm element within the shear transfer load-paths (ie top-plate to ceiling framing, ceiling framing to ceiling sheathing, etc.), they should be checked to ensure they and their connections have sufficient rigidity and strength to transmit the actions imposed on them. Where the ceiling lining is separated from the framing by non-rigid elements (eg profiled pressed light metal ceiling battens) then the 'roll-over' strength and stiffness of the separating element need to be assured. The in-plane shear behaviour of the connectors which attach the ceiling lining to the framing elements also needs to be assured.

- **The eaves elements:** The eaves are particularly visible elements within the roof system and thus often are subjected to the most severe serviceability limit state control criteria. The facia, upon which the gutter system is usually fitted is clearly visible and forms a key sight line for many buildings. Ripple effects are thus easily noticed (although they may be disguised behind the guttering) and should be limited to deflections of less than span/400 between trusses or ± 3 mm over each 3 m reference length.

- **The primary roof structure:** The serviceability limit state criteria for the primary roof structure (i.e. the trusses, rafters and framing elements) require consideration of the self-weight of the roof system and the combination of dead load and serviceability limit state intensity wind effects to be considered as separate load cases. In both cases the system is required to be sufficiently stiff so as to ensure no noticeable movement (either sag or uplift) under either loading combination which occurs. The magnitude of acceptable movement will be influenced by the texture and shape of the roof claddings, the visibility of the facia and eaves system, and the degree by which the roof system is isolated from the ceiling. The texture and visibility of the ceiling may also be significant.

5.9.3.3 Structural capacity issues

- The **roof sheathing** and supports must be sufficiently robust to sustain magnified maintenance related point loads (1.6 x1.1 = 1.75 kN). Wind loads applied as uniformly distributed loads over the roof surface, are to be withstood without rupture or the sheathing becoming disengaged from its supporting frames.

5.9.3.4 Verification methods

- Whilst **verification by calculation** is practical for the primary structural elements within a roof system, (ie the trusses or framing elements), and for the connections between the roof structure and the support walls, such an approach does not consider load sharing between adjacent trusses and thus tends to be conservative. Experience of roof systems which have experienced structural failure indicates that the connection between the roof system and the supporting structure is by far the most vulnerable and merits particular attention.

- **Verification by prototype testing** is however complicated and thus expensive. It tends to be limited as to the ability to extend beyond the geometry of the test specimen itself. It has thus become a means of validating the design models used as the basis for calculation.

5.9.4 Other NZBC performance issues

- **Durability issues:** The durability provisions of Clause B2 apply to all aspects of performance required to satisfy the health and safety criteria implicit in all the provisions of the NZBC. The 50-year intended life provision of B2 applies to all items whose function is essential to fulfilling the health and safety provisions of the Code and yet they are difficult to inspect and/or maintain (e.g. cast-in downpipes). The 15-year intended life provisions apply to claddings and their fixings provided they are moderately easy to inspect and if necessary to replace (roof sheathings, boxed gutters, etc.). Items which are open to easy inspection and are readily replaced are assigned a 5-year intended life (e.g. gutters, metal flues, etc.)

- **Fire provisions:** Refer to section 5.7.4.

- **External moisture:** The provisions of Clause E2 apply to all roofs. Acceptable Solution E2/AS1 details various profiles which are deemed to comply with the performance requirements of this section. Minimum roof pitches are prescribed for different types of roof cladding in Table 1 of E2/AS1. Acceptable roof cladding systems are specified in Table 2 of E2/AS1 together with the appropriate standard that these claddings are required to comply with. Where roof underlays are specified to be used, the installation and absorbency of these products is prescribed in clause 1.3 of E2/AS1.

- **Internal moisture:** The provisions of Clause E3 'Internal Moisture' relate to roof systems particularly with respect to preventing fungal growth. The high thermal gradient across roof cladding is likely to result in condensation and thus fungal growth unless the dew point at which condensation develops is controlled to occur in a location where the relative humidity of the air is kept low. Acceptable Solution E3/AS1 stipulates minimum insulation ratings for roofs ($R \geq 1.5$) in combination with adequate ventilation is needed to avoid fungal growth.

- **Energy efficiency**: The energy efficiency rating requirements of Clause H1 are directly applicable to roof spaces, these being considered as forming part of the building envelope. Insulation is generally provided within the roof space directly over the ceiling lining thereby entrapping warm air within the living space rather than within the roof space.

6. A STRATEGY FOR NEW SYSTEM INTRODUCTION

When embarking on the task of introducing a new framing system into the market (or indeed any new building system or component) it is essential that the requirements of each and all of the end users be clearly identified and addressed. These requirements will vary, and may require the preparation of specific information which focuses on one or more subsets of the end-user groups.

The information needs associated with the introduction and acceptance of any new system far exceed the technical compliance issues discussed until now. Discerning home owners need information and assurance that the new system performs at least as well as other traditional systems. They also generally demand that comprehensive and reliable assurances as to both initial and life-cycle costs of maintenance and repair are available (and credible) and that support and assistance will be available over the intended life of the building. The effect on re-sale of a house built with new systems needs to be considered and can discourage use of the system.

The impact of the new system on other related aspects of the building process such as secondary trades (e.g. electrical reticulation, plumbing and drainage services, and ease of application and quality of surface coatings and finishings), needs to be addressed, information provided and guidance and reassurance given as to the influence the system may have on each specific trade. The importance of addressing this aspect cannot be underrated with its oversight resulting in conservative sub-trade pricing reflecting that trade's 'high risk' perception of the system.

This a comprehensive trade and supply education and development programme, which targets the specific needs of each group within the building team (designers, builders, sub-tradesmen and building control officials), should accompany the introduction of a new system. A clear understanding of the scope of application is required. Information and guidance should be provided to demonstrate how each team member can achieve the required in-service performance for their particular discipline. It is essential that an adequate level of technical, advisory and practical support is available throughout the design, construction and maintenance period (and beyond) to allow each member to perform their respective roles efficiently and effectively. Such information must be presented in a manner appropriate for each specific end-user group so it can be readily understood and applied. Procedural changes in either design or construction must be clearly identified. Complications and pitfalls should be noted and means of avoiding or overcoming these presented. Only once the user groups have become familiar and confident that the system does not penalise their particular aspect of construction will it become widely accepted.

The style of presentation of such literature will vary from group to group. While the client group will primarily be attracted to pictorial images associated with the quality of the end result, with overall cost and long-term performance also being important, the designer and approving agencies are more specifically concerned with the technical verification of code compliance and limitations on scope to ensure the product is capable of attaining the required performance and is being appropriately used. The supplier, distributor and installer have more practical interests of ensuring ready supply and easy installation with the ability to readily adapt factory assembled components or systems to ensure true fit. Subtrades are interested as to how the new product will effect their ability to fulfil contract performance expectations. Where uncertainties exist within this latter group, unnecessary escalations in subtrade contract prices often occur.

The needs of each interested party can be quite different but are summarised in Table 8.

7. LITERATURE REVIEW

7.1 International Organisation for Standardisation

7.1.1 General

ISO (the International Organisation for Standardisation) publications hold a special place in the prescription of performance requirements for buildings. The ISO ideal is to provide an international basis for common acceptance of systems and components. As such most national standards organisations have a policy of adopting ISO guidelines and standards where these are available and appropriate for national use.
Within the domain of assessing the performance of building systems and components there are several ISO standards published and others under preparation. These often are in the form of guidelines which prescribe the format and contents by which national standards on particular issues should be prepared.

7.1.2 ISO Task Group 59/Sub-committee 3/Working Group 10

Of most direct relevance to this report was a decision of Subcommittee 3 to establish a working group, WG 10 to develop a performance standard for housing made during their meeting in Stockholm in October 1996. Australia was assigned secretarial responsibility for the working group which has a time frame of completing its work over a three year period (ie by 2000). During a workshop of this working group, held in Tokyo in January 1997, and attended by 15 delegates from 7 countries, the scope of the task was developed and recommendations put forward that the status of the working group be elevated to that of a Subcommittee thereby enabling various working parties with specific disciplinary expertise to be formed to address and develop performance criteria for the 15 primary attributes identified. This recommendation is to be placed before the full Task Group 59 during their June meeting in London.

The vision of the group is to develop multi-level performance criteria for one and two family houses. These may be connected horizontally (ie have walls in common) but not vertically (ie are to exclude units on top of each other). One of the primary uses for such a document was the ability of both the purchaser and the supplier of the building to be precisely aware of what the particular requirements for any given building or development project are to be. As with any international standard, the problems of varying local building controls and regulations have been identified as national variances which need to be specifically accommodated within the finished standard.

Two base documents were tabled for discussion, one being the draft of one part (structural) of a joint New Zealand/Australian standard on housing and the second a resource document produced by the National Institute for Standards and Technology for consideration by an ASTM committee which is also addressing this specific issue for the US. Each are discussed separately within this section.

7.1.3 ISO 6240 ‘Performance standards in buildings - Contents and presentation’ (ISO 1980)

ISO 6240 ‘Performance standards for buildings - Contents and presentation’ is a very brief document (4 pages) which prescribes the sections and the order of presentation preferred within a performance standard namely:

1. Scope	Detail the component or assembly which is the subject of the standard.
2. Field of application	States the intended use of both the standard itself and the component or assembly which is the subject of the standard.
3. Reference	References other related standards or documents.
4. Definitions	Defines all specialist terms used in the standard.
5. Purpose and context of use	Describes the role the assembly is intended to play in satisfying applicable functional requirement and indicates the agents (or actions) relevant to the performance of the component.
6. Performance requirements	Lists the performance requirements for the component in final use within the building and, if necessary, for the supply, transportation, intermediate storage, handling and installation with distinctions being drawn between those which apply long term and those which only apply in specific circumstances.
i) Definition of performance	Defines each performance requirement in terms of a function which is to be fulfilled, together with the physical or chemical properties on which assessment or verification will be based. Expresses these in quantifiable terms.
ii) Method of assessment or verification	Defines the means (measurement, calculation, test or method of examination) by which the achieved performance is to be assessed or verified, together with the means of predicting the performance over time for each performance requirement.
iii) Performance values	Specifies the upper and lower limits of the range of acceptable performance values or grades against which the performance of the component is to be assessed for each performance requirement.
iv) Commentary	Provides any observations or examples which may assist understanding the intent of each requirement and verification procedure stipulated.
7. Description of Achieved Performance	States any requirements applicable when describing the achieved performance of a product or component (i.e. how manufacturers should report the achieved performance).
8. Applicability of Certification	Gives details as to how applicable standard is to certification particularly with reference to quality control and product ‘marking’.

7.1.4 ISO 6241:1984(E) 'Performance standards in buildings - Principles for their preparation and factors to be considered' (ISO 1984)

ISO 6241 complements ISO 6240 by listing factors to be considered for performance standards. It specifically aims to assist committees charged with preparing performance-based building standards by providing a basis for the preparation of such standards and as an aide-memoire for drafting particular standards. The standard specifically aims to be a guide for preparing fundamental (level 1) standards and as such is intended primarily to assist standards committees in their work by stating the general principles for drafting performance standards for buildings.

The standard contains a useful set of general definitions which have direct application to performance-based standards.

The principles for preparing performance-based standards are given below. The overriding objective is to define the behaviour of the building either as a whole or as components or subassemblies. All such standards should contain statements about:

a) the performance requirements (expressed as a range of values or grades which relate to the user requirements and the relevant agents (actions) to which they are exposed.

b) methods of assessing each performance characteristic including performance over time under specified agents.

It is acknowledged that it may be more convenient to publish these as separate documents.

Methods of performance assessment are likely to include test, calculation or judgement. The selection of the appropriate means of assessment will depend on the extent of sound technical performance information available. For new buildings, a combination of calculation based on the behaviour of parts of buildings is most likely. For some user requirements, such as acoustics or ventilation, the extent of satisfaction of user requirements may involve assessment in parts by direct measurement or test of the building itself or of a sample or prototype. The choice of method of verification also depends on the level of accuracy appropriate to the relative importance and the order of priority of the performance requirement.

The primary focus of the standard is the four tables presented as Annex 1 to 4 which identify the main factors to be considered when preparing a performance-based standard.

User requirements (Table 1): lists the user requirement in and around the building in various categories such as stability requirements, fire safety requirements, safety in use requirements, tightness requirements (relating to water, air, gas snow and dust tightness), air purity requirements, acoustical requirements, visual requirements (relating to natural and artificial lighting, visual separation or privacy), hygiene requirements, dynamic requirements (including whole-body vibrations, ease of movement door and window manoeuvrability) and durability requirements.

Uses of buildings and spaces (Table 2): lists the primary uses to which rooms, spaces or whole buildings may be put. It is expected that the space will be named according to its primary use with secondary uses included. Thus housing blocks with ground floor shops or hospitals with office and catering spaces. The uses will usually affect the selection and order of importance of the user requirements.

Sub-systems of the building fabric (Table 3): lists the physical parts of the building fabric based on the consideration of the function only. Sub-systems may be formed of components or assemblies distributed throughout the whole building (e.g. heating and ventilation services). Conversely a component or assembly may be part of one or more sub-assemblies (e.g. a facade unit may be part of the load bearing structure of the building envelope of the heating and ventilation service and of the electrical service). Thus a component or assembly does not necessarily correspond to a 'functional' sub-system and its is expected that other subdivisions will be introduced for other specific criteria.

Agents relevant to the building performance (Table 4): lists the agents (actions) relevant to the performance of buildings and their constituent parts. The agents are listed according to their origins (e.g. external - atmospheric transmitted or ground transmitted, naturally generated or generated by man; internal (to the building envelope) - consequential to the building occupancy or the building design) and to their nature (e.g. mechanical, electromagnetic, thermal, chemical or biological). The agents are listed according to their own nature rather than the nature of their actions on the building.

This standard interrelates with ISO 6240. In particular the "scope" and "field of application" clauses mentioned above should relate to categories in Tables 2 and 3 of this standard, the "purpose and context of use" clauses should be drafted using Tables 1 and 4. When listing "performance requirements", the order suggested in Table 1 should be followed.

7.1.5 ISO 7162:1992(E) 'Performance standards in buildings - Contents and format of standards for evaluation of performance' (ISO 1992)

This standard establishes some rules for the content and presentation of standards for the evaluation of performance whole buildings, parts of buildings (components, assemblies, and sub-systems) and of the spaces within and around buildings.

Clauses recommended for inclusion in standards for evaluation of performance are as follows:

Scope	States the item and performance for which the standard gives evaluation method(s). It lists the properties on which the performance assessment is to be based and indicates whether performance is to be assessed before use and whether this will be by test, calculation, expert judgement or to be verified after the item is in use within the building.
References	Lists any related standards or existing tests.
Definitions	Defines all new and specialised terms used in the standard.

Principle	Describes the scientific or engineering principles upon which the performance evaluation is to be based.
Equipment	Describes all the test equipment and the level of accuracy required for test evaluations.
Condition of test piece(s)	Defines the intended state of the specimen at the time of testing (eg moisture content, temperature, etc.). Also defines the laboratory environment during execution of the test.
Procedure	Describes the operations and the sequences to be followed during the test indicating the number of measurements to be taken and the arrangement of the test equipment to be used. Any other details needed to safeguard the intended quality of results should also be given.
Precision of results	Indicate the expected precision of the results, preferably in terms of repeatability and reproduceability, in accordance with the principles given in ISO 5725.
Presentation and interpretation of results	List the items that are required to be stated in the evaluation report. Indicate whether these are to be expressed numerically or graphically and whether values are to be rounded.

Establishing a standard for evaluating performance is identified as requiring the following stages:

1. An understanding of all natural and man-made phenomena originating from the environment, the design and the uses which govern performance (eg humidity, wear, compatibility).
2. An understanding of the mechanisms by which the product develops and loses its performance for the requirement in question (eg resistance to bending, thermal transmittance, mechanism of degradation).
3. Provisional determination of an evaluation method, together with an agreed definition of its field of applicability (e.g. to groups of products with particular constructional or material characteristics, to particular geographic zones or particular conditions of use).
4. Verification of the assumed correlation between the results of the provisional method and the performance achieved to provide a confirmed method (with successive improvements if necessary).
5. A definition of the interpretation procedures and the reporting data.

7.1.6 ISO 9699:1994(E), Performance standards in buildings - Checklist for briefing - Contents of brief for building design. (ISO 1994)

The standard describes the content of a brief for building design. Its aim is to provide a consistent basis upon which clients are able to prescribe their needs, aims, resources and the context of the building project and any other problems arising. Such information is expected to result in a brief which can be expected to form the basis of commission for building consultants. Three checklists are provided (annexes A to C) and are expected to provide a standard framework for the presentation of the brief.

Annex A	Project Identification	Identifies the project, its purpose and scope, the participants and any other related groups.
Annex B	Context, aim and resources	Identifies the project management structure envisaged, applicable laws (regulations, codes and standards), financial and time constraints, any historical or background influences, locality and site related influences, client expectations, occupancy expectations and the intended effects of the project
Annex C	Design and performance	Prescribes the design and performance expectations of the site and its surroundings, of the building as a whole, of the building fabric, of groups of spaces, of individual spaces, and of plant, equipment and furnishings.

7.2 International Council for Building Research and Documentation (CIB)

In 1992 a CIB Task Group "Performance-Based Code", identified as CIB Task Group 11, was established with the objective of providing a discussion forum and information exchange for those working on the development of performance-based building codes. The task group comprised 30 members from 13 countries with very wide territorial and professional interests. Secretarial responsibility rested with the National Research Council of Canada and has culminated in a draft report (NRCC 1997) which is nearing publication.

This document primarily focuses on experiences and approaches used within different countries when developing performance-based building regulations and controls (such as the New Zealand Building Code). This is distinct from the development of building standards or performance criteria which can operate within the national regulations. There is recognition that any building code, including performance based codes, should respond to the needs of building users (i.e. the occupier), code users (i.e. designers, building officials, contractors, etc.) and to the general public. Each group has different needs. The building users expects the code to reflect societal expectations (often contained within the enabling legislation), and the functional needs of the building (often reflected in the plans and specifications for specific buildings, but may also be regulated in the national interests - e.g. energy conservation). The report identifies that code users expect any new building code would have the following:

1. A well defined scope
2. Satisfy public expectations
3. Clarity of content
4. Be easily understood
5. Appropriate classification of building uses
6. Provide certainty of outcome
7. Be flexible in application

8. Apply uniformly throughout the jurisdiction
9. Apply to all buildings
10. Ensure consistency of interpretation
11. Be easy to update
12. Be administered by a single body
13. Not hinder innovation
14. Make use of all available resources
15. Apply a consistent approach to risk
16. Minimise disputes
17. Have clarity of liability
18. Ensure cost-effective compliance
19. Be applicable to changes of use and alterations.

The report also outlines some reasons for moving from a traditional building control system to a performance-based system. These are:

1. Ease of understanding the intent of the regulation
2. Clarity of evaluation procedure for alternative/innovative solutions
3. Consistency of interface with the user
4. Ease of authoring and maintaining the code documents
5. Ease of representation and delivery in information technology systems and in supporting associated navigational and retrieval systems.

Three methods of assessing compliance with performance are identified, namely:

- Providing proof, using approved verification methods (e.g. insitu or laboratory testing or by calculation).

- Providing proof of conformance with a standard (or other reference) that describes a technical solution which is accepted in satisfying the required performance (often known as ‘deemed to comply’ solutions, ‘acceptable’ solutions or ‘accreditations’).

- Providing proof through expert judgement.

7.3 US Developments

7.3.1 NIST Resource Document for Performance Standards for one- and two-family dwellings (NIST 1996)

The most comprehensive document found on this subject from the USA was produced by the National Institute of Science and Technology and is an unpublished resource document aimed at providing input into the development of an ASTM (American Society of Testing and Materials) subcommittee E6.66 formed during 1996 and charged with the development of national performance-based standards for one and two family dwellings in the USA (NIST 1996). Whilst specifically developed as the basis for discussion within the US environment, it recognised the benefits from an internationally accepted consensus of acceptable performance criteria for housing and has been offered to Working Group 10 of ISO TC59 SC3 (refer 7.1.2).

The discussion document includes the following definition of the performance concept, which is appropriate for this report also:

> “A framework for specifying and evaluating qualities of building products and systems to meet user needs without limiting ways and means”

The discussion document is very comprehensive, extending to over 300 A4 pages. Thirteen functional attributes have been identified (refer Table 9) which combine to enable the dwelling performance to be fully described. While it is recognised that only some are suitable for standardisation or quantification, they are all worthy of consideration when trying to accurately describe or differentiate a client or user group need or performance expectation. Whilst these attributes focus on the functional user needs and expectations, a sub-system index provides the means of segmenting the building into components or assemblies which combine to form the completed structure. The intention is to enable system suppliers to readily identify each specific performance attribute that each sub-assembly is required to satisfy and the means by which compliance with the required performance can be demonstrated.

Each criterion is presented in a standard RCEC format under the headings as follows:

Requirement	which is a quantitative statement giving the user needs or expectations for the assembly being addressed. It is a general statement of what the product or assembly is intended to do.
Criteria	are quantitative statements giving the level of performance required to meet the user needs or expectations for the item being addressed.
Evaluation	set forth the methods of tests and/or other information upon which a judgement of compliance with the criterion will be based. It states the standards and inspection methods, analysis, review procedures, historical documentation, test methods, in-use performance, engineering analyses and models which may be used in evaluating whether or not the criterion has been satisfied.
Commentary	provides background for the reader and presents the rationale behind the selection of specific data presented in the requirement, the criterion or the evaluation. The commentary is provided for informational purposes.

AISI Residential Construction Guideline RG 934a (AISI 1994)

The American Iron and Steel Institute produced a user guide which provided designers and contractors with guidance on design, detailing and construction aspects of low-rise residential construction using cold-formed steel sections. Unfortunately many of the more complex issues such as moisture protection, thermal insulation, seismic design or design in high wind speed areas are identified as requiring special consideration and are specifically excluded from the scope of the guide.

The Guide is in two parts and take the form of a specification which relates to construction aspects (part 1) and to design aspects (part 2). The specification details covers aspects which relate to the framing system itself, the connections between framing members (nominally screws but welding or rivets being acceptable equivalent solutions), bracing and stiffener requirements and other miscellaneous issues (such as protective coatings). The design and detailing section of the guide is similarly structured.

The handbook provides load-span tables for cold formed beams and columns (together with design examples). These are based on the AISC Allowable Stress Design Manual with sections fabricated in accordance with the AISC specification with regards minimum yield stress (f_y = 240 MPa) and section thickness (1.5 mm). Within the New Zealand/Australian context, limit state design would be expected, minimum yield stress of 550 MPa and section thickness of 0.6 mm would be normal. Thus the tables are of little relevance for New Zealand construction.

A section is provided on fasteners for use with residential framed systems. Self-drilling screws of various head styles, are identified as the most common framing fixings in use in the USA. Allowable stress design strengths are tabulated for shear and pullout with the design values having been derived in accordance with the AISI criteria (CCFSS 1993).

Issues relating to the thermal design of steel framed walls are included in a 1995 annex to the manual (AISI 1995). This section is based on research work undertaken at the National Association of Home Buildings and on hot-box testing of 8 ft square panels conducted by Holometrix Inc. The essential features of this work is the proposal that for more moderate climates, normal full-width insulation can be used to attain the required energy resistance rating, while in the more severe climates (such as New Zealand) a thermal break is required between the outside face of the framing and the external cladding.

7.4 Australian Environment

7.4.1 Design criteria for timber framed houses

At the point of going to press with this report, Standards Australia are nearing completion of an Australian Standard which prescribes the design and engineering criteria for timber framed buildings. This is scheduled for publication within the next eight months (by April 2000). It will be produced as *AS 1684 Part 1: Design Criteria* and is presented as a comprehensive set of design and engineering procedures and assumptions on which all elements within a timber framed house can be designed. Compliance with the proposed Standard will enable manufacturers and others to verify the compliance of new or alternative systems with the prescriptive parts of AS 1684 in which member span tables and joint details will be published.

The pre-publication Standards committee draft was developed from an industry specification entitled *Design Methodology and Performance Criteria for Timber Framed Housing* (MacKenzie & Juniper 1996). It was then extensively reworked into a final committee draft (dated January 1999) with the criteria themselves being used as input to purpose-made computer software; from this the prescriptive parts of the framing Standard will evolve.

The draft of Part 1 of the revised AS 1684 is presented in six sections with four appendices laid out as follows:

1. Scope & General
2. Design of roof members (including rafters, purlins, beams & ceiling members)
3. Design of wall members (including posts & lintels)
4. Design of floor members (including joists & bearers)
5. Determination of wind pressures for the calculation of racking loads
6. Determination of uplift forces

Appendix A: Wind classification and dynamic gust pressures
Appendix B: Design of overhangs for parallel birdsmouth notched rafters

The stated intention of this document is to provide the engineering basis for the prescriptive solutions contained in other parts of the Standard. It is expected that alternative product suppliers will be able to introduce their specific solutions based on the same engineering assumptions and performance criteria which are applicable to the remainder of the Standard.

In each of sections 2 to 4 various loading diagrams and specific combination and reduction factors are detailed, which combine to provide specific details that can be used for practical design. This is perhaps one of the more clearly presented, comprehensive collections of housing performance criteria encountered during the review.

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Table 8: User group requirements

The Client	• Construction or first cost • Life time costs • Aesthetic appeal (if visible) • Life-time performance (no rattles, leaks or squeaks) • High quality surface finish • Long-term assurance of product support (is the supplier going to be around if there is a problem) • Minimum maintenance • Good market acceptance (resale & neighbourhood appeal)
The Designer	• Clearly defined, preferably widespread, scope of application • Aesthetic appeal (if visible) • Complete, technically sound, up to date, well considered supporting literature which includes all necessary physical properties of the product and deemed to comply solutions • Familiar documentation as to layout, content and style • High level of quality assurance in both production and supply • Building code compliance verification • Comprehensive suite of well developed installation details
The Supplier	• Large, preferably growing, market • Controlled establishment and set-up cost • Suitably skilled work force (or the ready means to develop one) • Quality assured supply of raw materials • Quality assurance procedures to assure consistent system output • Reliable established distributor network
The Distributor	• Reliable supply • Reliable product support • Sound technical support • Qualified installers
Approving Agency (Territorial Authorities)	• Sound, assured technical detail • Familiar documentation as to layout, content and style • Building Code compliance verification • Comprehensive construction and installation details & specification (of both the system itself and the related trades • Easy inspection and verification that installation is as specified
The Installer or Builder	• Clearly defined cost which is acceptable to owner • Straight forward order and supply procedure with no surprises (delivery or product • Easy installation (clear instructions with no surprises) • Easy alteration and on site modification • Low damage potential
Subtrades	• Easily installed linings & claddings preferably with standard fasteners & fittings • Easily attained good quality surface finish • Easily installed electrical reticulation • Easily run plumbing fittings and waste runs • Readily insulated (floors, walls & ceilings)

Table 9: Cross index of attribute against sub-system (NIST 96)

		ATTRIBUTE INDEX												
		FUNCTIONALITY	SAFETY SERVICEABILITY	FIRE SAFETY	ACCIDENT SAFETY	HEALTH & HYGIENE	ATMOSPHERIC ENVIRONMENT	ILLUMINATION	ACOUSTICS	AESTHETICS	DURABILITY	MAINTAINABILITY	FLEXIBILITY	ACCESSIBILITY
SUB-SYSTEM INDEX		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Building	1.0													
Spaces	1.1													
Common Spaces	1.1.1													
Lobbies	1.1.1.1													
Corridors	1.1.1.2													
Stairways	1.1.1.3													
Elevators	1.1.1.4													
Equipment Room	1.1.1.5													
Trash Spaces	1.1.1.6													
Other	1.1.1.7													
Private Spaces	1.1.2													
Hall	1.1.2.1													
Living Room	1.1.2.2													
Dining Room	1.1.2.3													
Kitchen	1.1.2.3													
Water Closet	1.1.2.5													
Terrace/Yard	1.1.2.6													
Bedrooms	1.1.2.7													
Bathroom	1.1.2.8													
Structure	1.2													
Foundation	1.2.1													
Superstructure	1.2.2													
Exterior Envelope	1.3													
Non-Vertical	1.3.1													
Roofs	1.3.1.1													
Slabs	1.3.1.2													
Other	1.3.1.3													
Vertical	1.3.2													
Walls	1.3.2.1													
Doors - Windows	1.3.2.2													
Other	1.3.2.3													
Interior Space Dividers	1.4													
Non-Vertical	1.4.1													
Floors	1.4.1.1													
Ceilings	1.4.1.2													
Other	1.4.1.3													
Vertical	1.4.2													
Walls	1.4.2.1													
Doors	1.4.2.2													
Other	1.4.2.3													
Distribution Network	1.5													
Plumbing	1.5.1													
Water Supply	1.5.1.1													
Drain Waste Vent	1.5.1.2													
Rainwater Piping	1.5.1.3													
Fire Protection Piping	1.5.1.4													
Electrical	1.5.2													
Power	1.5.2.1													
Telephone	1.5.2.2													
Television	1.5.2.3													
Lighting	1.5.2.4													
Fuel	1.5.3													
HVC	1.5.4													
Heating	1.5.4.1													
Ventilating	1.5.4.2													
Cooling	1.5.4.3													