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Review of Performance-Based Fire Safety Regulations in Selected Countries: New Zealand

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Definition of Terms

The following definitions are taken directly from the Building Act 2004 (Reprinted 2020), Building Regulations 1992 (Reprinted 2017), C/AS1 and C/AS2 Acceptable Solutions (2020), C/VM1 and C/VM2 Verification Methods (2020).

Acceptable solution Means an acceptable solution issued under section 22(1) of the Building Act 2004.

Alter In relation to a building, includes to rebuild, re-erect, repair, enlarge and extend; and **alteration** has a corresponding meaning.

Access route A continuous route that permits people and goods to move between the apron or construction edge of the building to spaces within a building, and between spaces within a building.

Adjacent building A nearby building, including an adjoining building, whether or not erected on other property.

Available safe egress time (ASET) Time available for escape for an individual occupant. This is the calculated time interval between the time of ignition of a fire and the time at which conditions become such that the occupant is estimated to be incapacitated (ie, unable to take effective action to escape to a place of safety).

Backcountry hut A building that—
a) is located on land that is administered by the Department of Conservation for conservation, recreational, scientific, or other related purposes, including any land administered under any of the following:
- i) the Conservation Act 1987;
- ii) the National Parks Act 1980;
- iii) the Reserves Act 1977; and

b) is intended to provide overnight shelter to any person who may visit and who carries his or her own food, bedding, clothing, and outdoor equipment; and
c) contains only basic facilities, which may include (but are not limited to) any or all of the following:
- i) sleeping platforms or bunks;
- ii) mattresses;
- iii) food preparation surfaces;
- iv) appliances for heating;
- v) appliances for cooking;
- vi) toilets; and

d) has been certified by the Director-General as being in a location that wheelchair users are unlikely to be able to visit; and
e) is intended to be able to sleep—
- i) no more than 20 people in its backcountry hut sleeping area; and
- ii) no more than 40 people in total; and

f) does not contain any connection, except by radio communications, to a network utility operator.

Boundary Any boundary that is shown on a survey plan that is approved by the Surveyor-General and deposited with the Registrar-General of Land, whether or not a new title has been issued.

Building Has the meaning given to it by sections 8 and 9 of the Building Act 2004. For the purposes of this Acceptable Solution and notwithstanding the definition of building, a number of separated buildings cannot be taken as a single firecell.

Building Act 2004 (the Building Act) The principal legislation dealing with building controls in New Zealand.

Building Code The regulations made under section 400 of the Building Act 2004.

Building consent Means a consent to carry out building work granted by a building consent authority under section 49 of the Building Act 2004.

Building consent authority Has the meaning ascribed to it by section 7 of the Building Act 2004.

Building element Any structural and non-structural component or assembly incorporated into or associated with a building. Included are fixtures, services, drains, permanent mechanical installations for access, glazing, partitions, ceilings and temporary supports.

Building height The vertical distance between the floor level of the lowest occupied space above the ground and the top of the highest occupied floor, but not including spaces located within or on the roof that enclose stairways, lift shafts, or machinery rooms.

Building work Work for or in connection with the construction, alteration, demolition, or removal of a building; and includes sitework.

Code compliance certificate Means a certificate to that effect issued by a building consent authority under section 95 of the Building Act 2004.

Combustible See non-combustible.

Combustible building materials Means building materials that are deemed combustible according to AS 1530.1.

Computational fluid dynamics (CFD) Calculation method that solves equations to represent the movement of fluids in an environment.

Concealed space Any part of the space within a building, excluding protected shafts, that cannot be seen from an occupied space.

Construct In relation to a building, includes to design, build, erect, prefabricate, and relocate the building; and **construction** has a corresponding meaning.

Design fire Quantitative description of assumed fire characteristics within the design scenario.

Design scenario Specific scenario on which a deterministic fire safety engineering analysis is conducted.

Determination Means a determination made by the chief executive under subpart 1 of Part 3.

Escape route A continuous unobstructed route from any occupied space in a building to a final exit to enable occupants to reach a safe place, and shall comprise one or more of the following: open paths and safe paths.

Evacuation time Time interval between the time of warning of a fire being transmitted to the occupants and the time at which the occupants of a specified part of a building or all of the building are able to enter a place of safety.

Exitway All parts of an escape route protected by fire or smoke separations, or by distance when exposed to open air, and terminating at a final exit.

External wall Any exterior face of a building (including a roof) within 30° of vertical, consisting of primary and/or secondary elements intended to provide protection against the outdoor environment, but which may also contain unprotected areas.

Fire The state of combustion during which flammable materials burn producing heat, toxic gases, or smoke or flame or any combination of these.

Firecell Any space including a group of contiguous spaces on the same or different levels within a building, which is enclosed by any combination of fire separations, external walls, roofs, and floors. Floors, in this context, include ground floors and those in which the underside is exposed to the external environment (e.g. when cantilevered). Note that internal floors between firecells are fire separations.

Fire damper A device with a specified FRR complete with fixings and operating mechanism for automatically closing off an airway where it passes through a fire separation. An airway may be a duct, plenum, ceiling space, roof space or similar construction used for the passage of ventilating air.

Fire growth Stage of fire development during which the heat release rate and the temperature of the fire are increasing.

Fire hazard The danger of potential harm and degree of exposure arising from—
a) the start and spread of fire; and
b) the smoke and gases that are generated by the start and spread of fire.

Fire load Quantity of heat which can be released by the complete combustion of all the combustible materials in a volume, including the facings of all bounding surfaces (Joules).

Fire load energy density (FLED) Fire load per unit area (MJ/M^2).

Fireplace A space formed by the chimney back, the chimney jambs, and the chimney breast in which fuel is burned for the purpose of heating the room into which it opens.

Fire resistance rating (FRR) The term used to describe the minimum fire resistance required of primary and secondary elements as determined in the standard test for fire resistance, or in accordance with a specific calculation method verified by experimental data from standard fire resistance tests. It comprises three numbers giving the time in minutes for which each of the criteria structural adequacy, integrity and insulation are satisfied, and is presented always in that order. There are two types of FRR: life rating and property rating.

Fire safety engineering Application of engineering methods based on scientific principles to the development or assessment of designs in the built environment through the analysis of specific design scenarios or through the quantification of risk for a group of design scenarios.

Fire safety systems The combination of all active and passive protection methods used in a building to—
a) warn people of an emergency; and
b) provide for safe evacuation; and
c) provide for access by, and the safety of, firefighters; and
d) restrict the spread of fire; and
e) limit the impact of fire on structural stability.

Fire source Means the combination of the ignition source and the item first ignited within a room, space, or firecell, which combination is considered to be the origin of the fire for the purposes of design.

Fractional effective dose (FED) The fraction of the dose (of carbon monoxide (CO) or thermal effects) that would render a person of average susceptibility incapable of escape.

Floor area In relation to a building, means the floor area (expressed in square metres) of all interior spaces used for activities normally associated with domestic living.

Functional requirements In relation to a building, means those functions that the building is required to perform for the purposes of the Building Act 2004.

Group Number The classification number for a material used as a finish, surface, lining, or attachment to a wall or ceiling within an occupied space and determined according to the standard test methods for measuring the properties of lining materials. The method for determining a Group Number is described in C/VM2 Appendix A.

Hazardous Creating an unreasonable risk to people of bodily injury or deterioration of health.

Hazardous substance Has the meaning ascribed to it by section 2 of the Hazardous Substances and New Organisms Act 1996.

Heat release Thermal energy produced by combustion (Joules).

Heat release rate (HRR) Rate of thermal energy production generated by combustion (kW or MW).

HVAC An abbreviation for heating, ventilating and air-conditioning.

Importance level As specified in Clause A3 of the Building Code.

Insulation In the context of fire protection, the time in minutes for which a prototype specimen of a fire separation, when subjected to the standard test for fire resistance, has limited the transmission of heat through the specimen.

Intended use In relation to a building,—
a) includes any or all of the following:
  - i) any reasonably foreseeable occasional use that is not incompatible with the intended use;
  - ii) normal maintenance;
  - iii) activities undertaken in response to fire or any other reasonably foreseeable emergency; but

b) does not include any other maintenance and repairs or rebuilding.

Intermediate floor Any upper floor within a firecell which because of its configuration provides an opening allowing smoke or fire to spread from a lower to an upper level within the firecell.

Licensed building practitioner Means a building practitioner whose name is, for the time being, entered in the register established and maintained under section 298(1) of the Building Act 2004.

Life rating The fire resistance rating to be applied to elements of construction that allows movement of people from their location in a building to a safe place.

Means of escape from fire In relation to a building that has a floor area—
a) means continuous unobstructed routes of travel from any part of the floor area of that building to a place of safety; and
b) includes all active and passive protection features required to warn people of fire and to assist in protecting people from the effects of fire in the course of their escape from the fire.

Multi-unit dwelling Applies to a building or use which contains more than one separate household or family.

Non-combustible Material either—
a) composed entirely of glass, concrete, steel, brick/block, ceramic tile, or aluminium; or
b) classified as non-combustible when tested to AS 1530.1; or
c) classified as A1 in accordance with BS EN 13501-1.

Occupant load The greatest number of people likely to occupy a particular space within a building. It is determined by:
a) dividing the total floor area by the m2 per person (occupant density) for the activity being undertaken, or
b) for sleeping areas, counting the number of sleeping (or care) spaces, or
c) for fixed seating areas, counting the number of seats.

Occupied space Any space within a building in which a person will be present from time to time during the intended use of the building.

Other property Any land or buildings or part of any land or buildings, that are:
a) not held under the same allotment; or
b) not held under the same ownership; and
c) includes a road.

Owner In relation to land and any buildings on the land—
a) means the person who—
    i) is entitled to the rack rent from the land; or would be so entitled if the land were let to a tenant at a rack rent; and
b) includes—
    i) the owner of the fee simple of the land; and
    ii) for the purposes of Building Act sections 32, 44, 92, 96, 97, and 176(c), any person who has agreed in writing, whether conditionally or unconditionally, to purchase the land or any leasehold estate or interest in the land, or to take a lease of the land, and who is bound by the agreement because the agreement is still in force.

Performance criteria In relation to a building, means qualitative or quantitative criteria that the building is required to satisfy in performing its functional requirements.

Place of safety means either—
a) a safe place; or
b) a place that is inside a building and meets the following requirements:
    i) the place is constructed with fire separations that have fire resistance sufficient to withstand burnout at the point of the fire source; and
    ii) the place is in a building that is protected by an automatic fire sprinkler system that complies with NZS 4541 or NZS 4515 as appropriate to the building's use; and
    iii) the place is designed to accommodate the intended number of persons at a design occupant density – depending on the usage this shall not be less than 1.0 m^2 per person; and
    iv) the place is provided with sufficient means of escape to enable the intended number of persons to escape to a safe place that is outside a building.

Property rating The fire resistance rating to be applied to elements of construction that allows for protection of other property.

Regulations Means regulations in force under the Building Act 2004.

Required safe egress time (RSET) Time required for escape. This is the calculated time period required for an individual occupant to travel from their location at the time of ignition to a place of safety.

Risk group The classification of a building or firecells within a building according to the use to which it is intended to be put.

Road Has the meaning ascribed to it by section 315 of the Local Government Act 1974 and includes a public place and also includes a motorway.

Separating element Barrier that exhibits fire integrity, structural adequacy, thermal insulation, or a combination of these for a period of time under specified conditions (in a fire resistance test).

Smoke production rate Amount of smoke produced per unit time in a fire or fire test.

Stability In the context of fire protection is the support provided to a building element having a FRR, intended to avoid premature failure due to structural collapse as a result of applied load, dead and live loads or as a result of any additional loads caused by fire.

Theatre A place of assembly intended for the production and viewing of performing arts, and consisting of an auditorium and stage with provision for raising and suspending stage scenery above and clear of the working area.

Unprotected area In relation to an external wall of a building, means:
a) Any part of the external wall which is not fire rated or has less than the required FRR, and
b) Any part of the external wall which has combustible material more than 1.0 mm thick attached or applied to its external face, whether for cladding or any other purpose.
Unprotected areas include non-fire rated windows, doors, or other openings, and non-fire rated external wall construction.

Verification method Means a verification method issued under section 22(1) of the Building Act 2004.

Visibility Maximum distance at which an object of defined size, brightness and contrast can be seen and recognised.

Executive Summary

The idea to move to performance-based or objective-based building regulations started in the 80s, but it is in the 90s and after, that some countries began putting together the structure, frameworks and content of these new regulations. Some of the countries that introduced these regulations include Australia, New Zealand and Canada.

This report summarizes the review of the New Zealand Building Code, one of the first performance-based building codes implemented in the world, conducted with regards to its fire and life safety provisions, including their development and regulatory framework. The objective of this review is to learn from their successes and experiences.

Regulatory Framework and Building Code

For much of the 1900's, New Zealand Standard 1900 (NZS 1900), consisted of a set of prescriptive building controls, was the model building bylaws, and each city would adopt the model bylaws with or without changes. In the mid 1970's, the building industry started to voice concerns that the increasing building controls had become a major factor in escalating building costs without reciprocal benefits in return to the industry or the society. The government also recognized the problem facing the building industry. This triggered over a decade of analysis, review and consultation regarding the regulatory system for building control, involving several branches of the New Zealand Government, a large cross-section of the building and property industry ranging from engineers to building owners, various interest groups and the public. The building regulation system at the time was revealed as being multi-levelled, complex, disconnected, inefficient and costly – 19 government departments administering provisions in over 30 Acts; local authorities establishing their own bylaws which differed around the country; and other authorities having jurisdiction over particular aspects of buildings. There was a consensus that the fragmented system needed to be reformed to provide a national system of building control and a harmonized performance-based national building code.

These decade-long efforts led to the Building Act 1991 legislated by the national parliament in 1991, which provided a nation-wide building law for the first time and established a performance-based code structure. The New Zealand government then issued the Building Regulations 1992 containing a performance-based Building Code in 1992. The Building Act 1991 and the performance based Building Code (1992) became into full effect in 1993, provided a national system for building controls across the country, and also allowed flexibility in the means of demonstrating code compliance. This performance-based building code was among the first of its kind in the world.

With the harmonized nation-wide Building Code (1992), the consistency of building work approvals was improved across the country. This resulted in some good innovations and cost effective solutions with various designs and materials being used since the performance-based regulatory regime granted some discretion for flexibility and innovation.

The initial introduction of the performance-based code and regulations was not without issues. Accountability issues arose related to design rigor, producer statements (used as compliant evidence), building workmanship and cost-cutting practices as well as effectiveness of supervision. In certain cases, non-compliant buildings were built, such as highlighted by the ‘leaky building’ crisis in the mid 1990’s to early 2000’s. Qualitative and vague code requirements at the time were identified as partly to blame for the interpretation of these code requirements and, therefore, the regulatory review of associated designs could be subjective. Vague or confusing performance criteria impeded the abilities of engineers and regulators to develop and review alternative solutions for code compliance and to accommodate emerging construction technologies.

To strengthen the accountability, legislation was updated. The Building Act 2004 became the new building law (replacing the Building Act 1991), introducing additional controls over practitioner licensing and accreditation of building consent authorities (building consent authorities are the authority having jurisdiction in New Zealand), etc. At the preparation of this report, the Building Act 2004 with all the amendments incorporated to 25 September 2020 [New Zealand Government, 2020] was the current principal legislation dealing with matters relating to the building code and building controls in New Zealand, and works alongside other legislation for health, safety, consumer protection and land use.

The Building Act 2004 triggered a major review of the Building Code (1992). That review resulted in significant changes in 2012 to the Building Code, setting better-quantified minimum performance requirements for stability, fire safety, access, moisture, safety of users, services and facilities, and energy efficiency.

The Building Code (2012) introduced new fire safety clauses C1 to C6 "protection from fire", consisting of objectives, functional requirements, and performances. Clause C1 provides fire safety objectives for people, other property, firefighting and rescue that apply to clauses C2 to C6. These objectives are ultimately set by the Building Act 2004 to reflect social objectives with respect to protection from fire.

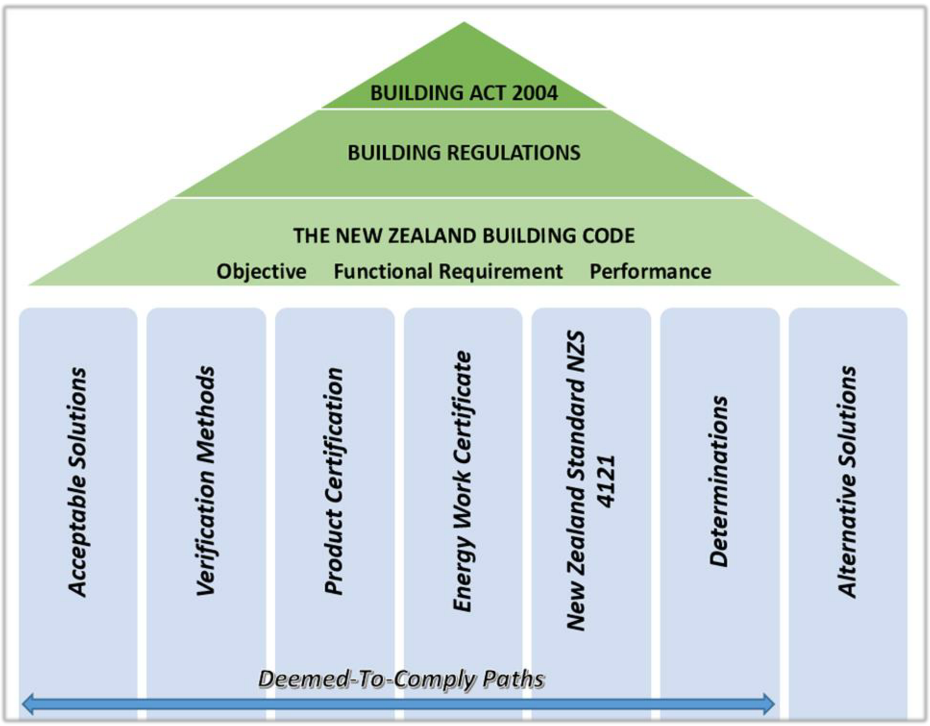
> "Clause C1 - Objectives of Clauses C2 to C6 (protection from fire)
> The objectives of clauses C2 to C6 are to:
> (a) safeguard people from an unacceptable risk of injury or illness caused by fire,
> (b) protect other property from damage caused by fire, and
> (c) facilitate firefighting and rescue operations."

The functional requirements mandate the functions that the building must perform to meet the objectives. Performance clauses state the performance criteria that the building must comply with in the intended use. (Buildings have seven categories of classified uses; a building with a given classified use may have one or more intended uses; see Table 2 for details.) By meeting the performance criteria, the objectives and functional requirements can be achieved. Functional requirements and performance criteria are set in clauses C2 to C6 (see section 2.2.3 for details).

> Clause C2 - Prevention of Fire Occurring
> Clause C3 - Fire Affecting Areas beyond the Source
> Clause C4 - Movement to a Place of Safety
> Clause C5 - Access and Safety for Firefighting Operations
> Clause C6 - Structural Stability

There are a total of 20 performance criteria within clauses C2 to C6. Ten performance criteria have been quantified and the other ten remain qualitative. The quantified performance criteria are expressed numerically for vertical and horizontal fire spread, means of escape, storage buildings and fire service vehicle access for rescue and firefighting operations. These quantitative performance criteria provide a greater clarity and consistency in the level of safety for all building designs to achieve. At the same time, designers still have the flexibility in design input values and safety factors.

The New Zealand building regulations are currently administered by the Ministry of Business, Innovation and Employment (MBIE). The Building Code, and associated Acceptable Solutions, Verification Methods and published guidance are regularly reviewed by the MBIE with annual public consultation and necessary updates to keep pace with innovation, modern construction methods and the needs of modern society. Since 2012, the Building Code (2012) remains relatively stable without changes to the fire clauses while the associated Acceptable Solutions and Verification Methods have been frequently updated, resulting from the annual review. This is an indication that the Building Code (2012) has been largely successful since being updated in 2012. The following graph illustrates New Zealand's building regulatory hierarchy and code compliance paths.



Building Regulatory Hierarchy and Code Compliance Paths.

Compliance

Compliance with the Building Code must be demonstrated using one or more compliance paths. Methods that are deemed to comply with the Building Code (2012) are those that follow the acceptable solutions, verification methods, product certification, energy work certificate, New Zealand Standard NZS 4121, and/or determinations made by MBIE.

Acceptable Solution C/AS2 and Verification Method C/VM2 (Framework for Fire Safety Design) are related to clauses C of the Building Code (2012). Buildings with complex features are generally outside the scope of C/AS2, buildings with special evacuation arrangements or fire hazards are outside of the scope of C/VM2, and alternative solutions are intended to provide an option to propose a solution to address such complex buildings.

Alternative solutions can be developed but must be demonstrated by evidence that they meet the performance requirements of the Building Code (2012). The development of an alternative solution for fire safety design needs expertise and good understanding of fire engineering principles related to fire dynamics, human behaviour and structural reaction to fire, and also requires proper application of these principles and various analysis methodologies in fire engineering process. In New Zealand, an alternative solution means all or part of a building design that deviates partially or completely from Acceptable Solutions or Verification Methods but still confirms to the performance requirements of the Building Code to the satisfaction of the building consent authority. All alternative solutions must be approved by the building consent authority. Alternative solutions can be developed using either:

- first principles (absolute approach), without the need to compare with a deemed-to-comply code benchmark; or
- a comparative approach that has to reference a benchmark.

The alternative solution path can be particularly helpful for unique, complex and specialized building designs, where there is no benchmark to compare with.

Enforcement

The building consent authorities are the authority having jurisdiction in New Zealand. They must be accredited by a building consent accreditation body appointed by the chief executive of the MBIE. A building consent authority can be a territorial or regional authority, a private organisation or person who has received accreditation and been registered.

Unless exempted, no buildings are allowed to be constructed, altered, demolished or removed without a building consent. A building consent authority:

- issues the building consent to authorize the building work if it is satisfied that a proposed building work complies with the Building Code,
- inspects and/or issues notices to fix during the building work, and
- grants a code compliance certificate after the completion of the building work.

The building consent authority is responsible to ensure that building work from plan to completion complies with the Building Code. This includes ensuring that an application (plan and specification) for a building consent meets all performance requirements of the Building Code. The building consent authority is obligated by law to accept the designs that follow the deemed-to-comply paths as evidence of compliance with the Building Code. The assessment and approval of a performance-based design via the alternative solution path can be challenging depending on its complexity.

The building consent authority is also responsible to inspect and issue notices to fix building work during the building process, ensuring that building work has been carried out in accordance with the building consent issued for that work. After all building work is completed to the approved plans and specifications, an application for a code compliance certificate must be submitted by the building owner. The building consent authority will then issue a code compliance certificate stating that the completed building work complies with the building consent, along with any required compliance schedule for future inspection, maintenance, and reporting.

A few low-risk types of building work (such as sheds, carports, outdoor fireplaces and ground-mounted solar panels) do not require building consents. Whether or not a building consent is required, all building work must comply with the Building Code.

Some Issues with Performance Criteria Used

Although an increased number of quantified performance criteria are used, the fire clauses C2 to C6 of the Building Code (2012) still have qualitative functional requirements and a considerable number of qualitative performance clauses. These qualitative functional requirements and performance clauses often use the term of "low probability" or "reduced likelihood". These can be problematic for both the designers and the building consent authorities who have to subjectively interpret the requirements and to argue what performance levels are acceptable. By making the decision based on subjective judgement on the matters, the building consent authority becomes liable for the decision.

On the other hand, while quantitative performance criteria can provide clearer expectations for acceptance, overly quantified values in performance criteria may become problematic too. There are ongoing discussions about potential issues relating to some values used in a few quantified performance criteria, for example:

- Performance criteria C3.4 for limiting the spread of fire on interior lining or surfacing materials uses quantified criteria which may unnecessarily constrain design options and perhaps needs more research.
- Performance criteria C3.5 for limiting vertical fire spread over the external cladding of multi-level buildings uses criteria that may lead to a conservative design for two-storey buildings with gable roof and for small tall single- or two-storey warehouse structures; also the term "over the external cladding" may imply only the outer most surface or components be considered while fire can spread through the vertical channels, insulation and combustible materials, and interior cavities of the external cladding systems.
- Performance criteria C4.3 for limiting exposure to untenable conditions during evacuation uses one-size-fits-all tenability criteria without considering increased risk to vulnerable populations or exposure to irritant gases.
- Performance criteria C4.4 is an exemption to clause C4.3 and permits assessing only the carbon monoxide exposure, which intends to promote the use of sprinklers but is questionable to assume occupants could evacuate through a smoke filled room (with zero visibility).

The Building Code fire performance criteria lack probabilistic quantification of risk. There are discussions on moving towards more risk-informed or risk-based fire provisions and designs. Further work is required to quantify each performance criterion to combine a specific limit with an acceptable probability not surpassing the limit.

Impact on Capacity of Building Industry and Authority

Qualified and competent fire engineers should be required to conduct fire engineering designs, their regulatory review and approval, and third-party peer review. However, such fire engineers, who have the expertise and good understanding of the fire engineering principles and process, are in short supply across the country. There are no regulations defining or restricting who can practice fire engineering in New Zealand. A large percentage of fire safety designs are prepared by designers who have no formal qualifications in fire engineering. Building consent authorities often do not have sufficient expertise to review and approve a performance-based design as an alternative solution. When building consent authorities engage third-party peer review, reviewers should have the relevant qualifications and experience for the proposed type of alternative solution and building design and use. However, this may not always be the case.

There are not enough numbers of qualified and competent peer reviewers, which causes difficulty in maintaining independence of the third party peer review.

In addition, the qualification of fire engineers is not explicitly defined and there are no legal protections for the term “fire engineer” in New Zealand. Fire practitioners can be either members of Engineering New Zealand, Chartered Professional Engineers or designers with no professional affiliations. Fire engineers desire a licensing scheme supported by formal fire engineering training in New Zealand. Training would also need to extend to the whole supply chain beyond the fire engineers to include associated building professionals (such as architects, structural engineers, building services engineers, installers of fire safety elements and systems, and building consent authorities) enabling them to understand and interface between the fire safety design and their areas of practice. Within New Zealand, post graduate training of fire engineers is currently only available at Canterbury University.

Under the Building Law Reform Programme, the New Zealand government plans to strengthen the regulations of engineers in the coming years to ensure that engineers provide engineering services with reasonable care and skill, operate within their areas and level of competence and are held accountable for substandard work or poor conduct so that the public can have confidence in the engineering profession within the construction industry.

Tools and Resources Needed by Building Industry and Authority

MBIE has published guide documents and handbooks to assist development and approval of alternative solutions for code compliance [MBIE, 2014b; 2018; 2020e]. These along with various existing resources and models, such as International Fire Engineering Guidelines [ABCB, 2005], SFPE Engineering Guide [NFPA, 2007] and Fire Dynamics Simulator [McGrattan et al, 2013] etc., have been used by the building consent authority and the building industry to support code enforcement and fire safety engineering design practices. One of these tools is New Zealand’s own fire safety engineering design modelling tool B-RISK developed by BRANZ and the University of Canterbury. B-RISK uses a physics-based model in combination with probabilistic analysis to produce results for a better understanding of uncertainty and risk associated with fires in building enclosures than deterministic approaches and to support risk-informed design decision-making.

In order to realize the benefit of the performance-based designs, stakeholders identified the following needs:

- The building and construction industry needed support to consistently develop performance-based designs and solutions, and the regulators needed support to consistently implement the performance-based code. Where the code clauses use qualitative terms such as “low probability or likelihood” as requirements or criteria, the designers and building consent authorities would need probabilistic acceptance criteria in order to remove the current subjective interpretation, judgement or argument among various parties. (For example, how low is the “low probability or likelihood”? Is it a 0.1 chance of occurrence, a 0.01 chance of occurrence, or a 1 x 10-6 chance of occurrence as the probabilistic acceptance criteria?)
- Appropriate computational tools and verification methods would need to be developed, validated, introduced, and supported. Most tools and methods that have been used for fire safety engineering designs are deterministic in nature. Probabilistic tools and methods for analyses of performance-based fire designs (quantitative risk analysis methods) are lacking.

- The building and construction industry and the building consent authorities needed continued training, which should extend beyond the fire engineers to include other associated building professionals. Associated regulations and mechanism would need to be established.

Potential and Benefits of Performance-Based Code

The development and implementation of the performance-based building code in New Zealand has been a challenging journey but the benefits outweigh the problems. Many issues arising have been associated with fundamental lessons learned while being one of the first performance-based building codes implemented in the world. Over the last 30 years, the New Zealand Building Code has evolved to be one of the best of its kind in the world. New Zealand has derived great benefits from its performance-based building code. It has enabled the development of innovative, flexible and cost effective building solutions to deliver the best possible results for building projects, especially for complex and unique building projects where the prescriptive code alone would offer no solutions to adapt emerging needs and technologies. The clearer performance requirements and a greater level of quantified performance criteria in the code have helped facilitate the development of code compliant fire safety designs. The Code has pioneered a systematic approach to fire engineering design within the New Zealand legislation to support a more transparent, consistent and efficient building regulatory system. Under a Building Law Reform Programme, the government is working with the building and construction industry and all stakeholders to further improve the building regulatory system and drive better outcomes for the industry and for New Zealanders.

Final Remarks

The New Zealand Building Code has evolved to be one of the best performance-based codes in the world and rendered great benefits outweighing the issues encountered. The issues with performance criteria (qualitative vs quantitative), stakeholder capacity (designers, authorities, peer reviewers, fire engineer qualification, etc.), tools and resources as well as risk-informed decisions making are not unique for New Zealand. These issues are quite common in all countries where performance-based codes have been implemented. New Zealand's experiences and successes can benefit others who may want to go down the road to performance-based codes; some key lessons learned include:

- Moving towards a performance-based building code would be a challenging undertaking with growing pains but the benefits could outweigh the drawbacks;
- A harmonized national code and regulatory approach would eliminate regional differences in evaluation and acceptance of designs and promote efficient and consistent application of building regulations across country as well as facilitate training and the development of resources to support the designers and building consent authorities;
- Code provisions would need to be clear, and properly quantified where possible, to minimize potential subjective interpretation and acceptance and to maintain safety while providing flexibility for innovation;
- Quantification of fire risk in a probabilistic manner would be desirable towards more risk-informed or risk-based fire provisions;
- Allowing alternative solutions to be developed from first principles (using an absolute approach) would be necessary for unique, complex and specialized building designs where there are often no deemed-to-comply benchmarks for comparison;

- Qualified and competent fire engineers should be required by regulations to conduct design, regulatory review and approval, and third-party peer review, of fire engineering solutions; and qualification of fire engineers should be explicitly recognized and defined in the regulatory system;
- Fire engineering training may need to be expanded at post graduate level and be extended to various building professionals (e.g., architects, structural engineers, building consent authorities, building services engineers and installers) enabling them to effectively and efficiently interact with the fire engineer and coordinate with fire engineering designs and their areas of practice;
- More computational tools and verification methods would need to be developed, validated, introduced, and supported to enable the building industry and the regulators to consistently implement performance-based codes; probabilistic tools, methods and criteria for quantitative risk analysis are particularly lacking.

The lessons learned from the introduction of performance-based codes in New Zealand emphasizes the fact that success requires a coordinated effort between all levels of government, professional associations, fire services, the academic and research community, certification bodies, and trades and contractors.

This review focused on the fire and life safety provisions in the New Zealand Building Code, and summarizes key lessons learned from their experiences in the development of their performance-based code.

Purpose of Report

This report is one in a series of reports intended for the "*Research towards a Performance-Based Building Code*" project. The other reports in this series include:

- N. Bénichou, *Review of Performance-Based Fire Safety Regulations in Selected Countries: Australia*, Report No. A1-018529.2, National Research Council Canada, 2021; and
- Robbins, *Research towards a Performance-Based Building Code Preliminary Analysis NBC Part 3 Fire and Life Safety Provisions*, Report No. A1-018529.3 National Research Council Canada, 2021.

This report summarizes the review of the New Zealand Building Code, one of the first performance-based building codes implemented in the world, conducted with regards to its fire and life safety provisions, including their development and regulatory framework. The objective of this review is to learn from their successes and experiences.

Review of Performance-Based Fire Safety Regulations in Selected Countries: New Zealand

1 Introduction

Performance-based building codes set out how buildings must perform in their intended uses as opposed to prescribing how the buildings must be designed and built. An advantage of a performance-based building code is flexibility to allow developments and innovation in building design, technology and systems.

In many countries, building regulations have been developed to minimize the impact of fires and other hazardous events on life, property, environment and economy. In the past, these building regulations tried to capture all the provisions in a few documents, which added more regulated areas, complexities and limitations. These led many countries to start thinking about changing their existing prescriptive regulations, which do not provide the understanding behind a design, to regulations that would be structured and focused on the construction of a building based on desired objectives and functions. This thought then led to a move by several countries to performance-based building regulations. This idea of moving to performance-based building regulations started in the 80s, but it was in the 90s and after, that some countries began putting together the structure, framework and content of the new building codes and corresponding new building regulations. In addition, some of the countries developed relations through various forums to exchange positive and negative experiences and dissemination of information. Now that we are more than 30 years from the initial start, the countries that have introduced full performance-based building regulations include: New Zealand, Australia, and others.

The National Building Code of Canada (NBCC) became an objective-based building code in 2005, which provides both the prescriptive acceptable solutions and the option to develop alternative solutions. The introduction of the objective-based code was originally envisioned as a step or a transition towards a performance-based code (PBC). Modernizing the NBCC to become a more performance-based code would encourage technological innovations for the construction industry. With a desire to initiate code harmonization across Canada, this represents an opportunity to renew movement towards a performance-based NBCC.

In response, an overall project, *Research towards a Performance-Based Building Code*, was initiated with the intent to investigate and collate international approaches, experiences and benefits observed so far so they can be considered in a Canadian context.

The overall scope of this research project intends to cover fire and life safety provisions in Part 3 and earthquake provisions in Part 4 of Division B of the 2015 version of the NBC. This project will ultimately require the coordination of efforts between the research and the code development communities to identify knowledge gaps and future research needs in the areas of fire and life safety and earthquake design. It is proposed that results from this project inform the code development system and, perhaps, the discussion whether to introduce a new performance-based compliance path in the NBCC, which would follow its due process, as determined by the Canadian Commission on Building and Fire Codes (CCBFC).

In support of the overall project, a review of performance-based building codes of selected countries was conducted with regards to fire and life safety provisions, including their development process and regulatory framework. The objective of this review is to learn from their lessons and experiences thus potentially help advance the development of performance-based requirements in Canada with regards to its fire and life safety provisions.

This review mainly include studies of two countries – New Zealand and Australia – to gain insight into their experiences, as these two countries have the most advanced experiences in developing performance based codes. This report documents the results of the review of the New Zealand Building Code.

2 New Zealand Performance-Based Regulatory System

For much of the 1900's, New Zealand Standard 1900 (NZS 1900), consisted of a set of prescriptive building controls, was the model building bylaws, and each city would adopt the model bylaws with or without changes. In the mid 1970’s, the building industry started to voice concerns that the increasing building controls had become a major factor in escalating building costs without reciprocal benefits in return to the industry or the society. The government also recognized the problem facing the building industry. This triggered over a decade of analysis, review and consultation regarding the regulatory system for building control, involving several branches of the New Zealand Government, a large cross-section of the building and property industry ranging from engineers to building owners, various interest groups and the public. The building regulation system at the time was revealed as being multi-levelled, complex, disconnected, inefficient and costly – 19 government departments administering provisions in over 30 Acts; local authorities establishing their own bylaws which differed around the country; and other authorities having jurisdiction over particular aspects of buildings. There was a consensus that the fragmented system needed to be reformed to provide a national system of building control and a harmonized performance-based national building code [Hubbard and Pastore, 1997; Hunn et al, 2002].

These decade-long efforts led to the Building Act 1991 legislated by the national parliament in 1991, which provided a nation-wide building law for the first time and established a performance-based code structure. The New Zealand government then issued the Building Regulations 1992 containing a performance-based Building Code in 1992. The Building Act 1991 and the performance based Building Code (1992) became into full effect in 1993, provided a national system for building controls across the country, and also allowed flexibility in the means of demonstrating code compliance. This performance-based building code was among the first of its kind in the world.

With a national Building Code, the consistency of building work approvals was improved across the country. This resulted in some good innovations and cost effective solutions with various designs and materials being used. However, some inconsistency and inefficiency still existed and certain non-compliant buildings were resulted due to issues with the evidence basis and building methods used, and the lack of design rigor and effective supervision in certain cases. Also because of code requirements being mostly qualitative at that time, developing alternative solutions was fairly difficult and heavily dependent on expert interpretation.

In response, the Building Act 2004 [New Zealand Government, 2004 – reprint 2020] became the new building law which introduced additional controls over practitioner licensing and accreditation of building consent authorities, etc. The Building Act 2004 triggered a major review of the Building Code. That review resulted in significant changes in 2012 to the Building Code including the introduction of new fire safety clauses C1 to C6 “protection from fire” with 50% of fire performance criteria being quantified [New Zealand Government, 2012; 2017]. Since then, the Building Code fire clauses remain unchanged but the associated Acceptable Solutions and Verification Methods have been reviewed and updated regularly (annually or bi-annually).

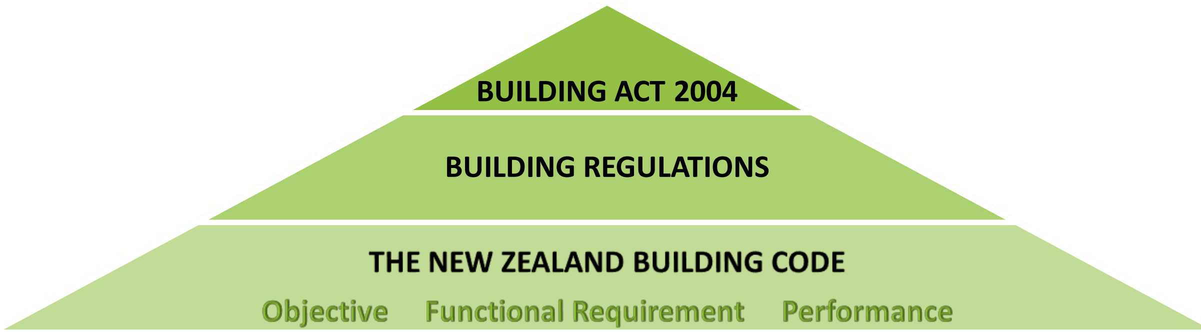


Figure 1. Framework for building control in New Zealand.

2.1 Regulatory Framework for Building Control

Figure 1 shows the regulatory framework for building control in New Zealand. The next sections will elaborate on the hierarchy of this regulatory framework.

2.1.1 National Legislation

At the preparation of this report, the Building Act 2004 with all the amendments incorporated to 25 September 2020 [New Zealand Government, 2020] was the current principal legislation dealing with matters relating to the building code and building controls in New Zealand, and works alongside other legislation for health, safety, consumer protection and land use. The Act sets a legal framework for regulating building work, establishing a licensing regime for building practitioners and setting performance standards for buildings. The Act governs the building sector and sets out the rules for the construction, alteration, demolition and maintenance of new and existing buildings in New Zealand. The Building Act also gives the government the authority to issue related building regulations and promotes the accountability of owners, designers, builders, and building consent authorities for ensuring that building work complies with the building code. It also provides mechanisms for dealing with complaints, appeals and offences. The Building Act is administered by the Ministry of Business, Innovation, and Employment (MBIE).

2.1.2 Building Regulations

Building Regulations are made under and in accordance with the Building Act. The Governor-General makes the regulations by Order in Council based on the recommendation of the MBIE Minister. All Ministers of the Crown are members of the Executive Council to advise the Governor-General to make Orders in Council; the MBIE Minister is the respective Executive Councillor for matters related to building regulations. Stakeholder consultations are required by the Building Act and conducted by MBIE before regulations are made concerning the building code, acceptable solutions, verification methods, building methods or products, building consents (approvals), licensing classes, etc. Regulations are also made dealing with matters related to accreditation, certification and licensing as well as associated levy and fee structure and declaring restricted building work.

2.1.2.1 Building Code

Since 1992, New Zealand has moved to a nation-wide performance-based building code which sets expectations of the performance standards that all buildings must meet while provides flexibility to allow development and innovation in building design, technology and systems. The

New Zealand Building Code (the Building Code) is contained in Schedule 1 of the Building Regulations 1992, with significant changes incorporated in 2012 by introducing the new fire safety clauses C1 to C6 "protection from fire". The Building Code sets minimum performance requirements for stability, fire safety, access, moisture, safety of users, services and facilities, and energy efficiency, including referenced Standards. All new building work must – and change of use or alteration of a building may trigger the need to – comply with the Building Code throughout New Zealand. The Building Code is administered by the MBIE.

2.1.2.2 Code Compliance

Compliance with the Building Code must be demonstrated using one or more of the paths described below. Among these paths, the acceptable solutions, verification methods, product certification, energy work certificate, New Zealand Standard NZS 4121 and determinations are deemed to comply with the Building Code; their deem-to-comply status is given by the Building Act. On the other hand, alternative solutions must demonstrate by evidence that they meet the performance requirements of the Building Code.

2.1.2.2.1 Acceptable Solutions

As regulatory documents, Acceptable Solutions are issued and maintained by the chief executive of the MBIE to provide one way of complying with the Building Code and, if followed, are deemed to meet the performance criteria of the related clauses of the Building Code. Acceptable Solutions often include specific construction details for commonly used building materials, systems and methods; and frequently refer to standards.

2.1.2.2.2 Verification Methods

As regulatory documents, Verification Methods are issued and maintained by the chief executive of the MBIE to provide one way of complying with the Building Code and, if followed, are deemed to meet the performance criteria of the related clauses of the Building Code. Verification Methods can be calculation methods using recognised analytical methods and mathematical models; or can be laboratory tests on prototype components and systems, tests-in-situ and standards.

2.1.2.2.3 Product Certification

A proprietor may voluntarily seek certification of its building method or product by a product certification body. The product certification body has the power to issue a product certificate to certify that a building method or product meets designated performance requirements of the Building Code. Building methods or products designed, used, installed and maintained in accordance within the scope of the product certificates are deemed to meet the performance requirements of the related clauses of the Building Code as specified in the certificates.

The product certification body must be accredited by a product certification accreditation body which is appointed by the chief executive of the MBIE. The chief executive of the MBIE can warn against or ban the use of particular building methods or products.

2.1.2.2.4 Energy Work Certificate

Gasfitting work or prescribed electrical work that complies with regulations made under the Electricity Act or the Gas Act with an energy work certificate must be accepted as complying with the relevant performance requirements of the Building Code.

2.1.2.2.5 New Zealand Standard NZS 4121

The New Zealand Standard Specification NZS 4121, “The code of practice for design for access and use of buildings by persons with disabilities”, is deemed as an Acceptable Solution for requirements of persons with disabilities.

2.1.2.2.6 Determinations

Determinations are legally binding decisions made by the chief executive of the MBIE dealing with code interpretation and dispute of compliance decisions. This power is granted by the Building Act. Theoretically, any party can seek a determination from MBIE. Typically, if a designer or developer disagrees with a decision made by a building consent authority related to building consent, code compliance certificate, compliance schedule or notice to fix, the designer or developer may seek a determination from MBIE. The building Code is the basis for MBIE to make the determination.

2.1.2.2.7 Alternative Solutions

An alternative solution is a building design that deviates partially or completely from the Acceptable Solutions or Verification Methods. The deviation can be minor or major, and single or multiple differences. The deviation may also include cases where Acceptable Solutions or Verification Methods are not available for a proposed building project or where the proposed project goes beyond the applicable scope of relevant Acceptable Solutions or Verification Methods.

The performance-based Building Code allows applicants to propose an innovative building work using the alternative solution compliance path. The applicant must identify which parts of the project deviate from an Acceptable Solution or Verification Method and which code clauses are involved, and must provide sufficient evidence to demonstrate to the satisfaction of the authority having jurisdiction that the proposed alternative solution complies with all relevant performance requirements of the Building Code.

The MBIE publishes guide documents to assist engineers and designers in developing alternative solutions for code compliance. The guide documents are provided for assistance but do not have the same regulatory status as Acceptable Solutions or Verification Methods under the Building Act.

2.1.2.3 Code Enforcement

2.1.2.3.1 Building Consent

Unless exempted, no buildings are allowed to be constructed, altered, demolished or removed without a building consent. Required by the Building Act, the building consent is an approval issued by a building consent authority, who has been satisfied that a proposed building work complies with the Building Code, to authorize an applicant to proceed with the construction, alteration, demolition or removal of a building.

The building consent authorities are the authority having jurisdiction in New Zealand, which must be accredited by a building consent accreditation body appointed by the chief executive of the MBIE. Among all building control responsibilities given by the Building Act, a territorial authority must gain accreditation to act as the building consent authority for its district or delegate this power to other accredited building consent authority to act on its behalf. In addition to territorial and regional authorities, private organisations or persons can also apply to be accredited and registered as the building consent authorities.

The building consent authority is responsible to ensure that building work from plan to completion complies with the Building Code. This includes ensuring that an application (plan and specification) for a building consent meets all performance requirements of the Building Code. While the building consent authority is obligated by law to accept the designs following the deemed-to-comply paths as evidence of compliance with the Building Code, the assessment and approval of a performance-based design via the alternative solution path can be challenging depending on its complexity (see section 2.2.4.3 for more discussion related to alternative solutions for fire protection).

The building consent authority must also provide copy of certain applications for building consent to Fire and Emergency New Zealand for advice on provisions for means of escape from fire and the needs of fire-fighters. Fire and Emergency New Zealand is the amalgamated national firefighting and emergency services authority, formally established by the Fire and Emergency New Zealand Act 2017.

A few low-risk types of building work (such as sheds, carports, outdoor fireplaces and ground-mounted solar panels) do not require building consents. Whether or not a building consent is required, all building work must comply with the Building Code.

2.1.2.3.2 Code Compliance Certificate

The building consent authority is also responsible to inspect and issue notices to fix building work during the building process, ensuring that building work has been carried out in accordance with the building consent issued for that work. After all building work is completed to the approved plans and specifications, an application for a code compliance certificate must be submitted by the building owner. The building consent authority will then issue a code compliance certificate stating that the completed building work complies with the building consent, along with any required compliance schedule for future inspection, maintenance, and reporting.

2.1.3 Licensing Building Practitioners

Under the Building Act, the Registrar of Licensed Building Practitioners, appointed by the chief executive of the MBIE, has the power to license and register building practitioners who meet the requirements and rules for licensing set by the Building Practitioners Board. Only Licensed Building Practitioners are allowed to carry out or supervise restricted building work that affects the primary structure and weathertightness of residential buildings as well as certain fire safety design of emergency warning, evacuation, suppression or control systems for small to medium sized apartments.

The use of Verification Methods or the development of Alternative Solutions related to the Building Code fire clauses need qualified and competent fire engineers who have expertise and good understanding of the fire engineering principles and process. However, there are no regulatory restrictions on who could practice fire engineering for building designs.

2.1.4 Dispute Resolution

Disputes may arise during the process of design, approval and construction of buildings. Parties involved should always try to resolve the dispute among themselves. If the parties cannot reach an agreement or compromise, resolution mechanisms are available under the Building Act.

If a complaint is about a decision made by a building consent authority related to building consent, code compliance certificate, compliance schedule or notice to fix, the party may seek a determination from MBIE. Determinations are legally binding decisions made by MBIE. The party may appeal to the District Court against the determination.

If a complaint is about MBIE's refusal to register the party as a building consent authority, the party may appeal to the District Court.

If a complaint is about the conduct of licensed building practitioners, the party may request the Building Practitioners Board (appointed by the MBIE minister) to investigate and take disciplinary actions. The practitioners may appeal to the District Court against the disciplinary decision of the Building Practitioners Board.

If a complaint is about decisions of the Registrar to decline to license the person as a building practitioner or suspend or cancel his or her licensing, the person may appeal to the Building Practitioners Board. The person may further appeal to the District Court against the decision of the Building Practitioners Board on these matters. The decision of the District Court on an appeal is final.

2.1.5 Latest Development – Building Law Reform Programme

The New Zealand building and construction sector is facing challenges of low productivity and inefficient practices and processes, skills and labour shortages, financial vulnerability and inadequate health and safety practices. To address the problems, a current programme established by the government has been working to lift performance of the regulatory system and drive better outcomes for the building and construction sector and for New Zealanders. As part of this building law reform programme, on 8 May 2020, the government introduced Bill 234 to amend the Building Act 2004 and consequentially amend other legislation.

This bill, entitled "Building (Building Products and Methods, Modular Components, and Other Matters) Amendment Bill", was read a first time in parliament on 27 May 2020 and referred to the Environmental Committee for studies. A committee report was published on 2 March 2021 with the recommendation that it be passed with committee revisions [Environment Committee, 2021]. The bill, now waiting for a second reading in parliament, seeks to:

- "strengthen the existing product certification scheme (known as CodeMark) to ensure that products sold in New Zealand comply with the building code;
- establish a new manufacturer certification scheme for non-traditional methods of construction, such as modular components and off-site manufacture'
- strengthen the penalties for breaches of the requirements, and create new offences for noncompliance;
- expand the use of the building levy to fund a broader range of functions and activities by the Ministry of Business, Innovation and Employment (MBIE); and
- clarify the definitions of "building product" and "building method", and introduce minimum requirements for information about products and methods, to support informed decision-making."

The legislative process still needs to run through a second reading, committee of whole House and third reading as well as royal assent before this bill becomes the law, which would then trigger related regulatory changes.

2.2 New Zealand Building Code

The New Zealand Building Code (NZBC) with significant changes incorporated in 2012 is contained in Schedule 1 of the Building Regulations 1992 [New Zealand Government, 2017]. The Building Code sets minimum performance requirements for stability, fire safety, access, moisture, safety of users, services and facilities, and energy efficiency, including referenced

Standards. All new building work must – and change of use or alteration of a building may trigger the need to – comply with the Building Code throughout New Zealand.

Table 1. Scope of New Zealand Building Code

Clause A	General provisions	A1 Classified uses A2 Interpretation A3 Building importance levels
Clause B	Stability	B1 Structure B2 Durability
Clause C	Fire Safety	C1 Objectives of clauses C2 to C6 C2 Prevention of fire occurring C3 Fire affecting areas beyond the fire source C4 Movement to place of safety C5 Access and safety for firefighting operations C6 Structural stability
Clause D	Access	D1 Access routes D2 Mechanical installations for access
Clause E	Moisture	E1 Surface water E2 External moisture E3 Internal moisture
Clause F	Safety of users	F1 Hazardous agents on site F2 Hazardous building materials F3 Hazardous substances and processes F4 Safety from falling F5 Construction and demolition hazards F6 Visibility in escape routes F7 Warning systems F8 Signs F9 Means of restricting access to residential pools
Clause G	Services and facilities	G1 Personal hygiene G2 Laundering G3 Food preparation and prevention of contamination G4 Ventilation G5 Interior environment G6 Airborne and impact sound G7 Natural light G8 Artificial light G9 Electricity G10 Piped services G11 Gas as an energy source G12 Water supplies G13 Foul water G14 Industrial liquid waste G15 Solid waste
Clause H	Energy efficiency	H1 Energy efficiency

2.2.1 Goal and Scope of the Code

The Building Act 2004 ultimately sets the goals for all New Zealand building regulations including the New Zealand Building Code to ensure that:

- people who use buildings can do so safely and without endangering their health; and
- buildings have attributes that contribute appropriately to the health, physical independence, and well-being of the people who use them; and
- people who use a building can escape from the building if it is on fire; and
- buildings are designed, constructed, and able to be used in ways that promote sustainable development.

The New Zealand Building Code has general provisions (Clause A) and technical provisions to cover various aspects of buildings – stability (Clause B), fire safety (Clause C), access (Clause D), moisture (Clause E), safety of users (Clause F), services and facilities (Clause G), and energy efficiency (Clause H). Table 1 shows the scope of the Code [New Zealand Government, 2017].

The general provisions include Clause A1 of classified uses. Buildings are classified according to type under seven categories as shown in Table 2. A building with a given classified use may have one or more intended uses.

For the purposes of fire protection, the general provision Clause A3 assigns buildings with different importance levels based on their potential risk posed to human life or the environment, or economic cost, should the buildings fail due to fire. Table 3 shows these assigned building importance levels.

Table 2. Classified Use of Building

Categories	Applied Building or Use	Example
Housing	self care and self service	detached dwelling, multi-unit dwelling or group dwelling
Communal Residential	assistance or care extended to principal users	community service: boarding house, holiday cabin, backcountry hut, hotel, motel, retirement village, time-share accommodation or camp, etc. community care – old people's home or a health camp, rehabilitation centre, prison or hospital, etc.
Communal Non-Residential	meeting place where care and service is provided by people other than principal users	assembly service: church, cinema, museum, public swimming pool, stadium, theatre or assembly house, etc. assembly care: early childhood education and care centre, college, day care institution, centre for handicapped, kindergarten, school or university, etc.
Commercial	place where natural resources, goods, services or money are either developed, sold, exchanged or stored	amusement park, bank, car-park, catering facility, coffee bar, computer centre, fire station, library, office, police station, post office, public laundry, radio station, restaurant, service station, shop, showroom, storage facility, television station or transport terminal, etc.
Industrial	place where natural resources or goods are extracted or produced, repaired and stored	agricultural building and processing facility, aircraft hanger, factory, power station, sewage treatment works, warehouse or utility, etc.
Outbuildings	accessory to the principal use but not intended for human habitation	carport, farm building, garage, greenhouse, machinery room, private swimming pool, public toilet, or shed, etc.
Ancillary	not for human habitation	a bridge, derrick, fence, free standing outdoor fireplace, jetty, mast, path, platform, pylon, retaining wall, tank, tunnel or dam, etc.

Table 3. Building Importance Level

Importance level	Building type	Example
1	Buildings posing low risk to human life or the environment, or a low economic cost, should they fail	typical small non-habitable buildings such as sheds, barns, or ancillary building not normally occupied.
2	Buildings posing normal risk to human life or the environment, or a normal economic cost, should they fail	typical residential, commercial, and industrial buildings, etc.
3	Buildings of a higher level of societal benefit or importance, or with higher levels of risk-significant factors to building occupants.	large primary/secondary school, daycare or adult education facilities; certain health care or utilities facilities; certain buildings with high occupancy or hazardous materials; jails and detention facilities, etc.
4	Buildings that are essential to post-disaster recovery or associated with hazardous facilities	hospitals, fire/rescue/police stations, emergency vehicle garages/aircraft hangars, facilities for emergency management facilities, emergency shelters, buildings with highly toxic gas or explosive materials capable of causing hazard beyond property boundaries, aviation control towers/centres, critical building for national defence, water treatment facilities for fire suppression, etc.
5	Buildings whose failure poses catastrophic risk to a large area or a large number of people	major dams, extremely hazardous facilities

2.2.2 Structure of the Code

For each aspect of the buildings, the technical clauses (B to H) of the Building Code are structured to three levels of provisions:

- **Objective** – Social objectives the building must achieve. Each objective of the Building Code is ultimately set by the Building Act 2004 for the protection of the health and safety, contribution to the physical independence and well-being, of the people who use buildings, as well as for the promotion of sustainable development.
- **Functional requirement** – Functions the building must perform to meet the Objective.
- **Performance** – The performance criteria that the building must comply with in the intended use. By meeting the performance criteria, the Objective and Functional requirement can be achieved.

Since the objective of this review is mainly targeting the fire and life safety provisions, the following sections will focus on the New Zealand Building Code fire clauses.

2.2.3 Key Fire and Life Safety Provisions

The current fire safety provisions in the Building Code are clauses C1 to C6 "protection from fire", consisted of objectives, functional requirements and performances for fire protection, which were introduced to the Code in 2012 and remain effective today without changes [New Zealand Government, 2017]. These clauses aim to protect people in buildings, limit fire spreading to other buildings, and help firefighting and rescue.

2.2.3.1 Clause C1 - Objectives of Clauses C2 to C6

Clause C1 provides fire safety objectives for people, other property and firefighting that apply to clauses C2 to C6. Table 4 shows the exact wording of Clause C1. These objectives are set by the Building Act that buildings must achieve to protect the people who use the buildings.

Table 4. Clause C1 - Objectives of Clauses C2 to C6 (protection from fire)

Provision	Limit on application
The **objectives** of clauses C2 to C6 are to: (a) safeguard people from an unacceptable risk of injury or illness caused by fire, (b) protect other property from damage caused by fire, and (c) facilitate firefighting and rescue operations.	

Functional requirements and performance criteria are set in Clauses C2 to C6 in order to achieve the objectives of protecting people in buildings, limiting fire spreading to other buildings, and helping firefighting and rescue.

2.2.3.2 Clause C2 - Prevention of Fire Occurring

Clause C2 sets requirements for the design, construction and installation of fixed appliances using controlled combustion and other fixed equipment in buildings in order to safeguard people from an unacceptable risk of injury or illness due to fire occurring. Table 5 shows the exact wording of Clause C2, including functional requirement and performance. It sets the limit of a maximum surface temperature for nearby combustible building materials and establishes the provision to require a low probability of explosive or hazardous conditions due to design, construction and installation.

Table 5. Clause C2 - Prevention of Fire Occurring

Provision	Limit on application
Functional requirement **C2.1** Fixed appliances using controlled combustion and other fixed equipment must be designed, constructed, and installed in buildings in a way that reduces the likelihood of illness or injury due to fire occurring. **Performance** **C2.2** The maximum surface temperature of combustible building materials close to fixed appliances using controlled combustion and other fixed equipment when operating at their design level must not exceed 90°C. **C2.3** Fixed appliances using controlled combustion and other fixed equipment must be designed, constructed and installed so that there is a low probability of explosive or hazardous conditions occurring within any spaces in or around the building that contains the appliances.	

2.2.3.3 Clause C3 - Fire Affecting Areas beyond the Source

Clause C3 requires building design and construction to achieve a low probability of injury or illness to people not in close proximity to a fire source. This requires that upper floors are protected from external vertical fire spread and that all buildings are protected against fire spread to other property vertically or horizontally across an applicable property line. Table 6 shows the exact wording of Clause C3, including functional requirement and performance. It specifies performance criteria that must be met for surface lining and finish materials, for limiting vertical fire spread over external cladding, for limiting radiation levels related to the property boundary, for external walls within 1m of a boundary and for unsprinklered buildings, etc.

Table 6. Clause C3 - Fire Affecting Areas beyond the Source

<table>
<tr><th>Provision</th><th>Limit on application</th></tr>
<tr><td>

Functional requirement

C3.1 Buildings must be designed and constructed so that there is a low probability of injury or illness to persons not in close proximity to a fire source.

</td><td></td></tr>
<tr><td>

C3.2 Buildings with a building height greater than 10 m where upper floors contain sleeping uses or other property must be designed and constructed so that there is a low probability of external vertical fire spread to upper floors in the building.

</td><td>Clause C3.2 does not apply to importance level 1 buildings.</td></tr>
<tr><td>

C3.3 Buildings must be designed and constructed so that there is a low probability of fire spread to other property vertically or horizontally across a relevant boundary.

Performance

</td><td></td></tr>
<tr><td>

C3.4 (a) materials used as internal surface linings in the following areas of buildings must meet the performance criteria specified below:

<table>
<tr><td>Area of building</td><td colspan="2">Performance determined under conditions described in ISO 9705: 1993</td></tr>
<tr><td></td><td>Buildings not protected with an automatic fire sprinkler system</td><td>Buildings protected with an automatic fire sprinkler system</td></tr>
<tr><td>Wall/ceiling materials in sleeping areas where care or detention is provided</td><td>Material Group Number 1-S</td><td>Material Group Number 1 or 2</td></tr>
<tr><td>Wall/ceiling materials in exitways</td><td>Material Group Number 1-S</td><td>Material Group Number 1 or 2</td></tr>
<tr><td>Wall/ceiling materials in all occupied spaces in importance level 4 buildings</td><td>Material Group Number 1-S</td><td>Material Group Number 1 or 2</td></tr>
<tr><td>Internal surfaces of ducts for HVAC systems</td><td>Material Group Number 1-S</td><td>Material Group Number 1 or 2</td></tr>
<tr><td>Ceiling materials in crowd and sleeping uses except household units and where care or detention is provided</td><td>Material Group Number 1-S or 2-S</td><td>Material Group Number 1 or 2</td></tr>
<tr><td>Wall materials in crowd and sleeping uses except household units and where care or detention is provided</td><td>Material Group Number 1-S or 2-S</td><td>Material Group Number 1, 2, or 3</td></tr>
<tr><td>Wall/ceiling materials in occupied spaces in all other locations in buildings, including household units</td><td>Material Group Number 1, 2, or 3</td><td>Material Group Number 1, 2, or 3</td></tr>
<tr><td>External surfaces of ducts for HVAC systems</td><td>Material Group Number 1, 2, or 3</td><td>Material Group Number 1, 2, or 3</td></tr>
<tr><td>Acoustic treatment and pipe insulation within airhandling plenums in sleeping uses</td><td>Material Group Number 1, 2, or 3</td><td>Material Group Number 1, 2, or 3</td></tr>
</table>

</td><td>Clause C3.4 does not apply to detached dwellings, within household units in multi-unit dwellings, or outbuildings and ancillary buildings.</td></tr>
</table>

(b) floor surface materials in the following areas of buildings must meet the performance criteria specified below:

Area of building	Minimum critical radiant flux when tested to ISO 9239-1: 2010	
	Buildings not protected with an automatic fire sprinkler system	Buildings protected with an automatic fire sprinkler system
Sleeping areas and exitways in buildings where care or detention is provided	4.5 kW/m^2	2.2 kW/m^2
Exitways in all other buildings	2.2 kW/m^2	2.2 kW/m^2
Firecells accommodating more than 50 persons	2.2 kW/m^2	1.2 kW/m^2
All other occupied spaces except household units	1.2 kW/m^2	1.2 kW/m^2

(c) suspended flexible fabrics and membrane structures used in the construction of buildings must have properties resulting in a low probability of injury or illness to persons not in close proximity to a fire source.

C3.5 Buildings must be designed and constructed so that fire does not spread more than 3.5 m vertically from the fire source over the external cladding of multi-level buildings.

C3.6 Buildings must be designed and constructed so that in the event of fire in the building the received radiation at the relevant boundary of the property does not exceed 30 kW/m^2 and at a distance of 1 m beyond the relevant boundary of the property does not exceed 16 kW/m^2.

C3.7 External walls of buildings that are located closer than 1 m to the relevant boundary of the property on which the building stands must either:

(a) be constructed from materials which are not combustible building materials, or

(b) for buildings in importance levels 3 and 4, be constructed from materials that, when subjected to a radiant flux of 30 kW/m^2, do not ignite for 30 minutes, or

(c) for buildings in Importance Levels 1 and 2, be constructed from materials that, when subjected to a radiant flux of 30 kW/m^2, do not ignite for 15 minutes.

C3.8 Firecells located within 15 m of a relevant boundary that are not protected by an automatic fire sprinkler system, and that contain a fire load greater than 20 TJ or that have a floor area greater than 5,000 m^2 must be designed and constructed so that at the time that firefighters first apply water to the fire, the maximum radiation flux at 1.5 m above the floor is no greater than 4.5 kW/m^2 and the smoke layer is not less than 2 m above the floor.

C3.9 Buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety system intended to control fire spread.

2.2.3.4 Clause C4 - Movement to a Place of Safety

Clause 4 includes provisions for fire warnings and the visibility of escape routes to facilitate movement to a place of safety. Table 7 shows the exact wording of Clause C4, including functional requirement and performance. This clause sets limits for evacuation time in relation to carbon monoxide levels, thermal effects and smoke obscuration in relation to automatic fire sprinkler systems and the number of occupants.

Table 7. Clause C4 - Movement to a Place of Safety

Provision	Limit on application
Functional requirement **C4.1** Buildings must be provided with: (a) effective means of giving warning of fire, and (b) visibility in escape routes complying with clause F6. **C4.2** Buildings must be provided with means of escape to ensure that there is a low probability of occupants of those buildings being unreasonably delayed or impeded from moving to a place of safety and that those occupants will not suffer injury or illness as a result. **Performance** **C4.3** The evacuation time must allow occupants of a building to move to a place of safety in the event of a fire so that occupants are not exposed to any of the following: (a) fractional effective dose of carbon monoxide greater than 0.3: (b) a fractional effective dose of thermal effects greater than 0.3: (c) conditions where, due to smoke obscuration, visibility is less than 10 m except in rooms of less than 100 m^2 where visibility may fall to 5 m. **C4.4** Clause C4.3(b) and (c) do not apply where it is not possible to expose more than 1 000 occupants in a firecell protected with an automatic fire sprinkler system. **C4.5** Means of escape to a place of safety in buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety systems.	

Note: fractional effective dose is calculated based on ISO 13571 [ISO, 2007].

2.2.3.5 Clause C5 - Access and Safety for Firefighting Operations

Clause C5 includes provisions of access and safety for firefighting operations as shown in Table 8. To facilitate firefighting and rescue operations and limit illness or injury to firefighters and emergency responders, buildings must provide proper access for fire service vehicles, firefighters and equipment, and the inlets to any automatic fire sprinkler systems or fire hydrant systems. Buildings must also deliver water for firefighting and clear information to assist firefighters.

Table 8. Clause C5 - Access and Safety for Firefighting Operations

Provision	Limit on application
Functional requirement **C5.1** Buildings must be designed and constructed so that there is a low probability of firefighters or other emergency services personnel being delayed in or impeded from assisting in rescue operations and performing firefighting operations. **C5.2** Buildings must be designed and constructed so that there is a low probability of illness or injury to firefighters or other emergency services personnel during rescue and firefighting operations.	
Performance **C5.3** Buildings must be provided with access for fire service vehicles to a hard-standing from which there is an unobstructed path to the building within 20 m of: (a) the firefighter access into the building, and (b) the inlets to automatic fire sprinkler systems or fire hydrant systems, where these are installed. **C5.4** Access for fire service vehicles in accordance with clause C5.3 must be provided to more than 1 side of firecells greater than 5,000 m^2 in floor area that are not protected by an automatic fire sprinkler system. **C5.5** Buildings must be provided with the means to deliver water for firefighting to all parts of the building. **C5.6** Buildings must be designed and constructed in a manner that will allow firefighters, taking into account the firefighters' personal protective equipment and standard training, to: (a) reach the floor of fire origin, (b) search the general area of fire origin, and (c) protect their means of egress. **C5.7** Buildings must be provided with means of giving clear information to enable firefighters to: (a) establish the general location of the fire, (b) identify the fire safety systems available in the building, and (c) establish the presence of hazardous substances or process in the building. **C5.8** Means to provide access for and safety of firefighters in buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety systems.	Performance requirements in clauses C5.3 to C5.8 do not apply to backcountry huts, detached dwellings, within household units in multi-unit dwellings, or to outbuildings, and ancillary buildings.

2.2.3.6 Clause C6 - Structural Stability

Clause C6 contains provisions for structural stability during fire. Table 9 shows the exact wording of Clause C6, including functional requirement and performance. Structural systems must be designed and constructed to provide firefighters with safe access to floors during and after fire, considering the factors that affect the fire severity and its impact on structural stability. The collapse of building elements of a lesser fire resistance must not consequentially cause the collapse of elements of a higher fire resistance.

Table 9. Clause C6 - Structural Stability

Provision	Limit on application
Functional requirement **C6.1** Structural systems in buildings must be constructed to maintain structural stability during fire so that there is: (a) a low probability of injury or illness to occupants, (b) a low probability of injury or illness to fire service personnel during rescue and firefighting operations, and (c) a low probability of direct or consequential damage to adjacent household units or other property. **Performance** **C6.2** Structural systems in buildings that are necessary for structural stability in fire must be designed and constructed so that they remain stable during fire and after fire when required to protect other property taking into account: (a) the fire severity, (b) any automatic fire sprinkler systems within the buildings, (c) any other active fire safety systems that affect the fire severity and its impact on structural stability, and (d) the likelihood and consequence of failure of any fire safety systems that affect the fire severity and its impact on structural stability. **C6.3** Structural systems in buildings that are necessary to provide firefighters with safe access to floors for the purpose of conducting firefighting and rescue operations must be designed and constructed so that they remain stable during and after fire. **C6.4** Collapse of building elements that have lesser fire resistance must not cause the consequential collapse of elements that are required to have a higher fire resistance.	

2.2.4 Demonstration of Compliance

All building work in New Zealand must meet the performance requirements of the Building Code (NZBC). Compliance with the Building Code must be demonstrated using one or more of the paths as described in 2.1.2.2. They include acceptable solutions, verification methods, product certification, energy work certificate, New Zealand Standard NZS 4121, determinations and alternative solutions.

This section takes a further look at acceptable solutions, verification methods and alternative solutions for code compliance. The acceptable solutions and verification methods are deemed to comply with the Building Code as accorded by the Building Act 2004. Alternative solutions must demonstrate compliance by evidence.

2.2.4.1 Acceptable Solutions (AS)

As a part of the building regulations, Acceptable Solutions are issued and maintained by the chief executive of the MBIE under the Building Act 2004 as individual regulatory instruments related to each aspect of the Building Code. Acceptable Solutions provide one way to comply with the New Zealand Building Code and, if followed, are deemed to meet the performance criteria of the related clauses of the Building Code. Acceptable Solutions often include specific construction details for commonly used building materials, systems and methods and frequently refer to standards.

For the aspect of fire safety, there are three Acceptable Solutions – C/AS1, C/AS2 and BCH/AS1 – that provide a means of establishing compliance with NZBC Clauses C1 to C6 for Protection from Fire. These relatively straightforward sets of solutions for buildings and parts of buildings can be used by building design professionals including designers who do not necessarily have specific fire engineering qualifications. Each of these Acceptable Solutions applies to specific risk group(s). The risk group is based on the risk presented by the activities to be carried out in a building or part of a building.

- BCH/AS1 Acceptable Solution for Backcountry Huts [MBIE, 2014]
- C/AS1 Acceptable Solution for Buildings with Sleeping (residential) and Outbuildings (Risk Group SH) [MBIE, 2020a]
- C/AS2 Acceptable Solution for Buildings other than Risk Group SH [MBIE, 2020b]

The Acceptable Solution BCH/AS1 applies to backcountry huts which are buildings with only basic facilities located on land administered by the Department of Conservation for conservation, recreational, scientific, or other related purposes. Backcountry huts are intended to provide overnight shelter to self-reliance visitors.

Table 10 shows respective risk groups covered by Acceptable Solutions C/AS1 and C/AS2. There used to be one Acceptable Solution per risk group prior to 31 October 2019 (i.e. C/AS1 to C/AS7). Since November 5th, 2020, Acceptable Solutions C/AS2 to C/AS7 have been merged into one Acceptable Solution C/AS2.

Table 10. Risk Groups: Scope and Limitations of Acceptable Solutions C/AS1 and C/AS2

AS	Risk group	Applicable to	Relevant to NBCC
C/AS1	SH – Buildings with sleeping (residential) and outbuildings	• Detached dwellings with a single household • Low-rise multi-unit dwellings where each household unit has its own escape route that is independent of all other household units • Detached dwellings where fewer than six people (not including members of the residing family) pay for accommodation • Outbuildings	NBCC Part 9
C/AS2	SM – Sleeping (non-institutional)	• Permanent accommodation (Apartment buildings etc.) • Transient accommodation • Educational accommodation	NBCC Part 3
	SI – Care or detention	Where people are unable to self-evacuate without assistance through requiring special care or treatment, or they are restrained, or their liberties are restricted • Care activities • Detention facilities (excluding prisons)	
	CA – Public access and educational facilities	Where people congregate, participate in group activities or where professional services or retail are provided • Crowd activities • Personal service activities	
	WB – Business, commercial and low level storage	Where people work • Professional activities • Industrial activities • Storage activities (low level) • Intermittently occupied buildings (other than outbuildings)	
	WS – High level storage or potential for fast fire growth	Where people store goods and other materials • Storage activities (high level) • Service activities	
	VP – Vehicle storage and parking	Where people park vehicles • Vehicle parking – within a building or a separate building	

Only Acceptable Solution C/AS2 is relevant to National Building Code of Canada Part 3 buildings for this review. Acceptable Solution C/AS2 has seven parts. Part 1 of Acceptable Solution C/AS2 introduces the scope of and process for using this Acceptable Solution as well as the determination of occupant loads.

The scope of Acceptable Solution C/AS2 is restricted to risk groups SM, SI, CA, WB, WS and VP as listed in Table 10. It covers buildings or parts of buildings where people carry out the activities as described in this table.

Acceptable Solution C/AS2 provides step-by-step instructions for compliance with the Building Code in the aspect of fire safety. The process involves the following steps:

- Step 1: Determine which risk group applies. There may be more than one risk group for a firecell.

- Step 2: Determine the parameters for the various risk groups. These include building height, floor area, wall openings and distances to relevant boundaries, and occupant loads for relevant occupied spaces.
- Step 3: Satisfy the fire safety requirements. Based on the occupant loads and on the building's dimensions and features where required, the fire safety requirements in Part 2 to Part 7 of Acceptable Solution C/AS2 must be satisfied:
    - Part 2: Firecells, fire safety systems and fire resistance ratings
    - Part 3: Means of escape
    - Part 4: Control of internal fire and smoke spread
    - Part 5: Control of external fire spread
    - Part 6: Firefighting
    - Part 7: Prevention of fire occurring

Buildings with following complex features are outside the scope of Acceptable Solution C/AS2:

- Atriums;
- Intermediate floors (other than limited area intermediate floors);
- Operating theatres, intensive care units, hyperbaric chambers, delivery rooms, and recovery rooms (SI);
- Recreation and event centres (with tiered seating for more than 2000 people) (CA);
- Buildings more than 20 storeys high;
- Prison buildings;
- Delayed evacuation or stay-in-place strategy; and
- Control, use, storage or processing of hazardous substances.

In such cases, Verification Method C/VM2 or an alternative solution can be used to demonstrate compliance.

2.2.4.2 Verification Methods (VM)

As a part of the building regulations, Verification Methods are issued and maintained by the chief executive of the MBIE as individual regulatory instruments related to each aspect of the Building Code. Verification Methods provide one way of complying with the Building Code and, if followed, are deemed to meet the performance criteria of the related clauses of the Building Code. Verification Methods include calculation methods using recognized analytical methods and mathematical models, laboratory tests on prototype components and systems, and non-destructive tests-in-situ.

For the aspect of fire safety, there are two Verification Methods – C/VM1 and C/VM2 – that provide a means of establishing compliance with NZBC Clauses C1 to C6.

- C/VM1 Verification Method for Solid Fuel Appliances [MBIE, 2020c]
- C/VM2 Verification Method: Framework for Fire Safety Design [MBIE, 2020d]

Verification Method C/VM1 is a relatively straightforward method to show solid fuel burning appliances complying with NZBC Performances C2.2 and C2.3 by meeting the appropriate test requirements of AS/NZS 2918 test standard.

Verification Method C/VM2 is an analysis method for buildings with simultaneous evacuation schemes that evacuate immediately to the outside, and with typical fire growth rates. It provides more specific fire scenarios and design fires, etc. Verification Method C/VM2 can be used for demonstrating compliance of fire designs of buildings with NZBC Clauses C1 to C6 Protection from Fire. For buildings where there is use, storage or processing of hazardous substances, the fire design should also consider compliance with NZBC F3 clauses and the Hazardous

Substances and New Organisms Act 1996 where applicable in addition to the requirements of Verification Method C/VM2.

Verification Method C/VM2 is intended for use by professional fire engineers who are capable of applying fire engineering methods. The method allows a certain degree of creativity and flexibility in fire engineering solutions. C/VM2 defines ten design scenarios as shown in Table 11. Each of these scenarios must be considered independently and designed for in order to achieve compliance with NZBC Clause C for Protection from Fire. The C/VM2 sets out the fire modelling rules, design fire characteristics and other parameters to be used in calculations required by the design scenarios and provides occupancy criteria and calculations for the movement of people. Some scenarios require quantitative analysis and modelling to ensure that the available safe egress time (ASET) is longer than the required safe egress time (RSET). Other scenarios can be satisfied by inspection or by the provision of specific features.

Figure 2 shows schematically an iterated fire design process for using Verification Method C/VM2 to analyze or test the fire design against the design scenarios. The sequence of assessing each of the design scenarios, communication process and documentation for Fire Engineering Brief (FEB) development as well as trial design test options may vary depending on the complexity and scale of a project and design issues. The FEB process has been described in the International Fire Engineering Guidelines [ABCB, 2005] and other internationally recognized publications [BS, 2002; SFPE NZ, 2017].

Outside the scope of Verification Method C/VM2 are following buildings that:

- Do not have simultaneous evacuation schemes that evacuate immediately to the outside;
- Require a managed evacuation; or
- Contain fire hazards that are not defined by C/VM2.

Examples of buildings outside of the scope of C/VM2 include hospitals, care homes, stadia, principal transport terminals, large shopping malls (greater than 10,000 m^2 and contain mezzanine floors), tall buildings (greater than 60 metres or 20 storeys in height) or tunnels. In such cases, an alternative solution can be used to demonstrate compliance.

Table 11. Design Scenarios in Verification Method C/VM2

Design scenario		Code objectives	Code criteria	Expected method/outcome
Keeping people safe				
BE	Fire blocks exit – fire in an escape route blocking an exit	C1(a)	C4.5	Solved by inspection (Demonstrate that a viable escape route (or multiple routes where necessary) has been provided for building occupants.)
UT	Fire in a normally unoccupied room threatening occupants of other rooms	C1(a)	C4.3, C4.4	ASET/RSET analysis or provide separating elements/suppression complying with a recognized Standard
CS	Fire starts in a concealed space – endangering people in another room	C1(a)	C4.3	Provide separating elements/suppression or automatic detection complying with a recognised Standard
SF	Smouldering fire – close proximity to a sleeping area	C1(a)	C4.3	Provide automatic detection and alarm system complying with a recognised Standard
IS	Rapid fire spread involving internal surface linings	C1(b)	C3.4	Suitable materials used (proven by testing)
CF	Challenging fire – occupied space, challenging fire safety systems threatening occupants	C1(a)	C4.3, C4.4	ASET/RSET analysis
RC	Robustness check – failure of fire safety system should not render the design failing to meet the code objectives	C1(a), C1(b), C1(c)	C3.9, C4.5, C5.8, C6.2(d)	Modified ASET/RSET analysis
Protecting other property				
HS	Horizontal fire spread – exposing external walls of neighbouring building or firecell	C1(b), C1(a)	C3.6, C3.7, C4.2	Calculate radiation from unprotected areas as specified
VS	External vertical fire spread – exposing external wall to vertical fire spread	C1(a), C1(b)	C3.5	Suitable materials used (proven by testing) and construction features specified (sprinklers etc.) as required to limit vertical fire spread
Firefighting operations				
FO	Firefighting operations	C1(b), C1(c)	C3.8, C5.3, C5.4, C5.5, C5.6, C5.7, C5.8, C6.3	Demonstrate firefighter safety

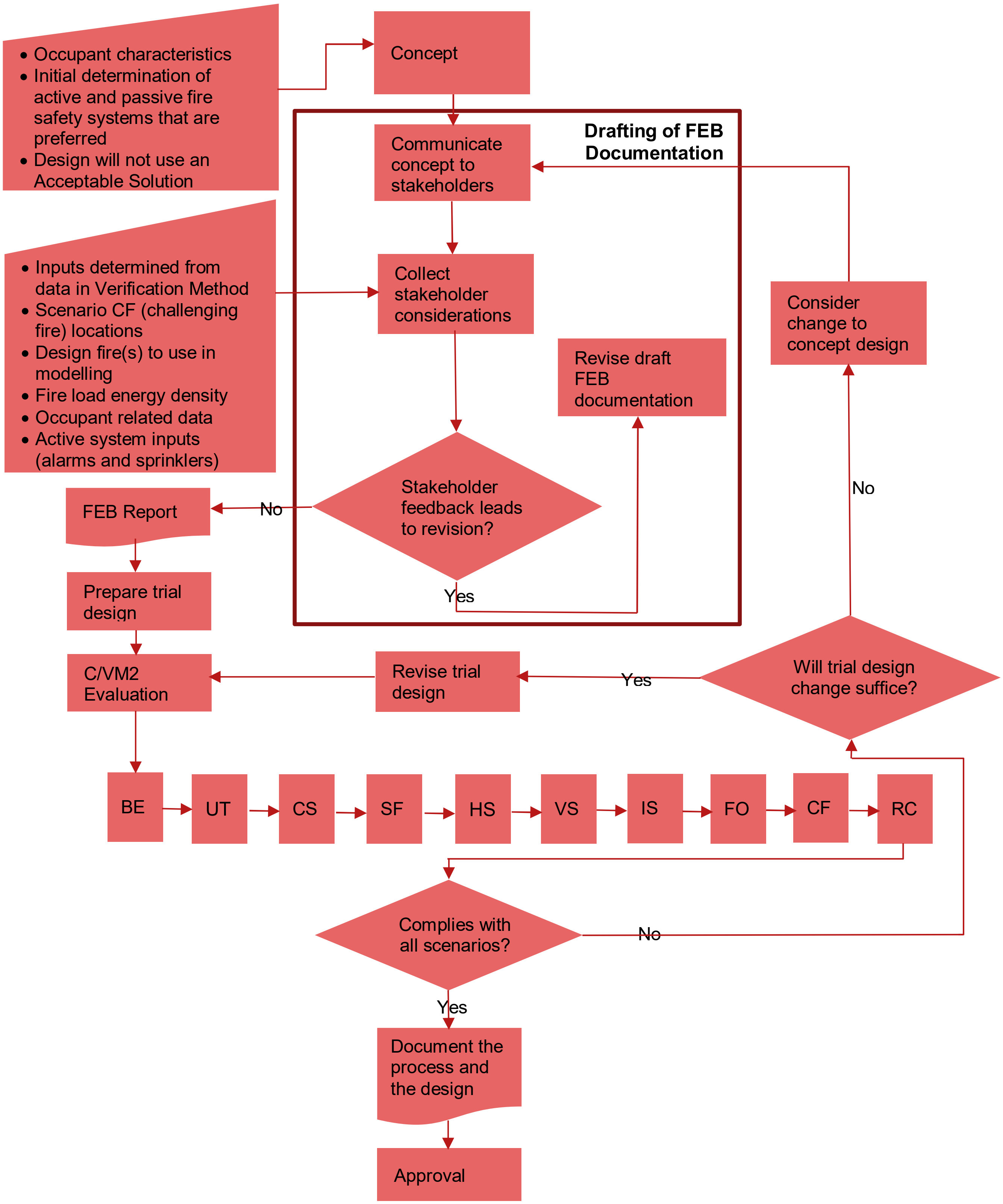


Figure 2. The design process overview for Verification Method C/VM2.

2.2.4.3 Alternative Solutions and Development

In New Zealand, an alternative solution means all or part of a building design that deviates partially or completely from Acceptable Solutions or Verification Methods (i.e., deemed-to-comply solutions or methods) but still conforms to the performance requirements of the Building Code to the satisfaction of the building consent authority. An alternative solution can have minor or major and single or multiple deviation(s) from the deemed-to-comply solution or method in materials, components or construction methods, etc.

Alternative Solutions have to be developed where Acceptable Solutions or Verification Methods are not available for a proposed building project or where the proposed project goes beyond the applicable scope of relevant Acceptable Solutions or Verification Methods. Through the alternative solution compliance path, the performance-based New Zealand Building Code opens the door to innovative, flexible and cost effective building solutions, which may deliver the best results for a building project.

In accordance with the Building Act 2004, MBIE's Chief Executive publishes guide documents to assist engineers and designers in developing alternative solutions for code compliance in each aspect of buildings. The guide documents are provided for assistance but do not have the same regulatory status as Acceptable Solutions or Verification Methods under the Building Act.

For the aspect of fire safety, a guide entitled "Alternative solutions for Building Code clause C Protection from Fire" is available online. It is not intended as a means of establishing the code compliance but to help fire engineers and designers developing alternative solutions for complying with the performance requirements of New Zealand Building Code clauses C1-C6. The guide can also help regulatory stakeholders and others in evaluating alternative solutions for these clauses.

The development of an alternative solution for fire safety design needs expertise and good understanding of fire engineering principles related to fire dynamics, human behaviour and structural reaction to fire, and of Acceptable Solutions and Verifications Methods for Clause C. This should be undertaken by capable and competent professionals who are capable to apply these principles in the development process.

The development of an alternative solution for fire safety design involves several essential steps:

1. Scope the project

This includes outlining the building and its features as well as the issue(s) that require an alternative solution.

2. Identify the Building Code clauses

All fire performance clauses that are affected by the alternative solution must be identified. The designer will seek to demonstrate compliance of the alternative solution with these clauses.

3. Establish the compliance pathway

The designer should determine what type of alternative solution to develop, which compliance path to pursue, and which parts of the project deviate from an Acceptable Solution or Verification Method. The deviation can be single or multiple, minor or major, or complete departures from the Acceptable Solution or Verification Method.

4. Follow the Fire Engineering Brief (FEB) process

All preceding steps should involve key stakeholders (regulatory stakeholders, building consent authority, Fire and Emergency New Zealand, et. al.). This stakeholder involvement can be carried out using the Fire Engineering Brief (FEB) process.

FEB is a process to define the scope of work and agree on the basis for the fire engineering analysis to be undertaken. The objectives, proposed trial designs, analysis approaches and methods, safety margin in the analysis if applicable, design acceptance criteria as well as whether to involve an independent peer review in the building consent review process, should all be agreed before the analysis commences. A FEB report should be prepared to document the results of this stakeholder consultation process, which forms the basis for the fire engineering analysis to start. The FEB report could be a short document for projects with a simple departure from a deemed-to-comply building solution or method but could be a major document for large and/or complex projects.

The FEB is an early and essential part of a typical fire engineering process. The fire engineering process normally includes first preparing FEB, then carrying out analysis, collating and evaluating results, drawing conclusions, and preparing a final fire engineering report.

5. Undertake the analysis

As determined by the FEB, the analysis of an overall fire safety system for the building can be undertaken to address:

- Fire Initiation and Development and Control
- Smoke Development and Spread and Control
- Fire Spread and Impact and Control
- Fire Detection, Warning and Suppression
- Occupant Evacuation and Control
- Fire Services Intervention

There are various approaches and methodologies for the development of analysis to support an alternative solution. The appropriate analysis approaches and methods would ideally be established at an early stage of the project through the FEB process. These approaches and methodologies for fire engineering analysis can be categorized as:

- Comparative or absolute approach. A comparative approach aims to determine whether the alternative solution is equivalent to (or better than) a deemed-to-comply design as a benchmark (including Acceptable Solutions, Verification Methods, a product previously accepted by a building consent authority, a determination issued by MBIE, etc.). An absolute approach aims to determine whether the alternative solution meets the objectives or performance requirements based on the agreed acceptance criteria without comparison with the benchmark.
- Qualitative or quantitative approach. A qualitative approach may suffice for cases of a single minor departure from the Acceptable Solution. A quantitative approach is required for a complex alternative solution with a major or multiple departure(s) from the Acceptable Solution or with a departure from the Verification Method.
- Deterministic or probabilistic approach. A deterministic methodology (based on physical relationships from theories and empirical results) always produces the same outcome for a given set of input parameters and initial boundary conditions but cannot indicate the probability of that outcome’s occurrence. A probabilistic approach applies a variety of risk based methodologies and combines multiple scenarios through probabilistic techniques.

The analysis of a proposed alternative solution that departs from the Verification Method C/VM2 would need to be undertaken by a qualified and experienced fire engineer with understanding of the C/VM2 and performance-based design process, and be carefully examined for any unintended consequences for other design scenarios within the Verification Method.

The analysis of a proposed alternative solution with a specific fire engineering design requires a high level of understanding of the Building Code and the inter-relationship between the Building Code clauses, and should use a range of international fire engineering guidelines, research and methodologies. This type of alternative solutions may be necessary for unique and specialized buildings, and can be developed from the first principles (absolute approach) or using the Acceptable Solutions or Verification Method as the benchmark for compliance (comparative approach). Several internationally recognized fire engineering guidelines provide more information on typical fire engineering processes, methodologies that may be used in undertaking the fire engineering process, and data that may be used in applying the methodologies.

An appropriate safety margin as agreed during the FEB process will have to be included in the analysis if the proposed alternative solution is a departure from C/VM2 or includes complex performance-based assessment of fire spread and evacuation. The safety margin is to address uncertainties in the input values, in the method of analysis or in its outputs, and known non-conservatisms in the method of analysis, etc.

A sensitivity analysis is also necessary for performance-based design to show what happens if any component of the system fails to operate, or if changes occur to particularly sensitive input values.

6. Provide evidence to demonstrate an alternative solution complies

The results from the fire engineering analysis will be collated and evaluated and conclusions drawn. A fire engineering documentation must be prepared with sufficient evidence to show the identified performance criteria of all relevant code clauses are met. The amount of evidence may be significant, depending on the complexity of the project.

The complexity of the review and approval process agreed with the building consent authority depends on how complex the proposed alternative solution is. The building consent authority will either assess a proposed alternative solution by itself or seek outside help (such as independent peer review) in assessing all or specific aspects of the proposal. The building consent authority will also consult Fire and Emergency New Zealand for advice on matters related to means of escape and needs for fire-fighting. The building consent applicant must demonstrate by evidence to the satisfaction of the building consent authority that the proposed alternative solution meets the performance requirements of the Building Code. Only then will a building consent be granted.

2.2.5 Referenced Documents

The New Zealand Building Code, Acceptable Solutions and Verification Methods reference standards and other documents from New Zealand, Australia and international organizations. Table 12 shows the referenced documents related to the aspect of “protection from fire” (Clause C). They provide practical information and guidelines for building solutions. The number of the Code clause, Acceptable Solution or Verification Method identifies where the particular document is referenced.

Table 12. Documents Referenced in NZBC, AS and VM Related to "Protection from Fire".

Issuing Agency	Document Number	Title of Document	Reference
Dept. of Conserv-ation		Hut Procurement Manual for Backcountry Huts (QD code VC 1414, March 2009, Version 4.0)	BCH/AS1
NZS/BS	476:- Part 21: 1987 Part 22: 1987	Fire tests on building materials and structures Methods for determination of the fire resistance of loadbearing elements of construction Methods for determination of the fire resistance of non-loadbearing elements of construction	 C/AS1, C/AS2 C/AS1, C/AS2
AS/NZS	1668:- Part 1: 1998	The use of ventilation and air conditioning in buildings Fire and smoke control in multi-compartment buildings (Amend: 1)	 C/AS1, C/AS2
AS/NZS	2918: 2001	Domestic solid fuel burning appliances – installation	C/VM1, C/AS1, C/AS2
AS/NZS	3837:1998	Method of test for heat and smoke release rates for materials and products using an oxygen consumption calorimeter (Amend: 1)	C/AS2, C/VM2
NZS	4232:- Part 2: 1988	Performance criteria for fire resisting enclosures Fire resisting glazing systems	 C/AS2
NZS	4332:1997	Non-domestic passenger and goods lifts	C/AS2
NZS	4510: 2008	Fire hydrant systems for buildings (Amend: 1)	C/AS1, C/AS2, C/VM2
NZS	4512: 2010	Fire detection and alarm systems in buildings	C/AS1, C/AS2, C/VM2
NZS	4514: 2009	Interconnected smoke alarms for houses	C/AS1
NZS	4515: 2009	Fire sprinkler systems for life safety in sleeping occupancies of less than 2000 m^2	C/AS1, C/AS2, C/VM2
NZS	4517:2010	Fire sprinkler systems for houses	C/AS1
NZS	4520:2010	Fire resistant doorsets	C/AS1, C/AS2
NZS	4541:2013	Automatic fire sprinkler systems	C/AS1, C/AS2, C/VM2
AS/NZS	5601:- Part 1: 2010	Gas installations General installations (Amend: 1)	 C/AS1, C/AS2
AS/NZS	60598:2001 Part 2.2	Luminaires Particular requirements – Recessed Luminaires (Amend: AA)	 C/AS1, C/AS2
AS	1366:- Part 1: 1992 Part 2: 1992 Part 3: 1992 Part 4: 1989	Rigid cellular plastics sheets for thermal insulation Rigid cellular polyurethane (RC/PUR) (Amend: 1) Rigid cellular polyisocyanurate (RC/PIR) Rigid cellular polystyrene – moulded (RC/PS-M) (Amend: 1) Rigid cellular polystyrene – extruded (RC/PS-E)	 C/AS1, C/AS2, C/VM2
AS	1530:- Part 1: 1994 Part 2: 1993 Part 4: 2005	Methods for fire tests on building materials, components and structures Combustibility test for materials Test for flammability of materials Fire-resistance tests of elements of building construction	 C/AS1, C/AS2, C/VM2
AS	1682:- Part 1: 1990 Part 2: 1990	Fire Dampers Specification 4.16.12, 4.16.14 Installation	 C/AS2 C/AS2
AS	1691: 1985	Domestic oil-fired appliances – installation	C/AS1, C/AS2
AS	4072:- Part 1: 2005	Components for the protection of openings in fire-resistant separating elements Service penetrations and control joints (Amend: 1)	 C/AS1, C/AS2
AS	4254:- Part 1: 2012 Part 2: 2012	Ductwork for air-handling systems in buildings Flexible duct Rigid duct	 C/AS2, C/VM2 C/AS2, C/VM2
AS	5113: 2016	Classification of external walls of buildings based on reaction-to-fire performance (Amend: 1)	C/AS2, C/VM2

BS	7273:- Part 4: 2007	Code of practice for the operation of fire protection measures Actuation of release mechanisms for doors	 C/VM2
BS	8414:- Part 1: 2015 Part 2: 2017	Fire performance of external cladding systems Test method for non-loadbearing external cladding systems applied to the masonry face of a building (Amend: 1 (2017)) Test method for non-loadbearing external cladding systems fixed to and supported by a structural steel frame (Amend: 1 (2017))	 C/AS2, C/VM2 C/AS2, C/VM2
BS	EN 12101:- Part 1: 2005	Smoke and heat control systems Specification for smoke barriers	 C/AS2
BS	EN 13501:- Part 1: 2018	Fire classification of construction products and building elements Classification using test data from reaction to fire tests	 C/AS2, C/VM2
CAE		Fire Engineering Design Guide, 2008	C/VM2
NZL		Education (Early Childhood Services) Regulations 2008	C/AS2
NZL		Health and Safety at Work (Hazardous Substances) Regulations 2017	C/AS2
NZL		Hazardous Substances and New Organisms Act 1996	C/AS1, C/AS2
ABCB		International Fire Engineering Guidelines (IFEG): 2005	C/VM2
ABCB	NCC 2015	National Construction Code (NCC) 2015	C/AS2
BRE	135:2013	Fire performance of external thermal insulation for walls of multi-storey buildings – Third Edition	C/AS2, C/VM2
Eurocode	DD ENV 1991 Eurocode 1: Part 2.2: 1996	 Basis of design actions on structures Actions on structures exposed to fire	 C/VM2
ISO	1182: 2010	Reaction to fire tests for products – Non-combustibility test	C/VM2
ISO	5660:- Part 1: 2002 Part 2: 2002	Reaction-to-fire tests – Heat release, smoke production and mass loss rate Heat release rate (cone calorimeter method) Smoke production rate (dynamic measurement)	 C/AS1, C/AS2, C/VM2
ISO	9239:- Part 1: 2010	Reaction to fire tests for flooring Determination of the burning behaviour using a radiant heat source	C3.4(b), C/AS1, C/AS2, C/VM2
ISO	9705: 1993	Fire tests – Full scale room test for surface products	C3.4(a), C/AS1, C/AS2, C/VM2
ISO	13571: 2012	Life-threatening components of fire Guidelines for the estimation of time available for escape using fire data	C4.3, C/VM2
ISO	13784:- Part 1: 2002	Reaction-to-fire tests for sandwich panel building systems Test method for small rooms	 C/VM2
ISO	13785	Reaction-to-fire tests for façades Part 1: 2002 Intermediate-scale test	 C/VM2
ASTM	D 2898: 2010	Standard practice for accelerated weathering of fire-retardant treated wood for fire testing	C/AS2
NFPA	285: 2019	Standard fire test method for evaluation of fire propagation characteristics of exterior wall assemblies containing combustible components	C/AS1, C/AS2, C/VM2
SFPE / NFPA		The Handbook of Fire Protection Engineering, 4th Edition, NFPA, Quincy, M.A., USA, 2008 Gwynne, S.M.V., and Rosenbaum, E.R., “Employing the Hydraulic Model in Assessing Emergency Movement”, Section 3 Chapter 13	C/VM2
SFPE		SFPE Engineering Guide to Predicting 1st and 2nd Degree Skin Burns from Thermal Radiation, 2000	C/VM2

Standards New Zealand (NZS)
British Standards Institution (BS)
New Zealand Legislation (NZL)
Building Research Establishment (BRE, UK)
American Society for Testing and Materials (ASTM)
Society of Fire Protection Engineers (SFPE)
Standards Australia (AS)
Centre for Advanced Engineering (CAE, New Zealand)
Australian Building Codes Board (ABCB)
International Standards Organisation (ISO, Geneva)
National Fire Protection Association (NFPA)

2.2.6 Changes to Building Code, Acceptable Solutions and Verification Methods

The Building Code, Acceptable Solutions and Verification Methods and published guidance are regularly reviewed by the MBIE with annual updates to keep pace with innovation, modern construction methods and the needs of modern society. MBIE leads the processes for these changes in consultation with stakeholders and the public.

Proposed changes for the annual update are generated by MBIE engineers, architects and other technical staff within the Building Performance and Engineering team based on current priorities and available resources. Additional advice on these topics is provided by the Code Advisory Panel appointed by MBIE. The public can recommend topics to MBIE for the updates.

Stakeholders likely to be substantially affected by these updates must be consulted to ensure the Building Code continues to set appropriate minimum standards for the performance of buildings. MBIE opens code consultation in April each year with opportunities for the public and building and construction sector to submit feedback on proposed changes. After the consultation closes and submissions are evaluated, the updates are finalized and published in November each year. (Note: the updates used to be twice a year prior to 2021 but will move to once a year from 2021 onward.)

Since becoming a performance-based code in 1992, the New Zealand Building Code had major changes in its fire safety provisions from mostly qualitative to more quantitative performance criteria in 2012. These changes were triggered by the Building Act 2004 and led to the new fire safety clauses C1 to C6 “protection from fire” in the New Zealand Building Code, supported by a new set of Acceptable Solutions and Verification Methods.

While the code Clauses C1 to C6 remain unchanged since 2012, the annual review and updates have resulted in more frequent changes to the Acceptable Solutions and Verification Methods. The most recent C/AS1, C/AS2, C/VM1 and C/VM2 are the 2020 versions.

2.2.7 Tools, Resources and Research to Support PBC, Design, Approval

MBIE publishes guide documents to assist development and approval of alternative solutions for code compliance, such as “Alternative solutions for Building Code clause C Protection from Fire” [MBIE, 2018], “New Zealand Building Code Handbook” [MBIE, 2014b] and “Fire performance of external wall cladding systems - Revision 2: 2020” [MBIE, 2020e], etc. The guidance on cladding systems discusses how New Zealand Building Code requirements should be interpreted and whether international alternative fire tests and evaluation methods are suitable for demonstrating code compliance. BRANZ is conducting further research in this area. Various other existing resources and models such as International Fire Engineering Guidelines [ABCB, 2005], SFPE Engineering Guide [NFPA, 2007] and Fire Dynamics Simulator [McGrattan et al, 2013] etc. are also used in the design, review and approval of building solutions.

A fire safety engineering design modelling tool called B-RISK [Baker et al, 2013; Wade et al, 2016] developed by BRANZ and the University of Canterbury has been used to support code development and performance-based fire engineering design practices. B-RISK uses a physics-based model in conjunction with probabilistic analysis to produce results for a better understanding of uncertainty and risk associated with fires in building enclosures than deterministic approaches and to support risk-informed design decision-making.

With emergence of new materials and construction methods and technologies, research and experiments were conducted to explore some critical aspects of fire safety design for buildings, leading to various tools and resources for fire safety design:

- Towards a risk-informed approach to fire-safety design [BRANZ, 2020a; Hare, 2019]. This research reviewed technical justifications for parameters and values used in the fire performance clauses and in Verification Method C/VM2. It investigated the statistical distributions of the parameters required for calculating the available safe egress time (ASET), the tenability limits for occupants, and the required safe egress time (RSET). It also explored a way to represent the uncertainties in these parameters using statistical probability density functions as the basis for risk-informed fire safety design.
- Toxicity of gases released by construction materials during building fires [BRANZ, 2020b]. This literature review investigated combustion products released by modern building materials during fires and examined the effectiveness of bench-scale approaches for assessing their toxicity.
- Escape route pressurisation systems [BRANZ, 2020c]. This work investigated ways to improve the verification of the effectiveness of escape route pressurisation systems and provided recommendations on revising the standards and procedures for the design, installation, functioning, inspection and testing of these systems.
- Escape route pressurisation systems: A pilot study of New Zealand data [Frank et al, 2020]. Although escape route pressurisation systems are not explicitly included in regulatory requirements, they are still being specified in buildings with an intent to protect key areas of the building from smoke ingress during a fire event. Given the lack of direct evidence on how well these systems would actually work under fire conditions, this pilot study investigated what could be learned about pressurisation system usage and effectiveness in buildings from fire incident data.
- A review of the regulations for managing fire in roofs lower than adjacent buildings [BRANZ, 2021a]. This work reviewed the regulations for managing fire spread from roofs to adjacent taller buildings in comparison with regulations in five other countries.
- Estimating the heat flux on walls from fire in adjacent lower roofs [BRANZ, 2021b]. This work investigated modelling approaches for calculating the thermal impact of fires from adjacent lower roofs, validated by limited small-scale experimental fires. There is no specific method for such a calculation in Verification Method C/VM2 or literature.
- Medium-density housing #7: Fire safety [BRANZ, 2018]. Moving from low-density to medium-density housing involves people living in closer proximity with implications for fire safety design.
- For residential buildings undergoing alterations, a consistent risk assessing process was developed for analyzing the risk of noncompliant fire-stopping and smoke-stopping [Frank et al, 2018]. A series of common noncompliant fire-stopping configurations were also studied using fire tests. A risk analysis tool was used together with this risk assessment process to systematically evaluate individual defects [Marks, 2018]. Frank et al suggested that further investigation would be needed for field applications.

2.3 Impacts, Acceptance and Potential of Performance-Based Code

2.3.1 Evolvement of New Zealand Building Code

New Zealand harmonized building controls nationally and moved to performance-based building regulations in the early 1990's. The New Zealand Building Code was one of the first performance-based codes in the world at that time.

The initial introduction of the performance-based code and regulations had mixed outcomes [Meacham, 2009]. The code provided a flexibility in building designs and a consistency in building approvals across the country, which resulted in some good innovations and cost effective solutions in various building projects. On the other hand, accountability issues arose relating to design rigor, evidence basis (producer statements of code compliance), building methods (workmanship and cost-cutting practices) and effectiveness of supervision. There were certain cases where non-compliant buildings were built, such as highlighted by the 'leaky building' crisis [May, 2003; Meacham, 2010]. Qualitative and vague code requirements were identified as partly to blame for the interpretation of these code requirements and the compliance review of the associated designs could be subjective. Vague or confusing performance criteria impeded the abilities of regulators and engineers responding to emerging needs and technologies.

The Building Act 2004 introduced additional controls over practitioner licensing and accreditation of building consent authorities, and triggered a major review of the Building Code. In 2012, significant changes were ushered to the Building Code including the new fire safety clauses C1 to C6 "protection from fire" with ten performance criteria being quantified and the other ten remaining qualitative. The quantified performance criteria are expressed numerically for vertical and horizontal fire spread, means of escape, storage buildings and fire service vehicle access. These quantitative performance criteria provide a greater clarity and consistency in the level of safety for all building designs to achieve. At the same time, designers still have the flexibility in design input values and safety factors [Fleischmann and Caldwell, 2014; Belsham et al, 2017].

2.3.2 Performance Criteria Used

Although fire clauses C2 to C6 have an increased number of quantified performance criteria, the functional requirements and half of the performance criteria are still qualitative provisions. They often use a probabilistic term of "low probability" or "reduces the likelihood". This has created problems for both the designers and the building consent authorities who have to subjectively interpret the requirements and argue what performance levels are acceptable. The decision makers would also be liable for his/her subjective judgement on the matters [Baker, 2020b].

While quantitative performance criteria can provide clearer performance requirements for buildings to meet, overly quantified values in performance criteria may become problematic. There are ongoing discussions about potential issues relating to some values used in a few performance criteria [Belsham et al, 2017; Glennie, 2020; Baker, 2020b], which were based on existing standards and available research data, for example:

- Performance criteria C3.4 directly references ISO 9705:1993 and ISO 9239.1:2010 with specific test criteria for limiting the spread of fire on internal surface lining or floor surfacing materials. The formulation of these performance criteria in the code may unnecessarily constrain innovative design options and perhaps needs more research data to support such quantification. Other design aspects such as the location of linings in proximity to the fire source are not reflected. Other alternative test methods and material assessments would have to be correlated back to the specific ISO standards, which may create a market barrier.
- Performance criteria C3.5 requires that fire spread no more than 3.5 m vertically from the fire source over the external cladding of multi-level buildings. Vertical fire spread on the exterior of the building would typically be expected not to spread more than one storey above the fire floor. This 3.5-m limit may lead to a conservative design for a two-storey building with gable roof exceeding 7.0 m in building height or for a small tall

warehouse as a single or two storey structure. The term “over the external cladding” may imply only the outer most surface or components be considered while in fact the external cladding systems often contain vertical channels, insulation and combustible materials as well as interior cavities through or over which fire could spread vertically.

- Performance criteria C4.3 requires that occupants not be exposed to untenable conditions (carbon monoxide, heat, smoke obscuration) during evacuation. The tenability criteria use a one-size-fits-all approach without considering increased risk to vulnerable populations. Exposure to irritant gases is not considered either which may delay the evacuation.
- Performance criteria C4.4 is an exemption to clause C4.3 and permits assessing only the carbon monoxide exposure, which intends to promote the use of sprinklers, but becomes one of the most controversial performance clauses. The ability of occupants to evacuate through a smoke filled room (with zero visibility) is questionable.

There are already discussions about moving towards more risk-informed or risk-based fire provisions and designs using a probabilistic approach in the future [Baker et al, 2013; Wade et al, 2016; Hare, 2019; BRANZ, 2020a; Baker, 2020a, 2020b]. Clauses C2 to C6 lack the probabilistic quantification of fire risk. Further work is required to quantify each performance criterion to combine a specific limit with an acceptable probability not surpassing the limit.

2.3.3 Impact on Capacity of Building Industry and Authority

Qualified and competent fire engineers are in short supply to conduct fire engineering designs (using Verification Method C/VM2 and/or alternative solutions), the regulatory approval and third-party peer review of the designs across the country [Meacham, 2018; Baker, 2020b]. There are no regulations defining or restricting who can practice fire engineering. A large percentage of fire safety designs are prepared by designers with no fire engineering qualifications. Building consent authorities often do not have sufficient expertise to review and approve a performance-based design and have to engage third-party peer reviewers. There are not enough peer reviewers, who have the relevant qualifications and experience for the proposed type of alternative solution and building design and use, to conduct a proper third party review with independence.

In addition, the qualification of fire engineers is not explicitly defined and there are no legal protections for fire engineers in New Zealand, which further complicate the issue of shortage of skilled fire practitioners. Currently fire practitioners can be members of Engineering New Zealand, Chartered Professional Engineers, or designers with no professional affiliations [SFPE NZ, 2019]. Fire engineers desire a licensing scheme supported by formal fire engineering training in New Zealand. Training would also need to extend to the whole supply chain beyond the fire engineers to associated building professionals such as architects, structural engineers, building services engineers, building consent authorities and installers of fire safety elements and systems, enabling them to understand and interface between fire engineering designs and their areas of practice. Currently, post graduate training for fire engineers is only available at Canterbury University within New Zealand.

Under the Building Law Reform Programme, the New Zealand government plans to strengthen the regulations of engineers in the coming years to ensure that engineers provide engineering services with reasonable care and skill, operate within their areas and level of competence and are held accountable for substandard work or poor conduct so that the public can have confidence in the engineering profession within the construction industry. Several international guidelines are available to help establish minimum technical competencies for fire engineers to practice fire engineering [ABCB, 2005; SFPE, 2018; SFPE, 2020].

Both the building industry and the regulators need support to consistently develop performance-based designs and implement the performance-based code, respectively. Where the code clauses use qualitative terms such as low probability or likelihood in functional requirements or performance criteria, the designers and building consent authorities do not have probabilistic acceptance criteria which are necessary to avoid subjective interpretation, judgement or argument in the building consent process. For example, how low is the "low probability or likelihood"? Is it a 0.1 chance of occurrence, a 0.01 chance of occurrence, or a 1×10^{-6} chance of occurrence? Subjective interpretations, judgements, and arguments over clauses using qualitative terms can lead to disputes which need to be resolved by the MBIE for determination or the District Court for appeal.

Appropriate computational tools and verification methods need to be developed, validated, introduced, and supported. Most tools and methods that have been used for fire safety engineering designs are deterministic in nature. Probabilistic tools and methods for quantitative fire risk analysis are lacking [Baker, 2020b].

The building industry and the building consent authorities need continued training, which should extend beyond fire engineers to associated building professionals – architects, structural engineers, building services engineers and installers [SFPE NZ, 2019].

2.3.4 Social Perception and Acceptance

The harmonized and performance-based building regulations in the 1990's were received warmly in New Zealand because they transformed the fragmented regional building controls to a national building regulatory system. The performance-based regulatory regime granted certain discretion in designs and brought out some good innovations and cost effective solutions with the flexibility of using various designs and materials. However, issues arose related to insufficient accountability in design rigor, producer statements, building workmanship, cost-cutting practices and supervision [May, 2003, 2004; Meacham, 2009]. These led to a 'leaky building' crisis in the mid 1990's to early 2000's as results of deficient accountability structure. Qualitative and vague code requirements partly contributed to the problem as subjective interpretation and discretion were unavoidable in the designs and approvals.

The Building Act 2004 strengthened the accountability legislation and triggered major changes to the Building Code. The new fire safety clauses C1 to C6 "protection from fire" of the Building Code (2012) have a greater number of quantified performance criteria (ten performance criteria are quantitative and the other ten qualitative), supported by a new set of Acceptable Solutions and Verification Methods including Verification Method C/VM2.

There was initial resistance to Verification Method C/VM2 from the market during 2012-2015 with complaints that the C/VM2 was too restrictive, had many gaps, and led to costly designs, etc. However, it was subsequently recognized that the C/VM2 effectively removed useless debate about various parameters and brought about more focus on good design, robustness and principle. The quantified fire performance clauses of the Building Code (2012) have proved to be largely successful since being updated in 2012 [Belsham et al, 2017; Meacham, 2018].

The Building Code (2012) and associated Acceptable Solutions and Verification Methods are regularly reviewed and/or updated annually including public consultation to keeps pace with innovation, modern construction methods and the needs of modern society. The Building Code (2012) remains relatively stable without changes to the fire clauses while the associated Acceptable Solutions and Verification Methods are frequently updated as results of the annual review since 2012. There is an increasing interest in the application of fire engineering principles to building designs.

2.3.5 Potential and Benefits

The development and implementation of the performance-based building code has not been painless, but the benefits do appear worth the effort. Over the last 30 years, the New Zealand Building Code has evolved to be one of the best performance-based building codes in the world. New Zealand has derived from the performance-based building code great benefits including, but not limited to, the following:

- Enabling the development of innovative, flexible and cost effective building solutions to deliver the best possible results for building projects, which is especially true for complex and unique building projects where the prescriptive code would constrain design options and offer no solutions to address emerging needs and technologies;
- Responding quickly to market needs for new construction methods and technologies;
- Providing clear performance requirements and an increased number of quantified performance criteria for developing code compliant fire engineering designs;
- Pioneering a systematic approach to fire engineering design within the New Zealand legislation;
- Supporting a more transparent, consistent and efficient building regulatory system;
- Addressing challenges with existing buildings;
- Being positioned to also address sustainability and other environmental challenges; and
- Facilitating international trade.

3 Summary

3.1 Building Code

New Zealand harmonized building controls across the country and adopted performance-based building regulations by the Building Act 1991. The New Zealand Building Code (1992) was one of the first performance-based codes in the world. The initial introduction of the performance-based code and regulations was not without issues. Major legislative and regulatory changes occurred a decade later with the Building Act 2004 becoming the new building law in 2004, followed by significant changes in 2012 to the Building Code (2012).

Still effective today, the New Zealand Building Code (2012) has introduced new fire safety clauses C1 to C6 “protection from fire”, consisted of objectives, functional requirements and performances, to provide fire protection for people, other property, firefighting and rescue. Fifty percent of the fire performance criteria have been quantified. In particular, quantified performance criteria for vertical and horizontal fire spread, means of escape, storage buildings and fire service vehicle access successfully provide a greater clarity and consistency to enable compliance and innovation with design flexibility.

The New Zealand building regulations including the Building Code (2012), associated Acceptable Solutions and Verification Methods, are administered and maintained by the Ministry of Business, Innovation and Employment (MBIE). Regularly review and public consultation are conducted annually. Since 2012, the Building Code (2012) remains relatively stable without changes to the fire clauses while the associated Acceptable Solutions and Verification Methods have been frequently updated as results of the annual review.

3.2 Compliance

Building works that follow the acceptable solutions, verification methods, product certification, energy work certificate, New Zealand Standard NZS 4121 and/or determinations made by MBIE, are deemed to comply with the Building Code (2012). Buildings with complex features are generally outside the scope of these deemed-to-complied building solutions or methods.

Alternative solutions can be developed but must demonstrate by evidence that they meet the performance requirements of the Building Code to the satisfaction of the building consent authority. An alternative solution means all or part of a building design that deviates partially or completely from Acceptable Solutions or Verification Methods but still confirms to the performance requirements of the Building Code. New Zealand Building Code allows alternative solutions to be developed from first principles (absolute approach) without the need to compare with a code benchmark, which is a particularly helpful approach for unique, complex and specialized building designs where there are no benchmarks for comparison. Alternative solutions can also be developed using a comparative approach with reference to a deemed-to-comply benchmark.

3.3 Enforcement

Unless exempted, no buildings are allowed to be constructed, altered, demolished or removed without a building consent. A building consent authority issues the building consent to authorize construction, inspects and/or issues notices for corrections, and grants a code compliance certificate after the completion of the building work. The building consent authority is responsible to ensure that building work from plan to completion complies with the Building Code.

3.4 Some Issues with Performance Criteria

The fire clauses C2 to C6 of the Building Code (2012) have qualitative functional requirements as well as a considerable number of qualitative performance clauses, which use “low probability” or “reduces the likelihood” in the provisions. These can be problematic for both the designers and the building consent authorities who have to subjectively interpret the requirements and to argue what performance levels are acceptable. While quantitative performance criteria can provide clearer performance expectations for buildings to meet, poorly quantified values in performance criteria may become problematic too. To enable more risk-informed or risk-based fire provisions and designs, there are needs for further research to quantify each performance criterion combining a specific limit along with an acceptable probability.

3.5 Some Issues with Capacity

Qualified and competent fire engineers should be required to conduct fire engineering designs, regulatory review and approval, and third-party peer review. However, such fire engineers are in short supply across the country. There are no regulations defining or restricting who can practice fire engineering in New Zealand. Building consent authorities often do not have sufficient expertise to review and approve a performance-based design. There are not enough numbers of qualified and competent peer reviewers to conduct independent third party review. In addition, the qualification of fire engineers is not explicitly defined and there are no legal protections for fire engineers in New Zealand. Fire engineers desire a licensing scheme supported by formal training.

3.6 Needed Tools and Resources

Various guide documents and handbooks published by MBIE and various tools developed in New Zealand and elsewhere have been used by the regulators and the building industry to support code development and implementation, and fire engineering design practices. One of these tools is New Zealand's own fire safety design modelling tool B-RISK developed by BRANZ and the University of Canterbury. B-RISK uses a physics-based model in conjunction with probabilistic analysis to produce results for a better understanding of uncertainty and risk associated with fires in building enclosures than deterministic approaches and to support risk-informed design decision-making.

Where the code clauses use qualitative terms such as low probability or likelihood in functional requirements or performance criteria, the designers and building consent authorities would need probabilistic acceptance criteria in order to remove the current subjective interpretation, judgement or argument in the building consent process. For example, low probability or likelihood is not quantified – how low is the "low probability or likelihood"? Is it a 0.1 chance of occurrence, a 0.01 chance of occurrence, or a 1×10^{-6} chance of occurrence as the probabilistic acceptance criteria? Appropriate computational tools and verification methods need to be developed, validated, introduced, and supported to enable the building industry and regulators to consistently develop performance-based designs and enforce the performance-based code. Probabilistic tools and methods for quantitative risk analysis are particularly lacking. The building industry and the building consent authorities also need continued training, which should also extend beyond the fire engineers to associated building professionals.

3.7 Final Remarks

Over the last 30 years, the New Zealand Building Code has evolved to be one of the best performance-based codes in the world and rendered great benefits outweighing the issues encountered. The issues with performance criteria (qualitative vs quantitative), stakeholder capacity (designers, authorities, peer reviewers, fire engineer qualification, etc.), tools and resources as well as risk-informed decisions making are not unique for New Zealand. These issues are quite common in all countries where performance-based codes have been implemented [Alvarez et al, 2013; IBQC, 2020; Meacham et al, 2005, 2017; Meacham, 2009, 2010, 2016, 2018].

The New Zealand Building Code enables the development of innovative, flexible and cost effective building solutions to deliver the best possible results for building projects, especially for complex and unique building projects. This Code has pioneered a systematic approach to fire engineering design within the New Zealand legislation to support a more transparent, consistent and efficient building regulatory system. Under a Building Law Reform Programme, the government is working with the building and construction industry and all stakeholders to further improve the building regulatory system and drive better outcomes for the industry and for New Zealanders.

New Zealand's experiences and successes can benefit others who may want to go down the road to performance-based codes; some key lessons learned include:

- Moving towards performance-based building code would be a challenging undertaking with growing pains but the benefits could outweigh the drawbacks;
- A harmonized national code and regulatory approach would eliminate regional differences in evaluation and acceptance of designs and promote efficient and

consistent application of building regulations across country as well as facilitate training and the development of resources to support the designers and building consent authorities;
- Code provisions would need to be clear, and properly quantified where possible, to minimize potential subjective interpretation and acceptance and to maintain safety while providing flexibility for innovation;
- Quantification of fire risk in a probabilistic manner would be desirable towards more risk-informed or risk-based fire provisions;
- Allowing alternative solutions to be developed from first principles (using an absolute approach) would be necessary for unique, complex and specialized building designs where there are often no deemed-to-comply benchmarks for comparison;
- Qualified and competent fire engineers should be required by regulations to conduct design, regulatory review and approval, and third-party peer review, of fire engineering solutions; and qualification of fire engineers should be explicitly recognized and defined in the regulatory system;
- Fire engineering training may need to be expanded at post graduate level and extend to various building professionals (e.g., architects, structural engineers, building consent authorities, building services engineers and installers) enabling them to effectively and efficiently interact with the fire engineer and coordinate with fire engineering designs and their areas of practice;
- More computational tools and verification methods would need to be developed, validated, introduced, and supported to enable the building industry and the regulators to consistently implement performance-based codes; probabilistic tools, methods and criteria for quantitative risk analysis are particularly lacking.

The lessons learned from the introduction of performance-based codes in New Zealand emphasizes the fact that success requires a coordinated effort between all levels of government, professional associations, fire services, the academic and research community, certification bodies, and trades and contractors.

This review focused on the fire and life safety provisions in the New Zealand Building Code, and summarizes key lessons learned from their experiences in the development of their performance-based code.

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