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Resilient Timber Homes

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1 Introduction

This Guide describes how sustainable timber homes can be designed and built with a resilience-focused Code+ approach, leveraging the combination of factors that make them the natural answer to the challenges from our changing climate, and provide safety and wellness to their occupants.

Extreme natural events such as bushfires, floods, storms, and other natural hazards are becoming increasingly common occurrences that significantly impact our communities, environment, and economy. Considerable time is required to develop and implement changes in buildings standards to obtain “minimum levels of performance” that will ensure adequate resilience to withstand the increased loads resulting from these extreme events. This publication will provide immediate guidance to design and building professionals involved in “upgrading” and repairing existing buildings affected by extreme events across Australia, or in designing and constructing new buildings in areas that present such risks.

Code-compliant and well-maintained timber frame homes are robust and resilient when subjected to adverse and extreme conditions, including those associated with floods, bushfires, and cyclones, for every location in Australia. They provide more than just life safety (the main objective of the National Construction Code) and adequate property protection, through good durability and easy maintenance.

This Guide presents comprehensive checklists and relevant details for designing, repairing, and constructing Resilient Timber Homes in Australia, demonstrating how they can be designed and built with a resilience-focused “Code+” approach to providing better safety and wellness for their occupants, while meeting triple-bottom-line (people, planet and profits) sustainability objectives, as well as creating increased value for both investors and the broader community.

The primary objective of this Guide is to demonstrate and explain the applicable compliance pathways, provide relevant generic details explaining how ‘specific hazard-area building practice fundamentals’ logically integrate with timber products, and achieve sustainability benefits.

While the initial cost of a resilient timber home may be slightly higher than conventional construction, the long-term benefits of sustainability, energy efficiency, and resilience can lead to significant cost savings and a positive environmental impact.

This Guide should be seen in conjunction with other WoodSolutions Technical Design Guides, refer to Figure 1, that provide more extensive information on a specific subject, i.e. designing for bushfire-prone areas, cyclones, etc. Moreover, the examples shown in the case studies, are appropriate for the time and place for which they were designed and approved and should not be transferred to different circumstances without a specific consideration of the applicable requirements.

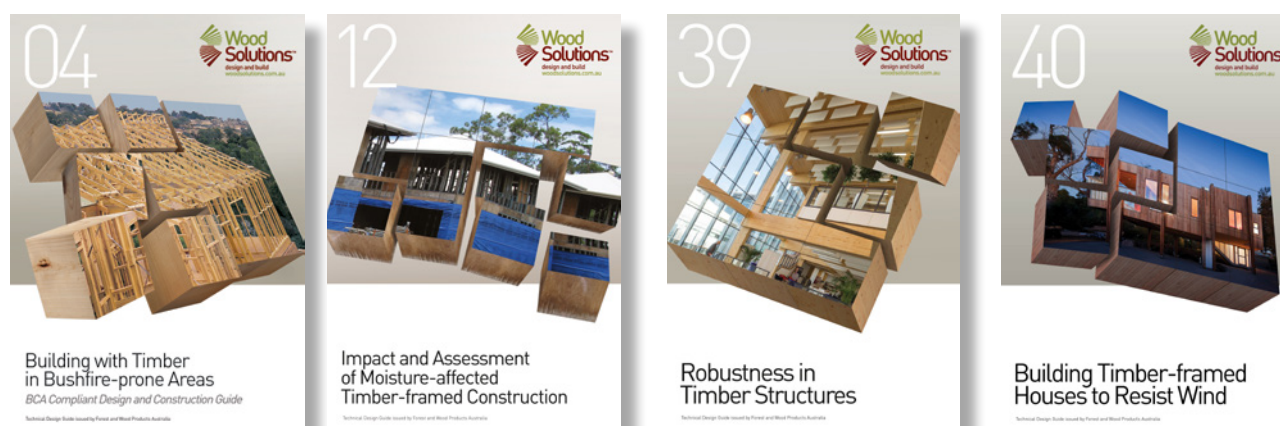


Figure 1: WoodSolutions has issued and regularly updates several guides that address specific design, detailing and compliance approaches, including the ones above. Please regularly check www.woodsolutions.com.au for the updates.

1.1 Increasing Cost of Natural Disasters

Extreme natural events such as bushfires, floods, storms, and other natural hazards are becoming increasingly critical for our communities, environment and economy. The latest report from the Australian Business Roundtable for Disaster Resilience and Safer Communities¹ updated previous estimates² of the costs of natural disasters and extended the analysis to different climate change scenarios. Its key findings were:

- In 2021, natural disasters cost the Australian economy \$38 billion annually, representing about 2% of Australia's Gross Domestic Product (GDP) in 2020. Even under a low emissions scenario – whereby timely action will see emissions start to fall and reach zero by 2100 – this cost will rise to at least \$73 billion annually by 2060, or 4% of Australia's 2020 GDP.
- Even if a CO2 low-emission scenario is achieved, the cumulative cost of natural disasters is forecast to be \$1.2 trillion over the next 40 years.
- Two-thirds of the costs from natural disasters over the next 40 years will occur in Queensland and NSW as they become more exposed to tropical cyclones and floods as warming oceans enable tropical cyclones to move further south.

Figure 2 best illustrates how “on average, insurance costs associated with natural hazards have increased from \$0.5-1 billion per year through the 1990s and early 2000s to around \$2.5 to 3.0 billion per year in the early 2020s (in 2022-dollar terms)”.

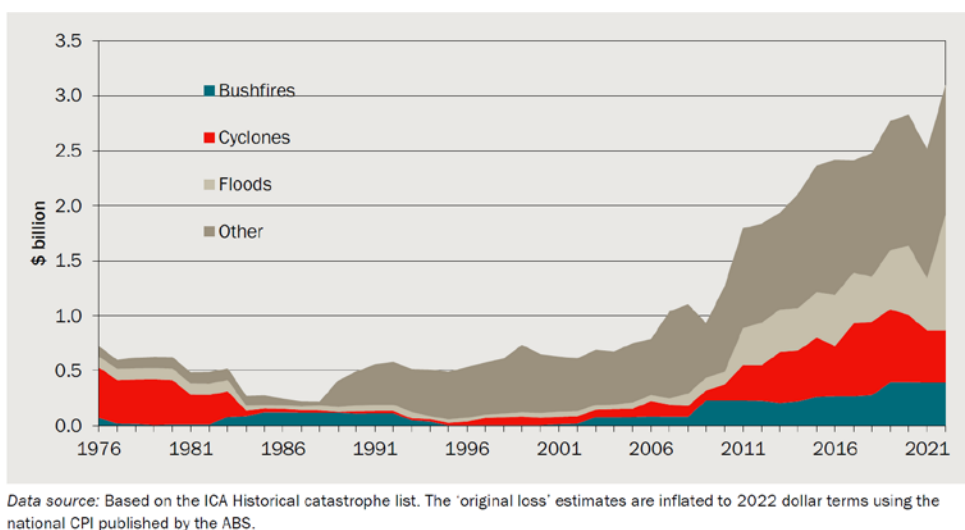


Figure 2: Annualised Insurance Losses from Natural Hazard Events. (Image Credit: CIE, Resilience, durability and the National Construction Code - Economic analysis, 2023³)

Furthermore, the Insurance Council of Australia reports⁴ that Australians are five times more likely to be displaced by a natural disaster than someone living in Europe, and the associated costs are significantly growing. Figure 3 presents the type of significant weather events that have caused substantial occupant displacement over the 2008-2021 period.

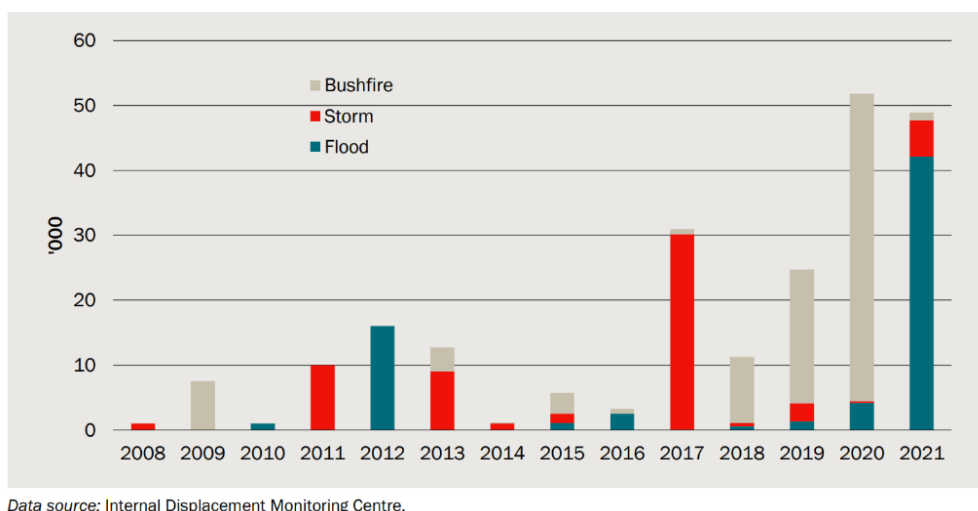


Figure 3: Number of People Displaced by Selected Natural Disasters. (Image credit: CIE, Resilience, durability, and the National Construction Code - Economic analysis, 2023³)

1.2 A bit of history

Carpentry is an essential craft in all communities and has been practised for millennia. In Australia, bush carpentry was mastered by Indigenous people, who cut branches and stripped bark from trees, using it for shelters that kept them from the natural elements. Some were only temporary shelters, but in other areas, the structures were strong enough to bear a person's weight, allowing them to climb onto the roof and perform maintenance.

At the time of European settlement, many settlers had no formal trade skills and learned bush carpentry from watching the Indigenous people or experimenting themselves. The bush carpenter was a practical make-do pioneer who innovated using natural products from their local environment. They practised sustainability in a period when it was a necessity for their very survival and relied on their ingenuity, adaptability, and wits.

The Australian climate has always been challenging, but the willingness to make the most of opportunities offered by some locations triggered the ingenuity of designers and builders, evolving into many site-tailored outcomes. A well-known example, the 'Queenslander', speaks eloquently of our lifestyle and is one of the most distinctive architectural designs in Australia⁵. This tradition originated with rough timber huts of early settlement, evolved into the high-set, multi-gabled roof and a characteristic veranda that extends around the house of the 1930s and, through many further iterations, to the many forms of contemporary, environmentally sustainable timber homes.



Figure 4: Left – Vertical slab-walled church (The Oaks, NSW, circa 1838)⁵. Right – A high-set Victorian-era Queenslander with a surrounding verandah⁶. (Image credit: Wikipedia)

1.3 Resilience and Building Regulations

The fundamental engineering principle of any structural design is to resist the anticipated forces applied to the structure, maintaining both safety and functionality for the intended life of the structure. Most structural design processes determine the forces they need to resist through historical data and information, such as wind (cyclones and storms) and earthquakes, regardless of the material used.

These forces are often codified and represent the **minimum** criteria a designer must consider. However, buildings are generally designed to withstand these forces for the intended life of the building. For houses, this is 50 years, whilst for institutional buildings such as hospitals, the design life is increased to 100 years. Nonetheless, basing loading codes simply upon historical data does not account for climate change. Climate change has caused a change in weather-dependent natural hazards, often occurring more frequently, with increased intensity or occurring in different locations than what has occurred in the past. Therefore, designers now need to consider the fact that the likely loads and the effect of these events on the performance of a structure throughout the life of the building may not be the anticipated loads or frequency of load events found in historical data.

Natural hazard – A natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation⁷.

These hazards include (but are not limited to):

- Avalanche
- Blizzard
- Bushfire (Wildfire)
- Coastal Hazards (surges)
- Cyclones
- Drought
- Dust storm
- Earthquake
- Flood
- Hail
- Heatwave
- Ice Storm
- Landslide
- Lightning
- Severe Thunderstorm
- Tornado
- Tsunami
- Volcano

Avalanches, blizzards, ice storms, and volcanoes are not considered in this Guide as they are unlikely to occur in Australia. Furthermore, due to their low occurrence, Tornadoes are also not included, as no design information is found in the wind design standard AS/NZS 1170.28 and AS 4055.9. However, the principles of high wind discussed later may improve the building's resilience to tornadoes.

1.4 The Effect of Natural Hazard on Timber Structures

To better understand what they can do to improve the resilience of timber homes, designers must first understand the effects or impacts of natural hazards on timber structures. These effects can be categorized by the type of force(s) occurring during the "event" and how the structure resists these. Furthermore, natural hazards may degrade or damage the integrity of the structure's materials, which must also be considered. Table 1 lists common natural hazards and describes the effect the hazard has, the force and resistance required by the structure and any effect the natural hazard may have on timber.

Table 1: Natural Hazards and the Type of Load Applied and the Effect on Timber

Hazard	Effect	Force and Resistance Type	Effect on Timber
Bushfire	Fire and wind	Lateral and uplift	Combustion
Coastal Hazards	Wind and water	Lateral and impact	Water and overloading
Cyclones	Wind and water	Lateral, impact and uplift	Water and overloading
Drought	Ground movement	Lateral	Shrinkage
Dust storm	Wind	Lateral and uplift	Nil
Earthquake	Ground movement	Lateral and uplift	Overloading
Flood	Water	Lateral, uplift, and impact	Water and overloading
Hailstorms	Impact and water	Impact and overloading	Water and overloading
Heatwave	Heat	Negligible	Shrinkage
Landslide	Ground movement	Lateral, impact and uplift	Overloading
Lightening	Fire	Negligible	Combustion
Severe Thunderstorm	Wind and water	Lateral, impact and uplift	Water and overloading
Tornado	Wind and water	Lateral, impact and uplift	Water and overloading
Tsunami	Water	Lateral and impact	Water and overloading

What Natural Hazard Should be Considered?

From Table 1, the most common forces and corresponding resistance requirements, in order of occurrence, are:

1. **Lateral loads:** (Bushfires, Coastal Hazards, Cyclones, Droughts, Dust storms, Earthquakes, Floods, Landslides, Severe Thunderstorms, Tornadoes and Tsunamis)
2. **Uplift loads:** (Cyclones, Dust storms, Earthquakes, Floods, Landslides, Severe Thunderstorms, Tornadoes and Tsunamis)
3. **Impact loads from hail or debris:** (Coastal Hazards, Cyclones, Floods, Hail, Landslides, Severe Thunderstorms, Tornadoes and Tsunamis)

Considering their influence on the possible degradation of structural timber (mould, decay and/or dimensional changes), the effects of water are the primary concern. The natural hazards that may cause these types of degradation would be Coastal Hazards, Cyclones, Floods, Hailstorms, Severe Thunderstorms, Tornadoes and Tsunamis.

Therefore, resilient timber home design strategies that focus on improving performance when subjected to lateral and uplift load, impact, and water degradation events, would provide the most relevant interventions for improving the resilience of timber buildings. Details of these strategies form the basis of the Guide.

1.5 Practical considerations for implementing a Code+ design strategy:

It is impractical and uneconomical to design a building to be “totally resilient” (without any proportional damage) in resisting all the above natural hazards. Therefore, when planning to build a new house or “upgrade” an existing dwelling, it is recommended to discuss and agree upon the appropriate level of resilience that is required with local designers such as Architects, building designers, certifiers, and engineers (civil, fire, structural), who have relevant experience and understanding of the expected natural hazard events for a particular region or location.

Often, the local council will have plans for natural hazards that are present in the area, for example, bushfires, flooding, and coastal zones, that need to be considered. However, suppose the planned structure borders areas of mapped natural hazards but is not located in them. In that case, consideration of the changing nature of the climate and addressing this natural hazard in the design of the building is recommended.

A risk management strategy for dealing with uncertainties is likely to entail undertaking multiple approaches, as discussed above, noting that there are common issues for most natural hazards, such as water ingress, lateral loads, and uplift. Addressing these three common issues will assist in making the structure more resilient.



The CLT House by fmd architects is a multi-generational family home in a BAL19 area that was given a new life with a second level extension built primarily from Australian cross-laminated timber (Image credit: FMD Architects and Dianna Snape).

2 Risk Assessment and Mitigation

This chapter examines the significant natural hazards impacting Australian communities, referencing planning guidelines for resilience. Each natural hazard is discussed along with associated risk factors and the potential influence of climate change.

An overview covers bushfires, cyclones, storms, flooding and more, detailing typical risk assessments and mitigation strategies used to protect homes during development, design, construction, and operation. Available tools encompassing building codes, Insurance, and beyond are explored for creating resilient homes.

2.1 Fires

This section discusses two fire-related hazards: house fires (structure fires) and bushfires.

2.1.1 Bushfires

Bushfires have been a natural, essential, and complex part of the Australian environment for thousands of years. Australia is the most fire-prone country on Earth, where Fire services respond to between 45,000 and 60,000 bushfires each year; refer to Figure 5.

The varied weather patterns across Australia mean that at any time of the year, some part of the country has a high risk of fire, moving south as winter turns to summer; refer to Figure 6.

Consequently, during most summers, Australia will experience a significant bushfire that can devastate lives and the environment, affecting both remote locations and the suburban fringes of the cities.

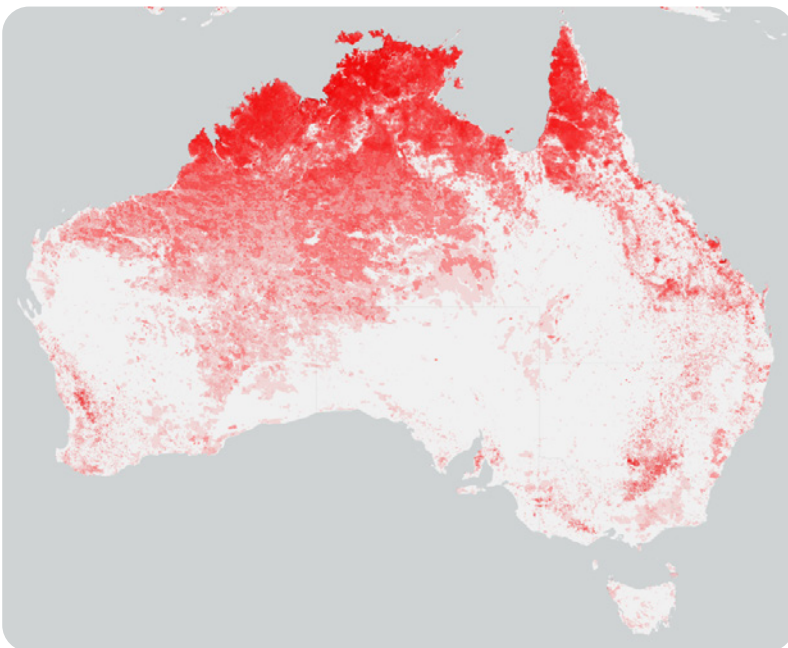


Figure 5: Burnt area across Australia from June 2001 to May 2019 (Credit: Wikipedia)

AUSTRALIAN FIRE SEASONS

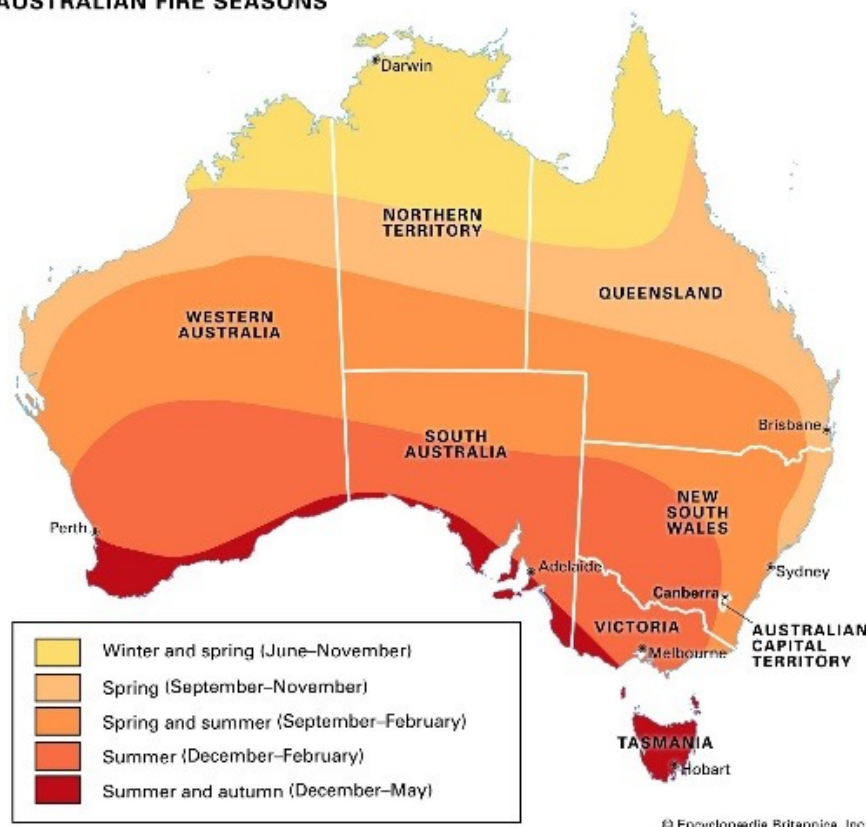


Figure 6: Bushfire location for each season (Image credit: Britannica⁹)

Structures and people can be affected by direct flames, radiant heat, embers, and fire-driven winds. Existing housing stocks have often been constructed during periods of (1) poor planning, building regulation and enforcement, (2) inadequate vegetation management, and (3) poor community understanding of the need to implement preventive measures for managing the impact of bushfire hazards. Each of these is an additional risk driver.

Climate change is considered to be associated with more frequent and dangerous bushfire conditions in some regions, particularly in southern and eastern Australia. Several studies show that fire seasons start earlier and finish later¹⁰. The heat from some intense bushfires can create massive, powerful clouds that lead to smoke-infused thunderstorms, which can spark new fires, trigger fire tornadoes, and make firefighting much more challenging.

Every state, territory, and some local government Authorities have bushfire risk assessment guidelines and laws relevant to local conditions. A specific Australian Building Code Board Handbook¹¹ assists in understanding the Bushfire Verification Method prescribed in the National Construction Code (NCC) Volumes One and Two¹². It addresses issues in generic terms and leaves regulatory requirements or detailed technical specifications to the National Construction Code.

The National Construction Code has specific construction details dependent on the level of exposure the structure has to the vegetation and the slope of the land under the vegetation. The specific construction requirements are found in the referenced Australian Standard AS 3959¹². This Standard has benefited from many years of scientific development and provides an extensive guide to building homes that minimise risk for different levels of bushfire vulnerability.

WoodSolutions Technical Design Guide #4¹³ has been written to help architects, designers, builders, and owners understand this Standard and what is required for each Bushfire Attack Level (BAL) area.

2.1.2 House Fires (structure fires)

Residential fires cause more deaths each year than floods, storms and bushfires combined, and the rate has remained steady over the past decade. On average, more than one person dies in a house fire in Australia every week. The elderly, the young, those who live alone and those who experience disability or poverty are most vulnerable to house fires. Smoking is the leading cause of preventable fire-related deaths, with the bedroom and living room identified as the most common areas of fatal fires.

Climate change is also associated with heightened home fire risk as extreme temperatures burden heating and cooling systems, making them more prone to overheating. More intense summer heatwaves and cooler winter spells stress appliances, making them prone to overworking and potential malfunction. Furthermore, lightning strikes from storms may increase the risk of ignition within the home or in its immediate surroundings.

Australia's fire protection agencies offer guidance enabling homeowners to reduce fire risks. The Australasian Fire and Emergency Service Authorities Council (AFAC) connects regulatory stakeholders with fire departments and communities around prevention. Their comprehensive Basic Home Fire Safety Learning Resource¹⁴ empowers property occupants through risk reduction checklists and training. This resource bridges vital knowledge gaps at the intersection of codes, construction, and occupant behaviour - equipping households to implement basic preparedness steps.

If a fire is initiated in a free-standing home, the only mandatory fire safety equipment is a smoke alarm. The alarm is a cue to tend to the fire or escape the dwelling. Knowledge about basic home fire safety and what to do if there is a fire in the home will reduce the possibility of fire occurring. Otherwise, suppression devices like sprinklers (although not mandatory in most cases) save lives. The impact of a fire can be minimised by preventing its spread, eliminating heat sources, or keeping them away from combustible fuels. Sources of heat include open flames and sparks, smoking materials, electrical equipment, hot surfaces, and other heat sources. Removing oxygen, fuel, or heat will stop a fire.

Specific separation of buildings generally deals with protection against the spread of fire between dwellings. Where buildings don't have the minimum separation, a fire-rated external walls, including openings, are required. WoodSolutions Technical Design Guide #15 contains details of fire-rated external walls.

2.2 Wind

This section discusses two wind types: Severe Storms and Cyclones.

Before discussing this section, understanding the current design wind speeds may provide a better-informed perception of the structural capacity of a well-designed building to withstand wind load events safely. Table 2 describes the commonly used wind classification system detailed in AS 4055⁹ against the Ultimate Limit State in m/s. Table 2 represents the relevant wind speed in meters per second and km per hour to understand the significance of the wind classifications.

Table 2: Ultimate Limit State Wind Speed Comparison

Wind Classification	Ultimate Limit State	
	m/s	km/h
N1	34	122.4
N2	40	144
N3 and C1	50	180
N4 and C2	61	219.6
C3	74	266.4

For perspective, a 108 km/h wind gust can sweep average-weight adults off their feet. In comparison, 145 km/h winds wield enough power to dislodge stationary vehicles, the latter being the design wind speed assumed for most non-cyclonic regions of Australia, i.e., N2 - 40 m/s or 144 km/h.

Furthermore, Table 3 details the maximum gust or cyclonic wind speed recorded in each major Australian capital city. The maximum wind speed experienced in each region aligns well with the expected average design wind speed category. Noting there is conservatism in this comparison in favour of the design wind speed, as weather stations typically measure wind speed at 10 m from the ground while the house level is usually 6 m or below. Constructions closer to the ground would experience roughness or shielding from the surrounding vegetation and structures, further reducing the wind on the structure.

Table 3: Maximum Recorded Gust Wind Speed¹⁶

City	m/s	Km/h	Expect Design Wind Speed m/s	Date, Wind type or Note
Adelaide	44.8	161	40 (N2)	4 Jan 1912 – severe storm
Brisbane	51.4	185	50 (C1)	18 Jan 1985 – severe storm
Darwin	56.9	205	74 (C3)	21 Dec 1974 - Cyclone Tracy Category 4
Hobart	37	133	40 (N2)	29 January 1949 – severe storm
Melbourne	33.6	121	40 (N2)	3 Sep 1982 – severe storm
Sydney	42.2	152	40 (N2)	15 Jan 1949 – severe storm*

* Sydney recorded a wind speed of 213 km/h at Kurnell in 2015¹⁶, which was likely from a tornado.

The current world record for wind speed is 408 km/h (113.3 m/s), recorded from Cyclone Olivia on 10 April 1996 at Barrow Island, Western Australia¹⁶. However, the record does not consider tornadoes due to the inability to record their speed.

2.2.1 Severe Storms

Severe storms that can produce hail, strong winds, heavy rainfall, flash floods and storm tides can happen anywhere in Australia and occur more often than all other natural hazard events. They range from localised storms that affect only a small area to powerful low-pressure systems that can affect an area spanning thousands of square kilometres. Severe storms can directly cause other hazards, like local flash flooding, riverine flooding, and coastal erosion.

Climate change may increase the frequency of severe storms and, therefore, the potential large increases for short-duration rainfall extremes, with larger uncertainties for extreme winds, tornadoes, hail and lightning.

While small hail can perforate some sheeting, major hailstorms inflict more significant harm - denting metal sheeting and shattering skylights and tiles. This extreme weather also propels hailstones to rupture glass and puncture lighter wall coverings and garage doors when coupled with strong wind gusts. Though imprinted, dented roof panels may remain functional temporarily prior to replacement. Furthermore, hail can accumulate on a structure, in blocked box gutters or roofs, causing water ingress into the building or, worse, the collapse of a roof.

Strong winds during thunderstorms can cause structural damage and, in some cases, failure of the building envelope elements, causing higher internal pressures that can combine with uplift pressures on the upper surface of the roof to damage it. The most damaging events (in terms of cost and impact) have occurred in large urban centres such as Brisbane and Sydney. However, isolated storms have also caused significant damage in Melbourne, Perth, and Adelaide and regional centres such as Geelong, Dubbo, and Mandurah.

Severe thunderstorms can induce many of the same effects as tropical cyclones, i.e., strong winds over several hours, torrential rain and increased ocean levels. However, they differ in that storm surges and significant wind-borne debris do not normally accompany them. Furthermore, severe thunderstorms are associated with hail and lightning, which are not found in tropical cyclones.

2.2.2 Cyclones

Cyclones are extreme weather events powered by warm tropical water. They start as tropical low-pressure systems over warm tropical water, and a combination of favourable atmospheric conditions and sea surface temperatures may mean that they intensify into tropical cyclones, refer to Figure 7 for recent cyclone paths across Australia. These large-scale systems have extremely strong winds rotating about a central eye, typically tens of kilometres in diameter. The wind speeds taper from the central eye, but winds higher than gale force can cover hundreds of kilometres. Tropical cyclones are larger than most Australian tropical towns and cities and can affect entire communities in their path.

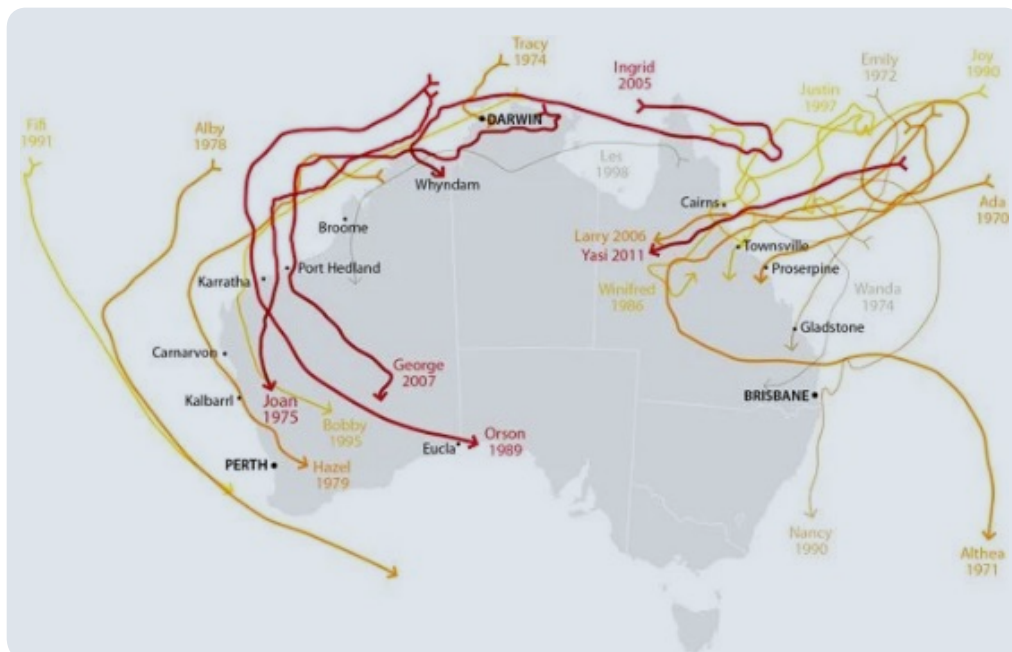


Figure 7: Paths of Cyclones across Australia (Image Credit: Australian Geographic¹⁷)

Cyclones can affect entire communities, making designing and constructing resilient infrastructure, including houses, necessary. The effect on continuing community life can be significant if community buildings such as schools and commercial facilities such as shops and workplaces are damaged. The continuing functionality of houses is equally crucial to individuals and the community. Even with Insurance covering the cost of repairs, this can profoundly impact affected people for years.

The high winds directly impact buildings, and extensive rain can lead to flooding. Prolonged strong winds over the ocean can push sea levels higher at the coast (storm surges). When the cyclone approaches land around the same time as a high tide, low-lying buildings can be seriously damaged.

Forms of damage noted in previous cyclones include:

- The strong winds damage cladding or overloading connections within the building structure. These strong winds could result in the loss of all or part of the roof or damage to windows, doors, or other wall-cladding elements.
- Damage from wind-borne debris. Strong winds can break vegetation and lift elements such as trampolines, outdoor furniture, unsecured sheds and caravans, and stored building materials. Any of these items could be blown against houses and can cause impact damage to cladding elements.
- Rainwater is driven into the building through or around windows and doors, blown up under flashings or through openings created by the wind. Water inside the building can damage plasterboard and other linings, ruin floor coverings such as carpet or overlay timber floors and damage home contents.
- In low-lying areas, prolonged rain may lead to flash flooding. Falling trees or other wind-blown debris blocking drainage channels may make this worse. Flooding can cause rising water that damages contents and building linings.
- In coastal areas, storm surges can bring seawater into homes. Where the house is close to the ocean, waves may affect it. For this reason, evacuation is the best course for residents close to the ocean and at elevations lower than 7 m Australian Height Datum (AHD).
- Where the site is close to the coast and at an elevation of less than 7 m, storm surge may affect the building. It will potentially be subjected to seawater inundation and waves that its design has not anticipated. Personal safety in these houses during the event cannot be assured, and evacuation may be required. The ingress of salt water may cause severe metal corrosion.
- Buildings near industrial facilities or other activities where there could be many unsecured items may be subjected to higher levels of wind-borne debris, but the design of all houses in cyclone areas should anticipate wind-borne debris, including in some cases even whole sheds or trampolines, may hit the building at more than 100 kph.
- The National Construction Code 12 prescribes minimum permissible levels of building, but exceeding the minimum requirements will lead to resilience that may significantly improve the performance of a house in future tropical cyclones.

The effects of climate change on tropical cyclones are still being studied but results so far indicate that the frequency of tropical cyclones will remain similar to current levels, but there will be more severe cyclones and fewer less severe events. For this reason, Australian wind loading standards AS/NZS 1170.28 have adopted a 1.05 climate change factor for wind speeds in cyclone-risk areas. These areas are from Gladstone in Queensland, around the northern coastline, to the town of Green Head in Western Australia.

However, climate change models indicate that cyclones may move poleward (in a southerly direction), which in Australia means communities south of the current cyclone risk area may be affected.

While current building codes and standards anticipate potential changes to cyclone severity and impacts under a future climate, many houses that have already been built do not have these safeguards. The large number of coastal communities in northern Australia contributes to the national cyclone risk.

Often, the Insurance claims process identifies structural upgrades required to an existing building due to a structural component (i.e. the roof covering) damaged by an Insurable event. A roof replacement triggers a Building Approval pathway, and subsequent upgrades to the roof frame are imposed, including batten replacement, tie-down connections, and bracing. This outcome improves the resilience of the building and the community and reduces the Insurer's risk at this property for future events.

The risk of tropical cyclones in Australia is related to latitude and distance from the coast. Houses within 100 km of the coastline and north of 25 degrees S on the east coast (i.e. Bundaberg, Queensland) and 30 degrees S on the west coast (i.e. Cervantes, Western Australia) must be designed to resist cyclonic events. With climate change, it is possible that houses south of those limits may also experience the effects of tropical cyclones; conservatively, this may include Brisbane and Perth.

2.2.3 Tornadoes

A tornado is a violently rotating column of air that is in contact with the Earth's surface and a cloud system. According to the Allen Research Group 18, 30 and 80 tornadoes are reported yearly across Australia. Winds inside a tornado can exceed 300 km/h, making them one of the most destructive phenomena in nature¹⁶.

The National Construction Code referenced design load standards for wind AS/NZS 1170.28 and AS 40559, but they do not consider the wind loads from tornadoes. However, many of the strategies discussed in this Guide a home's resilience to wind will also apply to tornadoes.

2.3 Floods

Several processes can cause floods, but rainfall is the dominant cause in Australia. Floods are a natural process, but society's activities affect flooding. Floods occur at irregular intervals and vary in size, area of extent, and duration.

Australians have lived with and adapted to highly variable rainfall since the earliest days of human settlement. In some locations, floods are a natural part of the environment. They result from rainfall over the catchments of local waterways or rivers. Flooding is also influenced by structures built in the floodplain and the water levels downstream, including sea levels. As flooding is driven by extreme rainfall, there will likely be more floods – even in a drier climate overall.

Figure 8 shows the rainfall trends over Australia from 1960 to 2020, showing the drying in south-western and south-eastern Australia and wetter conditions in north-west Australia.

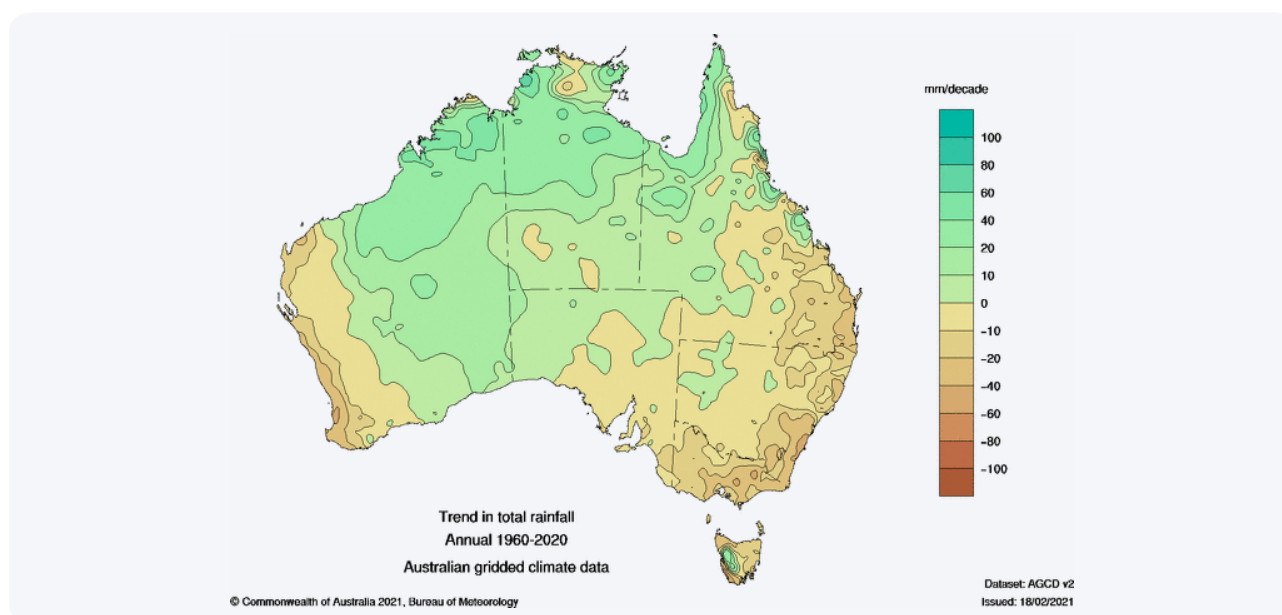


Figure 8: Rainfall trends over Australia from 1960 to 2020 (Image Credit: Australian Bureau of Meteorology¹⁶)

Riverine flooding poses the most significant risk to properties: more than 500,000 properties are classified as at 'high risk' of becoming uninsurable by 2030, and 80% of that risk is due to riverine flooding¹⁹.

Flood behaviour and effects are significantly influenced by climate change due to changes in flood-producing rainfall (frequency and intensity); refer to Figure 7 and the height of sea levels in the receiving waters of coastal catchments, including the ocean and coastal lakes.

2.3.1 Types of Flooding

There are four primary sources of flooding, and depending on the location of a property, flooding can occur from one or a combination of these sources. It is essential to understand a property's flood risk type to assist in applying the correct resilient strategies.

Riverine

Riverine flooding can last hours or days and occurs when widespread rain falls over the catchment of a river. Excess water flowing over its banks has a knock-on effect on any creek connected to the river. As riverine flooding can inundate areas for a long time, this type of flooding generally causes the most damage per event.

Creek

Creek flooding is like riverine and occurs when intense rain falls over a catchment of a creek, causing the excess water to flow over. The main difference is that inundation usually does not last as long, and the flow of water is faster moving. Typically, the damage is like that of a riverine flood.

Overland flow

Overland flow is flooding caused by rain run-off that occurs during heavy rainfall and is affected by the built environment and topography. Sometimes referred to as 'flash flooding', overland flow flooding is frequent, fast-moving, unpredictable, and usually very little notice is given prior to an event. Changes in land use and the development of previously undeveloped lands can influence overland flows. Communities can often be critical of infrastructure change or land use development projects as they can be seen as diverting overland flows to areas and volumes not previously experienced.

Storm tides

Storm tide flooding is caused in coastal regions where a storm surge creates higher-than-normal sea levels.

2.4 Heat

This section discusses two heat-type events: heatwaves and droughts.

2.4.1 Heatwaves

A heatwave is a long-lasting period with extremely high surface temperature. Multi-day heatwave events have increased in frequency and duration across many regions of Australia, with devastating effects: more deaths have been caused by heatwaves in Australia than bushfires, cyclones, earthquakes, floods, and severe storms combined. Heatwaves can cause significant health stress on vulnerable people, which may result in death at the time or well after the heatwave has passed.

Heatwaves directly increase bushfire risk, disrupt electricity and transport services, and cause a broad range of social impacts and disruptions. Wider risk drivers include:

- lack of planning regulations to avoid 'hotspots' areas to reduce heat island effects and to improve access to critical infrastructure
- lack of building regulations that address thermal comfort in buildings
- lack of heatwave warning systems and response plans.

Average temperatures across Australia have increased by about 1°C since 1900 due to human-caused greenhouse gas emissions. This warming trend has led to an increase in the number of extreme heat events that have occurred. Multi-day heatwave events have increased in frequency and duration across many regions of Australia; it is almost certain that climate change will continue to worsen and compound the impacts of extreme heat events, with longer heat waves, more frequent extreme heat days, and temperatures above historical records. Figure 9 compares deaths from various natural hazards.



Figure 9: Comparison of the number of deaths per natural hazards (Image credit: Queensland Government²⁰)

2.4.2 Droughts

Drought is one of the most feared and costly of all the climate challenges afflicting Australia. Apart from crop failure and stock losses, droughts can trigger bushfires, dust storms and land degradation. Severe droughts also impact infrastructure and large and small buildings, especially when built on reactive clay soil that expands when wet and cool and contracts when hot and dry. As reactive clay shrinks, the weight of the building may put significant stress on the whole building's structure, from the foundations up to the roof, and typically results in cracks, gaps, and misalignment of door and window frames.

The effects of droughts are already influencing the design and construction of new buildings: for instance, foundations may need to reach deeper into the ground to find the moisture level that will keep the building stable in case of droughts.

2.5 Earthquakes and Tsunamis

2.5.1 Earthquakes

Earthquakes are the vibrations of the Earth caused by the passage of seismic waves radiating from some source of elastic energy. Australia is on the Indian-Australian tectonic plate and so does not experience earthquakes as severe as those at tectonic plate boundaries, i.e. New Zealand. The main hazard is the resulting ground shaking that can damage or destroy infrastructure, compromise the structure's long-term stability, and threaten lives. Lack of community awareness and preparedness is Australia's primary risk driver.

Climate change is not reported to have any primary, direct influence on earthquakes. However, melting glaciers and thermal expansion of oceans may contribute to the impact and severity of damage resulting from an earthquake-related hazard. Rising seas are raising the water table in many places of the world, which can translate to an increased tendency for soil liquefaction during earthquakes. This issue was a significant damage factor during the earthquake in Christchurch, New Zealand in 2011.

There are more than 100 recorded earthquakes across Australia annually, ranging from minor to significant magnitudes. Australia's typical housing construction types, brick veneer, slab-on-ground or elevated floor systems with timber frame and lightweight cladding, fare reasonably well when subjected to earthquake velocities typically found in Australia, including the 2021 Rawson, Victoria earthquake of a 4.6 magnitude.

2.5.2 Tsunami

A Tsunami is a water wave generated by a sudden change in the seabed resulting from an earthquake, volcanic eruption, or landslide. The tsunami hazard Australia faces ranges from relatively low along the southern coasts to moderate along the coast of Western Australia. This area is more susceptible because of its proximity to large subduction zones along the south coast of Indonesia, a region of significant earthquake and volcanic activity.

Tsunami being an infrequent type of natural hazard, broader risk drivers are considered more relevant, such as:

- lack of understanding of the potential impacts of a tsunami on communities and lack of preparation to respond
- lack of appropriate tsunami detection systems and warnings to the public
- lack of tsunami land use planning and enforcement in exposed communities
- A warming climate increases the risk of both submarine (underwater) and aerial (above-ground) landslides, thereby increasing the risk of local tsunamis.

3 Resilient Design

Building legislation in Australia generally requires house construction to meet a minimum standard, which is generally found in the National Construction Code's Deemed-to-Satisfy provisions that often reference Australian Standards and other documents for the prescriptive details. In some cases, owners and/or other stakeholders may elect to design their structure to a higher level of performance than the minimum requirements set out in the NCC.

This section describes Code+ design principles and approaches that may be adopted to provide better resilience than the NCC's minimum requirements. This approach does not mean that they are generally and automatically applicable to all circumstances. A site-specific risk assessment appraisal is recommended before starting a design.

The NCC is constantly evolving, but this process requires time, and in some cases, designing for a Code+ performance is not only a safer but also a more cost-effective option from a mid-term perspective.

It is important to note that:

- A resilient design approach should also include appropriate ways to create better awareness and preparedness in the home users by, for example, visual evidence, prompts, simple daily manual operations, checks that have to be performed regularly, a specific user's manual
- The best design can be affected by poor construction methods and/or installation practices; therefore, making sure that the quality of the building is consistent with the expectation is necessary to ensure a resilient outcome.

3.1 Bushfires

3.1.1 NCC Deemed-to-Satisfy Requirements

Designing to 'build out' bushfires requires minimising the risk from embers, radiant heat and even flame contact. The extent of embers, radiant heat, and flame contact depends on the vegetation, the surrounding structure, the slope of land under the vegetation, and the structure's location in Australia.

The NCC generally references AS 3959 Construction of buildings in bushfire-prone areas¹² to comply with its performance requirements (some States and territories have variation to the NCC that take precedence over AS 3959 requirements). This Standard is a consensus-based standard that has the benefit of many years of scientific development and improvement and provides compliant solutions, including construction requirements for building homes to minimise risk for different levels of bushfire vulnerability. The Standard provides construction details to:

- improve the ability of a building to better withstand attack from bushfire
- provide the building with a level of protection while the front passes
- give occupants a level of protection while a fire front passes.

However, because bushfires are unpredictable and extreme weather conditions can present more difficulties, these measures cannot guarantee that a building will survive. Nonetheless, they provide an evidence-based set of criteria and details that are the basis of a resilient design. The emphasis is on keeping out embers and protecting against radiant heat, including flame contact. As part of revising AS 3959, scientific testing confirmed that these are the critical aspects of building out bushfires.

Refer to the Rosedale Beach House case study in the Appendix (A1).

WoodSolutions Technical Design Guide #4 *Building with Timber in Bushfire-prone Areas*¹³ thoroughly describes NCC-compliant design and construction. It explains alternative ways of compliance for every Bushfire Attack Level (BAL). Figure 10 details a BAL-FZ (Flaming Zone) sectional view from WoodSolutions Technical Design Guide #4 Deemed-to-Satisfy sheet metal roof and FRL 60/60/60 wall system. AS 3959 simply requires a wall to have an FRL of 30/30/30.

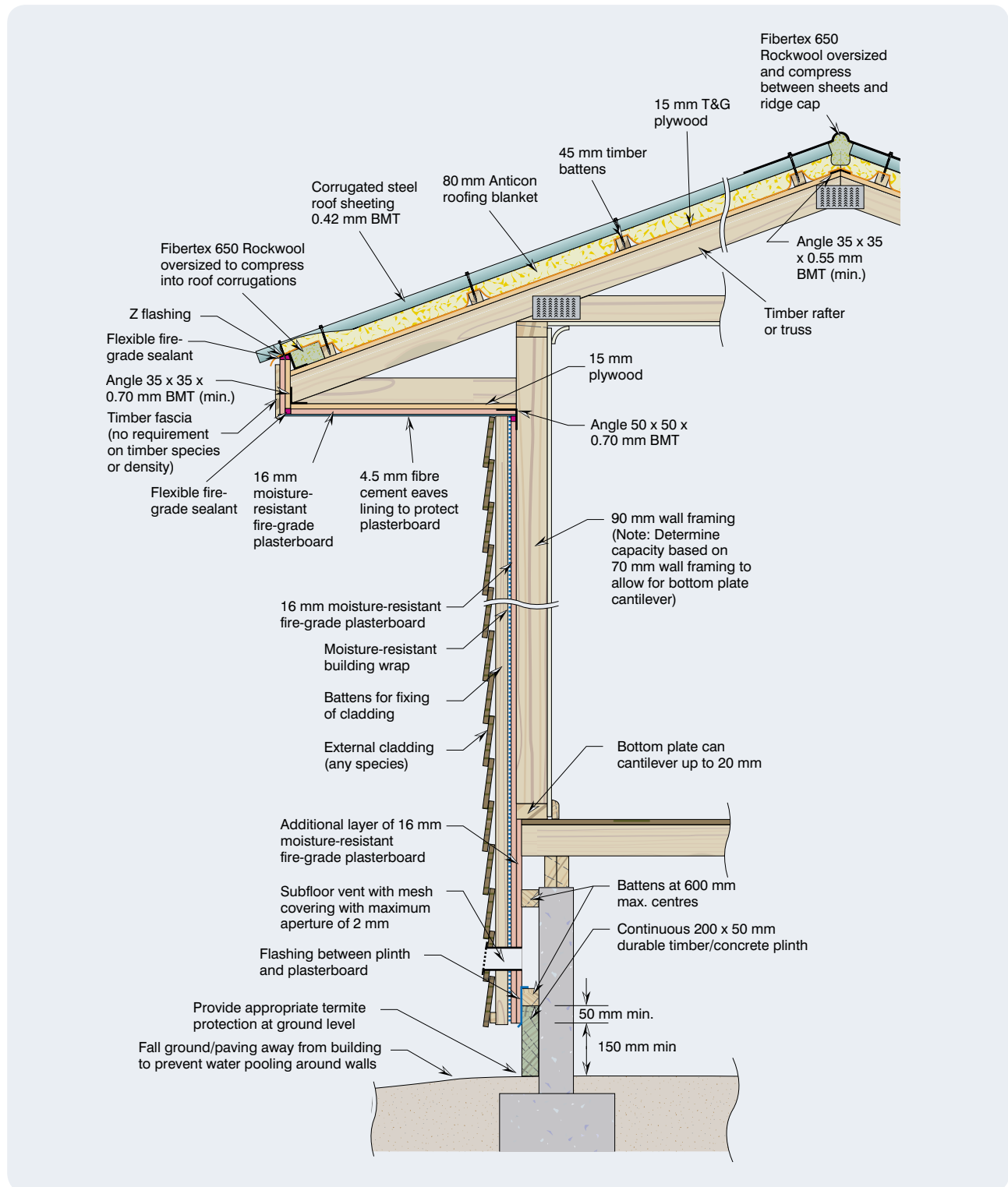


Figure 10: BAL- FZ (Flaming Zone) sectional view of a Deemed-to-Satisfy sheet metal roof and FRL 60/60/60 wall system (Image Credit: WoodSolutions Guide #4)

3.1.2 Code+ design

Although the current Standard has proven quite effective, some possible improvements may be considered when the risk assessment and/or the willingness to obtain additional performances suggest it.

Addressing areas of potential building vulnerabilities

The bushfire performance and survivability of a building can be improved by addressing potential vulnerabilities in simple ways, such as:

- Keeping the floor plan of a building essentially rectangular in shape, thereby minimising re-entrant corners, to eliminate areas around the building where burning debris and embers can accumulate
- keeping roof shapes essentially 'flat' (e.g. skillion-type roofs) to minimise the potential for the accumulation of leaves and other debris in roof valleys or box gutters
- providing leaf gutter guards or leaf-free gutters to prevent the potential for the accumulation of leaves and other debris
- protecting windows in higher BAL regions (e.g. BAL-40, BAL-FZ) from the impact of burning debris in high-wind events (i.e. with window shutters)
- providing 'clear zones' around the perimeter of a house (e.g. paved paths) to minimise the build-up of vegetation/mulch up to the building.

Other initiatives identified by the Insurance Council are:

- Storage of combustible materials (including firewood and gas cylinders): Place a fire-rated barrier -/30/30 or more, between the stored combustible material and the building. This fire resistance could be provided by

Walls

- brick veneer of the buildings
- Stone wool insulation (doubles up as the building insulation)
- fire rated textile
- fire rated plasterboard

Floor

- Stone wool insulation (doubles up as the building insulation)
 - fire rated textile
 - fire rated plasterboard
- Ember Resistance for structures within bushfire-prone areas but greater than 100 metres from the nearest vegetation - adoption of the principles of BAL-12.5 construction from AS 3959.

3.1.3 Bushfire Weather Effects

Bushfires can create their own weather systems in extreme conditions. Events such as fire thunderstorms (i.e. firestorms) can generate down bursts of high winds. The wind force is similar to the high winds experienced in a windstorm, and resilient design considerations are discussed in the "Cyclones and High Winds" section of this guide.

3.1.4 Roof ventilation in BAL-FZ

The ABCB's Housing Provisions Standard 2022¹⁸ (Clause 10.8.3 [2019: 3.8.7.4]) states that the ventilation of roof spaces subject to the BAL-FZ requirements, as described in AS 3959, is not required. However, the removal of water vapour from human occupancy and activity (e.g. breathing, perspiration, cooking, bathing, clothing washing) is essential to minimise the occurrence of condensation and mould.

Research is being undertaken to investigate the potential for passive roof ventilators incorporating fire dampers with a whirlybird exhaust to be used without compromising BAL-FZ performance.

3.1.5 External sprinklers

Using an external sprinkler system can provide additional protection against bushfire attacks. Although bushfire sprinkler systems are currently not referred to in AS 3959, the Australian Standard AS 5414²¹ for bushfire water spray systems provides details for the design, installation, commissioning and maintenance of water spray systems to provide a level of protection against burning ember attack and radiant heat fluxes up to 19 kW/m² (BAL-19).

Research is being undertaken to further investigate the effectiveness of various types of spray heads and configurations, droplet size, wind effects and the potential development of test methods to extend the use of water spray systems beyond BAL-19.

3.2 Cyclones and High Winds

3.2.1 NCC Deemed-to-Satisfy Requirements

The NCC requires all buildings to protect occupants by remaining stable, preventing failures, and avoiding loss of amenities and damage to other buildings. The intent of building construction in high-wind areas is to ensure the structure has sufficient strength to transfer wind forces to the ground with an adequate safety margin to prevent the collapse of the building and the building being lifted or slid off its foundations.

The NCC addresses design in the Structural provisions of the Code, relying on referenced Australian Standards AS/NZS 1170.28 and AS 4055⁹. Both Standards set out procedures for determining wind speeds and resulting wind actions to be used in the structural design of structures subjected to wind actions other than those caused by tornadoes.

The effect of wind forces on a building; refer to Figure 11, requires the consideration of the following:

- Racking – wall deformation
- Overturning – rotation of the building
- Sliding – slippage between storeys
- Uplift – holding building elements to the structure

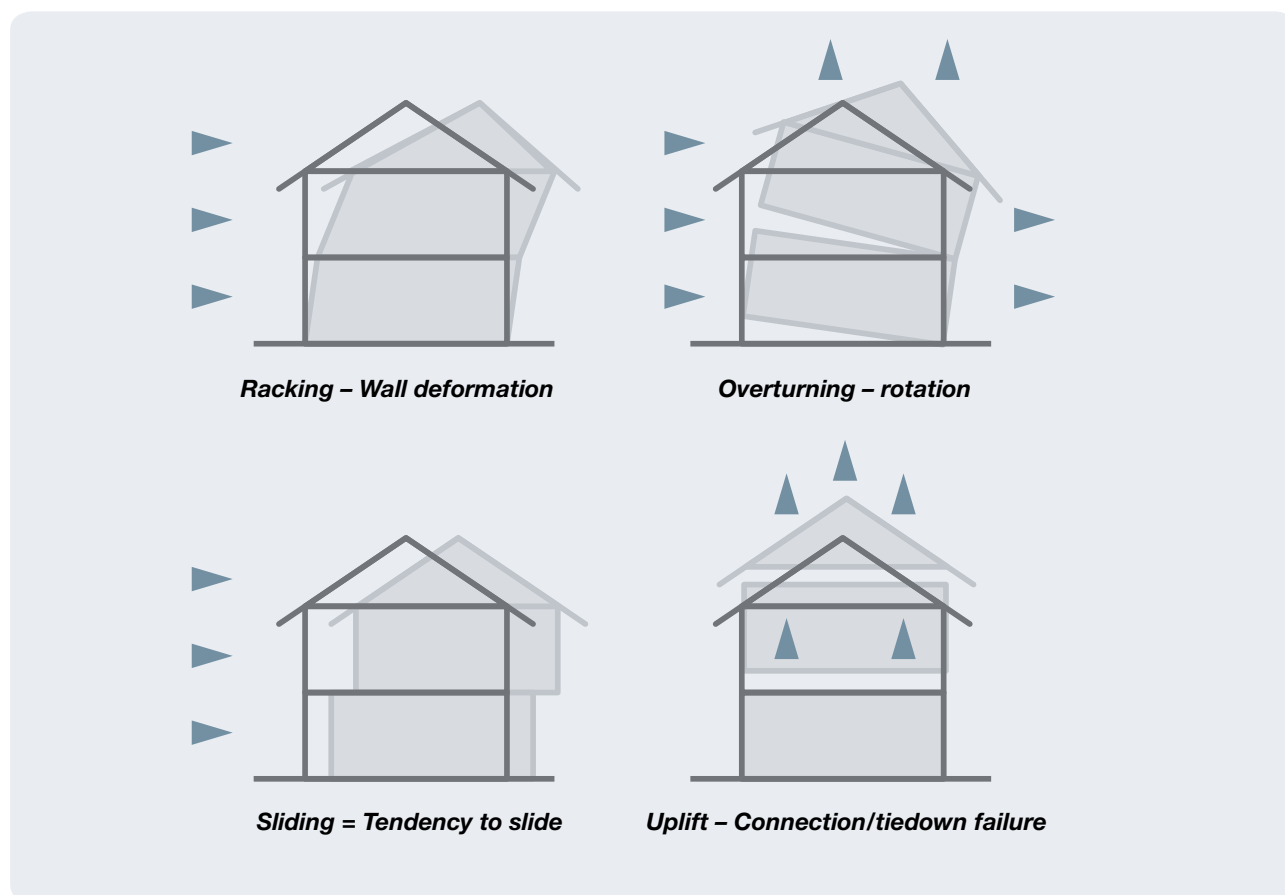


Figure 11: Effect of wind forces on a building (Image Credit: Based on Figure 1.4 from AS 1684)

To resist these forces, it is necessary to have:

- an anchorage or tiedown system, where the roof is connected through the walls to the footings by a series of connections forming the tiedown system
- a bracing system to prevent horizontal collapse due to wind forces
- shear mechanism(s) at each floor
- continuity of the system (continuous load path), where each structural element is connected to its adjoining structural element throughout the building.

Anchorage of the system is achieved by using a variety of connectors and/or tie-down rods. Each connector must be capable of carrying the uplift force because the ability of the building to resist the wind forces is directly related to its weakest link. Refer to Figure 12 for a traditional structural timber wall bracing.

Damage investigations following severe wind events in all parts of Australia have shown that recently constructed houses can be structurally damaged by winds less than the design wind speed if the design and construction do not meet the requirements of the relevant Standards. A nationwide study of houses under construction conducted by the CSIRO²² indicated that almost all houses contained elements or connections that were incorrectly designed and/or installed. These included:

- incorrect wind classification for the site
- incorrect selection of fasteners for batten-to-rafter or truss connections (e.g. nails instead of screws used for batten-to-rafter or truss connections in edge regions of roofs)
- incorrectly installed connectors between trusses and top plates or between rafters, under purlins, struts, and top plates
- insufficient tie-down in walls on either side of very large openings or for beams in large outdoor areas under the main roof.

Furthermore, timber-framed buildings are highly redundant, meaning many elements and alternative load paths exist to transfer load. However, areas such as batten to rafter/trusses and rafter/trusses to wall plates, particularly for metal sheet roofs, have low redundancy. Appropriate connectors should be installed in these areas to ensure load transfer to the foundations.

WoodSolutions Technical Design Guide #40 *Building Timber-framed Houses to Resist Wind*²³ thoroughly describes NCC-compliant design and construction and explains alternative ways of compliance for every wind region.

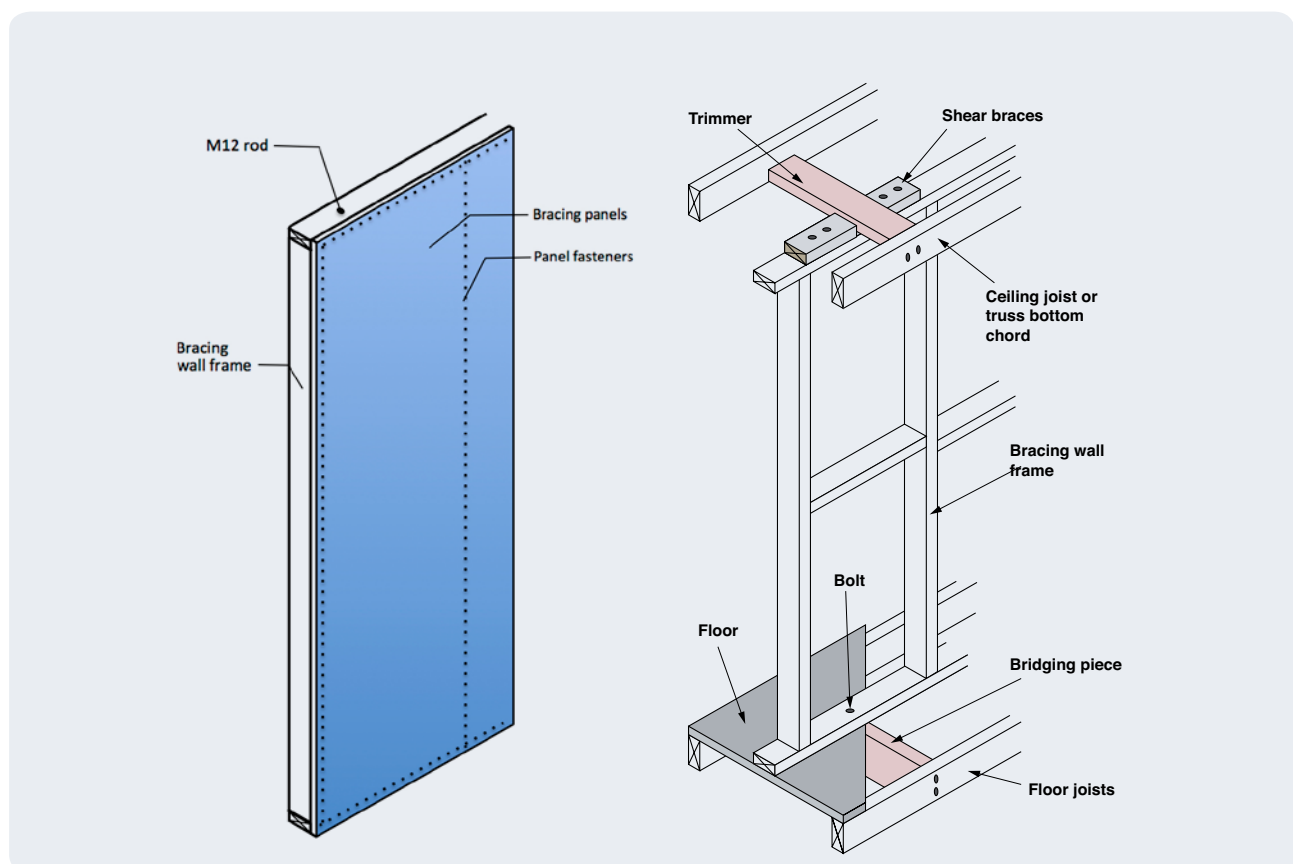


Figure 12: Example of structural wall bracing (Image Credit: WoodSolutions Technical Design Guide #40)

3.2.2 Code+ design

Cyclone Code+ design uses materials and construction systems that can withstand cyclonic and high winds and features that minimise water ingress under wind-driven rain. There is generally sufficient warning of the approach of a cyclone to take precautions before it arrives; however, high winds from severe storms often don't have a significant lead time. In both situations, the best way to provide adequate strength and resilience to resist the wind event safely is to correctly detail and install all structural connections, tie-downs, and bracing appropriate for the building location.

Cyclone Code+ design enables occupants to seek shelter during the cyclone and restore their building to operation (albeit at a reduced level) with minimal long-term disruption. There is still protection for the people inside the strong room.

Key features of the building can be designed to higher levels than required by the NCC. For example:

- Set the **site's lowest floor height above the expected storm tide or river flood level**. For example, suppose the building is located in a storm-tide area. In that case, it is recommended to use stainless steel metal fixings for components, even within the walls, to ensure the longevity of structural elements after future saltwater inundation.
- Design **tie-downs** in the roof and wall structure for one level higher than required under the NCC. This increase in tie-down resistance improves the resilience of the building to handle events greater than the design event and potentially arrest failures in the roof if they start due to debris impact or a hidden structural weakness. For example, if the house is classified as N3, installing roof and wall tie-downs sized to N4 will deliver extra resilience at a relatively low cost. If the wind classification of a house in a cyclone area is C1, the use of C2 tie-downs will deliver similar resilience.
- Design one room in a building as a strong room. This room's purpose is to provide a place to shelter in case a stronger-than-designed event occurs. Furthermore, it can offer personal protection if significant wind-borne debris hits the building. The James Cook University's Cyclone Testing Station lists the following characteristics of a strong room²⁴
 - The whole room is designed and built for at least one wind classification higher than the general house classification (not necessary if the entire structure is already designed for one wind classification higher).
 - The walls, windows and doors of the room are debris-resistant. This requirement includes internal doors and walls to the remainder of the house. It should be designed to offer protection from wind and wind-borne debris even if the rest of the house has blown away.
 - The ceiling of the strong room is independent of the ceiling and roof structure of the rest of the house, so if the roof is lost, there is still protection for the people inside the strong room.
 - The door is a strong, inward opening door so that after the event, the door can still be opened even if debris has piled up on the outside of the room.
 - Specify wind-rated garage doors when the garage is a part of the house, i.e., all under one roof.
 - Protect glass windows and doors using debris shutters. If the shutters are not permanently attached to the external wall or window, ensure they are stored close to where they will be used and kept in good condition.
 - Use solid-core front doors with robust hinges and latches. Single front doors are more resilient than double front doors.
 - Fasten flashings at no more than 500 mm centres using screws, not pop-rivets, on both faces of the flashing. This requirement will better resist the peak local wind pressures at corners of the building where flashings are typically located.
 - Use closed-cell builders' foam under flashings and roof edges to prevent wind-driven rain from being forced under roof edges, flashings, and ridges. The use of closed-cell foam is particularly important along the valley and box gutters.
 - Specify window and door systems that exceed the minimum water penetration requirements in AS 2047. The water penetration requirements in the NCC will still let in wind-driven rain, even at wind speeds lower than the average serviceability level.
 - Select moisture-resistant linings and materials (see section on flooding). In a cyclone, some water will inevitably be driven through the building envelope, and the use of water-resistant linings will minimise the internal damage.

3.2.3 Additional Considerations for Windstorms

Damage from hail can be accommodated by consideration of cladding elements. Use one of the following strategies.

- Thicker cladding elements are more resilient to denting from hail.
- Provide a secondary lining to the outside of all framing elements, using oriented strand board (OSB) or plywood to provide last-resort protection. Note that these secondary linings could do double duty by providing both bracing and tie-down resistance.

3.3 Floods

3.3.1 NCC Deemed-to-Satisfy Requirements

The NCC's flood design provisions are contained in the ABCB's *Standard for Construction of Buildings in Flood Hazard Areas*²⁶. The Standard is written in performance terms with little prescriptive requirements. Queensland has varied the NCC requiring compliance with Queensland Development Code 3.5 - *Construction of buildings in flood hazard areas*²⁶. Again, it is written in performance terms with few prescriptive requirements.

Both the Standard and Code are focused on life safety and structural integrity. While compliance with these performance requirements is prevalent from a design perspective, experience from recent flooding events shows that the costs and timeframe associated with repairing even superficial, non-structural damage, and the cleaning/sanitising activities needed to make the house habitable, can be very significant in some cases and generate considerable distress to the owners/occupiers. Preventing or limiting all types of damage by adopting solutions that make the recovery faster and easier needs to be addressed in the applicable Standards.

While the evolution of the Codes will likely achieve this objective, flood-resilient design is essentially a Code+ response – using appropriate materials, details, and construction systems to reduce the significant impact of damage and stress associated with a flood event.

Definitions for the most common terms related to floods are summarised in Chapter 4.

3.3.2 Lessons Learnt from Recent Flood Events

Sedgwick is an international insurance loss adjuster business that recently worked on the severe flooding that ravaged the Australian east coast in between 2019 and 2023; refer to Figure 13. These flood events, caused by unrelenting rainfall over a span of just a few weeks, took the lives of at least 23 people and were the fourth costliest natural disaster event in Australia's history, with claims to date totalling nearly \$4.8 billion. More than 140,000 properties across the major cities of Sydney and Brisbane and the regional towns of Maryborough and Lismore were affected by floods. Some buildings had their second storey underwater.

Sedgwick's team gleaned some valuable takeaways:

- Continually expect the unexpected and be prepared for anything – even unprecedented levels of rainfall and the ensuing potential for widespread destruction.
- Council defines the minimum habitable floor levels (also known as flood hazard levels) as a good starting point, but they can be exceeded, as seen in the past few decades.
- Weather events are unpredictable.
- The importance of sealing all sides and pre-drilled holes in timber surfaces.
- The cost savings from building resiliently before a flood far outweigh the additional material or labour costs to remediate the building after the flood.
- Removable walls that enclose the underfloor storage area of a dwelling allow water flow and reduce hydrostatic pressure.
- Corrosion of framing brackets, plates and fixings is a common occurrence.
- Use stainless steel screws, not zinc plated, in flood-affected areas.
- Corrosion and surface rust on non-galvanised steel members.
- Hollow section steel posts holding water.
- Cavities in construction require exposing and sanitary works to be performed.
- Erosion of footings is common.



River Murray flooding South Australia 2022-23. Slow flow, several months.



Southeast QLD and Northern Rivers flooding February 2022. Fast flow, some weeks.



Townsville region flooding QLD February 2019. Flash flooding, few days.

Figure 13: Major flood events across Australia in 2022 and 2023

3.3.3 Insurance claims assessment and typical repair costs

Regrettably, many people are familiar with the severe flooding that ravaged the Australian east coast in 2022. The floods, caused by unrelenting rainfall over a span of just a few weeks, took the lives of at least 23 people and were the fourth-costliest natural disaster event in Australia's history, with claims to date totalling nearly \$4.8 billion.

Facing the need to deal with more than 140,000 properties across major cities like Sydney and Brisbane and smaller towns like Maryborough and Lismore (where their second-story claims office was underwater), loss adjusters, Sedgwick, quickly entered full-scale catastrophe response mode. With the ongoing skilled talent shortage, lingering bottlenecks related to pandemic lockdowns and the scope of the flood damage, Sedgwick arranged a team of adjusters from their network around the world and were soon overwhelmed by an outpouring of support: 38 colleagues from their teams in the US, Canada, Mexico, UK and Ireland joined, bringing to Australia a wealth of technical expertise in flooding claims, commercial and residential loss adjusting and repair solutions.

Putting uniform devices and a common mobile app into the hands of the entire team enabled Sedgwick to speed up the training process and get them into the field faster. The app's intuitive prompts and pre-populated menu selections promoted data consistency and ensured that everyone collected all information necessary for compliance with Australian rules and regulations. The team also used satellite imagery and drones to gain visibility into hard-to-reach locations where road slip and landslides had occurred and to expedite assessments where an on-site visit was not required.

When a property is submerged by flood and an Insurance claims process commences, there are several professional service providers mobilised and processes activated. These activities attract considerable costs, typically covered by insurance companies but often the property owners are required to contribute due to Insurance limitations.

The activities and associated current costs in repairing a flooded, low-set four-bedroom home typically include the following (\$ figures refer to the time of writing, and include for the fact that after a large-scale event there is usually a shortage of trades/materials and so an increase in cost above the normal rates):

- Phase 1 (performed within days of the flood): Assessment and make safe activities – performed by Assessors and Building Contractors to mitigate further damage and to consider the extent of Insurance coverage, ranges between \$10,000 and \$20,000.
- Phase 2 (performed over weeks after the flood): Sanitary cleaning and structural drying works to satisfy Occupational Hygienist Certification confirming the property is fit for reinstatement and habitation, ranges between \$20,000 and \$40,000.
- Phase 3 (performed several months to a year after the flood): Reinstatement of linings, floor coverings, wet areas, joinery, plumbing and electrical to a pre-existing condition, \$100,000+, based on the size and level of finishes to the property. Overall, reinstatement of a flooded property to the pre-existing condition costs the insurance industry and consumers upwards of \$150,000 for a basic property. By comparison, a house-raising project where a low-set home is lifted above the Flood Hazard Level (FHL) costs in the vicinity of \$150,000 for a small home. Additionally, for properties undergoing retrospective resilience improvements, strategies can cost as low as \$20,000-\$50,000. Resilience strategies can remove the flood risk to the ground floor of a home and allow the property to remain habitable during and after a flood.

In summary, the investment of costs to remove flood risk, or reduce risk at a property, is comparable to the costs being spent by property owners and Insurers in reinstating properties to their pre-existing condition, and their ranges are also subject to location cost variations (i.e. metro vs. regional).

3.3.4 Code+ design

Flood-resilient design is the use of house design types, layout strategies, materials and construction systems that can withstand substantial and multiple inundations by reducing the effects of flooding and minimising the cost of recovery. Flood resilient design enables occupants to safely store belongings before a flood and easily clean, repair and quickly move back in with minimal long-term disruption to family and finances.

A common misunderstanding of flood resilience is the belief that a property will be 'immune' to flooding. This untrue statement gives homeowners a false sense of security about their flood risk. Flood resilience is about understanding flood risk and learning to live through it by minimising the damage and speeding up the clean-up process to minimise disruption.

Flood resilience strategies are an excellent way to minimise material damage and occupants' time being displaced; however, they can only go so far. For certain levels of flood damage (for example, days of inundation just over the floor of a house), a small amount of remediation work can prevent a near-total loss.

Types of flood resilience

There are three main approaches to flood resilience: wet-proofing, elevation, and dry-proofing; refer to Figure 14.

	Wet-proofing is the technique of treating the building elements through design, construction systems and materials, to enable floodwaters to enter and leave quickly and easily without causing significant damage. The goal of wet-proofing is to ensure occupants only need to clean and dry flood-affected areas, minimising material waste and damage while speeding up the cleanup process. This is done through a combination of using materials that can withstand inundation, reducing cavities in walls, floors and cabinetry where water can become trapped, and designing strategically for openings that allow water and debris to easily be washed out.
	Elevation is the technique of raising building elements above the Flood Hazard Level to reduce their risk of inundation. The most wholistic version of this is elevating the entire habitable floor level above the FHL of a house, which is an effective way of reducing the chance of inundation for an entire existing house, and it is required when building new construction. Elevation, however, only protects the house up to a certain flood level based on the most recent flood modelling, and as evidenced by the 2022 south-east Queensland floods, these levels can be exceeded. It is highly recommended to design with wet-proofing in mind for even areas above the FHL.
	Dry proofing prevents the entry of water by sealing the exterior of a house with flood barriers to prevent water from entering. This can be effective in low-level flooding, however at greater depths results in increased pressure from flood waters, which can result in additional property damage. As is known through many floods over the years, floods can be unpredictable, and <i>dry-proofing strategies for higher levels of flooding are not recommended as they are a single point of failure and rely on faultless installation</i>. In overland flow affected areas, this technique also has the added disadvantage of displacing additional water onto neighbouring properties.

Figure 14: Three main approaches to improving flood resilience.

This Guide is focused on wet-proofing and elevation techniques, as dry-proofing strategies are heavily reliant on products not commonly used in Australia, and in a retrofit scenario with higher levels of flooding, they pose a significant risk. Combining these techniques can help significantly reduce the impact of flood damage on the property and assist in cleaning, drying, and repairing it as quickly as possible.

Flood-resilient design principles

There are five main principles of flood-resilient design:

1. Allow the building to dry out quickly.
2. Prevent water from entering the wall and floor cavities.
3. Use flood-resilient materials.
4. Raise and protect essential services and utilities.
5. Allow water to flow through the building, speeding up the cleanup and drying process.

These principles are strategies to apply when retrofitting existing homes and building new resilient construction in flood-prone areas. These strategies present practical solutions to reduce significant flooding impacts and allow quicker reoccupation of the building.

Principle 1 – Allow the building to dry out quickly

This principle focuses on minimising damage caused by ongoing dampness and trapped water. This guidance is relevant for the parts of the frame that are likely to be inundated during a flood.

Timber Wall Framing

- Add holes in the wall frame bottom plate on raised floors for the water to escape. Holes must not be greater than one-eighth of the plate width and no closer than 600 mm apart (limits contained in AS 1684²⁷).
- Internal/external wall vents above the flood levels on raised floors assist in drying out the wall cavity.
- Avoid cavities in internal walls where water can get trapped (See also ‘Principle 2 – Prevent water entering the wall and floor cavities’).
- Use detachable linings below flood hazard levels.
- Use fasteners and connectors suitable for exterior environments, i.e., hot-dipped galvanised or preferably stainless steel.
- The insulation used within the wall frame must be hydrophobic and permeable.

Timber Floor Framing

- Where possible, do not install a ceiling.
- Place drain holes evenly spaced across the ceiling where a ceiling is required.
- The insulation used within the floor frame must be hydrophobic and permeable.
- Use fasteners and connectors suitable for exterior environments, i.e., hot-dipped galvanised or stainless steel.

Other wood-based components

- Design stairs with a removable bottom riser and cabinetry kickboards in areas where water can get trapped; refer to Figure 15.
- Designing cabinetry with removable kickboards
- for built-in bathtubs, install a removable panel for the cavity to dry out.



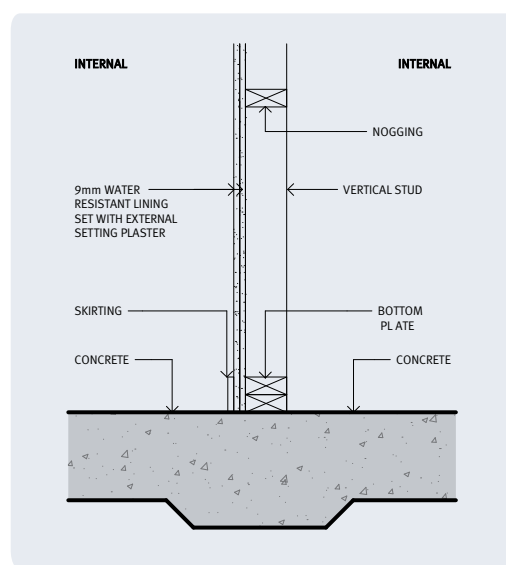
Figure 15: Removable stair riser provides the ability to drain. (Image credit: JDA)

Mould-resistant paints	Prevention of rot
Mould is a fungus that releases toxic spores and vapours into the air. It is caused by excess moisture, which occurs in cool, damp conditions, and is often found in areas that receive little natural light with poor ventilation, like bathrooms, kitchens, and laundries. Spores can lead to sneezing, a runny nose, red eyes, and skin rashes. In extreme cases, it can even cause allergic reactions and trigger asthma attacks. Mould spores are always present outdoors and in buildings; they can also erode certain surfaces and cause significant damage to property, furniture and personal belongings. Mould growth is superficial and will not influence the performance and/ or the durability of structural timber elements. But mould is likely to occur before decay fungi and is a sign that decay fungi growth could occur. Mould is more likely to occur if paint is used over bare wood without priming it first or painted over mould without removing it. As a form of prevention for areas that may be flooded, and in general terms for wet areas like kitchens, bathrooms and laundries, paint suppliers offer specific products with a 10-year guarantee against mould growth.	Keeping the timber below 20% moisture content usually prevents the growth of decay fungi (rot). Fungi require a food supply and oxygen to survive, which is derived from the wood cells. The optimum temperature for fungal activity is between 24°C and 30°C. Fungal activity is dormant at 0°C and diminishes beyond 30°C. If there is insufficient moisture, after fungal growth has started, the fungi do not die but become dormant. Active growth can start again, sometimes years later, when sufficient moisture returns. Where timber is expected to be in high moisture content environments, such as exterior environments or flood-prone areas, it is possible to eliminate the food supply by treating the timber with specific preservatives to H3 or better in accordance with AS/NZS 1604.1. Alternatively, use timber with high extractive contents or natural durability. The sapwood of all timber is susceptible to fungi attack.

Principle 2 – Prevent water from entering the wall and floor cavities

Cavities in floors and walls and under staircases create locations where flood waters can get trapped, causing mould and rot as the water sits inside the cavity. These locations can often be in challenging places to dry out (e.g. under built-in bathtubs) without removing significant amounts of wall lining or framing and often get forgotten as the damage may not be evident for some time. By minimising the locations where water can get trapped, there is a far lower risk of mould and rot occurring and fewer floor and wall linings to remove to let the cavities dry out, refer to Figure 16.

- Avoid cavities altogether.
- Use single-skin walls where possible.
- Avoid having cavities and storerooms under stairs as this is a common area for flood waters to become trapped and are very difficult to clean out; refer to Figure 18. When a storeroom under a stair is unavoidable, allow the bottom riser of the stair to be removable and accessible from the storeroom as discussed in Principle 1 ('Allow the building to dry out quickly').
- Waterproof the floors and walls up to the FHL or higher with a wet area waterproof membrane.
- Waterproof the floor-to-wall junction to prevent water from entering the cavity. This detail is particularly useful for overland flow due to the low but quick velocity of the water. Refer to Figure 19.
- Consider having a tile skirting on FC sheeting with a waterproof membrane in between that continues under the floor tiling. Ensure there is a silicone joint to the floor-to-wall junction.
- Raise floors above the *FHL*.
- Use no ceilings below the *FHL*; refer to Figure 20a.
- Avoid cavity sliding doors, use swing or face-of-the-wall sliding doors; refer to Figure 20b.
- Use a wall-hung basin or vanity; refer to Figure 20c.



Left: Figure 16: Timber wall frames are partially stripped to the nearest set joint in the wall lining to facilitate sanitary works and drying. (Image credit: JDA)

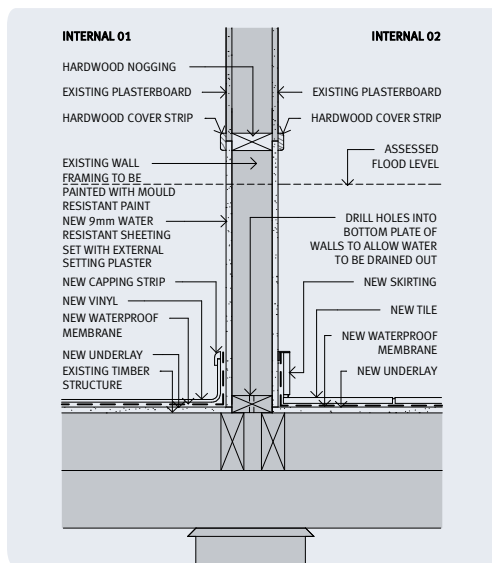
Middle and right: Figure 17: Single-skin internal walls, image and section detail (Image Credit: JDA)



Figure 18: Open stair tread (Image Credit: JDA)



Avoiding cavities under stairs



Single-skin walls

Figure 19: Waterproof the floor-to-wall junction (Image Credit: JDA)



Figure 20a: Floor with no ceiling (Image Credit: JDA)



Figure 20b: Wall-face-mounted sliding door (Image Credit: JDA)

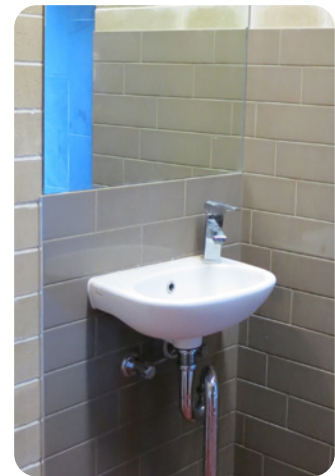


Figure 20c: Wall-hung basin (Image Credit: JDA)

Principle 3 – Use flood-resilient materials

Informed material selection is essential in designing flood resilience to reduce damage, waste, and mould.

Wall and floor framing

Where timber is likely to be used below the flood hazard level, refer to the following:

- The timber used should be durable, either above-ground natural durability Class 2 or preservative treated to Hazard Level 3 (Note: H1, H2, H2s and H2f treated timber are for borer and termite resistance). When the framing is expected to remain under water for 1-2 days (i.e. flash flooding risk only), then no need for a preservative treatment may be specified by the designer, providing the detailing is allowing the timber to dry out quickly.
- Use low hygroscopicity timber where possible or make the timber less prone to absorbing moisture.
 - High-density hardwoods and cypress have proven to have low hygroscopicity.
 - For softwood or low-density hardwood, apply a mould-resistant finish or boron treatment. Pre-primed outdoor timber is also an acceptable solution.
- Some Engineered Wood Products, e.g., I-joist, are limited for use below flood hazard levels. Refer to the product supplier or manufacturer's Product Technical Statement for advice on their use below flood hazard levels.

Where timber is used **above** the flood hazard level, there are no limits on the timber durability or hygroscopicity requirements as long as the other principles in this Guide are followed.

Refer to WoodSolutions Technical Design Guide #5 *Timber Service Life*²⁸ for more information on the durability of different wood species, preservative treatments, and associated design criteria.

Wall linings

Standard interior grade plasterboard is the most commonly used residential wall lining; however, it should be avoided in areas at flood risk as it soaks up flood waters and, after a flood, would need to be removed and replaced, refer to Figure 21a and 21c. Plasterboard creates a great deal of waste and is costly to replace.

Using flood-resilient wall linings allows wall linings to last through a flood and speeds up the cleaning process, refer to Figure 21b. Flood-resilient linings are, as an example:

- Cementitious boards - fibre cement, calcium silicate, etc.
- Exterior grade plasterboard, i.e., fibreglass mat gypsum sheathing (if tested and approved).
- Durable timber cladding and sheets – refer to Timber selection in Principle 1 – Allow the building to dry out quicker section of this Guide.



Interior Standard Grade Plasterboard



Interior Grade reconstituted timber panel e.g. MDF



Cementitious boards - fibreglass mat gypsum sheathing



Exterior grade plasterboard, i.e., fibreglass mat gypsum sheathing



Durable Timber cladding and sheets



Figure 21a: Plasterboard after a flood event. (Image Credit: Sedgwick)



Figure 21b: Fibre-cement vertical joint sheeting with hardwood mouldings and skirting after a flood event (Image Credit: Sedgwick)



Figure 21c: Plasterboard retains moisture content > 200 mm above flood event. (Image Credit: Sedgwick)

Cabinetry

Kitchens are often the costliest elements to replace after a flood since even low-level flooding can require entire kitchen units to become unusable due to warping caused by moisture absorption. Common cabinetry materials such as particleboard and Medium-Density Fibreboard (MDF) soak up water, resulting in swelling/expansion of the panels. As water soaks up through the boards, the cabinetry warps, causing doors to not close, shelves to sag, drawers not to work correctly, etc.



Particleboard



Medium density Fibre Board (MDF)



High Density Fibre Board with two-pack* finish



Marine Plywood or Exterior Plywood (with well-sealed edges)



Compact Laminate



Avoid built-in appliances below the flood

* Two-pack (sometimes written as 2-pac) finish is a typical finish on cabinetry that results in a thicker, harder, and more durable finish, which creates a seal around the board. In simple terms, it is when two liquids (a resin of acrylic paint and a hardening resin) are mixed together to harden. When applied to high-density fibre boards, this is great for flood resilience and creates a premium finish; refer to Figure 22a and 22b.



Figure 22a: Laminated medium-density fibre board kitchen after a flood (Image Credit: JDA)



Figure 22b: Two-pack finished high-density fibre board kitchen after a flood (Image Credit: JDA)

Internal doors

Typical internal doors are hollow core, meaning they are hollow inside with a cardboard honeycomb with two thin sheets on either face of the door. When they are subjected to a flood, they soak in water, and the water also gets trapped between the thin sheets, causing the doors to swell. Once that happens, they are not salvageable.

Solid core doors, refer to Figure 23, are usually used for external doors and are better built to withstand moisture than hollow core. Solid core doors with timber blockboard infills are flood resistant; however, solid core doors with MDF or particleboard infills should be avoided if they are at risk of flooding.

Homeowners may not want internal solid core doors to avoid heavy door slamming. In this scenario and where there is time to prepare before a flood (e.g. riverine flooding), an alternative to solid core doors is to use hollow core doors with lift-off hinges. This configuration allows a homeowner to easily remove at-risk doors and store them higher or at another location before a flood.



Hollow core door



Cavity sliding door



Solid core doors (with MDF or particleboard infill)



Solid core doors (with timber block board infill)



Solid timber doors (well sealed)



Face of wall sliding door (e.g. barn style)



Figure 23: Solid core door after a flood (Image Credit: JDA)

Flooring

Whether the depth of water is 50 mm or 2 metres, once a flood has gone above the floor level of a home it will affect all your floor lining. Depending on the size of the floor area at risk, the damage caused by this can be extremely costly to repair or replace. Flood-resilient flooring materials can survive inundation, making cleaning up after a flood significantly easier. However, where non-resilient floor linings such as carpets are installed, their removal after the flood results in tremendous waste.

Floor tile finishes are naturally porous due to cementitious grouts and the perimeter of the floor being unsealed and penetrable. In high-level floods, where floors are submerged 1 m to 2 m above floor level, the water is often retained for several days. Traditional tiled floor finishes can become compromised due to debonding of the adhesive; noting that this mainly occurs in older floors. However, experience has shown that some tiled floor finishes have fared well and have only required sanitary cleaning.

The age of a floor finish, the height of the water and how long the floor is submerged considerably influence the structural integrity and longevity of a tiled floor finish after a flood. High water combined with prolonged submersion can force flood waters into adhesive and substrate systems through hydrostatic pressure.

When installed as an impervious floor system, tiles can perform similarly to a monolithic concrete floor when submerged in flood water; refer to Figures from 24a to 24c. Creating an impervious tiled floor system requires using epoxy grouts, non-porous tiles, water-resistant adhesives, and skirting tiles to seal the perimeter of the floor system. Furthermore, epoxy or semi-epoxy grout and water-resistant adhesive are advised for all tile applications in flood-prone areas.



Carpet



Floor linings on a particleboard or OSB substrate



Hardwood flooring on timber subfloor – no underlay



Exterior grade plywood flooring on timber subfloor



Tiles with semi-epoxy grout and water-resistant adhesive



Waterproof vinyl with water-resistant adhesive (slab on ground only)



Polished concrete



Epoxy finish on concrete



Figure 24a: Tiles with epoxy grout after a flood (Image Credit: JDA)



Figure 24b: Polished concrete floor well sealed (light grind) (Image Credit: JDA)



Figure 24c: Epoxy finish on a concrete floor (Image Credit: JDA)

Insulation Selection

Any insulation for walls or floor framing below flood hazard level or on the exterior side of the building water control layer (vapour permeable membranes) must be hydrophobic (repel water) and permeable. Insulation such as stone wool or wood wool meets this criterion. Once insulation absorbs flood water it needs to be removed as it will expand and warp the walls, meaning even resilient wall linings have to be stripped to dispose of the insulation.



Loose-fill Insulation



Wool-based insulation



Stone wool or wood wool

Architraves and skirtings



Untreated softwood



MDF and particleboards



Treated plantation softwood profiles



Durable hardwood profiles



Tile skirting with semi-epoxy grout and water-resistant adhesive

Principle 4 – Raise and protect essential services and utilities

Utilities such as hot water, power, heating and cooling are essential to everyday life in a home, and the equipment for these services is usually outside, exposed to the elements and at risk of flood. This equipment is expensive to replace and means downtime for crucial services. Protecting these services by raising them above the flood levels (or as high as practical) dramatically reduces their flood risk.

- Raise the electrical switchboard.
- Raise the hot water unit. Consider replacing it with an instantaneous wall-mounted unit so it is easier to raise higher.
- Raise the air-conditioning condenser unit.
- Raise the washing machine and dryer.
- Raise the pool's pump and electrical power systems.
- Raise the water tank's pump and electrical power systems.
- Raise the general power outlets (GPOs) and data points.
- Separate circuits (with breakers) between the ground and first floor levels. This means the upper level can retain power if the home's lower floor is flooded.

Principle 5 – Allow water to flow through and speed up the drying and cleanup process

Cleaning up after a flood can be long, arduous, and often labour-intensive. Specific considerations implemented within the design process can assist with expediting cleanup following floods, including:

- For slab-on-ground properties, consider using tile skirting as this makes for easy cleaning, although it can make access to a cavity more difficult (if there is one).
- Flush sills where possible at doors and floors to allow for easy removal of mud and debris and easy cleanup. Allowing a recess for a door sill flush with the internal floor level makes it easier to clean out after a flood. When the sill is too high, a layer of flood water and debris is trapped inside and difficult to remove. Refer to Figure 25.
- Avoid cavities anywhere in the house that might require inconvenient disassembling or demolition to access for cleaning.
- Consider wall-hung cabinetry systems for bathrooms, kitchens and storage areas (removable kicks).
- Avoid stairs with closed-in storage under them. Make the first riser of the stairs removable for easy cleaning. Make the kickboards removable.
- If a cavity is unavoidable, make sure to allow for easy access for cleaning.
- Add floor level doors or access panels to cavity areas such as under the stairs.
- Designing a floor plan that allows for multiple openings saves time in the cleanup process. Floor plans with dead-ends trap debris, water and mud in rooms that can be difficult to hose out. Refer to Figure 26.
- Retrofit only: Adjust door configurations to increase the openable width, e.g., replacing a two-panel sliding door with a bi-folding door



Figure 25: Flush door sills (Image Credit: JDA)

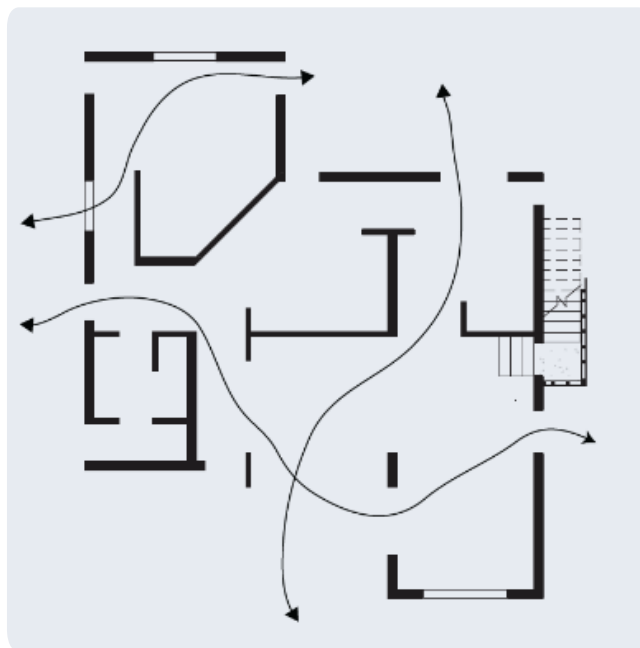


Figure 26: Flow through floor plan (Image Credit: JDA)

3.3.5 Flood-resilient retrofitting

Timber homes work well in floods because of their ability to dry out and their adaptability. Because of this, existing timber homes can be retrofitted with relative ease using resilient design and materials. When on a suspended floor, they can be practically elevated above the flood hazard level. Retrofitting in a flood-prone area is much more common than building new because:

- the vast majority of housing stock in flood-prone areas was built when flood risk data was not available or rudimentary
- new flood risk data shows that flood levels are actually higher than house levels built using older risk data
- new builds in flood-prone areas are often avoided unless they are built on properties where they have demolished an existing house or flood risk levels suggest only low levels of flooding or overland flow.

By understanding the five principles of the previous section, a timber home can be assessed to determine which strategies are most appropriate for flood resilience retrofitting. The flood-resilience advice in this Guide is built on the fact that people need to return to their homes quickly and safely. Most critically, floors, walls and essential utilities are necessary to enable this. To achieve the best level of resilience when considering a budget, the following order of priorities should apply:

1. Floors, walls, utilities	Retrofitting elements that are critical for returning home quickly after a flood should be the highest priority. With these built resiliently, occupants can return home protected from the outside elements with essential utilities such as electricity and washing facilities.
2. Strategies that assist the cleanup process (e.g. open riser stairs), and internal doors	These elements help speed up the cleanup process and reduce the amount of post-flood waste (e.g. damaged hollow-core doors) and should be prioritised second. Internal doors are necessary for privacy, room separation and returning to normal life.
3. Cabinetry, appliances	Though essential for returning to normal day-to-day life and expensive to replace, these items can be temporarily substituted by free-standing storage units, portable sinks, and cooking appliances after a flood.

There are a few approaches to retrofitting existing timber homes to manage the risks presented by a flood, and as mentioned previously, a combination of raising the building and wet-proofing provides the best outcome.

Raising an existing house above the Flood Hazard Level (FHL) should be considered if practicality allows. When house-raising, it is also recommended to retrofit resilient features into the building if the budget allows.

The following Figures 27, 28 and 29 demonstrate a common scenario of an existing single-storey timber-framed house at risk of flooding and two approaches to resilience depending on budget, practicality, and town planning.

Figure 27: A typical house at risk of flood - What to look out for in your home. (Image Credit: JDA)

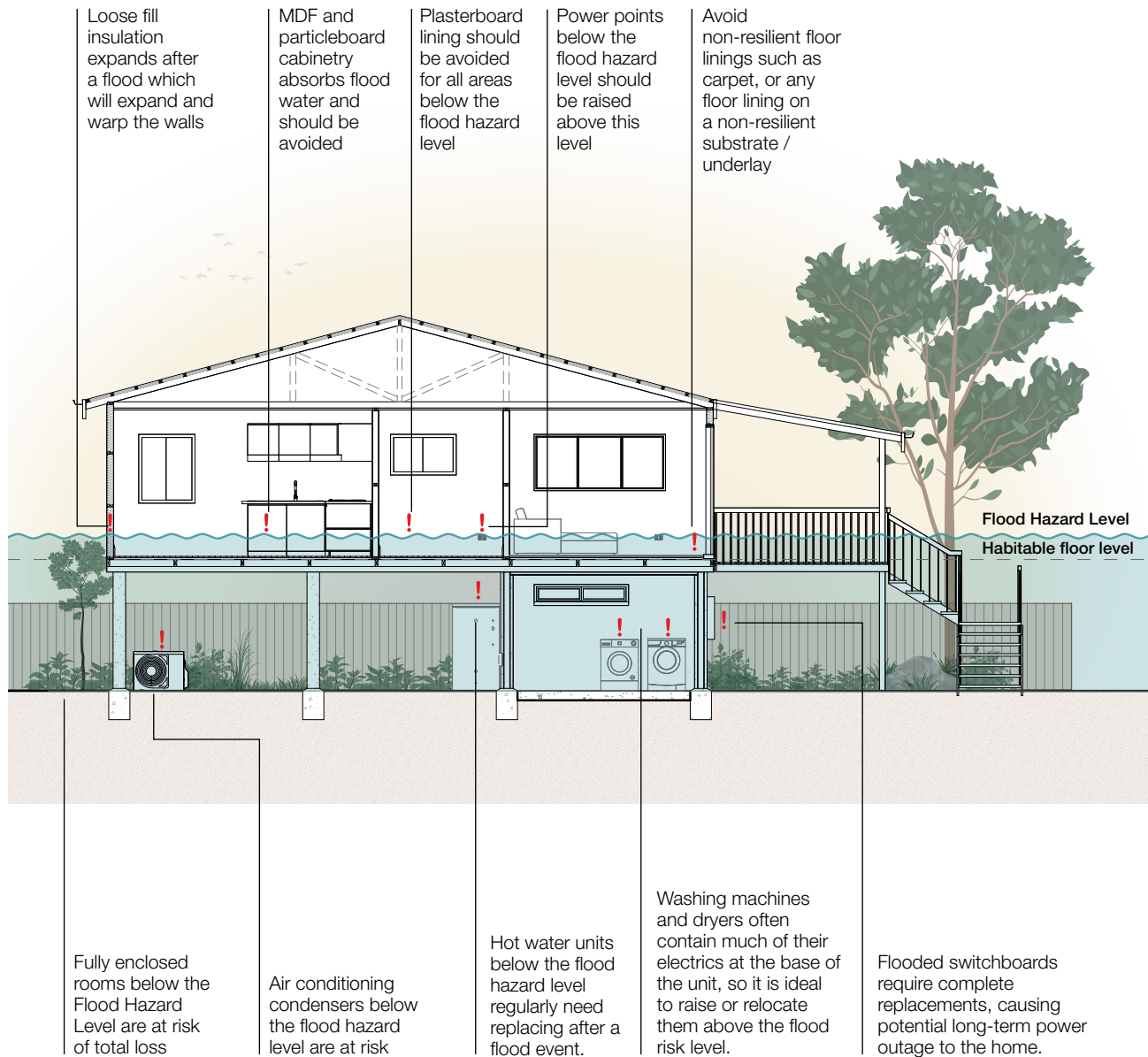


Figure 28: Retrofitting a timber house at risk. (Image Credit: JDA)

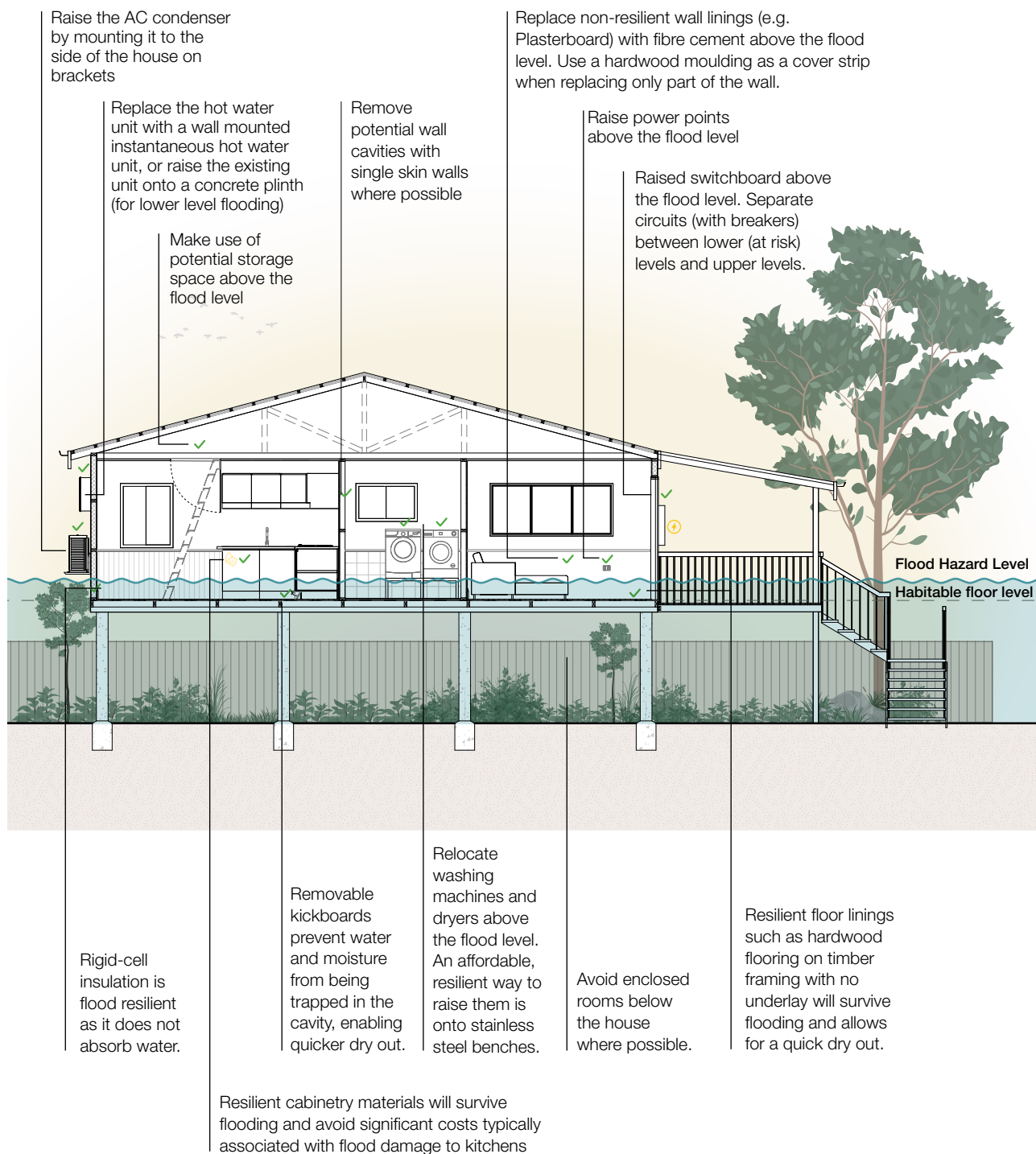
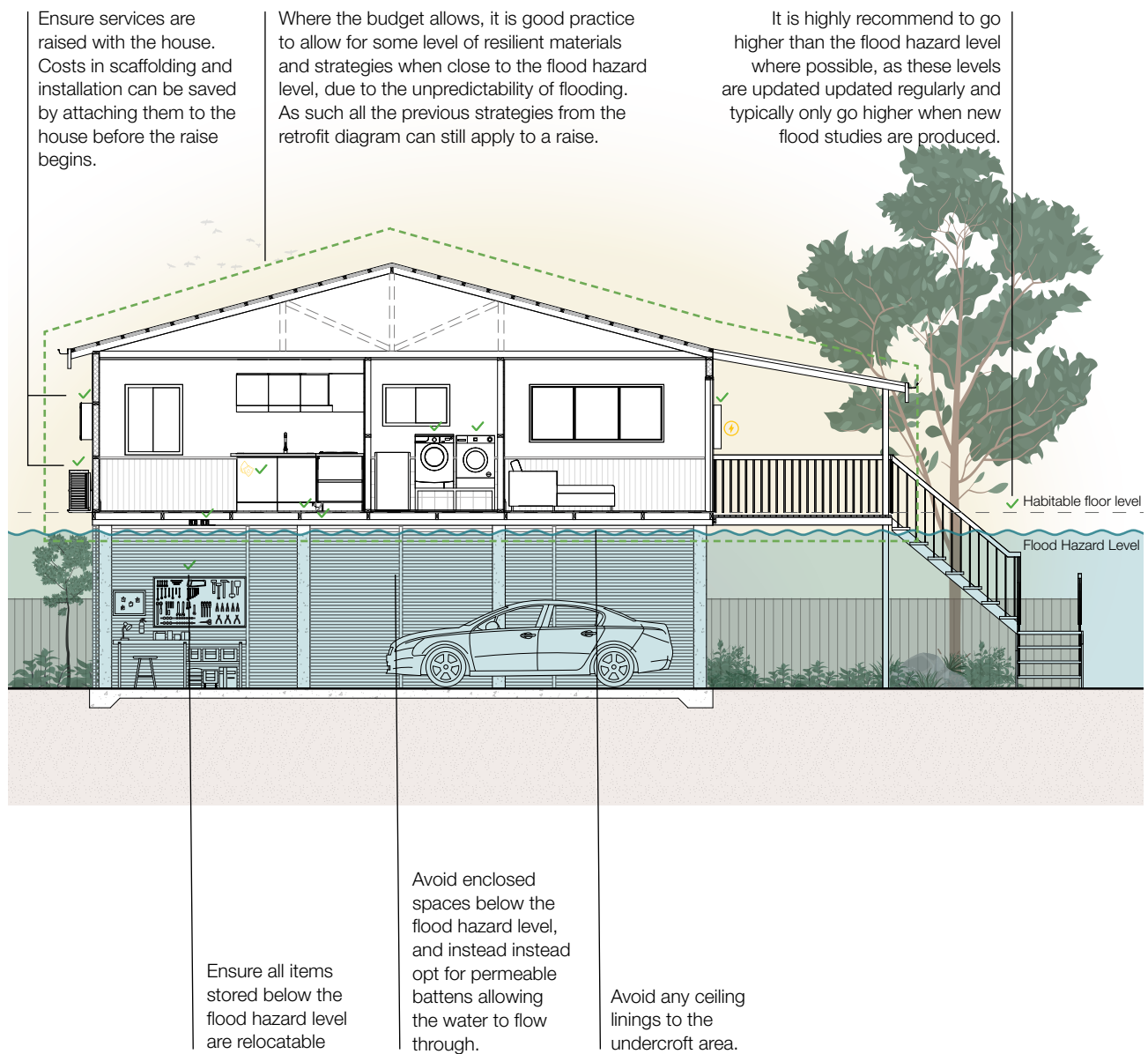


Figure 25 - Retrofitting and raising a timber house for resilience. Raising the house above the flood level.



3.3.6 Raising timber-framed houses in flood-prone areas

Raising the habitable floor levels above a defined flood hazard level (FHL) effectively reduces flood risk; refer to Figure 30. A great benefit to many existing timber-framed sub-floor houses is that they can often be elevated easily. A commonly practised example of this is the traditional Queenslander house. This vernacular house type is built on timber or concrete stumps, and through incremental lifting onto palettes and then re-stumping onto taller columns, the houses can be raised relatively quickly so that their habitable floor levels are above the flood level.

The habitable floor level of a house in a flood-prone area must be raised above the FHL. The council sets the FHL; however, to account for climate change, it is strongly recommended to go higher – 500 mm than this level when it is practical to do so, and the budget allows and within the local council height limits. It is also recommended to retrofit the raised level using flood-resilience principles discussed in this section in case flooding exceeds this level.

Some councils permit non-habitable rooms under raised homes if a minimum 2.1 m ceiling clearance is attainable. However, building approval is required, and this also falls short of flood-resilient best practices. If non-habitable rooms are built below the FHL, it is important to ensure they are built using resilient construction principles.

A brief summary of the house-raising process in a flood-prone area is given below.

3.3.6.1 Preparation

1. **Site Survey, Building Plans and Engineering** documentation are prepared to illustrate the existing and proposed house levels, and engineering drawings document the new structure support. Ensure that the habitable floor level is above the FHL and that the documentation clearly demonstrates this. In some flood-prone areas, a hydraulic assessment report will sometimes be required to determine the FHL and what can be built below that level.
2. Generally, a **Development Approval** is required. Consult a building certifier or town planner about the approval process and what is required to demonstrate compliance.
3. Obtain **Building Approval** through a building certifier to ensure all proposed works comply with the NCC and other local authority requirements.

3.3.6.2 Site process

1. **Demolition** of sub-floor or undercroft (asbestos removal where required).
2. **Structure supports** are placed below the floor to be used to raise the building. Either use the new engineered floor support structure, as per building and engineering plans or use temporary steel beams.
3. **Timber styes (box cribbing or cribbing) installed** underneath the floor structure to take the load of the house.
4. **Existing stumps/posts** disconnected.
5. **Hydraulic jacks** placed below the new engineered floor structure (or the temporary steel beams) to push up
6. The house one side at a time, at around 100 mm increments. Timber styes are added to the newly raised section bit by bit to re-take the load. This step is repeated until the proposed height above the *FHL* is achieved.
7. **Earthworks** undertaken to clear under the newly raised level and prepare the footings for the new posts. The new posts installed as per the structural engineering design.
8. **Hydraulic jacks** are positioned to re-take the weight of the house, and the timber styes are removed.
9. The house is lowered onto the new posts, the posts are fixed to the floor structure, and the cross bracing is installed. Remove hydraulic jacks from the support structure.
10. A **post-raise floor level survey** ensures that the new level matches the proposal, confirming that it is above the *FHL*.
11. **Utilities and stairs** are reconnected and constructed to suit the height of the new habitable floor level.

3.3.6.3 Issues to consider when house-raising

Local council height limits

Local councils set maximum height limits to ensure their streetscapes and neighbourhoods meet town planning design intentions and are in alignment with Obstacle Limitation Surface (OLS) restrictions imposed in areas that lie within flight path areas. Depending on the minimum habitable floor levels the council sets, a house raise may exceed this height limit. Some councils offer relaxations or town planning approvals due to flood risk considerations. It is recommended to consult the local council or a building certifier to determine whether a house raise is possible.

Streetscape and neighbouring context should be a consideration when house-raising, as some house heights can lead to undesirable street connections and significant shadowing of adjacent properties.



Figure 30: A house being raised on temporary styes (box cribbing or cribbing blocks). (Image Credit: JDA)

Accessibility

Minimum habitable floor levels can often be metres above the existing house level, meaning many more stair risers than previously. This height can be an issue, especially for residents with mobility restrictions, and should be considered when thinking of house raising.

Split levels and practicality

Some houses are more difficult (therefore more costly and complex) to raise. Homes with partial slab-on-ground sections and split levels may require additional design work, demolition and extensions to ensure they work with the new levels.

Acceptance of risk

Elevating a house can be costly for homeowners without long-term assurance that flood levels will not be revised higher at some point in the future. Over the years, through better modelling and real floods, many living in flood-prone areas have had their houses raised only to be at risk when flood levels have been re-evaluated. When house raising, be aware that flooding may still be possible above the FHL, as seen in the following case study.

Cost & Timing

House raising can be expensive, and there are a few things to consider that may reduce costs. Consider maintenance works such as replacing roof sheeting, and wall-mounting external services prior to raising to avoid high scaffolding costs. Utility companies can also take a long time to disconnect and reconnect services, so it is best to organise this early.

Refer to the Wilston Residence case study in the Appendix (A3).

3.3.7 Building new flood-resilient timber homes

Building new homes in flood-prone areas is not nearly as common as retrofitting; however, it still occurs for numerous reasons, such as:

- The unavoidable fact is that many residential zones across Australian cities and towns exist in flood-prone areas.
- Using the resilience principles outlined in this Guide, many appropriate ways exist to design new houses on properties with acceptable flooding or overland flow levels.

The issue occurs when flood levels are so high that the minimum habitable floor levels are impractical from an access, construction, or town planning point of view. It is not recommended to build new houses on land like this; however, if there are no other options, it is best to consult a design professional to see what alternative solutions are available to build resiliently.

The same resilient construction systems that apply to retrofitting also apply to new homes; however, they are much simpler to implement in the latter as the complexities and constraints of working within an existing built form are no longer present.

When building a new timber home in a flood-prone area, it is essential to understand the relevant council flood levels and likely source(s) of flooding. The *FHL* will determine how high to build a suitable habitable floor level. If practical, the best practice is to build higher (500 mm) than the required level to provide additional clearance above flood waters. Historical evidence has shown that minimum habitable floor levels have been exceeded on numerous occasions throughout Australia. Because of this, it is best practice to build with resilient construction methods and a habitable floor level as high as practicable if the building is located in an area of flood risk.

3.3.7.1 Design

From a design and planning perspective, a new build allows designing around issues that are simply impossible or cost-prohibitive in a retrofitting scenario. For best practice, designing a home with the following strategies in mind is recommended, as well as looking for experienced designers and builders who understand the issues and know how to implement possible options/solutions.

Where local council height limits allow, designing with multiple storeys is an excellent way to reduce flood risk and provide more options in preparation, during and after an event. The lower level should be designed with the wet-proofing strategies outlined in this Guide so that if this level becomes inundated in a flood, the damage and time to clean up can be minimised. Refer to Figure 31, demonstrating allocating zones to different functions helping to manage a flood better.

Although this should be at or above the *FHL*, as noted previously, historical experience has shown that flooding can exceed this level. It is best practice to think of this level as the first line of defence in a flood, and where possible, avoid bedrooms, built-in furniture, and built-in appliances on that level. Having a second storey means having a floor level that is well above the *FHL*, providing a safe space for refuge and storage.

Local councils have different rules for what allowances they have for non-habitable rooms below the *FHL*. Consult your local council for what rooms and areas it allows below the *FHL*. It is best practice to avoid any enclosed rooms below the *FHL*; however, if you are doing so, ensure these rooms are built with resilient materials, incorporating the principles outlined in this Guide.

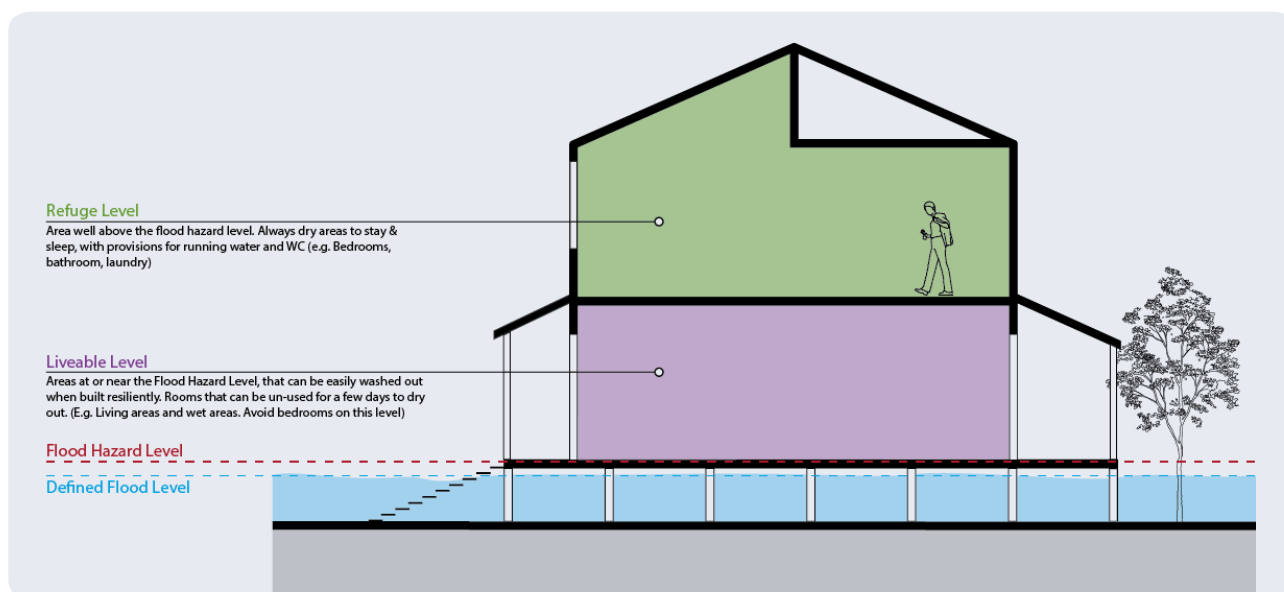


Figure 31: Allocating zones to different functions helps manage a flood better. (Image Credit: Gold Coast Flood Resilient Design Guideline²⁹).

When building a new building, logically planning the lower level to allow for the passage of floodwater in and out of the building greatly minimises post-flood cleanup times. This strategy can be achieved by designing large openings with flush sills at the ends of the building envelope. Make sure there are no 'dead ends' where flood water and debris can get trapped. Avoiding 'dead ends' can be done by including windows or doors that go all the way to the ground in each room.

In areas on or near overland flow paths, it is best (and often required) to have a raised floor so that water can flow under the house without being displaced onto neighbouring properties.

Construction

Although resilient retrofit construction strategies apply to new builds as well, given a clean slate with a new build, it is much easier to implement and, therefore, best practice to:

- Reduce the use of wall and floor cavities where water can get trapped. In a new build, this can be done through appropriate detailing. Hybrid masonry and timber-framed construction can also work well, as well as single-skin internal walls.
- Avoid ceiling linings on lower levels if possible.
- For concrete slabs, ensure all recesses allow for flush sills.
- Separating upper and lower circuits with isolation breakers is very simple in a new build but can be quite complex when retrofitting. It is also a good idea to have a generator input in the switchboard as a backup power supply in case of outages, which are very common during a flood.
- Permeable garage doors (e.g. battens) are recommended if they are not fully weather-tight. The force of flood waters on solid garage doors, much like solid fences, causes them to buckle.

Refer to the Chelmer Flood House case study in the Appendix (A2).

3.3.7.2 The Resilient Timber Homes Design Competition

This competition, part of the WoodSolutions Resilient Timber Homes program, was based on two distinct briefs requiring withstanding a slow-moving riverine flood lasting for 1 week and reaching a height of 1 m, exhibiting minor damage and easy recovery. In one case, that was also combined with resistance to a Severe Tropical Cyclone (Category 5).

The Jury explained their decision as follows:

- **Brief A Winner, Chris Gilbert** - Commercially grounded yet ambitious design featuring a flood-reversible solution that integrates prefabricated open wall cassettes with drainage plugs and airtight features within a modular DfMA scheme that will support fast-track delivery. The suggested use of blower door equipment to accelerate drying is both ingenious and reasonable.
- **Brief B Winner, Michael Croft** - Achieves robustness to cyclone impacts through a 'Flexible Room' which is well positioned and integrated with the floorplan. Thoughtful positioning of the electrical infrastructure, alternative floor design to cater for regional adaptability, accurate costing, and rational use of Passive House criteria all contribute to a thorough grasp of content and brief.

The following images (Figure 32) illustrate some of the features proposed by the winners.

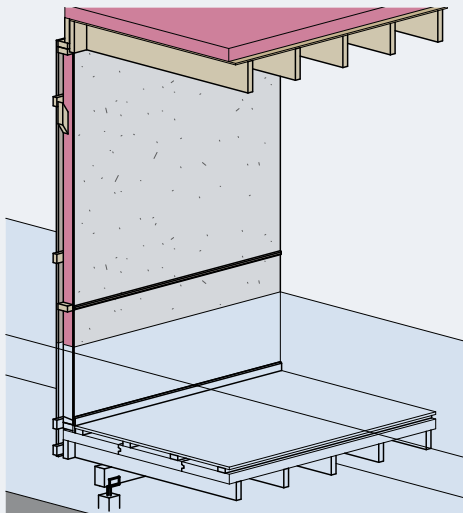
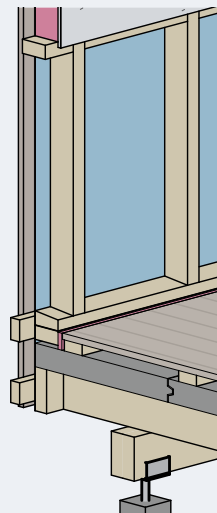
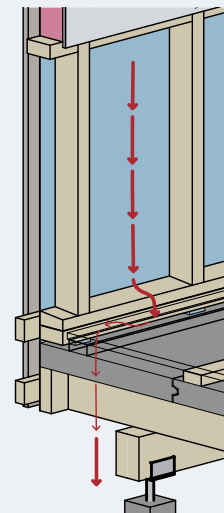


Diagram 03 - Flood Recovery Process

1. Defined flood event inundates dwell. Sacrificial wall lining exceeds flood level by 350mm, protecting upper wall linings, insulation and services



2. Skirting and dado cover strip are removed. Lower wall lining and insulation are removed.



3. Phenolic foam 'air plug' is removed. Lower portion of wall is able to freely drain down the bottom plate due to use of Hiandri bottom plate packers.

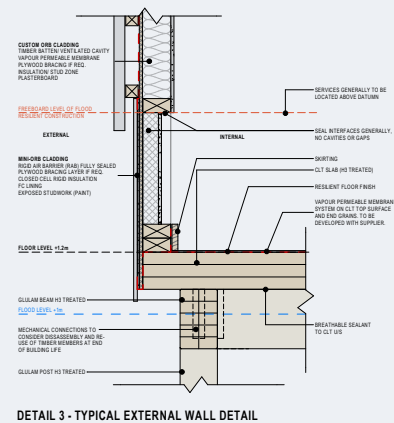
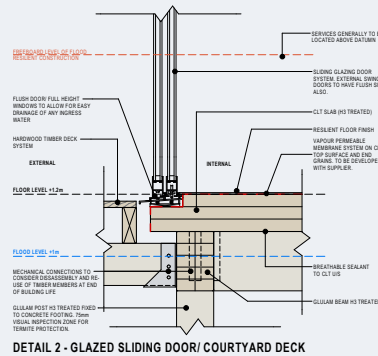
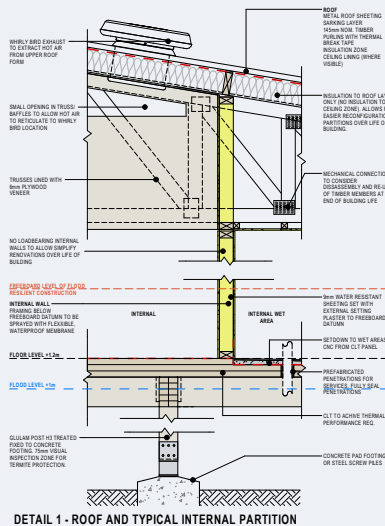


Figure 32: Design features proposed by the winners. Top: Brief A, Chris Gilbert. Bottom: Brief B, Michael Croft.

Understanding your flood risk – A summary

Refer to the local government authority's (Council) website to access flood risk information about the property. The council should provide information on the type of flooding likely to occur in the area. Once predicted flood levels are defined in relation to the relevant floor levels, the following general criteria apply to provide a resilient design/construction:

Existing home:

- Review any areas below the flood level for poor-performing materials, i.e., floor and wall construction systems.
- Note any utilities that are below the flood level that need to be raised or relocated.
- Raise the habitable floor level above the minimum council habitable floor level.
- Store any loose belongings above the likely level of the flood.
- In preparation for a flood, ensure any belongings at risk are moved higher, and if required, relocate vehicles to higher ground.

New home designs:

- Ensure the habitable levels are above the minimum habitable floor levels defined by the council.
- Design anything below this flood level with the flow of water in mind, with flood-resilient materials and construction systems.
- Ensure (in overland flow areas) that new building works are not diverting water to neighbours.
- Allow the building to dry out.
- Prevent water from entering the wall and flood cavities.
- Use flood-resilient materials.
- Ensure all essential services and utilities are above the flood level.
- Allow water to flow through the building easily.

4 Definitions

Defined Flood Level (DFL) – This is the level associated with a specific flood relative to the Australian Height Datum (AHD). In many councils in Australia, this is the 1% Annual Exceedance Probability (AEP) flood level. In other words, this level of flooding has a 1% chance of happening in any given year.

Freeboard – Freeboard is a clearance above the defined flood level (DFL) determined by authorities, which, in turn, determines the minimum finished floor level of a habitable floor. This additional clearance takes into account floor structure and localised hydraulic behaviour and is generally 300 mm or 500 mm, but can be higher depending on site-specific conditions and flood behaviour, as well as the intended use of the structure and if there may be a potential need to shelter in place for extended periods.

Flood Hazard Level (FHL) – Adding the defined flood level (DFL) and the freeboard produces the flood hazard level (FHL). This is the minimum habitable floor level in flood-prone areas as defined by councils. When building new homes in flood-prone areas, the habitable floor level must be at or above the FHL. This is also the minimum level to which this guide recommends resilience strategies be built.

Finished Floor Level (FFL) – The uppermost surface of a floor.

Habitable room – According to the NCC, it is a room that is used for normal domestic activities, and therefore the definition:

(a) includes a bedroom, living room, lounge room, music room, television room, kitchen, dining room, sewing room, study, playroom, family room, home theatre and sunroom

(b) excludes a bathroom, laundry, water closet, pantry, walk-in wardrobe, corridor, hallway, lobby, photographic dark room, clothes-drying room, vehicle parking area, storage area and other spaces of a specialised nature.

Habitable rooms are located on the habitable floor level.

Habitable floor level – This is a finished floor level of the house where normal domestic activities take place and contains habitable rooms. In the context of flooding – the habitable floor level must be at or above the flood hazard level for new construction and must have a minimum ceiling height defined by the NCC or State and Territory regulations.

High density fibre board - wood fibres boards made by compressing and bonded together high-density wood fibre with resin.

Hygroscopicity - is the tendency of a solid substance to absorb moisture from the surrounding atmosphere.

Medium density fibre board - wood fibres boards made by compressing and bonded together medium-density wood fibre with resin.

Non-habitable room – This is a room where not a great deal of time is spent, rooms that connect spaces and rooms of a specialised nature. Common non-habitable rooms include: bathrooms, laundries, water closets, pantries, walk-in wardrobes, corridors, hallways and storage rooms.

Non-habitable floor level – This is a floor level of a house that contains non-habitable rooms and must have a minimum ceiling height of 2.1 m. In the context of flooding – the non-habitable floor level can be situated below the flood hazard level.

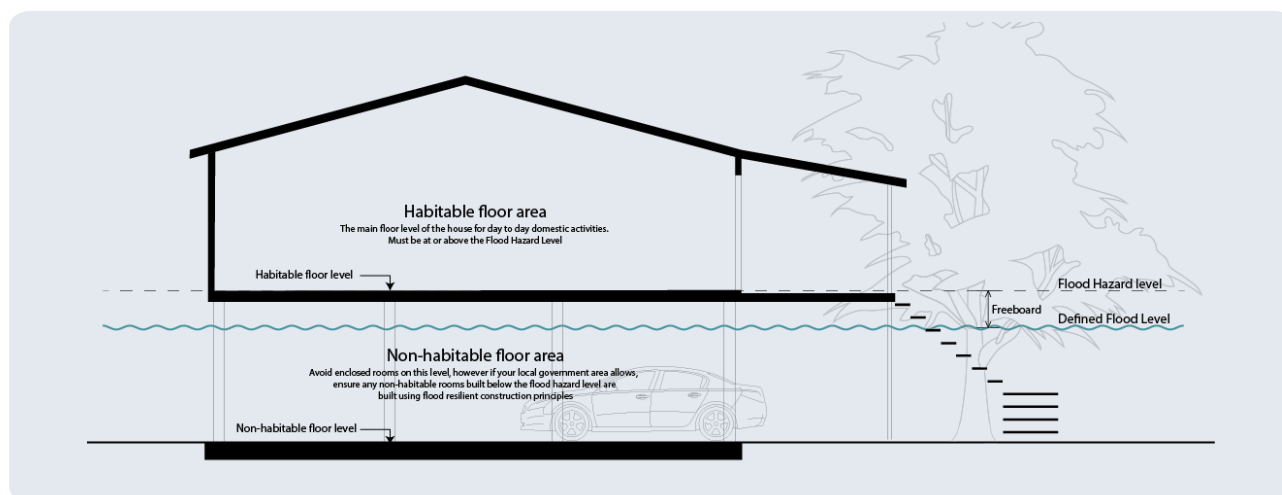


Figure 33: Illustrating critical flood terminology (Image Credit: JDA)

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Appendix – Case Studies

The design strategy and details used in the following case studies were appropriate for their respective time and location. Every project is different, therefore before applying any of the concepts contained in the case studies to your designs, check with local Authorities having jurisdiction.

A1 Rosedale Beach House (new building)

Context

A compliant AS 3959 Flaming Zone design built in 2017, Rosedale Beach House experienced a severe bushfire in 2020, refer to Figure A1. The same bushfire destroyed or severely damaged 18 nearby homes. The damage to the structure was minor, and repairs required only the substitution of some window gaskets, an outside plastic light over the door, and the external PVC plumbing pipes. There was no hint of smoke indoors.

Construction costs (in 2017 terms) were about 20-25% more than for a non-flame zone-compliant structure; however, the house was immediately occupiable after the fire event, making it an affordable option considering the cost of constructing a new home.



Figure A1: Rosedale Beach Flame Zone House by Thomas Caddaye Architects (Image Credit: Thomas Caddaye Architects)

Context

The 'Chelmer Flood House' is a renovation to an existing Queenslander house on concrete stumps, refer to Figure A2. The ground floor of the original house was partially built under but was predominantly used as garage and storage space with an under-croft laundry. Although the house was not affected in the 2022 floods, its history of riverine flooding and inundation in the 1974 Brisbane floods motivated the family to renovate with flood-resilient principles.



Figure A2: The 'Chelmer Flood House' before and after the renovation. (Image credit JDA)

Brief

The young family was growing and required significant additional space while wanting to preserve the existing heritage of the Queenslander. The proposal was to build-in the under-croft, increasing the liveable area with two bedrooms, a laundry, rumpus, guest room and office. The new works would use flood-resilient strategies to ensure they are prepared for any future flooding. Timber was the primary material used to further complement the Queenslander vernacular.



Figure A3: Summary of the flood-resilient renovation strategy at the 'Chelmer Flood House'. (Image credit: JDA)

Design

The proposed layout was arranged to allow for the passage of flood waters, focusing on making it easy to clean after the flood. Due to the scale of the house and the brief, two bedrooms on the ground floor were unavoidable.

Floor level windows were included in each room to allow water to flow out easily, speeding up the recovery period and minimising 'dead ends' where flood waters and debris become trapped. The ends of hallways utilise louvres for the same purpose. Such openings were added wherever possible and are all designed with sills that are flush to the ground, or in the case of the louvres, with a removable bottom lip.

Loose furniture was preferred, as it can be moved prior to a flood event. The only built-in cabinetry in the lower level of Chelmer house is the laundry benchtop which is made from recycled hardwood, and the storage cupboard shelves which are made with water-resistant cabinetry materials (compact laminate).

As a general rule, services were kept above the flood level where possible. Internal electrical fixtures such as power & data points were raised as high as practical, thus separating the circuits (with breakers) between upper and lower levels to allow power to continue running upstairs in case the lower level becomes inundated. The house is also equipped with solar power and a battery with a 'blackout mode' so that power can be supplied in the event of a grid outage, which is common during flood events.

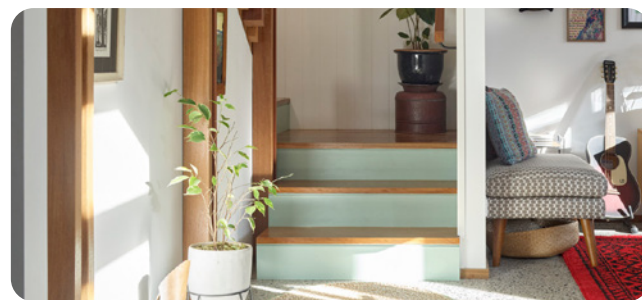
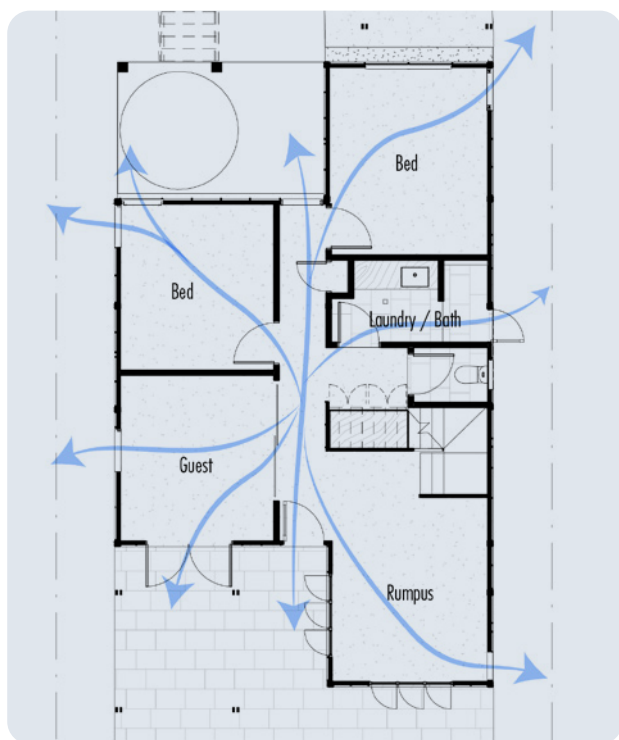


Figure A4: Details and finished result of the Chelmer Flood House (Image credit: JDA).

Result

The result of the Chelmer Flood House by JDA Co is a sustainable, flood-resilient timber home renovation for a young family. The Chelmer Flood House has been used as a model for the Queensland government's flood resilience design guidelines.



Figure A5: Finished result of the Chelmer Flood House. (Image credit: JDA)

A3 Wilston House (raise and retrofit)

Context

The existing house was a single-storey Queenslander cottage on stumps in the inner-city Brisbane suburb of Wilston. The house was primarily at risk of nearby creek flooding, and the existing habitable floor level was 300 mm below the *FHL*. The homeowners wanted to raise it above the *FHL* to make use of the space underneath. Figure A6 is a photo of the existing house before it was raised.



Figure A6: Wilston House before the raise. (Image Credit: JDA)

House raise

The homeowner, who had experience with flood resilience and Brisbane flooding, wanted to raise the floor level even higher than the *FHL*, given the events after the 2011 floods (when many houses were flooded higher than the *FHL*). This height had the added benefit of providing greater than 2.4 m ceilings to their ground floor level; refer to Figure A7.

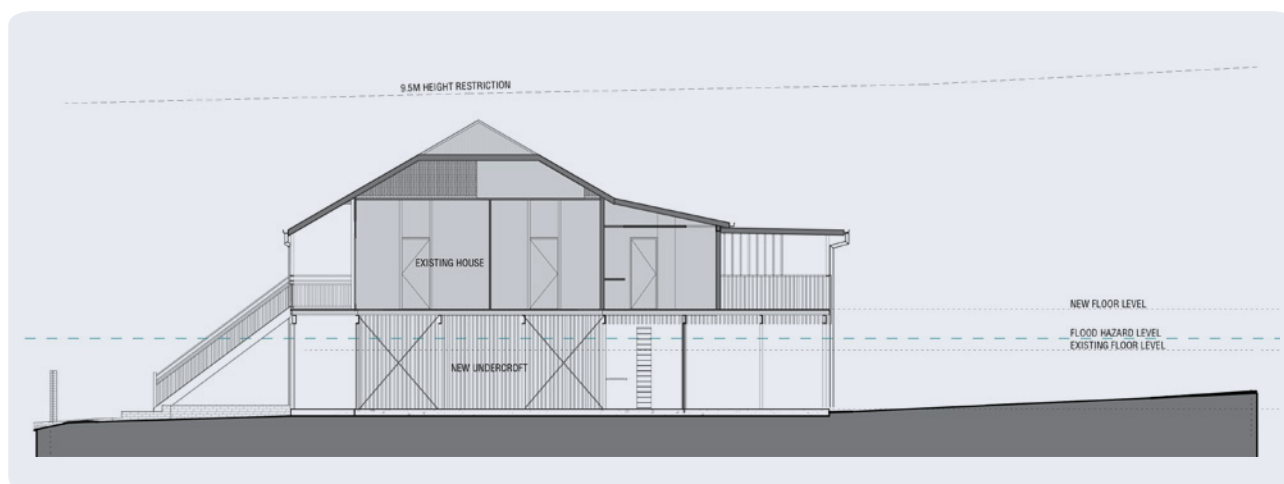


Figure A7: The first-floor level was raised higher than the *FHL*, with the added benefit of providing >2.4 m ceilings at the gbgvround floor level. (Image Credit: JDA)

The house underwent the typical house raise process, planning for their habitable level to be raised and non-habitable areas on the lower level consisting of a new workshop, carport, laundry, water closet and storage area; refer to Figure A8. The existing habitable floor level was already quite resilient: single-skin hardwood vertical-joint (VJ) walls and hardwood floor directly fixed to the joists. The proposed habitable level would be 1.2 m above the existing level.



Figure A8: Wilston House during and after the raise. (Image Credit: JDA)

The architects designed the lower level, which was below the *FHL*, with flood-resilient principles in mind. The only enclosed areas were built with single-skin walls made of durable timber frames and lined with sealed plywood. The ground floor finish is concrete with a burnished finish, and the floor plan is designed with large openings and a semi-enclosed carport with hardwood battens that allow the water to flow through.

The project was nearing completion when the February 2022 flood occurred.

During the floods

The February 2022 flood went above the Defined Flood Level (*DFL*) and almost to the *FHL*, meaning it would have affected the floor structure had the house been raised to the council-defined minimum habitable floor level. Thankfully, the house had been raised an additional metre above the *FHL*. This example is a perfect example of unpredictable floods and uncertain minimum habitable floor levels; refer to Figure A9.

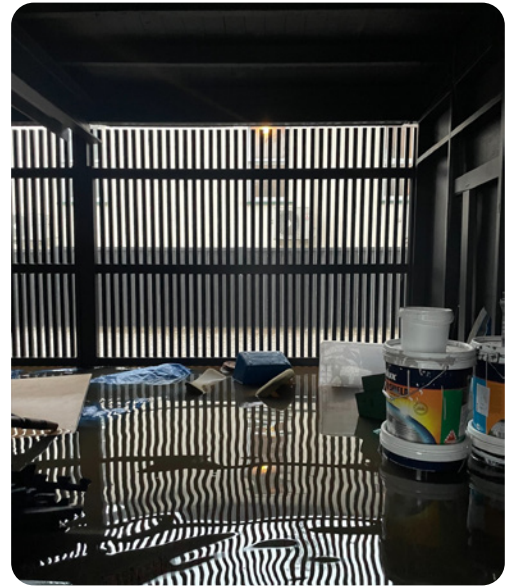


Figure A9: Wilston House during the February 2022 flood. (Image Credit: JDA)

After the floods

The day after the floods receded, there was a layer of mud and debris over the ground floor slab and a clear flood mark at the height which the flood waters peaked. With large openings, sealed ply walls, the concrete slab, hardwood framing and solid core doors, none of the materials needed replacing and could be cleaned with a simple hose wash; refer Figures A10 and A11.



Figure A10: Wilston House immediately after the February 2022 flood. The single skin walls meant there were no cavities for the flood waters to enter and be trapped. (Image Credit: JDA)



Figure A11: Permeable fencing at the front of the property meant that water could flow through without damaging the fence. (Image Credit: JDA)

After hosing out the walls and floors with water, the walls were back to normal two days after the floods, and the doors were functioning and dry; refer to Figures A12 and A13. The burnished concrete floor was easy to clean, and the tiles in the water closet and laundry were laid with epoxy grout and sustained no damage.

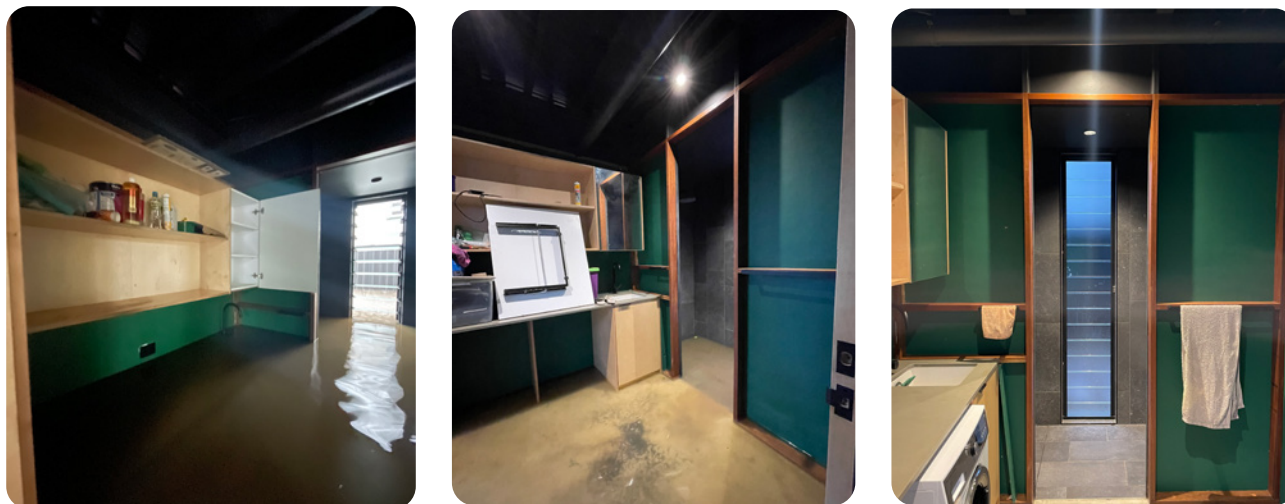


Figure A12: Wilston House immediately after the flood. From left to right: The laundry on the day of the floods, on the day after the floods, and a week later. (Image Credit: JDA)

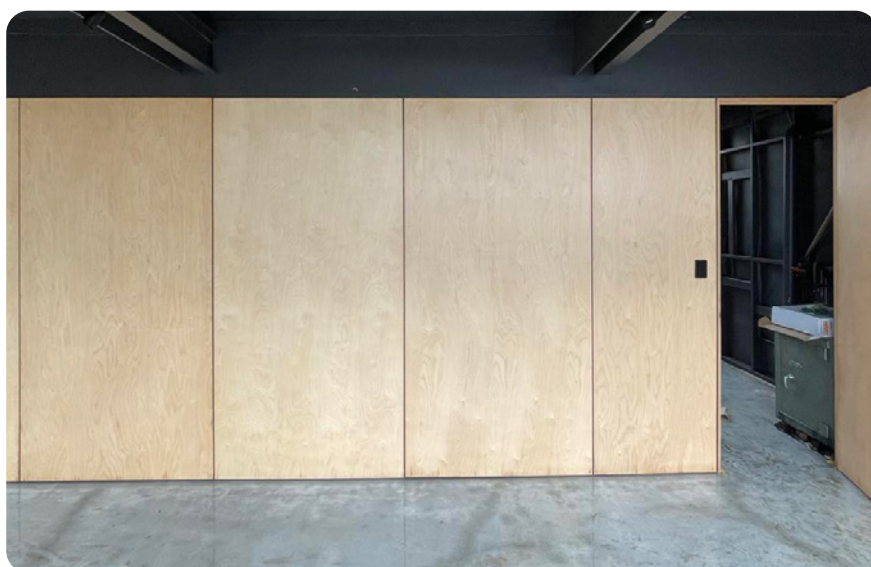


Figure A13: Wilston House two days after the flood. (Image Credit: JDA)

Although the waters rose quickly, there was enough time to detach and move the washing machine upstairs. The single-skin walls, durable frames and sealed plywood joinery all dried out and sustained no damage. Louvres to the ground made it easy to hose out debris from the laundry hallway.

An important learning from this flood was the need to seal the edges of timber products such as plywood. The only areas that sustained some damage were the bottoms of the plywood doors and wall panels, as they were only sealed on the tops and the sides. Similarly, when pre-drilling holes, the inner drilled section should be sealed, as these areas sustained minor warping, although after drying out, they returned to normal. There was some cosmetic streaking where the noggings were fixed to the plywood. This streaking occurred because there was no seal between the junction where the plywood meets the noggings, which allowed water to seep through this corner and cause some streaking in the ply.

Due to cost constraints, the switchboard and hot water unit had not yet been raised; they were submerged and needed replacing. With the help of government flood-resilience funding, the homeowners were able to re-install the switchboard on the upstairs deck and relocate their hot water unit above the *FHL*.

As a result of the resilience works done to the Wilston residence, the homeowner's insurance premiums were reduced by half following a re-assessment from their insurer.

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- 26 Rethinking Office Construction - Consider Timber
- 27 Rethinking Apartment Building Construction - Consider Timber
- 28 Rethinking Aged Care Construction - Consider Timber
- 29 Rethinking Industrial Shed Construction - Consider Timber
- 30 Timber Concrete Composite Floors
- 31 Timber Cassette Floors
- 32 EXPAN Long Span Roofs - LVL Portal Frames and Trusses
- 33 EXPAN Quick Connect Moment Connection
- 34 EXPAN Timber Rivet Connection
- 35 EXPAN Floor Diaphragms in Timber Buildings
- 36 EXPAN Engineered Woods and Fabrication Specification
- 37 Mid-rise Timber Buildings (Class 2, 3 and 5 Buildings)
- 37R Mid-rise Timber Buildings, Multi-residential (Class 2 and 3)
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