Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

Building and Energy Western Australia

General Inspection (Investigation) Report Five

Investigation into re-roofing of buildings

April 2021

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1. Glossary of Terms

Term/Acronym	Definition
AS/NZS	Australian Standard/New Zealand Standard
BSCRA Act	Building Services (Complaint Resolution and Administration) Act 2011
Building permit	In general, a building permit, granted by a permit authority, is required before building work can be carried out.
CDC	Certificate of design compliance
Compliance	Compliance is referred to herein as meeting the requirements of all applicable building standards, approved design documentation and manufacturer's installation instructions as appropriate. Compliance should result in something that is fit for purpose and does not pose a concern to the safety or amenity of building occupants or the wider public.
Connections	They are also referred to as fasteners e.g., nails, screws, bolts. Connections are an essential part of tie-downs that keep roofs securely anchored to the rest of the house in high winds.
CTS	Cyclone Testing Station, James Cook University, Townsville, Queensland.
DMIRS	Department of Mines, Industry Regulation and Safety of which Building and Energy is a division
GIR5	General Inspection (Investigation) Report Five: Investigation into the re-roofing of buildings
IB	Industry Bulletin as published by B&E / former Building Commission available on the DMIRS website
J-bolts	Also referred to as J-rods or hook rods. A threaded rod with a hooked end used to anchor roof structures to existing cavity brick walls. They are often used as a retrofit tie-down system when tile roof cladding is replaced with metal sheet roof cladding.
NCC	National Construction Code (Volumes 1 & 2 comprise the Building Code of Australia and Volumes 3 the Plumbing Code of Australia)
Over-battens	Battens (steel or timber) installed on top of metal roof sheeting above the external walls. They are connected to the ground or the floor using tie-down rods and a tie-down system for the roof structure.
Permit authority	The permit authority for the building or incidental structures as defined in section 6 of the Building Act 2011 – unless otherwise prescribed usually the local government in whose district the building or incidental structure is, or is proposed to be, located
Registered building service provider	Either a building practitioner or a building contractor, registered under the *Building Services (Registration) Act 2011*.
Re-roofing	Replacing an existing roof with a new roof. In this report, re-roofing refers to replacing tiles or asbestos sheeting with metal sheet cladding or replacing metal roof sheeting with new sheeting.
Tie-downs	Tie-downs refer to connections or systems that resist uplift forces during wind events.
Wind Classification	Wind classifications are a means of communicating the design wind speed at a house. They are used by designers and builders to specify building materials and systems that are strong enough to resist the winds at the site.

2. Executive Summary

As part of its role to monitor how well building standards have or are being applied in WA, the Department of Mines, Industry Regulation and Safety, Building and Energy Division (Building and Energy) investigates damage to buildings caused by wind events such as storms and tropical cyclones. Building and Energy uses the information to assess how the Building Code of Australia (BCA) and building Standards are being adhered to and to inform the building industry and public of any problems in building approval processes, building design or construction.

General Inspection (Investigation) Report Five – Investigation into the re-roofing of buildings (GIR5), provides an overview of Building and Energy's investigation into the cause of roof failures from physical inspection and desktop review of building documentation, as related to re-roofed buildings.

During investigations of damage to buildings and houses that had lost roofs during storms in the metropolitan area, Building and Energy found that around 50 percent of the damaged buildings had been re-roofed with the original heavy tile or asbestos cladding replaced with lightweight metal sheet cladding. Many older tile roofs, particularly in the metropolitan area, are being replaced with metal sheet roofs, and Building and Energy is concerned that these buildings are over-represented in the number damaged during wind events. Roofs that are lost during wind events present a risk to people sheltering inside the buildings and can create wind-borne debris that could injure people or damage other buildings.

Building and Energy and the Cyclone Testing Station (CTS) at James Cook University undertook a joint review of previous damage investigations in both cyclonic and non-cyclonic areas of WA to examine other instances of wind damage to re-roofed buildings. The study aimed to estimate the extent of the problem, identify causes of failure, and develop a plan to minimise future damage. The study was limited to damaged re-roofed buildings and did not include other re-roofed buildings undamaged by the same wind events.

The study found that metal sheet replacement roofs were damaged at less than design wind speeds in all wind regions. The most common causes of failure included:

- The existing roof structure and design upgrades had not been checked by a structural engineer or registered builder to ensure the tie-down system to resist the higher net wind uplift on the new cladding.

- Works were not performed under a building licence/permit as required or appropriate tie-down details were not included in the approved plans for the re-roof, so roof tie-downs were not checked and upgraded.
- Some of the original tile battens were used, which were not spaced appropriately or strong enough to resist the net uplift on metal sheet roof cladding.
- Some of the structural elements, such as the timber rafters and the roof connections, had deteriorated.
- In cyclonic areas, over-battens and tie-down rods were removed or cut, and an alternative tie-down system was not installed.

Building and Energy addressed some of the findings of the early damage investigations by initiating research projects, publishing several Industry Bulletins on the tie-down requirements for metal sheet roofs, and re-iterating the need to apply for a building permit if the type of roof cladding material is changed.

Building and Energy also intends to distribute information to the public and provide further information and training to permit authorities and the building industry regarding the requirements for re-roofing buildings.

3. Introduction and background

GIR5 presents the results of Building and Energy's investigations into wind damage to re-roofed buildings in both cyclonic and non-cyclonic regions in WA over the past 15 years. 'Re-roofed' in this report means that the roof cladding (i.e. tiles, asbestos or metal sheet) was replaced at some point in time.

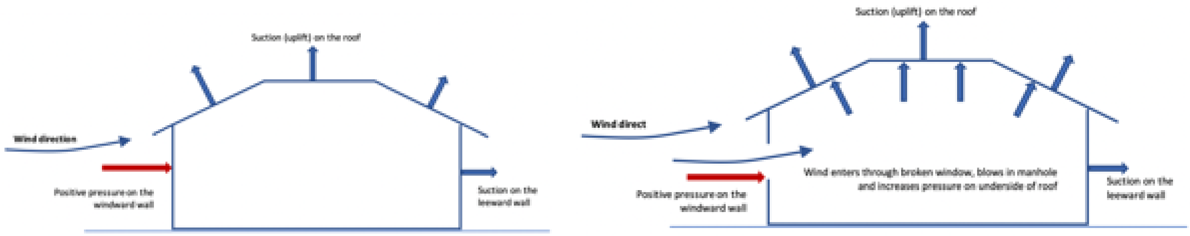
Original tile or asbestos cement roofs on older houses are often replaced with lightweight metal sheet cladding. Even if the replacement roof cladding is installed to the manufacturer's specifications, if the roof structure and tie-downs are not upgraded, roofs can be damaged by the higher net wind forces, as discussed in Section 5.1 - Causes of wind damage to re-roofed buildings. The roof structure and tie-downs must be strengthened when installing lighter weight cladding.

During investigations of damage to buildings and houses that had lost roofs during storms or cyclones, Building and Energy identified several that had previously been re-roofed. GIR5 investigates failures of replacement roofs to estimate the extent of the problem, identify causes of failure, and develop a plan to minimise future damage.

GIR5 discusses why roofs are more vulnerable to damage from wind events if the tie-down system in the roof structure is not adequately checked and upgraded as necessary during re-roofing. The report details the observations of damage to replacement roofs identified in Building and Energy and CTS investigations in both cyclonic and non-cyclonic areas and presents some options to minimise future failures.

3.1 Wind loads on roofs

Wind flowing over and around a building puts positive pressure (pushes) on the windward wall and negative pressure (pulls) on the roof and other walls, as shown in Figure 3-1(a). The pull or suction on the roof is in an upward direction. If the roof structure and cladding are not secured down sufficiently, the roof or part of the roof can lift off the building.



(a) Uplift forces on a roof *(b) Extra uplift forces created by an opening*

Figure 3-1 Wind pressure on buildings

Figure 3-1(b) illustrates how an opening on the wall facing the approaching wind (an open or broken window or door) can create pressure on the underside of the roof. The combination of upward push from within the building and upward suction from outside can almost double the uplift from when no large opening is present and the wind flows around the building (Fig 3.1(a)).

The net upward pull that a roof experiences is the wind uplift force or load minus the roof weight. The net wind uplift on roofs with metal sheet roof cladding is higher compared with roofs clad with tiles that around ten times heavier (see Appendix C2). Lighter roofs generally require more robust tie-down systems to resist higher uplift loads.

Like-for-like roof replacements include replacement of deteriorated cladding with the same type of material. This should not change the net uplift on the roof structure, but a check of the roof tie-down should still be conducted to ensure that the existing roof structure remain fit-for-purpose.

Where the type of roof cladding material is changed, the change in the overall push or pull forces acting on a roof must be catered for.

- If a metal sheet roof replaces a tile roof, the higher net wind uplift forces may require new battens with stronger batten-to-rafter connections. A suitably qualified professional (i.e. engineer) should design the new tie-down system.
- If a tiled roof replaces a metal sheet roof, net wind uplift forces will decrease, but the roof structure likely requires strengthening to carry roofing which weighs in the order of ten times more.

Refer to Appendix C for further information on wind loads on roofs.

3.2 Roof structure of older houses and buildings

Building standards have been updated in response to changes in building practices and research on the performance of buildings in severe wind events. Some buildings, particularly those built before the 1980s, may not comply with current building standards but they complied to the applicable standards at the time of construction. Additionally, the underlying roof structures in older houses and buildings often need to be upgraded because:

- timber members deteriorate over time (caused by rot or termite attack);
- unseasoned hardwood used for roof members dry out and shrink over time, and can split the timber roof members and loosen fasteners, and
- the existing battens that directly support the roof covering might be inappropriately spaced for the replacement roofing material.

3.3 Re-roofing practices in WA

3.3.1 Building approvals

Roof cladding may need to be replaced at least once in the lifetime of a building. A building permit is usually not required if the roof cladding is to be replaced with the same material, and the replacement works will not affect the roof structure or tie-down systems.

Even when the same material is used for re-roofing (i.e. re-sheeting a metal clad roof), the thickness, profile or even unit lengths of the replacement roofing may require upgrades to the existing roof structure. The permit authority (typically local government) determines whether a building permit is required (see IB 53) and should be consulted in all instances. There are penalties under the legislation for carrying out building work without a permit.

Building owners need to apply for a building permit to replace their roof cladding with a different material; for example, if owners want to replace roof tiles with metal sheet cladding. Where a building permit is required, a building surveyor (employed by the local government or privately) will determine the extent of building works that requires certification. Since the weight of footings below the soil may be required to resist uplift forces on the roof, the certification may extend to structural elements well below the roof cladding itself.

As part of the application for a building permit a suitably qualified professional must evaluate the wind classification for the house (refer to IB 124) or calculate wind loads on larger buildings (which will require an engineer). A suitably qualified professional (i.e., structural engineer, registered builder or building surveyor) should inspect the existing roof structure to ensure that the battens, rafters or trusses are in good condition and are strong enough and appropriately spaced to support the new roof. It is likely that the existing batten to rafter or truss connections, and sometimes the rafter to wall connections, need to be upgraded. These details must be designed by an engineer and documented in the plans submitted with the building permit application (Refer to Appendix C3 for an example).

NOTE: The permit authority (i.e., local government) for the proposed re-roofed building or a registered building surveyor can guide homeowners through the building permit process. Building and Energy is also available to provide advice on building matters via phoning 1300 489 099 or emailing be.info@dmirs.wa.gov.au

3.3.2 Roof cladding installation

If the value of the roof replacement exceeds $20,000 and a building permit is required, the work can only be carried out by a registered building contractor who must follow the manufacturer's instructions and relevant Australian Standards. Building and Energy is aware of several instances where replacement roof cladding did not follow the manufacturers' guidelines or applicable building standards, was completed without the appropriate building approvals by unqualified people and has since failed (refer to Section 5.3.

3.4 Damage to re-roofed buildings in Queensland

Failure of replacement roofs is not unique to WA. Over the past 40 years, teams of engineers from the CTS have investigated damage to buildings caused by severe wind events in Queensland. Investigations in both cyclonic and non-cyclonic regions have indicated that damage occurred to buildings that have been re-roofed. The CTS noted several examples of replacement roofs that were damaged or completely lost in the following storms or cyclones:

- Tropical Cyclone Larry, Innisfail, Queensland (2006)
- Storms in Brisbane (2008)
- Tropical Cyclone Yasi, Mission Beach, Queensland (2011)
- Storms in Brisbane (2014)
- Tropical Cyclone Debbie, Whitsundays, Queensland (2017)

Appendix D2 provides links to the Technical Reports on these investigations.

The re-roofed Queensland and WA buildings that failed had similar issues (detailed in Section 5.2). These include incorrectly designed or installed tie-down connections -. These roofs were damaged under wind speeds (often significantly) less than the design wind event.

4. Methodology

4.1 Role of Building and Energy

Building and Energy monitors the effectiveness of the building control legislation including how appropriately building standards are being applied. Building and Energy can also investigate instances where buildings collapse, where particular features on buildings fail, or buildings are damaged by strong winds, floods or other events.

(Refer to Appendix A for more information about the role and powers of Building and Energy.)

For the study presented in GIR5, Building and Energy identified re-roofed buildings as a subset of buildings damaged during wind events. This report and further guidance to the building industry provided through past and future planned seminars and industry bulletins, aims to improve compliance of re-roofed buildings.

4.2 Damage inspections

During investigations of damage to buildings and houses that had lost roofs during storms or cyclones, Building and Energy identified several that had been re-roofed.

Building and Energy examined the roof cladding, the roof structure and the tie-down connections between roof elements and the walls of seven re-roofed buildings to determine the cause of the failures.

Engineers from the CTS also examined some of the same buildings as well as several others. CTS did not have access to building approval documentation or engineering drawings for the inspected buildings. See Appendix D2 for links to CTS reports on damage investigations.

Information gathered and reviewed with respect to lost roofs included some or all of the following:

- type of building and materials used in original construction;
- the date of initial construction;
- the year the new cladding material was installed;
- local council building approval documentation;
- engineering drawings;
- the estimated wind speed when the failure occurred; and
- photos and details of the damage.

4.3 Limitations of the investigation/study

GIR5 is based on Building and Energy and CTS's previous damage investigations of re-roofed buildings. Re-roofed and other buildings that were not damaged in the same wind events were not inspected.

GIR5 does not address the potential for damage to buildings where tile roofs replace metal sheet roof cladding. Replacing lightweight metal sheet roofs with tiles is considered less common, however as there is no reliable data on the number of re-roofed buildings in WA, no statistical analysis is provided.

5. Observations

Building and Energy investigated damage to buildings caused by wind events such as severe storms and cyclones on an annual basis. In the past six years, around 50% of lost roofs investigated by Building and Energy in the metropolitan area had been re-roofed. These had lightweight metal sheet roofs replacing the originally tiled or asbestos sheeted roof coverings.

Deficiencies in the building approval processes (or lack thereof), design, or installation of these roofing systems contributed to these failures. In all cases, damage occurred at less than and often well below the ultimate design wind speed.

5.1 The extent of damage to re-roofed buildings

Figure 5-1 provides examples highlighting the type and extent of damage observed during the inspections by Building and Energy and damage investigations by the Cyclone Testing Station. Most of the buildings were so extensively damaged that occupants were at risk of serious injury. The damaged roof created significant wind-borne debris that also damaged other properties. People could not use the buildings until major repairs were completed.

(a) Damage to a two-storey commercial property in 2004. The original tiled roof was replaced with a metal sheeted roof.

(b) Damage to an apartment building during a storm in 2004. The original tile roof was replaced with metal sheet roof. The roof cladding and part of the roof structure damaged a neighbouring building.


(c) Roofing and roof structure loss during a tropical cyclone in 2007. The original metal sheet roof had been tied-down with over-battens, which were removed, and the tie-down rods were cut when the roof was replaced. No alternative tie-down system was installed.


(d) Damage to a two-storey house built in 1964. The original tile roof was replaced with a metal sheet roof in 2002. The roof cladding and roof structure were lost during a storm in 2014.

(e) Damage to a two-storey house built in 1979. The original asbestos roof sheeting was replaced with a metal sheet roof in 2004. The roof was lost during a storm in February 2020 with the owners still awaiting completion of repair works prior to moving back into their home at the time of this report

(f) Damage to an office and storage building built before 2000. The original roof was replaced in 2011, but the corroded tie-downs were not upgraded. The roof cladding and roof structure were damaged during Tropical Cyclone Damien in 2020.

(g) Damage to an apartment building during a storm in 2018. The original metal sheet cladding had been replaced with a new metal sheet roof, but the hardwood battens had not been replaced and split when the new roofing screws were installed.

Figure 5-1 Examples of damage to re-roofed buildings

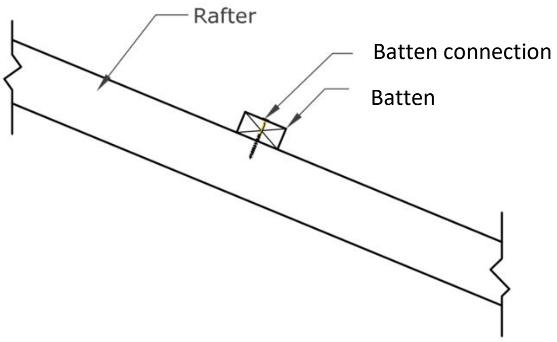
5.2 Causes of wind damage to re-roofed buildings

All replacement roof cladding should be installed to the manufacturer's specifications and the underlying roof structure checked and upgraded if necessary, so the new roof complies with the current NCC requirements. All roofs in all wind regions (cyclone or non- cyclone-prone areas) should be able to resist the expected winds for their location, complying with the NCC applicable to the building permit. Refer to Appendix C1 for further information on wind regions in WA.

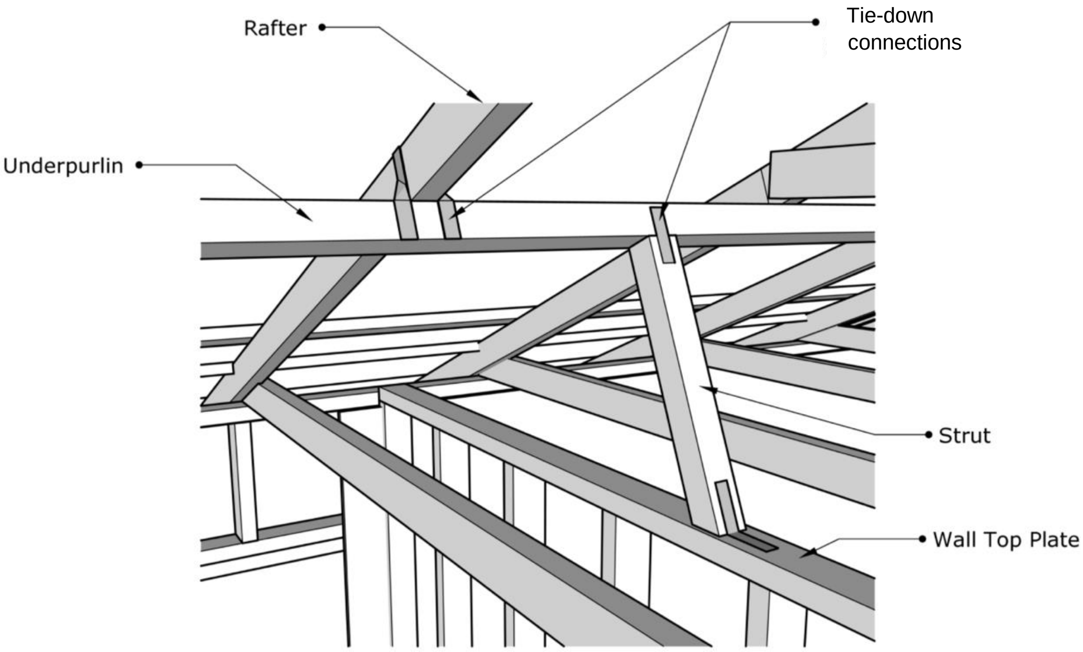
The following is a summary of the causes of failure for the re-roofed buildings covered in GIR5:

5.2.1 Non-cyclonic regions A and B

- The building approval process was not adequately followed. For example:
  - There was no record of any building approval to replace the previous roof cladding with a different material.
  - Documentation associated with building works that included the re-roofing were incomplete or incorrect lacking appropriate information such as a wind classification and tie-down details
- Connections in the roof structure were not strong enough to resist the net uplift forces in the replacement roof:
  - Batten to rafter connections used nails when screws were required, or used the wrong type of screws (Figure 5.2(a)). Roof cladding is fixed to the battens.
  - Rafter to supporting underpurlin connections or connections at each end of struts that support the underpurlins and roof ridge were not upgraded. For example, nails instead of straps or framing anchors were used. (Figure 5.2(b))
  - Tie-down connections from rafters to veranda, alfresco or garage beams and the beams themselves were inadequate.
- Some of the original tile battens were used as battens for the new metal sheet roof. The spacing of the roofing fasteners was too large, and the capacity of the tile battens was insufficient to resist the net uplift on the lighter weight roof.
- Hardwood rafters and battens (that had dried out over time) had split because the holes for new screws were not pre-drilled.
- The tie-downs could not resist the higher net uplift loads transferring from roof to walls when lightweight cladding replaced tiles. For example:
  - No extra tie-downs were installed.
  - Retrofit J-rods were installed but in insufficient number to provide adequate resistance (refer IB 109).
- Deterioration of structural members and connections. For example, rot in timber or corrosion in metal fasteners.



(a) Batten and rafter



(b) Rafter, underpurlin, and strut

Figure 5-2 Diagram of roof structural members

5.2.2 Cyclone regions C and D

The same issues described in Section 5.2.1 resulted in damage to re-roofed buildings in cyclone-prone areas of. Other failures occurred because:

- Over-battens that provided an engineered tie-down system for the original roof structure were removed, and the tie-down rods were cut when the new roof was installed. The CTS found seven examples of this failure during the investigation following TC George in 2007.
- Builders upgraded some connections (e.g., batten-to-rafter connections) but not others.

5.3 Observations of non-compliance in recent roof replacements

Building and Energy has been notified by a permit authority of at least sixteen houses within a cyclone prone local government area that have been re-roofed with metal sheeting without the required building permit being in place. Building and Energy is assisting the local government permit authority with its investigations into the alleged breaches of building laws and expects to find even more re-roofs conducted over the applicable two-year period. The investigation will consider the underlying causes and required actions; however, these had not been determined at the time of publishing this report.

5.4 Actions

In response to some of the earlier inspections of the damage to re-roofed buildings and houses during wind events, Building and Energy has already undertaken the following:

- Contacted the relevant local government permit authorities to review building permits and plans for the damaged buildings.
- Worked with Australian academic institutions to investigate the tie-down capacity of metal straps and J-rods embedded in brick walls. (Refer to Industry Bulletin 109)
- Issued Industry Bulletin 53 in 2015 to assist in clarifying building permit requirements for re-roofing.
- Issued other related Industry Bulletins, including 93, 109, 117, and 121. Refer to Section D1 for links to these documents.

5.5 Additional steps

Building and Energy will raise awareness by issuing **-**

- **Information for builders, building surveyors and local governments permit authorities** (i.e., councils) regarding considerations to demonstrate a proposed re-roofing will comply with applicable building standards. This has focused on details for the upgrade of tie-down connections expected within the documentation associated with a building surveyor's certificate of design compliance that is lodged with a building permit application.
- **A Guide for Homeowners** to emphasise the need to contact their local government if they intend to change their roof cover. The information also provides further advice as to how to ensure the re-roofing meets applicable building standards.

  The Awareness Campaign is being rolled out in line with the publication of GIR5.

Building and Energy also continues to investigate damage to buildings that have been re-roofed to identify any new causes of failure and determine whether revised awareness campaigns, regulatory change or further studies may assist compliance.

Building and Energy will also continue to refer non-compliant roofs and re-roofs to the local government permit authority for consideration of enforcement action under the Building Act.

APPENDICES

A ROLE AND POWERS OF BUILDING AND ENERGY

Western Australia has a suite of laws governing building control, including the *Building Act 2011* (the Building Act), the *Building Services (Complaint Resolution and Administration) Act 2011* (the BSCRA Act), and the *Building Services (Registration) Act 2011* (the Registration Act).

The BSCRA Act empowers the Building Commissioner to monitor buildings in WA to check that building standards are applied appropriately and that buildings comply with the NCC. The Building Commissioner is able to designate Building and Energy officers to inspect buildings during and after construction and review approval documentation.

The Registration Act provides a framework for registering building surveyors and builders and disciplinary provisions to manage sub-standard work and conduct by a registered building service provider.

For new building work that requires a building permit, the Building Act requires a registered building surveyor to sign a certificate of design compliance (CDC) for the building design. The CDC is to "contain a statement of the building surveyor signing the certificate to the effect that if the building or incidental structure that is the subject of the application is completed in accordance with the plans and specifications that are specified in the certificate, and the complies with each applicable standard."

Additionally, the Building Act requires builders to construct the building in accordance with the plans and specifications listed in the applicable CDC and requires the builder to ensure, on completion of the building or incidental structure, that the building complies with each applicable building standard. Builders have a responsibility to comply with both requirements under the Building Act.

Further information about the role of Building and Energy is available on the DMIRS website.

B AUSTRALIAN STANDARDS

Engineers use the following standards to evaluate loads on roof cladding and roof structural elements:

- AS/NZS 1170.2:2011 – This standard is the primary wind loading standard for Australia and New Zealand. It is a referenced document in the NCC. Engineers use it to select wind loads for any structural members of buildings
- AS 1562.1–2018 – This standard provides the requirements for designing and installing metal roofing and flashings.
- AS 1684–2010 – This suite of standards is used to determine member sizes and connections for tie-down in timber-framed houses. It can also be used for timber members in the roof of houses with brick walls. Part 2 includes a requirement for houses in non-cyclonic areas, and Part 3 is used for houses in cyclone areas.
- AS 4055–2012 – This standard is a simplified wind loading standard that can be used by engineers and other suitably qualified professionals and only applies to houses. It is compatible with AS/NZS 1170.2.
- NASH (2011) Residential and low-rise steel framing Parts 1 and 2, National Association of Steel-framed Housing, Victoria, Australia.

C WIND LOADS ON BUILDINGS

C1 Wind Regions

AS/NZS 1170.2 and AS 4055 include a map that divides Australia into four wind regions: A, B, C and D. The same map is published in the NCC and is shown in Figure C3-1. The design wind speeds are different for each region. Wind regions A and B are classified as "non-cyclonic areas", and wind regions C and D are classified as "cyclonic areas".

Strong winds can be generated by severe thunderstorms in any part of Australia and by frontal systems south of the tropics. Tropical cyclones only occur in Australia's northern coastal areas but can travel further south into non-cyclonic areas as they weaken.

- Wind Region A – design winds are associated with severe thunderstorms, large frontal systems or significantly weakened tropical cyclones.
- Wind Region B – design winds are generally associated with severe thunderstorms or tropical cyclones that have weakened a little.
- Wind Region C – design winds are associated with tropical cyclones as they cross the coast.
- Wind Region D – design winds are associated with severe tropical cyclones.

Engineers use the design regional wind speeds for the where a building is to be located, when calculating the wind forces to be resisted.

Figure C3-1 Excerpt from Figure 3.10.1.4 National Construction Code

C2 Comparison of wind loads on tile roofs and metal sheet roofs

Table C1 shows the net wind uplift on houses with tiled roof or metal sheet roofs for different AS 4055 wind classifications. It clearly illustrates that metal sheet roofs have higher net uplift forces than tile roofs for all wind classifications.

Table C1 Net uplift on tile and metal sheet roofs

Wind region	**Wind classification**	**Design net wind uplift (kPa)**	
		Tile roof	**Metal sheet roof**
A and B (Non-cyclone areas)	N1	0	0.33
	N2	0.14	0.59
	N3	0.68	1.13
	N4	1.40	1.85
	N5	2.44	2.89

	N6	3.58	4.03
C and D (Cyclone areas)	C1	1.35	1.80
	C2	2.40	2.85
	C3	3.92	4.37
	C4	5.58	6.03

C3 Roof replacement – example

This section presents a typical but hypothetical situation where a homeowner replaced their tile roof with metal sheet cladding.

The house was built in the 1970s: double brick walls with a tiled roof; hardwood rafters spaced 600 mm apart with collar ties joining every third rafter pair; karri tile battens spaced 330 mm apart; the batten-to-rafter connections were nails; the rafter-to-wall plate connections were skew nails. A wind classification was not determined at the time of original construction.

A builder checked the roof structure and confirmed that the hardwood rafters and wall plates were still in good condition. A structural engineer determined the site's wind classification and designed the upgraded roof structure for an N2 site. Details on the plans for the replacement roof cladding submitted to council specified installation of tie-downs for the new metal sheet roof, presented in Table C3.1:

Table C3.1 Comparison of tie-down details for original tile and new metal sheet roof (indicative example only)

Roof element	**Original tile roof**	**New metal sheet roof**
Cladding	Terracotta roof tiles	[*Manufacturer's product*] profile, 0.42 BMT pierce fixed
Battens	Hardwood 25x42 mm (remain unused on the roof)	(New) MGP10 90x35 mm
Batten spacing – edge zone of roof	330 mm	900 mm
Batten spacing – general zone of roof	330 mm	1200 mm

Batten-to-rafter connections	1 nail	75 mm bugle-head screw into pre-drilled holes in rafters
Rafters	Hardwood 100x50 mm @ 600 mm centres spacing	Existing hardwood 100x50 mm @ 600 mm centres spacing
Rafter to underpurlin connection	2 nails	Existing 2 nails reinforced with framing anchor fixed to suppliers details
Collar ties	Hardwood collar ties on every third rafter pair	Existing collar ties plus new MGP10 collar ties so that spacing between collar ties is no more than 1200 mm.
Rafter to wall plate connection	2 skew nails	Existing 2 nails reinforced with framing anchor fixed to suppliers details
Roof structure to brickwork	Top plates were not connected to the brick walls	12 mm diameter J-bolts @ max. 750 mm centres, embedded > 1200 mm below the wall plate and fixed to each rafter with a 50 x 6 EA cleat

D ADDITIONAL RESOURCES

D1 Department of Building and Energy publications

- Industry Bulletin 124 – Warning on inappropriate wind classifications
- Industry Bulletin 121 Tie-down of timber-framed sheet metal clad roofs to timber frame walls and beams
- Industry Bulletin 117 – Improving tie-down of timber-framed sheet metal clad roofs
- Industry Bulletin 109 – J-Bolt (hook rod) tie-down systems
- Industry Bulletin 93 – Documentation for timber-framed roof construction
- Industry Bulletin 53 – Roof cladding requirements – building permit requirements
- Industry Bulletin 49 – Connection of roof battens
- Industry Bulletin 32 – Durability of roof tie-down connector straps
- Building and Energy General Inspection Report One: A General Inspection into Metal Roof Construction in Western Australia
- Building and Energy General Inspection (Snapshot) Report Four: Wind classification compliance for Western Australian houses
- Checking roof compliance on-site (video presentation)
- Guidance on replacing asbestos roof cladding
    - Frequently asked questions
    - Reminder to replace asbestos roofing

D2 Cyclone Testing Station Technical Reports and videos

- Technical Report 65 – Tropical cyclone Damien Damage to buildings in the Pilbara Region of WA (pp.51, 53-55)
- Technical Report 63 – Tropical Cyclone Debbie Damage to buildings in the Whitsunday regions (pp. 37)
- Technical Report 60 – Investigation of Damage Brisbane 27 November 2014 Severe Storm Event (pp. 15-18)
- Technical Report 57 – Tropical Cyclone Yasi Structural damage to buildings (pp. 33, 35)
- Technical Report 55 – Investigation of Performance of Housing in Brisbane Following Storms on 16 and 19 November 2008 (pp. 51, 62)
- Technical Report 52 – Tropical Cyclone George Damage to buildings in the Port Hedland area (pp. 22, 32)

- Technical Report 51 – Tropical Cyclone Larry Damage to buildings in the Innisfail area (pp. 37, 40, 41)
- Boughton, G.N., 1999, *Tropical Cyclone Vance – Damage to buildings in Exmouth*, Department of Local Government. (pp. 31, 82)
- Videos for builders and homeowners on re-roofing

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