Resilient Buildings: Informing Maintenance for Long-term Sustainability

Final Research Report

Part 4: Development of a maintenance prevention strategy to mitigate wind-driven rainwater ingress through windows and external glazed doors in social housing

Prepared by Juliana Faria Correa Thompson Flores (Primary author), Kris Harm, Rodney Anthony Stewart, Edoardo Bertone, Oz Sahin; *Griffith University*

Research Project: P1.53 Resilient buildings: Informing maintenance for long-term sustainability

Project Leader: Lam Pham

Research Team:
Lam Pham and Palaneeswaran Ekambaram; *Swinburne University of Technology, Victoria*
Rodney A. Stewart, Oz Sahin, Edoardo Bertone, Juliana Faria Correa Thompson Flores; *Griffith University, Queensland*

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OUTLINE OF THE FINAL RESEARCH REPORT

The Final Research Report of SBEnrc Project 1.53 *Resilient buildings: Informing maintenance for long-term sustainability* is presented in the following set of separate documents:

Part 1: Overview of extreme events and maintenance

Part 2: Maintenance and resilience of buildings for bushfire risks

Part 3: Maintenance and resilience of buildings for flood vulnerabilities

Part 4: Development of a maintenance prevention strategy to mitigate wind-driven rainwater ingress through windows and external glazed doors in social housing

This Part 4 of the Final Report includes:

(a) Findings from a literature review to identify the failure modes of residential buildings from cyclones and high winds

(b) Thematic analysis of the results from workshops and interviews with stakeholders

(c) Specific recommendations to mitigate wind driven rain water ingress through windows and external glazed doors

Further Information and other reports: http://sbenrc.com.au/research-programs/1-53/

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Project Steering Group members, SBEnrc and industry representatives

Graeme Newton	PSG Chair
Carl Barrett	BGC Australia
Dan Gardiner	BGC Australia
Sarah Mewett	Department of Communities, WA
Veronica Pannell	Department of Communities, WA
Carolyn Marshall	Department of Finance, WA
Dean Wood	Department of Finance, WA
Rosemary Axon	Department of Housing and Public Works, QLD
Dean Luton	Department of Housing and Public Works, QLD
Jessica Dominguez	Land and Housing Corporation, NSW
Martin Nunez	Land and Housing Corporation, NSW
Emad Gad	Swinburne University of Technology
Keith Hampson	SBEnrc
Debbie Thackray	SBEnrc
Lauren Gubbin	SBEnrc

Project Affilate - Australasian Fire and Emergency Services Authorities Council (AFAC) and participants/ persons consulted from various stakeholder organisations including the Australian Windows Association, Australian Building Codes Board (ABCB), Commonwealth Scientific and Industrial Research Organisation (CSIRO), Department of Fire and Emergency Services (DFES) – Western Australia, and Facilities Management Association of Australia (FMA).

EXECUTIVE SUMMARY

The building envelope consists of various buildings elements that have to work together in order to protect the structure against rain, wind, sleet and snow. In coastal cities and towns in northern Australia, windows and external glazed doors in buildings are particularly vulnerable to recurrent serviceability failure caused by wind-driven rain during cyclone events.

Resilience of buildings is a national objective in disaster mitigation and maintenance prevention. Maintenance prevention strategies at the design, construction and inspection stage of building procurement are the missing links to improving lifecycle window and external glazed doors resilience to wind-driven rainwater ingress. Maintenance prevention strategies are particularly important for government infrastructure and building assets since government is responsible for the lifecycle maintenance of their significant assets.

To develop a maintenance prevention strategy, the research method commenced with a literature review phase to identify the failure modes of residential buildings from cyclones and high winds. The literature review was followed by a data collection phase including workshops and phone interviews with design and construction professionals from manufacturing and building firms, inspection firms and window installers, as well as government. Thematic analysis of the workshops and interviews identified a number of contributing factors to the susceptibility for wind-driven rainwater ingress through windows and external glazed doors in social housing. These included the standard of design and as-constructed documentation, installation quality, inspections regimes, Australian standards, and the knowledge and training of window installers.

A number of recommendations were suggested by research participants, predominately related to improving the quality assurance process to mitigate wind driven rain water ingress through windows and external glazed doors. Seven specific recommendations are provided in this report under the following headings: (1) construction documentation – drawings and specifications; (2) contract documentation; (3) preparation and installation procedure; (4) auditing check list (AC); (5) installation quality form (IQF); (6) openings certificate (OC); and (7) auditing check grade (AC grade). All of these are detailed in the final chapter of this report.

Implementation of the recommendations should lead to a reduced frequency and severity rate of damage from wind-driven water ingress through window and door openings within social housing in northern Australia.

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1 Introduction

This chapter provides background on the topic. It then introduces the research objectives and scope of the study.

1.1 Background

The Bureau of Meteorology defines Tropical Cyclones as low-pressure systems that form over warm tropical waters and have gale force winds (sustained winds of 63 km/h or greater and gusts in excess of 90 km/h) near the centre. They can persist for many days and the task to define the direction of the cyclone is quite unpredictable. The gale force winds can extend hundreds of kilometres from the cyclone centre but they usually dissipate over land or colder oceans. Cyclones affect the North of Australia from November to April every year. A severe tropical cyclone is defined when the sustained winds around the centre reach 118 km/h with gusts in excess of 165 km/h. These are referred to as hurricanes or typhoons in other countries, such as USA and Japan. Tropical Cyclones are dangerous because they produce destructive winds, heavy rainfall, flooding and damaging storm surges that can cause inundation of low-lying coastal areas. These very destructive winds can cause extensive property damage (The Australian bureau of Meteorology).

Cyclone Tracy in Darwin in December 1974 was the most significant tropical cyclone in Australia's history, accounting for 65 lives lost due to building failure. The city population at that time was 48,000 inhabitants. The cyclone destroyed between fifty and sixty per cent of the city's houses and buildings and caused extensive damage to most of the remainder including many of the commercial and industrial buildings. Only six per cent were classified as intact apart from minor damage to wall cladding or windows and most of the rest were regarded as uninhabitable without major repairs. In the 1970s, single detached residential houses was not adequately structurally engineered to withstand extreme cyclone events.

An investigation of the damage, organised by James Cook University in Townsville, identified the causes of the failures leading to new design practices. From that point Darwin was reconstructed. This disaster led to changes in the Building Code, the incorporation of Australian Standards, Australian building regulations and various design manuals for housing, and it has had an impact on building construction throughout Australia (Walker, 2010). Many other cyclones have crossed Australia since then and James Cook University has continued doing building damage investigations, providing reports and recommendations. In November 1977, University's research group become an institution named the Cyclone Testing Station (CTS), with a specialised research unit for wind effects on buildings.

The last severe cyclone that passed the Queensland coast was Tropical Cyclone Debbie in March 2017 and it caused wind and water damage to buildings in the area between Bowen and Mackay. The CTS report for Tropical Cyclone Debbie indicated the same problem as in previous damage investigations regarding the vulnerability of: windows, flashings, gutters and soffit linings. Newer buildings had significant damage from wind-driven rain entering through windows and doors or under flashings even though there was no structural damage to the building. In the CTS report, the level of damage description used was: minor (includes broken windows, fences, gutters, awnings, carports and minor roofing or water ingress related failures); moderate; and severe/total damage (generally included more extreme versions of those failures with a high likelihood of water ingress or roofing failures). In Proserpine, a town between Bowen and Mackay, 1283 houses were surveyed in which 36% were recorded as having some form of damage considered severe/total (6%) and moderate (18%). The most frequently reported damage was water ingress (41%). In most of these cases there was no mention of roof or window damage, indicating that building envelopes were not adequately designed to resist wind-driven rain (Boughton et al., 2017).

The CTS report for Tropical Cyclone Larry (in March 2006) indicated that over 70% of homes had some form of water ingress damage (Henderson et al., 2006) (Henderson, 2013). The Tropical Cyclone Debbie report from the CTS investigation fortifies findings from previous CTS investigations that indicated that houses dated as pre-1980s are more susceptible to structural failures than those constructed after the 1980s. However, vulnerability is less dependent on age for minor damage (gutters, flashings, etc.) (Boughton et al., 2017).

The literature review of cyclones and their impacts on houses and buildings (non-structural failures), presented in detail later in this report, as well as discussion with industry practitioners about persistent problems still occurring as a result of storms and cyclone events, led to the formulation of this study. The study focus was contained to the identification of issues and maintenance prevention strategies for water ingress through openings in social housing. The scope was targeted to implementing corrective recommendations in coastal cities and towns located in northern Australia which experience frequent cyclones and severe storms.

1.2 Objectives

The research comprised three main research phases, each having key objectives:

Phase 1 – Knowledge acquisition

- *Objective 1.1* – To acquire in-depth understanding of the types of non-structural failures due to cyclones and heavy winds that have being damaging properties in northern coastal regions of Australia.

Phase 2 – Qualitative analysis

- *Objective 2.1* – To understand to what extent water ingress through windows and doors, and the surrounding waterproofing system, is a common maintenance issue caused by cyclones and high winds occurring in northern coastal Australia.
- *Objective 2.2* – To understand the issues related to the manufacture, design, installation, inspection and certification of windows and external glazed doors in residential buildings in northern coastal Australia.
- *Objective 2.3* – To solicit opinions on potential recommendations from the government and industry professionals on effective maintenance prevention practices to improve the openings resilience during cyclones and high winds.

Phase 3 – Maintenance prevention strategy recommendations

- *Objective 3.1* – To design feasible maintenance prevention strategy recommendations.

1.3 Scope

The scope for this research was limited to:

- New Social Housing[1];
- Natural hazards cyclone and severe winds in coastal cities and towns located in northern Australia (i.e. wind regions C and D according to AS/NZS 1170.2:2011 R2016);
- Water ingress into the building envelope through openings, particularly through windows and external glazed doors;
- Single skin block and brick veneer construction; and
- Residential buildings NCC Class 1 and 2[2].

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[1] Social Housing according to the DHPW includes public housing, community housing and state-funded affordable housing targeting low to moderate income households (DHPW).

[2] The Building Code of Australia, provides buildings classifications. This research refers to Class 1 and Class 2. The respectively definitions are: Class 1, A single dwelling being a detached house, or one or more attached dwellings, each being a building, separated by a fire- resisting wall, including a row house, terrace house, town house or villa unit attached or detached, and single, double or multiple-storey; and Class 2, a building containing 2 two or more sole-occupancy units each being a separate dwelling (QBCC).

2 Literature Review

The knowledge acquired during the literature review was the focus of Phase 1 of this research, which developed a deep understanding of cyclones and high wind events that affect northern coastal centres in Australia. The influence of design, construction quality conformance and maintenance on building resilience in cyclones and high winds was studied. The literature review helped to identify the research gap. Wind-driven rainwater ingress through undamaged windows and external glazed doors causing minor to moderate damage and incurring repeated life cycle repair costs, was identified as a major issue. A summary of the literature review is described below.

2.1 Storm events impact on the built environment

During the warmer months, from November to April, tropical cyclones are developed over the warm oceans of Australia's north, potentially generating destructive winds, heavy rain and flooding in many coastal areas in Queensland, Northern Territory and Western Australia. They lead to increasing then decreasing winds along with changing wind direction, over a number of hours. The diverse impacts of a cyclone can be felt over many days, over an area of hundreds of square kilometres, with the most destructive winds experienced just outside the eye of the cyclone. These destructive winds can generate windborne debris and cause extensive property damage. Decaying tropical cyclones can also impact non-cyclonic areas and cause significant damage (Ginger et al., 2010).

The Australian Bureau of Meteorology (BoM) categorises cyclones with increasing severity from 1 to 5, in terms of the Australian Cyclone Severity Scale, according to the sustained wind and maximum expected wind speed (**Table 1**).

Since 2005, 17 severe cyclones have made landfall in northern Australia, including Tropical Cyclone Larry in 2006, Tropical Cyclone Yasi in 2011, Tropical Cyclone Marcia in 2015 and most recently Tropical Cyclone Debbie in 2017.

Cyclone Tracy in Darwin in December 1974 was the most significant tropical cyclone in Australia's history, accounting for 65 lives lost due to building failure. The cyclone destroyed between 50 and 60% of the houses and buildings and caused extensive damage to most of the remainder including many of the commercial and industrial buildings. Only 6% were classified as intact apart from minor damage to wall cladding or windows and most of the rest were regarded as uninhabitable without major repairs. An investigation of the damage, organised by James Cook University in Townsville, identified the causes of the failures leading to new design practices. From that point Darwin was reconstructed. This disaster led to changes in the Building Code, the incorporation of Australian Standards, Australian building regulations and various design manuals for housing, and it has had an impact on building construction throughout Australia (Walker, 2010). The 1974 Cyclone Tracy caused over U.S. $500 million in damages, while more recently Cyclone Larry in 2006 led to over U.S. $1 billion in damages, of which 20% was to housing. The estimated loss value for Tropical Cyclone Debbie, March 2017, was AUD$1.47 billion with 34,795 Residential Building Claims (Insurance Council of Australia). The cyclone damage to buildings was through a variety of failures, from structural to non-structural elements.

Table 1 Australian Cyclone Severity Scale

Category	Sustained Wind (km/h)	Strongest Gust (km/h)	Typical effects
1	63 - 88	Below 125	Negligible house damage. Damage to some crops, trees and caravans. Watercraft may drag moorings.
2	89 - 117	125 - 164	Minor house damage. Significant damage to signs, trees and caravans. Heavy damage to some crops. Risk of power failure. Small watercraft may break moorings.
3	118 - 159	165 - 224	Some roof and structural damage. Some caravans destroyed. Power failures likely (e.g. Winifred).
4	160 - 199	225 - 279	Significant roofing loss and structural damage. Many caravans destroyed and blown away. Dangerous airborne debris. Widespread power failures.
5	Over 200	Above 279	Extremely dangerous with widespread destruction.

2.2 Cyclones - the impact in buildings and losses due to them

Building failures occur when winds produce forces on buildings that they were not designed or constructed to withstand. Other failures may be attributed to poor construction, improper construction techniques and poor selection of building materials.

Cyclones, strong winds, heavy rain and flying debris created during a cyclone can cause negative effects or impacts on buildings causing damage if they were not well designed, built or maintained (CTS, 2008). Depending on the building´s vulnerability, the effect can be minimal or extremely negative leading to a building collapse. It is necessary to consider the social and economic impacts on individuals and communities in addition to the costs of repairing the building (Suncorp, 2015).

After Tropical Cyclone Tracy in 1974, James Cook University set up the Cyclone Testing Station (CTS), since when the CTS has been conducting field surveys and studying and providing reports about the performance of buildings in response to cyclones and severe wind. From the reports of cyclones Larry (2006), Yasi (2011), Olwyn (2015) and Debbie (2017), some common non-structural problems were identified (Henderson et al., 2006, Boughton et al., 2011, Boughton et al., 2015, Boughton et al., 2017). A common conclusion from those reports was that the majority of post-1980's houses perform well during high wind loads; this would indicate that buildings structurally well designed and constructed using the appropriate Codes and Standards are safe against the region's design wind speed. However, financial losses were still occurring due to non-structural problems (Henderson et al., 2006).

To protect a large group of people from the impacts of a severe tropical cyclone, Queensland public cyclone shelters are designed and constructed with specific features and services in addition to those required for normal day to day functions. They are located on high ground, above ocean storm tide inundation levels and river or creek flood levels, near the evacuating community, directly accessible from a public roadway, and away from tall structures and trees or places storing fuel or hazardous materials. The cyclone shelter's structure differs from normal buildings as it is designed to withstand more severe wind pressures and windborne debris caused by wind gusts of up to 306 km/h (Category 5 cyclones). Its roof, walls, windows, doors and ventilation grills are all constructed to resist windborne debris. The doors to cyclone shelters are fitted with barrel bolts to strengthen the door to resist wind loads. Shutters are fitted to the outside and closed during a cyclone to protect external glass doors from windborne debris.

2.3 Critical non-structural building elements

The majority of houses in northern Australia were not built to be cyclone resilient. Although modern building codes have ensured that new buildings are structurally more resistant to cyclones, there is no requirement for non-structural elements in general to meet the same standards. If not properly protected, these become the weakest points in the building and, once breached, wind and water can enter the house, causing damage to interiors and contents (Suncorp, 2015). Specifically, roof vents, windows and external doors, holes, cracks, gaps, or the location where a pipe or cable pierces the roof or wall, may lead to water leakage, causing damage to walls, ceilings and carpets that may be disruptive and expensive to repair or replace (CTS, 2008). A list of these critical non-structural elements in a building is presented in **Table 2**.

Table 2 Critical elements in a building and summary of possible impacts during a cyclone event

Critical element	Description
Roof connections	Roof connections, e.g. tile connections, truss/ rafter-to-wall connections, batten-to-truss/rafter connections and roof sheet-to-batten connections are of major concern for both a metal or tile roof, especially on houses built before the mid-1980s.
Gable end walls	Gable end triangles, especially taller ones, should be properly braced and anchored to avoid collapse and great risk of damage to the house.

Critical element	Description
Windows and doors	The impact of flying debris commonly breaks windows and doors, allowing strong winds into the house causing high internal pressures which increase the risk of wall and roof failure. Door and window locks, as well as French doors and some sliding doors that do not have a sufficient wind strength rating can also burst open during cyclone events. The frames of external doors and windows that are not adequately fixed to walls may not be strong enough to withstand the wind forces. Water ingress is a problem in both damaged and 'undamaged' buildings.
Garage doors	The mechanism of high internal pressures that happens with broken windows and doors in houses also occurs when garage doors fail. This could lead to roof and walls failure. Installing adequately wind and debris rated garage doors, or even a permanent or temporary bracing system to garage doors, would reduce the risk.
Roof eaves	Inadequate fixing or support for the eaves lining, or far spans of the lining, may let rain and wind into the roof space, damaging ceiling and wall linings inside the house.
Attachments and equipment	Outdoor objects and equipment, such as antennas, satellite dishes, solar water panels, swimming pool equipment, hot water tanks and air conditioning equipment, if not firmly fixed may become flying debris that could impact buildings nearby.

2.4 Economic losses due to severe storm events

The Insurance Council of Australia (ICA) provides historical data through its webpage on disaster events and collects catastrophe related claims data from the Australian market, recording insurance loss estimates for declared insurance catastrophe events since 1967.

Table 3 summarises the estimated insurance losses of 16 severe events in Australia since 1967.

Table 3 Estimated insurance losses from severe events in Australia since 1967 (Insurance Council of Australia)

State	Event name	Event date	Estimated loss value (2015)
QLD, NSW	Cyclone Debbie	March 2017	$1,403,000,000
NSW, QLD, VIC, TAS	East Coast Low	June 2016	$421,696,229
NSW	East Coast Low	April 2015	$949,615,700
QLD	Severe Tropical Cyclone Marcia	February 2015	$544,163,458
VIC	Melbourne Severe Storm	February 2011	$526,651,637
QLD	Cyclone Yasi	February 2011	$1,531,573,196
QLD	Cyclone Tasha	December 2010	$393,000,000

State	Event name	Event date	Estimated loss value (2015)
NSW	East Coast Low	June 2007	$1,675,000,000
QLD	Cyclone Larry	March 2006	$799,000,000
QLD	Cyclone Justin	March 1997	$650,000,000
NSW	Sydney Region Storms	January 1991	$625,000,000
WA	Cyclone Joan	December 1975	$398,000,000
NT	Cyclone Tracy	December 1974	$4,090,000,000
QLD	Cyclone Althea	December 1971	$648,000,000
QLD	Cyclone Ada	January 1970	$1,001,000,000
QLD	Cyclone Dinah	January 1967	$877,700,000

2.5 Improving building resilience to cyclones and storms

2.5.1 Building envelope

The National Building Code of Australia defines the building envelope "as the part of a building's fabric (basic building structural elements and components of a building including the roof, walls, floors, windows ,doors and foundation) that separate artificially heated or cooled spaces from the exterior of the building" (The Australian Building Codes Board, 2016). The building's envelope function is to protect the structure against rain, wind, sleet and snow. Whenever there is a failure in an element of the building envelope, for instance a window with glass failures or the frame, a significant quantity of water may enter the building causing damage to the inside of the home (Boughton et al., 2015).

The CTS reports have been recurrently reporting, from damage investigations in different cyclones, that windows and doors are very weak elements in new buildings and also critical components of a building's envelope. Wind and water (wind-driven rain) get into the building causing damage, even if closed or undamaged; however, most of the houses did not suffer structural issues. The water passes through small spaces and weepholes in windows and doors (Henderson et al., 2006, Boughton et al., 2011, Boughton et al., 2017, Boughton et al., 2015).

2.5.2 Features of a strategic approach

There seems to be an under-investment in mitigation and a significant over-investment in disaster recovery, with only 3% of disaster funding being directed to mitigation and prevention activities. This finding is supported by Suncorp and the Productivity Commission's Natural Disaster Funding Final Report (Productivity Commission, 2014; Suncorp, 2015). The predominant practice is to accept low levels of building and infrastructure asset resilience to severe events, meaning that such assets are at high risk of non-structural damage and are repeatedly being rebuilt to the same standard after each severe event. Any short-term efforts to contain premiums without sufficient focus on preventative maintenance will fail to shrink the cost of cyclone and storm event recovery. Moreover, in the long term there will be a necessary spike in insurance premiums and/or significantly greater reliance on government support. Instead, the solution is linked to better planning controls for developments in high risk areas, strengthening standards for new buildings and retrofitting existing buildings (Suncorp, 2015).

Smith (2015) indicated that an effective mitigation program would require a combination of traditional inspections completed by a qualified inspector, in conjunction with asset users completing self-assessments through smart-phone technologies. Smith (2015) recommended that the following activities are still required:

- Continued discussions with building associations to promote skills and market niche branding for structural retrofitting of older housing;
- Collaboration with building product manufacturers to explore economies of scale opportunities for creating low-cost severe event resilience retrofitting components (e.g. shed tie-down, fence supports, gutter brackets, door braces, roof space framing connectors);
- Engagement with building and construction commissions, regarding the development of building certification documentation for retrofitting work to older housing, to allow homeowners and insurers to demonstrate effective structural mitigation.

It is possible to apply many of the general resilience attributes considered in complex systems into the building context. Locating a building in a less hazard-prone area could enhance its avoidance resilience attribute. The selection of certain construction materials could enable rapid recovery. During disruptive events, the building envelope, communications, heating, ventilation and cooling (HVAC), and electrical systems must all integrate effectively for a building to sustain safe operations. Code standards do not necessarily address continuity of operations; instead, they typically focus on structural safety and integrity. In this way, resilient buildings are often thought of as structures that exceed minimum code requirements so that the key building systems continue to function, enabling the continued operation of the building (Jennings et al., 2013).

2.5.3 Understanding the risks

Tropical cyclones and storms have a range of sizes and strengths, and although historical records have been analysed and studies of cyclone formation and movement have been used to predict the probabilities of occurrence of severe wind events in the future, there is no way of accurately predicting the strongest wind speed that will hit any house during its life time. However, it is possible to estimate the level of wind damage risk for specific locations in Australia. The probability that the design wind speed will be exceeded during the life of a given structure is small and it is even harder to predict whether it will occur earlier or later, or how many times. In order to obtain a comprehensive assessment of this risk, the *Northern Australian Insurance Premiums* taskforce (NAIP, 2015) commissioned modelling work which indicated that the expected long-term future losses from cyclones in northern Australia are around $285 million per year.

Different property types often use the same building materials and are built to the same Australian Building Code; thus, they have similar vulnerability in a wind event. In most respects, different property types should be capable of resisting design wind events if properly designed and constructed. For instance, water ingress from wind-driven rain has been identified as a key factor in insurance claims. This risk could be minimised by seeking a better understanding of the relationship of wind gusts and intensity of rain and identifying possible economic solutions in reducing the amount of water ingress and resultant damage (Henderson, 2013).

2.5.4 Improving a buildings life-cycle performance

Obtaining building approval prior to commencement of building works is a requirement in most states of Australia. This requirement ensures high standards in the structural features of buildings, and for the safe and appropriate use of materials during construction. Such standards represent a means of protecting the public's health and safety, the welfare of the structure and its surrounds. Particularly, there are two wind load standards that can be used in the design of houses in Australia, a general wind load standard that can be used for most types of buildings and all houses regardless of size (AS/NZS1170.2 – Design actions), and a standard that can only be used on houses that are within some geometric constraints (AS4055 – Wind loads for houses). Homeowners are encouraged to ensure that their designer and builder are aware of these standards (QRA, 2011).

When comparing the performance of newer construction over older buildings (pre-1980) in recent windstorms, it is evident that housing standards promoted significant improvements. However, that does not mean that some aspects of design and construction cannot be enhanced. Contemporary buildings may still present certain vulnerabilities to withstanding cyclonic wind loads. In newer buildings, a great proportion of roller doors fail under wind loads, resulting in dominant openings. Many buildings that were built prior to the release of the Queensland Home Building Code have been refurbished, but structural details remain the same, meaning that they are still susceptible to wind damage (Ginger et al., 2010). As recommended by Boughton et al. (2011), the strength of these houses should be assessed and, where necessary, upgraded to comply with the current Standards. For timber structures, the current requirements can be found in AS 1684.3:2010 and supporting industry documentation. General information on upgrading structural performance in existing houses can be found in the Standards Australia Handbook HB 132.2.

Every seven to ten years, structural elements such as the ones within the roof space, veranda posts, house stumps and associated steel bolts should be inspected by qualified builders, building surveyors or structural engineers, and if any deterioration is identified, the element should be remedied. Special care should be taken, because partially damaged elements inside the roof structure may not be noticed by external inspections. Where sub-standard building elements are identified, retrofitting should be undertaken to improve wind resistance in future events (Boughton et al., 2017).

Strengthening and sealing openings in modern buildings would reduce damage from water ingress, to a similar extent that strengthening roof structures would reduce the vulnerability of older buildings (pre-1980) to cyclone damage. This could yield reductions in claims and, therefore, premiums (NAIP, 2015).

2.5.5 Hardening, mitigation and preventative maintenance

Establishing a suite of rectification measures for existing buildings, continuing education of builders and designers in resilient construction, developing resilient materials for use in new buildings, and improving design details, would certainly enhance building resilience. Simple rectification solutions for fascia and gutter systems, retrofitting fasteners to soffits, rectification of tiled roofs that are not properly fixed, braces for roller doors are examples of measures that would contribute in a great extent to higher building resilience. Improving community awareness and engagement could be extremely cost-effective, and even simple actions such as bringing outdoor furniture inside, removing shade sails and securing garden sheds would contribute to reducing the number of minor claims (Henderson et al., 2014).

Mitigation opportunities identified by James Cook University (JCU) and reported by Suncorp (2015) to make homes more cyclone resilient include:

- ***Window coverings***: DIY window coverings can be installed for around $1,360, and can reduce the cost of a claim by up to $15,000;
- ***Roller doors***: Around 90% of modern homes have roller doors and their failure contributes to almost one in three large claims. After-market bracing costs just $300 and could prevent up to $10,000 worth of damage in the event of a cyclone;
- ***Roof upgrades (for pre-1980 houses only)***: The options are full replacements, additional strapping or over-battens, ranging in cost from $3,000 to $30,000. All upgrade options focus on tying the roof to the ground to handle high wind speeds.

When accounting only for the water ingress problem, which partly originated from the overpressure developed across the building envelope during windstorms (which can exceed the serviceability test pressures specified in AS 2047 for window resistance), resilience could be improved by:

- Occupant education to the likelihood that wind driven rain will enter the house;
- Using water resistant internal linings;
- Reducing water ingress by complying with a higher serviceability test pressure (Ginger, 2010).

Whereas inspections to detect progressive deterioration of a building structure, such as pest inspections, are usually undertaken at one or two-yearly intervals, inspection and maintenance of structural elements within the roof space should be undertaken for all buildings after any severe storm event, or when the roofing is removed, or at seven to ten year intervals, whichever comes first. Factors such as coating protection, moisture and proximity to salt spray, determine the rate of deterioration of building materials (Boughton et al., 2017).

2.5.6 Life-cycle Management

It is recognised that buildings may fail due to one or more of the following reasons: failure in design, failure during the construction, poor maintenance, faulty materials and faulty use (Flores-Colen and de Brito, 2010). An indication that design improvements are required is when problems arise from accelerated deterioration or repeated failure necessitating designs to be refined (Takata et al., 2004). The Life-cycle management of a construction project, as the name explain, is a management process with interaction of planning, design, construction, commissioning, utilisation, maintenance and decommissioning of the project and has the purpose to share and coordinate information between designers, consultants, contractors and others (Plebankiewicz et al., 2016). A comprehensive framework was proposed by Guo et al. (2009) (**Figure 1**).

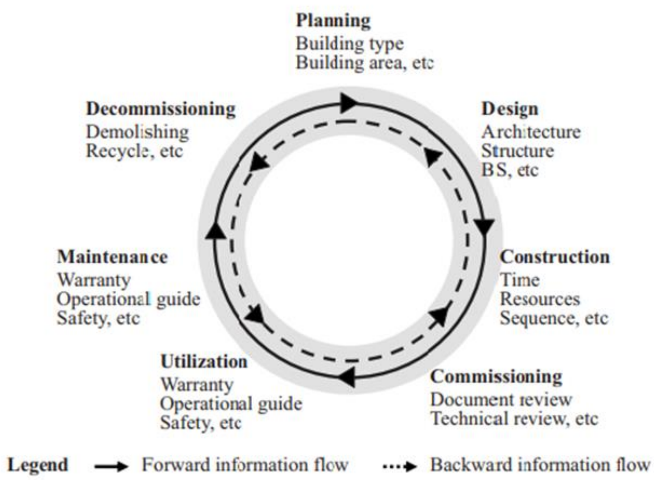

Figure 1 Lifecycle of a construction project Source: Guo et al. (2009)

The *planning* phase includes the conception; *design* involves initial design and detail design; *utilisation* means the use of the building; and decommissioning is the demolition and recycling of buildings or materials.

Guo et al. (2009) considered that the information of a phase influences and is influenced by successive phases. Whenever a decision is made, the impact is felt in predecessors and successors. For instance, during the design phase, if a product specification is erroneous, there is a risk factor that can interfere in other phases of the project. The Australian Window Association (AWA) declared that building plans usually do not designate the relevant wind loads for a building; this lack of quality specification causes important implications for choosing the correct window due to the diversity of requirements found in Australia for a diverse variety of buildings (Australian Window Association, 2017). During the *construction* phase, a random audit in Mackay in 2014 with 112 buildings found 9.82% (11 buildings) did not meet cyclone standards (Maddison, 2014). During the *utilisation* phase, there is a social aspect when the community, tenants and owners move in. The building may not be safe or may not have healthy living conditions, resulting in physical injury or damage to people or property. Many window defects, due to the lack of a good specification, present no increased risk of injury or damage to other property, but nevertheless affect the property owner or tenant or body corporate in the form of loss of use, diminution in value, and extra expenses incurred while defects are corrected. In addition, the replacement process might significantly inconvenience residents (Boughton et al., 2015).

Takata et al. (2004), consider the objective of the maintenance phase is to retain the condition of products so as to comply with their required functions throughout their life cycle. The *strategy planning phase* and *design phase* should be based on the evaluation of maintenance results where the maintenance team should consider having a mechanism for continuous improvement based on experience and knowledge gained through the life cycle.

2.6 Supply chain for wall openings (windows and doors)

A way to reduce cyclone damage is improving the resilience of homes. An effort from the openings (windows and doors) supply chain must be taken to address the wind-driven water issue. Those professionals are responsible for using the current Australian Building Code and appropriate Standards. This group is the Manufactures, the Architects, the Structural Engineers, the Constructors/Builders and the Building Certifiers. Each of these professionals plays an important role in the chain and must interact and work together, to provide client satisfaction.

2.6.1 Australian Building Code

Buildings codes are used worldwide with the purpose of ensuring safety. The Building Code of Australia has the same objective: the performance requirements for a building or structure are that it must remain stable and not collapse, prevent progressive collapse and avoid causing damage to other properties (Henderson, 2013). Building codes are drawn up by the Australian Building Codes Board; its job is to set minimum standards for the design, construction and performance of buildings to withstand extreme climate events related to natural hazards. Standards support the Building codes and buildings and houses must be designed according to them. However, it is suggested that there is still missing a large scope for increasing resilience and reducing the risk of loss if homes only meet the current standards (Suncorp, 2015). Some Building Codes were created or reviewed after a hazard happened. In Australia, the Building Codes have undergone a review in relation to wind speed against buildings, after Cyclone Tracy in 1974 devastated the city of Darwin; it was considered a big disaster, exacerbated by engineering failure (Walker, 2010). James Cook University conducted an investigation about the damage, resulting in new regulations applied into the new Australian Building Code introduced by the mid 1980s. In another example, Hurricane Andrew in the USA in 1992 did great damage in Florida; in response, the new Florida Building Code was adopted in 1994 based on the Australian studies and standard requirements developed after Cyclone Tracy (Salzano et al., 2010).

2.6.2 Windows and external glazed doors Standards

The current Standard test for water penetration, requires that openings can resist water on a normal windy day, but they are not tested to ensure that they will not leak in an ultimate limit states design wind event such as a cyclone. Boughton et al. (2011), suggest the development of a new standard for testing for weather tightness at or near the ultimate limit states wind speed.

The Standards related to this topic are:

- AS 2047 – 2014 Windows and external glazed doors in buildings; and
- AS/NZS 4420.1:2016 Windows, external glazed timber and composite doors – Methods of test. Part 1: Test sequence, sampling and test method.

Windows need to be tested for a number of conditions that will impact on their performance and durability. The AS 2047 – 2014 provides generic requirements. AS/NZS 4420.1:2016 “Windows, external glazed timber and composite doors – Methods of test. Part 1: Test sequence, sampling and test method” provides details of the tests. They are: 1. Design wind pressures; 2. Deflection/span ratio, 3. Operating force test; 4. Air infiltration; 5. Water penetration; and 6. Ultimate strength. Under the Building Code of Australia, window manufacturers are required to produce windows and doors that meet mandatory minimum specifications under Australian Standard AS 2047. All residential windows and doors must be marked with a performance label that confirms the windows or doors are certified to comply with Australian Standard 2047.

As the focus of the research is wind-driven rainwater ingress through windows and external glazed doors, the water penetration test is the one described next. The method for determining the resistance to water penetration is under a static wind load for windows in all classes of buildings. The water is sprayed uniformly and continuously over the exterior face of the test specimen. The visible inspection of the surfaces should be done throughout the water spray operation.

Boughton et al. (2015) were able to estimate the wind pressure on a window and compare it to the water penetration test pressure according to AS 2047 – 2014 / AS/NZS 4420.1:2016. The conclusion was that the estimated wind pressure was over two times the test pressure used to demonstrate the resistance to water penetration. The authors suggest the test method in AS/NZS 4420.1:2016 does not reflect the conditions that cause wind-driven rain ingress through undamaged windows during high wind events and that higher test pressures are necessary.

2.6.3 Manufacturers

The Australian Windows Association (AWA) is a group formed between manufactures and industry suppliers. **Figure 2** shows an example of a label from the AWA with specifications in accordance with AS 2047.

Figure 2 Windows label for accredited manufacturers from the AWA (Australian Window Association [Online])

The AWA has been providing valuable information about window and doors through guidelines and videos. The guidelines refer to: fixing, installation and materials selection (Australian Window Association, 2015, Australian Window Association, 2012, Australian Window Association, 2010). An example is the video "How to install an aluminium sliding window into brick veneer construction" (https://www.awa.org.au/). The Australian Fenestration Training Institute is part of the AWA and provides training classes and workshops to the industry (Australian Fenestration Training Institute).

2.6.4 Building Inspections

In relation to building approvals, Building Certifiers or Superintendents have responsibility to provide this, based on site inspections, if the building work complies with the building assessment. A compliance certificate is given based on provisions of the Building Act 1975 (BA) and the building development approval which includes the BA, the Building Regulation 2006 (BR), the National construction code and the Queensland Development code or relevant code from other States or Territories. Two certificates are given; the first one after excavation of the foundation material and before the footings for the building are laid; and a second certificate, named the Final Inspection Certificate, in the approval for the final stage of the building works. The guidelines developed by the Queensland Government, "Guidelines for inspection of class 1 and 10 buildings and structures" (DHPW, 2011) proposes a summary of the process to Building Certifiers and Builders to meet their responsibilities in relation to mandatory inspections. It is mandatory to have an inspection during the frame stage, which is the third inspection of four stages. The frame stage is the phase before the cladding or lining is fixed, or, for reinforced masonry construction, before the wall cavities are filled. This is the stage for windows and doors inspections.

2.7 Research gap

Wind-driven rainwater through windows and external glazed doors remains a recurrent issue during cyclones and high wind events and the research scope was therefore narrowed to those elements.

Heavy rain usually accompanies most cyclones and windstorms which generate large differential pressures across the building envelope (Henderson et al., 2006). Wind-driven rain moving through the building envelope arises from a high differential pressure between the inside and the outside of a building that may occur in high winds (Boughton et al., 2011). The wind-driven rain may pass through the building envelope via closed windows/doors, through linings or around flashings and/or through seals wherever the building envelope has been damaged. Consequences may include the replacement of carpets, change of linings and replacement or repair of devices/electronics (Henderson, 2013).

Miller (2014) suggests that current regulations address wind-loading associated with cyclones, but take no consideration of wind-driven rain (a major cause of water damage). The Standard AS 2047 provides information about the selection and installation of windows, but due to low test requirements for windows/doors, water ingress and associated damage to houses can be expected when heavy rain occurs with wind speeds greater than about 30ms/s or 120km/h (a cyclone Category 4) (**Table 1**). The actual wind speed occurring in a cyclone frequently exceeds the serviceability test pressure specified in AS2047 for window resistance to water ingress (Henderson and Ginger, 2008).

There is considerable evidence from the literature, which includes several reports made by CTS and published international journals, showing concern with the recurrent water ingress through undamaged windows, becoming critical in residential constructions in Australia (Henderson et al., 2006, Ginger, 2010, Boughton et al., 2011, Henderson et al., 2014, Boughton et al., 2015, Boughton et al., 2017, Lopez et al., 2011). Water ingress through windows is also a type of a recurring failure detected in Florida after hurricane events (Salzano et al., 2010).

Smith (2012) states “With this flood of systems there have been some serious issues around Australia in regard to how the penetrations are dealt with. We have witnessed many failures due to a lack of detail or just a lack of understanding of how these penetrations should be treated. Window and door systems definitely gain a large amount of attention from builders and consumers; it is often thought that the window systems are leaking, when in reality (in 75% of cases), it is actually the installation that is the problem. Doing it right the first time is the best thing”.

The most recent cyclone that passed Australia was Tropical Cyclone Debbie that reached the east of Airlie Beach, Queensland on Tuesday 28 March 2017 and was classified as a Category 4 cyclone. The estimated loss value was AU$1,711,298,765 with 34,795 Residential Building Claims (Insurance Council of Australia). The damage to buildings included a variety of failures, from structural to non-structural elements, with partial or total destruction of the building. During an investigation by CTS after Tropical Cyclone Olwyn in March 2015 in Western Australia, people were astonished at the large volume of water ingress into houses and the damage it caused (Boughton et al., 2015). Boughton et al. (2015) suggested the water ingress through undamaged windows was affected by the type of window (closing and opening mechanism); the type of seals; and the manufacture of the window or door.

2.8 Summary

Technical reports No.63 and No.57 from CTS revealed in detail the investigations performed in buildings and houses affected by Tropical Cyclones Debbie (2017) and Yasi (2011), which crossed the tropical Queensland coast with categories 4 and 5 respectively. Those reports provided an in depth understanding of the vulnerability to cyclone forces of some non-structural building components from the building envelope.

As learned from the first report, cyclones produce destructive winds and heavy rains. Water ingress inside the building, through the building envelope (windows, doors, roof and walls) was a common issue described previously. Each component of the building envelope is composed of connected pieces, but which are the ones that have being failing? For example, the parts of a window are: the window frame, the seals and bolts. The parts that compose a roof are: the tiles, the bolts, gutter, truss connections, roof-mounted items such as aerials and vents. A table was developed to summarise the investigations made by CTS in reports No.63 and 57 (**Appendix A**), adapted from (Boughton et al., 2017, Henderson, 2013, Boughton et al., 2011).

The analysis of the table resulted in identification of a set of categories of failures (**Figure 3**):

1. Material/design
2. Bad installation/material/design
3. Bad installation
4. Bad installation/material
5. Design
6. Design/bad installation
7. Material

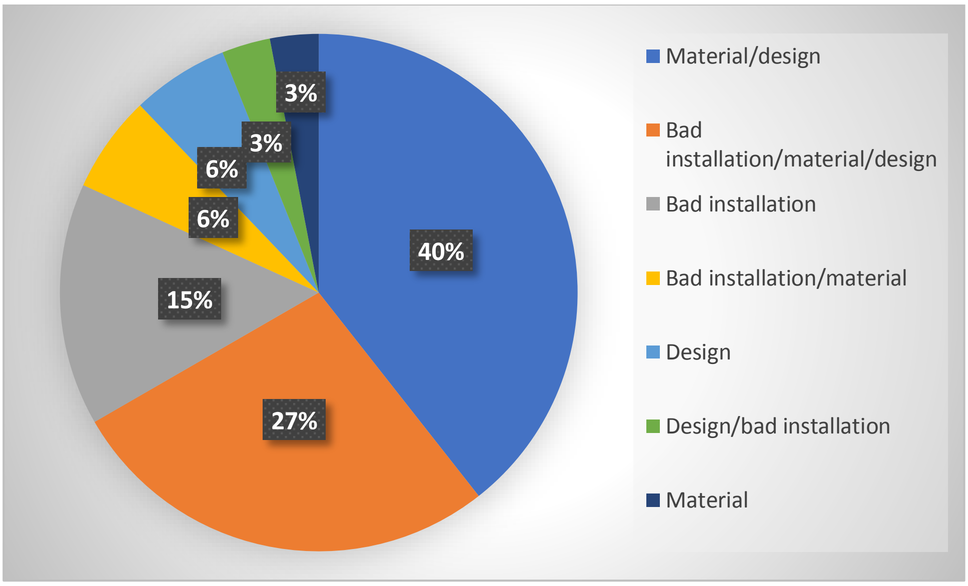

Figure 3 Categorisation of non-structural failures in buildings investigated in CTS reports No.63 and No. 57

3 Research Method

The literature review identified a gap in the research related to wind-driven water ingress through windows and glazed door openings that caused repeated minor to moderate damage in residential buildings located in northern Australia. The next phase of the research was to design and implement a research methodology to confirm this research gap and to identify causal factors and corrective recommendations. It was anticipated that industry knowledge would help to identify the types of actions required to mitigate wind-driven rain through windows and external glazed doors.

3.1 Planning the research method

A participatory modelling approach, to collect data through specialists' opinion, was considered ideal. For this study, a qualitative data collection process and analysis was chosen as the ideal approach due to the necessity for investigation of current practices in the 'openings' supply chain. A mixed research method was planned including phone interviews and workshops, which included the use of questionnaires. The identification and selection of potential participants for the phone interviews and workshops was an important consideration. The participants should incorporate different areas of expertise in order to obtain a wide overview.

It was considered that implementing an approach where participants were really engaged in the project would enable better understanding of what is really known about the building performance, level of design and level of product specifications.

During the analysis phase, transcriptions were studied with codes applied to individual participants to provide anonymity. Thematic analysis was used for the transcribed data to extract meaningful findings.

3.2 Data collection method

The data collection process revealed the causes of the wind-driven water ingress through windows and external glazed doors during cyclones and severe winds that are prevalent in northern Australia. Moreover, it identified a series of preventative maintenance recommendations. As well as phone interviews and a workshop, a field site visit and a field site laboratory visit were made. The data collection was conducted from November 2017 to March 2018. The phone interviews were conducted with industry practitioners including Building Certifiers, Installers/Builders, Manufacturers, Architects and Construction companies based in Cairns, Townsville and the Gold Coast. Three workshops were conducted: (1) National Glass & Aluminium Manufacturer staff based in Brisbane (large manufacturing company of aluminium windows/doors and glass products): (2) Building and Asset Services staff from the Queensland Department of Housing and Public Works and a Major Building contractor staff in

Townsville; and (3) Cyclone Testing Station (CTS) researchers from James Cook University in Townsville. The data collection and analysis procedure helped to: (a) understand the entire supply chain for the design; (b) understand the current level of construction and inspection of building openings; (c) identify the role of each involved professional; (d) understand the current level of design, products specifications and inspections; (e) identify barriers to changed practices; and (f) identify good practices and identify recommendations.

Phone interviews were conducted with 27 Industry and Government experts. A field site visit, a workshop and a field laboratory site visit were conducted with a total of 12 people, thus reaching a total of 39 participants. In **Appendix B**, a list of the participants and job roles is provided. Each participant has a code which was used for thematic analysis.

3.2.1 Phone interviews

Phone interviews were conducted with experts from the Gold Coast, as well as from two of the larger cities in northern Queensland (Townsville and Cairns), where respondents would be experienced with issues related to high wind events. Companies and contact numbers were found through phone directory and Google searches. The phone interviews included both structured and open questions. Purposefully, the approach was to give the interviewees the freedom to talk about the issue broadly, but with the interviewer asking some key questions to prompt discussion on those topics. This approach was used to help the respondents feel comfortable in talking and providing their knowledge about the problem, their work process, their concerns, complaints and recommendations. The full list of questions asked during the phone interviews is in **Appendix C (a)**. Interviewees were classified into five position categories: (a) 12 Building Certifiers; (b) 10 Installers/Builders; (c) 1 Aluminium Window/Door Manufacturer; (d) 2 Architects; and (e) 2 Construction companies.

3.2.2 Field site visit, workshop and laboratory visit

The field site visit occurred at a major glass and aluminium manufacturer in Brisbane; the workshop involved staff from the Queensland Department of Housing and Public Works (DHPW) in Townsville and the field laboratory site visit was at the CTS at James Cook University in Townsville.

The two-hour long field site visit and meeting on 1st of March 2018, in Brisbane, occurred in the office of the major glass and aluminium product manufacturer. The participants included the Branch Network Operations Manager, Senior Product Designer, Structural Engineer and the Commercial Technical Advisor. The themes of questions/topics discussed can be seen in **Appendix C (b).**

The three-hour workshop in Townsville on the 22nd of March 2018 took place at the DHPW office. Participants at the workshop included two Acting District Managers, an Acting Delivery Manager and a Senior Superintendents Representative from DHPW, as well as a North Queensland Manager and Project Manager from a major building contractor. This workshop focused on understanding the involvement of DHPW from the design to the construction and inspection stages. The questions used as a guide to generate a discussion between the participants can be found in **Appendix C (c).**

The site/laboratory visit at the CTS, at James Cook University, was held in the afternoon of 22nd March 2018 in Townsville and had the presence of the Director and a Senior Research Fellow of the institution. The meeting was an open discussion about reported issues and a laboratory visit to the test rigs. At the test rigs, two simulations were performed. One of them was a simulation of the impact of debris in a window and the other was a simulation of a window receiving a high dynamic wind driven rain pressure that replicates a fluctuating cyclonic pressure. The water penetration test at the AS 2047 – 2014 in accordance with AS/NZS 44020.1:2016 specifies only a static pressure.

4 Data Analysis and Findings

After each data collection activity was completed (i.e. phone interviews, workshop, field site visit and field site laboratory visit) a transcription was carried out for that activity. The transcripts resulted in four broad categories of water ingress issues through building openings and formed the basis of the strategic recommendations.

Table 4 to 7 present the results of the thematic analysis. These tables include the barriers and preliminary recommendations mentioned by respondents. Respondent codes are provided in **Appendix B**. Four core categories of barriers were identified, including: a) Standards; b) Inspection regime; c) Installation quality documentation; and d) Liability and recourse.

The *Standards* category focused on the adequacy of serviceability testing requirements for windows (AS 2047-2014 and AS/NZS 4420.1:2016). The *inspection regime* category was focused on the difficulties in inspecting windows and the level of design documentation provided by builders for new buildings. The *Installation quality regime* category presented issues related to workmanship quality documentation (i.e. Form 16 utilisation and extent of completion for Queensland). The final *liability and recourse* category focused on the importance of responsibility assignment for issues related to water ingress through windows/doors.

This stage of research was focused on revealing the main causal factors leading to window serviceability failure modes. The findings revealed many opportunities to improve process and procedures for asset owners of Social housing as well as wider industry. These included improvements in practices related to documentation, inspection, liability assignment, and installation training for building windows/doors, especially in locations where severe winds are prevalent (i.e. northern Australia). Insights from the interviewees are available in **Appendix E**.

The results of the performed thematic analysis revealed similar responses coming from different respondent categories.

4.1 Standards category

In **Table 4**, the frequency of water ingress through wind-driven rain is something that was mentioned during every interview and workshop, field site visit and the field site laboratory visit, confirming the research gap. This issue was acknowledged as a significant cause of maintenance in high wind category regions. This repetitive process of failure of these building elements and the resulting minor to moderate repair requirements afterwards is relatively commonplace in the coastal areas of northern Australia where high wind events are quite prevalent.

Some participants suggested that improvements to Australian Standards are required to reduce water ingress during extreme wind driven rain since "*they are currently not sufficient*". While a critical issue for examination, the scope of this research does not cover a thorough investigation on building standards and codes related to serviceability requirements for windows, so it will only make broad recommendations on this topic.

4.2 Inspection regime and installation quality regime

Table 5 and **Table 6** provide the issues related to installation and inspection.

For the workshop and the field site visit, the participants mentioned two key issues, being: a) a lack of control during installation and in the inspection process; and b) the workshop with DHPW included also the lack of clear rules / specification scope for tendering and responsibilities during the process.

As the data collection only had participants from Queensland, Form 16 (DHPW) was highly cited, which is a Queensland certificate that can be issued by installers at the completion of any works performed on new buildings**.** People from the workshop, from the field site visit and from the phone interviews indicated that when this form is completed, it is often with insufficient details, mostly just being a sentence stating that the window has been installed in accordance with relevant standards. Inspecting windows and glazed door installations is not viewed as a critically important milestone for residential building construction (i.e. like frame stage) so it is often not carefully inspected. Moreover, since there is a very limited time available to inspect windows and associated waterproofing efforts, they are not often checked independently. Given that there is little in-depth inspection of windows and poor quality documentation provided by installers, when preventable water ingress occurs after high wind events, there is little chance that a building owner can link failure modes to liable parties.

DHPW representatives from Townsville mentioned a few simple information requirements that could be added to Form 16 that would ensure that installers of windows and glazing, as well as builders would feel more responsible for the quality of their work. One person interviewed said that "*poor construction can be mitigated by focusing on the liability of the builder*".

4.3 Liability and recourse

Related to worker skills, the comments were mixed with some interviewees not mentioning any concern while others mentioned that workers had insufficient knowledge on waterproofing and installation practices.

During the workshop with DHPW, there were some concerns on the low level of design documentation required from contractors during the construction stage of a project. Having less detailed drawings and specifications made it challenging for inspectors to decipher whether work was completed according to good practice.

Many mentioned that the lack of good documentation and specification for openings combined with a lower level of concern by builders and inspectors to check the quality of these non-structural elements, meant that there was a lower level of concern to ensure a quality installation than for other building elements. Moreover, the hidden nature of opening preparation and waterproofing, as well as window/door installation works, meant that it could be easily overlooked.

Finally, given that water ingress results in only minor to moderate damage and does not result in any catastrophic failure or loss of life, the poor installation of window and glazed door openings is often not fully understood until a few years after construction has been completed. At this time, it is very difficult to determine the causal factors leading to the problem, as well as the responsible parties, and owners will typically just complete minor repairs after each storm event on an ongoing basis. **Table 7** outlines factors related to the liability and recourse category.

Table 4 Participant responses in the *Standards category*

Respondent Group	Issue	Respondent code[1]	Issue consequences	Issue mitigation recommendations	Recommendations made by	Respondent code[1]
Manufacturers, Architects, Builders, Building Inspectors	Standards for water penetration serviceability requirements inadequate (AS 2047-214 and AS/NZS 4420.1:2016)	BC11; BC6; M1; IA; A2; I/B1; I/B3; I/B10; BC10; BC11; BC12	Water ingress through the windows/doors frames, seals and glazing	CTS from JCU is conducting tests to replication high dynamic range (HDR) pressure similar to a cyclonic pressure. They intend to propose HDR testing as a requirement in AS 2047-214 and AS/NZS 4420.1:2016	Manufacturers, Architects, Builders, Building Inspectors	IA
Builders, Installers and Building Inspectors	Lack of knowledge with Australian Standards for specification, installation and waterproofing of windows and external glazed doors	M1; M2; BC1; BC3; BC4; BC6; I/B3; I/B7; I/B10; G	Poor quality and low level of inspection of work related to the preparation of the window/door opening, its installation and waterproofing, which leads to instances of water ingress	Industry training to improve familiarisation with relevant windows and glazed doors installation and waterproofing standards	Builders, Installers and Building Inspectors	M1;G; BC1;BC7; BC9;I/B1; I/B2;I/B4; I/B5;I/B8; I/B10

Notes: [1]Refer to Appendix B for respondent comment codes.

Table 5 Participant responses in the *Inspection regime category*

Respondent Group	Issue	Respondent code[1]	Issue consequences	Issue mitigation recommendations	Recommendations made by	Respondent code[1]
Building Certifiers	Not actively inspecting windows/doors	M1;BC1; BC2;BC3; BC4;BC6; BC8;M1; I/B1;I/B3; I/B7;G	There are four mandatory stages requiring inspection, the third stage is the frame stage which considers before the cladding or lining is fixed or, for reinforced masonry construction, before the wall cavities are filled. There is no appropriate timing to inspect the preparation stage (waterproofing system) to finally, the opening installation.	Audit a certain percent of installed windows/doors by builders and inspectors	Building Certifiers	
Superintendents /Inspectors from DPHW	Superintendents have less work oversight than previously when traditional construction documentation was more detailed. Builders are tendering and constructing works with lower levels of design documentation than previously due to the current procurement method chosen by HPW.	G;I/B4; CC1;BC3	Less control of the building process. Previously, detailed design documentation was provided to prospective builders at the tender stage, which provided HPW with greater control over the level of building specification they wanted. This also enabled inspectors to better review building works completed and to identify any deficiencies.	Either greater degree of design documentation by HPW or requirement for builder to provide more detailed as-constructed information and certification on works quality	Building Certifiers	G;I/B4; CC1

Notes: [1]Refer to Appendix B for respondent comment codes.

Table 6 Participant responses in the *Installation quality regime category*

Respondent Group	Issue	Respondent code[1]	Issue consequences	Issue mitigation recommendations	Recommendations made by	Respondent code[1]
Builders and Manufacturers	Installation work quality documentation (i.e. Form 16 in Qld) often not completed or completed with limited information (i.e. statement saying that works according to AS)	M1;M2; BC1;BC3; BC6;BC8; BC9;BC11; I/B7;G	Lack of work quality documentation means installers place less emphasis on critical serviceability aspects and greater rates of water ingress during high wind events	Require builders to provide clients a detailed windows/doors installation quality form including details of fixing requirements, waterproofing process and materials, photos, etc.	Building Certifiers	M1;G; BC9
Building Certifiers (Superintendents from DPHW)	Superintendents have less work oversight than previously when traditional construction documentation was more detailed.	G;I/B4; CC1;BC3	Lower involvement and thus ownership of the construction process by HPW staff and a lower level of ability and authority to request builders to rectify substandard works	Provide more detailed specification at the design stage and require builders to provide detailed as-constructed information on the work completed including photos	Building Certifiers	M1;I/B4; G

Notes: [1]Refer to Appendix B for respondent comment codes

Table 7 Participant responses in the *Liability and recourse category*

Respondent Group	Issue	Respondent code[1]	Issue consequences	Issue mitigation recommendations	Recommendations made by	Respondent code[1]
Architects, Manufacturers, Builders, Installers	Poor quality work with regards to installing windows and doors	G;BC1; BC6;BC7; I/B;I/B2; I/B3;I/B4; I/B5;I/B7; I/B8;I/B9; I/B10;BC6	Water ingress through windows/doors during severe wind-driven rain events in prone areas of Australia	1. Better specification in drawings in relation to waterproofing systems and include in the windows/doors drawings, provided by manufactures, type of fixing and spacing 2. Promote more training to trades 3. Make builders more responsible for meeting serviceability expectations	1. Architects 2. Builders to trades	BC6
Architects, Manufacturers, Builders, Installers and Building Certifiers	Limited documentation of installation work quality (i.e. Form 16)	BC1;BC2; BC6;BC11; BC12;I/B1; I/B12;M1; G;M1	No evidence available to indicate whether installer / builder is responsible for poor quality work during building operation stage	clients a detailed windows/doors installation quality form including details of fixing requirements, waterproofing process and materials, photos, etc.	Builders and Building Certifiers	M1;G
Building Certifiers	Limited inspection of windows and glazed doors	M1;BC3; BC11;BC12; I/B3;I/B7; I/B12;G	Limited inspection means that installers are less focused on providing a very high standard of work quality for building	Audit a certain percent of installed windows/doors by builders and inspectors	Building Certifiers	M1

			elements that are viewed as being less critical			
Architects, Manufacturers, Builders, Installers and Building Certifiers	Repetitive incidences of wind-driven rain water ingress	BC12;BC3; BC4;BC6; BC8;BC9; BC10;BC11; BC12;I/B3; I/B5;I/B6; I/B9;I/B10; G;CC1;M1; IA;G	Water ingress through windows/doors every severe wind event in northern Australia causing maintenance requests for minor to moderate repairs (e.g. change of carpet, change of plasterboard, paint walls, etc.)	1. Investigate the cause effectively with quality information to identify causes and responsibilities 2. Development of KPI to monitor building performance 3. Develop targets and plans to reduce incidences 4. Raise awareness of issue through internal communication in HPW	DHPW Maintenance Team	BC4; BC6
Builders, Installers and Building Certifiers	Industry culture whereby installers and builders have a lower level of concern for the serviceability of buildings elements such as windows and glazed doors	BC1;BC2; BC4;BC6; BC8;I/B1; I/B5;I/B7; M1;BC2; BC9;BC11; BC12;M1; G;M1	Limited inspection and documentation of window and glazed door installations; Less focus on meeting serviceability requirements by installers and builders; limited education on relevant serviceability standards	Educate builders and installers of the importance of quality installation of windows and glazed doors in order to reduce life cycle maintenance costs	DHPW Maintenance Team, Building Inspectors, Architects, Builders, Manufactures	BC6

Notes: [1]Refer to Appendix B for respondent comment codes

5 Recommendations

5.1 Recommended quality assurance process

Research from this project has indicated that the current glazing process is sometimes of insufficient quality, resulting in recurrent repairs and the overall lower quality of the construction. There is little opportunity for government representatives to inspect and assure work quality with the current standard of documentation and during the preparation and installation currently provided.

In many industries, the implementation of a quality assurance method proves to be an invaluable technique when developing methods to achieve a desired quality in a service or product. The following recommendations are proposed to ultimately mitigate water ingress through windows and external glazed doors during the design and construction process. In order to implement the recommendations, a quality assurance process has been designed involving the supply chain for wall openings. The objective is to perform continuous quality control processes during the design and construction phase for windows and external glazed doors.

Seven core recommendations are described below.

- **Recommendation 1:** Construction documentation – drawings and specifications
- **Recommendation 2**: Contract
- **Recommendation 3:** Preparation and installation procedure
- **Recommendation 4:** Auditing check list **(AC)**
- **Recommendation 5:** Installation quality form **(IQF)**
- **Recommendation 6:** Openings certificate **(OC)**
- **Recommendation 7:** Auditing check grade **(AC grade)**

Figure 4 provides a schematic quality assurance process to be implemented throughout the design and construction of a project, including the seven core recommendations.

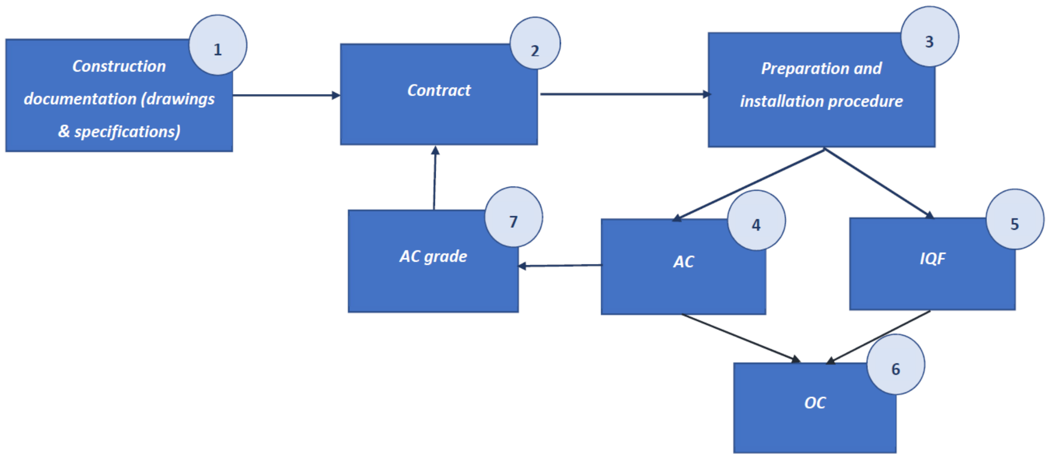

Figure 4 Schematic quality assurance process during design and construction of openings

5.2 Recommendation 1: Construction documentation

5.2.1 Drawings and specification requirements

The Department of Housing and Public Works (DHPW) procures Social housing through two main procurement models. The differing nature of each method has an effect on the outcome for resilience of the completed wall openings; they are described below:

(a) Completion of detailed design and documentation before negotiating a contract for *"Construction only"*

For ***"Construction only"***, DHPW directly controls the design and documentation to ensure that complete and thorough documents are used for the construction tender. The construction documentation (drawings and specification) is completed by private Consultants and included within the tender documents for the construction tender. Once a tender offer from a builder is accepted, the Construction documentation (drawings and specification) then become part of the Contract that the builder agrees to (**Figure 5).**

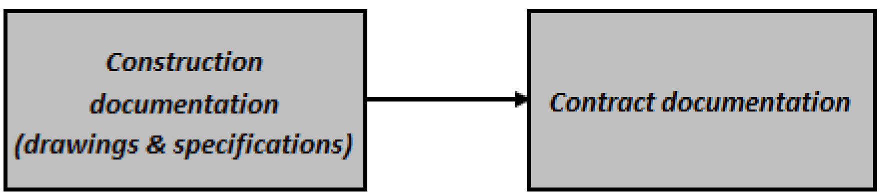

Figure 5 Procurement contract for *"Construction only"*

(b) Completion of a feasibility study and/or preliminary design before negotiating a contract for *"Design and Construction"*

For the ***"Design and Construction"*** process, DHPW enters a contract earlier but has less control of the design and documentation than in ***"Construction only".*** Tender documents (including the Contract) are prepared by DHPW and then a tender is called for a developer to design, document and build the project according to criteria defined in the Contract. It is a different contract to the one used in "Construction Only". Sometimes this Contract includes a preliminary design and/or specification that must be complied with, sometimes it doesn't. The **"*Design and Construction*"** contract does not define the level of detail required in the Construction Documentation (drawings and specifications) to be prepared by the developer (**Figure 6**).

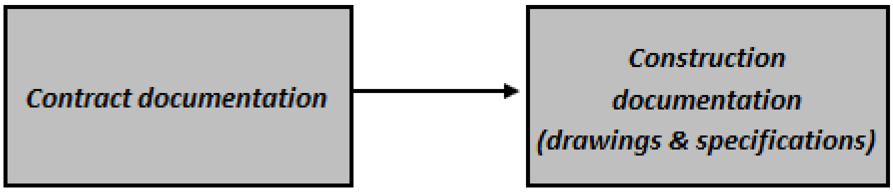

Figure 6 Procurement contract for *"Design and Construction"*

The recommended quality assurance process (**Figure 4**) for use by DHPW, has to adapt the order of items 1 and 2 according to the ***"Construction only"*** and ***"Design and Construction"*** process explained in **Figure 5** and **Figure 6**. For ***"Design and Construction"***, Contract documentation (item 2) is before Construct documentation (drawings and specifications) but for ***"Construction only***", the process in **Figure 4** is the same.

Research on the current design specifications/details for Social Housing projects indicated that the move towards "***Design and Construct***" procurement for public housing in government departments, has resulted in poorer quality design and as-constructed information being produced by contractors. The workshop with DHPW identified this issue and the need for improved documentation. It was concluded that there is a need to provide more detailed requirements within the tender documents that indicate the level of detail required from the contractor when providing their construction design documentation.

This recommendation suggests that for ***"Design and Construction"*** arrangements, either:

- That process be limited to projects where detailed documentation is not required, or
- The building contractor be required to provide fully detailed construction documentation and specifications for the documentation stage and for as-constructed records on handover of the project.

For ***"Construction Only"*** projects, the recommendation is that:

- DHPW should ensure that fully detailed construction documentation and specifications are provided in the documentation stage and,
- The builder is required to provide as-constructed records on handover of the project. This documentation should include detailed design documentation and specifications to describe the installation of windows and external glazed doors.

5.2.2 Design details for wall openings

Generally, it was identified that simply providing a greater quality check and approval system incorporating design details for each wall opening can reduce the overall ongoing cost of the building. For windows and external glazed doors, a typical waterproofing system detail should include specifications for the substrate, sub-sill, waterproofing membrane system, head, side angles and watertight seal.

Related to buildings in Wind Regions C and D of Australia, there is a need for better construction documents for windows and glazed door openings. The following recommendations and specifications should be considered for the design phase:

1. Durability and compatible sealants;
2. Preparing the substrate;
3. Preparing the opening with appropriate membrane system;
4. Curing;
5. Head, side angle flashing, sub-sill and dam ends;
6. Flashings, drip moulds, storm moulds and trims;
7. Fasteners; and
8. Consideration for storm shutters.

1. Durability and compatible sealants

The quality of the sealant material can often determine the durability of the window or door installation over a period of time. Without durable materials, any construction project leaves itself open to short and long-term resilience issues. With this in mind, a poor-quality sealant has the potential to be the sole cause of leakage of water through windows and doors.

The recommendation is the use of a polyurethane-based sealant. This must be used with a compatible primer and the substrate must be free from dust, grease and loose material. This will ensure the cleanliness and increase durability and adhesive bonding between the sealant and substrate. The technical datasheet must be reviewed to ensure the overall performance of the waterproofing system, ensuring the approved primer and sealant is used for a watertight seal.

2. Preparing the substrate

The substrate specification must be detailed to include appropriate falls of no less than 15 degrees as suggested by the Australian Window Association (AWA) to ensure the free flow of water drainage toward the exterior of the structure, with the exception of residual water remaining due to surface tension. The design must also include a perimeter water stop. Examples of designed substrates are provided in **Figure 7** and **Figure 8**.

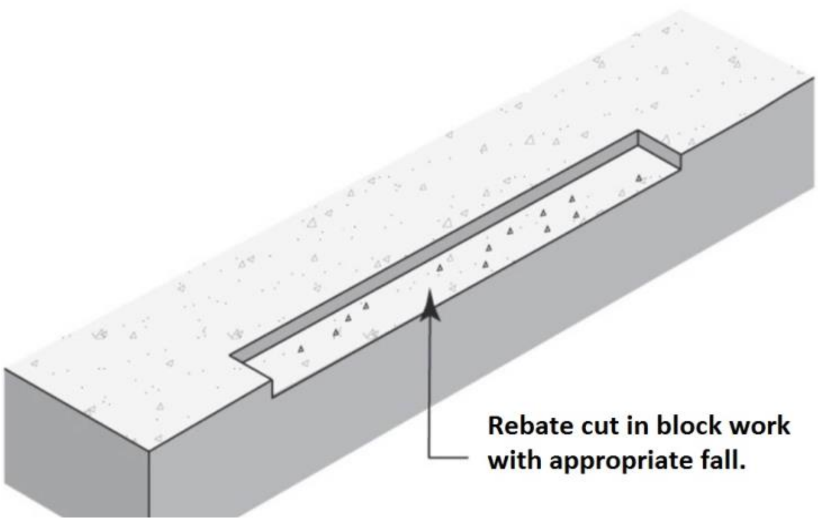

Figure 7 Example of physically cut rebate with appropriate fall of no less than 15 degrees (Source: AWA)

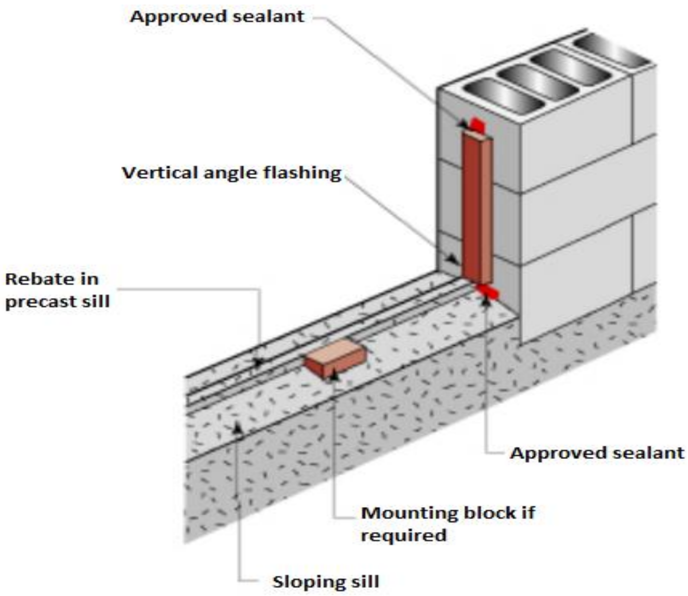

Figure 8 Example of precast sloping sill (Building Science Corporation)

3. Preparing the opening with appropriate membrane system

The membrane preparation must follow *AS 4654.2.2012 waterproofing membranes for external above ground use Part 2 Design and installation*, item 2.5.3.1. Whereby the preparation of the opening for fully-bonded or liquid-applied membranes shall result in the surface of the substrate being smooth, without protrusions, voids or formwork distortions, clean, dry, and free from dust and contamination. Design specifications must include a note stating liquid waterproofing system should extend to a minimum length of 200 mm beyond the opening and must be continuous.

4. Curing

The importance of curing components of a membrane system is highlighted in *AS 4654.2.2012, Section 2.6.2*. Manufacturer's specifications must be consulted in relation to curing times of products. Further work should not be commenced until the membrane is cured. Premature covering of the membrane may prevent it from curing and may lead to its degradation. Due to varying curing times, intervals between applied membrane coatings must be considered. Design specifications must include a note highlighting the importance of curing when designing the structure and the necessity of the verification of the manufacturer's datasheet for further details of the product.

5. Head, side angle flashing, sub-sill and dam ends

Appropriate designed sub-sill incorporating dam ends installed with head and side angle flashings to allow for the free flow of water without any obstructions.

6. Flashings, drip moulds, storm moulds and trims

Ensure an appropriate design of external flashings, drip moulds, storm moulds and trims. The importance of this is to be highlighted where surface runoff of water down the side of the structure can enter a window or door below. Design of these must be provided by the window and door manufacturer or architect.

7. Fasteners

Corrosion resistant fasteners must be used in accordance with engineer's specifications. Fasteners must be over and under-sealed to prevent moisture penetrating the opening and causing a failure of the membrane system. It is important to provide a water-tight seal and allow for appropriate clearances for thermal expansion and free-flowing drainage.

8. Consideration for storm shutters

It is recommended to implement storm shutters for social housing projects in exposed cyclonic regions of Australia. Storm shutters will deflect flying debris and will reduce the quantity and pressure of wind-driven water being directed laterally toward the window. This will effectively reduce the likelihood of water ingress into the structure

5.3 Recommendation 2: Contract documentation

The tendering process should include the recommended quality assurance process within the Contract for all forms of procurement. The Contract requires agreement between both the client and contractor. The contract should describe a quality assurance process relating to the preparation and installation of windows and external glazed doors in an effort to increase quality and direct liability in the construction phase. Examples to be implemented are provided below:

- ***Recommendation 3:*** Preparation and installation procedure
- ***Recommendation 4:*** Windows and external glazed doors installation quality form (IQF)
- ***Recommendation 5:*** *A*uditing check list (RAC)
- ***Recommendation 6:*** Openings certificate (OC)

- ***Recommendation 7****: Auditing check grade (AC grade)*

5.4 Recommendation 3: Preparation and installation procedure

Research has indicated that the correct wall opening preparation and installation procedure can reduce the probability of failure; thus, reducing the life-cycle maintenance requirements.

The preparation and installation procedure of windows and external glazed doors to masonry openings is detailed in two stages as shown below; ***Stage 1*** being the openings preparation and ***Stage 2*** being the openings installation. On completion of Stage 1 an acceptance inspection is required by the developer and superintendent. It is recommended that these procedures are included in the contract documentation.

Stage 1 – Openings preparation

1. Ensure all primer, waterproofing membrane and sealants are compatible before installation.

2. Prepare the substrate in accordance with AS 4654.2 and Australian Window Association to provide appropriate fall as per design (minimum 15 degrees as per AWA).

3. Ensure opening is clean, dry and free from debris before the application of any primer, membrane and sealant.

4. Provide a continuous water-stop throughout the perimeter of the opening (rebate and/or fixed angle).

5. Prepare opening with appropriate primer and waterproofing membrane system in accordance with AS 4654.2 (waterproofing membranes for external use). Multiple layers of membrane should be applied to ensure membrane is free from any holes or gaps that will allow water to penetrate the substrate. The waterproofing membrane must extend a minimum of 200 mm past the opening.

6. Components of membrane systems shall be cured as per manufacturer specifications. Intervals between applied membrane coatings should be taken into account due to varying curing times.

7. Install appropriate specified sub-sill, angled metal dam ends, head drip moulds and side angles that are required before the window frame is installed. **Figure 7** gives an example of a sub-sill incorporating metal dam ends. It should be noted that the head-sill, side angle and flashings must be directed to flow into the sub-sill without any obstructions. The back and end dams provide additional water-stop; this ensures that any inadvertent water entry via the frame is directed to flow out the front of the sub-sill due to the force of gravity.

8. Ensure approved primer and sealant is used for a water-tight seal. Ensure appropriate corrosion resistant fasteners are used as per specified wind load or engineer's specifications. Fasteners must be over and under-sealed to prevent moisture penetrating the opening. Ensure a water-tight seal and allow appropriate clearances for thermal expansion and free flowing drainage.

Stage 2 – Openings installation

1. Ensure the correct window and door specifications for the terrain category and height of the building.

2. Ensure weep holes are free from debris and are free flowing.

3. Install window and door and frame to the opening as per manufactures specifications.

4. Ensure appropriate specified flashings, mouldings and trims are installed to ensure the prevention of water ingress.

5. Storm shutters and awnings are to be installed as per manufactures specifications.

5.5 Enhanced quality assurance procedure

To ensure the correct installation of windows and external glazed doors and to ensure the quality of the construction, the following tools and certifications should be implemented. In Reference to **Figure 4**, the following quality assurance documentation is required:

- ***Recommendation 4:*** Auditing check list **(AC)**
- ***Recommendation 5:*** Installation quality form **(IQF)**
- ***Recommendation 6:*** Openings certificate **(OC)**
- ***Recommendation 7:*** Auditing check grade **(AC grade)**

5.6 Recommendation 4: Auditing check list (AC)

The Auditing checklist (AC) provided in **Appendix F** is designed to be completed during the inspection of windows or external glazed doors by superintendents. The objective of the AC is to check if the external openings have been installed adequately. Following this inspection, a grade will be given as *Satisfactory* or *Unsatisfactory*. The score obtained on the check list will provide evidence of work provided by the primary contractor.

The second objective of the AC is to place a degree of responsibility and liability on contractors and superintendents by emphasising the importance of windows and external glazed doors to the building envelope. The AC is to be completed by the superintendent, accompanied by the supervisor responsible for the activity.

The AC is to be completed in two stages of the construction phase; upon completion of the opening membrane and flashing system and on completion of the glazing installation. The superintendent must give reasonable notice (2 weeks) in advance to the primary contractor before performing the AC. A notice for an AC must be given in a format agreed between the builder and the building certifier. A building certifier may also inspect building work at any time, whether or not the certifier is given a notice for AC for the work. At this stage, the primary contractor should inform the superintendent when Stage 2 will commence to allow for the conclusion of the AC.

The number of windows and external glazed doors to be checked on site will be a minimum of 25%. These are to be identified by a unique identification tag or sticker to prevent double checks on the same openings. An Installation quality form (IQF) completed by the primary contractor will display a unique sicker to ensure the appropriate number of inspections occur. Multiple level construction requires the auditing to be carried out evenly over all levels of the building. The frequency will vary according to the site schedule. Each opening will have its own independent check list. Before attending to the site, the Superintendent should plan the auditing visit verifying the numbers of openings that require the AC.

5.7 Recommendation 5: Installation quality form (IQF)

The primary contractor's responsibility is to complete the Installation quality form (IQF) in conjunction with relevant installation documentation (e.g. in Queensland – Form 16) and provide this to the superintendent. The IQF must include photographic documentation of each completed stage of the installation as provided in **Appendix G**. The objective is to provide visual evidence to the superintendent that the openings were satisfactorily installed by the primary contractor according to the preparation and installation procedure.

The number of windows and external glazed doors to be documented is a minimum of 25%. This will ensure sufficient variations of openings are documented. An indicator (tag or sticker) must be allocated once the opening has been documented.

The *IQF* must be held by the primary contractor, then signed and approved together with the superintendent. The objective is to ensure that both parties are taking responsibility for the installation.

The first objective of the IQF is to check if the external openings were installed satisfactorily. The second objective of the IQF is to raise liability and responsibility for contractors/builders in placing sufficient attention to windows and external glazed doors as a building element that is significantly important to the building envelope.

5.8 Recommendation 6: Openings certificate (OC)

Once the AC and IQF have been completed, the superintendent is able to provide the Openings Certificate (OC) to the contractor. The AC and IQF together will have documented 50% of the openings of the project.

The aim of the OC is similar to that of the AC and the IQF in that it documents responsibility for the information provided from both the contractor and superintendent. For both government and private industry projects, the AC and IQF are recommended for inclusion to the requirements for all building projects located in Wind Regions C and D. Moreover, the approach could be considered for all building projects where vulnerability to wind-driven rain has been identified (e.g. coastal high-rise building windows and glazed doors).

For example, in Form 16 in Queensland, the AC and IQF should be added in item “4 Description of component/s certified”. The first part of Form 16, “1 Indicate the type of certificate”, refers to “Aspects of building work”, Windows and external glazed doors satisfactorily installed.

5.9 Recommendation 7: Auditing checklist grade

The AC will be used as well to provide a grade to the work provided by the primary contractor for windows and external glazed doors. During the AC, all openings inspected must have 100% of the check list as “Yes” to provide a “Satisfactory” result as provided in **Figure 9**.

The grade highlights the importance of providing a satisfactory installation to mitigate the potential for water ingress. It is recommended to implement the AC and the IQF for different activities during the construction process and the results can be used as quality indicators of the as built construction and used in subsequent tendering. Where tenderers have a poor record of providing quality construction, they will receive poor experience ratings for subsequent government tenders.

This grade is provided for each of the primary contractors and should be reviewed on acceptance of the tendering process. This information can be used to provide an indication of the overall quality of future work. The procurement section of DHPW should consider implementing this work quality score process, so it can assess the scores when analysing future tender bids.

Building Certifier Companies logo	PROJECT:	AUDITING CHECK LIST (RAC)	Date:
	BUILDER:	ACTIVITY: Installation of windows and external glazed doors	Level:

Check list items	Window												External glazed door												Comments
	Unit												Unit												
	1		2		3		4		5		6		1		2		3		4		5		6		
	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	
1																									
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16																									
Sum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Satisfactory		Unsatisfactory	
Initials and Signed as completed by:			

Figure 9 Proposed AC grading system for installation of windows and external glazed doors

5.10 Other recommendations

This research has identified other recommendations. These recommendations are to the wider industry and not within the control domain of the industry partners.

5.10.1 Australian standards

The 'openings' standard for Australia is the AS 2047 – 2014. The water penetration resistance test is described in the AS/NZS 4420.1:2016 and occurs under static wind load. The test specimen shall be subjected to water sprayed uniformly and continuously over the exterior face. The Cyclone Testing Station (CTS) is conducting tests to replicate high dynamic range (HDR) pressure consistent with cyclonic pressure. Their preliminary findings indicate that static pressure water penetration tests are inadequate for characterising cyclonic events and most windows would have some form of water penetration during cyclone conditions. The CTS based at JCU may propose new requirements for AS 2047-2014 and AS/NZS 4420.1:2016.

5.10.2 Knowledge transfer and education

More effort must be placed on educating builders and installers on the importance of quality installation of windows and glazed doors in order to reduce the life-cycle maintenance costs of buildings. The Australian Window Association (AWA) provides industry training to improve familiarisation with relevant windows and glazed doors installation. The Australian Institute of Waterproofing (AIW) provides industry training to improve familiarisation with waterproofing systems. While there are courses and online materials available, installers in regional northern Queensland may not be receiving adequate training on the latest best practice installation and waterproofing procedures.

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Appendix A – Building failure modes under strong wind and rain conditions

No.	Failure Modes	Building envelope elements	Damage through pieces or components attached:	Cause and effect:
1	Material/design	Windows	Louvres	Water ingress through louvre window; some houses with louvered windows did not have water ingress.
2	Material/design	Windows	Open gaps between sashes, frames and through seals	1. Water ingress through undamaged windows 2. Worn or damaged window seals 3. Wind-driven rain passed through building envelope at openings such as windows and doors (even if closed), around flashings, through linings. A high differential pressure between the inside and the outside of the building is established in strong winds. This differential pressure can force water through gaps and spaces that it would otherwise not penetrate. The air flow around and over a building in an extreme wind event can drag water upwards over the building envelope. The movement in a direction opposite to its normal movement means some flashings that channel downward-moving water away from the envelope, may direct the upward-moving water into the building.
3	Material/design	Windows	Weep holes, gaps and around seals	Water ingress through undamaged doors (glass sliding door, under swinging doors and bi-fold doors).

				The report was not able to describe the windows that have performed well or the ones that have let water into the building. Weep holes are designed in windows and sliding glass doors to allow condensation and minor leakage around seals to pass from the inside to the outside of the building. In high winds, the driven rain passes through the weep holes and through other gaps in the building envelope. The windows without significant water ingress had weep holes that were covered by external rubber strips. (i.e. Bi-fold and swinging windows and doors with gaps installed without a sill.) Water ingress - small amounts and large volumes of rainwater damage to vulnerable elements like plasterboard wall linings and ceilings, floor coverings and personal belongings.
4	Material/design	Doors	Weep holes, gaps and around seals	
5	Material/design	Doors	Sash and tracks in aluminium sliding glass door, aluminium swinging glass door and timber sliding glass door	1. Failure of the sash (sash bent, door laminated glass did not brake), high internal pressure into the house, causing wind and water ingress into the building. 2. Sliding door panels disengaged from their tracks. 2.1 Because of the failure of the sash, 2.2 Because of differential air pressure. 3. The timber sliding glass doors came out causing water ingress, the sash come out of the frame because of the rail and rollers deformation.
6	Material/design	Doors	Free bolts in aluminium bi-fold door	Free bolts caused breaking of the hinges causing water ingress allowing door repeatedly to swing.
7	Material/design	Doors	Hinges and latches in timber bi-fold door	Failure of latches and bolts in the entrance door causing wind and water ingress:

8	Material/design	Doors	Latches and bolts in entrance timber double swinging door	1. Because of wind forces on the doors. 2. Wind ratings are required for windows and glass doors but not required for non-glazed entrance doors. The consequences of failure of entrance doors were similar to those of failure of glass doors.
9	Material/design	Doors	Door lock in the entrance door	Door locks fail, not able to withstand the wind pressure causing wind and water ingress: 1.The failures of doors were from inadequate locks and/or drop bolts which were not able to withstand the wind pressure allowing the doors to be pushed open. The door and window failures then caused pressure and wind driven rain to exacerbate internal damage. Houses constructed in vulnerable locations, exposed coastal locations or site on hills. 2. The failure of the door lock, because the wind to the wall generated large internal pressure which contributed to the failure of the entire roof. This house had metal screens over the windows, but still was exposed to internal pressures from dominant openings because of the failure of the door lock.
10	Material/design	Doors	Tempered glass in the door	Tempered glass fragmented because of wind pressure, causing wind and water ingress
11	Material/design	Roof	Soffit, gutter, fascia, gable linings	Loss of partial or total components/pieces causing wind and water ingress. This loss allows pressurisation of roof space and wind-driven rain to enter. Poor performance is due to a combination of connection capacity.
12	Material/design	Roof	Roof structure	Loss of roof over the outrigger, causing damage to the flashing at the top of the windward wall; consequent water ingress to the building, possible inadequate design.

13	Material/design	Roof	Rubber bot and sealant in vent pipes	Rubber boot and sealant deteriorated allowing water to enter into ceiling space and incorrect location.
14	Bad installation/material /design	Roof	Flashings, gutters, soffit lining	1. Missing or damaged or inadequate or poor fixing of flashings, gutters and soffit linings. 2. Flashings not fixed to the barge, flashings fastened with pop rivets allowed water ingress causing damage to vulnerable elements like plasterboard wall linings and ceilings; floor coverings; and personal belongings. 3.Water ingress under flashings, through tie down connections; rainwater inside the building trough under flashings, causing damage to or collapse of ceilings, flashings are made to protect the entrance of rainwater into the building that come in descendant direction. At the time of the cyclone, fierce winds with changing directions will be happening. The rainwater will be projected into the roof in an ascendant direction. Gutter: rainwater driven under the roof sheeting and into the ceiling space due to gutter damage/lost/blocked: 1. Damaged or lost - gutter attached to fascia with clips or fixing that do not have the capacity to resist the wind forces. 2. Blocked - by the considerable volume of broken trees and plant debris that are part of the current of air throughout the cyclones. 3. Box gutters usually only have a drain at one end. Strong winds can drive water pooled in the gutter to the opposite end to the drain where it piles up and overflows into the ceiling space.

15	Bad installation/material /design	Roof	Air conditioning units/ aerials, fascia or, gable ventilators, sarking and soffit lining, louvres or ventilators louvres and connections	1. Failure or loss of the components causing damage to timber, steel or concrete structure such as lining infiltration with consequent water ingress due to the fixing into the roof. 2. Rusting or blocked guttering (e.g. vegetation). 3. Water penetration in: cladding (facade); through tie down connections between roof structure and walls; sarking under shingles roof that were able to redirect water that has overflowed the valley gutters and flashings into the eaves gutters.
16	Bad installation/material /design	Roof	Gable, eaves, ridge vent	Missing or damaged or inadequate fixing because of the strong wind caused small and large volumes of rain water, sometimes causing ceiling damage.
17	Bad installation/material /design	Windows	Through the frame to wall window fixing / window frame	Window frame separated from the building/ house providing water ingress: 1. Did not have the appropriate frame to wall fixings for the window resulting in the window and frame being "blown" into the house. The door and window failures then caused pressure and wind-driven rain to exacerbate internal damage. Houses constructed in vulnerable locations, exposed coastal locations, or site on hills. 2. Possible the frame was badly anchored to the building fabric and so separated from the building causing a large opening allowing wind pressure that contributed to the failure.
18	Bad installation/material /design	Doors	Connection in door frame	Door frame separated from the building, causing water ingress because of inadequate connections between the timber frame and the timber house.

19	Bad installation/material /design	Roof	Hip & ridge tile	Failure modes of the tiles were loss of ridge capping (both apex and hip tiles), loss of tiles near gable ends and cut tiles associated with hips. On most houses that had lost ridge capping, no mechanical fixings such as clips or screws on the ridge tiles were observed. The dislodgement of the ridge or other tiles generally led to additional damage to the tile roof and to adjacent structures through wind-borne debris. 1. Due to high local pressures. 2. Material deteriorated because of age around hip and ridge tiles may reduce the strength possibly contributing to the damage caused by wind and water ingress.
20	Bad installation/material /design	Walls	Brick cladding	Failure of brick veneer away from the structural masonry wall. Possible causes of failure: Lack of brick ties and/or masonry reinforcement in a brick/masonry veneer wall.
21	Bad installation/material /design	Doors	Fixing	Doors failed due to no adequate fixing into the building; only one side of the frame was secure and because of the wind the doors failed. The high internal pressure was caused by the loss of the door frame.
22	Bad installation/material /design	Roof	Solar hot water, photovoltaic panels, skylights, aerials, vents	Many of those items had no wind damage and no damage to the roof; in some of them, the mounting brackets between roof and item failed. When it failed, the report could not provide enough evidence if it was from items fixed to the roof itself or to the roof structure. Inadequate fixing to the roof caused loss of the aerials/vents causing water ingress contributing to damage the ceiling.
23	Design/bad installation	Walls	Light gauge steel framing	Wall fail because of the discontinuous studs, perhaps a not very good design or bad installation.

24	Bad installation/material	Windows	Fixing	Strong wind. No adequate fixing into the building made the windows fail, the frame of the window was stapled into the building frame. Probably the staples were located temporarily, and a proper fixing would be done later. The high internal pressure was caused by the loss of the window frame on the windward wall.
25	Bad installation/material	Roof	Batten-to-rafter / truss connections	Partial loss of the roof, inadequate / poor connection / loss of function initiated by the fastener corrosion enabling rain water entering the building. Failure of connections between roof structures and walls.
26	Bad installation	Roof	Vents	Inadequate fixing to the roof caused water ingress contributing to damage the ceiling.
27	Bad installation	Roof	Tiled roof	Because of the strong wind, the tile damaged caused loss of the ridge cap, possible cause unlined eaves.
28	Bad installation	Roof	Cladding	Cladding disconnected from purlins or battens causing damage near edges of walls or roofs and roof not installed conforming to specifications; flashings damaged possibly contributed to the damage.
29	Bad installation	Roof	Metal roof tile	Loss of metal roof tiles, tiles not installed correctly, did not penetrate enough to the tile.
30	Bad installation	Roof	Pierce-fixed metal	Loss of the roof, battens stayed attached, roof not installed conforming to specifications; flashings damaged possibly contributed to the damage.
31	Material	Roof	Roof vents	Whirly bird vent deformed and, in some cases, contributed to water ingress into the ceiling because of the strong wind.

32	Design	Facade/ cladding / lining	Punctured cladding	Caused water ingress, make sure balconies/patios have drainage points.
33	Design	Balcony / veranda	Veranda	Loss of veranda, fail between connections with veranda beams and posts or walls (fail observed in timber, steel and concrete). Buildings in exposed locations are submitted to high wind speed and so pressure; large verandas have higher loads beams. Straps and bolts nailed incorrectly to the veranda beam (probably inadequate design specification).

Appendix B – Data collection participants

Table 8 Field site visit participants for Manufacturer 1

Window/door Manufacturer		
Code:		**Participants**
1	M1	Operations Manager Branch
2	M1	Senior Product Designer
3	M1	Commercial Technical Advisor
4	M1	Engineer

Table 9 Workshop participants from DHPW Government Team and major building contractor

Date: 22nd March 2018		
DHPW Government		
Townsville		
Code:		**Participants**
1	G	Acting District Manager (DHPW)
2	G	Acting District Manager (DHPW)
3	G	Senior Superintendent (DHPW)
4	G	Acting Delivery Manager (DHPW)
5	CC1	Manager North Queensland (Construction Company 1)
6	CC1	Project Manager (Construction Company 1)

Table 10 Field site visit to Cyclone Testing Station – James Cook University

Cyclone Testing Station		
James Cook University Townsville		
Code:		**Participants**
1	IA	Director
2	IA	Senior research fellow

Table 11 Phone interviews with Building Certifiers

Code:		Building Certifiers
1	BC1	Building Certifier 1
2	BC2	Building Certifier 2
3	BC3	Building Certifier 3
4	BC4	Building Certifier 4
5	BC5	Building Certifier 5
6	BC6	Building Certifier 6
7	BC7	Building Certifier 7
8	BC8	Building Certifier 8
9	BC9	Building Certifier 9
10	BC10	Building Certifier 10
11	BC11	Building Certifier 11
12	BC12	Building Certifier 12

Table 12 Phone interviews with Installers/Builders

Code:		Installers/Builders
1	I/B1	Installer/Builder 1
2	I/B2	Installer/Builder 2
3	I/B3	Installer/Builder 3
4	I/B4	Installer/Builder 4
5	I/B5	Installer/Builder 5
6	I/B6	Installer/Builder 6
7	I/B7	Installer/Builder 7
8	I/B8	Installer/Builder 8
9	I/B9	Installer/Builder 9
10	I/B10	Installer/Builder 10

Table 13 Phone interviews with Manufacturer, Architects and Construction companies

Code:		Manufacturer
1	M2	Manufacturer 2
		Architects
2	A1	Architect 1
3	A2	Architect 2
		Construction Company
4	CC2	Construction company 1
5	CC3	Construction company 2

Appendix C – Workshop and interview questions

(a) Full list of questions asked during the phone interviews

1. What are the most critical causes of water ingress in windows/doors/building envelope? How can they be mitigated?
2. What type of damage occurs due to rain driven water ingress in the building envelope (e.g. carpets replacement, plasterboard softening, mould, termite, etc.)? Can the incidence and severity of damage be reduced with some good strategies - their opinions?
3. Documentation related to installation of flashings, windows/doors? Example: What to use? What not to use? Quality rating.
4. What type of inspection is conducted for waterproofing of building envelope? Particularly windows/doors? Is this a challenge to inspect? Is this work inspected before block work or internal walls are completed?
5. Documentation related to the waterproofing of the building envelope/windows/doors/flashing/etc. Apart from builders providing certificates on window quality, is there any quality documentation provided about window installs and building envelope waterproofing such as flashing, etc.? Would inspectors like builders to provide them with some sort of quality documentation about the window/door/building envelope installation process in addition to the product quality information?
6. Perceptions of installer labour and skills in region? What qualification the installers have? Training/qualifications? Do installers of windows and waterproofing of building envelope receive sufficient training on recommended practices (e.g. AWA and manufacturer guidelines)?
7. Is the level of specification provided by builders sufficient for HPW inspectors to inspect works? We have been told that builders are only required to provide light specification for HPW projects. Is it contractually difficult for HPW inspectors to state that builders have not confirmed to requirements for windows/doors/building envelope waterproofing? What level of documentation would they like to have?
8. Do the inspectors notice whether builders of public/domestic housing are using lower quality windows (i.e. potentially inferior windows)?
9. For Building Certifiers, how do they conduct the windows inspection? What stage and how they see they could improve? Form 15/16 enough responsibility?

(b) Field site visit – National Glass & Aluminium manufacturer - themes of questions/topics discussed

- The main failure modes for windows from cyclones and heavy winds, inspection practices, standards, quality of labour, documents and inspections.
- The design, manufacturing and installation process, including product specification, manufacturing process (what makes a product different from non-cyclonic areas to cyclonic areas), product delivery to the construction site, installation process, and product quality guarantees.
- Quality procedures to ensure high standards of workmanship for the installation, of windows.

(c) Workshop – DHPW and Building Contractor - questions used as a guide to generate a discussion between participants

1. What are the most critical causes of water ingress in windows/building envelope? How can they be mitigated?
2. Have you noticed a trend of greater wind-driven caused issues after cyclone events?
3. What are the main issues (minor/moderate damages) caused by the wind-driven rain through the building envelope (windows)?
4. Is the level of specification provided by Architects/Designers sufficient for HPW inspectors to inspect works? Any suggestion for an improvement?
5. Apart from builders providing certificates on window quality, is there any quality documentation provided about window installs and building envelope waterproofing such as flashing, etc.?
6. Is there any issues with waterproofing of the building envelop, particularly windows?
7. Do/can building inspectors inspect the building envelope (windows) for water proofing?
8. Do installers have skills to do the job, or receive any formal training? Do the inspectors believe they follow practices or cut corners when it comes to these details?
9. Is it contractually difficult for HPW inspectors to state that builders have not confirmed to requirements for windows/building envelope waterproofing? Is there any procedure for reporting any irregularities in windows/water proofing?

Appendix E – Insights from the interviews

Involved people (Code)	Insights from interviews with people
CATEGORY: Standards	
M1	Manufacturer 1 does training with employees for their own installations. With contractors, there are site visits but are rare. However, estimated roughly the same quality in the final installed product
	Education is a key too
G	Tradies are cutting corners, they should know. Northern Qld less qualified people.
BC1	We require an improvement to training and licencing (QBCC). Key issues toward water ingress are poor construction.
	Improve the licencing aspect from QBCC
	Include another inspection for windows wouldn't help. What is necessary is a better trade's education system which is terrible.
BC3	Skills are satisfactory. AWA provide installation information online.
BC4	Generally good work. Many resources are found online if required.
BC5	Skills and labour are satisfactory for the region.
BC6	The training and skills are there. Key issues are cutting corners to save money. Referring to glazing where no inspection can be made, relying on form 16. Not enough liability on installers.
BC7	Professional installation of waterproofing and flashings
BC8	In tropical regions the skills and labour are better as higher quality builds are required. Rely on Form 16 as assurance of high quality install.
BC9	Incorrect materials being used (Roofing: wrong size screws/corrosion resistant elements. Glazing: manufacturers provide incorrect materials)
BC9	Labour and skills are to a high standard in North QLD. There is an online workplace that most trades use to share/help information.
BC10	Skills and labour are satisfactory for the region.
BC11	Skills and labour are to a high standard in North QLD.
I/B1	Insufficient training of carpenters to install windows/doors. Has met carpenters onsite that have never installed before.
I/B1	Carpenters should know what is required. Have seen substandard windows used to cut costs.
I/B2	Insufficient training for apprentice carpenters, AWA should provide some training.
I/B3	Insufficient training for carpenters, experience is key to a quality install.
I/B3	General knowledge of the construction industry leads to knowing how to correctly waterproof flashings.
I/B4	Further training is required.

I/B5	Further training is required.
I/B7	Skills are lacking in some areas
I/B8	Skills are lacking, provide better training
I/B9	Use specialised trades for best results. Some better than others.
I/B10	Better training for new workers should be implemented.
M1	Test pressure insufficient to cyclone winds
IA	Test pressure insufficient to cyclone winds. Test pressure insufficient to cyclone winds. A test rig was builded in order to create a high dynamic range pressure to several types of window to test the water penetration resistance
A2	Test pressure insufficient to cyclone winds
I/B1	Blocked weepholes, Windows/Doors cannot handle the force of high category cyclones, Substandard window design for the area
I/B3	Cyclonic wind driven rain will make any window/door/roof leak to an extent. Storm shutters can stop 90%
M1	Products attends standards that are made for minimum requirements
G	The standard is made to meet the minimum requirements, so the products meet the minimum required by the standard
BC10	Most windows and doors allow for water ingress during extreme wind driven rain. Improvement to Australian Standards windows/door design is required.
BC11	Failing Australian Standards relating to tropical climates
BC12	Rework of AUS Standards
I/B10	Cannot stop water ingress from wind facing windows and doors in a cyclone
G	Every year
CC1	Every year
M1	Every 2 years
IA	Every cyclone and high wind event
BC1	Water ingress is a common issue during cyclonic events
BC3	After an extreme weather event there is a spike in water ingress related maintenance. Usually minor repairs (carpet, gyprock)
BC4	After severe storm events there are many maintenance teams out there to repair and dry damages related to water ingress
BC6	Always a large influx of insurance claims after an extreme weather event. Cannot make a building entirely waterproof. We need to make manufactures test glazing post install and make builders responsible for a high standard of install
BC8	After severe storm events notice a spike in water ingress
BC9	Water ingress is very common after an extreme weather event
BC10	A lot of repair and maintenance is required after an extreme weather event in North QLD
BC11	After severe storm events there is a spike in water ingress
BC12	After severe storm events there is a spike in water ingress

I/B5	Most buildings will leak in an extreme cyclonic event (about every 3 years). Regular maintenance required every 3 years (cleaning sills to avoid blockage) (cleaning gutters)
I/B6	Always have issues with water ingress caused by cyclonic weather. Cannot prevent water ingress in these situations. Care must be taken in own home (put towels etc around windows)
I/B9	Every structure will leak to some degree in a cyclone. Nothing is completely waterproof
I/B10	Extreme weather every 3-5 years therefore structures require sufficient maintenance in this period

Involved people (Code)	**Insights from interviews with people**
CATEGORY: Inspection Regime	
M1	Private certifier does not check, they just get the form 16
	Form 16 could have extra questions about if fixing requirements are met
	An extended Form 16 would not be too time consuming as long as there is enough training and personal integrity for QDHPW supervisors
	Form 16 essentially declares that the product has been installed as per Form 15 (design).
	Not clear who should signed the Forms, apparently even QBCC that have made the Forms are not sure
	Today superintendents inspect documents
	Self-regulation is bad, needs to be policed
G	Current Form 15/16 leave minimal liability when certifier signs off
	IDEAS to include at Form16: · Photo of flashings and install · Type of fixings and spacing. · Type of products used
BC1	Form 15/16 is only documentation. Information can be found on the glazing manufactures website
BC2	Buildings certifiers only check structural elements, not windows. For windows, the form 15 must be filled for the engineer/designer for the window specification and the manufacturer for the installation. The form 16 must filled by the engineer inspector or building inspector for the foundation and footing slabs
BC3	Inspection checklist: Anchoring @ 300mm centres, Sealing (mastic), Glass specification, Form 15/16
	Flashings cannot be inspected after install, Typical install follows NCC (National Construction Code) and Australian Standards (2188 Glazing). Form 15 from manufacture (glass thickness) derived from glazing standards, where windows are designed for wind driven water.

BC4	Final inspection (only check glass classification and form 15/16) No improvement required
BC6	The training and skills are there. Key issues are cutting corners to save money. Referring to glazing where no inspection can be made, relying on form 16. Not enough liability on installers
	Inspection checklist: Anchoring, mastic, glass specification, frame design, Form 15/16. Not enough responsibility
	Only looking for Form 15/16. (This is not enough in his opinion). Key issues: Sub contractors and Installers have no responsibility to install to a high standard. (They focus on being quick and the minimal use of waterproofing products)
BC8	In tropical regions the skills and labour are better as higher quality builds are required. Rely on Form 16 as assurance of high quality install.
	Improve the licencing aspect from QBCC
BC9	Check sticker on glazing C1, C2, C3 cyclone rated (thicker glass, required to have heavy duty seals etc.) Rely on Form 15/16. Improvement could be for the builder to supply effective waterproofing statement (this would enforce the testing of the waterproofing of the structure)
BC10	Form 15/16 provides necessary information. Check seals and glass rating
BC11	Has not worked with HPW. Basically, have a failing system in tropical regions were certifiers rely on the design from manufactures (Aus Standards currently not sufficient), Also rely on installation were if not done properly it will fail. Key to reduce water ingress is maximise eve/awning coverage
	No official check lists. Check anchors. Rely on installers to provide correct install to Australian Standards. Rely on manufacturers to provide correct design as per Australian Standards
BC12	Check anchoring and mastic. Flashing and sub sills cannot be seen. Rely on Form 16
I/B1	No inspections, Form 16 is provided (by licenced person under QBCC)
I/B2	Knows of AWA but never bothered to look. Assumes that manufactures provide correct windows. Provides form 16 after install
I/B3	No inspections, Form 15, 16 is provided by the Manufacturer
I/B5	Form 15/16, not enough responsibility for professional install.
I/B7	Certifier inspects building envelope. Cannot inspect flashings once constructed
I/B8	Form 16 is provided to certifier
I/B10	Form 15 and 16 provided to certifier. Flashings cannot be seen once window/door installed

Involved people (Code)	Insights from interviews with people
CATEGORY: Installation quality documentation	
M1	Private certifier does not check, they just get the form 16
	Form 16 could have extra question about if fixing requirements are met
	An extended Form 16 would not be too time consuming as long as there is enough training and personal integrity for QDHPW supervisors
	Form 16 essentially declares that the product has been installed as per Form 15 (design)
	Form 16 is about installation, no requirements for the installer indicating what details (screws, seals, etc)
	Not clear who should signed the Form 16
G	Current Form 15/16 leave minimal liability when certifier signs off
	Data from maintenance events are inserted in the system in a generic way
	IDEAS to include at Form 16: · Photo of flashings and install · Type of fixings and spacing. ·Type of products used
BC1	Form 15/16 is only documentation. Information can be found on the glazing manufactures website
BC2	Buildings certifiers only check structural elements, not windows. For windows, the form 15 must be filled for the engineer/designer for the window specification and the manufacturer for the installation. The form 16 must filled by the engineer inspector or building inspector for the foundation and footing slabs
BC3	Inspection checklist: Anchoring @ 300mm centres, Sealing (mastic), Glass specification, Form 15/16
	Flashings cannot be inspected after install, Typical install follows NCC (National Construction Code) and Australian Standards (2188 Glazing). Form 15 from manufacture (glass thickness) derived from glazing standards, where windows are designed for wind driven water.
BC4	Final inspection (only check glass classification and form 15/16) No improvement required
BC6	The training and skills are there. Key issues are cutting corners to save money. Referring to glazing where no inspection can be made, relying on form 16. Not enough liability on installers
	Inspection checklist: Anchoring, mastic, glass specification, frame design, Form 15/16. Not enough responsibility
	Improve the focus of liability on builders to guarantee the waterproofing to the building envelope is installed to a high standard (by providing a personal guarantee rather than form 15/16)

	Only looking for Form 15/16. (This is not enough in his opinion). Key issues: Sub contractors and Installers have no responsibility to install to a high standard. (They focus on being quick and the minimal use of waterproofing products)
	Improve the focus of liability on builders to guarantee the waterproofing to the building envelope is installed to a high standard (by providing a personal guarantee rather than form 15/16)
BC8	In tropical regions the skills and labour are better as higher quality builds are required. Rely on Form 16 as assurance of high quality install
	Form 15/16 is only documentation from manufacturer and installer. (Usually Manufacturer 1 provides both)
BC9	Check sticker on glazing C1, C2, C3 cyclone rated (thicker glass, required to have heavy duty seals etc.) Rely on Form 15/16. Improvement could be for the builder to supply effective waterproofing statement (this would enforce the testing of the waterproofing of the structure)
BC10	Form 15/16 provides necessary information. Check seals and glass rating
BC11	Has not worked with HPW. Basically, have a failing system in tropical regions were certifiers rely on the design from manufactures (Aus Standards currently not sufficient), Also rely on installation were if not done properly it will fail. Key to reduce water ingress is maximise eve/awning coverage
	Form 15/16
BC12	Check anchoring and mastic. Flashing and sub sills cannot be seen. Rely on Form 16
	Form 15/16 provides assurance that AUS Standards have been adhered to
I/B1	No inspections, Form 16 is provided (by licenced person under QBCC)
I/B2	Knows of AWA but never bothered to look. Assumes that manufactures provide correct windows. Provides form 16 after install
I/B3	No inspections, Form 15, 16 is provided by the Manufacturer
I/B5	Form 15/16, not enough responsibility for professional install
I/B6	Form 15/16 is provided by the Manufacturer
I/B7	Form 15/16 is provided by the Manufacturer
I/B8	Form 16 is provided to certifier
I/B10	Form 15 and 16
M1	Form 16 is about installation, no requirements for the installer indicating what details (screws, seals, etc)
	Windows installer has to tell more often if an opening is not fit for purpose
M2	Most of the plans don´t come with specification they have to ask the builder or the architect or the engineer
	Form 16 is about installation, no requirements for the installer indicating what details (screws, seals, etc)
G	Design standards are lacking

	Provide design specs for all windows including all flashings for the tender process
	Increase scope definition of projects
	Clearly specify design for key elements (roof/window/door/flashing/gutter/fixings/etc)
	Provide detail designs from engineer/architects instead of "Refer to Australian Standard"
CC1	The concluded design is approved by Certifiers that are given to Builders according to certain requires and rules for the design of Social Housing, poor requires and rules
BC3	Has done work for HPW before. Additional required specifications should be provided to the builder throughout the tendering process
BC9	Incorrect materials being used (Roofing: wrong size screws/corrosion resistant elements. Glazing: manufacturers provide incorrect materials
BC11	Manufacturer 1 supply and install provide most effective waterproofing system at the moment however having minimal eve/awning coverage creates problems
I/B1	Manufacturers do not provide a window/door installation guide/check list. Would like to see information from manufacture relating to installation guide/standards attached to the window (sticker or small booklet), not just online
I/B8	Biggest issues are brick veneer. Block construction is much better. Provide waterproofing membrane and sub sill as best practice. Provide better training to apprentice carpenters
M1	Private certifier does not check, they just get the form 16
	An extended Form 16 would not be too time consuming as long as there is enough training and personal integrity for QDHPW supervisors
	Today superintendents inspect documents
	Outside windows installers are paid on fixed price, not quality
	Self-regulation is bad, needs to be policed
	Other manufactures no training; anyway, if one contractor does a bad job, they will probably not get the next tender. So, they are somehow forced to do a good job
G	Require due diligence on all parts of construction process to form cohesion
	Current Form 15/16 leave minimum liability when certifier signs off
BC1	Form 15/16 is only documentation. Information can be found on the glazing manufactures website
	Has seen incorrect glazing installed
BC3	Incorrect windows and doors being used in tropical region
	Flashings cannot be inspected after install, Typical install follows NCC (National Construction Code) and Australian Standards (2188 Glazing). Form 15 from manufacture (glass thickness) derived from glazing standards, where windows are designed for wind driven water.
BC4	Have seen incorrect glass provided from manufacturer

BC6	Always a large influx of insurance claims after an extreme weather event. Cannot make a building entirely waterproof. We need to make manufactures test glazing post install and make builders responsible for a high standard of install
	Incorrect windows and doors being used. Incorrect roofing and gutter being used. Poor construction. Can be mitigated by focusing liability on the builder (personal guarantee)
	The training and skills are there. Key issues are cutting corners to save money. Referring to glazing where no inspection can be made, relying on form 16. Not enough liability on installers
	Inspection checklist: Anchoring, mastic, glass specification, frame design, Form 15/16. Not enough responsibility
	Improve the focus of liability on builders to guarantee the waterproofing to the building envelope is installed to a high standard (by providing a personal guarantee rather than form 15/16)
	Only looking for Form 15/16. (This is not enough in his opinion). Key issues: Sub contractors and Installers have no responsibility to install to a high standard. (They focus on being quick and the minimal use of waterproofing products)
BC8	In tropical regions the skills and labour are better as higher quality builds are required. Rely on Form 16 as assurance of high quality install
BC11	Has not worked with HPW. Basically, have a failing system in tropical regions were certifiers rely on the design from manufactures (Aus Standards currently not sufficient), Also rely on installation were if not done properly it will fail. Key to reduce water ingress is maximise eve/awning coverage
	No official check lists. Check anchors. Rely on installers to provide correct install to Australian Standards. Rely on manufacturers to provide correct design as per Australian Standards
BC12	Check anchoring and mastic. Flashing and sub sills cannot be seen. Rely on Form 16
I/B2	Knows of AWA but never bothered to look. Assumes that manufactures provide correct windows. Provides form 16 after install
I/B3	No inspections, Form 15, 16 is provided by the Manufacturer
	General knowledge of the construction industry leads to knowing how to correctly waterproof flashings
I/B4	Builder should check/monitor install process. Depends on type of build, timber frame can be checked before cladding is installed
I/B5	Form 15/16, not enough responsibility for professional install
I/B8	Form 16 is provided to certifier

Involved people (Code)	Insights from interviews with people
CATEGORY: Liability and recourse	
M1	Private certifier does not check, they just get the form 16
	Self-regulation is bad, needs to be policed
	An extended Form 16 would not be too time consuming as long as there is enough training and personal integrity for QDHPW supervisor
G	Current Form 15/16 leave minimal liability when certifier signs off
BC1	Form 15/16 is only documentation. Information can be found on the glazing manufactures website
BC2	Incorrect windows and doors being used in tropical region
	Flashings cannot be inspected after install, Typical install follows NCC (National Construction Code) and Australian Standards (2188 Glazing). Form 15 from manufacture (glass thickness) derived from glazing standards, where windows are designed for wind driven water
BC4	Have seen incorrect glass provided from manufacturer
BC6	Inspection checklist: Anchoring, mastic, glass specification, frame design, Form 15/16. Not enough responsibility
	Improve the focus of liability on builders to guarantee the waterproofing to the building envelope is installed to a high standard (by providing a personal guarantee rather than form 15/16)
	Only looking for Form 15/16. (This is not enough in his opinion). Key issues: Sub contractors and Installers have no responsibility to install to a high standard. (They focus on being quick and the minimal use of waterproofing products)
BC8	In tropical regions the skills and labour are better as higher quality builds are required. Rely on Form 16 as assurance of high quality install
BC9	Check sticker on glazing C1, C2, C3 cyclone rated (thicker glass, required to have heavy duty seals etc.) Rely on Form 15/16. Improvement could be for the builder to supply effective waterproofing statement (this would enforce the testing of the waterproofing of the structure)
BC11	Has not worked with HPW. Basically, have a failing system in tropical regions were certifiers rely on the design from manufactures (Aus Standards currently not sufficient), Also rely on installation were if not done properly it will fail. Key to reduce water ingress is maximise eve/awning coverage
BC12	Check anchoring and mastic. Flashing and sub sills cannot be seen. Rely on Form 16
I/B8	Form 16 is provided to certifier

Appendix F – Auditing check list (AC)

AC - Auditing Checklist

Use this checklist to help identify potential water Ingress risks that may be caused by an insufficient waterproofing membrane and flashing system. This inspection is to be carried out after the opening has been prepared for the installation of the window or door.

To: .... ***Attn:*** .... ***Date:*** ....

Project: .... ***Project No.:*** .... ***Time:*** ....

Issued By: .... ***Received By:*** .... ***Comments:*** ....

Superintendent

	MEMBRANE & FLASHING SYSTEM	YES	NO
1.	Adhesion of waterproofing membrane	☐	☐
2.	Waterproofing membrane termination	☐	☐
3.	Sealants, over sealing & adhesion	☐	☐
4.	Minimum falls in substrate	☐	☐
5.	Continuous water stop	☐	☐
6.	Sub head & sub sill	☐	☐
7.	Dam ends	☐	☐
8.	Appropriate drip moulds & flashing	☐	☐
9.	Fasteners	☐	☐

Further information provided below:

1. Check waterproofing is free from protrusions & voids. Check adhesion with sealants & substrate.
2. Check waterproofing membrane cover (minimum 180mm).
3. Check adhesion with waterproofing membrane and substrate. Ensure the over sealing of fasteners.
4. Check fall are In accordance with AS 4654.2.2012 (minimum 1:100).
5. Check water stop provided (Rebated and/or fixed metal angle).
6. Check sub sill up & down turn flashing heights and sealant are sufficient.
7. Ensure dam ends have sufficient sealing and allow for drainage.
8. Ensure the flow of water down he building is directed away from openings below.
9. Check the amount & fasteners used are appropriate for the region.

Further Comments:

Appendix G – Installation quality form (IQF)

IQF – Installation quality form

Use this checklist to help identify potential water Ingress risks that may be caused by an insufficient waterproofing system. This inspection is to be carried out after the opening has been prepared for the installation of the window or door.

To:.. **Attn:** .... **Date:** ....

Project: .... **Project No.:** .... **Time:** ....

Issued By: .... **Received By:** .... **Comments:** ....

Building Contractor

	MEMBRANE & FLASHING SYSTEM	YES	NO
1.	Compatible primer, membrane & sealants	☐	☐
2.	Minimum falls in substrate	☐	☐
3.	Continuous water stop	☐	☐
4.	Application of membrane system as per AS 4654.2	☐	☐
5.	Curing of primer, membrane & sealants	☐	☐
6.	Sub head, side/jamb flashing & sub sill	☐	☐
7.	Primed & sealed fasteners & dam ends	☐	☐
8.	Appropriate drip moulds	☐	☐
9.	Photo documentation of the membrane & flashing system. Inspection and acceptance testing as per AS 4654.2	☐	☐

Further information provided below:

1. Ensure the compatibility of all products used on the substrate (Consult the material technical data sheet).
2. Ensure falls are In accordance with AS 4654.2.2012 (minimum 1:100).
3. Ensure a continuous water stop around all sides of the opening.
4. Ensure appropriate primer and membrane system installed on a clean surface. Multiple layers of membrane being without protrusions or voids. Membrane minimum cover 180mm.
5. Ensure curing or membrane and sealants as per manufactures specifications.
6. Ensure sub sill flashing heights and sealant are sufficient. Ensure an unobstructed flow of water from head to sill.
7. Ensure dam ends are incorporated with head and side flashings to ensure the unobstructed flow of water. Ensure sufficient priming & sealing and allow for drainage.
8. Ensure drip moulds are installed to direct the flow of water away from openings.
9. Provide photo documentation of the membrane & flashing system

Comments:

IQF - Installation quality form

Use this checklist to help identify potential water Ingress risks that may be caused by an insufficient waterproofing system. This inspection is to be carried out after the opening has been prepared for the installation of the window or door.

To: ………………………………………………………… ***Attn:*** ………………………………………………………… ***Date:*** …………………………………………………

Project: …………………………………………………… ***Project No.:*** ………………………………………… ***Time:*** …………………………………………………

Issued By: ……………………………………………… ***Received By:*** ………………………………………… ***Comments:*** ……………………………………………

Photo Documentation :