WATER TRANSFORMED:
SUSTAINABLE WATER SOLUTIONS FOR CLIMATE CHANGE ADAPTATION

MODULE A
ADAPTING TO CLIMATE CHANGE

This online textbook provides free access to a comprehensive education and training package that brings together the knowledge of how countries, specifically Australia, can adapt to climate change. This resource has been developed formally as part of the Federal Government’s Department of Climate Change’s Climate Change Adaptation Professional Skills program.

CHAPTER 1: UNDERSTANDING THE RISKS AND ADAPTING TO CLIMATE CHANGE

LECTURE 1.2: REDUCING RISKS TO THE BUILT ENVIRONMENT – FROM CYCLONES AND HAILSTORMS
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Adapting to Climate Change

Lecture 1.2: Reducing Risks to the Built Environment & Infrastructure – from Cyclones and Hailstorms

Educational Aim

This lecture will outline why climate change, if not mitigated globally, is likely to result in more intense hailstorms and cyclones. CSIRO found that while the number of mid-latitude storms affecting southern Australia has decreased over the last few decades, their intensity has increased, and modelling suggests that this trend will continue. This lecture will discuss how climate change is likely to lead to cyclones of higher intensity and destructive power this century, as well as what measures can be taken to reduce the risks of damage for residential, commercial and industrial buildings from cyclones. As climate change is also forecast to lead to more extreme weather events, such as hailstorms, this lecture will discuss what design changes can be made to buildings to reduce the risks of damage from hailstorms.

Key Learning Points

1. Tropical cyclones are among the most feared extreme weather phenomena. Their destructive winds (gusts approaching 300km/h), torrential rains (approaching one metre of rain within 24 hours), storm surges, and wild seas have inflicted significant damage on communities and even caused loss of life. Cyclones affect tens of thousands of people annually.

2. Cyclones are known by different terms around the world. For tropical cyclones in the Northern Hemisphere which start in the Atlantic or Caribbean Sea the term ‘hurricane’ is used. In Asia, ‘typhoon’ is the term used, and in Australia the term ‘cyclone’ is used.

3. Climate change is expected to influence the intensity of cyclones because sea temperature is a key factor in the formation of cyclones. To initiate a cyclone there are a range of factors needed, including sea-surface temperature rising to above 26.5°C. The IPCC 4th Assessment\(^1\) references studies which indicate a ‘likely increase in the proportion of the tropical cyclones in the more intense categories, but a possible decrease in the total number of cyclones.’\(^2\) The IPCC also has found evidence of a pole-ward shift due to climate change for cyclones over the last thirty years.

4. Australia’s research scientists have found similar trends. Abbs et al in their 2006 study on the Projections of Extreme Rainfall and Cyclones\(^3\) predict that, if current trends continue, an increase in the intensity of the most extreme storms of 60 per cent by 2030 and 140 per cent by 2070 for Australia. This study also shows a decrease in tropical cyclone numbers by 44 per cent by 2070 off the coastline of Western Australia, while off the east Australian coastline small decreases of

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only 9 per cent are predicted.\(^4\) Studies also show that while the number of mid-latitude storms affecting southern Australia has decreased over the last few decades, their intensity has increased, and this trend is predicted to continue.\(^5\)

5. In Australia it, homes in Far North Queensland and the far north of Australia have been required by the building codes to be designed for specific wind loads from gale force winds since the late 1970s. After Cyclone Tracy hit Darwin in 1974, a number of changes to the building codes were implemented to ensure buildings were better prepared for tropical cyclones. Since that time, research by the Cyclone Testing Station at James Cook University has shown that there has been a significant reduction in damage to buildings which were built after the changes to the codes,\(^6\) showing that changes to building design can significantly reduce the amount of damage that cyclones can inflict.

6. This does not mean to say that there is no room for improvement in the Australian building codes. Recommendations of ways to improve the relevant building codes and standards based on the lessons from recent cyclones like the 2006 Cyclone Larry are outlined in the Brief Background Reading section. Abbs et al's modelling predicts a pole-ward shift of 70 km on average tropical cyclone genesis region by 2070 and a shift of almost three degrees latitude in the average decay location.\(^7\) Thus it is recommended that the area of Australia deemed to be cyclone prone, and thus which comes under the specific cyclone building codes, is reviewed and applied gradually further south than is currently required.

7. There is no practical method of construction that can guarantee complete protection for a building from a cyclone. But the risks of damage to buildings can be significantly reduced if the following steps are undertaken:

- Securing the roof to be able to withstand appropriate uplift forces from cyclonic winds.
- Designing verandas and pergolas so they are not attached to the main roof of the house. This ensures that if gale force winds overcome the design strength of these elements, the rest of the house and its roof will not be directly affected.
- Ensuring, if the roof is tiled, that each tile is individually attached and effectively tied down to the roof.
- Placing effective metal wire screens or shutter protection on windows to protect the most vulnerable point of the house from flying debris in a cyclone.
- If the house or commercial building has a garage, ensuring that the door is effectively sealed and can withstand expected cyclone pressure. Garage doors have been found to be a weak point in most homes and commercial buildings.

(These and other measures are discussed in detail in the Brief Background Information section.)

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Climate change is also forecast to lead to more extreme weather events. An example of this is hailstorms. The Australian east coast is particularly prone to large hail and intense hailstorms. Economic losses from hailstorms in Australia account for 34 per cent of the total losses from 1967-2003 from natural disasters, according to the Insurance Disaster Response Organisation, the largest proportion for any natural peril. Hail damage is responsible for fifty per cent of the top twenty insurance losses in Australia since 1967. The scale of the costs from hailstorm damage is shown by the fact that in the past twenty years, Sydney has been hit by six severe hailstorms, causing billions of dollars in damages, including the 1999 hailstorm which cost AUD$1.7 billion, of which AUD$1.3 billion was insured.

Unless buildings are made more hail resistant, there will be significant increases to the costs and damage from hailstorms this century due to climate change. CSIRO modelling shows that due to climate change, hail-days per year for 2030 and 2070, on the east coast of NSW, are projected to almost triple, increasing from one to two days per annum to approximately four to six. To reduce damage from hailstorms to buildings, and particularly to roofs and windows, a range of actions can be taken, such as:

- **Ensuring the pitch of the roof is designed correctly**: Several hail damage testing agencies recommend increasing roof pitches over 6:12 can dramatically improve hail resistance.

- **Designing more appropriate window protection**: The same rules apply here as in cyclones. Windows can be protected from gale force winds and flying debris by putting appropriate metal wire protective screens or shutters in place.

- **Ensuring roofs are well maintained**: Often it is not until heavy rain or hailstorms occur that homeowners or renters report cracked tiles or other problems with the roof. It is much easier to check the roof for damage and fix it during clear weather.

- **Ensuring roof materials are hail resistant**: There are a range of options to consider in the choice of roof materials for new and existing buildings to make them more hail resistant. These options are worth considering because the damage and inconvenience caused by hailstorms can be significant.

(These and other strategies to reduce the risks of hail damage are outlined in the Brief Background Information section.)

Currently no specific building code or Australian Standard exists which seeks to address and reduce the risks of hail damage. Professor Jeary has recommended that the Australian Building Codes Board and Standards Australia draw confidence from the success of their specific code for buildings in cyclone prone areas implemented in the late 1970s and 1980s and now also create a specific code and standard for houses in hailstorm prone areas. Australia’s building stock turns over roughly every fifty to one hundred years, hence mandating more hail resistant building design now for new homes in hail prone areas of Australia will ensure that, by 2070, the risks of damage from hailstorms is significantly reduced.

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Brief Background Information

Cyclones and Climate Change

Cyclones are one of the most feared phenomena in the natural world due to their capacity to cause significant damage and loss of life, with little or no pattern or warning. Specifically, according to Geoscience Australia, ‘A tropical cyclone is a low-pressure system which develops in the tropics and is sufficiently intense to produce sustained gale force winds of at least 63 km/h [34 knots]. If the sustained wind reaches hurricane force of at least 118 km/h [63 knots] the system is defined as a severe tropical cyclone.’ Tropical cyclones cause damage through heavy rainfall and gale force winds, which can cause damage to property by felling trees, lifting roofs and tiles, breaching windows and doors, and picking up items that can become dangerous missiles. Strong winds also lead to increased wave height, which can create storm surges, leading to coastal flooding, and erosion. This is covered in Lecture 1.4.

Climate change is expected to influence the intensity of cyclones because sea temperature is a key factor influencing the causation of cyclones. As GeoScience Australia explains, ‘The main source of energy for tropical cyclones is the warm oceans in the tropical regions.’ Variations in the number of tropical cyclones in Australia correlate well with local sea surface temperature before and near the start of the cyclone season. The strongest correlation is with October sea surface temperatures. The IPCC 4th Assessment referenced a range of studies showing that sea surface temperatures have increased over the last century (as shown in Figure 1.2.1), and concludes, from the evidence, that climate change has been the main contributor to the increased intensity of tropical storms and cyclones since the 1970s. Other research also concludes that increases in tropical cyclone intensity correlates with the observed changes in sea surface temperature over the last thirty years. The IPCC has also found evidence to suggest that these cyclonic storms are shifting poleward due to climate change.

Globally, estimates of the potential destructiveness of hurricanes show a substantial upward trend since the mid-1970s, with a trend towards longer storm duration and greater storm intensity, and the activity is strongly correlated with tropical sea surface temperature... Specifically the number of category 4 and 5 hurricanes increased by about 75% since 1970. The largest increases were in the North Pacific, Indian and Southwest Pacific Oceans. However, numbers of hurricanes in the North Atlantic have also been above normal in 9 of the last 11 years... Based on a variety of measures at the surface and in the upper troposphere, it is likely that there has been a poleward shift as well as an increase in Northern Hemisphere winter storm track activity over the second half of the 20th century.

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12 Ibid.
Australia’s research scientists have found similar trends. Using the IPCC A2 Scenario, Abbs et al in their 2006 study on the Projections of Extreme Rainfall and Cyclones predict that if current trends continue, we can expect an increase in the intensity of the most extreme storms of 60 percent by 2030 and 140 per cent by 2070 for Australia. This study also shows a decrease in tropical cyclone numbers by 44 per cent by 2070 off the coastline of Western Australia, while off the east Australian coastline small decreases of only 9 per cent are predicted. This study also predicts more long-lived tropical cyclones off the east coast of Australia, that is, more cyclones which take longer to lose their energy. Studies also show that while the number of mid-latitude storms affecting southern Australia

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22 Ibid.

has decreased over the last few decades, their intensity has increased, and this trend will continue. Abbs et al plus two other recent studies predict a sharp increase in Category 3-5 storms.

Risks and Costs from Cyclones

Tropical cyclones and hurricanes can have major economic, social and environmental impacts in Australia and globally. CSIRO noted that there has been a statistically significant increase in the cost of damage due to severe storms in Australia between 1967 and 1999, in large part due to the increase in population in storm prone areas. In addition to increasing population densities the relationship between wind speeds and risk of damage to buildings has been found not to be linear, but rather exponential, as shown in Figure 1.2.2.

![Image of Figure 1.2.2](image.png)

**Figure 1.2.2** IAG building claims versus peak gust speed showing disproportionate increases in claims cost from small increases in peak gust speed

*Source: IAG (2003)*

The Bureau of Transport and Regional Economics estimates that the total cost of cyclones for Australia since 1967 has tipped AUD$8.8 billion. Total damages from Hurricane Mitch to Honduras was the equivalent of 75 per cent of Honduras’s annual national GDP. Hurricane Katrina and the economic losses totalled more than US$100 billion. According to the IPCC, ‘Up to 119 million people are on average exposed every year to tropical cyclone hazard’. Worldwide, from 1980 to 2000, a total of more than 250,000 deaths were associated with tropical cyclones, of which 60% occurred in Bangladesh. The death toll has been reduced in the past decade due largely to improvements in warnings and preparedness, wider public awareness and a stronger sense of community responsibility. The most-exposed countries have densely populated coastal areas, often comprising deltas and mega-deltas (China, India, the Philippines, Japan, Bangladesh).

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24 Ibid.
Australia is not immune to a Hurricane Katrina style cyclone disaster. The low-lying canal developments on the Gold Coast are particularly vulnerable and are outside mandated cyclone-proof building codes in North Queensland. Since Cyclone Tracy hit Darwin in 1974, changes to the building code have been implemented in the late 1970s and early 1980s to reduce the risk of damage from tropical cyclones. Since that time, research by the Cyclone Testing Station based at James Cook University shows that the building code reforms have significantly reduced the damage to buildings from tropical cyclones Winifred, Vance, Ingrid and Larry. The commonly used insurance damage curves developed by Walker show up to a 5-fold improvement for post code buildings compared to pre code buildings in the likely damage costs. This shows that changing building design is worth the effort to reduce the risks of damage from cyclones. In addition, these changes can reduce the amount of potentially deadly flying debris from roofs and tiles, and thus reduce the number of lives lost and persons injured from cyclones.

An investigation into what can be done to reduce risks of damage from cyclone induced storm surges on coastal communities is covered in Lecture 1.4 and in Module C. The following sections overview some of the main issues regarding the design of buildings to make them more cyclone proof to help reduce the risks of loss of life and damage costs from cyclones.

Cyclone Proofing Buildings

There is no practical method of construction that can guarantee complete protection from a cyclone. Efforts to reduce the damage to structures from cyclones are hindered by a number of complicated concerns and variables, such as:

- The intensity and path of the cyclonic winds relative to the structure,
- The effect of flying debris generated by loose items, trees, power lines or disintegrating buildings,
- The fact that lightweight structures with wood frames are generally the most vulnerable to cyclones and are widely used in the regions affected,
- Older structures are more likely to have deteriorated components (corrosion, rot, termite/insect impacts, weathering), leading to a reduction in strength along the critical load path within the building, and
- Incorrect or poor construction practices, such as houses made of un-reinforced or poorly constructed concrete block, which increases vulnerability.

All of these factors can lead to significant damage to buildings. Furthermore, the degree of exposure of land and buildings will affect the velocity of the cyclone wind at ground level - with open country or seashore areas being the most vulnerable. For instance, when Cyclone Larry hit Far North Queensland in 2006, houses that otherwise met cyclone prevention standard, were still excessively damaged because of a failure to take these topographical characteristics into account. The Cyclone

Testing Station\textsuperscript{37} found that, in this case, the design had not properly assessed the likely increased wind strengths and speeds in the more exposed areas.\textsuperscript{38} Furthermore that the design had failed to properly implement the requirements of Australian Standard AS4055,\textsuperscript{39} which outlines the required detailing of wind speeds for a particular building site.\textsuperscript{40} A rough guide for the likely exposure to wind speeds and hence the likely level of cyclone related building standards (AS4055\textsuperscript{41} – C1, C2 or C3) can be determined by the amount of view the house site has. If there is minimal view then the house probably is surrounded by other houses on a flat contour and hence it receives some protection from the wind and requires AS4055 C1 to be applied. If there is some view then AS4055 C2 standards should be applied. If the building has an expansive view, AS4055 C3 standards should be applied to give the building the best chance of surviving a cyclone. Compounding this, settlement patterns may create a ‘tunnel effect’ that increases the wind speed between buildings, leading to even greater damage. In the case of construction of a group of buildings, a cluster (zig-zag) arrangement of buildings can be used to significantly reduce the tunnel effect.

![Figure 1.2.3 Alignment of Buildings can affect Local Wind Speeds](source)

Much can be done to individual buildings to reduce the risks of damage from the gale force winds associated with cyclones,\textsuperscript{43} which are discussed in the following.

**Roofing**

Gale force winds lifting roofing, either fully or partially off the house, is one of the major areas of building failure in cyclones. Traditionally building designers have used the weight of the roof to hold it down and focused on ensuring that the structural design of the building was sufficient to hold the weight of the roof up. But in a cyclone the forces lifting the roof are the equivalent of the upward force of the weight of a small car, one-and-half-tons, so roofs need to be tied down to resist this uplift pressure from cyclonic winds.\textsuperscript{44} As Ankush Agarwal from UNDP explains,

*Roofing coming off is caused by a combination of inadequate fastening devices, inadequate roof thickness and insufficient frequencies of fasteners in the known areas of greater wind*
As the corners and the roof edges are zones of higher local wind suction, the connections of cladding/sheeting to the truss need to be designed for the increased forces. In Cyclone Larry, the Cyclone Testing Centre, based at James Cook University, found that the major sources of failure which led to all or parts of the roof coming off were:

- ‘loss of roof battens which were fastened to rafters with one or two nails.
- loss of roof rafters or trusses when anchored by only one nail.
- loss of struts, ridge members, and connected rafters when struts are not tied down.
- loss of roof tiles because they were not all individually fastened.

Hence they recommended that designers and builders should do the following:

- ‘Rafter and strut anchorage to top plate should be brought up to capacity required by AS1684.3 by framing anchors or straps.
- Batten or rafter anchorage should be brought to an appropriate level by installation of batten straps or screws.
- Cladding should be fixed in accordance with manufacturers specifications for the site wind classification.

For roofs with tiles, all individual tiles should be fastened to the roof.

These recommendations are based on extensive research by the Cyclone Testing Station, the results of which are summarised in over 50 freely available extensive technical reports.

Other aspects of the design of a house can help reduce the risks of damage in a cyclone. For instance, in order to lessen the effect of the uplifting forces on the roof, the roof pitch should be no less than 22 degrees. Also, experts warn, you should avoid a low pitched roof, and use a hip roof or a high pitched gable roof, with a preference for the former. Experience and experiment have

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shown that, of all types of roof, the hip roof is the most effective at coping with gale force winds, with the pitch somewhere between 25 and 40 degrees.\footnote{Ibid.}

Figure 1.2.4 Schematic of Hip, High Gable and Flat Roof designs

\textit{Source: UNDP (2007)}\footnote{Ibid.}

Overhangs, patios and verandas can experience high wind pressures, and thus it is wise to design these elements to be separate to the main structure, rather than extensions of the main building. This ensures that, if they do blow off, they can do so without damaging the house, as shown in Figure 1.2.5.

Figure 1.2.5 Overhangs, Verandas Rooves, and Patio Rooves Are Vulnerable to experience high wind pressures

\textit{Source: UNDP (2007)}\footnote{Ibid.}

Walls

There are many different ways to reinforce walls to consider cyclone wind loading and make walls stronger. In cyclone or earthquake zones the UNDP recommends reinforcing walls with: longitudinal reinforcements (shown as 1 in Figure 1.2.6), lateral ties (2), and vertical reinforcing bars in the corners (3).\footnote{Ibid.}
The design of many homes allows for a range of different types of small wall openings to enable ventilation, thereby reducing condensation within the wall cavity space. However, necessary as they are for managing ventilation, these are also sources of weakness in a cyclone. The UNDP recommends the following steps be followed to minimise the problem:

1. ‘Openings in load bearing walls should not be within a distance of h/6 from the inner corner for the purpose of providing lateral support to cross walls, where ‘h’ is the storey height up to eave level.

2. Openings just below roof level should be avoided except for two small vents without shutters provided in opposite walls to prevent suffocation in case room gets filled with water and people try to climb up on tables, chairs to breathe.

3. Since the failure of any door or window on the windward side may lead to adverse uplift pressures under roof, the openings should have strong holdfasts as well as closing/locking arrangement.

Glass Windows

In a cyclone, glass windows are vulnerable points of buildings which can be broken by flying debris. This can provide an opening for gale force winds to build up pressure in the home to lift parts of or even the whole roof off. Providing wire screens to protect windows from debris can reduce this problem. In Cyclone Larry, surveyors found little evidence that such wire screens were being used in the town of Innisfail leading to broken windows due to the impact of debris. Interestingly, wire screens over windows are also recommended to protect homes from bushfires and hailstorms as well (as covered in other lectures in this module). Ensuring that windows are not smashed open by debris also helps the home to maintain its seal against water inundation. In cyclones, gale force winds can lead to penetrating rain following wind patterns and even moving horizontally. Therefore if windows break they create an opening for rain to flood the house and cause damage.

Foundations

The forces from cyclonic winds, when combined with favourable situations (such as a window breaking enabling pressure to build up in the home), can sometimes pull buildings completely off the
ground. Obviously lighter timber framed buildings are more vulnerable to this. Therefore, to prevent this from happening, timber framed buildings need to ensure a larger and heavier foundation is used that will be cyclone resistant as well as ensuring that the superstructure is properly fixed to the foundation.

**Roller Doors on Garages**

One of the key findings from the Cyclone Testing Station’s investigation of 2006 Cyclone Larry was that the roller doors on garages of homes and commercial facilities failed. Any structural failure like this creates potentially lethal debris which can cause further damage. In addition, once the roller door is broken it enables gale force winds to enter and lift the roof off by building up pressure in the confined space. In Cyclone Larry, the failure of roller doors led to greater destruction of garages and buildings than should have occurred (see Figure 1.2.7). According to the James Cook University’s Cyclone Testing Station, ‘roller doors need to comply with the wind loading standard and the domestic garage door standards AS/NZS4505. The filaments and supports of a roller door must be sufficient to high wind pressures or the garage must be constructed assuming that the roller door will fail.’

![Figure 1.2.7 Two of the Failed Roller Doors from Cyclone Larry](image)

Source: Cyclone Testing Station

A range of studies have shown that these basic lessons on why buildings fail have yet to adequately be incorporated into building design codes and practices. David Henderson and John Ginger from the Cyclone Testing Station have distilled these lessons and researched how Australia’s building code and construction standards are performing and can be improved in this area. They conclude that:

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59 Ibid.


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Post windstorm damage surveys have shown that houses designed and built to the revised standards since the mid-eighties, perform better structurally than houses built prior to that. The studies have also indicated that the current suite of loading, design and construction standards are effective without being overly conservative. However, there were examples of houses designed and built that did not conform to the relevant standards, because of the:

- Use of non-conservative design parameters, for example not accounting for high internal pressure caused by a dominant opening, or use of incorrect wind acceleration or shielding multipliers.

- Poor or faulty construction practices such as unattached or missing fasteners, overdriven nails, component or connection spacing in excess of specified minimum distances.

- Inappropriate use of materials for durability requirements (non-galvanized fasteners, untreated timber, etc).

- Use of products that have not been designed, tested or installed for appropriate wind region (unrated roller doors and awnings, cladding and battens that have not been fatigue tested, etc).

- Education and awareness of the consequences in making non-conservative design assumptions, and of faulty construction (e.g. damage to property and risk to life) is required in every step of the building process (regulation, design, construction, certification and maintenance) and by all parties (designer, builder, certifier, and owner).

The Cyclone Testing Station’s work shows that a still greater education and community awareness program is needed. They specify the following areas as needing more attention in this regard:

- ‘Correct interpretation of the Building Code of Australia (BCA) provisions,

- Correct application of design standards,

- Testing and certifying building materials, connections, etc to the relevant standards,

- Diligent construction practices, and correct application of materials and components as per manufacturer’s instructions,

- Appropriate inspection and certification at time of construction, and

- Ongoing inspections and maintenance for serviceable life of building.  

For further detailed information on these and other important aspects of building design to ensure buildings are as cyclone proof as possible please see the technical reports of the Cyclone Testing Station. Preparing for cyclones is not just a job for designers and builders - the community has a key role to play, and Townsville City Council, a leader in local government sustainable development programs, has created a comprehensive To-Do list, to help ensure that homes are as cyclone proof as possible.  

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Hailstorms

Climate change is forecast to lead to more extreme weather events across the world that will have the potential to cause significant damage to public and private infrastructure and assets. Of particular interest to Australia, particularly the east coast, is the threat of hailstorms. 67 Technically speaking, according to GeoScience Australia:

Hail forms in strong thunderstorm clouds, particularly those with intense updraughts, great vertical extent, high liquid content with large water droplets and where a good portion of the cloud layer has a temperature below freezing (0°C). Hail forms on condensation nuclei such as dust, insects or ice crystals when supercooled water freezes on contact. If the hailstones grow large enough, they become too heavy to be supported by the thunderstorm's updraught and fall out of the cloud.68

Hailstorms are most common in mid-latitudes during early summer where surface temperatures are warm enough to promote the instability associated with strong thunderstorms, but the upper atmosphere is still cool enough to support ice. Accordingly, hail is actually less common in the tropics despite a much higher frequency of thunderstorms than in the mid-latitudes because the atmosphere over the tropics tends to be warmer over a much greater depth.

Climate Change and Hailstorms

Whether or not hailstorms form is very sensitive to subtle changes in atmospheric parameters. Therefore to determine how climate change will affect the frequency and intensity of hailstorms is best studied region by region. In the last four years there has been extensive modelling of the effects of climate change on the likelihood and intensity of hailstorms for the Sydney basin and NSW coast.69 These studies show that there is a correlation between climate change and likely increases in both the frequency and intensity for the Sydney and NSW coastal areas.70

There are a number of factors that contribute to the overall trend for hailstorms of greater intensity in the future climate for the Sydney region and NSW coast. The most important factor is the temperature of the East Australian Current. This will increase due to climate change this century. As a result of this, winds from the north-east will deliver more moisture into the pre-storm environment over the western Sydney Basin and other basins up the NSW coast. In addition, maximum air temperatures are forecast to increase due to climate change throughout the hailstorm season of October to April. Therefore the pre-storm environment for the Sydney Basin and other basins on the NSW coast will have increased surface temperatures and dew points when compared to the

70 Ibid.
historical climate, which will also increase the pre-storm "Convective Available Potential Energy" (CAPE) - the key indicator of the likelihood and potential severity of storms.\textsuperscript{71} Climate modelling indicates the possibility of extreme hailstorms with hail sizes in excess of 12 cm in diameter over limited areas. The Sydney Basin, Wollongong, the Blue Mountains and the hinterland of the Central Coast are forecast to be particularly at risk this century of severe hailstorm events.\textsuperscript{72}

CSIRO’s extensive 2007 study of climate change in Australia also found that hail risk may increase over the southeast coast of Australia especially up the east coast.\textsuperscript{73} Figure 1.2.8 shows projected changes in hail-days per year for 2030 and 2070 from CSIRO modelling as well as showing that on the east coast of NSW, the hailstorm risk is projected to almost triple, increasing from one to two days per annum to approximately four to six.

![Figure 1.2.8](image)

**Figure 1.2.8** Projected changes in hail risk (hail-days per year) for 2030 and 2070

*Source: CSIRO (2007)*\textsuperscript{74}

### Cost of Hailstorms

Economic losses from hailstorms in Australia account for 34 per cent of the total losses from 1967-2003 from natural disasters, according to the Insurance Disaster Response Organisation, the largest proportion for any natural disaster. Hail damage is responsible for fifty per cent of the top twenty insurance losses in Australia since 1967.\textsuperscript{75} The city of Sydney, being situated in a warm/temperate zone, with both ocean and desert influences, has the climatic conditions necessary to be affected by severe convective storms which can produce hail. Sydney has experienced six significant hailstorms in just over the last 20 years or so. (See Table 1.2.1)

**Table 1.2.1** Insurance losses from hail events in Sydney

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Cost (billion AU$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>November 1976</td>
<td>Western Sydney</td>
<td>0.73</td>
</tr>
</tbody>
</table>

\textsuperscript{71} Ibid
\textsuperscript{72} Ibid
<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 1986</td>
<td>Western Sydney</td>
<td>0.71</td>
</tr>
<tr>
<td>March 1990</td>
<td>South Western Sydney</td>
<td>1.47</td>
</tr>
<tr>
<td>January 1991</td>
<td>Turramurra</td>
<td>0.58</td>
</tr>
<tr>
<td>February 1992</td>
<td>Girraween &amp; Toongabbie</td>
<td>0.45</td>
</tr>
<tr>
<td>April 1999</td>
<td>Eastern Suburbs</td>
<td>3.3</td>
</tr>
<tr>
<td>December 2007</td>
<td>Blacktown</td>
<td>0.41</td>
</tr>
</tbody>
</table>

(Source, Jeary, A, 2009)

The most costly hailstorm to date was in Sydney in 1999. Huge hailstones, some the size of cricket balls fell in this hailstorm causing significant damage.

![Hailstones](image)

**Figure 1.2.9** Hailstones collected during the Sydney hail-storm of 14 April 1999 compared with a seven centimetre diameter cricket ball

*Source: Bureau of Meteorology*

The onslaught of such large hailstones damaged or destroyed at least 35,000 buildings, mostly homes, causing extensive roof damage. Insurance losses from the storm were the highest ever for a natural disaster. In addition to the physical and insurance costs there were significant human, emotional, and time costs for all those involved. The roofing damage from the Sydney hailstorm of 1999 affected so many homes, that it took many months to repair, significantly affecting tens of thousands of families. It took 6 months to finalise just half of the buildings claims, and a year after the storm 20 per cent of claims still had not been finalised. This left many Sydney homeowners using tarpaulins to protect their homes over months.
The afternoon of Friday the 18th of January, 1985, delivered what is considered the worst hailstorm in Brisbane’s history. This hailstorm produced hailstones as large as 6 cm in diameter. The storm was accompanied by gale force winds which reached almost 200 km/h [106 knots] making such large hailstones effectively missiles. The storm hit Brisbane during peak hour traffic, causing significant damage to vehicles, with an overall damage bill estimated to be more than AUD$300 million. Severe hailstorms have also struck Melbourne and Adelaide. Hail damage during the 1990s in the USA has been calculated at approximately US$1.2 billion per year for both property and crop loss.\(^{82}\)

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Adaptations to Reduce the Risks of Damage from Hailstorms

The area or part of a building that is most susceptible to damage from hailstones is that facing the sky. Hailstones are not moved significantly in a horizontal direction\(^{83}\), and so windows on the sides of houses are rarely affected, whereas roofs, skylights, antennas and coverings are affected. The following steps are recommended to reduce the risks of damage from hailstorms:

1. **Ensuring roofing design can withstand higher wind speeds and hail impact:** The same rules apply here as in cyclones. The roof ideally is a hip shaped roof with at least a 22 degree angle, rather than a flat one, to reduce the average force of impact. Several hail damage testing agencies recommend increasing roof pitches over 6:12\(^{84}\) to dramatically improve hail resistance. The roof tiles should be individually tied down so that high wind speeds cannot lift them as in cyclones.

2. **Ensuring roofs are well maintained:** Following a hailstorm or heavy rain, many homeowners and renters report water damage caused by leaking roofs. Most don’t know they have cracked roof tiles until heavy rain hits. It is recommended that all residents organise to have their roofs checked while the weather is clear.

3. **Ensuring roof materials are hail resistant:** There are a range of options to consider in the choice of roof materials for new and existing buildings to make them more hail resistant. These options are worth considering because once hail has broken through the roof, water gets into the roof, creating internal damage and destroying contents, increasing the costs for repair and replacement. In addition to most new tiles on the market, which tend to be more hail resistant than the old tiles like slate, there are a range of specialty hail resistant tiles available. These tend to cost a bit extra per tile but pay for themselves in the long run.\(^{85}\) A number of experts are recommending that governments encourage Australian households to make this investment.

Insurance Australia Group’s Technical Research Centre has investigated roof materials and their resistance to hailstorm damage. They have been using an experimental facility and using a hail gun, which propels hail-shaped ice blocks at roofing materials to assess which is the most hail resistant. The results of their experiments are summarised below in Table 1.2.1.\(^{86}\)

<table>
<thead>
<tr>
<th>Roof material (in order from best to worst performing)</th>
<th>Breaking point (What size hailstone caused the roof to crack?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrugated steel sheets</td>
<td>10cm in diameter</td>
</tr>
<tr>
<td>Concrete tiles (new)</td>
<td>7cm in diameter</td>
</tr>
</tbody>
</table>


Jeary et al.⁸⁸ have correlated work performed in Australia by the IAG Technical Research Centre and others ⁸⁹ with the work by Torro ⁹⁰ in the UK to produce the following table which outlines the risks of damage for different hail diameters. This table shows that experiments in the UK found similar results to Australian experiments in this area. (See Table 1.2.2)

<table>
<thead>
<tr>
<th>Hail Diameter (mm)</th>
<th>Damage (Torro)</th>
<th>Damage (SGIO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>Slight crop damage</td>
<td>-</td>
</tr>
<tr>
<td>15-20</td>
<td>Significant crop damage</td>
<td>-</td>
</tr>
<tr>
<td>20-30</td>
<td>Glass and plastic damaged</td>
<td>-</td>
</tr>
<tr>
<td>30-40</td>
<td>Vehicle and widespread glass and plastic roofing broken</td>
<td>Glass and plastic roofing broken</td>
</tr>
<tr>
<td>40-50</td>
<td>Tiled roofs damaged, slate broken</td>
<td>Old slate 100+ years old, Old tiles 50+ years old, cracked</td>
</tr>
<tr>
<td>50-60</td>
<td>Tiled roofs broken, metal roofs dented</td>
<td>Old slate tiles broken, new tiles crack</td>
</tr>
<tr>
<td>60-75</td>
<td>Severe roof damage, tiles broken, slate shattered</td>
<td>New concrete tiles and terracotta tiles break</td>
</tr>
<tr>
<td>75-85</td>
<td>Severe damage to aircraft bodywork, tiles shattered, slate destroyed</td>
<td>Sheet metal dented – all other roofing broken</td>
</tr>
<tr>
<td>85-90</td>
<td>Severe damage to aircraft bodywork, tiles shattered, slate destroyed</td>
<td>Sheet metal dented – all other roofing smashed</td>
</tr>
<tr>
<td>&gt;90</td>
<td>Extensive structural damage &amp; sheet metal penetrated</td>
<td>Sheer metal roofing penetrated/ cracked</td>
</tr>
</tbody>
</table>

The Australian and UK tests are backed up by similar hail damage surveys that have been undertaken in the US. The US tests have found roughly the same breaking points for standard roof materials. These tests were conducted at 90 degrees to replicate a worst case scenario, i.e. hail impacting directly onto the roof surface. The speeds varied from 100 km/h to 160 km/h to mimic common wind speeds during a hailstorm. Haag Engineering Co, Texas USA, has released these findings of its trials on different types of tiling materials.⁹¹ (See Table 1.2.3)

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Table 1.2.3 Percentage of Common Roof Materials Broken from Hail Impact at Different Diameters.

<table>
<thead>
<tr>
<th>Type of Roofing Product</th>
<th>Age (yrs)</th>
<th>25mm</th>
<th>32mm</th>
<th>38mm</th>
<th>44mm</th>
<th>50mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-tab fibreglass shingles</td>
<td>11</td>
<td>0</td>
<td>60</td>
<td>90</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>3 tab organic shingles</td>
<td>11</td>
<td>-3</td>
<td>90</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>30 year Laminated shingles</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>Cedar shingles</td>
<td>11</td>
<td>0</td>
<td>20</td>
<td>80</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Heavy Cedar shakes</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>Fibre Cement tiles</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>80</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Flat Concrete Tiles</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>50</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>S-shaped Concrete Tiles</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>Built up Gravel Roofing</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>Number of Products Damaged</td>
<td></td>
<td>1/9</td>
<td>5/9</td>
<td>7/9</td>
<td>7/9</td>
<td>9/9</td>
</tr>
</tbody>
</table>


Haag Engineering Company has also undertaken more than a dozen hail damage surveys in hailstorm prone cities in the USA. Similar hail damage surveys have also been undertaken in the USA by Charlton and Kachman. These surveys correlated well with the test results in Tables 1.2.1 and 1.2.2. The implication from these tables so far is that that the return period for hailstones of a size sufficient to cause significant damage to tiled roofs in Sydney, is between 15 and 20 years. This is because most tiles on Sydney roofs can be damaged with hailstorms above 70 mm as most have terracotta tiles. (See Table 1.2.4)

Table 1.2.4: Roof types by percentage in Sydney.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Terracotta Tiles</td>
<td>75</td>
<td>69</td>
<td>17%</td>
</tr>
<tr>
<td>Steel Sheeting</td>
<td>12</td>
<td>10</td>
<td>41%</td>
</tr>
<tr>
<td>(Colorbond)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Tile</td>
<td>-</td>
<td>19</td>
<td>31%</td>
</tr>
<tr>
<td>Slate</td>
<td>10</td>
<td>1</td>
<td>161%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>2</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

(SOURCE: Jeary, A et al, 2009)

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Recommendations

Over the previous two decades there is a trend emerging for more frequent and intense hailstorms in Australia. In this case, as in all areas of natural disasters considered in these lectures (cyclones, hail, bushfires and sea-level rises) the costs of inaction are greater than the costs of action. Yet, today most roofs of houses and buildings in hailstorm prone areas are currently not designed to cope with major hailstorms. Evidence for this comes from the most recent hailstorm in Sydney in 2007 which saw damage of more than AUD$400 million recorded in the Blacktown area leading to thousands of insurance claims. Also, research by Jeary et al shows that the return period for hailstones of a size sufficient to cause significant damage to tiled roofs in Sydney, is between 15 and 20 years.96

Significant market failures, such as imperfect information and split incentives, have, to date, significantly slowed progress to improve the hail resistance of roofs in hail prone areas in Australia;

- **Imperfect Information:** Building owners clearly have a strong self interest in protecting themselves and their properties from the risks and consequences of a hailstorm event but many are not fully informed of the risks, nor aware of the options and costs of solutions.

- **Split Incentives:** The benefits of hailstorm protection of buildings do not accrue to the party that designs or builds the house. Those responsible for the design and construction of buildings are not then responsible for the ongoing operational and maintenance costs of those buildings. Hence in a competitive market place builders and developers will tend to resist measures which add to the costs of building homes such as using more hail resistant tiles. In addition, currently in the marketplace, those builders which try to do the right thing will be penalised competitively as their homes will cost more to build than their competitors. Hence there is a role for government and regulation here.

As outlined previously, in the late 1970’s to early 80’s, specific building codes were implemented that addressed tropical cyclone wind loads on residential buildings. Since then surveys and research has shown a significant reduction in damage costs from cyclones in post code buildings compared to pre code buildings. This shows that the building industry and Australian homeowners have a great capacity to adapt to changes in the building codes. Currently no specific building code or Australian Standard exists which seeks to address and reduce the risks of hail damage.

This partly is a result of the fact that these boards where important decisions are being made in regards to planning and building codes in Australia have had no representatives from the insurance sector. Even though the costs of extreme weather events are largely reflected in insurance losses, and hence are an important consideration in deciding on the level and scale of response required.97

This needs to change to ensure that the potential future negative impacts of climate change are reduced through effective adaptation measures being updated regularly in the Australian building codes and standards.

The Australian Building Codes Board and Standards Australia should draw confidence from their experience with developing a specific building code for cyclone prone areas and now create a specific code and standard for houses in hailstorm prone areas. Mandating more hail resistant building design measures in the relevant building codes and standards for new homes would help to build a market for hail resistant tiles and roofs. It would help to encourage economies of scale and

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innovation which would bring down the unit costs to individual households of implementing such measures over the coming decades this century. It is thus recommended that such changes are mandated initially for all new homes built in hail prone areas of Australia. Building stock turns over roughly once every fifty to one hundred years depending on a range of factors. Hence, by requiring from hereafter all new buildings in hailstorm prone areas to be built to be hailstorm resistant, it will ensure by 2070 that most homes are better prepared for the risks of hailstorms.

Recent detailed statistical analysis and research by Professor Jeary and Charles Slack-Smith⁹⁸ has provided data which supports these recommendations. Professor Jeary and Charles Slack-Smith⁹⁹ have shown that that hailstones capable of damaging the type of roof used by 75% of Sydney’s domestic houses, occurs with a yearly probability of 6.7 per cent (15-year mean return period). As Jeary and Smith explain, “this probability is far more than that used for design for synoptic winds or for earthquakes which consider that probabilities of 5 per cent every 50 years and 67 per cent in 500 years (1000 and 500 year return periods respectively) are appropriate.”¹⁰⁰

The Building Code of Australia includes a performance requirement that roofs shall be proof against water penetration. However, at the last drafting, an analysis, such as the one undertaken recently by Professor Jeary and Charles Slack-Smith¹⁰¹, was not available partly due to the lack of relevant data.¹⁰² The implications of this recent study¹⁰³ by Jeary et al is that the occurrence of damage to roofs in Sydney, and thus the risks of water damage, is likely to be far greater than would probably be deemed acceptable to the Australian public given other standards for cyclones, earthquakes or bushfires.

Finally, we recommend that the Australian Building Code Board and Standards Australia investigate and undertake more detailed cost benefit analysis of the potential mixes of regulations, incentives and rebates to encourage households to invest in retrofitting their homes to significantly increase their capacity to resist damage from hailstorms.

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⁹⁹ Ibid.
¹⁰⁰ Ibid
¹⁰¹ Ibid
¹⁰² Ibid
¹⁰³ Records of the diameter of hail from hailstorms have only been kept for the last twenty years in Australia.
Key References


**Other Useful Links**