

Climate Change Adaptation for Building Designers: An Introduction

Mark Snow and Deo Prasad

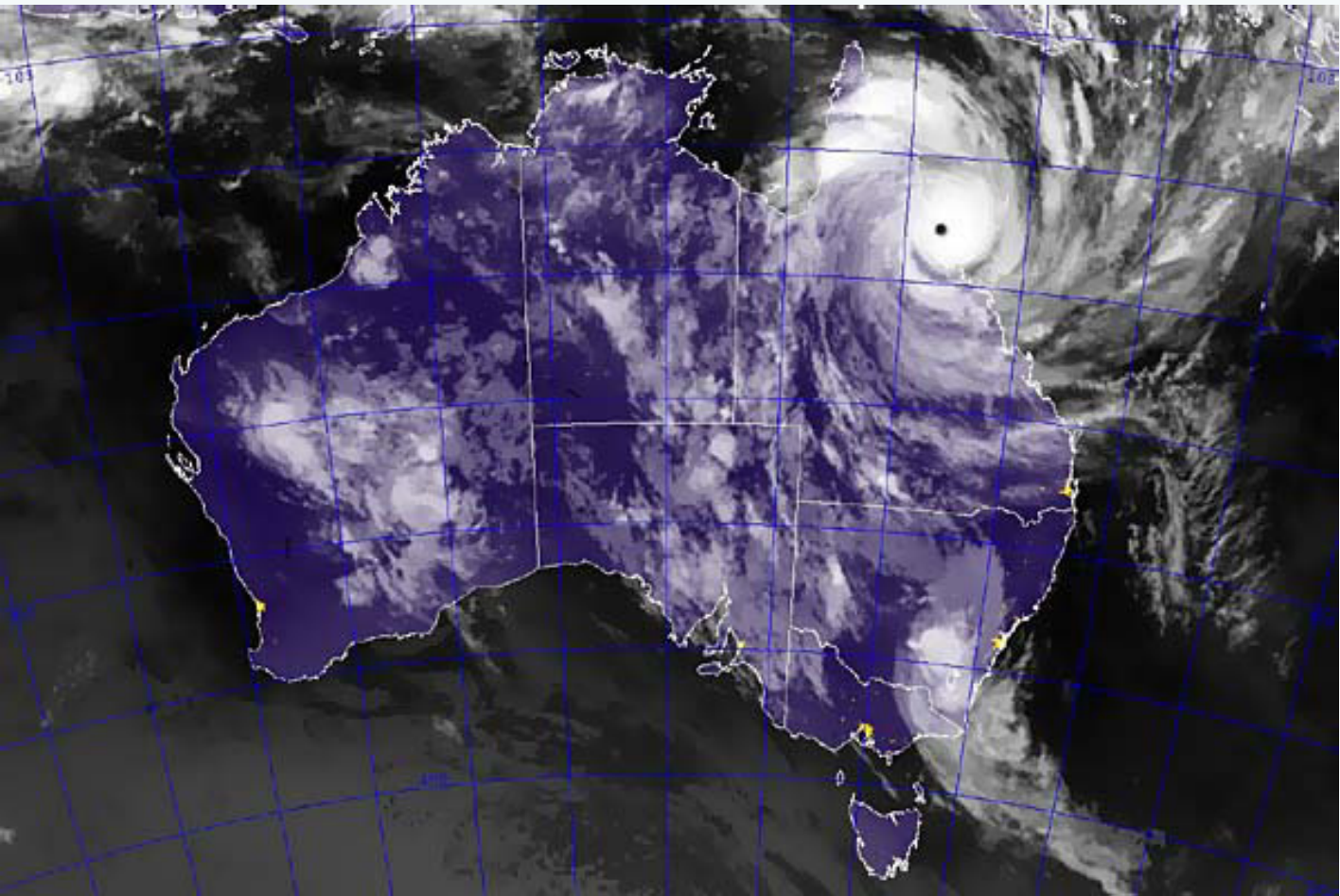


Figure 1: Cyclone Yasi off the coast of Far North Queensland, 2 February 2011. Extreme weather events such as tropical cyclones are predicted to become more frequent and intense as a result of climate change.

(Image: NOAA, 2011)

ABSTRACT

Adapting building designs for climate change is about managing the unavoidable. While there is debate around what level of adaptation is needed, there is growing awareness that design practices need to take into account predictions of increased risk and intensity of extreme events. This paper examines potential climate change effects on buildings, highlights the potential for capacity building through education, and presents examples of adaptive strategies for building design.

Introduction

This paper is a product of the Federal Government's Climate Change Adaptation Skills for Professionals (CCASP) program. The program aimed to determine the preparedness of Australian professionals to adapt to climate change, and to develop resources and accreditation courses that will build that capacity.

CCASP was a direct result of findings from the ARIES (Australian Research Institute in Education for Sustainability) research conducted by Macquarie University (Lyth et al. 2007). ARIES' research indicated that professionals generally understand the need for climate change adaptation, but not its practical implications. It also concluded that adaptation responses need to be an integral part of sustainable design principles. This paper builds on that pioneering work.

This paper highlights the dispersed geographic nature and climatic variability of Australia and the need to prepare for climate change at a regional level. It presents descriptions of a range of climate change impacts on buildings, and includes a perspective from the insurance industry. This is followed by a clarification of the terms 'climate change adaptation' and 'climate change mitigation' and the notion of maladaptation. Commentary is given to the possible design strategies to combat climate change impacts, addressed as localised risks. Concluding remarks emphasise the need for the architectural profession to up-skill to incorporate adaptive design approaches.

Preparing for Climate Change

An architect who designs for climate change adaptation (CCA) recognises that the nature of weather events is unlikely to remain the same throughout a building's lifetime.

At the national scale, historical data and modelling by the Bureau of Meteorology and CSIRO (2010) point to significant increases in mean annual temperatures, coupled with reduced annual rainfall in most locations. The study predicts an increased risk and intensity of extreme events such as bushfires, tropical cyclones, floods, hailstorms and droughts, which are likely to result in considerable economic costs to the nation.

Ash (2010) stresses the importance of not becoming bogged down in forecasting the precise level of climate extremes for a given location. Decisions can be (and are) made without accurate predictions of the future. It is better to use a range of plausible scenarios

combining climate projections and other factors to explore outcomes and risks, rather than try to predict exact climate outcomes.

Risk	Possible Effects
Rising temperature	Impact on external surfaces; thermal performance of building
More intense rainfall	Greater intensity of runoff; issues of structural integrity; drainage; opportunities for capturing rainfall
More frequent / intense cyclones	Greater strain on building material fixtures, claddings and fasteners; greater wind loading requirements
More frequent flooding	Sea level rise leading to coastal and inland flooding; more coastal salt spray; water damage to building contents; contamination from sewage, soil and mud; undermining of foundations
More fire events	Total or partial fire damage; smoke and water damage
More hail storms	Impact damage (mostly roofs, guttering, windows) and subsequent rain/moisture penetration
Increased humidity	Mould; condensation; decreased thermal performance of building
Decreased humidity	Higher risk of fire

Figure 2: Potential effects of climate change on buildings

It is important to bear in mind that small increases in temperature above normal levels can increase hazards dramatically, including the intensity of cyclone wind speeds, bushfires and flash flooding (Mills et al. 2001). Insurance Australia Group (IAG 2002) calculated that a 25 per cent increase in peak gusts causes 650 per cent increase in building damage.

A 25 per cent increase in peak gusts causes 650 per cent increase in building damage. (IAG 2002)

Mitigation and Adaptation

The United Nations Framework Convention on Climate Change (UNFCCC) uses two significant terms: mitigation, which is aimed at reducing emissions to minimise global warming or 'avoiding the unmanageable', and adaptation, which is 'managing the unavoidable' (GTZ/PIK 2009).



Figure 3: Yarra Glen house destroyed in the Victorian bushfires of February 2009
(Image: Wikimedia Commons)

While neither mitigation nor adaptation measures on their own can prevent significant climate change impacts, taken together they can significantly reduce risks. Parry et al. (2007) and Klein et al. (2007) show how adaptation and mitigation measures are mutually re-enforcing and thus should not be considered in isolation.

Baum et al. (2009), in studying the climate change, health impacts and urban adaptability of Queensland's Gold Coast, makes a simple distinction between mitigation and adaptation, where 'climate friendly' development (mitigation) leads to low greenhouse gas emissions and 'climate safe' development (adaptation) leads to low vulnerability to direct (temperature and water) and indirect (flooding, saline intrusion) effects of climate change.

While mitigation efforts are clearly important in terms of slowing the rate of climate change, given the climate system has already changed, and will continue to do so irrespective of mitigation efforts, at least in the short to medium term, investment in climate change adaptation is a prudent course of action. An adaptation approach acknowledges that there will be a need to adjust to unavoidable climate change to minimise building and infrastructure upkeep costs and maintain healthy ecosystems and liveable urban areas.

Importantly, strategies for adapting to unavoidable climate change impacts must not undermine mitigation efforts to stabilise greenhouse gas emissions to acceptable levels. Likewise, strategies for mitigation have the potential to be 'maladaptive' if they compromise adaptation. For instance, one possible side effect of improving the energy efficiency of dwellings is an increase in summer overheating of well-insulated, airtight dwellings (Hacker et al. 2005).

What is Adaptation?

The Intergovernmental Panel on Climate Change (IPCC 2008) defines four kinds of adaptation:

Anticipatory (proactive) adaptation: Adaptation that takes place before actual climate change impacts occur. Such adaptation is a pre-emptive measure to prevent or to minimise potential climate change impacts. It weighs up the vulnerability of natural and man-made systems as well as the costs and benefits of action versus inaction.

Planned adaptation: Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to maintain or achieve a desired state.

Reactive adaptation: Adaptation that takes place after impacts of climate change: for instance when new building regulations follow a severe bushfire event.

Autonomous (spontaneous) adaptation: Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems.

Managing Risk

A major challenge is to predict with confidence the extent of vulnerability of our buildings and cities to climate change, which will vary regionally throughout Australia. This complexity is compounded by planning for future population needs.

Building regulation amendments, planning controls and adjustments in building insurance value all aim to manage localised risks of climate change, and will in turn help drive design responses.

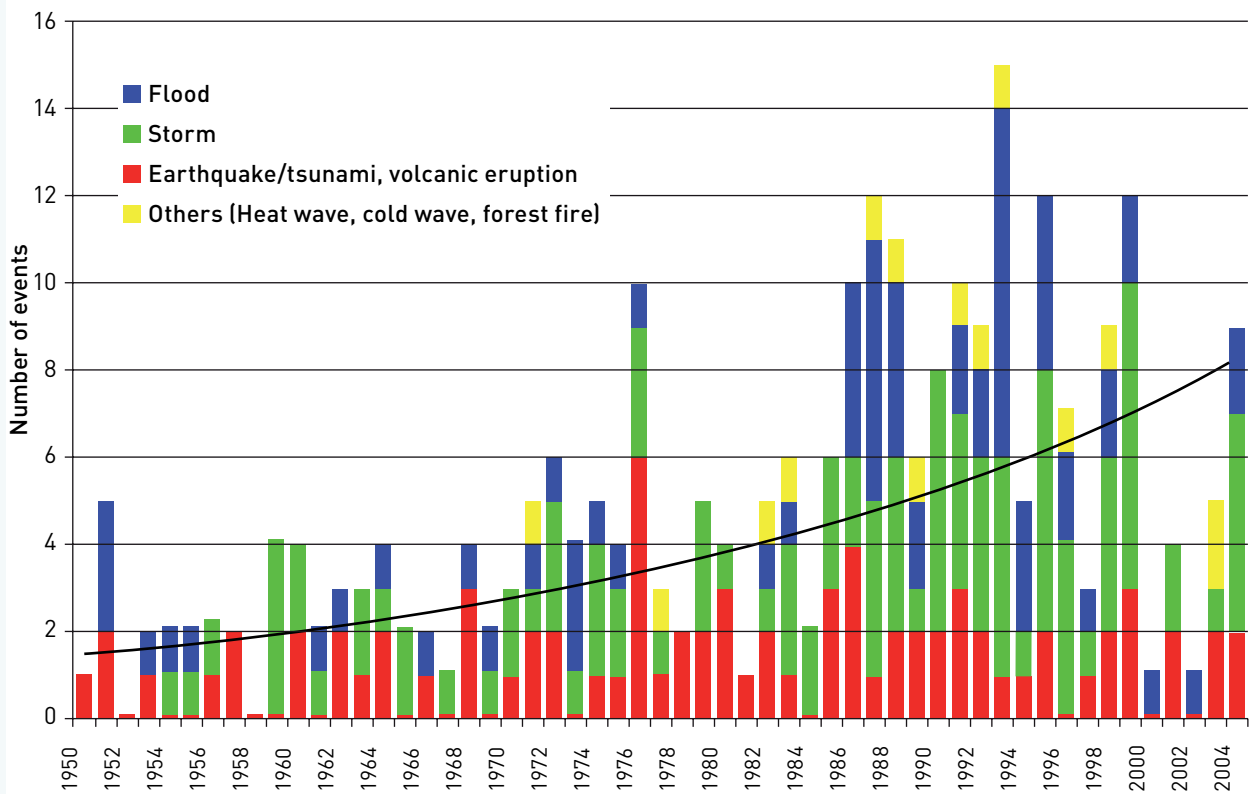


Figure 4: Weather-related catastrophes, 1950–2004
 [Source: Munich RE, 2005]

Regulation and Planning

Regulation (and targeted procurement) by governments can help to inform and guide the architectural profession as to necessary changes in practice. Historically, regulation has most often been reactive in nature: for instance where flooding, coastal inundation and bushfire disasters have accelerated modifications to building regulations and design requirements for rebuilding communities devastated by such occurrences.

At the planning level, Kousky and Cooke (2009) argue that successful adaptation policy might effectively decouple risks. The 1906 earthquake in San Francisco is given as an example where both an extreme earthquake and a resultant fire which burned for three days damaged a city, destroying 28,000 buildings. The severity of the damage was increased by the city's dependence on gas and water pipes that could not withstand a high magnitude quake. If gas pipes break, fire is more likely, and if water pipes break, flames cannot be controlled, leading any fire to likely be a conflagration. In this case, de-coupling the knock on effects of these two risks involves the design and installation of pipes that can better withstand extreme earthquakes.

Building design also has urban-scale impacts, and also has the potential to decouple risks. For example, higher building density can increase local urban heat

island effects and urban flooding, while strategies of greening buildings can ameliorate such issues. For example, capturing and filtering water that falls on buildings also will reduce excessive runoff during flash flooding. Interrelationships between built environment professions are at the core of integrated, whole urban design principles. They will be essential if the habitability and asset value of existing and new buildings are to be preserved in the face of increasingly unpredictable and extreme climate change threats.

Insurance and Risk Management

A compelling case for building owners and designers to take climate change impacts seriously is the shift in approaches by the major building insurance companies from reactive risk to rational action (Munich RE 2010). Typically, the costs from natural disaster building insurance claims were previously recouped by increasing premiums across a large client base. Now insurance companies are taking greater care in assessing the vulnerability of assets they insure at a local level.

Munich RE (2005) surveyed insurance claims from 1950 to 2004, revealing a massive increase in major weather-related natural catastrophes during that time. Between 1994 and 2004 there were almost three times as many weather related disasters as in the 1960s

(Figure 4). Economic losses increased by a factor of 5.3 in the same period and insured losses by a factor of no less than 9.6. The main causes in both cases were floods and windstorms, whereas geophysical disasters (earthquakes) remained fairly constant.

Adaptive Strategies for Building Design

Building flexibility into design to allow for the unexpected makes investment decisions robust to most possible changes in climate conditions. This may include no-regret strategies that bring benefits even in the absence of future climate change, e.g. strengthening tile fixtures securely to a roof to avoid wind damage, or polishing or tiling a concrete ground floor to allow quick recovery after a flood.

Beyond these measures, designers should be researching localised risks of climate change and preparing their buildings for the predicted hazards which may include:

- increasing temperatures
- coastal storm surges and inundation
- flooding
- tropical cyclones
- intensified downpours
- hail events

Increasing Temperatures

Passive design strategies have the double benefit of countering increasing temperatures without undermining mitigation efforts. The fundamentals of passive design are:

Thermal mass to reduce the internal temperature variation

Insulation and the use of low emissivity roofing paints and high performance glazing to reduce the rate of heat transfer through building structures

External shading of vulnerable building surfaces, and strategic siting of deciduous vegetation

Cross ventilation and mixed-mode design to cool internal spaces (ensuring insect-repellent screens are also used)

The Environment Design Guide contains a number of papers exploring individual elements of passive design. The Your Home Technical Manual (www.yourhome.gov.au), produced by the Federal Government, also provides a helpful overview of passive design options

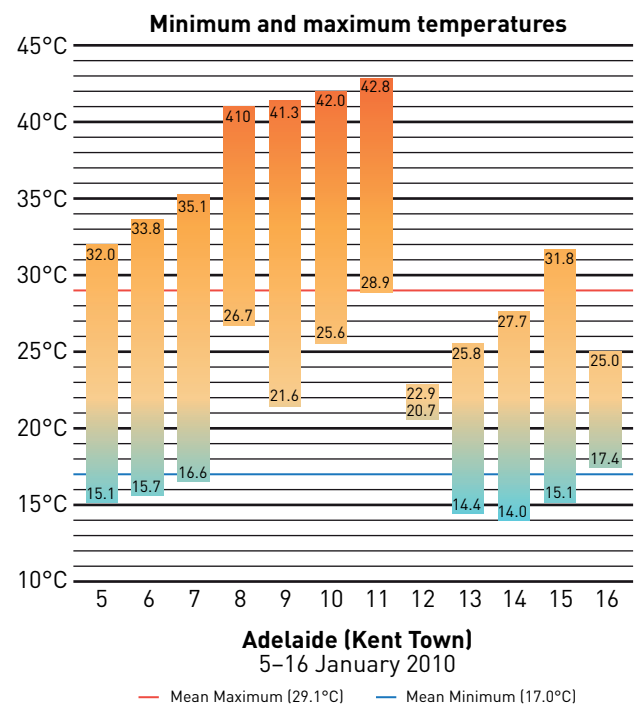


Figure 5: Adelaide heatwave, January 2010

[Adapted from: Wikimedia Commons, using data from BOM]

to reduce temperatures fluctuation of internal spaces when outdoor ambient air conditions are hot or cold. Strategies typically revolve around the key elements of passive design.

There are significant opportunities for the deployment of systems that use renewable energy sources, as well as highly energy-efficient technologies, including:

- Green roof and roof design technology
- Photovoltaic glazing
- Low heat producing lighting, equipment and plant
- Photovoltaic, solar, biomass, and wind-powered cooling technology
- Co-generation technologies (including waste heat capture technology)

Alternative construction strategies should also be explored. In South Australia (as elsewhere in Australia), staff are required to cease work once outside (or inside) temperatures reach 36 degrees Celsius. With more very hot days predicted, work disruption is likely to increase, potentially increasing building delays and costs. This provides opportunities for different and improved construction practices that allow staff to keep working with extreme heat, such as:

- Prefabrication and off-site construction
- Provision of on-site shading and ventilation
- Management of delays through contractual agreements



Figure 6: The Toowoomba flash flood of 2011, one of many flooding events in Queensland in 2010–11.

(Image: Wikimedia Commons)

- Management of concrete placement to ensure the maximum strength and durability of concrete structures is maintained (CIRIA 2005)

Coastal Storm Surges and Inundation

With over 85 per cent of the population living in coastal regions, strategies to reduce the threat of coastal storm surge and inundation are of critical importance. Through development of a National Coastal Vulnerability Assessment (NCVA), a detailed report was released to determine the risks of climate change for the whole of Australia's coastline (DCCEE 2009). Three overarching strategies underpin the designing of higher resilience from storm surge and inundation:

Protect land infrastructure and buildings from coastal storm surges and inundation by constructing hard structures (such as seawalls) and using soft measures (such as beach nourishment) so that existing land occupation can be maintained.

Accommodate surges and inundation, e.g. by elevating buildings on piles and designing the building foundation and any portions subject to flooding to withstand design flood conditions.

Retreat from coastal areas under significant threat.

Generally, designers should be guided by local government risk assessments and planning controls.

Flooding

In 2010–11, flooding events in Queensland, ACT, NSW and Victoria produced a heightened sense of the need to better plan and design buildings and infrastructure to reduce vulnerability to flooding risk.

In 2002, the Bureau of Infrastructure, Transport and Regional Economics (BTRE) made a number of recommendations associated with the benefits of flood mitigation in Australia. A key focus of the study was on property modification measures, which avoid or minimise loss by keeping development away from floodwater through land-use planning and smart building design, siting and material options. A key strategy to reducing flood problems is one of avoiding siting buildings on river flood plains and low-lying coastal areas (a critical planning and development issue).

Building codes establish the minimum standards required for a given locations and circumstances and are typically increased following an extreme events. Architects should assess whether these provide sufficient protection against climate change impacts anticipated for the lifetime of the building. Given that individuals can pay off the higher construction costs over the life of a mortgage, building design measures that can adapt to a certain level of flooding can be a cost-effective and affordable approach.

Beside siting, there are many options available to reduce the flooding risk and damage potential when designing and constructing new buildings. In order of priority, these are:

- Exceed minimum floor levels
- Consider multi-storey construction
- Design and construct buildings for flooding occurrences
- Use water-resistant materials (see Figure 7)

- Design to ensure water can easily escape once flooding has subsided (especially vital for cellars and foundations)
- Install essential vulnerable equipment as high as possible
- Raise flood awareness and preparedness with building occupants, including designing and providing information about access routes

For existing buildings, the recommendations are similar to those for new buildings:

- Raise or move the building
- Build a second or multiple stories and use the lower storey as non-living or 'non-productive' space
- Replace cladding, flooring, and linings with water-resistant materials
- Move services (hot water, meter board) above flood levels
- Build a levee or flood wall around the building
- Raise flood awareness and preparedness with building occupants

Exceeding the minimum floor level clearance requirements for the area can substantially reduce the risk of flood damage. This is more easily achieved with a suspended floor (concrete or timber), than a concrete slab-on-ground floor, although some waffle-raft slab systems can give large ground clearances. A pole house (or building) can give a very high floor level and as a co-benefit, in sub-tropical Queensland and the Northern Territory, are useful passive design options for housing in regions where the weather will become hotter and more humid.

Typically, commercial buildings are at greater risk of flooding than houses, mostly due to their urban location, being surrounded by impermeable surfaces, and the likelihood of urban stormwater drainage systems being overburdened. Therefore, these buildings may be at risk of more damage than houses. On the other hand, commercial buildings are almost invariably constructed of water-resistant materials.

The water-resistant materials listed in Figure 7 below are better able to withstand direct contact with flood waters for more than 72 hours, and are more likely to require only a low-cost cosmetic repair, such as repainting.

	Water resistant	Non-water resistant
Insulation	Closed cell foam (polystyrene polyurethane)	Fibreglass, mineral wool, wool, cellulose foil
Floors	Concrete (bare or coated) Floorboards, durable or treated timber Concrete or clay tile	Particleboard, MDF, plywood Ceramic tile
Walls	Fibre-cement Concrete block Durable or treated timber PVC Brick (glazed or faced)	Particleboard, plywood
Interior	Concrete block Fibre-cement Durable or treated timber	Plasterboard Plywood Hardboard Softwood Carpet or vinyl Particleboard

Figure 7: Water-resistance of some common building materials

(Source: Camilleri, 2001)

Extreme Weather Events

Tropical Cyclones and Storms

Climate scientists predict that wind speeds, extreme rainfall events and intense local storms will generally increase over the whole continent, including all major cities, and potentially be most marked in the north and north-east, including Darwin, Cairns and Brisbane. Australia's cyclone-prone areas to the north are accustomed to more stringent wind loading codes and standards, and these could conceivably become more stringent. It is also quite possible that regions south of these areas will have to review their strategies for countering extreme storm events.

The main concerns with tropical cyclones and storms are the effects of extreme winds, coastal storm surges and driving rain. Wind loads on new buildings can be reduced by designing and building more aerodynamically efficient structures that assist in minimising wind loads, e.g. employing curved corners and minimising eave overhangs – though this type of alteration would need to be balanced with requirements to prevent driving rain and reduce solar gain (Sanders and Phillipson 2003).

There are also additional construction and fixing requirements which are necessary to hold down roofs (gable and roof edges are susceptible to damage) against cyclone uplift wind forces. Note that greatly increasing the strength in only one area, e.g. roof fasteners, may be counterproductive, as it may only change the mode of failure (such as the whole roof lifting). Bracing in the roof, fixing of roof material and the connection of roof to walls are the key areas for additional engineering.

For existing houses, the most important and feasible areas for upgrading are in the roof structure (including roofing fasteners, batten to rafter connections, and rafter to wall connections) and in the sub-floor fasteners. Replacement fasteners should be in a new hole (Camilleri 2001).

To reduce the vulnerability of buildings to the effects of driving rain, good moisture management can be achieved through attention to the 'Four Ds' (after Hazleden and Morris 1999):

1. **Deflection:** keeping water out in the first instance
2. **Drainage:** if water gets in, making sure it can drain out
3. **Drying:** allowing drying if materials get wet
4. **Durability:** using materials that can withstand the effects of getting wet

Attention to the Four Ds is most relevant to timber framed and clad houses (common in older residential building stock across most sites in Australia and in newer buildings in Cairns, Darwin and Alice Springs). For new buildings, attention to detailing and the specification of a drainage cavity ameliorates most problems. Existing homes can be retrofitted by removing the weatherboards and adding a drainage cavity, though this is a relatively difficult option as the windows may need adjusting as well.

Timber framed, brick clad buildings (common in Brisbane, Gold Coast, Sydney, Canberra, Mildura, Coffs Harbour, Melbourne, Hobart and Adelaide) perform better with respect to moisture ingress as these have typically been built with a cavity (20 mm gap between the bricks and the timber framing) because bricks, being porous, do not prevent water entry.

For better detailing, the building elements that need to be considered are: roof edges, open decks, walls and joinery, retaining walls, floors, balconies, wall/roof junctions and roofs.

Options for better building performance with respect to cyclones, winds and intense storms include:

- Impact resistant building materials, especially external claddings and glazing
- Better window designs. For example, increased thickness of glazing to reduce wind forces, or reduced panel sizes
- Improved fixing systems (roof to walls, walls to floors). For example, stiffer structural framework sealants to reduce flexure in storms
- Aerodynamic building designs that reduce deflection and resonance. For example, dynamic stabilisation systems, better foundation design
- Better planning guidance to avoid wind tunnel effects

There is also room to raise awareness of the issues among building owners. There is a current and pressing need for owners to ensure the structural fixings have not worn, loosened or warped from previous cyclones, or simply corroded over time. In areas like Darwin, where buildings may be 30 years old and the structural fixings never checked or maintained, the risk of widespread damage is significant. To reduce that risk, there needs to be adequate levels of public education and engagement.

It is likely that all buildings will leak during a tropical cyclone, due to the combination of near-horizontal rainfall and high wind pressures. Good attention to fastening, waterproofing and drainage detailing of all building elements, especially flashings, vents and penetrations, is therefore recommended.

Increased Storm Intensity

Under AS/NZ 3500, stormwater products for buildings are typically measured to withstand five-minute durations based on a 20-year period of annual rainfall intensity (ARI). This may be appropriate for external eaves but for internal and box gutters the diameter and durability should be able to withstand a 100-year ARI.

While more intense storms test the performance of building drainage systems and high flow runoff, there can also be opportunities to collect and usefully redirect rainwater, for example by diverting rainwater from gutters directly to street tree root zones (Daniels 2010). This would in turn offer significant advantages in reducing urban heat island effects.

Hail Events

Hailstorm scenarios are very location or site dependent, and there has been a limited number of studies in this particular area of climate change. The Bureau of Meteorology's State of Climate report speculates that as a result of climate change hail events could decrease in Melbourne but increase in Sydney (BOM & CSIRO 2010).

Regardless of the uncertainty surrounding future hail events, the potential for significant building damage (Figure 8) and subsequent financial losses makes it advisable to secure buildings in hail-prone areas. Adaptation options include:

- Ensuring roofing can withstand higher wind speeds and hail impact
- Designing more appropriate window protection
- Creating greater capacity to detain and harvest water from a deluge
- Ensuring roofs are well maintained

Larger, multi-storey commercial buildings with typical concrete roof construction are less susceptible to hail impact damage. There is the possibility of glazing damage (depending on the angle of impact from the hail stones).

Roof material (in order best to worst performing)	Breaking point What size hailstone caused the roof to crack? (Diameter)
Corrugated steel sheets	10cm
Concrete tiles (new)	7cm
Terracotta tiles (new)	7cm
Old slate (100 years-old)	5cm
Old Terracotta (50 years-old)	5cm

Figure 8: Vulnerability of roofing materials to hail damage
(Source: NRMA, 2005)

In commercial buildings, the most vulnerable areas are externally fitted services or signage (e.g. air-conditioning systems on roofs). Adaptation options include the re-siting of these services or the addition of protective coverings.

When to Adapt?

The question as to whether or when to adapt becomes more complex when conventional expectations (Figure 9) of the lifetime of buildings and building materials are called into question. Some locations which are at high risk to extreme events may even be appropriate for design solutions that are quickly demountable and replaceable, and hence more temporary in nature.

It is sensible to assume that doing nothing increases the level of risk. Strategies that are set in place at an early stage through precautionary action will reduce the frequency of future intervention (NZ Ministry for the Environment 2008), including the extent to which there is a transfer of burden to future generations.

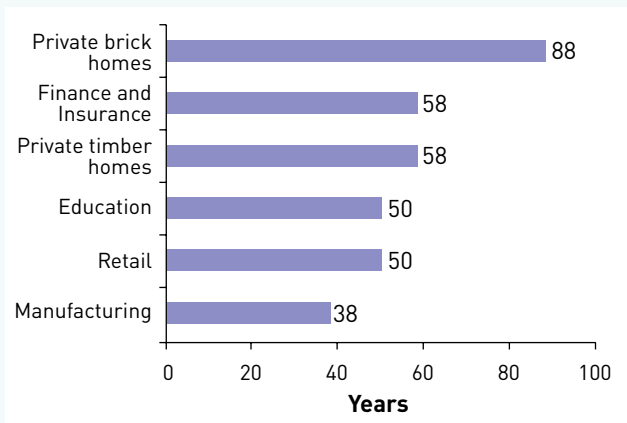


Figure 9: Mean asset life of Australian buildings
(Source: Iyer-Raniga, 2010)

As a rule, it becomes more costly and difficult to retrofit a building the older it gets. Retrofitting also becomes less cost effective the closer a building is to the end of its life. So if a retrofit is worth doing, it is worth doing sooner rather than later, as being reactive simply incurs expenses rather than deferring them.

Camilleri (2001) states that 'adaptation to the direct impacts of climate change is only needed for buildings that will still be standing and have a useful economic life concurrent with climate change impacts'. He derives estimates of the likelihood of residential buildings surviving until 2030 and 2070 and concludes that:

- Houses built before the 1920s do not need to be adapted (heritage buildings or structures with significant cultural or intrinsic value are not included here)
- Houses built in the 1920s to 1940s should be adapted for the moderate levels of climate change (2030)
- Houses built in the 1950s and later (including new houses currently being built) should be adapted for the more extreme climate change of 2070

In addition to age, for it to be worthwhile to adapt an existing house:

- The climate change impact should be severe enough and thereafter persistent to justify the adaptation cost
- The house should have a good chance of surviving until the climate change impact occurs

Capacity Building through Education

Under the Climate Change Adaptation Skills for Professionals (CCASP) project, the Institute, through

its continuing professional development (CPD) resources, is developing a website portal of climate change adaptation design strategies for a range of building typologies and geographical locations. This is intended to be integrated within the Australian Institute of Architects' Archivison platform and will grow over time. Further work under the CCASP project is also being undertaken at the tertiary education level. This is not intended to overburden the architecture curriculum and add a new competency discipline, but to shift thinking by embedding climate change adaptation design in studios and lecture topics.

Conclusion

It is evident from ongoing developments in the regulatory and insurance spheres that climate change adaptation (CCA) will be an increasingly important consideration for architects. This is regardless of whether one holds to precautionary principle or other views about the environment.

This paper highlights the significant challenges the built environment faces through more frequent and intense extreme weather events. While some may be sceptical of the level of impact, the shift in thinking by the insurance industry and regulators to more precisely determine risks to buildings and infrastructure at a location-specific level will stimulate design solutions to reduce vulnerability to climate change impacts. Architects who develop skills to retrofit and design buildings that offer reduced liabilities to extreme weather impacts that extend beyond jurisdictional building controls and land-use planning will position themselves well in the marketplace.

References

- Ash, A, 2010, 'Climate change and Coasts: Impacts, vulnerability and the need for adaptation', *Climate Change Adaptation Forum*, Canberra
- Baum, S, Horton, S, Low Choy, D, Gleeson, B, 2009, 'Climate Change, Health Impacts and Urban Adaptability: Case study of Gold Coast City', *Urban Research Program Research Monograph 11*
- BOM & CSIRO, 2010, *State of Climate*, Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation, www.bom.gov.au/inside/eiab/State-of-climate-2010-updated.pdf
- Camilleri, M, 2001, *Implications of Climate Change for the Construction Sector: Office buildings*, BRANZ Ltd Study Report 96, Judgeford, Porirua, NZ
- CIRIA, 2005, *Climate Change Risks in Building: An introduction*, CIRIA, London
- Daniels C.B (ed), 2010, *Adelaide: Water of a City*, Wakefield Press, Adelaide
- DCCEE, 2009, *Climate Change Risks to Australia's Coast*, Australian Government, Department of Climate Change and Energy Efficiency, www.climatechange.gov.au/publications/coastline/climate-change-risks-to-australias-coasts.aspx
- GTZ/PIK, 2009, *Climate Change Information for Effective Adaptation: A practitioners manual*, German Federal Ministry for Economic Cooperation and Development and the Potsdam Institute for Climate Impact Research, Germany
- Hacker, J.N, Belcher, SE, Connell, RK, 2005, *Beating the Heat: Keeping UK buildings cool in a warming climate*, UK Climate Impacts Programme briefing report, UKCIP, Oxford
- Hazleden, D.G and Morris, P.I, 1999, *Designing for Durable Wood Construction: The 4Ds*. 8th International Conference on Durability of Building Materials and Components, Vancouver, Canada
- IAG, 2002, *The Impact of Climate Change on Insurance Against Catastrophes*, Insurance Australia Group, <http://www.iag.com.au/sustainable/media/presentation-20021219.pdf>
- IPCC, 2008, 'Impacts, Adaptation and Vulnerability', Working Group II contribution to the *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, 2008
- Iyer-Raniga, Usha et al., 2010, 'Detonate or Renovate? The Life Cycle Perspective', *Green Building and Design Conference*, Melbourne, 2010
- Klein, R.J.T, Huq, S, Denton, F, Downing, T.E, Richels, R.G, Robinson, J.B, Toth, FL, 2007, 'Inter-Relationships between Adaptation and Mitigation' from *Climate Change 2007: Impacts, Adaptation and Vulnerability*, contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M.L, Canziani, O.F, Palutikof, J.P, van der Linden, P.J, Hanson, C.E (Eds.), Cambridge University Press, Cambridge, UK, p. 745-777

Kousky, C, Cooke, R.M, 2009, 'Climate Change and Risk Management Challenges for Insurance, Adaptation, and Loss Estimation', RFF DP 09-03, Resources for the Future, www.rff.org/RFF/Documents/RFF-DP-09-03.pdf

Lyth, A, Nichols, S, Tilbury, D, 2007, *Shifting Towards Sustainability: Education for climate change adaptation in the built environment sector*, a report prepared by the Australian Research Institute in Education for Sustainability (ARIES), Macquarie University, NSW

Mills, E, Lecomte, E, Pears, A, 2001, *Perspectives of the U.S. Insurance Industry on Climate Change*, Report No. 45185, Lawrence Berkeley National Laboratory, Berkeley

Munich RE, 2005, *Worldwide Natural Disasters – Effects and Trends*, NatCatSERVICE, Munich Reinsurance Company, Germany

Munich RE, 2010, *Half-Year Natural Catastrophe Review*, www.iii.org/assets/docs/pdf/MunichRe-070710.pdf

NZ Ministry for the Environment, 2008, *Coastal Hazards and Climate Change: A guidance manual for local government in New Zealand*, 2nd edition, revised by D Ramsay and R Bell, National Institute of Water and Atmospheric Research (NIWA), New Zealand

Parry, M, Arnell, N, Berry, P, Dodman, D, Fankhauser, S, Hope, C, Kovats, S, Nicholls, R, Satterthwaite, D, Tiffin, R, Wheeler, T, 2009, *Assessing the Costs of Adaptation to Climate Change: A review of the UNFCCC and other recent estimates*, International Institute for Environment and Development and Grantham Institute for Climate Change, London

Sanders, C.H, Phillipson, M.C, 2003, *UK Adaptation Strategy and Technical Measures: The impacts of climate change on buildings*, Building Research & Information (BIM), no. 31, pp. 210–221

Further Reading

Pittock, B, 2009, *Climate Change: The science, impacts and solutions*, CSIRO Publishing, Collingwood, Victoria

About the Authors

Dr. Mark Snow, BSc, PhD is a senior researcher at the Faculty of the Built Environment, University of New South Wales specialising in sustainable buildings and energy. He has worked as an Australian expert to the International Energy Agency (IEA) solar power program for over 10 years with a focus on building-integrated solar technologies. His work has included feasibility studies assessing the potential impact of climate change on the Australian built environment, and the Climate Change Adaptation Skills for Professionals project, from which this paper is drawn.

Professor Deo Prasad, BArch, MArch, MSc, PhD, FRAIA is director of the Sustainable Development Program at the University of New South Wales. He has a long-standing international reputation for research in the field of sustainable buildings and has publishing numerous papers and books. He was recipient of the 2006 Australian Institute of Architects National Award for contribution to research and design of sustainable buildings.

DISCLAIMER

The views expressed in this paper are the views of the author(s) only and not necessarily those of the Australian Institute of Architects (the Institute) or any other person or entity.

This paper is published by the Institute and provides information regarding the subject matter covered only, without the assumption of a duty of care by the Institute or any other person or entity.

This paper is not intended to be, nor should be, relied upon as a substitute for specific professional advice.

Copyright in this paper is owned by the Australian Institute of Architects.