**ACCARNSI DISCUSSION PAPER**

NODE 3 – BUILT ENVIRONMENT, INNOVATION AND INSTITUTIONAL REFORM

# ASSESSING THE CLIMATE CHANGE ADAPTABILITY OF BUILDINGS

---

MALAY DAVE, ARVIND VARSHNEY & PETER GRAHAM

**JUNE 2012**

---

**City Futures Research Centre**

Faculty of Built Environment, UNSW

# ACKNOWLEDGEMENTS

This material was produced with funding from the University of New South Wales based Australian Climate Change Adaptation Research Network for Settlements and Infrastructure (ACCARNSI) of the National Climate Change Adaptation Research Facility (NCCARF). We gratefully acknowledge the financial and other support received, without which this work would not have been possible. Contributions, both financial and in-kind, have made the completion of this report possible.

# AUTHOR AFFILIATIONS

**Malay Dave**, Casual Academic/Researcher
Faculty of the Built Environment, UNSW
Associate
Kennedy Associates Architects, Sydney
E: malay.dave@unsw.edu.au T: 0403 597 881

**Arvind Varshney**, Spatial Technologies Leader, HASSELL
E: avarshney@hassellstudio.com T: +61 2 9101 2096

**Peter Graham**, Senior Lecturer, Architecture
Faculty of the Built Environment, UNSW
Technical Advisor -Sustainable Buildings & Climate Initiative
United Nations Environment Programme
E: peter.g@unsw.edu.au

# TABLE OF CONTENTS

# EXECUTIVE SUMMARY

Buildings present a significant amount of opportunity for climate mitigation. Since they are long-lived assets, they also present great challenges for adaptation to projected as well as unexpected climate change impacts. These impacts will have consequences for building design and fabric, as well as for people in and around buildings and for their health and well-being. It is essential that we identify the nature and extent of their vulnerabilities and resilience if they are to be adapted in a timely and effective manner.

There are many assessment tools and methods being developed and used for identifying vulnerability and adaptive capacity of various systems from planning to urban governance. However, there appears to be a knowledge and policy gap in the area of assessment of buildings in particular measuring their vulnerability and aiding in creating climate-adaptable and resilient buildings.

This paper aims to identify knowledge and policy gaps for climate-adaptable buildings. The specific objectives of this research are:

- To identify major issues and challenges with regard to existing and new buildings
- To identify what measures have already been proposed or implemented
- To outline past, current and planned research activities
- To identify knowledge gaps and priority areas of research and policy

The study was conducted based solely on a literature review (approximately 200 documents were sourced and about 100 annotated). The first part presents a general background of the subject. The research focused on understanding emerging themes and various definitions on adaptability and resilience in buildings from various Australian and international literature sources. This along with an exploration of the complexities associated with defining climate-adaptable buildings is explored in the second part of this paper. The third part of the paper deals with adaptation approaches for buildings, which is the core focus of this paper. This part is divided in to two sections: the first presents a compilation of various assessment tools, methodologies and metrics being used internationally and in Australia; and the second presents a collection of various design and policy approaches including regulatory initiatives being used internationally and in Australia. Past, current and planned research activities that specifically relate to the subject are also outlined in this part. The paper concludes with observations and recommendations for research and policy priorities, which include:

- a need for clear and consistent definition of climate-adaptable buildings;
- a knowledge and policy gap in the area of assessment of vulnerability and resilience; the need for further research to develop common metric and consistent methodologies of assessment of existing and new buildings;
- development of a national level building adaptability and resilience assessment system that can be used for both existing and new buildings by policymakers, regulatory authorities, property insurers, building design and construction industry professionals as well as householders;
- a need for improved skills and preparedness of building professionals to advise, encourage and implement adaptation measures;
- opportunities to link adaptation with mitigation so that climate resilience measures are integrated in the GHG emission reduction agendas for all types of buildings;
- a need for regulatory framework governing the process of climate change adaptation in existing buildings;
- building regulations need a holistic review in the context of climate change adaptation; they have an important role to play in preparing our settlements for a safe and sustainable future.

# 1. BACKGROUND

There is a growing concern that we may be approaching or may have already passed an early ‘tipping point’ that may expose us to irreversible and adverse environmental trends (Pittock 2009b). Furthermore it has been argued that even the most aggressive global movements to reduce carbon emissions can do little to avoid a significant shift in the global climate system (Barker et al. 2007). The reasons for this include greenhouse gases (GHG) that have already been released and the inertia in the climate system. For instance, as the 2007 Report from the Intergovernmental Panel on Climate Change (IPCC) states, stabilising emissions at present levels would lead to more than a 60% increase in the present level of $CO_2$ concentration by the year 2200, a 50% reduction in emissions would lead to about a 25% increase in the concentration by 2200 and a 100% reduction would reduce concentration by only about 11% by 2200 (Pittock 2009). This means that climate change is inevitable and irrespective of the scale of mitigation measures, adaptation measures will be necessary.

It has been understood that there are significant risks in not adapting. Based on historic observations and the analysis of Australia’s climate the Bureau of Meteorology and CSIRO (2010) predict significant increases in mean annual temperatures and reduced annual rainfall in most locations. Hennessy et al. (2007) predict 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 cost to the nation. There are also significant potential impacts identified for buildings and their occupants (Amitrano et al. 2007). A summary of various climate change pressures and their effects on buildings is presented in Appendix B.

With the understanding that the need to reduce the vulnerability of buildings to climate impacts is accelerating, Dessai et al. (2004) and Adger et al. (2009) have stressed that the policy makers and those able to affect change and implement adaptive strategies must not become bogged down in forecasting the precise level of climate extremes for a given location. Ash (2010) reinforced this by highlighting that decisions can be made 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 be concerned about trying to predict exact climate outcomes.

IPCC (2007b) suggests that adaptive measures can be prioritised based on observed and projected impacts. It provides a list of criteria to aid in identifying key vulnerabilities, which includes magnitude, timing, persistence/reversibility, likelihood/certainty, importance and equity issues of the impacts. On the other hand, however, there appears to be a distinct lack of knowledge on what these vulnerabilities may mean for buildings and their occupants. At one level there are consequences for the various climate impacts on building design and retrofitting, structural durability, building techniques, selection of materials and finishes, as well as for operation and ongoing maintenance of buildings. At the other level, there are consequences for people in and around buildings and for their health and well-being. It is critical that we identify ways in which buildings may need to adapt in response to these impacts and vulnerabilities in different spatial and temporal contexts.

Whilst there have been assessment tools and methods used for identifying vulnerability and adaptive capacity of various systems from planning to urban governance, there appears to be a knowledge and policy gap in the area of assessment of existing and new buildings to identify and quantify their vulnerability and adaptive capacity. There are also implications of the various priorities for adaptation on assessment criteria for buildings that need to be identified if we are to develop appropriate, timely and effective design and policy measures for adapting existing and new buildings to climate change.

## 2. CLIMATE-ADAPTABLE BUILDINGS

Adaptation and adaptability are not new concepts in the built environment. Research shows that terms like ‘Design for Adaptability’, ‘Adaptive Architecture’, Climate Adaptive Building Shells’, ‘Adaptable House/Housing’ and ‘Climate Adaptive/Adaptable/Adapted Buildings’ refer to some of the concepts that are widely used in the built environment context. As the next section of this paper outlines, most of these concepts have no direct reference to the need to adapt to the current or future climate change impacts; only one refers to climate in the sense of being climate-responsive. However, they all seem to offer insights into what would be the characteristics of a climate-adaptable building. With a wide range in the focus of these various concepts and definitions, it is also important to gain clarity on the definition of ‘climate-adaptable buildings’ in the context of climate change.

### 2.1. Adaptability in Buildings

**Adaptation as Modification:**

Historically the term ‘building adaptation’ has been widely used to describe generic building modifications, ranging from small scale alterations to large scale additions. The works of Teo & Lin (Teo & Lin 2011a, 2011b) and Wilkinson, James & Reed (2010) are only some of the examples of the literature that refers to adaptation in the built environment as modifications without necessarily linking the term with climate change.

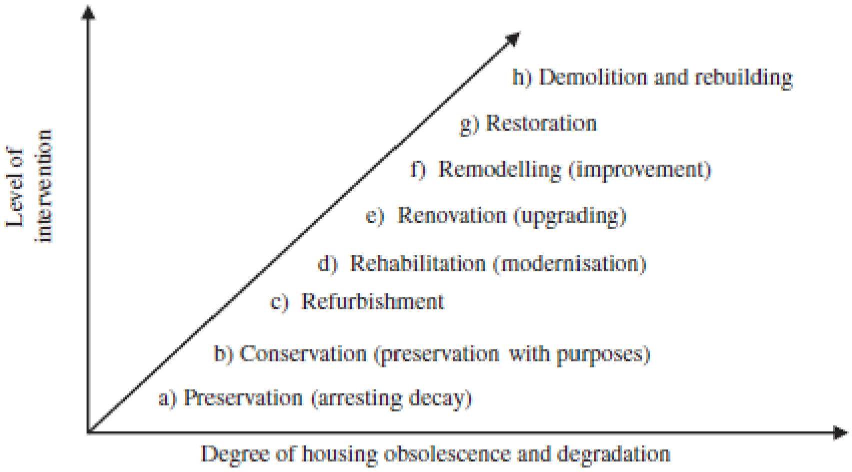


Figure 1: The range of building adaptation activities (Teo & Lin 2011b, p. 1481)

**Design for Adaptability:**

Inspired by the concern of sustainable use of materials and resources in the built environment this concept is aimed at maximising the time that buildings, building components and materials remain in productive life. Graham (2005) explains '*Design for Adaptability' as "a strategy used to avoid building obsolescence, and the associated environmental and cost impacts of resource consumption and material waste*."

Figure 2: An example of a modular design and detailing for deconstruction (Graham 2005, p. 7)

This strategy looks at the concept of building as a system of constructed layers with different life spans, instead of as a static object. Designing for adaptability provides a framework for making strategic decisions about the right mix of flexibility and durability in buildings. A building that is designed for adaptability, according to this approach, would be designed:

1. with the end of the building life in mind
2. considering it as a system of temporal layers and designed for accommodating the changes the building and its components would undergo during the entire lifecycle
3. for long-life; or for long term durability and sustainability of the building and durable amenity for its occupants
4. for loose-fit; or for spatial flexibility, structural flexibility, flexibility to assist materials and components change
5. for deconstruction; or for independence between different layers or components with different functions to aid in disassembling for reuse, recycling or replacement.

### Adaptable Architecture/Buildings:

'Adaptable Architecture' (Lelieveld, Voorbij & Poelman 2007), 'Adaptable Buildings' (Beadle et al. 2008; Gibb et al. 2007; Manewa et al. 2009; N. Davison 2006; Omi 2007) or 'Buildings for Adaptability' (Russell & Moffatt 2004; Schmidt et al. 2008) are all concepts that are generally concerned with the flexibility in the function, physical form or experience in buildings along with a desire to develop systems for mass-customisation and pre-fabrication of building components. Figure 3 illustrates different external stimuli for adaptable buildings and different forms of adaptability in this approach. Lelieveld, Voorbij & Poelman (2007) define Adaptable Architecture as "*an* *architecture from which specific components can be changed in response to external stimuli, for example the user or environment.*"

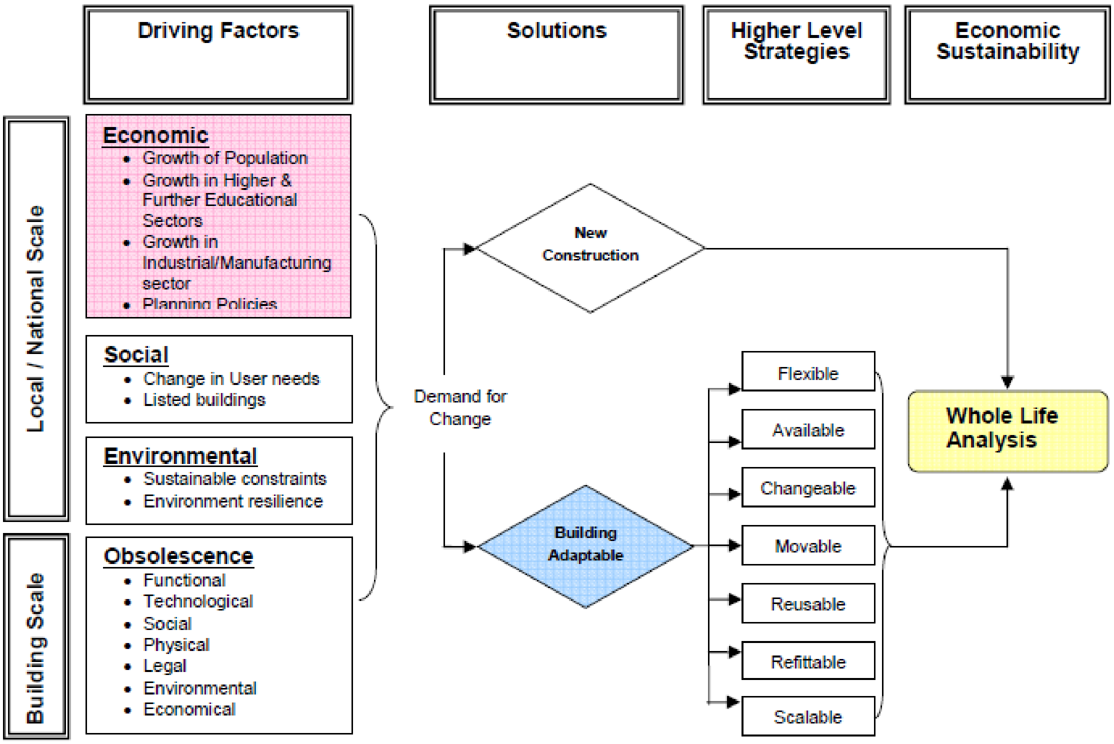


Figure 3: Conceptual framework (Manewa et al. 2009)

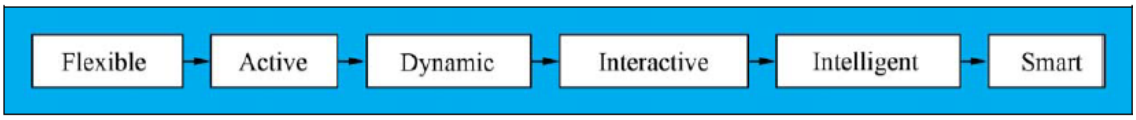


Figure 4: Levels of adaptation in order of sophistication (Lelieveld, Voorbij & Poelman 2007)

Omi (2007) presented a prototype "self-standing self-build" infill unit to propose a method of realising adaptable buildings, which includes prefabricated, modular 'infill' elements that remain structurally separate from the 'skeleton' of the building and as a result provide flexibility of assembly, disassembly or reconfiguration as required.

Research undertaken at Loughborough University in the UK, for its Adaptable Futures project, focused on two design strategies: pre-configuration and re-configuration (Beadle et al. 2008). Pre-configuration deals with initial design choices and has resulted in development of a component building system called 'Newways' that creates any of the three predetermined building types from the same basic components. Re-configuration on the other hand looks at subsequent changes in use and has resulted in development of a customisable multi-use building design system called 'Multispace' that can be built as or into offices, residential apartments, hotels or retail.

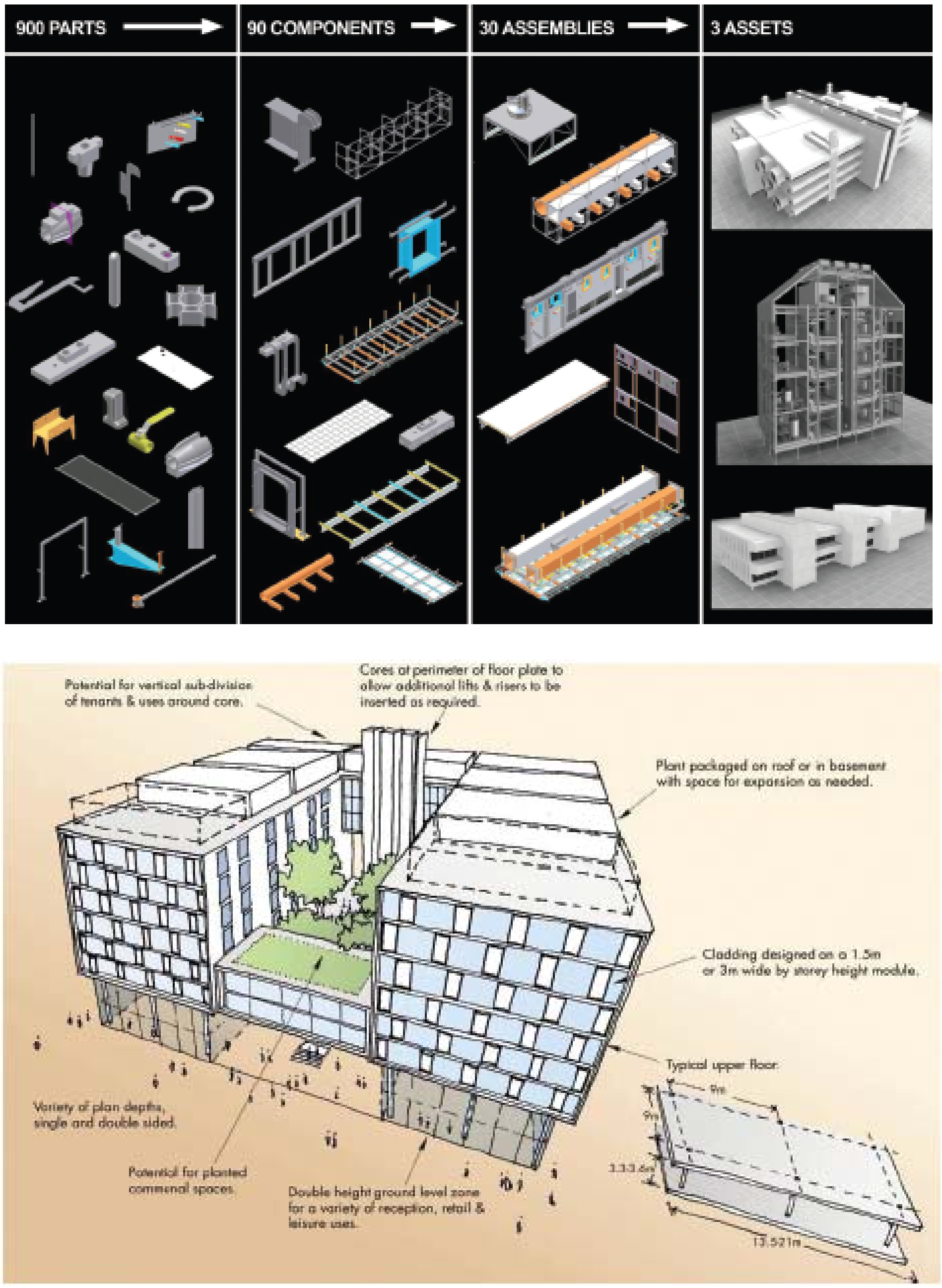


Figure 5: ‘Newways’ and ‘Multispace’ concepts (Beadle et al. 2008)

### Adaptable House/Housing

The ‘Adaptable House’ is a term used by the Australian Standard AS4299 to refer to a house that adopts the idea of a ‘Universal House’ and in addition is able to be easily adapted to become an ‘Accessible House’ (Palmer & Ward 2008). The Universal House design includes features, fittings and products that can be utilised by people of all ages and abilities, without the need for any adaptation or specialised design. The ‘Accessible House’ is a house that meets the accessibility requirements of the Australian Standard AS1428.1.

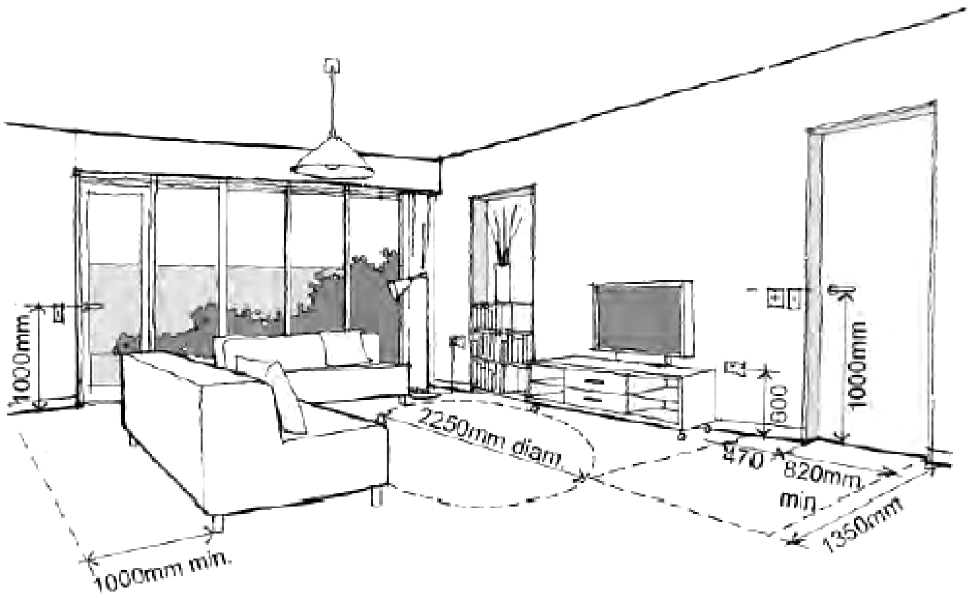


Figure 6: An example of an adaptable space (Palmer & Ward 2008, p. 54)

The Adaptable House, in compliance with the Standards, facilitates minimum dimensions required for access and safety, and it includes provisions for additional future modifications to meet the changing physical needs of an occupant. The future modifications may include changes to the kitchen joinery, alteration to the laundry and bathroom, increase in lighting levels, introduction of support devices such as grab rails, and/or provision of security measures to improve the access and usability of the house. The Standard provides design guidance to accommodate varying degree of physical ability over time. This minimises the need to relocate to alternative housing with changing life needs and increases the serviceable lifespan of the building.

### Climate Adaptable / Adaptive / Adapted Buildings

Climate Adaptive Building Shells (CABS) is an expression of a concept, which is closely linked with many other terms, such as, active, dynamic, kinetic, intelligent, responsive and smart, that were generally categorised under the umbrella term of ‘Adaptable Architecture/Buildings’ earlier in this paper. The concept of CABS specifically focuses on the building shell or building envelope and explores the possibilities of various forms of adaptability in this shell in response to changing climatological boundary conditions or user’s preferences.

Loonen et al. (2010) define CABS as a building shell that “*has the ability to repeatedly and reversibly change some of its functions, features or behaviour over time in response to changing performance requirements and variable boundary conditions. By doing this, the building shell improves overall building performance in terms of primary energy consumption while maintaining acceptable indoor environmental quality.*” They argue the Building Performance Simulation (BPS) can predict when, why and how a building will consume energy; and map the dynamics between the building and its systems, the ambient environment and occupants. They stress that the BPS and other innovative building materials and technologies have an important role to play in design and development of the CABS and their real-time and effective adaptability.

Loonen (2010) discusses two design strategies that contribute to the system's ability to handle change: robustness and flexibility; and argues that the conventional buildings have to rely on their robustness to cope with real-time changes in the context, while the CABS use their real-time flexibility to change their function, features or behaviour in response to the external change in addition to being able to respond to changing user preferences.

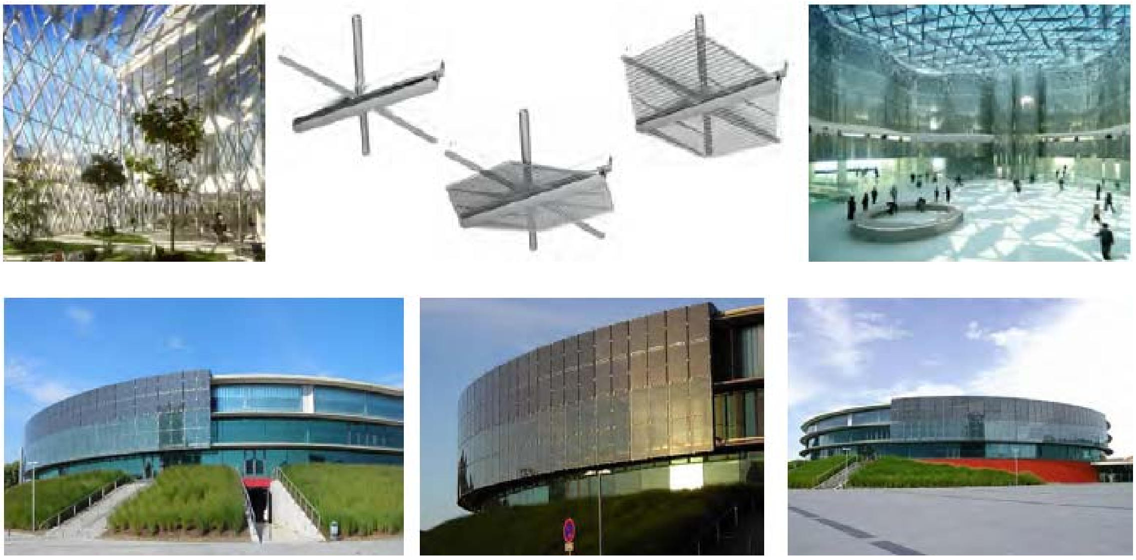


Figure 7: Examples of CABS: top - real-time light level sensing and retractable shading devices in Spain; bottom – kinetic double-skin facade with integrated PV panels in Germany (Loonen, R 2010)

The research also highlights a portion of existing literature that refers to building adaptation in the context of climate, but not necessarily in the context of climate change. Clarke and Pullen (2008), for example, have discussed the need for adapting existing commercial buildings for climate change by focusing initially on mitigation measures. They state, "*There are a considerable number of barriers preventing the existing commercial buildings in SA from being adapted to mitigate the impacts of climate change*" (2008, p. 74) and "*Adaptation of existing buildings is seen as an effective strategy for improving their performance with regards to environmental sustainability*" (2008, p. 78). In the first part of the paper they refer to adaptation as retrofitting and adjustment in buildings to improve their capacity to mitigate climate change. This concept is progressed later on in the paper, referring to potential climate impacts on buildings and proposing adaptation strategies along with mitigation measures.

Bullen (2004) as well as Love & Bullen (2009) refer to building adaptation in response to, both, varying climate conditions as a result of climate change, and other factors of change such as varying user needs, increased mitigation requirements and a need to extend useful life of existing buildings. They further explore the synergies between the strategies of adaptation and mitigation in buildings.

A journal article on climate-adaptive buildings by Lehmann (2009) largely focuses on theory and case studies of 'climate-responsive architecture', 'passive design principles' and other strategies of climate mitigation. The adaptive measures it suggests are: long life-loose fit type design, thermal mass, entirely passive operation of buildings, district cooling systems using waste heat from tri-generation system and reducing the volume of materials used, in addition to urban heat-island reduction measures. The terms ‘climate adaptive buildings’ and ‘climate adaptable buildings’ are also used in the workshop report from the Australian Academy of Technological Sciences and Engineering (ATSE 2010). The report considers climate-adaptive buildings as one of the key issues under the category of building design in the context of climate change and the urban environment. The report calls for development of a clear vision of what constitutes a climate-adaptable and resilient building.

Jaques and Sheridan (2006) used the term ‘climate-adapted buildings’ in their study report for BRANZ, which looked into the mitigation and adaptation issues and design strategies in new domestic buildings. They acknowledged that various terms such as climate-adapted building, climate-mitigated building and carbon-neutral building needs to be well defined in order to correctly examine climate related building issues and propose strategies to significantly improve climate-readiness in buildings. They define climate-adapted buildings as “*those which are built to withstand the predicted negative impacts of climate change and also those which can maximise any positive impacts of a change in climate*” and note  that resilience, resistance and adaptive capacity are important aspects of climate adaptive buildings (Jaques & Sheridan 2006, p. vi). Three more currently ongoing studies for NCCARF are using the term ‘climate-adapted’. The first study ‘*Pathways to Climate Adapted and Healthy Low Income housing*’ (NCCARF 2011b) is being conducted at CSIRO by Guy Barnett.. The second study ‘*Australia’s Country Towns 2050: What will a Climate Adapted Settlement Pattern Look Like?*’ (NCCARF 2011a) is being conducted by Andrew Beer at the University of Adelaide. The third study ‘*What would a climate-adapted Australian settlement look like?*’ (NCCARF 2011d) is being conducted by David Griggs at Monash University.

## 2.2. Definition of ‘Climate-Adaptable Buildings’

“*In a very real sense, climate adaptation is an attempt to hit a moving target from a moving foundation, as neither climate nor society is stationary nor are they ever likely to reach a truly static state in the future.*” (Preston & Stafford-Smith 2009, p. 16)

There is a lack of a clear and well-accepted definition for climate-adaptable buildings; and the possibility is that no such definition exists. It has also been observed that, apart from few exceptions discussed above, most of the literature does not use terms such as ‘climate-adaptable buildings’ or ‘climate-adaptive buildings’, where ‘adaptable’ and ‘adaptive’ denote a particular quality of buildings or an end product. The use of such terms raises few questions that would require further clarification, for example:

- What is a climate-adaptable building?
- What does it look like? Or what are its characteristics?
- Where and when is it adaptable; and where and when is it no longer adaptable?

It has been observed that the common usage, instead, is of ‘climate adaptation in buildings’ or ‘adapting buildings for climate change’, where the ‘adaptation’ and ‘adapting’ refers to the process or the measures of adaptation. This approach, at one level, may be avoiding the issues and questions centered on the definition, but at another level, it contributes to the lack of clarity and exploration of measurability and assessability aspects of climate adaptation in buildings.

To denote the quality of buildings, the term ‘resilience’ is used relatively more frequently, as in ‘resilience in buildings’ or ‘resilient buildings’, compared to climate-adaptable buildings. There is a need to define ‘resilience’ distinct from adaptability in order to get a clear vision of what constitutes ‘climate resilient buildings’ – a terms sometimes used interchangeably with climate-adaptable buildings (ATSE 2010).

We have a reasonable amount of information in the context of climate adaptation and the built environment that intends to answer the question of 'adapt how'. In an attempt to formulate a correct terminology for defining climate adaptability in buildings, we are faced with a number of other key questions that are yet to be clearly answered:

- **Adapt what**
  Are we to adapt buildings, building services, amenities or something else?
  Are we to adapt, or facilitate adaptation of, occupants?

  Brager and de Dear (1998) through their work on an adaptive model of thermal comfort and Steemers (2003) through the study of sustainable building design point to the physio-psychological aspects of occupant comfort and adaptability, that also has implications for climate-adaptable buildings and needs further investigation.

- **Adapt to what,**
  As discussed earlier there are multiple climate change impacts that buildings and their occupants may be exposed to. A building adaptable for one impact may or may not be adaptable for another. This means it may be more appropriate to call a building a 'bushfire adaptable building' or a 'flood adaptable building' rather than using a generic term like 'climate-adaptable building'.

  While this paper focuses on the more direct biophysical factors affecting buildings, it is to be noted that, as Preston & Stafford-Smith (2009) have identified, adaptation strategies need to target both the biophysical as well as the socio-economic factors contributing to the present and future vulnerabilities of the buildings and their occupants.

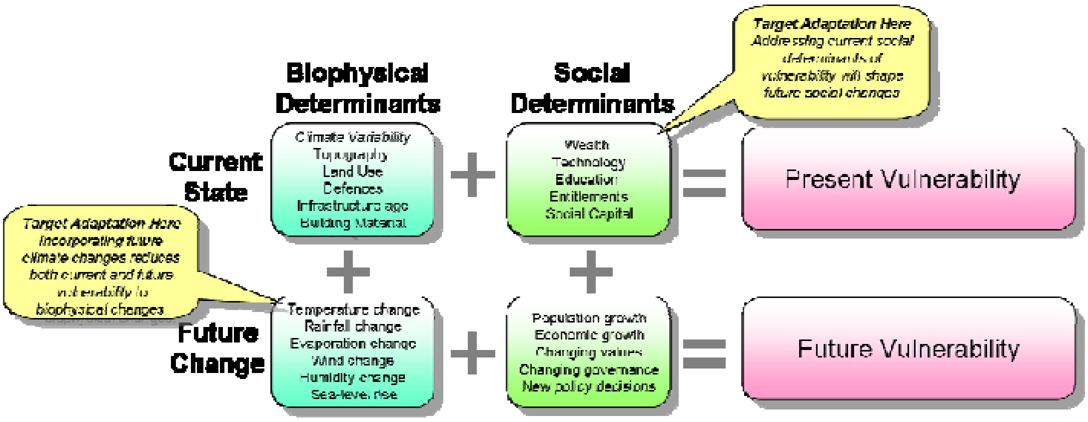


Figure 8: Biophysical and social determinants of present and future vulnerability (Preston & Stafford-Smith 2009, p. 18)

- **Adapt where**
  Climate change may create different levels of impacts in different geographic regions. It is essential that the spatial boundaries of climate impacts are defined in order to adapt buildings appropriately for that particular geographic region. This means that one building design or construction method that is adaptable for one region may not be fully adaptable to climate impacts of another region.

- **Adapt when**
  Climate change impacts may have different levels of frequency and intensity of occurrence at different stages in the future. It is essential that the temporal

boundaries of climate impacts are also defined in order to adapt buildings for a particular time frame.

Therefore, as illustrated in Figure 8, it is important to consider the magnitude as well as the rate of change in both the current and future climates to ensure that adaptation measures address both the present as well as future vulnerability issues.

- **Adapt for what,**
  The important question is “What do we want to achieve as an outcome of adaptation?” As discussed earlier, ‘Accessible House’ meets the access and mobility requirements and the ‘Adaptable House’ is able to be easily adapted to become an ‘Accessible House’ when required (Department for Families and Communities 2011; Palmer & Ward 2008). Similarly adaptable may also mean one that can be adapted in the future; one that may not be already adapted to the climate or readily resilient to the impacts of a changing climate but may be adapted in the future to achieve resilience.

  This means, if a building is climate adaptable for the purpose of becoming climate-resilient, then a building may be either,
  1. adaptable (for now) but not resilient (for now or the future) or
  2. resilient (for now) but not adaptable (for the future) or
  3. resilient (for now) as well as adaptable (for the future)

## 2.3. Synthesis definition of climate-adaptable buildings

Whilst there has been a shift in the predominant focus from mitigation measures to adaptation measures in buildings in recent times, research so far suggests that there is a lack of literature that focuses on climate-adaptability of buildings. In the midst of many similar terms in varied contexts and with an increasing focus on adapting new and existing buildings to climate change, there is a pressing need to define what ‘climate-adaptable buildings’ means.

# 3. ADAPTATION APPROACHES FOR BUILDINGS

In order to determine adaptation strategies that are timely, relevant and appropriate it is essential to investigate both vulnerability and adaptive capacity or resilience of existing and new buildings.

## 3.1. Assessment Tools, Methodologies and Metrics

Improving the climate-readiness of existing and new buildings is fundamental to tackling the impacts of climate change. Assessment tools and methodologies play an important role in estimation of current and future vulnerability of buildings. It is also essential that there is clarity and consistency in the way in which the buildings’ climate adaptability, adaptive capacity or resilience, or the lack of them, are measured and assessed. Metrics, therefore, are the key. The United Nations Environment Program’s Sustainable Buildings & Climate Initiative defines metric as a method of measuring building performance indicators (UNEP SBCI n.d.).
Preston & Stafford-Smith (2009) have investigated and outlined various approaches to assessments for climate change adaptation that includes impact assessment, vulnerability assessment, adaptation assessment and integrated assessment. They

have considered climate change assessments as a fundamental part of adaptive decision-making consisting of various steps:

- defining the characteristics of a system and its larger context, and acquiring knowledge of how the system is likely to behave in response to potential climate change
- identification of those that are particularly vulnerable or at risk
- cost and benefit assessment of various adaptation options for selection
- actual implementation of an adaptation policy or measure; including ongoing monitoring and assessment of effectiveness of the adaptation action

It has been argued that impact assessments that focus on actions to reduce risks by relying on climate scenarios generally tend to be top-down, and have limitations in taking into consideration the complexity of societal and environmental responses to climate change. On the other hand vulnerability assessments tend to be bottom-up, thoroughly investigating the vulnerabilities and adaptive capacities of the systems of concern, and hence are considered to be a more robust tool.

However, vulnerability assessments also have limitations: they often rely on subjective assumptions, give only an indication of areas of greater or lesser vulnerability, do not necessarily give indication of which specific measures would be more effective based on their costs and benefits, and they do not generate quantitative estimates of likelihood or consequences of climate change that may be useful in decision-making. Both impact and vulnerability assessments may also limit their scope to only the direct impacts of climate change on a particular system. On the other hand, more comprehensive integrated assessments or multi-criteria analysis may capture greater complexities of both biophysical and socioeconomic factors, and of system interactions and feedbacks. In addition they also help in evaluating different adaptation options, testing the effectiveness and appropriateness of adaptation decisions, and in generating quantitative outcomes to aid in the decision-making process. Such assessments, however, have been primarily used for mitigation rather than adaptation analysis, and have been applied at larger spatial scales at national and international level rather than at the smaller scales of buildings and cities.

There are also other risk assessment and management methodologies that focus on broad framework for decision-making by using multiple assessment tools and approaches in order to assess the effectiveness of various adaptation strategies instead of focussing on a specific assessment methodology.

Preston & Stafford-Smith (2009) have noted that a large amount of the assessments conducted in Australia were not executed to be in support of any adaptation decision-making process but were conducted to either educate public, specific sectors or levels of government about the potential impacts and the magnitude of the consequences. This, along with the diversity of available assessment approaches and methodologies, has contributed to challenges in synthesising information on vulnerability, impacts or risk to inform specific adaptation options. They argue that since different assessments are aimed at different end-points, it is often difficult to compare different assessments on common terms. For example, an impact assessment of buildings may generate quantitative estimates of impacts of various climate scenarios. A vulnerability assessment of buildings, on the other hand, may identify factors that contribute to the vulnerability, e.g. age, materials or usage of the building. A risk assessment may generate qualitative description of the consequences and likelihoods. The lack of common metrics poses challenges in employing different assessment methods and comparison across assessments.

The Australian Institute of Landscape Architects (AILA) in partnership with the International Federation of Landscape Architects (IFLA) has conducted a review of 54 different international and Australian climate adaptation tools for sustainable settlements. The tools reviewed are applicable at regional, metropolitan and neighbourhood scales and at strategic planning, pre-design/design, construction and post-construction stages of development. Although the report (IFLA-AILA 2010), focuses on the broader built environment context including urban planning, design and management, deliberately excluding single domain and building scale approaches from its scope of inquiry, it presents findings that are relevant and valuable to the subject on hand. It notes that currently there are no identified common legislative or strategic planning frameworks in place to guide climate adaptation responses at either a national or international level. There are also no currently accepted standards for measurement metrics, normalised approaches or indicator sets for the development or comparison of assessment methods or climate adaptation tools.

### 3.1.1 International Examples

The UK Climate Impacts Program (UKCIP) has developed a very comprehensive set of tools to fit and aid in its risk, uncertainty and decision-making framework. As illustrated in Figure 9 it is an iterative 8 stage process to help decision-makers identify and manage climate risks.

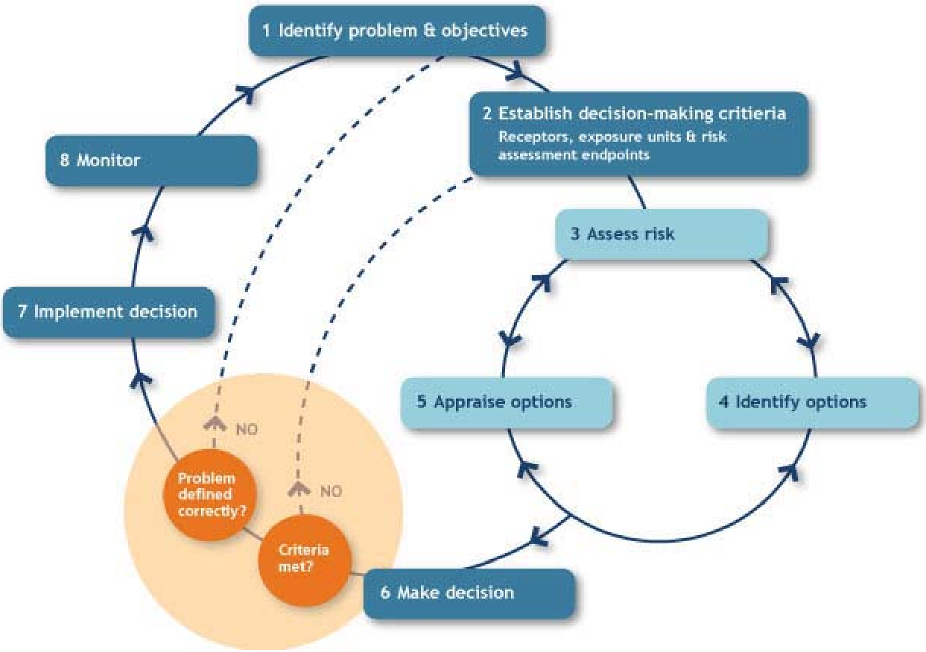


Figure 9: Risk based decision-making framework (UKCIP 2011)

The program has also prepared several working examples for applying this framework to various fields including the built environment. An illustrative example of adapting an existing office building to climate impacts is presented using structured questions and responses in each of the above eight stages of the framework (UKCIP n.d.).

A comprehensive study conducted by Hacker, Belcher & Connell (2005) also used the above risk based decision-making framework. It focused on impacts of heatwaves on buildings, and how decisions can be made through qualitative and quantitative risk-assessment processes to adapt buildings to these impacts. The study examined the likely implications of climate change in the form of increased thermal discomfort, heat stress and carbon dioxide emissions with the help of computer modelling. The case study buildings used included three types of buildings: house, office and school buildings; each in two categories: old and new; each having two scenarios: ‘as built’ and ‘adapted’; and in three different locations in the UK: London, Manchester and Edinburgh. The performances of these 6 hypothetical but realistic case study buildings were then computer modelled, tested against various performance targets and then compared for the selection of appropriate adaptation options.

The work of Deichmann et al. (2011) at the Global Facility for Disaster Reduction and Recovery (GFDRR) has shown that the use of high resolution satellite data can be an extremely useful tool in the identification of natural disaster risk in urban areas. They stress that the information provided by the very high resolution (VHR) imagery is routinely used in post-disaster damage assessment, and it could also be utilised in conducting risk assessments to prevent such damage in the first place. This method largely uses four novel technologies to support disaster risk identification: earth observation systems that provide pictures of the earth’s surface, field data collection tools and global positioning system (GPS) technology that provide precise geographic location, tools for spatial data handling such as geographic information system (GIS) and image processing systems, and web based dissemination of this combined information for the visualisation of the tools.

The VHR imagery is considered most useful in assessing exposure; and with the integration of additional information can also support the estimation of hazard probabilities. Assessment of physical vulnerability is also possible with the help of additional field data. The building characteristics considered relevant and important for vulnerability assessments include:

- Building size
- Building height
- Colour
- Settlement historical growth
- Geographical setting
- Context

Although, this work focuses on identifying risk of natural disasters, the method and technology themselves certainly remain applicable and useful in identifying risks of climate impacts.

The Adaptation and Resilience in a Changing Climate (ARCC) Coordination Network (ACN) is a network established to enhance cooperative development and dissemination of research exploring the impacts of and adaptation to climate change within the built environment and infrastructure including transport, water resources and energy systems. Since its establishment with funding from the UK Engineering and Physical Sciences Research Council in 2009, the ACN has been involved with a series of research projects, many of which inform the building sector. The relevant projects are briefly summarised below (ARCC 2011):

**ARIES**: Adaptation and Resilience in Energy Systems
The project is aimed at delivering a comprehensive risk framework to assess and manage UK energy system resilience to climate change. It includes capturing the climate-driven changes in gas and electricity demand in domestic and non-domestic buildings and their response to changes in building design, behaviour and micro-generation. The project is expected to start later in 2011.

**BIOPICCC**: Built Infrastructure for Older People in Conditions of Climate Change
The project aims to develop locally sensitive and efficient adaptation strategies during the period up to 2050 to ensure infrastructure and health and social care systems supporting the well-being of older people are resilient to climate change. It includes

identification of design and management strategies to adapt and improve the resilience of built infrastructure related to health-care systems. The three year project started in 2009 and is currently ongoing.

**COPSE**: Coincident Probabilistic climate change weather data for a Sustainable built Environment
The project aims to develop a methodology for deriving weather data for building designers based on future data rather than observational records from the last 20 years or so. The project will also include assessment of the adaptation potential for carbon emission reduction from new and refurbished buildings, using the new methodology and data. The three year project was anticipated to finish in mid 2011.

**De2RHECC**: Design & Delivery of Robust Hospital Environments in a Changing Climate
The aim of the project is to investigate the design and delivery of economical and practical strategies for the adaptation of the UK's National Health Service (NHS) Retained Estate to increase its resilience to climate change whilst meeting the challenge of carbon reduction goals and performance requirements of the NHS. The objectives of the project include defining the meaning of resilience and method for its evaluation; identification of existing typical case study building and assessment of their resilience to future climate scenarios; identification of barriers to adaptation; and development of decision-making protocols. The project is currently ongoing and is expected to be completed in late 2012.

**DOWNPIPE**: Design Of Water Networks using ProbabilistIc PrEdiction
The project aims to use probabilistic climate scenarios in decision making for adaptation of building and property drainage. It will include identification of location and extent of under-capacity of existing systems with the help of extensive simulation modelling, and assessment of adaptation strategies based on risk reduction, cost and planning consent. The three year project is currently ongoing and was anticipated to be completed in late 2011.

**Low Carbon future**: Decision support for building adaptation in a low carbon climate change future
The project aims to produce a general, deterministic and computationally efficient methodology for adequately sizing HVAC (heating, ventilating, and air-conditioning) plant and equipment in buildings. It will investigate projected climate scenarios, explore ways to facilitate information communication between design and stakeholders, and incorporate the findings into the existing standards and building regulations. The currently ongoing project is expected to be completed in mid 2012.

**PROCLIMATION**: The use of probabilistic climate scenarios in building environmental performance simulation
The aim of the project was to develop and implement methodologies for using probabilistic climate projections in building simulation and other related analytical procedures. It included finding methods of using case studies to demonstrate potential usefulness of probabilistic climate data compared to traditional stationary climate data. It also aimed to illustrate ways of using the research outcome for risk-based decision-making in the design and refurbishment of buildings. The two year project was completed in 2010.

**PROMETHEUS**: The use of probabilistic climate data to future proof design decisions in the buildings sector
This project aimed at developing a new set of probabilistic reference years that can be understood and used by building designers. The scope of work included developing

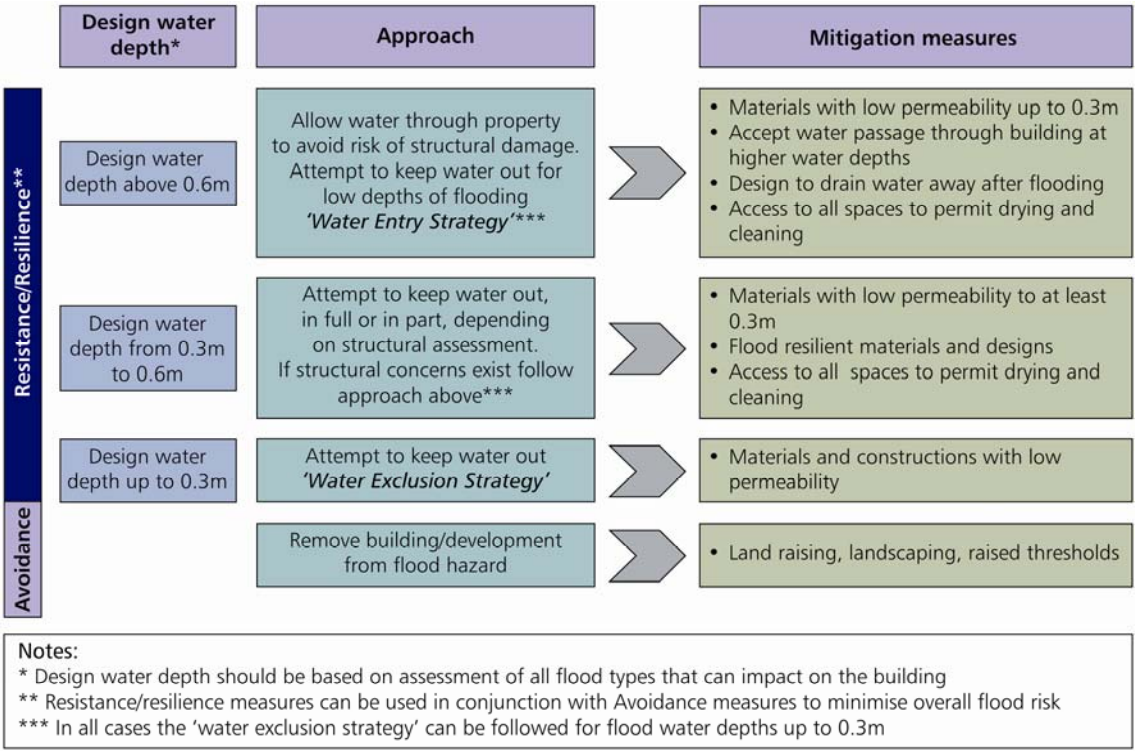
nationally consistent probabilistic future test reference years including wind direction and speed; developing a method for the use of such data for simulation and design; assessment of future building behaviour based on these probabilistic climate data; and a case study based evaluation of adaptation possibilities and strategies in buildings and their costs. The two and a half year project was completed in 2010.

**ADAPT** or Assessment and Design for Adaptation to Climate Change tool is a prototype planning tool developed by The World Bank (2011) to assess sensitivities of various development projects to climate change. The tool is currently available for Africa and India only. The tool is set to provide climate related predicted and historical data, information on climate impacts on agriculture, water resources, and health, as well as data on disaster impacts for any selected location in the world. Although, no impact data specific to buildings is provided, this tool itself represents a good model of how complex information can be simply presented for multiple stakeholders to aid in quick risk assessment based decision-making at design stage.

The work carried out by Bowker, Escarameia & Tagg (2007) for the Department for Communities and Local Government Buildings Regulations (Sanitation) Research Framework in the UK focused on improving the flood resilience of buildings through improved materials, methods and details. The report aimed at providing guidance to developers and designers on how to improve the resilience of new properties in low or residual flood risk areas by using suitable materials and construction details. It follows a sequential approach to construction measures to reduce the flooding risk at a site. It differentiates between and defines approaches of flood avoidance, flood resistance, flood resilience and flood repairable.

The avoidance approach aims at constructing a building and its surroundings to avoid it being flooded. The measures include not building in flood risk areas, raising ground or floor levels, creating local bunds, landscaping elements or boundary walls and fencing with water resistance materials. The resistance approach includes constructing a building to prevent floodwater entering the building and damaging its fabric. The measures include using low permeability materials in the construction to prevent floodwater from entering into the building, minimising the impact of floodwaters directly affecting buildings; and to give occupants more time to relocate. They are expected to only be effective for a short duration and for low flooding depth i.e. less than 0.3m. Flood resilience includes constructing a building in such a way so that no permanent damage or loss of structural integrity is caused to the building and drying and cleaning are facilitated if flood water enters it. The repairable approach aims at constructing a building in such a way that if the flood water enters it, the damaged elements can be easily repaired or replaced. This is also considered a form of flood resilience.

The document provides advice on the suitability of common building materials, floor and wall construction and other features and fittings for improving the flood resilience of buildings. The flood resilience characteristics of materials and elements include possibility of water penetration, drying ability and retention of pre-flood dimensions and integrity. The water penetration in the building is estimated based on ‘flood depth’ or ‘design water depth’, which is calculated by subtracting the ground floor level from the predicted flood level. This depth in metres indicates the level of flood resilience in the building and what approach should be taken to mitigate the flood impacts.



| | Design water depth* | Approach | Mitigation measures |
|---|---|---|---|
| Resistance/Resilience** | Design water depth above 0.6m | Allow water through property to avoid risk of structural damage. Attempt to keep water out for low depths of flooding *'Water Entry Strategy'**** | • Materials with low permeability up to 0.3m<br>• Accept water passage through building at higher water depths<br>• Design to drain water away after flooding<br>• Access to all spaces to permit drying and cleaning |
| | Design water depth from 0.3m to 0.6m | Attempt to keep water out, in full or in part, depending on structural assessment. If structural concerns exist follow approach above*** | • Materials with low permeability to at least 0.3m<br>• Flood resilient materials and designs<br>• Access to all spaces to permit drying and cleaning |
| | Design water depth up to 0.3m | Attempt to keep water out *'Water Exclusion Strategy'* | • Materials and constructions with low permeability |
| Avoidance | | Remove building/development from flood hazard | • Land raising, landscaping, raised thresholds |

Notes:
* Design water depth should be based on assessment of all flood types that can impact on the building
** Resistance/resilience measures can be used in conjunction with Avoidance measures to minimise overall flood risk
*** In all cases the 'water exclusion strategy' can be followed for flood water depths up to 0.3m

Figure 10: Rationale for design strategies (Bowker, Escarameia & Tagg 2007)

The document provides guidance on various factors affecting the resilience of a building, which includes building materials, foundations, floors, walls, doors and windows, fittings and services. Other factors not included in the guidance include cost, durability, ease and practicability of construction, and environmental, social and aesthetic acceptability.

**Climate Change Sustainability Index (CCSI)** (Camilleri 2000, 2001) is an assessment framework developed by the Building Research Association of New Zealand (BRANZ) to assess the vulnerability of houses and offices to climate impacts. The common assessment framework for CCSI is based on internationally used environmental assessment methods. It generates a numerical rating for a house or houses in a region against a range of climate impacts including summer overheating, inland and coastal flooding, and tropical cyclone risk. It also generates a separate rating for greenhouse gas emissions from space and water heating.

The CCSI uses a non-linear, capped system adopted from the Green Building Assessment Tool (GBAT) for credit allocation based on the performance of a building. It uses negative scoring to penalise poor performance with capping at -2 for significantly inferior performance, gives 0 to normal performance and positive credits for enhanced performance with capping at 5 for exceptional performance. The ratings for different impacts are combined in one using equal weight.

As an example, the assessment of the vulnerability of a building to overheating is based on three main factors along with the climate of the location:

1. Solar window area to floor area ratio
2. Insulation level
3. Thermal mass level

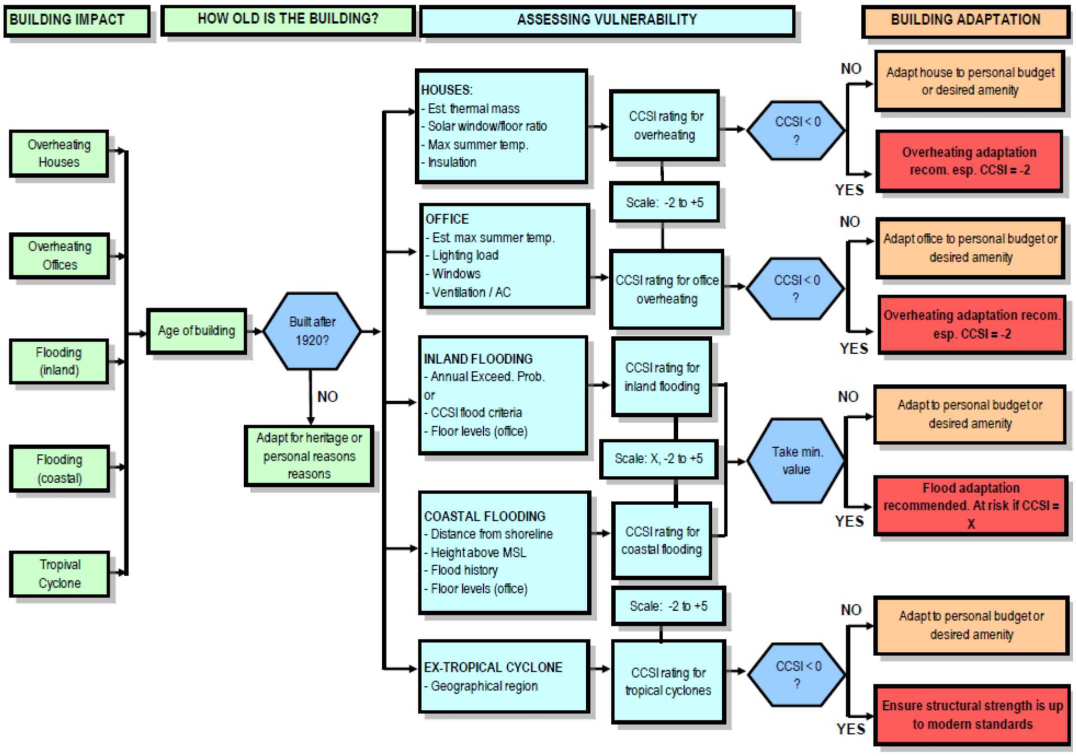


Figure 11: CCSI assessment framework (Bengtsson, J, Hargreaves & Page 2007)

The maximum indoor summer temperature is calculated based on the above three factors. Then a further modifier value is applied to that number based on the location (climate) of the house. This gives a final number for modified maximum indoor summer temperature. The corresponding CCSI credit, from a range between -2 and 5, gives a rating for the performance of a house against overheating.

In a similar way CCSI credits are also calculated for flooding and cyclones; largely on the basis of the location, extent and frequency of historic impacts, physical contexts, materials of construction etc. CCSI for climate change impacts is finally defined as an average of separate credits in three impact categories.

Some other works (Bengtsson, Jonas et al. 2007; Bengtsson, J, Hargreaves & Page 2007) have utilized extensive simulation modelling based on different climate change scenarios (Mullan et al. 2006) for assessing the vulnerability and the need to adapt buildings in New Zealand. BRANZ (2006) prepared a simple checklist type tool, which included 20 questions, each giving one point for a positive answer. Finally the total score could be placed on a simple scale to generate an indication of an overall ‘climate change readiness’ of a house design.

### 3.1.2 Australian Examples

In 2007, the Australian Greenhouse Office published a seminal report (Amitrano et al. 2007) based on an extensive study conducted by BRANZ. The study was an assessment of the capacity of Australian building stock and building practices to maintain their current level of amenity in the face of climate change. It was based on climate projections for 2030 and 2070 for thirteen different locations in seven of the eight climate zones used by the Australian Building Codes Board (ABCB). It used energy modelling as a method to predict energy consumptions in residential, commercial and hospital buildings and to estimate resilience and suggest possible adaptation measures for Australia's building stock. The study also included a rough estimation of costs for three adaptation options - energy adaptation, storm/wind adaptation and fire attack adaptation - to aid in the analysis of the viability of adaptation options for new and old housing stock. In addition, the study conducted an investigation into the impacts of climate change on social, lifestyle and health needs of the vulnerable population, and the need for buildings to be better adapted to meet them. The study also investigated the various climatic contexts, different types of vulnerable groups and associated potential climate impacts. Furthermore, it discussed various adaptation options in different climate zones that may make buildings more or less equipped in reducing the vulnerability of the population at risk.

The report estimated resilience of existing and new building stock in Australia on the basis of various building features that contribute to improved resilience in each of the following five key climate change impact areas:

1. Building over-heating,
2. Tropical cyclones, intense storms and increased wind speed,
3. Flooding,
4. Degradation of foundations,
5. Bushfires

Resilience appears to have been taken as a by-product of the current sustainability/energy efficiency provisions in the regulations and building codes. The report uses or proposes no specific methodology to assess or quantify resilience.

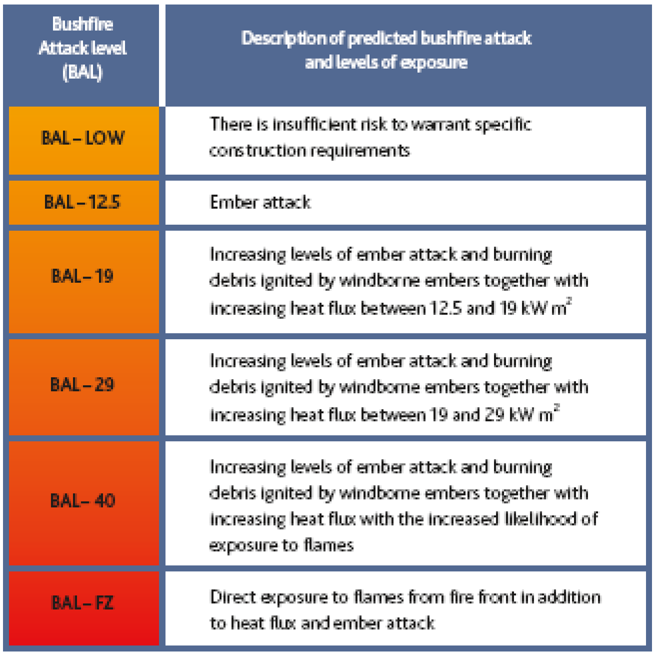
In late 2009, the Australian Government released a report on its first national assessment of climate change risks to the whole of Australia's coastal zone in order to support informed decision making on adaptation actions by policy-makers, business and industry, resources managers and the community (Department of Climate Change and Energy Efficiency 2009). The report identified significant risks to natural coastal ecosystems, beaches, landscapes and human settlements. The report also assessed and analysed the extent of residential properties at risk of inundation and erosion from sea level rise and other consequences of climate change. The risks to residential buildings were assessed based on spatial and quantitative analysis, while other risks were analysed based on literature review and expert opinion. The assessment in this report focused on impacts and risks at the end of this century, excluding the impacts in the near future and those beyond 2100 from the scope of this report.

The report also identified insufficiency in the availability of national data as well as limitations in analytical capacity. A more recently released supplement to the first pass national assessment addressed many of these limitations (Department of Climate Change and Energy Efficiency 2011).

A study undertaken by Carthey, Chandra and Loosemore (2008, 2009) for NSW Health's Environmental Health Branch has focused on preliminary investigation of adaptive capacity of the health infrastructure in New South Wales to climate related extreme weather events. In accordance with the recommendations from many national and international organisations the researchers developed a risk management approach towards adaptation strategies and commenced the study with a Risk and Opportunity Management (ROMS) workshop involving selected stakeholders. The research highlighted the knowledge gaps regarding the quantum and nature of likely specific climate impacts on health services and infrastructure. It recommended the use of technologies such as Geographic Information Systems (GIS) and Laser Radar (LIDAR) to examine predicted incidence and variability of extreme weather events and their potential impact on existing infrastructure, and to assess the suitability of specific locations for proposed new facilities.

In response to the devastating bushfires in early 2009 Victoria adopted and applied Australian Standard AS 3959-2009 which aims to improve the ability of buildings to withstand attacks from bushfires. The Standard sets out construction requirements based on the Bushfire Attack Level (BAL). The Building Commission in Victoria has developed a simple guide (Victoria. Building Commission 2009) for assessing a property's BAL through an easy six step process:

1. Determine your Fire Danger Index (FDI), which is based on the geographic location of the property,
2. Determine your site's vegetation types out of seven types of textual and visual classifications,
3. Determine the distance from the building site to the vegetation,
4. Determine the slope in degrees of the land under the vegetation,
5. Determine the BAL out of six levels referring to the tables provided, and
6. Apply construction requirements that correspond to the calculated BAL as set out in the Australian Standard.



| Bushfire Attack level (BAL) | Description of predicted bushfire attack and levels of exposure |
|---|---|
| BAL – LOW | There is insufficient risk to warrant specific construction requirements |
| BAL – 12.5 | Ember attack |
| BAL – 19 | Increasing levels of ember attack and burning debris ignited by windborne embers together with increasing heat flux between 12.5 and 19 kW m$^2$ |
| BAL – 29 | Increasing levels of ember attack and burning debris ignited by windborne embers together with increasing heat flux between 19 and 29 kW m$^2$ |
| BAL – 40 | Increasing levels of ember attack and burning debris ignited by windborne embers together with increasing heat flux with the increased likelihood of exposure to flames |
| BAL – FZ | Direct exposure to flames from fire front in addition to heat flux and ember attack |

Figure 12: Bushfire Attack Levels under Australian Standard 3959-2009 (Victoria. Building Commission 2009)

This simplified method, as an alternative to a more detailed method specified in the Australian Standard, can be used by an owner, architect, building designer, building surveyor or builder to determine a BAL and appropriate building construction method for a site.

The researchers Wakefield, He and Dowling (2009) identified that there are limitations in our understanding of the performance of solid timber wall constructions under bushfire conditions. Their experimental study assessed the performance of eight log wall specimens with and without various protection coatings. These specimens were exposed to a thermal radiation field in accordance with the relevant Australian test standards. They measured and compared:

- The heat flux on the exposed surface,
- Temperatures on both the exposed and unexposed surfaces,

  - Flaming combustion and self-extinguishment when external radiant heat varied from 40 kW/m2 to 16 kW/m2, and
  - The charring depth of the log walls.

These performance indicators were evaluated against the relevant standard. The study concluded that solid log wall construction can be resistant to severe bushfire impacts if sufficiently thick and well sealed.

Stewart & Wang (2011) at CSIRO conducted a risk assessment study of climate adaptation strategies for extreme wind events in Queensland. Their research tested three adaptation strategies: increase in design wind speeds specified in Australian Standards AS4055-2006, retrofitting pre-1980 constructions to current standards, and repairing wind damaged pre-1980 houses to current standards. They used an advanced spatial and temporal stochastic simulation method to assess the economic viability of each of these climate adaptation strategies for four cities between 2030 and 2100. This method took into consideration various parameters including potential climate change impacts on wind field characteristics, uncertainty of wind vulnerability of houses, cost of adaptation, timing of adaptation, discount rates, future growth in new housing, and time depended increase in wind speed. The results were presented in the form of cost-effectiveness, where the cost was the cost of the adaptation strategy and the benefit was the reduction in the damages associated with the adaptation strategy.

Geoscience Australia (2011) has developed models, methods, information and tools to analyse various hazard risks and impacts and to aid the adaptation decision making process. It has constructed consistent national information on residential, commercial, industrial buildings and infrastructure systems for engineering-based modelling of exposed elements affected by disaster events, monitoring and collecting data on natural hazards and man-made disaster events including bushfires, cyclones, earthquakes, floods, landslides, severe weather, tsunami, volcanoes as well as nuclear monitoring.

Geoscience Australia’s Climate Change Project is aimed at determining potential current and future climate change impacts and risks to infrastructure, community assets and the environment. It focuses on hazards such as severe winds, sea level rise, storm surge, flooding and bushfire. The Engineering, Economics and Exposure Project (E3P) is aimed at developing an understanding of what assets, business activities and people are exposed to severe events, how vulnerable they are and what are the consequences of their exposure. This project is developing engineering, economic and social vulnerability models for the built environment, which includes buildings, critical infrastructure and the economic activity associated with them.

The National Exposure Information System (NEXIS) database by Geoscience Australia (2006, 2010) is a national database containing information about buildings across Australia in a consistent format. It combines the best information available on the location and characteristics of the built environment with information on hazard modelling and spatial analysis to facilitate the identification of buildings and infrastructure that are exposed to a particular national or mane-made hazard. NEXIS as an online tool is currently under development and contains national residential building information. The tool allows a user to search by Local Government Area (LGA) to view summarised information on residential building types, roof types, wall types, building ages, income groups, building replacement and contents costs. Information on Commercial and Industrial buildings is under development and will include information on location, construction materials, replacement values, business types, employees, customers and turnover.

In 2011, the Insurance Council of Australia initiated and hosted a Resilient Housing Design competition. The competition aimed to encourage the adoption of designs, building techniques and materials to reduce the level of 'brittleness' and improve the resilience of residential properties to extreme weather over its planned life-cycle. Their design criteria and the characteristics expected from the winning entries provided a good example of resilience indicators for multiple climate impacts such as flood, hail, extreme rainfall, fire and windstorm. In addition to complying with existing BCA requirements, the winning design for a three bedroom residence (not exceeding 220m2 in size) was required to be durable to extreme weather hazards without needing major repairs following two or more of the following specific events:

- A sustained 20 minute hailstorm with hail up to 8cm in size at velocities of 125kmh
- Water inundation above the floor sill height of the property
- Exposure to external fire risks where radiant heat exceeds 40kW/m2
- Exposure to extreme rainfall in excess of 50ARI for 1hr (excluding catchments flooding issues, i.e. building is protected against immediate ingress if water falling on envelope)
- Gusting exposure to winds in excess of 279kmh

The criteria for selection also included total cost as well as life-cycle costs to achieve the increased durability, and aesthetic and architectural appeal of the design.

Significant progress towards ensuring easy access to reliable information, standardised methodology and consistent metrics for climate resilience has been made by the Insurance Council of Australia's recent commissioning of Edge Environment and Climate Risk to design a web-based Resilience Rating Tool (RRT) (Edge Environment 2011, 2012). The RRT is aimed at providing an overall rating for individual dwellings based on the materials of constructions, information on its exposure to individual weather hazards and its geographic location, which in turn can potentially inform insurance premiums. The tool is currently at the stage of user testing, feedback and broad stakeholder engagement. An illustration of what the tool might look like is provided in Appendix C.

## 3.2. Building Design and Policy Responses

Assessment tools, methodologies and metrics help define the issues and refine our understanding of the scope and limitations of the challenges we face. This knowledge, however, is only useful when it supports the implementation of tangible and effective adaptation. Building design and policy responses play a vital role in the implementation process. Following are a few key examples showing different approaches and strategies used in adapting buildings for climate change.

### 3.2.1 International examples

The Three Regions Climate Change Group (2005) in the UK published a report entitled 'Adapting to Climate Change: a Checklist for Development', which provided a checklist summarising important climate issues that need to be considered when planning a development. It covered location, site layout, building design, structure, envelope and materials, ventilation and cooling, drainage, water, outdoor spaces and connectivity.

Town and Country Planning Association (TCPA) also published a guide on Climate change adaptation by design (Shaw, Colley & Connell 2007) for planners, urban designers, developers and anyone engaged in creating sustainable communities to show how adaptation can be integrated into the planning, design and development of new and existing communities. The guide illustrates how adaptation options are influenced by geographical location and the scale of development and demonstrates effective adaptation strategies through case studies from around the world. The strategies and case studies are presented for managing high temperatures, flood risks, water resources and water quality, as well as ground conditions; all at three scales – catchment or conurbation scale, neighbourhood scale and building scale.

The Technology Strategy Board, in partnership with academia, industry and government, has been leading 'Design for Future Climate, Adapting Buildings', the largest program on climate change adaptation for buildings in the UK. The program which started in 2008 and will run until 2013, is increasing client demand and developing skills within design professions for adaptation. The program has generated two publications and funding of £5m to develop adaptation strategies on 50 major UK building projects and improve climate resilience of building projects worth a total of £4.2bn. The publications have informed government policy, climate change risk assessment work, a skills audit on adaptation needs and other recommendations for the Building Schools for the Future program and updating of building regulations and codes (Technology Strategy Board n.d.).

In 2010, for the first time all government departments in the UK published Departmental Adaptation Plans setting out in detail their adaptation and mitigation agendas. The Department for Communities and Local Government included their work plans and time scales for incorporating adaptation aspects of building construction into Building Regulations and the Code for Sustainable Homes alongside other mitigation measures. The British Standards Institution is also involved in scoping the work needed to update standards to address the issues of projected climate change impacts. There is also a proposal to provide enhanced standards, in addition to the minimum standards, for those individual organisations that opt for an additional level of reassurance against specific climate impacts particularly relevant to them (Gething 2010).

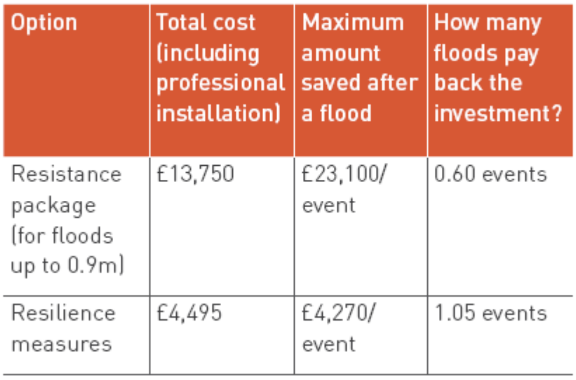
There are also major world class cities that have recognised the imperative of adaptation and are leading city-wide movements to improve the climate resilience of their buildings, precincts and communities at large. The city of Chicago in the US developed its Chicago Climate Action Plan in 2008 that included five major strategies to tackle climate change. Its Adaptation Strategies include:

- managing heat,
- pursuing innovative cooling,
- protecting air quality,
- managing stormwater,
- implementing green urban design,
- preserving our plants and trees,
- engaging public,
- engaging businesses, and
- planning for the future

Its two year progress report (City of Chicago 2009) highlighted that, in addition to many mitigation related achievements, more than 4 million square feet of additional green roofs have been installed or are under construction to manage urban heat island effect and to decrease local impacts of extreme heat.

Rotterdam in the Netherlands is targeting to be '100% climate proof' by 2025 through its 'Rotterdam Climate Initiative' that started in 2007. The city has collaborated with the other delta cities of New York, Tokyo, London, Jakarta, Shanghai and Hong Kong to find innovative solutions for achieving resilience against floods, extreme downpours and long hot summers as a result of climate change. The city plans to employ flood-proof construction techniques to create adaptive buildings. By 2040 in the Stadshavens (the existing areas outside of the levees), floating districts of around 13,000 climate-proof houses will be built, of which around 1,200 will be on the water. A pilot project to test and monitor construction technologies was completed in 2010 in the form of an innovative pavilion complex of three floating half-spheres (Rotterdam Climate Initiative n.d.).

While it is well accepted that new buildings will need to be adaptable and resilient to various climate impacts, it is also crucial that existing buildings are adapted appropriately so that they are fit for purpose when exposed to changed climate conditions. A report entitled ‘Your home in a changing climate’ by Three Regions Climate Change Group (2008) was an outcome of a ground breaking study in the context of existing residential buildings. The report was intended for policy makers, housing professionals and householders in the three regions of London, the East and the South East of England to illustrate ways of adapting existing houses so that they are liveable, comfortable and sustainable in the face of flooding, water stress and overheating. A collection of the resistance, resilience and external measures are presented with their indicative cost comparison as an example in Appendix D. The resistance measures are aimed at preventing or limiting the amount of water entering the home, while resilience measures are focused on reducing time and cost of recovering from a flood. A case study of a detached house concluded that whether resistance or resilience measures were installed, the investment was recouped after just one flood.  The resistance measures are of ‘all or nothing’ type where every possible ingress point for flood water needs to be sealed and hence requires a large single investment by the householder.



| Option | Total cost (including professional installation) | Maximum amount saved after a flood | How many floods pay back the investment? |
|---|---|---|---|
| Resistance package (for floods up to 0.9m) | £13,750 | £23,100/ event | 0.60 events |
| Resilience measures | £4,495 | £4,270/ event | 1.05 events |

Figure 13: Payback period study of resistance and resilience measures (Three Regions Climate Change Group 2008)

### 3.2.2 Australian examples

Focus on adaptation to climate change in Australia has only happened relatively recently when compared to mitigation efforts. The majority of work done in this area has occurred in the last five years. The BRANZ report by Amitrano et al. (2007) for AGO was the first of its kind. It compiled an extensive list of possible adaptation measures for buildings to cope with various impacts of climate change (see Appendix E). The authors also assessed viability of adaptation options through rough costing exercises and highlighted research needs including the need for risk and condition assessment and cost-benefit analysis of adaptation options. They acknowledged the lack of sufficient information on the existing stock of buildings and the need to develop guidance on whether older buildings should be adapted. They discussed current building regulations that deal with the five key climate change issues identified in the report namely building over-heating, tropical cyclones, flooding, degradation of foundations and bushfires, and identified potential changes to building codes, standards and planning systems. The report also included two adaptation case studies from Australia.

The winning entry by PIDCOCK Architecture & Sustainability for the Insurance Council of Australia's Resilient Housing Design competition (Insurance Council of Australia 2011; The Fifth Estate 2011a) embodies many aspects of the building design strategies discussed earlier. With Cairns' climatic conditions in mind, the two storey 3 bedroom house was designed to deliver resilience against hail, flood, bushfire, extreme rainfall and cyclone with the help of strategically selected materials and design features. An overhanging steel roof to protect external walls from hail, a composite steel and concrete wall system to provide sealing and flood resistance, corrugated steel walls with rockwool insulation to provide resistance against fire and oversized gutters and downpipes to withstand extreme rainfall are some of the features that were employed in the schematics. The design aimed to allow the building to remain structurally sound and to provide post-disaster shelter to affected families.

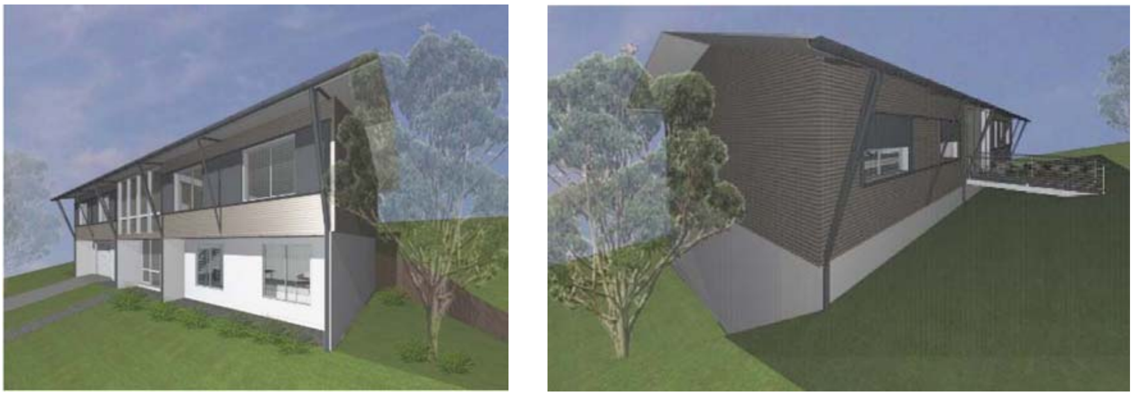


Figure 14: Illustrations of the resilient house design by PIDCOCK Architecture & Sustainability (The Fifth Estate 2011b)

It has been argued that the regulatory approach has often been selective and reactionary such as the design requirements for bushfire prone regions (Edge Environment 2011; Snow & Prasad 2011). Government responses have fallen short of regulation and have instead relied on non-mandatory guideline documents, such as the 'Durability in Buildings Handbook' (ABCB 2006), 'A guide to retrofit houses for Bushfire protection' (Building Commission & Country Fire Authority 2010), the 'Department of Local Government and Planning – Repairing your house after flood' and the 'Hawkesbury-Nepean Floor Plan Management Steering Committee- Reducing vulnerability of buildings to flood damage' (Edge Environment 2011).

Following the recommendations of the 2009 Victorian Bushfires Royal Commission, ABCB developed a Performance Standard for Private Bushfire Shelters (ABCB 2010b). Following a Regulated Impact Statement (RIS) study (CIE 2011), ABCB made recent amendments to include private bushfire shelter provisions for Class 1a dwellings into the BCA, and hence added building class 10c for private bushfire shelter in BCA 2011 (ABCB 2011b).

A number of cyclone events in Australia in recent years have triggered a proposal to revise building codes for construction in cyclone affected regions. Acknowledging the need to regulate the regions in Australia in which buildings must be designed to resist tropical cyclones, and the level of stringency in cyclone and adjacent non-cyclone regions, the ABCB is conducting an RIS study to examine a number of regulatory proposals (ABCB 2010a). Similarly, ABCB is also currently undertaking a project to develop a technical standard and an accompanying non-regulatory handbook for housing and other low-rise residential buildings in flood prone areas (ABCB 2011a, n.d.). It is anticipated that the standard will be available for adoption in the National Construction Code (NCC) Volumes One and Two in 2013.

NCCARF (2011c) has commissioned Matthew Mason of Macquarie University to lead a project on managing flood risk to buildings. The project 'Damage to buildings during the 2010-2011 Eastern Australia flooding events' will examine building damage caused by the recent Eastern Australian floods and explore the role that planning, design and construction regulations may have played in building failure. The researchers will review legal requirements in the flood affected areas along with various interviews with damage assessors and builders involved in reconstruction. The project aims to identify weaknesses in current systems and propose effective solutions to mitigate damage and financial loss from future floods.

Standards Australia (2011) released a Draft Adaptation Standard for public comment in September 2011. The scope of the DR AS 5334 Climate Change Adaptation for Settlements & Infrastructure (public draft for comment) is limited to infrastructure and settlements and provides a framework for decision makers. The Standard aims to provide principles and generic guidelines on the identification and management of risks from climate change; and describe a systematic approach to planning the adaptation of settlements and infrastructure based on the risk management process. Its scope of settlements and infrastructure includes buildings of residential, commercial, industrial, recreational, public, retail, institutional, historic and tourism type.

The Climate Change Task Group of the Australian Sustainable Built Environment Council (ASBEC 2011) is also currently working on developing a Policy Framework for Climate Change Adaptation in the Built Environment. With support from the Australian Institute of Architects, the Property Council of Australia, Consult Australia, the Planning Institute of Australia, the Federal Department of Climate Change and Energy Efficiency and the WA Department of Finance, the Task Group considered the range of applications received in response to its Call for Proposals. AECOM was commissioned to lead the resulting project which adopted a range of approaches, including extensive surveys across the wider ASBEC membership, desktop research of voluntary and regulatory examples of adaptation policy, both domestic and international, and workshops with Task Group members. AECOM identified a number of trends, including confusion between mitigation and adaptation among built environment professionals and a lack of professional tools available to support the consideration of adaptation at a practitioner level. The policy framework is expected to be ready for public release in June 2012.

In September 2011, the Productivity Commission announced an inquiry into the "Barriers to Effective Climate Change Adaptation". An Issues Paper (Productivity Commission 2011) was released to assist individuals and organisations to prepare submissions to the inquiry. The inquiry will review current regulations and policies that may present barriers to effective adaptation to climate change and will examine the costs and benefits of options to remove those barriers. The inquiry will also assess the role of markets and non-market mechanisms in facilitating adaptation, and the appropriateness of government intervention. On review of the submissions received, the draft report was released in April 2012, inviting the public to provide written comments and to attend a public hearing. The final report is scheduled to be delivered to the Federal Government in September 2012.

The Green Building Council of Australia (GBCA) is currently developing two rating tools aimed at supporting climate change adaptation in addition to mitigation. The new Green Star – Communities and the Green Star – Performance tools are designed to provide credits such as 'adaptation and resilience credits' and 'heat island credit' that will directly address climate change impacts. These credits will require planners and developers to develop Climate Adaptation Plans and Disaster or Emergency Preparedness Plans. The Green Star – Performance tool will for the first time require buildings to be green not only 'by design' or 'as built' but also through ongoing operation using measurement and tracking to maintain its performance (Green Building Council Australia 2011).

# 4. CONCLUSION

Lack of consistent, up to date and appropriate information and knowledge is often cited as one of the barriers to effective adaptation. This is well-reflected in the confusion that surrounds the use of different terminologies related to and different notions of adaptability in buildings. With a wide range in focus and preference, these various concepts and definitions seem to offer insights into what would be the characteristics of a climate-adaptable building. There is also lack of a clear and well-accepted definition for climate-adaptable buildings distinct from other often interchangeably used terms such as climate resilient buildings.

Whilst there are assessment tools and methods used for identifying vulnerability and adaptive capacity of various systems from planning to urban governance, there appears to be a knowledge and policy gap in the area of assessment of existing and new buildings to identify and quantify their vulnerability to climate impacts. It is essential that there is clarity and consistency in the way in which the buildings' climate adaptability and resilience, or the lack thereof, are measured and assessed. There is a pressing need for further research to develop common metric and consistent methodologies of assessment of how adaptable and resilient our existing and new buildings are to projected and unexpected climate impacts. There are also implications of the various priorities for adaptation on assessment criteria for buildings that need to be identified if we are to develop appropriate, timely and effective design and policy measures for adaptation.

It is to be noted that currently there are no common legislative or strategic planning frameworks in place to guide climate adaptation responses at either a national or international level. There are also no currently accepted standards for measurement metrics, normalised approaches or indicator sets for the development or comparison of assessment methods or climate adaptation tools. Development of a national level building adaptability and resilience assessment system that can be used for both existing and new buildings by policymakers, regulatory authorities, property insurers, building design and construction industry professionals as well as householders could be highly beneficial.

The research also found gaps between knowledge and practice of adaptation and mitigation. There also appears to be confusion around the interface and synergies between adaptation and mitigation strategies. There is a need for improved skills and preparedness of building professionals to advise, encourage and implement adaptation measures. There are considerable opportunities in linking adaptation with mitigation so that the climate resilience measures become integrated in the GHG emission reduction agendas for all types of buildings. This will lead to both low-carbon and climate resilient buildings and cities.

There is also currently no regulatory framework governing the process for climate change adaptation of existing buildings. There are significant opportunities available for policy and decision makers with the ongoing development of new tools, techniques and technologies for assessment, analysis and decision making for climate adaptation for both, new and existing buildings. Building regulations need a holistic review in the context of climate change adaptation; they have an important role to play in preparing our settlements for a safe and sustainable future. An appropriate policy mix will be required to deliver climate adapted and resilient buildings to cope with these impacts. Existing buildings can be made climate resilient by ensuring that adaptation becomes an integral part of the housing stock upgrade process.

There are many possible barriers to effective adaptation: lack of knowledge, information asymmetries, lack of skills, cost, split incentives, and behavioural issues to name but a few. On the other hand, there are significant risks in not adapting. Moreover, there are numerous examples worldwide that show how design and technological strategies, policy innovations, regulatory and non-regulatory initiatives, financial and non-financial incentives, as well as increased environmental awareness can provide impetus strong enough to address these barriers successfully.

The result of such effective adaptation will be more resilient and robust buildings better able to cope with projected climate impacts throughout their lifecycle e.g. increased flexibility to cope with uncertainty without massive failure and economic cost. The amount of activity that is currently happening in this area in Australia, with more than half a dozen significant projects of research, reviews, inquiries or rating tool developments, points to a promising and exciting future for action in climate adaptation.

# REFERENCES

ABCB 2006, *Durabiilty in Buildings - Handbook*, Australian Building Codes Board, <http://www.abcb.gov.au/index.cfm?objectid=E63CE792-2C93-11DF-AD33001143D4D594>.

ABCB 2010a, *Consultation Regulation Impact Statement (RIS 2010-01): Proposal to Revise Building Code of Australia requirements for Construction in Cyclone Affected Regions*, Australian Building Codes Board, <http://www.abcb.gov.au/index.cfm?objectid=4D4FF138-9B83-11DF-A133001143D4D594>.

ABCB 2010b, *Performance Standard for Private Bushfire Shelters*, Australian Building Codes Board, <http://www.abcb.gov.au/index.cfm?objectID=C617CEFF-53FB-11DF-AA90001143D4D594>.

ABCB 2011a, *Annual Business Plan 2011-2012*, Australian Building Codes Board, <http://www.abcb.gov.au/~/media/Files/Download%20Documents/ABCB%20docs/2011-12%20Business%20Plan.ashx>.

ABCB 2011b, *List of Amendments to The Building Code of Australia 2011 - NCC Volume Two*, Australian Building Codes Board, <http://www.abcb.gov.au/index.cfm?objectid=2B2F3C36-79F1-11E0-9903001143D4D594>.

ABCB n.d., *Buildings in Flood Prone Areas*, Australian Building Codes Board, viewed 16 July 2011, <http://www.abcb.gov.au/index.cfm?objectid=7384D703-28B9-11DE-835E001B2FB900AA>.

Adger, WN, Lorenzoni, I & O'Brien, KL (eds) 2009, *Adapting to climate change. Thresholds, values, governance*, Cambridge University Press, Cambridge, UK.

Amitrano, L, Hargreaves, R, Page, I, Hennessy, K, Lee, T, Snow, M, Winton, L, Woodruff, R & Kjellstrom, T 2007, *An assessment of the need to adapt buildings for the unavoidable consequences of climate change*, Australian Greenhouse Office, Australian Government Department of the Environment and Water Resources, Canberra, Australia.

ARCC 2011, *Project Summaries*, Adaptation and Resilience in a Changing Climate, viewed 21 July 2011, <http://www.ukcip-arcc.org.uk/content/view/587/517/>.

ASBEC 2011, *Task Groups: Climate Change Task Group*, viewed 30 December 2011, <http://www.asbec.asn.au/about_us/task_groups>.

Ash, A 2010, *Climate change and Coasts: Impacts, vulnerability and the need for adaptation*, Climate Change Adaptation Forum, Canberra.

ATSE 2010, *Climate Change and the urban environment: managing our urban areas in a Changing Climate - Workshop Report*, Melbourne.

Barker, T, Bashmakov, I, Bernstein, L, Bogner, JE, Bosch, PR, Dave, R, Davidson, OR, Fisher, BS, Gupta, S, Halsnæs, K, Heij, GJ, Ribeiro, SK, Kobayashi, S, Levine, MD, Martino, DL, Masera, O, Metz, B, Meyer, LA, Nabuurs, G-J, Najam, A, Nakicenovic, N, Rogner, H-H, Roy, J, Sathaye, J, Schock, R, Shukla, P, Sims, REH, Smith, P, Tirpak, DA, Urge-Vorsatz, D & Zhou, D 2007, 'Technical Summary ', in ORD B. Metz, P. R. Bosch, R. Dave, L. A. Meyer (ed.), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Baum, S, Horton, S, Choy, DL & Gleeson, B 2009, *Climate change, health impacts and urban adaptability: Case study of Gold Coast City*, Urban Research Program Research Monograph 11, <http://www.griffith.edu.au/__data/assets/pdf_file/0011/119864/urp-rm11-baum-et-al-2009.pdf>.

Beadle, K, Gibb, A, Austin, S, Fuster, A & Madden, P 2008, *Adaptable Futures: Setting the Agenda*, Department of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, United Kingdom, <http://www.adaptablefutures.com/downloads/Beadle_et_al_2008.pdf>.

Bengtsson, J, Bennett, J, McKernon, S, Mullan, B & Page, I 2007, 'Climate Change Impacts in New Zealand: A Cross-Disciplinary Assessment of the Need to Adapt Buildings, with Focus on Housing', paper presented to Sustainable Building 2007 Conference, New Zealand.

Bengtsson, J, Clément, V & Davies, T 2008, *Adaptation to Climate Change through Building Regulation*, Edge Environment, <http://www.edgeenvironment.com.au/docs/ANU%20climate%20change%20adaptation%20-%20Edge%20Environment%2021Nov08(2).pdf>.

Bengtsson, J, Hargreaves, R & Page, IC 2007, *Study Report No. 179 (2007) - Assessment of the Need to Adapt Buildings in New Zealand to the Impacts of Climate Change*, Building Research Association of New Zealand (BRANZ), Wellington, New Zealand.

BOM & CSIRO 2010, *State of the Climate*, Bureau of Meteorology and Comonwealth Scientific and Industrial Research Organisation.

Bowker, P, Escarameia, M & Tagg, A 2007, *Improving the Flood Performance of New Buildings: Flood Resilient Construction*, RIBA Publishing, UK, <http://www.planningportal.gov.uk/uploads/br/flood_performance.pdf>.

Brager, GS & de Dear, RJ 1998, 'Thermal adaptation in the built environment: a literature review', *Energy and Buildings*, vol. 27, no. 1, pp. 83-96.

BRANZ 2006, *Desiging Homes for Climate Change: How to significantly improve the climate readiness of your proposed home through the design brief*, Building Research Association of New Zealand (BRANZ).

Building Commission & Country Fire Authority 2010, *A guide to retrofit your home for better protection from a bushfire*, Building Commission & Country Fire Authority, Victoria, <http://www.cfa.vic.gov.au/firesafety/buildingandregulations/documents/bushfire_home_retrofit.pdf>.

Bullen, PA 2004, 'Assessing Sustainable Adaptation of Existing Buildings to Climate Change', paper presented to COBRA 2004, Leeds Metropolitan University, 7-8 September, <http://www.rics.org/site/download_feed.aspx?fileID=2162&fileExtension=PDF>.

Camilleri, MJ 2000, *STUDY REPORT No. 95 (2000) - A Draft Climate ChangeSustainability Index for Houses*, Building Research Association of New Zealand (BRANZ), Judgeford, New Zealand.

Camilleri, MJ 2001, *Study Report SR 107 - Implications of Climate Change for Construction Sector: Adaptation and Mitigation Strategies and Revised CCSI*, Building Research Association of New Zealand (BRANZ), Wellington, New Zealand.

Carthey, J, Chandra, V & Loosemore, M 2008, 'Adapting NSW Health Facilities to Climate Change - A Risk Management Approach', paper presented to W89 International Conference in Building Education and Research (BEAR), Kandalama, Sri Lanka, 10-15 February, <http://www.fbe.unsw.edu.au/chaa/resources/publishedworks/2008_Carthey,Chandra&Loosemore_AdaptingNSWHealthFacilities_BEAR.pdf>.

Carthey, J, Chandra, V & Loosemore, M 2009, 'Adapting Australian Health Facilities to Cope with Climate-Related Extreme Weather ', *Journal of Facilities Management*, vol. 7, no. 1, pp. 36-51.

CIE 2011, *Final Regulation Impact Statement: Proposal to amend the Building Code of Australia to include requirements for private bushfire shelters*, Australian Building Codes Board, <http://www.abcb.gov.au/index.cfm?objectid=D730B40F-3013-11E0-944C001143D4D594>.

City of Chicago 2009, *Chicago Climate Action Plan: Progress Report 2008-2009*, City of Chicago, US.

Clarke, B & Pullen, S 2008, 'The Need for Adaptation of Existing Commercial Buildings for Climate Change', in *2008 AIBS South Australian Conference - Climate Change: Engaging the Elements*, pp. 74-90.

COAG 2007, *National Climate Change Adaptation Framework*, Council of Australian Governments.

Deichmann, U, Ehrlich, D, Small, C & Zeug, G 2011, *Using High Resolution Satellite Data for the Identification of Urban Natural Disaster Risk*, Global Facility for Disaster Reduction and Recovery (GFDRR), Washington, DC, USA, <http://www.gfdrr.org/gfdrr/sites/gfdrr.org/files/publication/using_high_resolution_data.pdf>.

Department for Families and Communities 2011, *Design Criteria for Adaptable Housing*, Department for Families and Communities, Government of South Australia, <http://www.dfc.sa.gov.au/pub/tabid/256/itemid/333/default.aspx>.

Department of Climate Change and Energy Efficiency 2009, *Climate Change Risks to Australia's Coast: A First Pass National Assessment*, Department of Climate Change and Energy Efficiency, Australian Government, Canberra.

Department of Climate Change and Energy Efficiency 2011, *Climate Change Risks to Coastal Buildings and Infrastructure: A Supplement to the First Pass National Assessment*, Department of Climate Change and Energy Efficiency, Australian Government, Canberra.

Dessai, S, Adger, WN, Hulme, M, Turnpenny, J, Köhler, J & Warren, R 2004, 'Defining and experiencing dangerous climate change', *Climatic Change*, vol. 64, no. 1, pp. 11-25.

Edge Environment 2011, *Response to Productivity Commission Issues Paper – October 2011: Barriers to Effective Climate Change Adaptation*, Productivity Commission, Australian Government, <http://www.pc.gov.au/__data/assets/word_doc/0004/114745/sub054.doc>.

Edge Environment 2012, *The Path to Resilience Ratings for Australian Buildings*, viewed 21 January 2012, <http://edgeenvironment.com.au/the-path-to-resilience-ratings-for-australian-buildings/>.

Geoscience Australia 2006, *National Exposure Information System (NEXIS)*, Australian Government, Canberra, <http://www.ga.gov.au/image_cache/GA10003.pdf>.

Geoscience Australia 2010, *NEXIS Database*, Australian Government, viewed 19 June 2011, <http://www.ga.gov.au/hazards/our-techniques/data-collection/databases/nexis-database.html>.

Geoscience Australia 2011, *Hazards*, Australian Government, viewed 15 December 2011, <http://www.ga.gov.au/hazards.html>.

Gething, B 2010, *Design for Future Climate: opportunities for adaptation in the built environment* Technology Strategy Board, UK.

Gibb, A, Austin, S, Dainty, A, Davison, N & Pasquire, C 2007, 'Towards Adaptable Buildings: pre-configuration and re-configuration – two case studies', paper presented to ManuBuild 1st International Conference - The Transformation of the Industry: Open Building Manufacturing, Rotterdam, 25-26 April.

Graham, P 2005, 'Design for Adaptability - An Introduction to the Principles and Basic Strategies', *Environment Design Guide*, no. GEN 66, pp. 1-9.

Green Building Council Australia 2011, *Barriers to Effective Climate Change Adaptation - Submission to Productivity Commission*, Productivity Commission, <http://www.pc.gov.au/__data/assets/pdf_file/0020/114752/sub061.pdf>.

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, Belcher, S & Connell, R 2005, *Beating the Heat: keeping UK buildings cool in a warming climate*, UKCIP, Oxford, UK.

Hennessy, K, Fitzharris, B, Bates, BC, Harvey, N, Howden, SM, Hughes, L, Salinger, J & Warrick, R 2007, 'Australia and New Zealand', in ML Parry, OF Canziani, JP Palutikof, PJ van der Linden & CE Hanson (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK, pp. 507-40.

IFLA-AILA 2010, *Climate Adaptation Tools for Sustainable Settlements (CATSS) Report*, <http://www.aila.org.au/climate/catss/docs/IFLA_AILA-CATSS-Report.pdf>.

Insurance Council of Australia 2011, *2011 Annual Resilience Award $50,000 - for Durable Housing*, Insurance Council of Australia, <http://www.insurancecouncil.com.au/Portals/24/Resilience%20Award/Resilience%20Award%202011.pdf>.

IPCC 2007a, *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC 2007b, *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, UK.

IPCC 2007c, *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, Geneva, Switzerland.

Jaques, R & Sheridan, A 2006, *Study Report No. 150 - Towards Carbon-Neutral and Climate-Adapted Domestic Buildings - Background Document*, Building Research Association of New Zealand (BRANZ), Wellington, New Zealand.

Klein, RJT, Huq, S, Denton, F, Downing, TE, Richels, RG, Robinson, JB & Toth, FL 2007, 'Inter-relationships between adaptation and mitigation', in ML Parry, OF Canziani, JP Palutikof, PJ van der Linden & CE Hanson (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK, pp. 745-77.

Lehmann, S 2009, 'Developing a Holistic Pathway to Climate-Adaptive Buildings', *Journal of Green Building*, vol. 4, no. 3, pp. 91-102.

Lelieveld, CMJL, Voorbij, AIM & Poelman, WA 2007, 'Adaptable Architecture', in *Building Stock Activation 2007*, Tokyo, Japan, pp. 245-52.

Loonen, R 2010, 'Climate Adaptive Building Shells: What can we simulate?', MSc thesis, Eindhoven University of Technology, The Netherlands.

Loonen, RCGM, Trčka, M, Cóstola, D & Hensen, JLM 2010, 'Performance simulation of climate adaptive building shells - Smart Energy Glass as a case study', paper presented to 8th International Conference on System Simulation in Buildings, Liege, 13-15 December <http://www.bwk.tue.nl/bps/hensen/publications/10_ssb_loonen.pdf>.

Love, P & Bullen, PA 2009, 'Toward the sustainable adaptation of existing facilities', *Facilities*, vol. 27, no. 9/10, pp. 357-67.

Manewa, A, Pasquire, C, Gibb, A & Schmidt, R 2009, *Towards Economic Sustainability Through Adaptable Buildings*, <http://www.adaptablefutures.com/downloads/Manewa_et_al_2009_SASBE.pdf>.

Mullan, B, Burgess, S, McKenzie, R, Ramsay, D, Reid, S, Stephens, S & Thompson, C 2006, *Climate change scenarios for BRANZ study of built environment vulnerability*, National Institute of Water & Atmospheric Research Ltd, Hamilton, New Zealand.

N. Davison, AGG, S.A. Austin, C.I.Goodier 2006, 'The Multispace adaptable building concept and its extension into mass customisation', paper presented to Adaptables2006, TU/e, International Conference On Adaptable Building Structures, Eindhoven The Netherlands, 03-05 July, <http://www.adaptablefutures.com/downloads/Davison_et_al_2006.pdf>.

NCCARF 2011a, *Australia's Country Towns 2050: What will a Climate Adapted Settlement Pattern Look Like? - Project Synopsis*, National Climate Change Adaptation Research Facility, <http://www.nccarf.edu.au/sites/default/files/S&I-11%20146%20Website%20snippet%20Beer.pdf>.

NCCARF 2011b, *NCCARF Adaptation Research Grants Program — Currently Funded Project Summary for Settlements & Infrastructure*, National Climate Change Adaptation Research Facility, <http://www.nccarf.edu.au/sites/default/files/NCCARF%20ARGP%20Projects%20@%20July%202011%20S&I.doc>.

NCCARF 2011c, *Newsletter September 2011*, National Climate Change Adaptation Research Facility, <http://www.nccarf.edu.au/sites/default/files/September%20Newsletter.pdf>.

NCCARF 2011d, *Submission by the National Climate Change Adaptation Research Facility*, Productivity Commission, Australian Government, <http://www.pc.gov.au/__data/assets/pdf_file/0003/114546/sub049.pdf>.

Omi, Y 2007, 'Examination of Adaptable Building By "Self-Standing and Self-Build" Infill Space Unit', in *Building Stock Activation 2007*, Tokyo, Japan, pp. 277-80.

Palmer, J & Ward, S 2008, 'The Adaptable House', in P Downton (ed.), *Your home: Design for lifestyle and the future. Technical Manual*, 4 edn, Australian Government Department of the Environment, Water, Heritage and the Arts, pp. 52-6.

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.

Pittock, B 2009, *Climate Change: The Science, Impacts and Solutions*, 2 edn, CSIRO Publishing, Collingwood, Victoria.

Preston, BL & Stafford-Smith, M 2009, *Framing vulnerability and adaptive capacity assessment: Discussion paper*, CSIRO Climate Adaptation Flagship Working paper No. 2, <http://www.csiro.au/files/files/ppgt.pdf>.

Productivity Commission 2011, *Barriers to Effective Climate Change Adaptation: Productivity Commission Issues Paper*, Productivity Commission, Australian Government, <http://www.pc.gov.au/projects/inquiry/climate-change-adaptation>.

Rotterdam Climate Initiative n.d., *100% Climate Proof: Projects*, viewed 27 October 2011, <http://www.rotterdamclimateinitiative.nl/en/100_climate_proof/projects>.

Russell, P & Moffatt, S 2004, *Assessing Buildings for Adaptability: Annex 31 Energy-Related Environmental Impact of Buildings*, International Initiative for a Sustainable Built Environment (iiSBE).

Schmidt, R, Mohyuddin, S, Austin, S & Gibb, A 2008, 'Using DSM to Redefine Buildings for Adaptability', paper presented to Stockholm, Sweden, 10th International Design Structure Matrix Conference, DSM'08, 11-12 November, <http://www.adaptablefutures.com/downloads/Schmidt_et_al_2008_Stockholm.pdf>.

Shaw, R, Colley, M & Connell, R 2007, *Climate change adaptation by design: a guide for sustainable communities*, Town and Country Planning Association, London.

Smit, B & Wandel, J 2006, 'Adaptation, adaptive capacity and vulnerability', *Global Environmental Change*, vol. 16, no. 3, pp. 282-92.

Snow, M & Prasad, D 2011, 'Climate Change Adaptation for Building Designers: An Introduction', *Environment Design Guide*, no. 66 MSa, pp. 1-11.

Standards Australia 2011, *Draft for Public Comment Australian Standard: DR AS 5334 Climate change adaptation for settlements and infrastructure*, Standards Australia, <http://www.asbec.asn.au/files/DR_AS_5334_Draft_Adaptation_Standard_8Sept2011.pdf>.

Steemers, K 2003, *Establishing research directions in sustainable building design - Technical Report 5*, Tyndall Centre for Climate Change Research, Norwich, UK.

Stewart, MG & Wang, X 2011, *Risk Assessment of Climate Adaptation Strategies for Extreme Wind Events in Queensland*, CSIRO, Canberra.

Technology Strategy Board n.d., *Adapting buildings to climate change*, viewed 24 November 2011, <http://www.innovateuk.org/ourstrategy/innovationplatforms/lowimpactbuilding/adapting-buildings-to-climate-change.ashx>.

Teo, EAL & Lin, G 2011a, 'Building adaption model in assessing adaption potential of public housing in Singapore', *Building and Environment*, vol. 46, no. 7, pp. 1370-9.

Teo, EAL & Lin, G 2011b, 'Determination of strategic adaptation actions for public housing in Singapore', *Building and Environment*, vol. 46, no. 7, pp. 1480-8.

The Allen Consulting Group 2005, *Climate Change Risk and Vulnerability - Final Report*, Australian Greenhouse Office, Canberra.

The Fifth Estate 2011a, *Bluescope and Caroline Pidcock win insurance competition for resilient housing* The Fifth Estate, viewed 6 May 2011, <http://www.thefifthestate.com.au/archives/23640>.

The Fifth Estate 2011b, *BlueScope Steel wins Insurance Award for Durable Housing*, The Fifth Estate, viewed 20 May 2011, <http://www.architectureanddesign.com.au/article/BlueScope-Steel-wins-Insurance-Award-for-Durable-Housing/529563.aspx#>.

The World Bank 2011, *Climate Change Knowledge Portal: for Development Practitioners and Policy Makers*, The World Bank, viewed 24 July 2011, <http://sdwebx.worldbank.org/climateportal/>.

Three Regions Climate Change Group 2005, *Adapting to climate change: a checklist for development: Guidance on designing developments in a changing climate*, Greater London Authority, UK, <http://www.climatesoutheast.org.uk/images/uploads/Adaptation_Checklist_for_Development_Nov_2005.pdf>.

Three Regions Climate Change Group 2008, *Your Home in a Changing Climate: Retrofitting Existing Homes for Climate Change Impacts*, Greater London Authority, London, UK.

Tol, RSJ, Bohn, M, Downing, TE, Guillerminet, M, Hizsnyik, E, Kasperson, R, Lonsdale, K, Mays, C, Nicholls, RJ, Olsthoorn, AA, Pfeifle, G, Poumadere, M, Toth, FL, Vafeidis, N, Werff, PEvd & Yetkiner, IH 2006, 'Adaptation to five meters of sea level rise', *Journal of Risk Research*, vol. 9, pp. 467-82.

UKCIP 2011, *What is the Risk Framework*, UK Climate Impacts Program, viewed 24 July 2011, <http://www.ukcip.org.uk/risk/what-is-risk-framework/>.

UKCIP n.d., *Incorporating Adaptive Measures to Climate Change in the Built Environment: An Example of Decision-Making Under Conditions of Uncertainty*, UK Climate Impacts Program, <http://www.ukcip.org.uk/wordpress/wp-content/PDFs/UKCIP_CS_risk_Built_Env.pdf>.

UNEP SBCI n.d., *Common Carbon Metric for Measuring Energy Use & Reporting Greenhouse Gas Emissions from Building Operations*, United Nations Environment Program's Sustainable Buildings & Climate Initiative, <http://www.unep.org/sbci/pdfs/UNEPSBCICarbonMetric.pdf>.

Victoria. Building Commission 2009, *A guide to assessing your property's Bushfire Attack Level (BAL)*, Building Commission, Melbourne, <http://www.buildingcommission.com.au/resources/documents/Building_Commission-BAL_Guide_(3).pdf>.

Wakefield, T, He, Y & Dowling, VP 2009, 'An experimental study of solid timber external wall performance under simulated bushfire attack', *Building and Environment*, vol. 44, no. 10, pp. 2150-7.

Wilkinson, SJ, James, K & Reed, RG 2010, 'Building Adaptation in the Melbourne CBD: The relationship between adaptation and building characteristics', paper presented to FIG Congress 2010: Facing the challenges: Building the Capacity, Sydney 11-16th April, <http://www.fig.net/pub/fig2010/papers/ts04m%5Cts04m_wilkinson_james_et_al_3779.pdf>.

# APPENDIX A. Glossary of Key Adaptation Concepts

### Climate Change Adaptation

There are multiple definitions used for adaptation. The Built Environment Climate Change Adaptation Wiki (BECCA), which is an online resource set up by the Australian Security Research Centre and funded by the Australian Government Department of Climate Change and Energy Efficiency, provides a summary of the various adaptation definitions.

Adaptation is defined in the Council of Australian Governments (COAG) National Climate Change Adaptation Framework (COAG 2007) as: "*the principle way to deal with the unavoidable impacts of climate change. It is a mechanism to manage risks, adjust economic activity to reduce vulnerability and to improve business certainty."*

The IPCC in its Fourth Assessment Report on Mitigation (IPCC 2007a) as well as in its Synthesis Report (IPCC 2007c) defines adaptation as "*Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects.*" In its Fourth Assessment Report on Adaptation IPCC (2007b) defines adaptation as: "*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.*" The IPCC (2007b) refers to various types of adaptation in response to varying types of approaches to potential climate disasters.

These are:

- Anticipatory (Proactive) Adaptation: Adaptation as a pre-emptive or preventative measure that takes place before actual impacts occur. This approach assesses the vulnerability of a system to potential climate impacts and weighs the costs and benefits of action versus inaction.

- Reactive Adaptation: Adaptation that is undertaken after the impacts have been observed; for instance, changes in building regulations as a reaction to an extreme weather event.

- Autonomous (spontaneous) Adaptation: Adaptation that takes place as an unconscious response to climate stimuli; for instance, changes in the natural system as a result of environmental changes or changes in the human systems triggered by changes in the markets or welfare systems.

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

### Adaptation vs. Mitigation

The whole framework of the United Nations Framework Convention on Climate Change (UNFCCC) revolves around two key terms: 'mitigation' which is aimed at reducing GHG emissions to minimise resultant global warming or 'avoiding the unmanageable', and 'adaptation' which is to cope with a changed climate of the world or 'managing the unavoidable' (GTZ/PIK 2009).

Tol et al. (2006) have drawn attention to the fact that we are no longer dealing with the question of adaptation versus mitigation; that both are now essential in the face of the impacts of climate change. It has been further re-emphasised by Parry et al. (2009) and Klein et al. (2007) that adaptation and mitigation measures can be mutually reinforcing and hence should not be considered in isolation.

Baum et al. (2009) have made a simple distinction between mitigation and adaptation, where ’climate friendly‘ development (mitigation) contributes to lowering of GHG emissions and ’climate safe‘ development (adaptation) leads to low vulnerability to direct (temperature and water) and indirect (flooding, saline intrusion) impacts of climate change.

The interrelationships between mitigation and adaptation are significant but they are distinct in their own right. The distinctions and interactions need to be understood and given relevance to the built environment community. This will not only assist in framing decisions and actions associated with climate adaptive design for buildings but also highlight the consequences of these actions for broader mitigation measures.

**Other Related Concepts:**

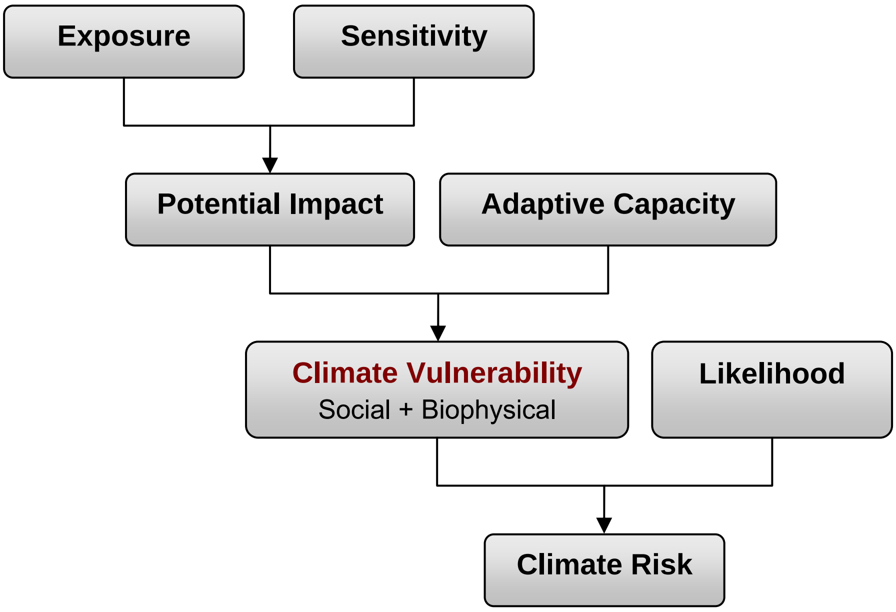


Figure 15: Interrelationship between various concepts related to adaptation. Adapted from The Allen Consulting Group (2005) and Preston and Stafford-Smith (2009)

The concepts of vulnerability, adaptive capacity, exposure and sensitivity are closely related to the concepts of adaptation and have wide application to global change science. These concepts are used in different ways and are given different emphasis in various fields. As illustrated in Figure 15 vulnerability of any system depends on the exposure and sensitivity of that system to hazardous conditions and the ability or capacity or resilience of that system to cope, adapt or recover from the effects of those conditions (Smit & Wandel 2006). The IPCC (2007b) defines adaptability and adaptive capacity as the same, which is: “*the ability of a system to adjust to climate change (including climate variability and extremes) to more potential damages, to take advantage of opportunities or to cope with the consequences*” and defines vulnerability as: “*the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes.*” Preston and Stafford-Smith (2009) have made further distinction between social vulnerability, arising due to social, economic, political or cultural processes, and biophysical vulnerability, arising due to biophysical processes.

As Smit and Wandel (2006) suggest, ‘adaptations are manifestations of adaptive capacity, and they represent ways of reducing vulnerability’. In other words, for any system, higher levels of exposure and sensitivity to climate stimulus or hazard creates greater vulnerability and higher levels of adaptive capacity result in less vulnerability.

Referring to a host of other literature, Smit and Wandel (2006) as well as Preston and Stafford-Smith (2009) have clarified that adaptive capacity is similar to or closely related to many other commonly used concepts, including adaptability, response capacity, coping ability, potentiality, stability, robustness, flexibility and is also used as an alternative term for resilience. The IPCC defines resilience as, “*The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change*” (IPCC 2007b).

# APPENDIX B. Climate Change Pressures & Effects on Buildings

The following table summarises the potential effects of climate change on the built environment, which includes impacts on the life and performance of buildings along with health and wellbeing issues on the occupiers and inhabitants.

| Climate Change Pressures | Potential effects on buildings and their performance |
|---|---|
| Increased rainfall | - localised flooding events, depending on drainage system capacity (including roof damage, drainage pipes, sewer connections, etc) (see Flooding)<br>- weathering (e.g. corrosion of metals) leading to higher maintenance requirements<br>- more frequent filling of dams in areas with maximum rain in summer e.g. in the tropics.<br>- |
| Reduced rainfall | - pressures on urban water resources<br>- soil drying and cracking, potentially affecting foundations and walls (drying out and cracking of mortar). |
| Higher average temperatures and more extreme temperature events | - increased cooling loads (and cooling costs)<br>- building envelope (roofing, cladding, window systems) at increased risk of cracking/ failure. Sealants and finishes are also potentially affected<br>- soil drying and movement (could affect foundations, especially clay soils)<br>- increased thermal discomfort and heat stress for occupants<br>- reduced winter heating loads and costs<br>- reduced water heating loads and associated costs. |
| More intense cyclones and storms | - structural loading by pressure forces, leading to structural failure (e.g. removal of individual tiles or iron sheeting through to uplifting of entire roof or walls)<br>- general structural failure of building components leading to potential for total building collapse and destruction<br>- impact damage from flying debris<br>- rain/moisture penetration leading to internal damage (see Flooding). |
| Decreased humidity | - reduced mould-related problems<br>- reduced condensation problems<br>- reduced lag-time of corrosion commencement of reinforced concrete in commercial buildings<br>- higher Forest Fire Danger Index (resulting from an extended fire season). |
| Increased radiation | - Plastics, wood and surface coatings subject to greater |

| | |
|---|---|
| | degradation<br>- increased requirements for solar glare control<br>- benefits for solar hot water and electricity. |
| Decreased radiation | - plastics, wood and surface coatings less subject to degradation<br>- reduced solar glare control required<br>- less energy for solar hot water and electricity. |
| Sea-level rise, coastal and inland flooding | - water damage to building contents (interior linings, furnishings, appliances, equipment and plant)<br>- possible contamination of interior of building from sewage, soil and mud<br>- undermining and/or destruction of foundations, potentially leading to structural collapse<br>- salt spray (coastal) affecting most material's durability<br>- coastal erosion (in some areas likely to be severe) resulting in loss or damage to property. |
| Increased hail events | - potentially increased likelihood of damage (mostly roofs, guttering, windows) and subsequently more rain/moisture penetration. |
| Decreased hail events | - potentially reduced likelihood of damage (mostly roofs, guttering, windows) and subsequently less rain/moisture penetration. |
| Increased bushfires | - total or partial fire damage to building property and contents<br>- smoke and water damage to building property and contents<br>- health and safety of occupants at risk<br>- more resources for emergency services and early warning systems<br>- increased clearing of vegetation around houses, leading to decreased shading by the natural environment and green space. |

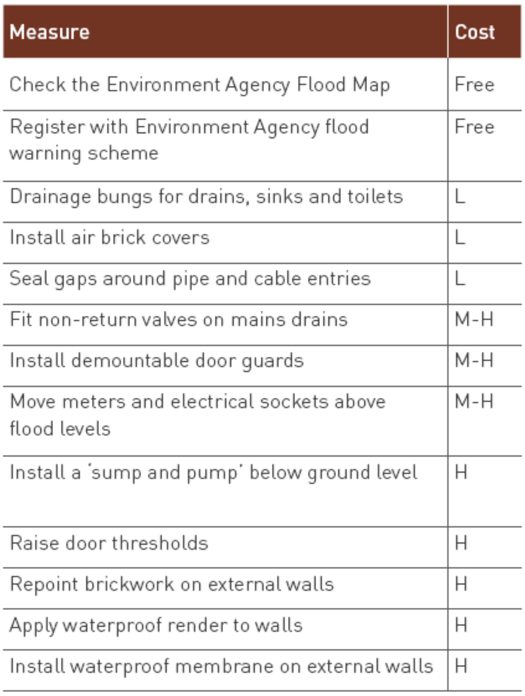
Figure 16: Summarised from Amitrano et al. (2007)

## APPENDIX C. Resilience Rating Tool

Figure 17: Illustration of what the final web-based Resilience Rating Tool from the Insurance Council of Australia might look like (Edge Environment 2012).

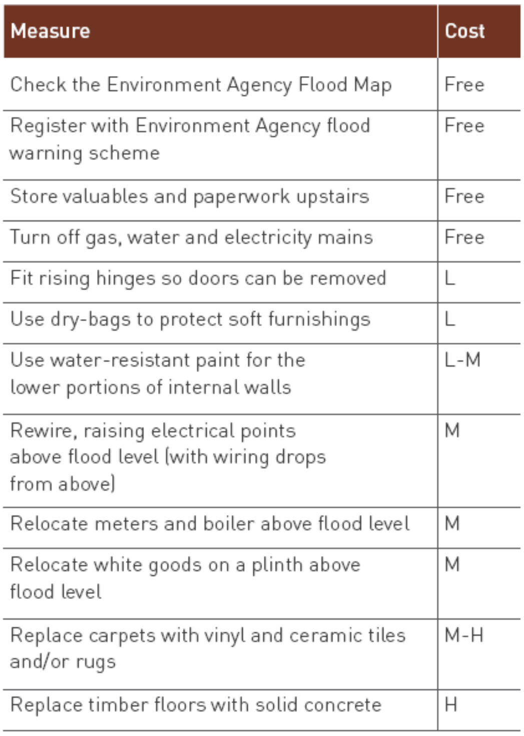
# APPENDIX D. Measures for Adaptation to Flooding

## Resistance Measures:



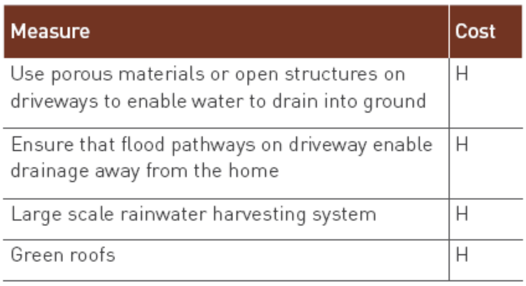
| Measure | Cost |
|---|---|
| Check the Environment Agency Flood Map | Free |
| Register with Environment Agency flood warning scheme | Free |
| Drainage bungs for drains, sinks and toilets | L |
| Install air brick covers | L |
| Seal gaps around pipe and cable entries | L |
| Fit non-return valves on mains drains | M-H |
| Install demountable door guards | M-H |
| Move meters and electrical sockets above flood levels | M-H |
| Install a 'sump and pump' below ground level | H |
| Raise door thresholds | H |
| Repoint brickwork on external walls | H |
| Apply waterproof render to walls | H |
| Install waterproof membrane on external walls | H |

## Resilience Measures:



| Measure | Cost |
|---|---|
| Check the Environment Agency Flood Map | Free |
| Register with Environment Agency flood warning scheme | Free |
| Store valuables and paperwork upstairs | Free |
| Turn off gas, water and electricity mains | Free |
| Fit rising hinges so doors can be removed | L |
| Use dry-bags to protect soft furnishings | L |
| Use water-resistant paint for the lower portions of internal walls | L-M |
| Rewire, raising electrical points above flood level (with wiring drops from above) | M |
| Relocate meters and boiler above flood level | M |
| Relocate white goods on a plinth above flood level | M |
| Replace carpets with vinyl and ceramic tiles and/or rugs | M-H |
| Replace timber floors with solid concrete | H |

## External Measures:

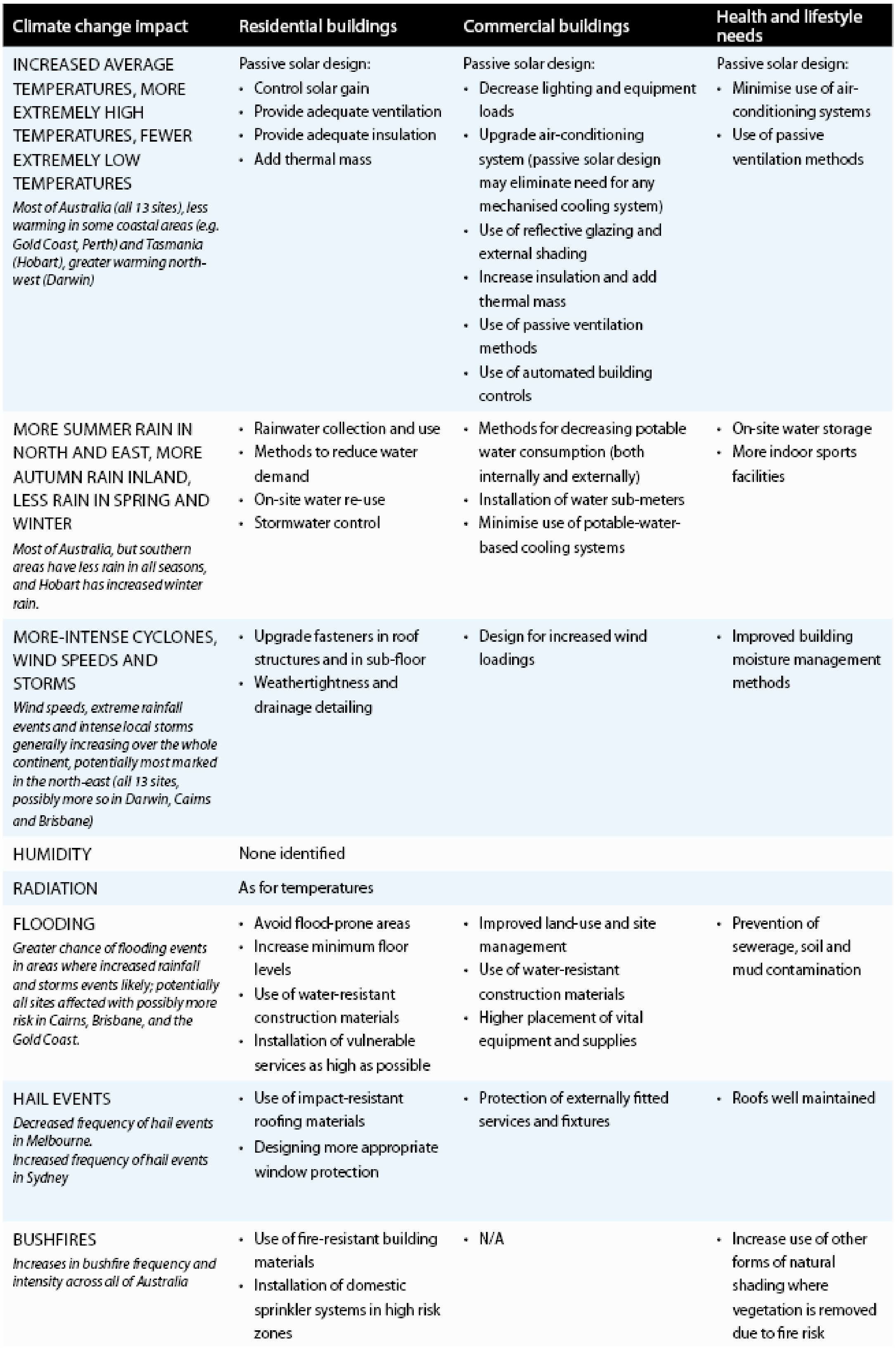


| Measure | Cost |
|---|---|
| Use porous materials or open structures on driveways to enable water to drain into ground | H |
| Ensure that flood pathways on driveway enable drainage away from the home | H |
| Large scale rainwater harvesting system | H |
| Green roofs | H |

**Cost bands:**
**Free** **L -** Low (£1-£100)
**M -** Medium (£101 - £1000)
**H -** High (£1001+)

Figure 18: Compiled from Three Regions Climate Change Group (2008)

# APPENDIX E. Summary of Adaptation Options



| Climate change impact | Residential buildings | Commercial buildings | Health and lifestyle needs |
|---|---|---|---|
| INCREASED AVERAGE TEMPERATURES, MORE EXTREMELY HIGH TEMPERATURES, FEWER EXTREMELY LOW TEMPERATURES<br>*Most of Australia (all 13 sites), less warming in some coastal areas (e.g. Gold Coast, Perth) and Tasmania (Hobart), greater warming north-west (Darwin)* | Passive solar design:<br>• Control solar gain<br>• Provide adequate ventilation<br>• Provide adequate insulation<br>• Add thermal mass | Passive solar design:<br>• Decrease lighting and equipment loads<br>• Upgrade air-conditioning system (passive solar design may eliminate need for any mechanised cooling system)<br>• Use of reflective glazing and external shading<br>• Increase insulation and add thermal mass<br>• Use of passive ventilation methods<br>• Use of automated building controls | Passive solar design:<br>• Minimise use of air-conditioning systems<br>• Use of passive ventilation methods |
| MORE SUMMER RAIN IN NORTH AND EAST, MORE AUTUMN RAIN INLAND, LESS RAIN IN SPRING AND WINTER<br>*Most of Australia, but southern areas have less rain in all seasons, and Hobart has increased winter rain.* | • Rainwater collection and use<br>• Methods to reduce water demand<br>• On-site water re-use<br>• Stormwater control | • Methods for decreasing potable water consumption (both internally and externally)<br>• Installation of water sub-meters<br>• Minimise use of potable-water-based cooling systems | • On-site water storage<br>• More indoor sports facilities |
| MORE-INTENSE CYCLONES, WIND SPEEDS AND STORMS<br>*Wind speeds, extreme rainfall events and intense local storms generally increasing over the whole continent, potentially most marked in the north-east (all 13 sites, possibly more so in Darwin, Cairns and Brisbane)* | • Upgrade fasteners in roof structures and in sub-floor<br>• Weathertightness and drainage detailing | • Design for increased wind loadings | • Improved building moisture management methods |
| HUMIDITY | None identified | | |
| RADIATION | As for temperatures | | |
| FLOODING<br>*Greater chance of flooding events in areas where increased rainfall and storms events likely; potentially all sites affected with possibly more risk in Cairns, Brisbane, and the Gold Coast.* | • Avoid flood-prone areas<br>• Increase minimum floor levels<br>• Use of water-resistant construction materials<br>• Installation of vulnerable services as high as possible | • Improved land-use and site management<br>• Use of water-resistant construction materials<br>• Higher placement of vital equipment and supplies | • Prevention of sewerage, soil and mud contamination |
| HAIL EVENTS<br>*Decreased frequency of hail events in Melbourne.*<br>*Increased frequency of hail events in Sydney* | • Use of impact-resistant roofing materials<br>• Designing more appropriate window protection | • Protection of externally fitted services and fixtures | • Roofs well maintained |
| BUSHFIRES<br>*Increases in bushfire frequency and intensity across all of Australia* | • Use of fire-resistant building materials<br>• Installation of domestic sprinkler systems in high risk zones | • N/A | • Increase use of other forms of natural shading where vegetation is removed due to fire risk |

Figure 19: Source: Amitrano et al. (2007)