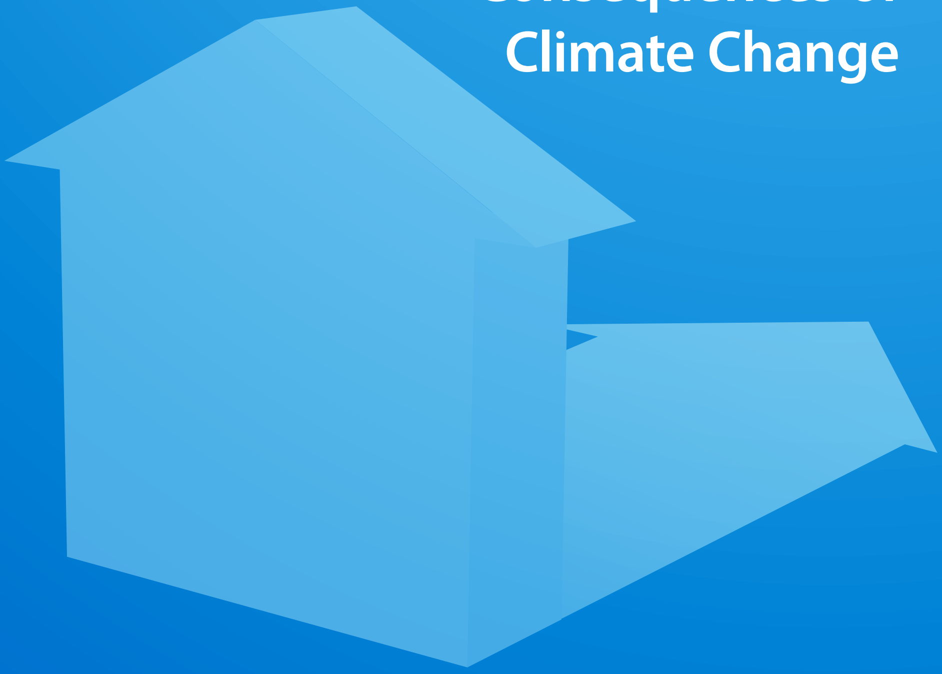
Australian Government
Department of the Environment and Water Resources
Australian Greenhouse Office

# An Assessment of the Need to Adapt Buildings for the Unavoidable Consequences of Climate Change



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# An Assessment of the Need to Adapt Buildings for the Unavoidable Consequences of Climate Change

**Final Report**

**August 2007**
**Report to the Australian Greenhouse Office,**
**Department of the Environment and Water Resources**
**by BRANZ Limited**

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**Final Report to the Australian Greenhouse Office, Department of the Environment and Water Resources**
**by BRANZ Limited**

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**Reviewer**: Rachel Hargreaves

## Please note:

**This report is published in two parts to enable easy access on the internet.**

**Part 1 is the actual report, while Part 2 contains the appendices to the report. Both parts should be read in conjunction with the other.**

**The report is designed to be printed double-sided in colour.**

**This document is Part 1 – The report.**

# EXECUTIVE SUMMARY

Climate change is likely to affect buildings in a range of ways that have potential implications for both the existing building stock and the design of new buildings. This study is a first step in examining the capacity of Australia's building stock and building practices to maintain current levels of amenity in the face of a changing climate and the scope to consider changes in building practices to adapt to climate change.

### *Climate change*

There is now overwhelming evidence that anthropogenic emission of carbon dioxide and other greenhouse gasses is changing the world's climate. Average global surface temperatures have increased by 0.6°C since 1900 and average surface temperatures in Australia have increased by about 0.7°C over the same period.

The complexity of the climate system and uncertainty about future greenhouse gas emissions make prediction of the future climate impossible. However, projections of future climate change can be made using climate models based on the physics of the climate system together with scenarios of future greenhouse gas emissions. These are indications of the changes we might expect under different scenarios rather than predictions of what will happen.

Climate projections for Australia point to higher temperatures, rising sea levels and an increase in the frequency or intensity of a number of extreme events. Projections of rainfall are less certain, and trends are expected to be different in different parts of Australia. However, expected increases in evaporation suggest that soils will dry and stream-flow may be reduced even in places where rainfall increases modestly.

This study was based on climate projections for 2030 and 2070 for thirteen locations chosen to span seven of the eight climate zones used by the Australian Building Codes Board. The locations were Darwin and Cairns (zone 1), Brisbane and the Gold Coast (zone 2), Alice Springs (zone 3), Mildura (zone 4), Adelaide, Sydney and Perth (zone 5), Melbourne (zone 6), Hobart and Canberra (zone 7).

The climate projections used in this study are summarised in Table 1.

Table 1: Summary of Climate Change Factors.

| FACTOR | PARAMETER | CHANGE | | REGIONAL IMPACT |
|---|---|---|---|---|
| | | 2030 | 2070 | |
| **Temperature** | Annual average | +0.4 to + 2.0°C | +1.0 to +6.0°C | Temperature increases in most areas |
| | Extreme daily events (above 35°C) | +10 to +100% | +20 to +600% | More hot events in most locations |
| | Extreme daily events (below 0°C) | -20 to -80% | -50 to -100% | Fewer cold events in most locations |
| **Rainfall** | Summer / Autumn | -10 to +10% | -35 to +35% | More summer rain in the north and east, more autumn rain inland, summer and autumn rain in the south |
| | Winter / Spring | -10 to +5% | -35 to +10% | Less rainfall in most locations, but increased winter rain in Tasmania |
| **Cyclones** | Peak winds | +2 to +5% | +5 to +10% | Generally higher in most locations |
| **Daily rainfall** | Peak rainfall | +10 to +15% | +20 to +30% | |
| | Intensity (1 in 20 yr event) | up to +10% (SA) | +5 to +50% (NSW) (2050)<br>+5 to +70% (Vic) (2050)<br>up to +30% (Qld) (2040) | Increased daily rainfall intensity at most locations |
| | Extreme winds (over 95th percentile) | | | Generally more in most areas, all seasons |
| **Relative Humidity** | Annual and seasonal average | -3 to 0% | -9 to 0% | Generally decreased most areas |
| **Radiation** | Annual average | -5 to 0% | -15 to 0% | Generally decreased (summer/autumn), |
| | | 0 to +5% | 0 to +15% | generally increased (winter/ spring) |
| **Flooding** | Sea-level rise | 3-17 cm | 7-52 cm | Whole coastline |
| | Storm tide height (1 in 100 yr event) | | +0.4 to 0.7 m (Cairns) (2050) | Increases in flooding and landslides in some areas |
| **Hail** | Frequency | | | Possible decreases in SE Australia. Possible increases over Sydney |
| **Fire** | Fire Danger Index | | +5 to +20% (ACT) | Generally increase most areas (linked with increases in very hot days and decreased humidity) |

### *Possible effects on buildings*

Many buildings erected today will still be in use in 40 – 60 years. It is therefore important to consider the likely effect of climate changes expected over this period on the structure and functionality of buildings being constructed now.

The main impacts of climate change with implications for Australian buildings are:

- increased energy consumption due to higher temperatures
- health effects of over-heating
- increased risk of damage from more intense tropical cyclones and storms and stronger winds, and from increased cracking of drier soils and from increased ground movement impacting on foundations and pipe work
- increased damage from flooding
- increased bushfire risk

Energy modelling conducted as part of this study shows an increased cooling load for all locations, offset by decreased heating loads for locations in cooler climate zones (see Figure 1). The results are similar for office buildings, except that offsets due to reduced heating loads in cooler climates are less significant due to the high internal loads from equipment and lighting (see Figure 2).

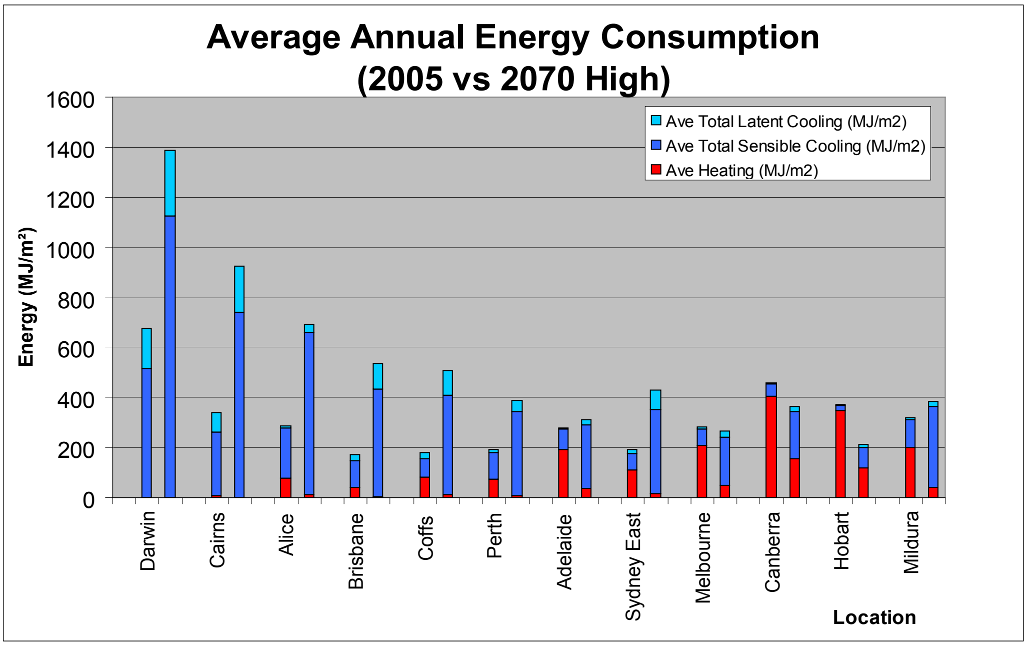


Figure 1: Simulated Average Energy Consumption of Seven base house types (including one apartment).

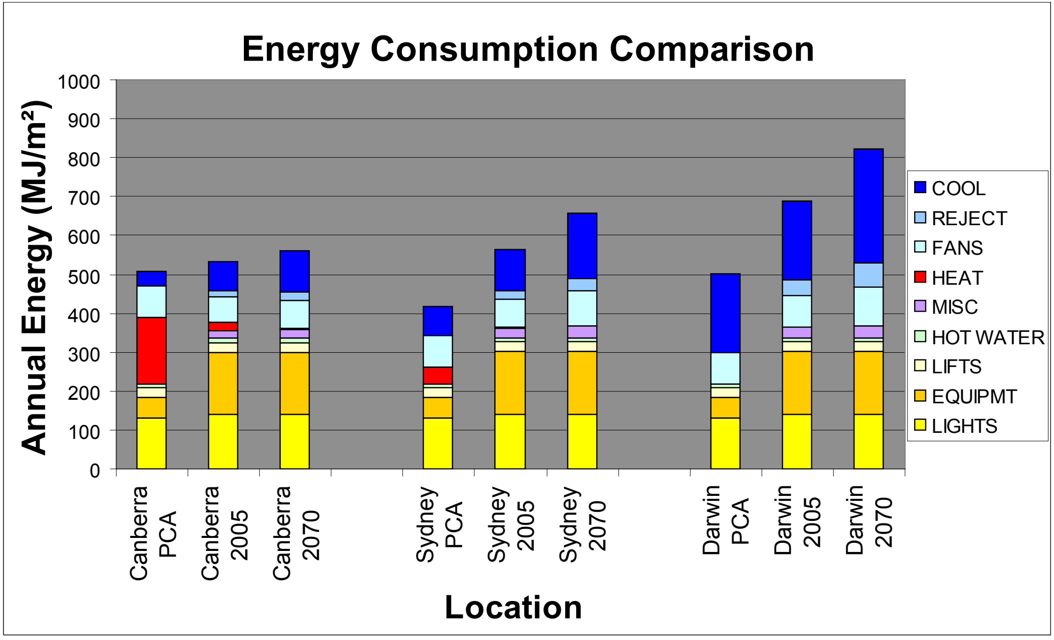


Figure 2: Simulated Energy End use Consumption of 10-Storey Offices in Key Locations.

For comparison purposes, the simulated energy performance results have been graphed against the respective energy performance targets published by the Property Council of Australia (PCA), (Energy Guidelines 2001).

More frequent hot spells could have significant health implications because elevated temperatures over extended periods stress the cardiovascular system, especially when temperatures remain relatively high overnight. The temperatures people experience during hot spells will be influenced by the buildings they inhabit.

Temperature also affects the capacity to work. Fatigue increases at higher temperatures, workers find it harder to concentrate and accidents are more likely to happen. The threshold at which capacity to work begins to decrease depends on acclimation and type of work. There are possible implications for workers in buildings without air conditioning.

Climate change may increase the risk of structural damage to buildings, especially damage resulting from strong winds associated with more intense tropical cyclones and storms. Residential buildings are considered more vulnerable to such damage than commercial buildings. A lesser risk to the structure of buildings arises from possible increased cracking as soils become drier.

The risk of bushfires is expected to increase as the climate changes and this will increase the risk to property. It should be noted, however, that the likelihood of severe bushfire returning to a particular location is very low because of the time needed for fuel loads to rebuild.

Flooding is expected to become more frequent as the climate changes and the risk to buildings in some areas will increase.

### *Resilience of Australia's building stock*

This study draws three broad conclusions about the resilience of Australia's new building stock to the likely impacts of climate change:

- New buildings are reasonably resilient to expected changes in average climate conditions but may not be as resilient to changes in extreme events such as storms and flooding.
- Some recent changes to buildings codes and practices, while not designed to address the impacts of climate change, have increased the resilience of new buildings. For example, higher energy efficiency standards mean that buildings are better able to cope with more frequent hot spells.
- There is considerable scope to improve the resilience of new buildings although further research may be required before specific measures can be formulated. Options are discussed below under 'possible adaptation measures'.

The resilience of Australia's older building stock to the likely impacts of climate change is more difficult to assess, partly due to lack of information about the stock of buildings. Good maintenance and, where appropriate, upgrading is the key to resilience for older buildings. Deciding whether to upgrade older buildings to increase resilience to the impacts of climate change will depend on a combination of considerations including the expected life of the building, significance of the building, cost and the risk. There would be merit in developing some guidance on whether older buildings should be modified.

Buildings that include sustainable measures (e.g. strong passive solar design principles, efficient water usage systems such as grey water systems) will be more resilient to the impacts of climate change.

### *Possible adaptation measures*

Possible adaptation measures identified in this study are summarised in Table 2.

In some instances there may be a case for reviewing building codes and standards. For example, design criteria for cyclones, storms and high winds are based on current climate conditions and there may be merit in updating it to take into account possible future increases in high wind events.

In other cases existing standards may be adequate but there may be a need to apply them differently. For example, buildings built to Level 3 of the standard AS3959-1999 should cope with bushfire risk but changes in risk may change the areas in which this standard needs to apply. There may also be a need to retrofit homes built before 1996, when the standard was introduced into the building code.

A related issue is the link between building standards and planning systems. In some cases the vulnerability of buildings to climate change impacts will depend on a combination of building standards and planning decisions. For example, building code requirements for flooding are generally ad hoc, with most residential buildings designed to cope with flooding based on previous flooding events or have no requirements at all. However, this may not be important if planning decisions ensure that buildings are not sited on flood plains, areas at risk to erosion, or are protected by suitable engineering structures.

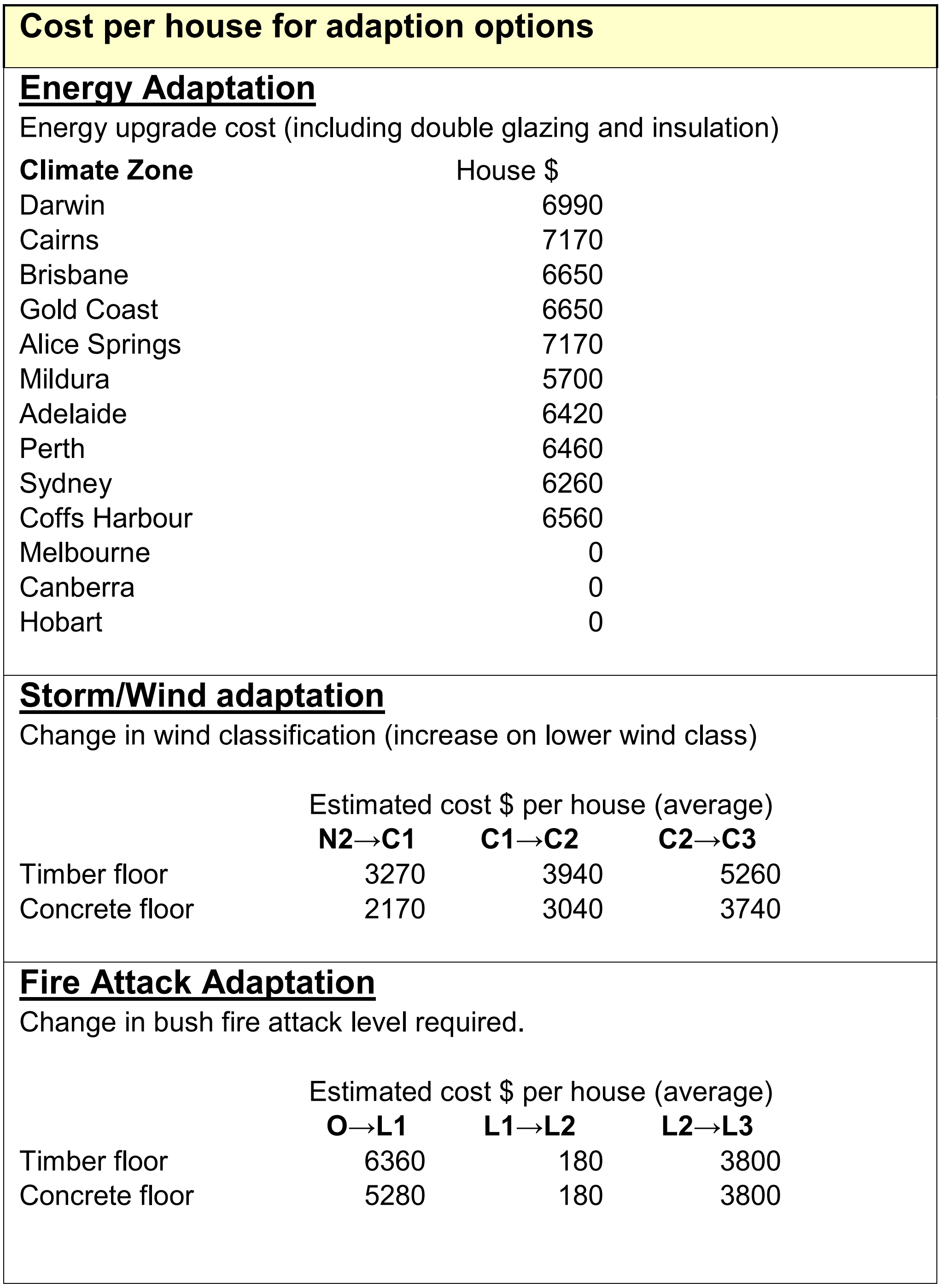
Table 2: Summary of Adaptation Options

| 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 |

### *Costs of adaptation*

The costs of adaptation options will be a critical consideration in any analysis of their viability. At this stage it is not possible to do more than provide a rough estimate of the likely costs of selected adaptation options using some fairly crude assumptions. This study considers the costs of three adaptations for housing for both new and old housing stock, however for the existing housing stock it was difficult to quantify given the baseline of the existing building stock was not defined. A summary of the costs at a house level is provided in Table 3.

Table 3: Summary of Costs per House for Adaptation Options.



**Cost per house for adaption options**

**Energy Adaptation**

Energy upgrade cost (including double glazing and insulation)

| **Climate Zone** | House $ |
|---|---|
| Darwin | 6990 |
| Cairns | 7170 |
| Brisbane | 6650 |
| Gold Coast | 6650 |
| Alice Springs | 7170 |
| Mildura | 5700 |
| Adelaide | 6420 |
| Perth | 6460 |
| Sydney | 6260 |
| Coffs Harbour | 6560 |
| Melbourne | 0 |
| Canberra | 0 |
| Hobart | 0 |

**Storm/Wind adaptation**

Change in wind classification (increase on lower wind class)

| | Estimated cost $ per house (average) | | |
|---|---|---|---|
| | **N2→C1** | **C1→C2** | **C2→C3** |
| Timber floor | 3270 | 3940 | 5260 |
| Concrete floor | 2170 | 3040 | 3740 |

**Fire Attack Adaptation**

Change in bush fire attack level required.

| | Estimated cost $ per house (average) | | |
|---|---|---|---|
| | **O→L1** | **L1→L2** | **L2→L3** |
| Timber floor | 6360 | 180 | 3800 |
| Concrete floor | 5280 | 180 | 3800 |

### *Opportunities*

Climate change may lead to opportunities as well as risks for buildings. For example, projected future climate conditions are likely to lead to improved performance of some renewable energy technologies such as photovoltaic cells and solar hot water systems.

### *Research needs*

**R1:** The climate change scenarios used in this scoping study were based on readily available material.

- More information is needed on potential changes in extreme events such as heavy rainfall, flooding, hail, tropical cyclones, wind gusts, storm surges and bushfire that may affect decisions about regional building standards. For example, do buildings need to be built to higher standards for extreme winds and bushfires.

**R2:** Further investigation is necessary into a framework that allows climate change to be harmoniously incorporated into both land-use planning and building standards, so they work effectively together ensuring no 'gaps' in the building process. This is particularly important for both urban water use and flooding. Developing a framework will allow localised areas e.g. councils to concentrate of the specific issues in their area but use the framework guidelines to ensure consistency with other councils.

**R3:** Future proofing and protecting Australian buildings against climate change may require incorporation of adaptation options into the building code. The inclusion of sustainability as a goal in the BCA provides an opportunity for doing this (by incorporating separate, new clauses – or worked in as part of existing clauses).

**R4:** Encourage and support initiatives that are aimed at mainstreaming sustainable design and construction e.g. use of the Your Home manual, HIA's Greensmart programme, etc. This will by default improve the resilience of new buildings to the impacts of climate change.

**R5:** Encourage and support research into novel systems and technologies for the adaptation of residential and commercial buildings to climate change.

**R6:** There is also a need to research prospective home-owner aspirations and needs in terms of home design versus the expectations and strategies of home designers and builders, and the extent to which either/both are in alignment or conflict with home design which is appropriate to deal with the challenges of climate change.

**R7:** Develop a risk and condition-assessment methodology to determine benchmark levels for retrofitting and/or accelerating retirement of Australian residential and commercial building stock.

**R8:** It is recommended that a methodology for assessing the costs and benefits of taking retrofit action (based on the assessment of risk / determination of the benchmark level) be developed.

## LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| **ABCB** | Australian Building Codes Board |
| **AGO** | Australian Greenhouse Office (in Dept of the Environment and Heritage) |
| **AS** | Australian Standard |
| **BCA** | Building Code of Australia |
| **BIPV** | Building Integrated Photovoltaics |
| **CAPE** | Convective Available Potential Energy |
| **CBD** | Central Business District |
| **CCSI** | Climate Change Sustainability Index |
| **CO2** | Carbon Dioxide |
| **ESD** | Environmentally Sustainable Development |
| **HVAC** | Heating, Ventilation, Air-Conditioning |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **NCEPH** | National Centre for Epidemiology and Population Health |
| **NZS** | New Zealand Standard |
| **NSW** | New South Wales |
| **NT** | Northern Territory |
| **ppm** | Parts per million |
| **Qld** | Queensland |
| **SA** | South Australia |
| **SRES** | Special Report on Emissions Scenarios |
| **TAS** | Tasmania |
| **VIC** | Victoria |
| **WA** | Western Australia |

## GLOSSARY OF TERMS

| | |
|---|---|
| Adaptation | Adjustments in natural or human (built) systems that take into account altering climate conditions, to lessen potential damages, or to benefit from opportunities associated with climate change (McCarthy *et al*, 2001). |
| Blackwater | Blackwater is wastewater containing human excreta. (Your Home, 2004). |
| Climate change | Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. (IPCC, 2001). |
| El Niño -Southern Oscillation (ENSO) | El Niño, in its original sense, is a warm water current which periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. This oceanic event is associated with a fluctuation of the intertropical surface pressure pattern and circulation in the Indian and Pacific oceans, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon is collectively known as El Niño-Southern Oscillation, or ENSO. During an El Niño event, the prevailing trade winds weaken and the equatorial countercurrent strengthens, causing warm surface waters in the Indonesian area to flow eastward to overlie the cold waters of the Peru current. This event has great impact on the wind, sea surface temperature and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world. The opposite of an El Niño event is called La Niña. (IPCC, 2001). |
| Forest Fire Danger Index | The Forest Fire Danger Index (FDI) is used to predict the likelihood of ignition and difficulty of suppression of bushfires (Luke and McArthur, 1978). |
| Greenhouse gases | Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapour ($H_2O$), carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), methane ($CH_4$) and ozone ($O_3$) are the primary greenhouse gases in the Earth's atmosphere. Beside $CO_2$, $N_2O$ and $CH_4$, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride ($SF_6$), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). (IPCC, 2001). |
| Greywater | Greywater is wastewater which does not contain human excreta. (Your Home, 2004). |
| Heat wave | A heat wave is a prolonged period of excessively hot weather, which may be accompanied by excessive humidity. The term is relative to the usual weather in the area, so temperatures that people from a hotter climate find normal can be a heat wave if they are outside the normal pattern for a cooler area. The term is applied both to "ordinary" weather variations and to extraordinary spells of heat which may only occur once a century. (Ref: en.wikipedia.org/wiki/Heat_wave) |

| | |
|---|---|
| Humidity | Humidity is the quantity of moisture in the air. It can be expressed as absolute humidity, which is the mass of water in a specific mass of air, or more commonly as relative humidity, which is the ratio of absolute humidity divided by that absolute humidity that would make dew form at the same temperature. (Ref: en.wikipedia.org/wiki/Humidity) |
| Mitigation | A human intervention to reduce the sources or enhance the sinks of greenhouse gases. (IPCC, 2001). |
| Passive solar design | Passive solar design is design that does not require mechanical heating or cooling. Homes that are passively designed take advantage of natural energy flows to maintain thermal comfort. (*Your Home*, 2004). |
| Retrofit | Any change made to an existing structure to reduce or eliminate damage to that structure from flooding, erosion, high winds, earthquakes, or other hazards. (Ref: www.csc.noaa.gov/rvat/glossary.html) |
| Solar radiation | Solar radiation is the essential source of energy for the world's climate system and thus determines weather and climate. Total solar radiation values are highest in clear, sunny conditions and lowest during cloudy days. When heavy clouds block the sun or the sun is below the horizon, direct solar radiation is zero. (Ref: rps.uvi.edu/WRRI/glossary.html) |
| Stormwater | Stormwater is the term given to pure rainwater, plus anything the flowing rainwater carries along with it. (Your Home, 2004). |
| Thermal comfort | The relationship between a person's thermal sensation and the stimulus in the form of the thermal environment in conditions of moderate heat stress (generally taken to include thermal discomfort)<br>(Ref: www.learn.londonmet.ac.uk/packages/clear/glossary/glosstoz.html) |
| Thermal mass | Thermal mass is the ability of a material to absorb heat energy. A lot of heat energy is required to change the temperature of high density materials like concrete, bricks and tiles. They are therefore said to have high thermal mass. Lightweight materials such as timber have low thermal mass. (Your Home, 2004). |
| Tropical cyclone | A tropical cyclone (also referred to as a tropical depression, tropical storm, typhoon, or hurricane depending on strength and geographical context) is a type of low pressure system which generally forms in the tropics. While they can be highly destructive, tropical cyclones are an important part of the atmospheric circulation system, which moves heat from the equatorial region toward the higher latitudes. (Ref: http://en.wikipedia.org/wiki/Tropical_cyclone) |
| Urban heat island | The term urban heat island refers to the tendency for urban areas to have warmer air temperatures than the surrounding rural landscape, due to the low albedo of streets, sidewalks, parking lots, and buildings. These surfaces absorb solar radiation during the day and release it at night, resulting in higher night temperatures. (Ref: www.pewclimate.org/global-warming-basics/full_glossary/terms_s.cfm) |

IPCC, 2001. *Climate Change 2001. The Scientific Basis*. Cambridge University Press, Cambridge, UK.

Luke and McArthur, 1978.

McCarthy J.J., Canziani O.F., Leary N.A., Dokken D.J. and White K.S. (Eds) 2001, *'Climate change 2001: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change',* Cambridge University Press, Cambridge, UK

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**Appendices to this report are in a separate document**

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# 1. INTRODUCTION

## 1.1 Client

The client for this study is the:

Department of the Environment and Water Resources
Commonwealth of Australia
John Gorton Building
Administration Place
PARKES ACT 2600

## 1.2 Background

There is overwhelming scientific evidence that anthropogenic greenhouse emissions are changing the climate. Global average surface temperatures have rise by 0.6°C in the last century and climate models suggest that they will rise, due to inertia in the climate system, by about the same amount even if anthropogenic greenhouse gas emissions stop immediately.

This means that despite mitigation efforts, adaptation to a changing climate will be a vital component in future climate policy. The sooner adaptation planning begins the better prepared the population – including vulnerable industries and communities– will be for the impacts of climate change. Buildings and the built environment are a key component. Buildings, whether residential, commercial or public, new or existing, play a fundamental social, cultural and economic role in our lives. We need to know which buildings are likely to be most affected and where, and what action should be taken in the short, medium and long term.

## 1.3 Purpose

This study is designed to inform governments, business, industry and the community of the vulnerability of residential and commercial buildings to the impacts of climate change and to identify options to adapt existing and new residential and commercial building practices for climate change.

Buildings, because of their long life, will be affected by climate change. For existing buildings, we need to know what adaptation will be warranted for safety, health and functional reasons. For new buildings, we need to know how to adapt design and construction Codes and standards, and buildings and material technology to equip new buildings for lifetimes of 50-years or more in the era of climate change.

## 1.4 Scope

This study provides scoping-level information on the following issues.

### *Climate change aspects*

Investigate and quantify the vulnerability of Australian residential and commercial buildings to the impacts of climate change (including changes in tropical cyclones, wind speed and intense storms, rain, hail, temperatures, humidity, solar radiation, flooding and bushfires)

### *Social aspects*

Investigate the effects climate change may have on the social, lifestyle and health needs of Australians at home, in the workplace and in the community and the requirements (if any) for adaptation of buildings to meet these needs

### *Technical aspects*

Identify options for reducing the vulnerability of Australian residential and commercial buildings. This includes changes to:

- building design philosophy
- building standards for design and construction e.g. increased structural loadings, stronger fabric materials
- building operations
- building materials
- infrastructure supporting the built environment e.g. stormwater management.

For existing buildings, consider possible benchmark levels for taking retrofit actions to accommodate the effects of climate change e.g:

- enhanced building structure or fabric
- the need to upgrade building services
- relocating buildings due to flooding.

Identify the opportunities that may come from climate change e.g. solar radiation technologies, rainwater collection etc.

### *Financial aspects*

Assess the financial costs of the various options identified for reducing the vulnerability of Australian residential and commercial buildings

The project covers:

- residential, commercial and public buildings
- new and existing buildings
- the whole of Australia
- the medium (2030) and long term (2070).

The climate change information (provided by CSIRO) identified scenarios for:

- average temperature and rainfall
- extreme daily temperatures and rainfall
- tropical cyclones and intense local storms
- relative humidity
- solar radiation
- coastal and inland flooding
- hail
- fire
- sea-level rise.

## 1.5 Methodology

### *Issue One: "Investigate and quantify the vulnerability of Australian residential and commercial buildings to the impacts of climate change"*

Based on the climate change scenarios provided by CSIRO (listed above), the project team firstly identified a number of probable generic impacts on buildings and the built environment as a result of each climate change aspect. After this was determined, information on Australia's building stock was gathered from 13 selected sites (selected by major urban area, population, climate variation and data availability). The Gold Coast was selected as a specific example because of the challenges they face with high density and growth in a low lying coastal area. These sites were grouped using the Australian Building Code Board's Energy Efficiency climate zone categorisation).

From this information, the project team was able to draw some preliminary conclusions about the resilience of Australia's building stock to the likely impacts of climate change. Past and present building regulations were also discussed.

### *Issue Two: "Investigate the effects climate change may have on the social and lifestyle needs (including health) of Australians at home, in the workplace and in the community and the requirements (if any) for adaptation of buildings to meet these needs"*

The information for this section of the project was gathered first by a desktop study of a wide body of existing literature concentrating on the health and social related aspects of climate change and the built environment. This was followed up with interviews of experts involved in the climate change debate (in particular those with social and lifestyle expertise).

This approach enabled the project team to provide a good overall assessment of the likely effects that climate change may have on the social and lifestyle needs of Australians at home, in the workplace and in the community and the requirements. Based on this information, adaptation requirements of buildings were identified where appropriate (included as part of Issue 3).

### *Issue Three: "Identify options for reducing the vulnerability of Australian commercial and domestic buildings"*

Using the results from Issues 1 and 2, a number of options for adapting buildings were established for each climate change scenario. Options included recommendations related to materials used, infrastructure variations, typical building practice, typical landscaping practice, etc. The options were categorised and summarised as follows:

- new and existing residential buildings
- new and existing commercial buildings
- social and lifestyle needs

Where applicable, potential changes in building regulations and other non-regulatory approaches were also identified.

### *Issue Four: "For existing buildings, consider possible benchmark levels for taking retrofit actions to accommodate the effects of climate change (including risks and costs of such actions)"*

The project team used existing literature to identify the possible benchmark levels for retrofitting existing buildings. A framework (index) for assessing retrofit capacity was included, and a number of case studies were used to illustrate what adaptation actions have been undertaken in Australia. This work is relevant to the aims of the National Climate Change Adaptation Programme (NCCAP).

### *Issue Five: "Identify the opportunities that may come from climate change e.g. solar radiation (PV electricity generation or hot water), rainwater collection"*

The project team investigated the potential opportunities that could emerge as a result of adapting buildings to the various climate change scenarios. This included ideas such as:

- increases in temperature and changes in radiation impacting on passive and active solar thermal conditions and building integrated photovoltaics (BIPV)
- increases in wind and implications for building cooling, natural ventilation and energy generation
- increases in comfort indices and reduced mechanical heating in temperate zones of Australia during winter months
- capacity of building and landscaping surfaces to capture heavy rainfall occurrences through design adaptability
- advantages associated with raising the standard of building operation through new and retrofit design strategies such as shading and natural ventilation to improve adaptability to extreme weather conditions.

***Issue Six: "Assess the financial costs of the various options identified for reducing the vulnerability of Australian residential and commercial buildings"***

This section of the study used the options identified for reducing the vulnerability of Australian buildings and the suggested benchmark levels for retrofit action, and determined the costs of adapting Australia's building stock to key climate change impacts. The economic analysis was carried out using current total stock information and costs data from publicly available sources e.g. Rawlinson's *Australian Construction Handbook* (Edition 22).

## 1.6 Consultation process

This study was conducted in consultation with the key stakeholders to ensure a holistic overview. This was initiated with a road show at the draft stage of the report where the main preliminary findings were presented in each state. This provided an opportunity for the stakeholders to engage in the study and provide essential information or feedback. There was also an opportunity to comment on the draft report by any of the stakeholders that attended the presentations or were part of the formal review process. A schedule of the consultations held nationally is at Appendix D.

## ISSUE ONE
## "Investigate and quantify the vulnerability of Australian residential and commercial buildings to the impacts of climate change"

# 2. THE EFFECTS OF CLIMATE CHANGE ON BUILDINGS IN AUSTRALIA

Climate change is a reality. While international and national efforts to reduce emissions in greenhouse gases will limit the changes, adaptation strategies based on assessment of potential changes in regional climate and their impacts on buildings are also necessary.

The following provides Australian climate change scenarios for use in an assessment of impacts on residential and commercial buildings, for the years 2030 and 2070.

## 2.1 Observed climate change

The Earth has warmed by about 0.6°C on average since 1900 (IPCC 2001). There has been an increase in heatwaves, fewer frosts, warming of the lower atmosphere and upper ocean, retreat of glaciers and sea-ice, a rise in sea-level of 10-20 cm and increased heavy rainfall in many regions. Many species of plants and animals have changed their location, or the timing of their seasonal responses, in ways that provide further evidence of global warming. Australia's average temperature has risen by about 0.8°C from 1910–2004. Most of this increase occurred after 1950. Minima have generally increased more than maxima. Australian rainfall has varied substantially over time and space. Since 1950, there has been an increase in rainfall in the north-west and a decrease in the south and east.

## 2.2 Future climate change

To estimate future climate change, scientists have developed greenhouse gas and aerosol emission scenarios. These are not predictions of what will actually happen. They allow analysis of "what if?" questions based on various assumptions about human behaviour, economic growth and technological change. This report uses scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). Some IPCC scenarios assume "business as usual" without explicit policies to limit greenhouse gas emissions, although other scenarios include other environmental policies that indirectly affect greenhouse gases. These are described in the Special Report on Emission Scenarios (SRES 2000). Other IPCC scenarios include actions to reduce carbon dioxide ($CO_2$) emissions and stabilise $CO_2$ concentrations at some level above the current value of 375 ppm. These would postpone or avoid some of the more serious damages associated with higher rates of warming.

Computer models of the climate system are the best tools available for simulating climate variability and change. These models include representations of the dynamical behaviour of the atmosphere, oceans, biosphere and polar regions. A detailed description of these models and their reliability can be found in IPCC (2001). Projected changes in selected climate variables over Australia have been derived from up to 13 climate models simulations, driven by the SRES scenarios. Each of these models was found to have an acceptable simulation of Australia's climate under current conditions.

Australian scenarios are presented as ranges rather than a single value. The ranges incorporate quantifiable uncertainties associated with the range of future emission scenarios, the range of global responses of climate models, and model to model differences in the regional patterns of climate change.

The results are summarised in Section 3. Full details can be found in Appendix A.

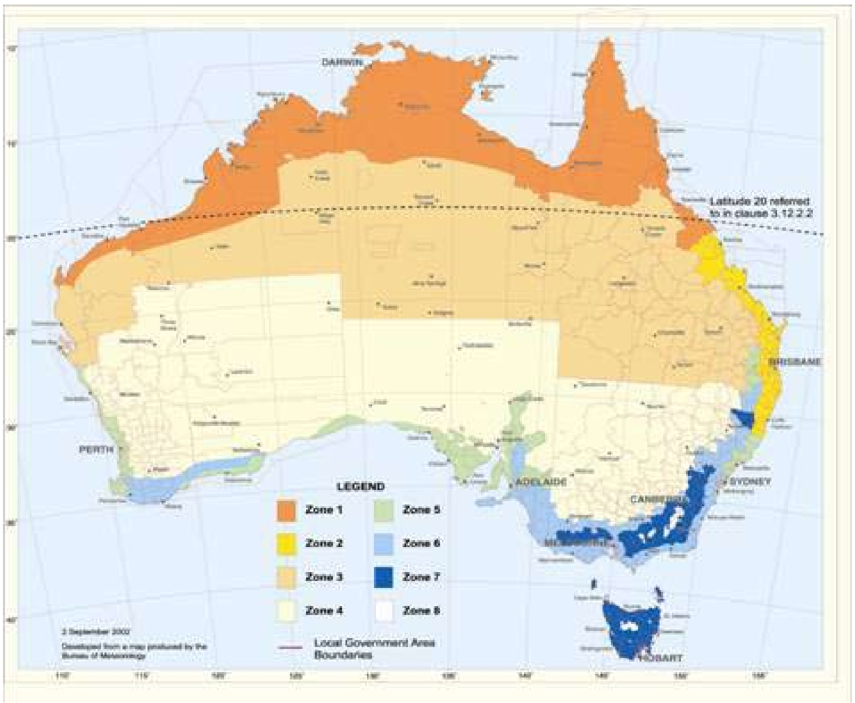


Figure 3: Building Code of Australia, Climate Zone Map

## 2.3 Australia's building stock

In clarifying to what extent the anticipated climate changes may affect Australia's built environment, an understanding of the composition of Australia's building stock is required. Generalised and specific building stock information (for residential and commercial buildings) was determined where possible (see Section 4). The variation of building type and composition is not particularly high (especially for buildings in the past 20-years or so, designs across Australia have become much more generic – as opposed to older building stock which have distinct regional variations e.g. Queenslanders).

The selected sites were grouped using the ABCB Energy Efficiency climate zones:

- Zone 1 (Hot Humid): Darwin, Cairns
- Zone 2 (Warm Humid): Brisbane, Gold Coast
- Zone 3 (Hot Dry, warm winter): Alice Springs
- Zone 4 (Hot Dry, cool winter): Mildura
- Zone 5 (Temperate): Adelaide, Perth, Sydney, Coffs Harbour
- Zone 6 (Hot Dry, cold winter):Melbourne
- Zone 7 (Cool Temperate): Hobart, Canberra

Zone 8 (alpine) was not included in the analysis because of the small site area, small population and the lack of available data in this area.

# 3. CLIMATE CHANGE SCENARIOS AND IMPACTS ON BUILDINGS

In this section the predicted climate change scenarios for Australia are summarised, including the typical impacts that these changes are likely to have on Australian buildings. Future climate is presented as ranges rather than as single values, to represent the range of uncertainty in the climate models and in future levels of greenhouse gas concentrations. Note: full climate change scenario information, including partial baseline data, can be found in Appendix A.

## 3.1 Average rainfall

In summer and autumn, projected rainfall ranges for most locations are –10% to +10% by 2030 and –35% to +35% by 2070, or tend towards increase (–10% to +20% by 2030 and –35% to +60% by 2070). The latter occur mainly in parts of southern inland Australia in summer and inland areas in autumn. In some parts of northern and eastern Australia in summer, and inland Australia in autumn, the tendency for wetter conditions is –5% to +10% by 2030 and –10% to +35% by 2070. However, for the far south-east of the continent and Tasmania, projected rainfall is more likely to decrease in both of these seasons (–10% to +5% by 2030 and –35% to +10% by 2070). In winter and spring, most locations tend towards decreased rainfall (or are seasonally dry). Ranges are typically –10% to +5% by 2030 and –35% to +10% by 2070. Projected decreases are stronger in the south-west (–20% to +5% by 2030 and –60% to +10% by 2070), while Tasmania tends toward increases in winter (–5% to +20% by 2030 and –10% to +60% by 2070).

**Impact of more rain (summer and autumn for northern and eastern Australia, winter and spring for far south-east and Tasmania):**

- localised flooding events, depending on drainage system capacity (including roof damage, drainage pipes, sewer connections, etc) (see Flooding)
- weathering (e.g. corrosion of metals) leading to higher maintenance requirements
- more frequent filling of dams in areas with maximum rain in summer e.g. in the tropics.

**Impact of less rain (winter and spring for northern and eastern Australia, summer and autumn for far south-east and Tasmania):**

- pressures on urban water resources
- soil drying and cracking, potentially affecting foundations and walls (drying out and cracking of mortar).

NB: these impacts are likely even when there is a small increase in rainfall combined with increased evaporation/ temperatures

## 3.2 Average temperature and extreme daily temperatures

By 2030, annual average temperatures are likely to be 0.4 to 2.0°C higher over most of Australia, with slightly less warming in some coastal areas and Tasmania, and there is potential for greater warming in the north-west. By 2070, annual average temperatures are likely to increase by 1.0 to 6.0°C over most of Australia with spatial variation similar to those for 2030. The range of warming is greatest in spring and least in winter. In the north-west, the greatest potential warming occurs in summer.

In Australia, the frequency of extreme hot events (e.g. hot days and nights) has generally increased since the mid-1950s, and the frequency of extreme cold events (e.g. cold days and nights) has generally decreased (Nicholls and Collins, in press). Over the 1957 to 2003 period, the Australian average shows an increasing trend in hot days (35°C or more) of 0.08 days per year, an increasing trend in hot nights (20°C or more) of 0.18 nights per year, a decreasing trend in cold days (15°C or less) of 0.14 days per year and a decreasing trend in cold nights (5°C or less) of 0.16 nights per year.

Further increases in extreme daily temperatures are likely due to global warming. Significant decreases in cold events and increases in hot events are likely to become evident. By the year 2030, the average number of days below zero generally decreases by 20-80%, while the number of days above 35°C increases by 10-100% (larger percentage increases are possible in tropical and sub-tropical places such as Darwin, Cairns, Gold Coast and Brisbane).

Based on the information provided by the projections it is certain that temperatures will increase across all parts of Australia, over the next 70 years. None of the projections ranges show a decrease in temperature for both annual and seasonal temperature changes. There is less confidence in the overall direction of rainfall given all ranges go from a negative percentage change (decrease in rainfall) to a positive percentage change (increase in rainfall). Also for most areas if it is wetter in the winter seasons it tends to be drier in the summer and vice a versa.

**Impacts of average temperature increases and more extreme temperature events:**

- increased cooling loads (and cooling costs)
- building envelope (roofing, cladding, window systems) at increased risk of cracking/ failure. Sealants and finishes are also potentially affected
- soil drying and movement (could affect foundations, especially clay soils)
- increased thermal discomfort and heat stress for occupants
- reduced winter heating loads and costs
- reduced water heating loads and associated costs.

## 3.3 Tropical cyclones and intense local storms

Tropical cyclones generate oceanic storm surges and extreme waves. Severe coastal flooding is common and breaking waves can erode the coastline and damage infrastructure. Nicholls *et al* (1998) and Hennessy (2004) found that the frequency of tropical cyclones in the Australian region has decreased since 1967, along with an increase in cyclone intensity (decreased central pressure). For the whole southern hemisphere, the frequency of tropical cyclones shows no significant trend from the 1979/80 to 1998/99 season (Kuleshov 2003), suggesting that the decline in numbers in the Australian region is associated with a shift in the preferred areas of formation. However, the decline is partly due to an improved discrimination between tropical cyclones and other low pressure systems, leading to a drop in the number of weak cyclones in the mid-1980s. If weak cyclones are excluded from the analysis, the trend is more gradual and mainly follows the downward trend in the Southern Oscillation Index (i.e. fewer cyclones occur near Australia in El Niño years (Kuleshov 2003) and there have been more El Niños since the mid-1970s).

The IPCC (2001) concluded that, by the late 21st century (e.g. 2070), tropical cyclone frequency may change in some regions, peak winds may increase by 5-10% and peak rainfall rates may rise by 20-30%. Using simple linear interpolation, a scenario for 2030 would be a 2-5% increase in peak winds and a 10-15% increase in peak rainfall.

Intense local storms can also cause major damage near the coast, as well as inland. Extreme wind, rain and oceanic storm surges are mainly responsible. Past trends in extreme wind and storm surges are difficult to quantify. Analysis of extreme daily rainfall observations (Haylock and Nicholls 2000) shows a strong decrease in both the intensity of extreme rainfall events and the number of extremely wet days in the far south-west of Australia, and an increase in the proportion of rainfall falling on extremely wet days in the north-east. Hennessy *et al* (1999) found an increase of about 10% in the intensity of Australian heavy rainfall from 1910-1995 in all seasons except winter, with increases exceeding 20% in some States. In south-west Western Australia, where there has been a significant decline in mean rainfall, a 15% decrease in heavy rainfall intensity during winter has been observed.

Under enhanced greenhouse conditions, increases in extreme rainfall are simulated in mid-latitudes where average rainfall increases, or decreases slightly (IPCC 2001). For example, the intensity of the 1-in-20-year daily-rainfall event may increase by up to 10% in parts of South Australia by the year 2030 (McInnes *et al* 2003), by 5 to 50% in some NSW regions by the year 2050 (Hennessy *et al* 1998), 5 to 70% by the year 2050 in Victoria (Whetton *et al* 2002), and up to 30% by the year 2040 in south-east Queensland and northern NSW (Abbs and McInnes, in preparation). Walsh *et al* (2001) found that by the year 2050, the 1-in-20-year daily-rainfall intensity in northern Queensland may increase by 25%. Decreases in extreme rainfall are likely in the Sydney region (Hennessy *et al* 2004).

Projected changes in extreme wind-speed were based on the monthly 95th percentile, i.e. the monthly wind–speed exceeded only 5% of the time. A tendency for stronger winds is evident over most of the continent in summer, especially over Darwin, Alice Springs and Adelaide, but the area near Cape York Peninsula and Cairns shows a tendency for weaker winds. In autumn, there is a tendency for weaker winds in coastal areas (except the south-west) and a tendency for stronger winds in southern inland areas. In winter, most of the northern half of Australia has a tendency for stronger winds, while southern coastal areas have a tendency for weaker winds (except Victoria and Tasmania). In spring, most of Australia has a tendency for stronger winds.

The information provided indicates the intensity of storms and cyclones is likely to increase and an increase in frequency of these extreme events.

**Impact of more intense tropical 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 roofs or walls)
- general structural failure of building components leading to potential for total building collapse and destruction
- impact damage from flying debris
- rain/moisture penetration leading to internal damage (see Flooding).

## 3.4 Relative humidity

Projected changes in annual and seasonal average humidity show a general tendency for a decrease over most of the continent in future. In summer and autumn, most of the continent has decreases of up to 3% by 2030 and up to 9% by 2070, but increases of up to 1.5% by 2030 and 4% by 2070 are possible in parts of NSW, southern Queensland, western Northern Territory and central Western Australia. Largest decreases in humidity occur in winter and spring, reflecting the decreases in rainfall (refer to Section 2.1).

**Impact of decreased humidity:**

- reduced mould-related problems
- reduced condensation problems
- reduced lag-time of corrosion commencement of reinforced concrete in commercial buildings
- higher Forest Fire Danger Index (resulting from an extended fire season).

## 3.5 Solar radiation

Projected changes in annual and seasonal average downward (incoming) solar radiation at the surface have been based on two simulations for which monthly data were available. This is a very limited sample of models, so the results should be treated with caution. Simulated changes in radiation are caused by changes in cloud cover.

Results show that annual average radiation decreases in the western half of Australia, with the possibility of increases or decreases in the east. Decreases in radiation are strongest in summer and cover most of western and southern Australia. In autumn, decreases in radiation affect most of the continent. In winter and spring, increases occur in southern and eastern areas, while decreases affect the north-west.

**Impact of increased radiation:**

- Plastics, wood and surface coatings subject to greater degradation
- increased requirements for solar glare control
- benefits for solar hot water and electricity.

**Impact of decreased radiation:**

- plastics, wood and surface coatings less subject to degradation
- reduced solar glare control required
- less energy for solar hot water and electricity.

## 3.6 Coastal and inland flooding

The projected increases in extreme daily rainfall described earlier would enhance the potential for flooding, landslides and coastal erosion in some areas. In Australia, this issue has been investigated for a limited number of regions.

Schreider *et al* (2000) applied a rainfall-runoff model to three different catchments upstream of Sydney and Canberra under doubled $CO_2$ conditions. They found increases in the magnitude and frequency of flood events, but these effects differed widely between catchments because of the different physical characteristics of each catchment. Abbs *et al* (2001) analysed the sensitivity of flooding to increases in storm intensity, varying the time sequence of rainfall, and varying its spatial pattern in the Albert-Logan Rivers system inland of the Gold Coast. The study also looked at the effects of differing wetness of the catchment prior to the storm. For each 1% increase in rainfall intensity there would be a 1.37% increase in peak runoff. Large variations in peak runoff resulted from changes in time sequences and smaller changes from variations in the direction of approach of the storm. An increase in storm intensity has the potential to increase runoff and flooding significantly, but this could be partially compensated for by any long-term reduction in average rainfall, which would reduce soil wetness prior to such a storm.

CSIRO has developed an integrated modelling system which couples a high-resolution atmospheric model of storm events with a non-linear flood event model suitable for use in urban areas (Abbs *et al* 2000). This has been applied to the historic case of flooding by Cyclone Wanda, and by integrating the modelling system with a GIS, flood levels and damage estimates were made for the Gold Coast region. For a 10-40 cm rise in mean sea-level by the year 2050, there was an increase of between 3 and 18% in the number of dwellings and people affected (Abbs *et al* 2001).

Severe storms can produce temporary increases in sea-surface height. These increases may occur as a result of several different mechanisms such as wind setup, inverse barometer effect, current setup, wave setup and wave run-up (Hennessy *et al* 2004). While wind and pressure are responsible for generating sea-level extremes, other factors such as coastal geometry and the presence and width of the continental shelf play a crucial role in determining the relative contribution by waves and storm surge. Wide shallow continental shelves favour large storm surges, while narrow or non-existent continental shelves favour large waves. This is because waves steepen and break as they encounter shallow coastal waters. The wave breaking leads to loss of energy and loss of wave height.

Conversely, deeper waters lying adjacent to coastlines enable waves to travel closer into shore before finally breaking. Few studies have considered the effect of climate change on storm surges. McInnes *et al* (2000 and 2003) estimated the height of storm tides in Cairns for the present climate and for the year 2050. The present 1-in-100-year storm tide height of about 2.3 m increased to about 2.6 m by 2050 due to increased cyclone intensity (10 hPa drop in central pressure). With an additional 10 to 40 cm sea-level rise, the 1-in-100-year event would be about 2.7-3.0 m. Much of the township of Cairns would remain above the flood line, with the inundation of about 32 square km largely confined to the wetlands and Admiralty Island to the south-east of the township.

**Impact of sea-level rise, coastal and inland flooding:**

- water damage to building contents (interior linings, furnishings, appliances, equipment and plant)
- possible contamination of interior of building from sewage, soil and mud
- undermining and/or destruction of foundations, potentially leading to structural collapse
- salt spray (coastal) affecting most material's durability
- coastal erosion (in some areas likely to be severe) resulting in loss or damage to property.

## 3.7 Hail

Hail losses account for 34% of the total Australian economic losses in the 1967-2003 Insurance Disaster Response Organisation database (IDRO 2004), the largest proportion for any natural peril (Schuster 2003). Hail damage was involved in 10 of the top 20 insurance losses since 1967. NSW experiences the highest insurance losses due to hail. McMaster (2001) found that 32% of severe thunderstorms recorded in NSW are severe hailstorms (hail diameter exceeding 2 cm) that tend to occur from September to March.

Few studies have considered the effect of climate change on hail in future. McMaster (1999) assessed large-scale hail precursors simulated by three global climate models over Moree and Wagga for present and doubled $CO_2$ conditions. A tendency for decreased hail damage to winter cereal crops was found due to an increase in the height of the freezing level necessary for hail formation. However, these results were based on models without a fully-coupled ocean or a good representation of the El Niño Southern Oscillation, so they should be interpreted with caution.

The Insurance Australia Group commissioned a study of the sensitivity of the April 1999 Sydney hailstorm to changes in key atmospheric and oceanic parameters (Coleman 2001). Initial results showed a gradual increase in frequency and intensity of hailstorms over the next five decades.

> **An ensemble of six model configurations of the Oklahoma University Couple Atmosphere – Ocean General Circulation Model was then run over the period form 1970 through to 2050 for both the current climate and future climate (IS92a) scenarios. The current climate model simulations produced a simulated hail climatology that matches the current hail climate of Schuster et al relatively closely. The model runs also demonstrate that there is considerable inter-decadal variability in the frequency of large and giant hailstorms but with no identifiable long-term trends. The future climate simulations depicted a climate in which there is a gradual increase in the frequency and intensity of hailstorms over the next five decades.**
>
> Provided by IAG Insurance Australia Group – www.iag.com.au

Niall and Walsh (in press) analysed hail occurrence at Mount Gambier and Melbourne, over the months August to October for the period 1980-2001. A statistically significant relationship between hail incidence and a measure of atmospheric instability (CAPE) was established. The CSIRO Mk3 climate model was used to simulate values of CAPE for Mount Gambier under double pre-industrial concentrations of $CO_2$. The results showed a significant decrease in CAPE values in the future for this region. Assuming the relationship between CAPE and hail remains unchanged under enhanced greenhouse conditions, it is possible that there will be a decrease in the frequency of hail in south-eastern Australia.

At present this is the best information available, but should be used with caution as this study did not allow for specific modelling for hailstorms. However, CSIRO plans to undertake an analysis of potential changes in hail risk in 2005-06 which will provide better scenario results than currently available. Therefore at present it is not possible to provide with confidence any projections for hailstorm frequency or intensity for Australia. Even with further analysis it is likely to be very site specific.

**Impact of decreased hail events (Melbourne):**

- potentially reduced likelihood of damage (mostly roofs, guttering, windows) and subsequently less rain/moisture penetration.

**Impact of increased hail events (Sydney):**

- potentially increased likelihood of damage (mostly roofs, guttering, windows) and subsequently more rain/moisture penetration.

## 3.8 Bushfires

Bushfires, often occurring in times of drought, have been a regular feature of the Australian environment, costing hundreds of lives and causing extensive economic damage. The nature of droughts in eastern Australia appears to be changing. Since 1973 droughts have become hotter, with the 2002 drought being the hottest in the past 100-years (Nicholls 2004). The 2002 drought was particularly severe because low total precipitation was exacerbated by high potential evaporation (Karoly *et al* 2003).

Climate change is projected to increase the frequency of hot days, especially in summer. These changes would increase bushfire intensity and frequency, with the number of days of very high and extreme fire danger increasing across the country. Projected decreases in rainfall and humidity would also increase fire danger.

Williams *et al* (2001) have examined the impact of climate change on bushfire danger in Australia. They did this by estimating changes in weather conducive to bushfire potential as determined by the McArthur Forest Fire Danger Index. This index is widely used in eastern Australia to estimate fire danger and declare Total Fire Ban days. The study found that a doubling of atmospheric $CO_2$ concentrations increased fire danger at all sites studied, by raising the number of days of very high and extreme fire danger. The main driver of increased fire potential and risk was increases in daily maximum temperatures as a result of regional climate change.

Cary (2002) estimated that there may be small to moderate (5-20%) future increases in the Fire Danger Index in the ACT up to 2070, with commensurate increases in the frequency of fire occurrences. For example, the current average interval between fires of a given intensity is 43-years – this drops to 20-years under a moderate climatic change scenario and 12 years for a worst case scenario.

(NB: A study on climate change and fire weather in the ACT, NSW, Victoria and Tasmania is being undertaken by CSIRO and the Bureau of Meteorology in 2004-05, using two CSIRO climate change simulations).

**Impact of increased risk of bushfires:**

- total or partial fire damage to building property and contents
- smoke and water damage to building property and contents
- health and safety of occupants at risk
- more resources for emergency services and early warning systems
- increased clearing of vegetation around houses, leading to decreased shading by the natural environment and green space.

## 3.9 Identified research needs and opportunities

The climate change scenarios used in this scoping study were based on readily available material, consistent with scenarios for 2030 and 2070 being used in two parallel assessments of impacts on energy infrastructure and cities. If further research is to be conducted on the potential impacts of climate change on buildings, then more specific scenarios are needed.

- Since some impacts depend on combinations of changes in multiple climate variables e.g. temperature and rainfall, it is important to assess links between changes in temperature and rainfall, rather than broad ranges of change based on many climate models. The recommended approach is to provide climate-model-specific scenarios for as many climate variables as possible, using at least two climate models that perform well in the regions of interest. This was the approach used by McMichael *et al* (2003), who considered health impacts in 2020 and 2050.
- More information is needed on potential changes in extreme events such as heavy rainfall, flooding, hail, tropical cyclones, wind gusts, storm surges and bushfire.

# 4. AUSTRALIA'S BUILDING STOCK

This section provides an overview of the residential and commercial building stock in Australia. This has been done to gain an understanding of the typical performance of each building type with a view to be able to make a subjective assessment of vulnerability to the predicted climate change impacts (as detailed in the previous section).

The majority of Australia's building stock (since 1996) complies with the Building Code of Australia (BCA). Thus, most buildings meet minimum performance requirements "to enable the achievement and maintenance of acceptable standards of structural sufficiency, safety (including safety from fire) health and amenity for the benefit of the community now and in the future" (BCA 2005). A key issue for this project is assessing the need for additional performance requirements in light of the predicted climate change impacts.

## 4.1 General building stock characteristics

*Dwelling structure and size*

In 1999 (as in 1994), 79% of homes across Australia were separate dwellings. This predominance was even more pronounced in rural areas (95%). Of the States, Tasmania (88%) and Queensland (84%) had the highest proportions of separate dwellings, whereas NSW had the highest proportion of flats (17%).

Ninety percent of owners lived in a separate house compared to 55% of private renters and 46% of renters in State or Territory housing authority homes. The majority (57%) of separate houses had three bedrooms, while a further 29% had four or more bedrooms. In contrast, 58% of semi-detached homes and 86% of flats had only one or two bedrooms.

*Age of dwelling*

The majority (57%) of Australian homes were reported by their occupants to be 20 or more years old. Tasmania had, marginally, the highest proportion of homes built 50 or more years ago (23%), while the Northern Territory had the highest proportion of dwellings less than five years old (13%).

*Dwelling materials*

Brick veneer homes have been common in many areas of Australia but are becoming increasingly common across Australia. In 1999, 71% of dwellings had walls of either brick veneer or double brick walls, compared to 65% in 1994. In 1999, the majority of homes featured timber frames (64%) and had roofing of either tiles (63%) or metal sheeting (33%). These proportions had changed little from 1994.

*Housing condition*

Most Australian dwellings were reported to be in good condition, with the majority of households (80%) reporting no major structural problems. For those with problems, cracks in walls or floors were the most often reported (by 473,300 or 7% of households). Other problems were sinking or moving foundations (5%), rising damp (4%) and walls or windows being out of plumb (4%).

Forty-three percent of households reported that repairs were required to the inside of their home, and a similar proportion (45%) reported that repairs were required to the outside of the dwelling. However, of these, almost two-thirds (63% and 62% respectively) rated the need for repair to be desirable but low.

However, there is concern over brick houses and apartments and cracking that can occur due to the moisture levels in soils reducing because of drought. The cost of cracking can be quite substantial if left as it can lead to structural damage or other defects such as leaking roofs or damaged pipes. The Archicentre national data base shows 38% of the homes on which Archicentre had conducted pre-purchase inspections have cracking. They believe that 10% of all homes are likely to have or will develop serious cracking (see http://www.archicentre.com.au/media/ACJUNE72005TASCracking.htm).

*Repairs and maintenance*

Fifty-five percent of households reported that repairs or maintenance had been carried out to their current dwelling within the last 12 months. The most commonly reported types of repair or maintenance were painting (31%), plumbing (24%) and electrical work (17%). Ten percent of households renting where repairs or maintenance had been carried out indicated that they had met at least some of the costs themselves (ABS 1999).

## 4.2 Specific building stock characteristics

Gaining specific building stock information for the 13 selected sites (grouped according to Climate Zone) proved very difficult. We regard this as a significant information gap. Without this information, accurate determinations are not easily made about the condition, and therefore the resilience, of new or existing buildings to the predicted impacts of climate change. For example, although the Building Code did not introduce standards for houses in bushfire-prone areas until 1996, it is likely that many houses built in the 1950s (by design or by default) have fibre-cement sheeting exterior wall linings which have a low flammability. Indeed, in terms of the building stock built prior to 1996, it is virtually impossible to predict how these buildings will cope with future climate change. Just because a building is old (or pre-BCA) does not necessarily mean that it will perform poorer than new buildings. For an objective assessment of vulnerability, detailed, accurate building stock information on Australia's buildings needs to be fully determined.

### 4.2.1 Residential buildings

Information on average floor area has been provided. Floor size has a relationship with the ability of a house to maintain a comfortable temperature and, therefore, the predicted increase in temperature for the climate change information and the running cost of this if mechanical ventilation is installed. The new average floor area is based on 2002 figures while the existing average floor area is based on 1984 figures.

Percentage of households with insulation is provided from a survey (ABS 2002) that owners and occupiers filled out. Therefore it is likely the percentages given refer to ceiling insulation only and the quality and amount of the insulation cannot be determined. The percentage of dwellings using reverse cycle air-conditioning as their main heater have been determined as state-wide values, but not specifically for each site (ABS 2002). The results are:

Note: BCA is notionally NatHERS 4 star for Climate Zones 4-8 and 3.5 stars in Climate Zones 1-3 plus service provisions (e.g. insulation of ducts and hot water pipes) with a deemed-to-satisfy option. Currently there is a BCA proposal to move towards NatHERS 5 star on 1 May 2006 with a tighter, hence more complex, deemed-to-satisfy option.

*Zone 1 (Hot Humid)*

| Size | Construction | Insulation and Ventilation |
|---|---|---|
| **Darwin**<br>No. of Dwellings: 41,443<br>Average Floor Area:<br>New 183m²<br>Existing 135m² | Typical: Timber framed, timber cladding and concrete floor.<br>Secondary:<br>Timber framed, brick cladding and concrete floor.<br>Older:<br>Timber framed, timber cladding and timber floor. | Energy requirements (New Houses): BCA with state variation to the Building Sealing requirements<br>Households with some insulation: 42%<br>Households with wall insulation: 36%<br>Dwellings with air-conditioners: 89% |
| **Cairns**<br>No. of Dwellings: 49,003<br>Average Floor Area:<br>New 233m²<br>Existing 155m² | Typical:<br>Timber framed, brick or timber cladding and concrete floor.<br>Secondary:<br>Timber framed, brick cladding and timber floor.<br>Older:<br>Timber framed, timber cladding and timber floor. | Energy requirements (New Houses): BCA with state variation for two storey buildings and wall insulation<br>Households with some insulation: 36%<br>Households with wall insulation: 26%<br>Dwellings with air-conditioners: 39% |

*Zone 2 (Warm Humid)*

| Size | Construction | Insulation and Ventilation |
|---|---|---|
| **Brisbane**<br>No. of Dwellings: 364,587<br>Average Floor Area:<br>New 233m²<br>Existing 155m² | Typical:<br>Timber framed, brick cladding and concrete floor.<br>Secondary:<br>Timber framed, brick cladding and timber floor.<br>Timber framed, timber cladding and timber floor.<br>Older:<br>Timber framed, timber cladding and timber floor.<br>*Queenslander | Energy requirements (New Houses): BCA with state variation for two storey buildings and wall insulation<br>Households with some insulation: 36%<br>Households with wall insulation: 26%<br>Dwellings with air-conditioners: 39% |
| **Gold Coast**<br>No. of Dwellings: 187,103<br>Average Floor Area:<br>New 233m²<br>Existing 155m² | Typical:<br>Timber framed, brick cladding and concrete floor.<br>Secondary:<br>Timber framed, brick cladding and timber floor.<br>Older:<br>Timber framed, timber cladding and timber floor.<br>*Queenslander | Energy requirements (New Houses): BCA with state variation for two storey buildings and wall insulation<br>Households some with insulation: 36%<br>Households with wall insulation: 26%<br>Dwellings with air-conditioners: 39% |

* The 'Queenslander' is a name given to timber framed, timber clad and timber floor houses with wide covered verandas, which were very popular in sub-tropical and tropical east coast Australia (they were set with floors 1.5 to 2.0 m off the ground for maximum air circulation). Although they are still copied today, they are expensive to build. Consequently, the contemporary generic home has a concrete slab on-ground with cavity wall, is either steel or timber framed, and has a masonry external skin.

### *Zone 3 (Hot Dry, Warm Winter)*

| Size | Construction | Insulation and Ventilation |
|---|---|---|
| **Alice Springs**<br>No. of Dwellings: 13,918<br>Average Floor Area:<br>New 183m$^2$<br>Existing 135m$^2$ | Typical:<br>Timber framed, timber cladding and concrete floor.<br>Secondary:<br>Timber framed, brick cladding and concrete floor.<br>Older:<br>Timber framed, timber cladding and timber floor. | Energy requirements (New Houses): BCA with state variation to the building sealing requirements<br>Households with some insulation: 42%<br>Households with wall insulation: 36%<br>Dwellings with air-conditioners: 89% |

### *Zone 4 (Hot Dry, Cool Winter)*

| Size | Construction | Insulation and Ventilation |
|---|---|---|
| **Mildura**<br>No. of Dwellings: 18,151<br>Average Floor Area:<br>New 222m$^2$<br>Existing 164m$^2$ | Typical:<br>Timber framed, timber cladding and concrete floor.<br>Secondary:<br>Timber framed, brick cladding and timber floor.<br>Full brick, concrete floor.<br>Older:<br>Full brick, timber floor. | Energy requirements (New Houses): NatHERS 5 star + solar WH or rain tank (which currently allows transitional concession for lower rating)<br>Alteration or re-erection: NatHERS 3 star<br>Households with some insulation: 72%<br>Households with wall insulation: 35%<br>Dwellings with air-conditioners: 53% |

### *Zone 5 (Temperate)*

| Size | Construction | Insulation and Ventilation |
|---|---|---|
| **Adelaide**<br>No. of Dwellings: 458,002<br>Average Floor Area:<br>New 197m$^2$<br>Existing 160m$^2$ | Typical:<br>Timber framed, timber cladding and concrete floor.<br>Secondary:<br>Timber framed, brick cladding and timber floor.<br>Full brick and concrete floor.<br>Older:<br>Full brick and timber floor. | Energy requirements (New Houses): BCA with state variation for sealing requirements, limitation for electric resistance HW through Waterworks regulations.<br>Households with some insulation: 76%<br>Households with wall insulation: 36%<br>Dwellings with air-conditioners: 80% |
| **Perth**<br>No. of Dwellings: 552,006<br>Average Floor Area:<br>New 229m$^2$<br>Existing 185m$^2$ | Typical:<br>Full brick and concrete floor.<br>Secondary:<br>Timber framed, brick cladding and concrete floor.<br>Older:<br>Full brick and timber floor. | Energy requirements (New Houses): BCA with State variation to the air movement requirements<br>Households with some insulation: 65%<br>Households with wall insulation: 8%<br>Dwellings with air-conditioners: 59% |

| | | |
|---|---|---|
| **Sydney** | | |
| No. of Dwellings: 1,546,691<br>Average Floor Area:<br>New 245m²<br>Existing 159m² | Typical:<br>Timber framed, brick cladding and concrete floor.<br>Secondary:<br>Timber framed, brick cladding and timber floor.<br>Older:<br>Timber framed, timber cladding and timber floor. | Energy requirements (New Houses): BASIX (has separate requirements for heat and cooling, water heating etc)<br>Households with some insulation: 50%<br>Households with wall insulation: 27%<br>Dwellings with air-conditioners: 44% |
| **Coffs Harbour** | | |
| No. of Dwellings: 19,485<br>Average Floor Area:<br>New 245m²<br>Existing 159m² | Typical:<br>Timber framed, brick cladding and concrete floor.<br>Secondary:<br>Timber framed, brick cladding and timber floor.<br>Older:<br>Timber framed, timber cladding and timber floor. | Energy requirements (New Houses): BASIX (has separate requirements for heat and cooling, water heating etc)<br>Households with some insulation: 50%<br>Households with wall insulation: 27%<br>Dwellings with air-conditioners: 44% |

*Zone 6 (Hot Dry, Cold Winter)*

| Size | Construction | Insulation and Ventilation |
|---|---|---|
| **Melbourne** | | |
| No. of Dwellings: 1,344,624<br>Average Floor Area:<br>New 222m²<br>Existing 164m² | Typical:<br>Timber framed, brick cladding and concrete floor.<br>Secondary:<br>Timber framed, brick cladding and timber floor.<br>Older:<br>Timber framed, timber cladding and timber floor. | Energy requirements (New Houses): NatHERS 5 star + solar WH or rain tank (which currently allows transitional concession for lower rating)<br>Alteration or re-erection: NatHERS 3 star<br>Households with some insulation: 72%<br>Households with wall insulation: 35%<br>Dwellings with air-conditioners: 53% |
| **Canberra** | | |
| No. of Dwellings: 114,073<br>Average Floor Area:<br>New 228m²<br>Existing 149m² | Typical:<br>Timber framed, timber cladding and concrete floor.<br>Secondary:<br>Full brick and concrete floor.<br>Older:<br>Full brick and timber floor. | Energy requirements (New Houses): NatHERS 4 star<br>Additions: Min R-values for roof/ceiling and walls<br>Households with some insulation: 80%<br>Households with wall insulation: 40%<br>Dwellings with air-conditioners: 29% |

*Zone 7 (Cool Temperate)*

| Size | Construction | Insulation and Ventilation |
|---|---|---|
| **Hobart** | | |
| No. of Dwellings: 82,813 | | Energy requirements (New Houses): BCA |
| | Typical: | |
| Average Floor Area: | Timber framed, timber cladding and concrete floor. | Households with some insulation: 70% |
| New 178m$^2$ | | Households with wall insulation: 32% |
| Existing 150m$^2$ | Secondary: | |
| | Timber framed, brick cladding and timber floor. | Dwellings with air-conditioners: 10% |
| | Full brick and concrete floor. | |
| | Older: | |
| | Full brick and timber floor. | |

### 4.2.2 Commercial buildings

A new commercial office building in Australia would typically be made of steel reinforced concrete for the structure and window glazing with interior fit-outs from timber framing and panels.

In NSW and Victoria, approximately 75% of all high-rise commercial buildings are now being double glazed, which has been a significant increase over the last 18 months. Smaller commercial properties are more likely to have single glazing. The disclosure requirement of the energy rating at point of sale will be required after 1 May 2006 for commercial buildings. The awareness the disclosure information provides is likely to increase the double glazing use across all new commercial buildings.

The table below provides an outline of the commercial office space in each of the selected 13 sites and the energy efficiency Code requirements. (Note: the BCA requirements do not come into effect until 1 May 2006). These are important because one of the biggest climate change impacts for commercial buildings is the increase in temperatures.

Table 4: Commercial Office Area (m$^2$) for Selected Sites.

| Site | Commercial Office Area (floor - m$^2$) | *Energy efficiency requirements |
|---|---|---|
| Darwin | | None |
| Cairns | | BCA |
| Brisbane | 1,692,095 | BCA |
| Gold Coast | | BCA |
| Alice Springs | | None |
| Mildura | | BCA + state variations for class 2, 3 & 9c buildings. |
| Adelaide | 896,969 | BCA with state variation for sealing requirements, limitation for electric resistance HW through Waterworks regulations |
| Perth | 1,309,059 | BCA |
| Sydney | 4,574,366 | BCA + BASIX (has separate requirements for heat and cooling, water heating etc) |
| Coffs Harbour | | BCA + BASIX (has separate requirements for heat and cooling, water heating etc) |
| Melbourne | 3,363,282 | BCA + state variations for class 2, 3 & 9c buildings. |
| Canberra | 1,572,799 | BCA |
| Hobart | | BCA |

* Some municipalities have their own requirements in addition to those of the relevant State/Territory.

NB: a blank cell = information currently not available.

## 4.3 Changing trends in new buildings and movements in populations

The preliminary estimate resident population (ERP) of Australia was 20,229,800 persons as at December 2004 (ABS 2005), and is expected to grow to 23,365,400 by 2021 and 26,418,500 by 2051 (ABS 2003). On the other hand, the number of households in Australia is projected to increase from 7.4 million in 2001 to between 10.2 and 10.8 million in 2026, an increase of between 39% and 47%. This growth is faster than Australia's projected population growth of 25% for the same period (ABS 2004). Based on an assumption that the ratio of the number of households to dwellings is very close to one-to-one, this means that the number of new dwellings required to be built by 2026 will be in the order of 2.8 to 3.2 million (not including replacement of existing dwellings).

The average household size in 1971 was 3.3 people, decreasing to 2.7 people in 1996, with a further drop to 2.6 people in 2001 (ABS 2002). By 2026, it is expected to decline to between 2.2 and 2.3 people per household (ABS 2004). Lone person households accounted for 22.9% of all households in 2001, up from 22.1% in 1996 and 18.1% in 1971 (ABS 2002). It is forecast that around one-third of households will be lone person households by 2016. While older people are more likely to be living alone than younger people, more young people are likely to be living alone than in the past in absolute terms. Although all people aged 75 years and over represented only 5.8% of the Australian population in 2001, they represented 21.6% of people living alone. This is an increase from 20.1% in 1996 and from 16.3% in 1971.

In 2001 there were 1.1 million people aged 75 years and over in Australia, representing 6% of the total population. Over the period 2001 to 2026, this number is projected to more than double to around 2.5 million people or around 10% of Australia's population (ABS 2002). The median age in Australia was 35.4 years in 2000 and is expected to rise to 46.7 years by 2050 (ABS 2004).

Around 64% of the Australian population lives in one of the eight capital cities, all of which are on the coast except for Canberra. The proportion living in capital cities is expected to rise to 65% in 2021 and to 67% in 2051. Queensland is by far the fastest growing state, expecting to increase its population by 34% by 2021, and 73% by 2051, by which stage its total population (6,429,700) will have well and truly overtaken that of Victoria (6,199,900). Most of this extra growth in Queensland will come from the southern States, and much of it will end up in one of the major coastal urban centres (mainly Brisbane, the Sunshine Coast and the Gold Coast) in south-east Queensland.

Table 5: Growth in Dwellings (Households) vs Population

| Area | Households in 2001 (millions) | Households in 2026 (millions) | | | |
|---|---|---|---|---|---|
| | | Lower projection | | Higher projection | |
| | Households | Households | % growth | Households | % growth |
| Total Aust | 7.4 | 10.2 | 39% | 10.8 | 47% |
| QLD | 1.4 | 2.3 | 63% | 2.4 | 76% |
| WA | 0.7 | 1.1 | 39% | 1.2 | 47% |
| VIC | 1.8 | 2.4 | 35% | 2.6 | 41% |
| NSW | 2.5 | 3.3 | 33% | 3.4 | 38% |
| SA | 0.6 | 0.7 | 17% | 0.8 | 26% |
| Total these States* | 14.4.0 | 20 | 40% | 21.2 | 49% |
| People per household** | 2.6 | 2.25 | | 2.25 | |
| Population* | 18.2 | 22.0 | 21% | 23.4 | 29% |

* The smaller States and Territories (TAS, NT and ACT) have not been included in this table as figures are not given.

** Mean of projections used for 2026 (ABS, 3236.0, 2004).

Table 6: Population Size: Observed and Projected. (ABS 2003)

| 30 June 2002 | State or Territory ('000) | Capital City ('000) | Capital as % of total |
|---|---|---|---|
| NSW | 6640.4 | 4170.9 | 63% |
| VIC | 4872.5 | 3524.1 | 72% |
| QLD | 3707.2 | 1689.1 | 46% |
| SA | 1520.2 | 1114.3 | 73% |
| WA | 1927.3 | 1413.7 | 73% |
| TAS | 472.7 | 198.0 | 42% |
| ACT | 321.8 | 321.8 | 100% |
| NT | 198.0 | 107.4 | 54% |
| Total | 19660.1 | 12539.3 | 64% |
| 30 June 2002 | State or Territory ('000) | Capital City ('000) | Capital as % of total |
| NSW | 7637.8 | 4910.8 | 64% |
| VIC | 5654.8 | 4188.9 | 74% |
| QLD | 4993.0 | 2288.0 | 46% |
| SA | 1592.0 | 1181.2 | 74% |
| WA | 2407.9 | 1804.9 | 75% |
| TAS | 474.6 | 203.2 | 43% |
| ACT | 364.9 | 364.9 | 100% |
| NT | 240.4 | 141.9 | 59% |
| Total | 23365.4 | 15083.8 | 65% |
| 30 June 2002 | State or Territory ('000) | Capital City ('000) | Capital as % of total |
| NSW | 8355.6 | 5652.5 | 68% |
| VIC | 6199.9 | 4792.8 | 77% |
| QLD | 6429.7 | 3018.5 | 47% |
| SA | 1475.6 | 1134.6 | 77% |
| WA | 2874.5 | 2235.2 | 78% |
| TAS | 386.5 | 175.7 | 45% |
| ACT | 389.6 | 389.6 | 100% |
| NT | 307.1 | 199.3 | 65% |
| Total | 26418.5 | 17598.2 | 67% |

While around one million extra people are expected to move to Sydney over the next quarter of a century or so, many others are likely to leave for a 'cleaner' environment, most likely choosing a less populated and/or more amenable city or town up or down the coast. ABS figures already project massive growth in Queensland coastal areas for this and other reasons. Indeed, the beach still holds an iconic status in our culture. Coastal regions have long been a favourite place for Australians to take their holidays and relax (ABS 2004). With climate change drying out many inland locations making them less desirable to live in, the trend to the coast may well increase faster than current projections suggest.

However, people moving to these locations may also find a growing need for internal spaces to be designed for extremes of weather e.g. storms, heatwaves, wave surges, etc. In particular, they may need increasingly to stay indoors (or at least protected from or out of the sun). Fry observes that "Beach culture in Australia has dramatically changed since the arrival of a massive hole in the ozone layer, which has exposed the population to much higher levels of ultra-violet light and markedly increased the risk of skin cancer." (Fry 2001). One response is expected to be a reconfiguration of dwelling space to include more inside-outside areas (e.g. partially enclosed or shaded decking, see page 42). Extension of the deck area to cover or enclose the swimming pool is also occurring in increasing numbers. This extends the period during which the pool can be used, and also reduces evaporation. However, if doors are left open it also has implications for internal air quality and health.

Although the average number of people in households is steadily declining (see page 39), home sizes have been steadily increasing to a point where a recent study by the

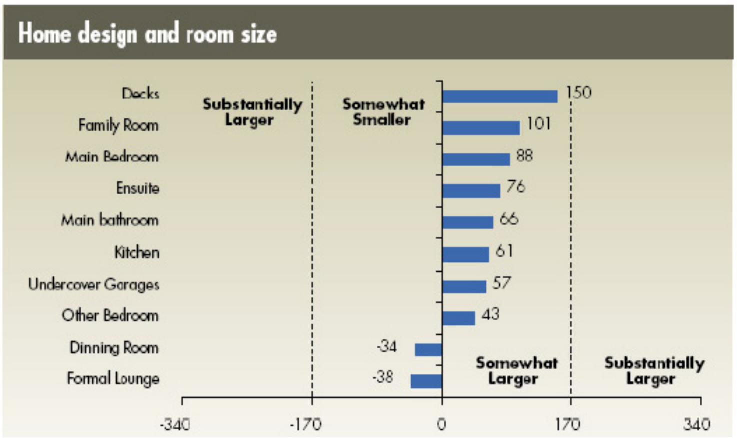
Housing Industry Association (HIA) and CSR claims that 44% of home buyers now want homes larger than 250 square metres, and that some 58% of homes currently built are over 150 square metres (HIA-CSR 2005). They go on to say that a home with four bedrooms and two bathrooms "is the new standard for Australia", and that their research suggests a trend towards two-storey homes containing larger rooms. On the other hand, block sizes are getting smaller, having reached a point where the most common block size in recent years has been in the 700 to 1,000 square metres range. They say that the most common block size of houses being planned now has fallen into the 551 to 700 square metres range.

Although smaller blocks are in part a reaction to increasing land prices, and in some cases the scarcity of available land, in many cases it is also in response to changing lifestyle patterns (both parents working, more away-from-home activities for them and children, etc). They are also a response to the growing perceived scarcity of water resulting in increasingly severe water restrictions over a decade and therefore less inclination to plan and attempt to maintain an attractive and large garden. Most Australian capital cities and many towns are experiencing unprecedented water concerns.

In recognising the changing needs of new home buyers in Australia, the HIA also identified four main segments of new home buyers. The first segment (who they call 'Generation Xers') comprises a majority of the market at present (58%), and is made up largely of first home buying 28 to 42 year old childless couples looking for single-storey homes with multiple car spaces at the lower end of the market. The second main segment (24%) comprises 42 to 48 year old first home buyers who are mostly couples with children still living at home ('Trailing Baby Boomers'), who are mainly looking for double-storey homes with two car spaces, four bedrooms and a rumpus room. The third main segment consists mainly of 43 to 51 year old trade-up buyers looking for a second home ('Leading Baby Boomers'), among whom there is a strong demand for four or five bedrooms, two bathrooms and a study or computer room. They add that people aged 59 years and over are rarely first home buyers, generally wanting a larger block size, but with less need for multiple car spaces or more than two or three bedrooms (HIA-CSR 2005). Many major renovations and extensions to existing homes also seem to be reflecting this pattern, with whole streets of older single-storey homes in some suburbs being converted to (or knocked down and replaced by) two-storey homes with many more rooms, and footprints covering a much larger proportion of the block than the old homes.

The HIA study also shows that people are generally seeking an increase in the amount of common 'casual' space available to their households (e.g. larger decks and family rooms) and a reduction in formal spaces (e.g. formal lounges and dining rooms). In part, this seems to be a result of increasing use of the home (including 'inside-outside' spaces such as decks which are often covered or shaded) as a living and recreational space as opposed to being out in direct sunlight and subject to whims of the weather.

Table 7: Home Design and Room Size (HIA-CSR 2005)



## 5. RESILIENCE OF BUILDING STOCK TO CLIMATE CHANGE

This section determines what the key climate change risks are likely to be as a result of the preceding information, including a discussion on existing building regulations that deal with these impacts.

### 5.1 Key climate change issues

**Key climate change issues identified for Australia's building stock are:**

- building over-heating
- tropical cyclones, intense storms and increased wind speeds
- flooding
- degradation of foundations
- bushfires

***Building over-heating***

This is not a new phenomenon for Australia; buildings have been designed to cater for extremes of temperatures for hundreds of years. In general terms, smaller, older residential building types are able to cope with increases in temperature and extreme temperature events. Built in the days where mechanised cooling systems were not available, they were built with good shading and other passive solar design principles in mind. Today's new, larger buildings, with their move away from effective eaves, bigger windows and reliance on mechanical cooling systems, are least able to cope with increased temperature events (reliance on mechanised systems to cool buildings, with associated power consumption implications).

On 1 January 2003, energy efficiency requirements for Class 1 and 10 buildings[1] were introduced into the Building Code of Australia (BCA), and these have recently been extended to Class 2, 3 and 4 buildings (introduced May 2005). Requirements for these building classes mean that buildings are to be built to a 3.5 or 4 Star standard, with Star rankings defined by the Nationwide House Energy Rating Scheme (NatHERS).

*Variations:*

- *In Victoria, Class 2 buildings must comply with the 5 Star standard (as per Classes 1 and 10, using FirstRate or NatHERS software).*
- *In NSW, Class 2 buildings must comply with BASIX requirement (25% reduction in energy consumption, increasing to 40% July 2006) (as do Classes 1 and 10).*

However, new provisions to the BCA propose an increase to the energy efficiency requirements for Class 1 and 10 buildings of 5 Stars (proposed to be introduced in 2006). Changes in the BCA to achieve this involve increases/ improvements in insulation and glazing requirements.

For non-residential buildings (Classes 5-9), the BCA proposed provisions are for energy efficiency requirements (to be introduced May 2006). The proposed requirements embrace lighting, glazing, building envelope insulation (wall, floor and ceiling) and air-conditioning. The requirements also extend to building sealing, air movement and hot water supply services, as well as broad maintenance provisions. The proposed changes are expected to result in a 20-25% reduction in energy consumption in these building Classes.

Passive solar design is different for the hot humid climates of northern Australia where solar gain into the house needs to be minimised all year round, to the colder southern climates where solar gain during winter is preferred. As temperatures increase across the continent, the change point or dividing line between these two recommend styles is likely to move further south as cooling increasingly becomes the dominant need.

### *Tropical cyclones, intense storms and increased wind speeds*

Buildings are currently covered by AS/NZS 1170.2:2002 Structural design actions – Wind actions. However, the design criteria for cyclones, storms and high winds is based on existing data and does not include any reference to or predictions for future change. The increased wind speeds and increased intensity of cyclones will put additional pressure on both commercial and residential buildings. It is likely that there will be damage to residential buildings as a result of the predicted higher wind speeds across most of Australia. Due to the heavier weight of construction of office buildings, they are more likely to cope with the added pressures, although they are still susceptible to impact damage from flying debris (especially glazing).

Further work has been undertaken to assess housing performance (resilience) in the face of increased intensity of tropical cyclones and severe storms: see the following publication as an example:

http://www.longpaddock.qld.gov.au/ClimateChanges/pub/OceanHazardsStage4.html#exec

The main concerns are ensuring good quality construction of wind-resistant buildings, the securing of elements which can blow away e.g. metal sheeting, roofing, fences, signs, plus the engineering of infrastructure elements to withstand wind forces and water damage (including storm surge).

### *Flooding*

Building Code requirements for flooding are generally ad hoc, with most residential buildings not specifically designed to cope with flooding. While there are building codes for other natural hazards (e.g. bushfire) there is none specifically for building in flood prone area. Instead, each area that is subject to flooding will have it's own set of rules typically applied at local government level and are often based on historic data without adjustment for climate change. Therefore, this design consideration is overlooked resulting in some houses being more vulnerable to damage (both structural and non-structural) when flooding occurs. There is also a lack of awareness that many houses are built on flood plains because often there is no desire to highlight this issue at a council or community level. If the highest recorded flood level on the Hawkesbury River (in 1967) were to occur again, 30,000 or more houses would be flooded, Hawkesbury-Nepean Floodplain Management Steering Committee (2004).

In some areas where planning requirements have been introduced (e.g. Gold Coast), higher minimum floor levels or two story housing designed for the lower level to flood, will mean these houses will cope better. Another key mechanism to reduce the likelihood of damage is to prevent the siting of building on floodplains. Land-use management to limit the use of floodplains for development are typically covered by planning and development regulations, as is the engineering of structures in the floodplain to withstand flood forces e.g. levee banks, flood walls, dams etc. Relying on the local councils to enforce, inform and educate their communities on the risks of flooding can be problematic because at the same time they are continually trying to promote their local areas.

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[1] Volume 1 of the BCA covers Class 2 to 9 buildings (such as apartments, hotels and motels, single caretaker's flat attached to a commercial building, offices, shops, carparks, warehouses, factories, hospitals, theatres, churches, libraries and gymnasiums etc.) Volume 2 of the BCA covers Class 1 and 10 buildings (such as single dwellings, small boarding houses and garages).

### *Degradation of foundations*

In some areas of Australia the stability and performance of building foundations may be impacted by climate change as soils either dry and crack leaving foundations unstable in the ground or the mortar in the foundations dries and cracks weakening the structure upon which the rest of the building sits. The building code take into account potential change in soil type and at present there is very little research to show this is required and the likely impact and size of this issue for buildings across Australia.

The degradation of foundations can have a significant impact on the service the building can provide. The most likely risks to a building associated with degrading foundation are movements of pipes causing leaks (e.g. water and gas pips), weakening of the structure so to he extent the building is compromised by high winds or storm events and for commercial and larger buildings potential lift malfunction. At this stage the amount of risk associated with degradation of foundations through climate change is unknown and it requires greater exploration to fully understand the associated issues.

### *Bushfires*

Residential only: bushfires have always been a risk in Australia. Although the related standard AS3959-1999 was not introduced into the Building Code until 1996, many older homes may have used materials and building techniques that reduced the risk of fire entering the building. Without detailed building stock information, we have been unable to determine how many dwellings were built in this way.

Although the frequency of bushfires is likely to increase, because of the nature of a bushfire it is not likely that the frequency in any area can be more than 15 years (the time allowed for the bush to regenerate). Therefore dwellings built to meet Level 3 of the standard should cope to 'acceptable' levels.

## 5.2 Estimation of resilience of buildings

Based on the findings as described in the previous section, it would seem that Australia's newer building stock is, by default, reasonably prepared for the impacts of the changes likely to occur due to climate change. The reason for this is that building regulations, while not specifically addressing climate change impacts per se, include some provisions to reduce the vulnerability of buildings to Australia's already challenging climate. For example, the daily temperature swings are far greater than the expected increase in temperature due to climate change. Where buildings are most vulnerable is when they have not been designed for a certain impact (e.g. bushfires or cyclones) but due to climate change there is a shift in the boundaries of where the impact typically occurs. Also as the extremes become greater the intensity and frequency of many extreme weather events is likely to increase. Despite being reasonably prepared there is still an opportunity to improve the resilience of the building stock in relation to climate change. For the older building stock, a key area is maintenance and upgrading (dependent on their expected lifetime). For new, which will still be in existence in 2070 and beyond (when climate change impacts will be more extreme and most likely will still be increasing), there is the opportunity to design taking into account the future climate.

The potential for additional requirements to the BCA are identified in Section 9 (Issue 3: Adaptation Options).

An informative narrative of Australia's response to natural disasters is provided in the text box on the following page.

To summarise, there appears to be a 'grey' area between planning legislation and building legislation in Australia. In most jurisdictions, it is unclear (at least from an 'outsider's' view) where planning responsibility lies in relation to building regulations. In some cases, e.g NSW and Victoria, planning requirements are driving better building practice through mandatory and non-mandatory sustainability requirements that directly relate to building performance.

There needs to be recognition of the linkage between land-use planning and building standards and a way of ensuring smooth interaction between the two. As a result, we suggest that the greatest gains in adapting Australia's built environment to the impacts of climate change can be made in the implementation of environmentally sustainable development (ESD) principles throughout the planning, design and construction process.

Some Councils are driving this agenda through their planning and development controls already (especially those in NSW and Victoria). The emergence of a multitude of building environmental rating tools is also advancing this agenda.

The ABCB adopted sustainability as a goal (May 2004). Over time, this will allow the inclusion of sustainable construction elements to be included in the Code requirements (at a minimum level). At the writing of this report no specific sustainability clauses had been added into the BCA (although the energy provisions are a subset of the broader area of sustainability).

## 5.3 Identified research needs and opportunities

The state of Australia's residential and commercial building stock is largely unknown (especially site variations). It is recommended that region specific 'building condition surveys' (or similar) are undertaken and opportunities are explored to gradually raise the standard of existing buildings that do not comply with flooding and fire prone standards.

The inclusion of sustainability as a goal in the BCA provides an opportunity for implementing climate change adaptation options (by incorporating separate, new clauses – or worked in as part of existing clauses).

**Changes in Building and Planning requirements as result of natural disasters**

(Adapted from Walker 1999)

**With building adaptations to natural disasters, there have been major developments post-1970, although they have occurred in a segmented hazard-specific manner. The most significant development has been the wind-resistant design of housing, where changes have been radical, particularly in the tropical cyclone-prone regions of Australia. After Cyclone Tracy, the primary change was the implementation of a structural performance requirement that all buildings, including single family dwellings, be designed to resist loads specified in the Wind Code (Standards Association of Australia 1989). The Code itself has been updated to reflect current international best practice. This occurred at a time when building regulations were becoming uniform at state level, ensuring the Code was widely used and also eliminating the variability of application and enforcement of building standards that had been prevalent until then.**

**When the Building Code of Australia was developed in the late 1980s, this resulted in a common approach to the wind-resistant design of buildings based on the Wind Code being adopted and enforced across Australia. These developments resulted in reduced vulnerability to wind of all new building construction. For example, dramatic reductions in tropical cyclone-prone areas were observed following TC Winifred (1985) and TC Aivu (1989), both affecting north Queensland communities.**

**With regard to flood mitigation, although there have been periodic attempts to develop a national strategy, this has remained firmly in the hands of State government departments. Moreover, these departments are generally different from those that are responsible for building regulations and emergency services. Restrictions on development in floodplain areas vary across Australia, from good in some places to very poor in others. The dependence on dams and levees still appears to be the primary form of mitigation. A lack of publicly available flood risk maps highlights the problem arising from a political reluctance to draw attention to flood-prone areas for fear that an adverse effect on land prices and local development will ensue.**

**A standard for the construction of houses in bushfire-prone areas has been produced and is incorporated in the Building Code of Australia (AS 3959-1999). However, its application is subject to the designation of bushfire zones by appropriate authorities; an outcome that has been undertaken in very few areas. As a consequence, in most bushfire-prone areas the use of the standard is voluntary. The main adaptive issue appears to be whether it is better or worse for residents to stay in their houses when a bushfire is approaching.**

**Although hail is the cause of significant economic loss, it is not the subject of adaptation, except in relation to hail nets to protect crops and vehicle sale yards. Moreover, there does not seem to be any public pressure to change this, even after the severe hailstorms in Sydney during 1999. On the other hand, while ground subsidence, like hail, does cause significant economic losses, it is not a danger to life. It is, nevertheless, the subject of rigorously enforced building regulations designed to mitigate damage to houses from this hazard (Standards Association of Australia 1996).**

**The building and planning mitigation practices described above only apply to new construction. Consequently, in most hazard-prone areas the majority of houses are still likely to be vulnerable. To date, apart from government-owned property in tropical cyclone-prone areas, little effort has been made to reduce the vulnerability of older construction. To correct this situation with respect to wind resistance in Queensland, Standards Australia and the Insurance Council of Australia have published guidelines for upgrading older houses in high wind areas. What impact this has with regard to adaptation has yet to be seen.**

# 6. ENERGY MODELLING FUTURE SCENARIOS

With future climate change scenarios indicating increased temperatures it is necessary to see how well buildings will cope with these increases and the associated energy usage. To determine this, energy modelling can be used. This project has modelled two different building types: housing (seven different options) and a commercial building for all 13 selected sites. Also, a public building (a hospital representing a critical building) for one site only (Melbourne) has been modelled. The detailed modelling assumptions, methodology and results are provided in Appendix B (housing and offices) and Appendix C (hospitals). The following is a summary of the results for housing and offices.

## 6.1 Results

### *Housing*

The results of simulations of all seven houses in all four orientations have been analysed. Figure 4 shows the average heating and cooling loads for each location. The average is derived from all the orientation and house type combinations.

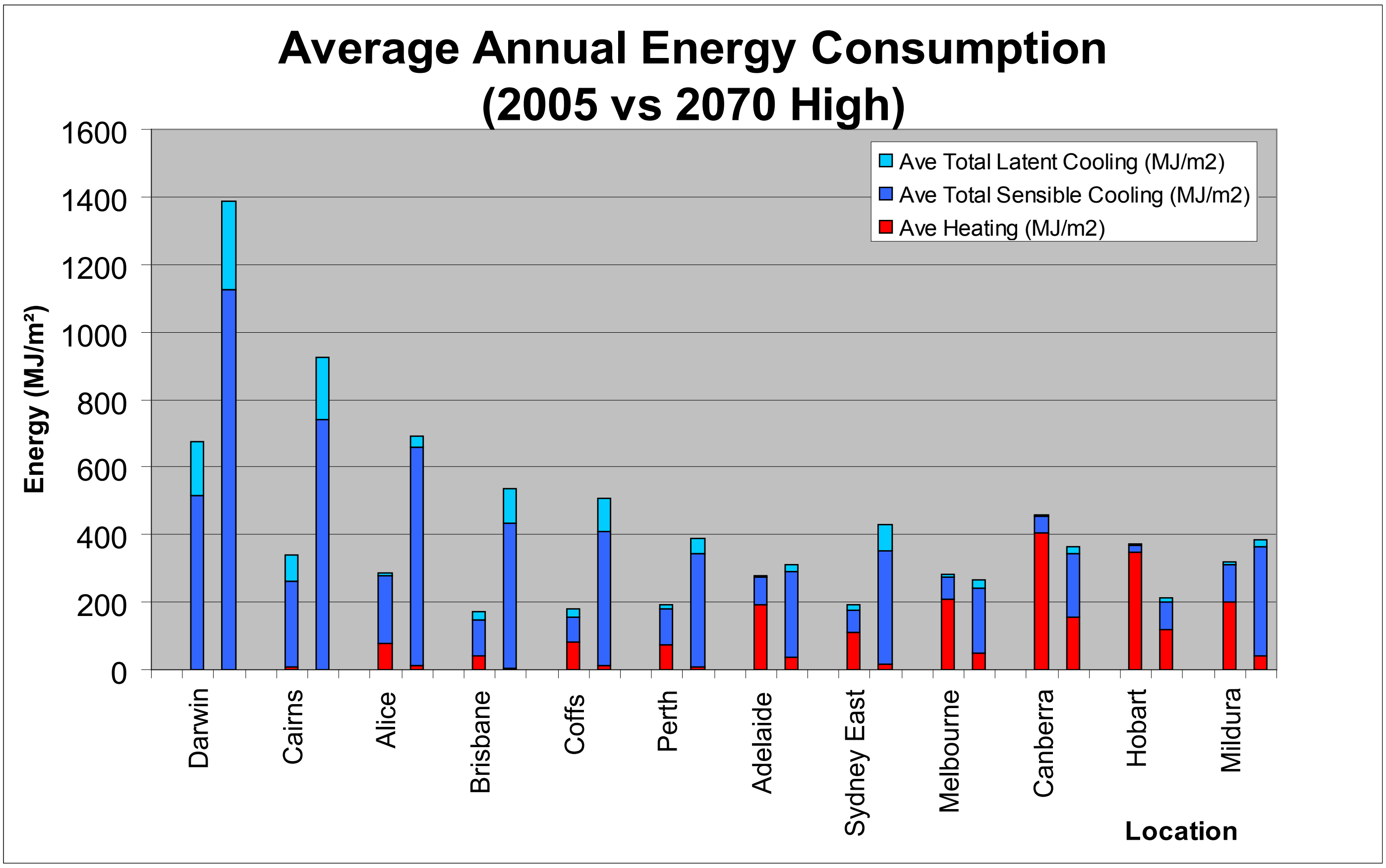

Figure 4: Simulated Average Energy Consumption of Seven base house types (including one apartment).

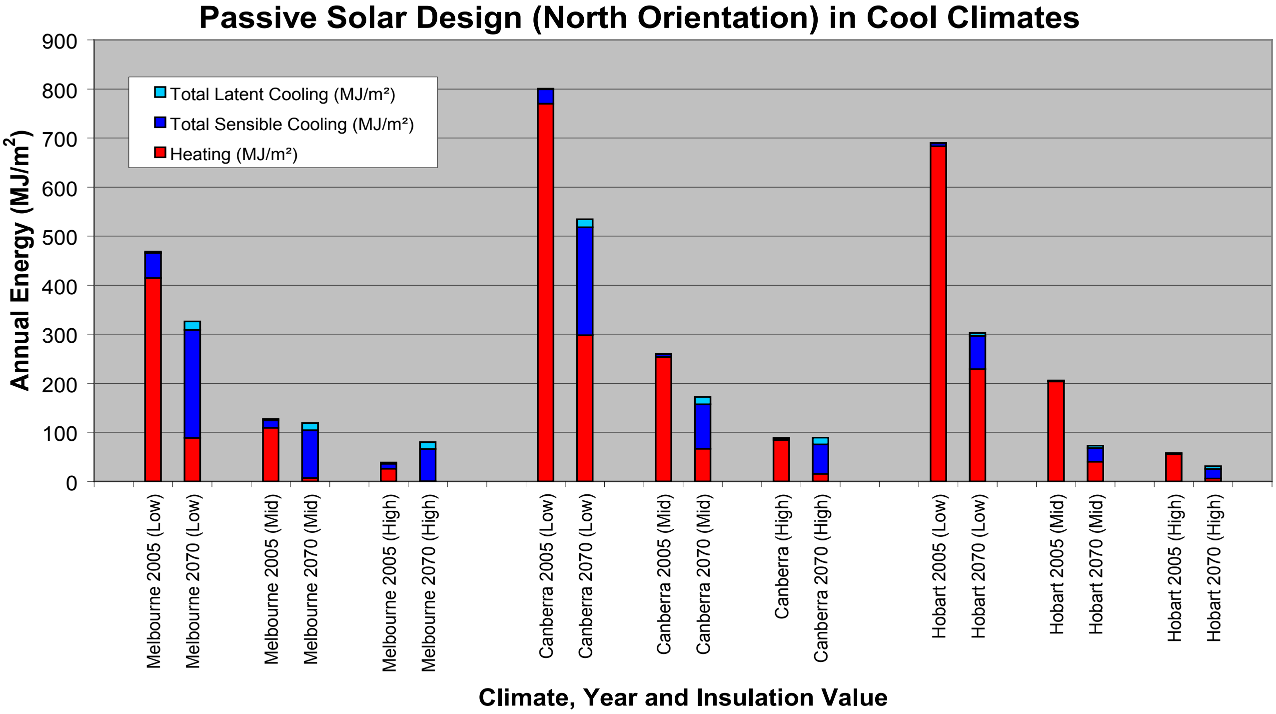

Figure 5: Three Insulation Levels Applied to the "Passive Solar" Design in Cooler Climates.

The increased simulated cooling load is significant with the nation-wide average being a demand of more than triple current levels by 2070. Although smaller in magnitude (on average), a noticeable heating load decrease is apparent in the cooler Climate Zones. In general, home conditioning energy requirements increase by an average of 76% across the country. As expected the increasing demand for cooling is most marked in the warmer and higher humidity climates, while in some cases (i.e. the Melbourne, Canberra, and Hobart climates) the reduction in heating requirements result in a net reduction of building conditioning energy load.

It is reasonable to assume that houses built today are likely to still be functioning in 2070 and will need to provide comfortable temperatures for the occupants. The modelling showed for all climates the benefits of adding insulation to decrease the energy loads based on the climate change predictions for 2030 and 2070 (cooling load in the hot climates and heating load in the warm climates). This is shown in Figure 5, a passive solar house with high thermal mass design and large areas of north-facing glazing, optimal in cooler climates. It presents results of simulations of the passive solar model in each of the cooler climates, and includes the effect of variation to insulation levels.

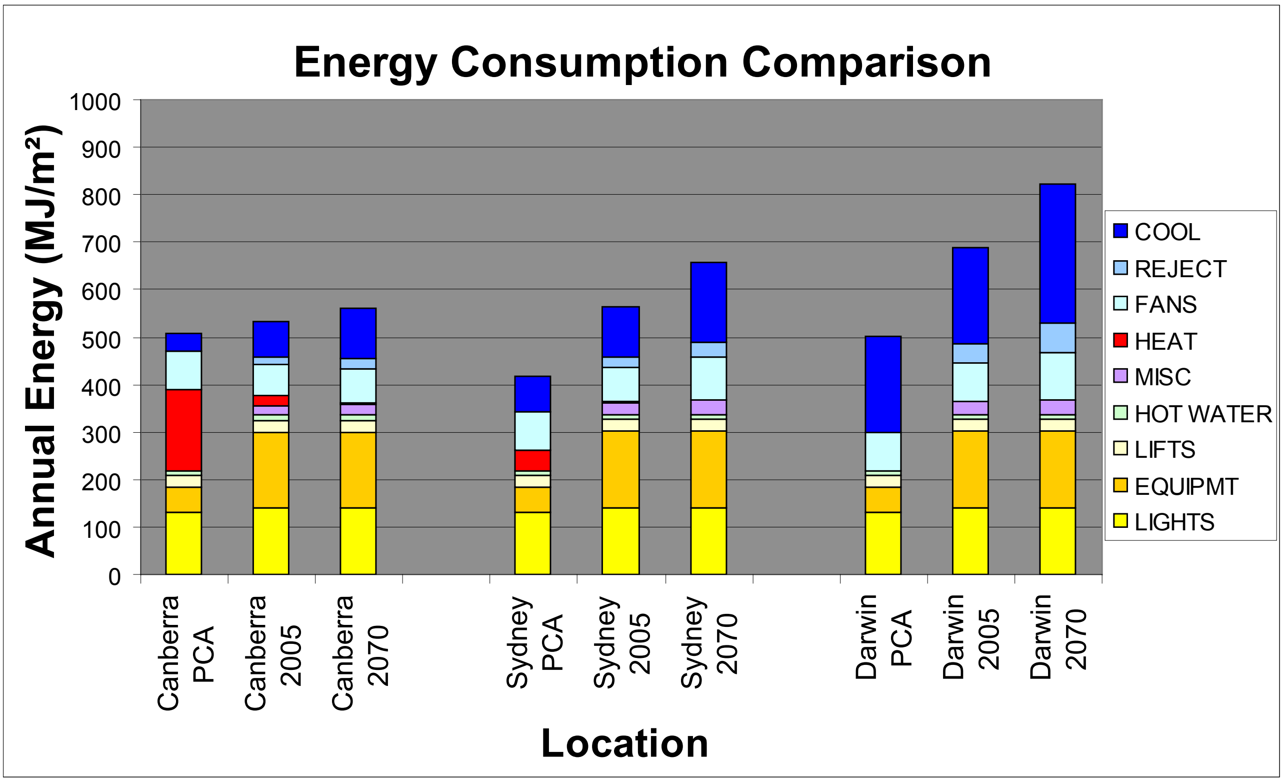

Figure 6: Simulated Energy End Use Consumption of 10-Storey Offices in Key Locations.

### *Offices*

Partly because of the high internal loads from tenant lighting and power consumptions assumed in the simulations, heating was only a small fraction of the space conditioning energy demands in all current climates – a far smaller fraction than is generally experienced in practice. Consequently, the simulated results show only modest savings in heating energy consumption, and even in Canberra they show increases in energy consumption overall. The energy implications of current and forecast 2070 High scenario conditions are compared with Property Council Energy Guidelines for the key climates of Darwin, Sydney and Canberra to show the relative impacts on office towers in hot temperate and cool temperate climates in Figure 6.

The equipment loads used were those assumed in the Australian Building Greenhouse Rating Scheme (http://www.abgr.com.au/new/default.asp), 15% of lights and 50% equipment remain on out of hours. It is apparent that these assumptions have a large bearing on the heat energy consumption in particular. Therefore, to indicate the sensitivity of the simulation results to a key building performance parameter, comparative values were plotted for a range of assumed air change rates in Figure 7. The results show that changes to this key building performance parameter generates only a minor change to the annual energy end use consumption.

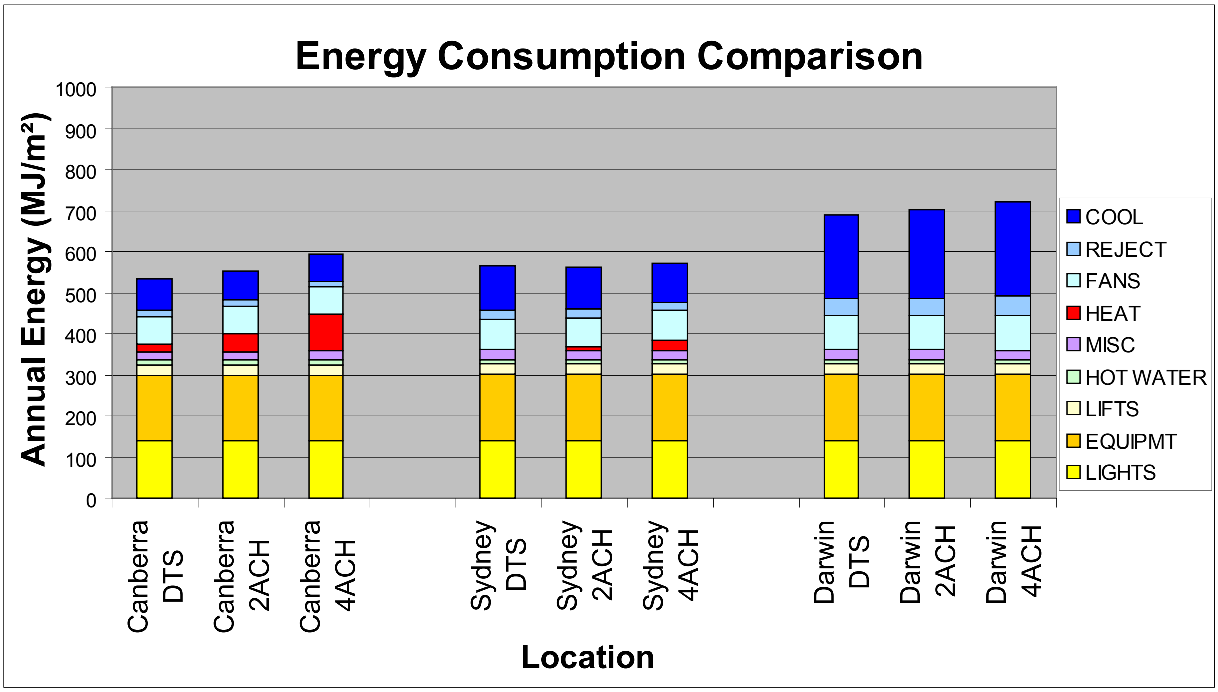

Figure 7: Simulated Energy End Use Consumption of 10 Storey Offices with HVAC sensitivity (includes HVAC performance sensitivity to the Air Change Rate (ACR) of the building).

### *Hospital modelling*

Energy modelling and analysis of one hospital was completed to help understand the implications of climate change on critical buildings. An overview of the modelling and results is provided below with the full report detailed in Appendix C.

The study was completed to predict the variance in plant performance of a Melbourne based hospital when subject to different climatic conditions. Eight climatic weather files were modelled including the IWEC, a CSIRO base case provided by BRANZ and six predicted weather files developed by Energy Partners based on CSIRO specifications for the years 2030 and 2070.

The simulations were carried out utilising Integrated Environmental Solutions' Virtual Environment software package incorporating the powerful Apache thermal software module. A 3-Dimensional computer model of the hospital facility was created and an analysis was carried out to ascertain the model's HVAC systems energy consumption. The hospital consists of three above ground levels, rooftop plantrooms and two underground car park levels.

The simulation results demonstrate that the overall energy consumption for the facility on a MJ per metre squared basis is slightly lower than the IWEC weather file. Not unexpected, this is due to the reduction in gas consumption from the boilers which, in the Melbourne climate, operate for a longer period of time than the chillers.

However, although the gas fired boilers operate less, the chillers operate for longer. Consequently the greenhouse gas emissions increase for the predicted weather file scenarios due to the increased reliance on electrical energy in lieu of gas.

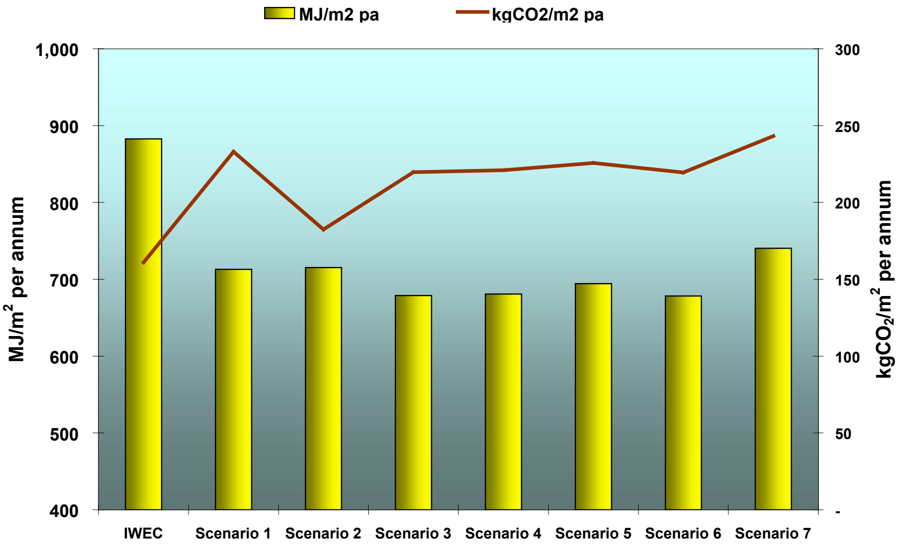

Figure 8: Energy Consumption and Greenhouse Gas Emission Variance based on Predicted Weather Files

| | |
|---|---|
| **IWEC:** | Current Melbourne International Weather File for Energy Consumption |
| **Scenario 1:** | Current CSIRO Weather file provided by BRANZ |
| **Scenario 2:** | 2030 High (all 4 elements changed max amount) |
| **Scenario 3:** | 2070 High Temp (RH, wind and solar as for now) |
| **Scenario 4:** | 2070 High Temp and Solar (RH and wind as for now) |
| **Scenario 5:** | 2070 High Temp and High Reduction RH (wind and solar as for now) |
| **Scenario 6:** | 2070 High Temp and Wind (RH and solar as for now) |
| **Scenario 7:** | 2070 High (all 4 elements changed max amount) |

The internal design temperature analysis demonstrates that there is an increase in the number of hours that the internal design temperature cannot be met with the installed air conditioning system using the predicted weather files. Despite the fact that the number of hours above 25˚C triples, the actual number of hours over the design condition is around 3 - 4.5 per annum in lieu of 1.2 hours for the IWEC file. This increase of 3-4.5 hours per annum over the design condition is not significant.

It is noted that the energy consumption of the hospital when the IWEC weather file is applied is significantly higher than the other scenarios. The cause for this is not fully understood, however it is appears that the IWEC file is a colder year than the other files resulting in a greater requirement for heating.

## 6.2 Conclusions

For both residential and commercial buildings (offices) the largest increase in energy consumption due to climate change was for cooling. Not unexpectedly the difference in the current cooling load requirements compared to the 2070 scenario increased in warmer and more humid environments. The nationwide impact of this is significant with cooling demand more than tripling current levels by 2070 and for homes and increase in air conditioning by an average of 76%.

The hospital modelling was carried out for a Melbourne location which did not show the same trend but a small reduction energy consumption. This shows the that in colder climates, and dependant on design and use due, the reduction in heating need can compensate for some if not all of the increase in cooling needs.

For all areas or Australia (both cooling and heating climates) increasing insulation has a significant impact in reducing the predicted energy loads based on the 2070 scenario. Given the difficulty with some building components to increase insulation as the climate changes, this provides and opportunity to look at whether higher levels of insulation should be installed in buildings at construction to ensure they are future-proof.

## ISSUE TWO

**“Investigate the effects that climate change may have on the social and lifestyle needs (including the health) of Australians at home, in the workplace and in the community and the requirements (if any) for adaptation of buildings to meet these needs”**

# 7. SOCIAL AND LIFESTYLE NEEDS AS A RESULT OF CLIMATE CHANGE

Climate plays an integral role in our lives for a whole range of decisions about where we decide to live, what we wear, whether we play outside or inside, how we think and act in our workplace and how we feel generally etc. Any significant change in climate is likely to have some effect on the social and lifestyle needs of Australians at home, in the workplace and in the community. This section of the report looks at these issues and examines the possible need for adaptation of buildings to meet them.

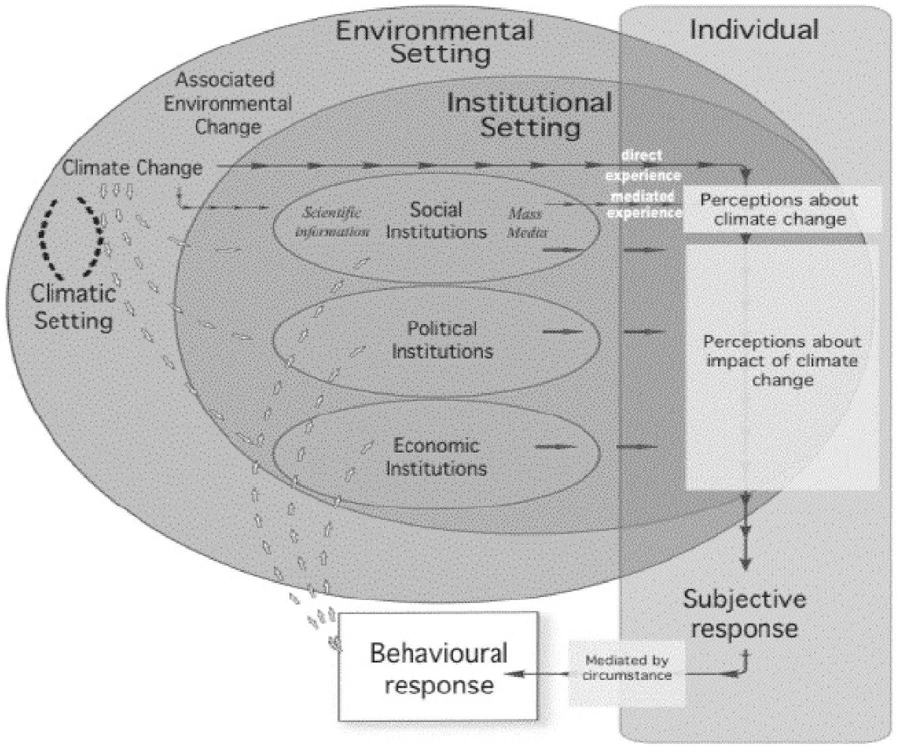

Figure 9: Conceptual Framework (Niemeyer *et al* 2004).

## 7.1 A conceptual framework – perception versus reality

Much of the literature suggests that as a result of climate change, eventually many current building standards, materials and designs will no longer be suitable, especially as we generally look to buildings having an effective long-term life (at least 50 to 100 years). For solutions, the argument generally follows that more energy-efficient new building design will reduce greenhouse gas emissions. This will reduce humankind’s contribution to future climate change, and more effective new building design changes will reduce the effects of climate change on humankind, as will effective retrofitting and redesign of older buildings, at least in terms of lengthening their effective lives.

However, as a range of experts point out, “there are a number of difficulties in developing a framework for exploring social responses to rapid climate change. Conceptualising rapid climate change within the natural sciences is complicated enough: adding human behaviour even more so. There are a number of complicating factors. First, humans are active agents within larger environmental systems. They act ‘reflexively’ rather than passively in response to environmental stimuli or, to put it another way, facts do not determine behaviour so much as perceptions about those facts. Second, these perceptions are mediated by a range of factors, such as public understanding of science and institutional settings (role of the media, provision of social security and defensive measures etc). Finally, the relationship between perception and behaviour is itself complex.” (Niemeyer *et al* 2004)

Early in the debate, scenarios of climate change were so dire and cataclysmic that few people could grasp their meaning, and even if they did, felt that there was little they could do about it anyway. With scenarios now being largely within understandable and meaningful limits (for urban Australia), people’s perceptions are likely to have changed considerably, although there is no Australian-based social research evidence to show how far views have changed or the extent to which people are prepared to act in response. Artcraft Research has examined the issues in passing in extensive qualitative research on appliance energy efficiency rating labels which supports this view. However, a program of research is recommended to establish and expand on our understanding of how people perceive the situation, what they understand and how they relate to various strategies of ‘response’, ‘coping’ and ‘adaptation’. This program would also help to assist and guide development of any communications strategy aimed at changing the community’s perceptions and behaviour in this area.

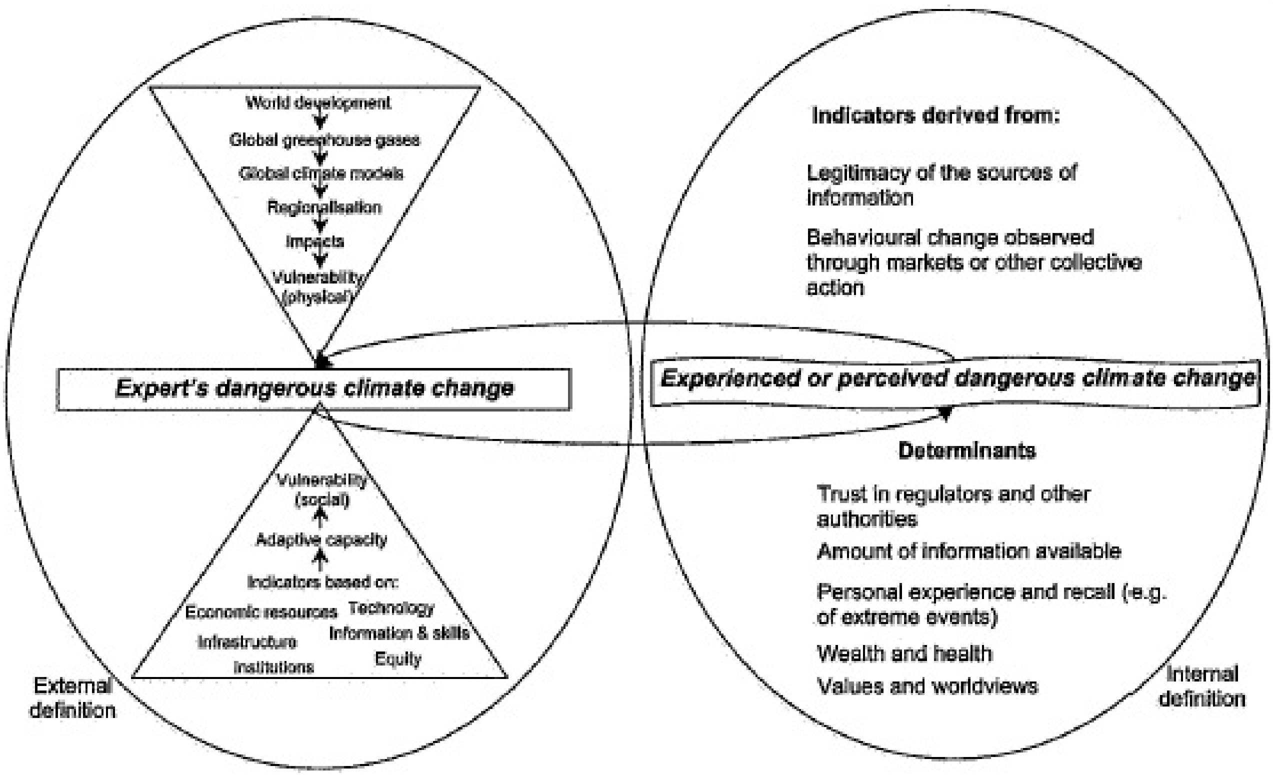

Figure 10: Componenets of external and internal definitions of dangerous climate change (Dessai *et al* 2004).

According to Wilkinson (2002), "In considering appropriate strategies to deal with climate change, whether they are labelled 'response' or 'coping' or 'adaptation', we must consider the nexus between sensitivity to changes, capacity to change and adapt, and vulnerability to change. These factors will inform cost/benefit estimates and the social and political assessment of acceptability of risk. Ultimate action on responses will also be driven by a sense of ethics and morals."

The Intergovernmental Panel on Climate Change points out in its Third Assessment Report (IPCC 2001), that:

> *Causal models of social processes have large uncertainties, and pose problems that are of a qualitatively different character than those encountered in modelling non-human components of the Earth system. This is due, first and foremost, to the inherent reflexivity of human behaviour; i.e. the fact that human beings have intellectual capabilities and emotional endowments enabling them to invent new solutions and transcend established 'laws' in ways that no other species can do. As a consequence, predictive models may well alter the behaviour that they seek to predict and explain – indeed, such models are sometimes deliberatively used for this purpose. … research on human drivers and responses to climate change cannot be expected to produce conventional predictions beyond a very short time horizon.*

## 7.2 Encouraging a response – pull vs push

In Australia, one leading designer and advocate of social change comments that "The non-scientific community, the design community, in its broadest sense, needs to acknowledge that climate change will change the mood of people at large and at the same time, the mood of the community needs to be changed towards the situation – the latter needs to prefigure the former. A disposition towards a questioning, observing, understanding, thinking, exploring and acting responsibly needs to be designed by intensifying the will, mood, climate to do these things." (Fry 2001).

Some sources suggest using social marketing[2] to guide and accelerate desired behaviour change, both to limit our contribution to future climate change and to react appropriately to climate change that is already developing. One example of this is to be found in the objectives of the UK Department for Environment, Food and Rural Affairs' proposed communication strategy launched in February 2005 (DEFRA 2005), which are:

- to develop a detailed short to mid-term climate change communications programme designed to raise awareness, change attitudes and encourage changing public behaviour, and

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[2] Social marketing is the planning and implementation of programs designed to bring about social change using concepts from commercial marketing.

- to provide a written report containing fully-developed solutions to the challenge of improving on-going Government communications on energy efficiency and other climate change related issues.

In Australia, a number of strategies are already in place to educate and attempt to convince consumers to change behaviour (e.g. compulsory energy efficiency labelling of domestic electrical and gas appliances, plus some water using appliances, home energy rating schemes etc). Introduction and regular upgrading of minimum energy performance standards (MEPS) attempts to speed up this process.

More recently, we have seen the banning of top-loading washing machines (which use around twice to three times as much water per load as front loading washing machines) at least raised as an option in a Victorian Government options paper (DSE 2003) South Australian Premier Mike Rann announced on 3 June this year that electric hot water storage systems will be banned in all new houses from 1 July 2005 in South Australia "as part of the campaign against climate change" (Kelton 2005), together with substantial subsidies for owners of existing houses to replace their existing electric system with a solar hot water system.

## 7.3 Adapt, modify or move

Perhaps one of the most fundamental questions to be asked in terms of buildings is how will people react to (further) changes in climate – will they accept changes to the internal environments of buildings, or will they adapt buildings to counter them? We suspect that inevitably it will be a combination of both. And, indeed, a third possibility is to move to a different building, a different town or city or even a different climatic region.

Take, for example, the fact that while most people will still accept some (often considerable) temperature variation in their homes, they will generally accept far less temperature variation in their offices, shopping malls or other public buildings. To respond to climate change by accepting greater temperature variation in offices, shopping malls and other public buildings would presumably be logical (i.e. thereby not increasing greenhouse gas emissions through continuous air-conditioning, but also because they accept some temperature variation at home already).

However, the increasing move to install ducted (whole-house) air-conditioning in homes suggests otherwise. It is suggested that this latter movement will possibly require two new coal-fired power stations to be built in NSW, with the percentage of homes in that State with air-conditioners increasing from 27.7% in 1999 to 54.1% in 2005, and showing no signs of abating (Energy Efficient Strategies 2006).

Unless well-designed, the response to air-conditioned accommodation (with open-able windows and circulating fans, in which air-conditioning or heating is used only when temperatures rise or fall by, say, 5°C) can be negative. On the other hand, the air-conditioning systems in office (and public) buildings are usually set at a constant temperature (rather than set to come on only when the temperature within the building rises or falls outside an agreed temperature range). While this is often required by workers occupational health and safety standards, it is not necessarily ideal for most people. Studies of air-conditioned offices suggest that while most people will find the temperature reasonably 'comfortable', a large proportion report it as too warm or too cold, depending on their own metabolism and also on the amount of activity their job requires.

The whole issue of what constitutes 'comfort' in different environments has been examined extensively, with Shove and Chappells (2004) concluding that:

> *… responses (to user feed-back surveys and post-occupancy studies) are extraordinarily difficult to interpret, partly because 'comfort' means so many things to different people and because professionals and 'lay' users often have different interpretations of the causes and sources of discomfort. In the real world, feeling comfortable and being productive may, for instance, be more to do with feeling cared for or with having control over one's immediate environment than with temperature, humidity or ventilation. What actually happens with respect to the day-to-day management of indoor climate depends, in part, on the social and institutional organisation of the building and its controls and on the strategies and actions of those in charge.*

Chappells and Shove (2004) observe that "The extent to which domestic air-conditioning becomes 'normal' depends on the ready availability of appropriate technology and on how such systems are defined and understood not only by 'end' consumers but also by designers, developers and estate agents." A well-designed building with ample eaves and windows and good air circulation aided by fans may reduce (and in some areas eliminate) the need for air-conditioning in the home, yet the installation and continuous use of domestic air-conditioning is still on an upwards trajectory.

Indeed, with most cars now being sold with air-conditioning (often as a 'free' or heavily discounted inclusion), it is possible for people to leave their air-conditioned homes in their air-conditioned cars, spend all day in air-conditioned offices, except perhaps for brief lunch-time trips in their air-conditioned cars to air-conditioned shopping malls, then return home to their air-conditioned homes, without ever (or only for very brief periods) being subjected to the weather/climate 'outside'. In a sense, some people have already established a more-or-less climate-independent lifestyle, but at what cost in terms of increased greenhouse gas emissions?

The climate change projections suggest that the intensity and frequency of bushfires are likely to increase overall. In cities like Sydney and Canberra, many people live adjacent to 'the bush', and both these cities have had major bushfires penetrate the city boundaries in recent years. When such experiences are perceived as 'rare' events, most people will generally accept this and remain where they are on the basis that the positives of a location adjacent to bushland outweigh the negatives (in their view), or simply that this is where they have chosen to live. Some may do little more than ensure that they have some cleared area around their homes; others may modify their homes so as to be better equipped to meet the next challenge.

Climate change will possibly reduce the frequency of sea breezes over areas of eastern Sydney (i.e. near the coast) and possibly increase the frequency of temperature inversions over western and particularly south-western Sydney (i.e. in the lee of the Blue Mountains), combining to reduce the amenity and decrease the quality of the air in Sydney overall. While many will stay put and modify their homes to meet this challenge (e.g. install air-conditioning so that doors can be closed), some others will move to a different part of the city or move out of Sydney altogether.

## 7.4 Identified research needs and opportunities

A program of ongoing social research is needed to evaluate the knowledge and views of the population concerning climate change, and to gain an understanding of the factors likely to stimulate appropriate responses towards the implications of climate change in both the home and workplace (or other buildings in which they spend much of their time).

In particular, there is a need to research the 'sea change' response to climate change, that is, those people who will choose to move (to what they perceive as a more appropriate climate for them) rather than adapt.

There is also a need to research prospective home-owner aspirations and needs in terms of home design versus the expectations and strategies of home designers and builders, and the extent to which either/both are in alignment or conflict with home design which is appropriate to deal with the challenges of climate change.

A program of ongoing social marketing is needed to reinforce good behaviours and to assist other people to adopt new and appropriate behaviours. In this case, the program would take full advantage of (rather than ignore or compromise) the opportunities provided by adaptation of buildings (and other relevant energy efficiency and sustainability initiatives) to meet the challenges of climate change.

# 8. HEALTH IMPLICATIONS OF CLIMATE CHANGE

## 8.1 Heat and cold-related mortality and morbidity

The microclimate we live in intimately influences our health. There is a narrow band of ambient temperature – between 20°C and 40°C – within which the naked human body can maintain the required steady state body temperature of 36-37°C (Leithead and Lind 1964). An elaborate physiological control mechanism for body temperature involves (i) heat loss or gain through evaporation of sweat or condensation of humid air on the skin, (ii) direct heat transfer to solids contacting the body, (iii) heat convection from moving air or water, and (iv) heat radiation to and from the body (Kerslake 1972). The climatic factors that influence this heating and cooling are temperature, relative humidity (influences the ability of the body to cool through sweating), wind-speed (influences the cooling by convection due to air movement over skin), and heat radiation from the sun or hot objects near a person.

Both cold and hot temperatures can have deleterious effects on health (see Table 8). The use of clothing, the construction of buildings, and measures to reduce dehydration are the main ways by which these health effects are prevented. Cold temperatures lead to increased morbidity and mortality from (principally) respiratory diseases, and hot temperatures lead to increased cardiovascular disease and death. A New Zealand review of housing energy and health (Matheson, Howden-Chapman *et al* 2001) highlighted the role played by humidity and damp conditions in health impacts from poorly insulated dwellings. Humidity also plays an important role in the effects of hot environments, as high relative humidities reduce the function of the body's sweating mechanism in regulating temperature (Kerslake 1972).

Some local climate and epidemiological data illustrate the health impacts that may occur. A comparison of variations of average monthly temperatures in Sydney and Darwin shows that Darwin temperatures vary little across the year, while in Sydney they vary by a factor of two (Figure 11). In corresponding fashion, the variation in monthly total mortality in Darwin (Figure 12) is small and shows little obvious pattern, while in Sydney some 40% more deaths occur among people over age 65 in winter than summer (Figure 12), and there is a small winter excess in the younger age group.

Table 8: The Health Effects at High and Low Temperatures on Human Physiological Functioning. (With Consideration of Indoor Temperature and Dampness).

| Extreme | Temperature range | Physiological condition |
|---|---|---|
| Hot | > 24°C | Cardiovascular strain with increase of strokes and death can occur following prolonged exposure to night-time temperatures above 24°C (there appears to be a delay of one to three days before effects occur). |
| Cold | Between 16°C and 19°C for most of the time | Only a small risk of adverse health effects. |
|  | Below 16°C | Increased risk of respiratory and cardiovascular conditions. |
|  | Below 10°C | Cold air streams can affect the respiratory tract and the immune system and reduce the resistance to infection. |
|  |  | A risk of hypothermia, especially for older people (65 years +). |

* Source: Adapted from (WHO 2004).

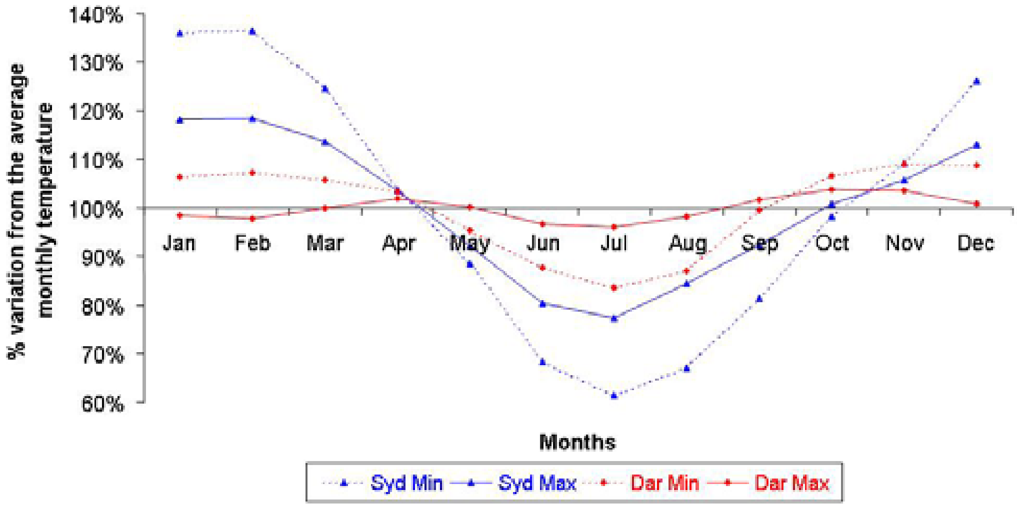

Figure 11: Climate Variation in Sydney and Darwin: Percentage increase or Decrease in Average Monthly Temperatures from the Annual Average Temperature.

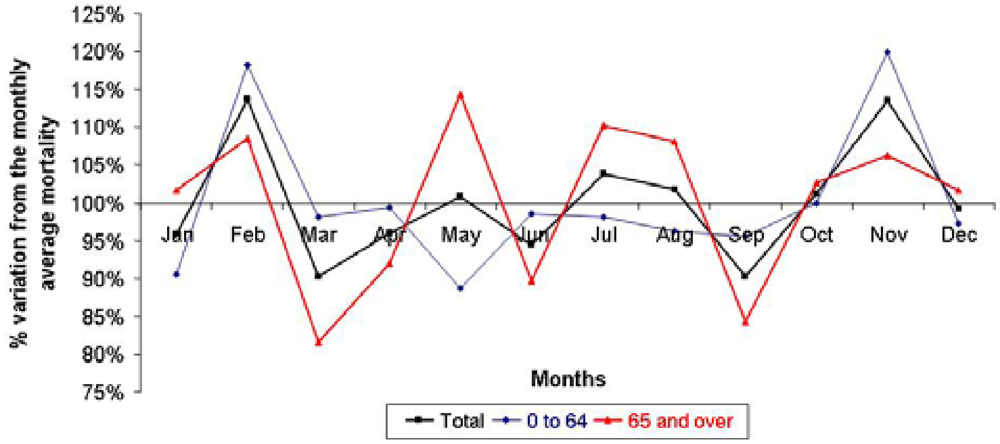

Figure 12: Seasonal Variation in Mortality for Older and Younger People in Darwin: Percentage Increase or Decrease in Average Monthly Mortality from the Annual Mortality

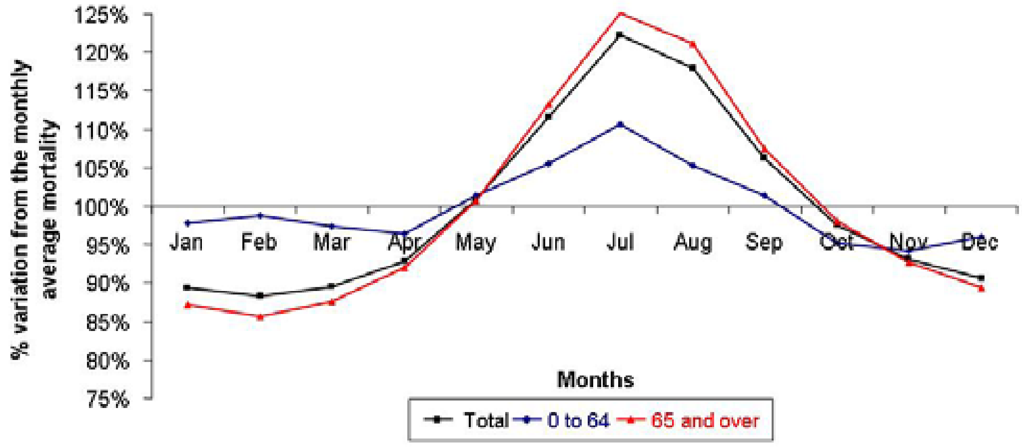

Figure 13: Seasonal Variation in Mortality for Older and Younger People in Sydney: Percentage Increase or Decrease in Average Monthly Mortality from the Annual Mortality Figure.

Time series analysis has been widely used to quantify the relationship between mortality and temperature. Linear, V- or J-shaped relationships have been described, with mortality increasing both at the cold end and the hot end beyond a range of no effect. Mortality is lowest in the range 23-27°C for maximum temperature and in the range 16-23°C for the minimum. However, people are able to slowly acclimatise to environments outside these ranges. People in lower latitude (hotter) cities can withstand higher temperatures, but are more affected by colder temperatures, and people in higher latitude (colder) cities can withstand cooler temperatures, but are more affected by warmer temperatures (Keatinge, Donaldson *et al* 2000; Curriero, Heiner *et al* 2002). Regions where housing provides poor indoor and outdoor protection against cold have higher levels of winter excess mortality than expected for the coldness of their winters

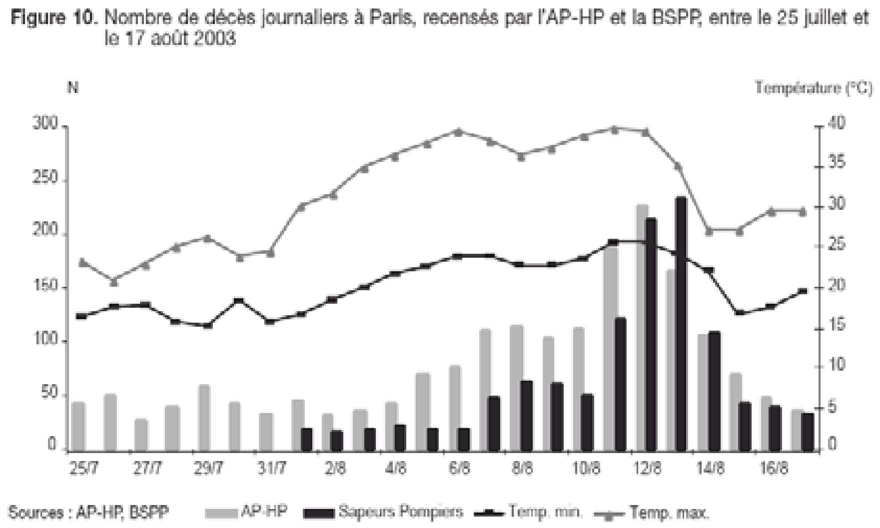

Figure 14: Daily Deaths, Maximum and Minimum Temperatures in Paris during the 2003 Heatwave (July to August) (Institute de Veille Sanitaire 2003).

(Keatinge, Donaldson *et al* 2000). Periods of sustained high temperatures appear to have larger impacts on mortality, probably because of the physiological stress posed by high night-time temperatures.

These estimates represent mortality thresholds for outdoor temperatures. The most suitable indoor temperatures for comfort, concentration and fine motor ability have been estimated to be between 18°C and 24°C under normal "dwelling circumstances" (WHO 1984). Slightly higher temperatures (ca. 2°C) are allowed for elderly people due to their more sedentary lifestyle (WHO 1984). Another document recommends a narrower range of 20-22°C as the optimum air temperature for residential rooms (WHO 1982). The scientific literature has mostly agreed upon the range 18-22°C (Collins 1993). Maximum temperatures for working conditions should not exceed values of more than 24, 25 or 26°C (depending on the country) (Collins 1993). Active and passive heating and cooling of buildings, air-conditioning, and space heating can create indoor climates that are comfortable when outside temperatures exceed or are below these comfort ranges.

Projected climate change is expected to increase the average and variability of temperature, rainfall and wind, which in turn would influence how buildings protect us from these elements. Heatwaves are rare events that vary in character and impact. They could become more frequent, intense and longer with climate change. The most recent major heatwave outside Australia occurred in France and neighbouring countries during August 2003. Detailed estimates indicate that at least 15,000 people died in France during the two weeks of unusually hot weather (Institute de Veille Sanitaire 2003). The situation in Paris is shown in Figure 14. Other studies of mortality and morbidity in relation to heatwaves or variations in temperature (Hajat, Kovats *et al* 2002; Kovats, Hajat *et al* 2004) show that respiratory disease morbidity and mortality increased among the elderly during a London heatwave.

An assessment of temperature-related mortality risk in people over 65 in Australia for 2020 and 2050 (conducted by McMichael and others in 2003), concluded that:

> *Temperate cities [at baseline and in the future] show higher rates of deaths due to heat than tropical cities. Global warming is projected to reduce the number of cold winter days, and a few cities [i.e. Canberra] are expected to experience fewer annual deaths in the short-term. In the medium-term, however, these health gains would be greatly outnumbered, and climate change is expected to increase the overall number of temperature-related deaths in all cities, assuming no human adaptation to these changes.*

Perth and Adelaide were estimated to currently have the highest number of temperature-related deaths per capita in the 65+ age-group (rates of 199/100 000 and 127/100 000), due to the high frequency with which maximum temperatures above 35°C are recorded each summer.

Although health *benefits* are expected to be very small in terms of mortality, the overall warming is likely to reduce the winter-time peak of respiratory morbidity that is observed in most capital cities. However, given the relatively minor contribution that cold weather is expected to make on the burden of disease in Australia in the medium- and longer-term, the rest of this section focuses on issues relating to the hot end of the temperature spectrum.

### *Vulnerable groups (relevant to the current project)*

The physiological functioning of elderly people is less able to compensate for exposures to cold and heat, and consequently they are vulnerable to cardiovascular strain and death (WHO 2004). In particular, they have a reduced sweating capacity, and it is essential that the sweat they do produce evaporates (Havenith 2001). This does not happen if ambient water vapour pressure is high. They are also more likely to have a chronic medical condition that upsets the normal thermoregulatory mechanism. Most deaths from thermal stress occur at home or in nursing homes before people can seek medical attention (O'Neill, Zanobetti *et al* 2003; Dhainaut, Claessens *et al* 2004). Older people, the sick, and in some situations people with disabilities, are less able to travel to cooler environments (such as public spaces) during heatwaves. They are also physically weaker and may be unable to open and close stiff windows or other portals unassisted. An analysis of the heat-related deaths in the Chicago heatwave of 1995 (Semenza, Rubin *et al* 1996) showed that those at greatest risk of dying were people without air-conditioning who were socially isolated and had pre-existing medical illnesses. Infants and small children are also vulnerable to climate exposures due to their small body size, insufficiently developed heat and cold regulation, and inability to take personal protective actions (WHO 2004).

The excess deaths that occur during heatwaves are not just deaths of those who would have died anyway in the next few weeks or months due to illness or old age. There is strong evidence that these summer deaths are indeed 'extra' and the result of heat-related conditions alone (UK NHS 2005).

### *Building-related risk factors*

From a health perspective, increased temperatures over long periods will have a major impact and minimum night-time temperatures are the most critical during heatwaves in terms of mortality. When they are high, people have no respite from hot temperatures and the stress on the cardio system builds over several days.

People spend, on average, 90% of their days inside buildings so it is important their homes can provide cooler evening temperatures during hot periods or heatwaves. High thermal mass houses that are not insulated (e.g. most double brick buildings in Australia) generally work well in summer in Climate Zones like Canberra (which has a wide diurnal range), because you can open the windows and cool the house down. However during a heatwave, temperatures in these buildings increase over several days (because there are no cool night-time breezes). Buildings with high thermal mass that are insulated on the outside, and have external shutters to prevent radiation onto internal floors and walls, work much better in terms of reducing heat build-up during heatwaves. Even these buildings would probably need some additional cooling mechanisms to manage night-time heat during prolonged heatwaves (just because insulation is never perfect; people come in and bring some heat with them etc). In tropical climates and climates without a substantial summer diurnal variation, the best building structure is one that is lightweight (i.e. no mass). Houses with mass will not cool off in these regions because the temps at night are not low enough. The best building in this Climate Zone, from a health and comfort perspective, would be a light structure on stilts that can pick up breezes and cool all around the house (for further information on adaptation options see Section 9).

A comparison of seasonality of mortality for people who lived in "warm homes" and people living in "cold homes" in the United Kingdom (Wilkinson, Armstrong *et al* 2001) showed that people living in the coldest 25% of homes had a much higher mortality (about 50%) in the winter than those living in the 25% of warmest homes. In the summer there was no difference (NB: summer temperatures in the United Kingdom do not, generally, intrude into the mortality risk range). Although this does not directly apply to Australia because we do not have the winter temperatures as cold as the United Kingdom, it does show the relationship between temperature, buildings and health.

Building-related health risk factors, particularly in urban areas, cannot be considered in isolation from air pollution. Cold periods during winter coincide with the use of wood fires for heating in some urban areas in Australia. This leads to high levels of carbon monoxide and particulate matter in the air, especially at night. Many epidemiological studies (e.g. in Christchurch, New Zealand – Hales *et al* 2000; Kjellstrom *et al* 2002) have shown that daily temperature and air pollution independently increase daily mortality, especially among elderly people. Several studies in Australian cities (Sydney, Melbourne and Brisbane) have also documented the importance of considering both climate and air pollution when interpreting health effects of either factor. Heatwaves coincide with peak air pollution, primarily nitrogen dioxide and ozone. Increased mortality in relation to these factors has also been documented in studies in Europe, including the recent extreme heatwave in France in 2003.

### *Urban heat island and thermal mass*

People living in urban environments are at greater risk than those in non-urban regions during heatwaves (Smoyer, Rainham *et al* 2000). The "urban heat island" phenomenon – wherein concrete-and-asphalt, often treeless, environments trap and retain heat – combine to raise temperatures (particularly overnight) relative to surrounding rural areas (Oke 1982; McGeehin and Mirabelli 2001). This is due to many factors, including less radiant heat loss in the urban canopy layer, lower wind velocities and increased exposure to radiation. The temperatures of urban heat islands tend to increase with the number of inhabitants, the size of the city, and the density of buildings (Oke 1982; Hogan and Ferrick 1998).

During heatwaves, inhabitants of urban areas may experience sustained thermal stress both day and night. Buildings discharge heat in winter (from space heating) and summer (from cooling), and from the use of domestic appliances all year round (lighting, computers and photocopiers etc). The amount of heat released depends on the role of insulation and ventilation in a building (Arnfield 2003). Buildings can also retain heat at night if ventilation *between* buildings is inadequate (WHO 2004). Green spaces play an important part in the urban bio-climate, by increasing shade and hence reducing radiative load. They also have an evaporative cooling affect. Urban design thus plays a crucial role in micro-climate control in built-up areas.

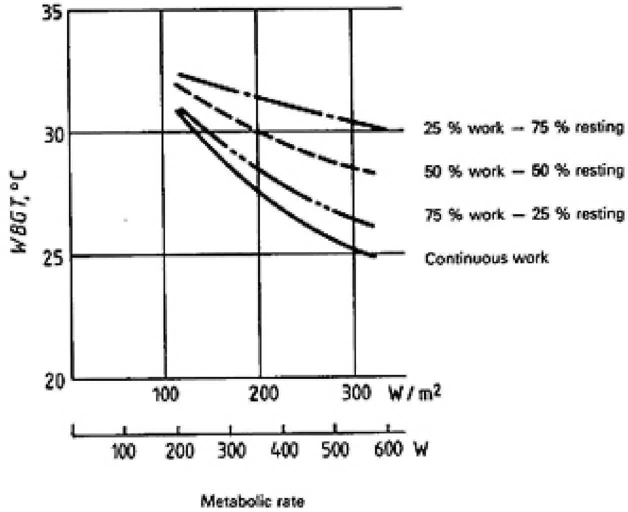

Figure 15: Curves for Work/Rest Cycles at Different Wet Bulb Globe Temperature (WBGT) Heat Loads (International Standards Organization, 1989).

NB: The work intensities on the bottom scale (200 to 500 Watts) correspond to: office desk work (200 W), average manufacturing plant work (300 W), construction work (400 W) and very heavy labouring work (500 W).

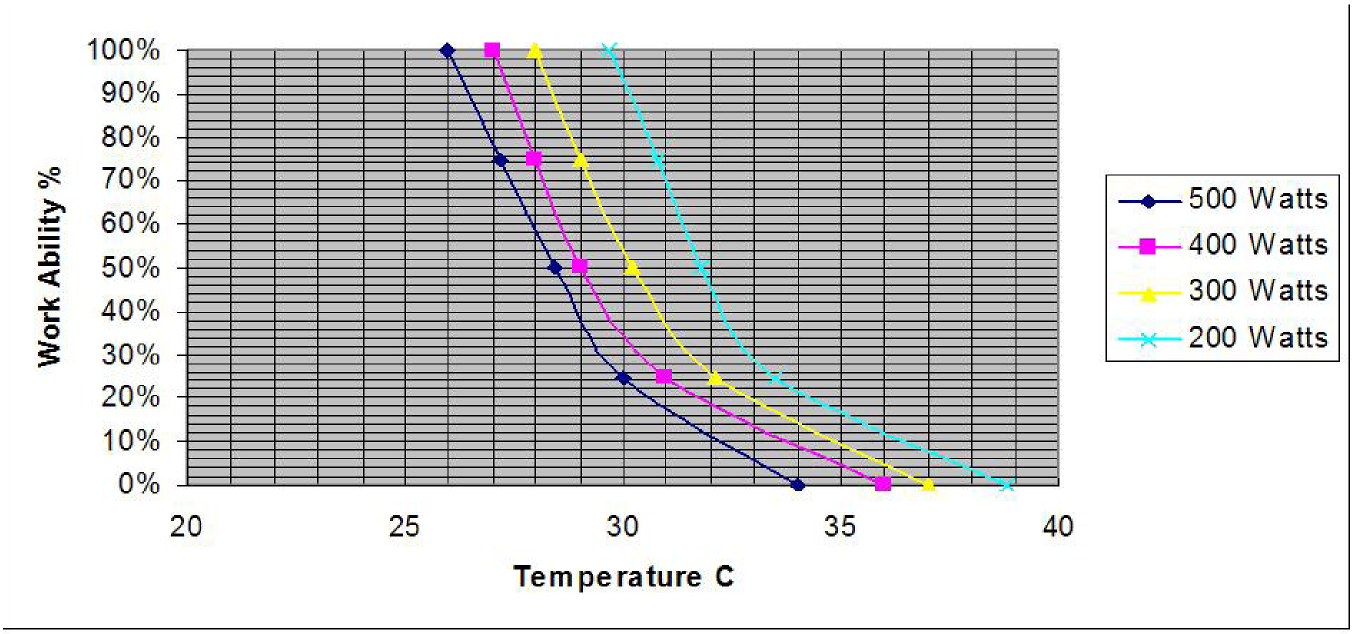

Figure 16: Relationship between Wet Bulb Globe Temperature Heat Loads (degrees Celsius) and Estimated Ability to Work at Four Work Intensities (Watts) for Acclimatised Workers.

"Work Ability %" is the time that a worker can actually work. The remaining time he/she needs to rest to comply with the ISO health standard

### 8.1.1 Impact of heat on ability to work

The work environment presents significant challenges and risks. First, people are often required to work during set hours, which are usually not dictated by the suitability or comfort of the climatic environment. Second, certain types of workplaces cannot easily or economically be air-conditioned, and many are not equipped for indoor comfortable climate control.

Too hot working environments are not just a question of "comfort", but a real concern for health protection and the ability to perform work tasks. If heat builds up in the body, the core body temperature will increase from the usual 36-37°C and heart rate will increase (Hales and Richards 1987). As the core body temperature increases, the person will experience increasing "fatigue", which can be measured with objective performance tests or with subjective perception scales (Williamson, Feyer *et al* 2000). For un-acclimatised people, the ability to perform at full capacity is reduced at temperatures above 22.5°C. For people who are acclimatised this reduction starts at 26°C. These temperature values are given in the form of wet bulb temperature, a measure that incorporates the impact of relative humidity, heat radiation and air movement into a heat index.

The international standard for work in hot environments (ISO 1989) provides a framework for analysing the reduction of physical ability to work as temperature increases. The International Standards Organization (ISO) standard identifies maximum wet bulb globe temperatures for different lengths of work days (8 hours, 75% reduction of work hours, 50% reduction, etc) depicted in Figure 15. If work continues beyond these temperature limits, a worker is at a high risk of diminished physical ability to work (Kerslake 1972; Dawson 1993), diminished mental task ability (Ramsey 1995), increased accident risk (Ramsey *et al*, 1983), and eventually heat exhaustion or heat stroke (Hales and Richards 1987). The ISO standards are intended to maintain core body temperature well below 39°C. When a person's core body temperature exceeds 39°C, acute heat disorders may occur. Above 40.6°C, life-threatening hyperpyrexia starts to occur (Leithead and Lind 1964).

The temperature relationships for different physical work intensity can be converted into curves showing how the ability to work reduces as temperature increases. The impact of changing temperatures can be assessed from these (see Figure 16 from (Kjellstrom 2000) based on the data in Figure 15). If a typical person works without a rest beyond the temperature limits, their body temperature will rise and physiological signs of exhaustion will start occurring.

Hypothetical reductions in the ability to work, even for a one degree increase in temperature, can be quite dramatic. The reduction in ability to work starts at 26ºC. For each additional degree the reduction is as much as 20% or greater (even small temperature increases above already hot temperatures may be very significant).

This impact on human function is likely to have significant impact on the productivity and economic performance of an organisation. For countries in the tropical zone, the workforce would already be limited in their ability to work due to climate conditions (compared to workers in temperate zones). Climate variability leading to hotter temperatures would further exacerbate this situation. The economic losses may occur in farm work, industrial work, and office work, and they may occur in both the informal and formal labour sectors. The wet bulb globe temperature range, within which these effects would be expected to occur, is between 26–39°C (Figure 16).

The effects can be translated into productivity losses by measuring the output per work-hour in specific jobs at different wet bulb globe temperatures. They can also be assessed as health impacts, in terms of loss of function or "disability", as the impact of heat exhaustion on ability to work would be the same as a clinical disease that stops the person from working. The heat effects are reversible, but on a population basis their impact on the economy would be similar to clinical disease occurring at the same daily rate.

These impacts on ability to work and resulting "disability" impacts are dependent on the microclimate created in work places. Building designs that allow for a comfortable working environment even under conditions of climate change is essential for economic productivity and occupational health.

### 8.1.2 Mosquito-borne diseases

Climatic conditions are of great importance for the geographic distribution of mosquito-borne diseases, many of which are serious threats to public health.

#### *Current and future diseases of public health importance*

The risk of diseases transmitted by mosquitoes varies across Australia, depending on climatic zone, environmental setting and population density. A number of viruses relevant to human health are indigenous to Australia (Ross River, Barmah Forest, Murray Valley). Of these, Ross River virus and Barmah Forest virus are now established in all States and Territories. Outbreaks of disease from these viruses occur at different times of the year and at different intensities between years, depending on climatic conditions. Murray Valley encephalitis is a very serious disease (~30% fatality rate) which is endemic in the Kimberley. Very occasional (and notably large) outbreaks have occurred in the south-eastern states following extreme rainfall.

In addition, several diseases (which have a human as a host) are regularly imported into the country by infected travellers. Local transmission of dengue following the importation of virus from a traveller now occurs in most years in the northern and eastern parts of Queensland. Malaria cases are also reported each year in travellers who have acquired the disease overseas.

#### *The impact of climate change on patterns of mosquito-borne disease*

Little research has been conducted on the impact of climate change on patterns of Ross River and Barmah Forest virus diseases. Both diseases have a complex ecology, and the baseline relationship between climate and disease is still being explored. There are some small regions in Australia where the virus is not known to be enzootic in local wildlife (such as Canberra), and it is possible that warmer temperatures could expand the ecological niche of vector species into these areas. In the tropical and sub-tropical areas where disease is endemic, climate change is likely to extend the months when transmission can occur. This may happen also in temperate regions – provided sufficient rain occurs there as well.

McMichael *et al* (2003) conducted an assessment of future populations at risk of living in regions where dengue and malaria could be transmitted. There was a high likelihood that malaria and dengue would both extend their southern range by 2050 – in the case of malaria to include regional towns as far south as Rockhampton, Gladstone and Bundaberg. For dengue, climatic conditions may be suitable down to Carnarvon in the southwest, and Maryborough and Gympie in the south-east. The risk of infection and the complexity of prevention and control are higher for dengue than for malaria in Australia. Factors affecting these include the availability of treatments for malaria, the fact that malarious people remain infectious for a shorter period, the biting habits of the malaria mosquito, and the prevention options.

Many factors other than climate influence whether a disease such as dengue could become established in Australia, and if so how far south it could do so. Nonetheless, the experience of Cairns (in terms of the resources required to ensure that dengue does not become established), and the increase in tourism predicted for Australia, suggests it is prudent to consider building-related prevention options for dengue. These include screening all portals in buildings (i.e. windows, doors, chimneys etc). Buildings should also be designed to minimise the risk of water pooling in the infrastructure. It is also prudent to consider the high probability of an increase in the season of transmission of Ross River and Barmah Forest virus diseases in the (currently) temperate zones bordering on the sub-tropics. In addition, Japanese encephalitis may be considered a potential threat for people living in north-eastern Australia, although no research has estimated future risk zones for this disease.

This highlights the importance of an integrated approach with the heath authorities when setting requirements to "future proof" our homes.

### 8.1.3 Bushfire deaths and injuries

People living in bushfire-prone regions are at higher risk of burns, smoke inhalation, and the possibility of fire-related death. The increased risk of bushfires frequency and intensity in future, combined with risk of loss of life or damage to property and livelihood, may affect people's desire to live in bushfire-prone regions. Building Code requirements for building construction and location in high-fire risk regions has been discussed in Section 3.8.

## 8.2 Conclusion

Climate change will have an impact on social, health and lifestyle needs at home, in the workplace and in the community. However, with climate change occurring so slowly it is difficult for people to conceptualise the issue and therefore unlikely they will make any change now to reduce the future impact as facts do not determine behaviour as much as perceptions about those facts. With the greater awareness of the issue this however is slowly changing.

Increased temperatures and variability of temperatures will have an impact on people health. Health benefits are expected to be very small however there is likely to be a reduction of respiratory morbidity during the winter-time peak in colder climates. The increased temperatures are likely to have a greater negative impact on peoples health in particular the most vulnerable, the very young and the old as they are more likely to be able to regulate their internal body temperature. Periods of sustained high temperatures will have the largest impact such as heat waves.

It is important buildings are designed protect their occupants for variable temperature and prolonged heat, in particular being able to provide cooler evening temperatures during hot periods.

The increased temperatures are likely to have an impact on working environments, both health protection and ability to perform tasks, particularly when working hours are set and certain types of workplaces or buildings e.g. and open warehouse, cannot be climate controlled. The reduction in the ability to work starts at 26°C. For each additional degree the reduction is as much as a 20% drop in productivity.

**ISSUE THREE**
**"Identify options for reducing the vulnerability of Australian commercial and domestic buildings"**

# 9. ADAPTATION OPTIONS

This section outlines the various adaptation options for Australia's building stock with respect to each climate change issue, for:

- new and existing residential buildings
- new and existing commercial buildings
- health and lifestyle needs

Where applicable, suggested Code changes to meet these adaptation options have been highlighted.

## 9.1 Average temperature increases and more extreme temperature events

*Most of Australia (all 13 sites), less warming in some coastal areas (e.g. Gold Coast, Perth) and Tasmania (Hobart), greater warming in the north-west (Darwin)*

### *New and existing residential buildings*

There are significant opportunities for improving the design of all new residential buildings (and retrofits) so that they can cope more effectively with very hot weather. Four key options for reducing the vulnerability of houses against increased temperatures and extreme temperature events include methods to:

1. control solar gain
2. provide adequate ventilation
3. provide adequate insulation
4. provide thermal mass where appropriate.

There are many different products and technologies available to the industry to incorporate these options into buildings. To encourage synergies with greenhouse gas mitigation efforts, preferred options are those that utilise passive solar design principles, with minimal use of active or mechanised systems (unless powered by renewable energy sources or they are 'very' energy efficient).

Incorporation of passive solar design principles will reduce the vulnerability of buildings to over-heating. The *Your Home Manual*, Chapter 1 "Passive Design" provides technical information for incorporating these features into residential dwellings (Commonwealth of Australia 2004). An overview of actions for each climate area is provided below (responsibility for the implementation of these actions is spread across planning and development regulations, building regulations, and personally through lifestyle choice)

**• Zone 1 (Hot Humid): Darwin, Cairns**

- Employ lightweight (low mass) construction.
- Maximise external wall areas (plans with one room depth are ideal) to encourage movement of breezes through the building (cross-ventilation).
- Site for exposure to breezes and shading all year.
- Shade whole building summer and winter (consider using a fly roof).
- Use reflective insulation and vapour barriers.
- Ventilate roof spaces.
- Use bulk insulation if mechanically cooling.
- Choose light-coloured roof and wall materials.
- Elevate building to permit airflow beneath floors.
- Consider high or raked ceilings.
- Provide screened, shaded outdoor living areas.
- Consider creating sleep-out spaces.
- Design and build for cyclonic conditions.

**• Zone 2 (Warm Humid): Brisbane, Gold Coast**

- Use lightweight construction where diurnal (day/night) temperature range is low and include thermal mass where diurnal range is significant.
- Maximise external wall areas (plans ideally one room deep) to encourage movement of breezes through the building (cross-ventilation).
- Site for exposure to breezes.
- Shade whole building where possible in summer.
- Allow passive solar access in winter months only.
- Shade all east and west walls and glass year round.
- Avoid auxiliary heating as it is unnecessary with good design.
- Use reflective and bulk insulation (especially if the house is air-conditioned) and vapour barriers.
- Use elevated construction with enclosed floor space, where exposed to breezes.
- Choose light-coloured roof and wall materials
- Provide screened and shaded outdoor living.

**• Zone 3 (Hot Dry, Warm Winter): Alice Springs**

- Use passive solar design with insulated thermal mass.

- Maximise cross-ventilation.
- Consider convective (stack) ventilation, which vents rising hot air while drawing in cooler air.
- Site home for solar access and exposure to cooling breezes.
- Shade all east and west glass in summer.
- Install reflective insulation to keep out heat in summer.
- Use bulk insulation in ceilings and walls.
- Build screened, shaded summer outdoor living areas that allow winter sun penetration.
- Use garden ponds and water features to provide evaporative cooling.

**• Zones 4 and 6 (Hot Dry, Cool/Cold Winter): Canberra, Melbourne, Mildura**

- Use passive solar principles with well-insulated thermal mass.
- Maximise night-time cooling in summer.
- Consider convective (stack) ventilation, which vents rising hot air while drawing in cooler air.
- Build more compact shaped buildings with good cross-ventilation for summer.
- Maximise solar access, exposure to cooling breezes or cool air drainage, and protection from strong winter (cold) and summer (dusty) winds.
- Shade all east and west glass in summer.
- Provide shaded outdoor living areas.
- Consider adjustable shading to control solar access.
- Auxiliary heating may be required in extreme climates. Use renewable energy sources.
- Use evaporative cooling if required.
- Avoid air-conditioning.
- Use reflective insulation for effective summer and winter application.
- Use bulk insulation for ceilings, walls and exposed floors.
- Use garden ponds and water features in shaded outdoor courtyards to provide evaporative cooling.
- Draught seal thoroughly. Use airlocks to entries.

**• Zone 5 (Temperate): Adelaide, Perth, Sydney, Coffs Harbour**

- Use passive solar principles.
- High thermal mass solutions are recommended.
- Use high insulation levels, especially to thermal mass.
- Maximise north facing walls and glazing, especially in living areas with passive solar access.
- Minimise all east and west glazing. Use adjustable shading.
- Use heavy drapes with sealed pelmets to insulate windows.
- Minimise external wall areas (especially E & W).
- Use cross-ventilation and passive cooling in summer.
- Encourage convective ventilation and heat circulation.
- Site new homes for solar access, exposure to cooling breezes and protection from cold winds.
- Draught seal thoroughly and use entry airlocks.
- No auxiliary heating or cooling is required in these climates with good design.
- Use reflective insulation to keep out summer heat.
- Use bulk insulation to keep heat in during winter. Bulk insulate walls, ceilings and exposed floors.

**• Zone 7 (Cool Temperate): Hobart**

- Use passive solar principles.
- High thermal mass is strongly recommended.
- Insulate thermal mass including slab edges.
- Maximise north facing walls and glazing, especially in living areas with passive solar access.
- Minimise east and west glazing.
- Use adjustable shading.
- Minimise south-facing glazing.
- Use double glazing, insulating frames and/or heavy drapes with sealed pelmets to insulate glass in winter.
- Minimise external wall areas (especially E & W).

  Use cross-ventilation and night-time cooling in summer.
- Encourage convective ventilation and heat circulation.
- Site new homes for solar access, exposure to cooling breezes and protection from cold winds.
- Draught seal thoroughly and provide airlocks to entries.
- Install auxiliary heating in extreme climates. Use renewable energy sources.
- Use reflective insulation to keep out heat in summer.
- Use bulk insulation to keep heat in during winter. Bulk insulate walls, ceilings and exposed floors.

(Adapted from *Your Home Manual*, Commonwealth of Australia 2004).

### *New and existing commercial buildings*

As office buildings are occupied during the day, and most people are often unable to change their location in a building, control of over-heating in commercial spaces is very important. The majority of commercial buildings in Australia are air-conditioned, and with increasing temperatures, air-conditioning use is also likely to increase (with associated increases in greenhouse gas emissions). Measures to prevent or minimise building over-heating in commercial buildings include:

**Reducing lighting and equipment loads.**

- Reducing lighting and equipment loads are often the easiest and most cost-effective measures (especially for existing buildings) for keeping buildings cool, as a reduction of only 10 W/m$^2$ will reduce internal temperatures by about 1°C (Energy Group 2000).
- Use of energy-efficient lighting and equipment (less heat produced).
- Use of light sensors which will automatically dim levels to utilise natural light.

**Upgrading the air-conditioning system to maximise operational efficiency.**

**Use of reflective glazing and external shading (trade-off between preventing heat entry and natural light penetration).**

**Increasing insulation and use of thermal mass.**

**Inclusion of passive ventilation methods.**

**Use of integrated automation controls, to integrate lighting, HVAC, ventilation and security systems.**

(Mathieson 2005)

Table 9: Homebuyer Priorities (HIA-CSR 2005).

### *Health and lifestyle needs*

There is a growing tendency towards buying a home with air-conditioning and/or central heating and of having either or both retrofitted in existing homes. However, there is also still a yearning to have some (periods of) natural air-flow, with 'natural flow through ventilation' being the top priority according to an HIA study (HIA-CSR 2005) (see Table 9). Increasing frequencies of high temperatures will increase energy use in warmer months. If such high temperatures are rare, people may be convinced to set air-conditioning so that it only comes on when very high temperatures are reached (Willis 2001). However, as such events become more frequent, and especially when high temperature days occur in succession, people are more likely to use air-conditioning continuously: either consciously (e.g. "We need it all the time now") or unconsciously (e.g. forgetting one morning to turn it off for the day, and leaving it on as the "default option"). Uptake of air-conditioning use is likely to happen earlier and be used more frequently if 'inside-outside' living increases (i.e. large sliding doors onto deck left open while people are using the deck). Shutters (outside windows) and curtains (inside windows) can work to reduce heat flow out of or into a building, and can reduce the demand for air-conditioning. Modern shutters can be rolled up and down from inside the window and are easy to operate. In countries like France, where winters are typically cold and summers hot, shutters on the outside of windows are standard equipment. These options would all require a change in current building design fashion (which favours windows opening onto decks etc).

Public health heat warnings typically advise people to stay in cool homes (i.e. homes that are either well-constructed or mechanically cooled). Where these are not available, people are advised to move to buildings where thermal comfort is provided (e.g. shopping centres). However, as noted previously, the groups most at risk during heatwaves are also those least able to easily get to cooler environments (unless assisted).

Air-conditioned buildings maintain thermal comfort and perceived good air quality by controlling the indoor air temperature and humidity (Wargocki, Sundell *et al* 2002). The benefits of air-conditioning in extremely hot conditions have been indicated in studies in nursing homes (Marmor 1978) and in ordinary households (Rogot, Sorlie *et al* 1992) where the presence of air-conditioning has significantly reduced the risk of mortality compared to buildings without air-conditioning. As yet, there are not public health guidelines in Australian states for protecting against heatwaves. In the United States and the United Kingdom, public health agencies now recommend that people in high-risk groups stay in air-conditioned buildings, at least for some part of each day (Centers for Disease Control and Prevention 2005). However studies have not compared the risk of dying among people living in poorly designed homes compared to people living in well-constructed passive solar houses. Therefore we cannot yet effectively evaluate the importance of air-conditioning *per se* as a protective factor.

In addition, the use of air-conditioning (or other form of mechanical ventilation) as a central strategy for avoiding heat-related disease during heatwaves may have some undesirable consequences:

a) Air-conditioned systems that do not operate effectively can have below-standard air exchange rates. This can lead to exposure to unsafe levels of indoor air pollutants in a home or workplace if pollutant levels accumulate. The main health effects of indoor air pollution include lung and respiratory tract problems, allergic reactions (asthma, skin and eye irritations), some cancers (mainly lung, chest, abdominal), and virus and bacteria reactions (fever, chills, nausea, vomiting). Strong evidence now links these diseases with various pollutants including indoor mould, house mites, chemical exposures from building materials or cleaning products, gaseous pollutants, or environmental tobacco smoke. An increased prevalence of "sick building syndrome" symptoms has been associated with the use of air-conditioning in buildings (Mendell and Smith 1990; Menzies and Bourbeau, 1997).

   Acceptable levels, from a health point of view, of indoor air pollutants can be achieved by: (i) eliminating or controlling the sources of these compounds, (ii) successfully filtering out contaminants, or (iii) increasing air exchange rates (mechanically or through natural ventilation). Opening windows can increase ventilation rates considerably. The downside is that the incoming air needs to be heated or cooled, which carries an energy penalty (Engvall, Norrby *et al* 2003). In addition, in some regions the air outside may have high levels of other pollutants.

b) Mechanical ventilation systems can increase the level of disease-causing bacteria within buildings (such as species of Legionella). Such systems depend on a supply of external air, which is usually pre-filtered and then possibly treated by cooling systems. Bacteria in building air can come from micro-organisms which are airborne (on wind from soil, vegetation, sewerage etc), or which are present as a direct result of human activity (breathing, sneezing, etc). They may be circulated through the air by the internal air-conditioning system, or they may colonise in the ductwork of the cooling systems, the water cooling towers, or the interior building materials and furnishings. Poorly maintained systems can become contaminated over time by bacterial populations that thrive on moisture-laden surfaces caused by water condensation. The reduction of air humidity through an increased supply of fresh air may significantly diminish, and in some cases, even eliminate house-dust mites in homes (Harving, Korsgaard *et al* 1994). Given that bacteria will always be present in external air, regular maintenance is necessary to reduce risk in mechanically heated and cooled environments (Australian Department of Health and Aged Care 2000).

   People in homes are at particularly high risk of unsafe levels of indoor air pollution. The Commonwealth Department of Health and Aged Care have identified the following relevant issues on this matter:

   - Exposure standards for atmospheric contamination in the occupational environment are controlled by the National Occupational Health and Safety Commission. Workplace chemicals are well documented and workers have the opportunity to determine the consequences of exposure.
   - The general public do not have ready access to information on levels of exposure, or the option to determine safe levels in their own dwelling (as the cost of analysis is prohibitive).
   - There is little information on the consequences of specific exposures and thus people cannot decide on the acceptability or otherwise of the risk. In many cases, the community has no option but to tolerate the exposure.
   - The option to exit cannot be exercised easily, particularly in the home environment.

c) Air-conditioning relies on energy consumption, and hence is part of the problem driving increased emissions of greenhouse gases and hence climate change. The increasing ownership of air conditioners and their use during heatwaves will result in higher electricity peak demand leading to increased potential for power failures.

d) Energy-dependent space cooling systems (depending on building insulation) increase the amount of heat discharged from buildings into the surrounding urban environment, and hence potentially exacerbate heatwave conditions.

To summarise, although the increased uptake of air-conditioning for domestic buildings is an intuitively simple adaptive strategy for reducing the risk of exposure to heatwaves, there may be undesirable consequences for the health of susceptible groups. These may be ameliorated to some extent by increasing education about the importance and requirements for regular maintenance of mechanical ventilation systems. The groups most vulnerable in heatwaves – older people, mentally ill – are likely to be less aware of these issues.

In addition to the possible health side effects, there are environmental costs in the form of increased energy consumption and the production of greenhouse gases if a greater proportion of the population take up air-conditioning as the main heatwave adaptation strategy. Passive solar design techniques should be considered to reduce, and in some Climate Zones eliminate, the need for most people to rely on mechanical air-conditioning requirements for comfort or safety. Even under this scenario though, a small proportion of the population (i.e. people at highest risk in hot weather, such as older people and the infirm) are likely to need to selectively use air-conditioning during hot weather periods. People living in passive solar designed houses are likely to be at lower risk of mortality if power failures occurred during heatwaves.

For commercial spaces, many people are still required to work in buildings with little climate control (e.g. factories, workshops) or in the open-air (e.g. gardeners, builders). Particularly in the latter case, climate change will make working conditions increasingly risky. Fry (2001) comments that the time will come when we will need to consider "new thermally controlled and fully enclosed forms of protective clothing for conditions of extreme wet, sun/heat, wind, dust, with monitoring devices to warn and instruct a wearer in high risk settings."

Many major office complexes and industrial parks are being planned to include cafés, restaurants, convenience stores, and other amenities for staff, and to share such facilities as gymnasiums, sports centres, and undercover parking, about which surveys tend to record high staff approval levels. This is not only because of internal benefits of convenience and community, but also increasingly because of worsening external factors such as traffic congestion and the weather. While most workers tend to prefer (for whatever reasons) to live some distance from their workplace, an increasing proportion are happy to live (near) where they work. Inclusion of a range of housing options in or adjacent to these complexes points to the concept of mini-cities developing within cities.

For individual workplaces, it has been found in a series of studies since the late 1990s in Sydney that temperatures in the range of 20.2°C to 26.2°C are acceptable to around 80% of the population. However, while most workers are able to adapt to a range of temperatures by passive means, those with access to supplementary heating and cooling use it actively to adapt their environments and express greater satisfaction and comfort (Rowe 2004). Apart from being significantly less expensive in capital and operating costs than full air-conditioning, hybrid or mixed mode ventilation (a combination of occupant-controlled supplementary cooling/heating systems with operable windows) provides higher levels of thermal comfort, perceptions of higher air quality, higher levels of satisfaction and greater perceived positive effects on (work) performance (Fahey and Rowe 2004).

However, virtually all major office accommodation is still being built to rely on being fully air-conditioned or climate controlled, and while the above examples show that people may adapt to the alternative (by choice or force of circumstance), there is no evidence of any increase in the demand from workers themselves for more environmentally-friendly large office alternatives. There are, nervertheless, indications of recent trends that companies are sourcing green building office outfits as part of their strategy to secure and retain staff. Chappells and Shove (2004) say that "It is important to recognise that people have different expectations of different environments. For example, users generally have, and expect to have, greater 'adaptive opportunity' (i.e. more ways of making themselves comfortable) at home than in a shopping mall or office block."

At the other extreme, with the growth of web-based services and emails it has become increasingly easy for many workers to work from home or a series of localised offices or outlets rather than a major centralised office. Many newspapers, magazines, insurance companies, consultancies and other organisations already have a number of their employees or partners working from home. There has also been some growth in flexible organisations having virtual offices formed by (often) loose networks of people with common interests working from diverse locations (again often from home). While these advances do not suit every industry, more and more organisations are finding ways to have at least some of their staff working 'off-site'. And many workers (e.g. working parents, those with a disability, those seeking solitude) embrace this idea enthusiastically. This trend may relieve some of the pressure for the provision of major office accommodation, but it will place greater pressure on home design, both in terms of different configurations to adapt to a home office or additional space for a home office, and the fact that many dwellings will now be occupied by, and therefore need to have their environments made comfortable for, at least one person around the clock.

Last, but not least, daily physical activity is an important element of obesity prevention. Hot, humid weather or very cold weather reduces the likelihood of people exercising. Building design and town-planning that creates comfortable conditions for exercise or active transport (walking or bicycling for daily transport) are factors of importance as the conditions may become more unfavourable with global climate change.

### *Potential Code changes*

As mentioned previously, a number of energy-efficiency measures are already in place for both residential and commercial buildings in the BCA. Further potential measures to reduce the vulnerability of buildings and occupants to over-heating include:

- mandatory passive solar design for new homes and significant retrofits/additions

- requirements for minimum standards on cross-ventilation (and other passive or non-energy intensive ventilation methods)
- requirements for security screen standards for elderly in public housing and community homes (including ease of operation for frail people)
- requirement that people working in outdoor or semi-outdoor conditions have access to shaded rest areas.
- assessing standards for building spacing, green spaces, ventilation and insulation in relation to minimising night-time temperatures in urban areas (i.e. heat island). This would require a link across planning and building standards
- requirement to screen all portals in buildings located in high-risk mosquito-borne disease regions
- design buildings to minimise the risk of water pooling in the infrastructure (for mosquito-borne disease prevention).

Other approaches include:

- encouraging rebates on energy usage for the elderly and people on low incomes
- providing improved information and education for consumers about maintenance requirements for mechanical ventilation units (focus on elderly and non-English speaking); establish a standard "energy advice service" in all states to provide advice.
- encouraging voluntary (or mandatory) uptake of best practice models, such as Green Star, NABERS and the ABGR as methods for improving thermal performance and comfort
- education and planning requirements to minimise heat re-radiation and reflection around buildings (e.g. through the use of vegetation)
- research needed into the possible protective benefits of well-constructed passive solar housing in reducing heatwave mortality.

## 9.2 Changing rain patterns across Australia

*More summer rain in the north and east, more autumn rain inland, less rain in winter and in spring. For southern areas less rain in all seasons, and Hobart has increased winter rain.*

### *New and existing residential buildings*

Most Australian jurisdictions already recognise that water use is a critical resource issue for buildings. Key options (for both planning and building controls) for reducing the vulnerability of residential buildings to water resourcing issues are methods for:

**Rainwater collection and use**

- Specifying the installation and use of rainwater tanks, with the collected water used for non-potable purposes.

**Reducing water demand, including on-site water re-use**

- Specifying high rating (WELS)[3] or AAA rated showerheads, dual flush toilets and appropriate water saving tapware
- Allowance for on-site wastewater re-use. Common options include:
  - greywater for garden use and toilet flushing
  - septic tank systems for black and greywater
  - aerated wastewater treatment systems (AWTS)
  - reed beds and sand filters
  - wet and dry composting systems.

**Stormwater control**

- Planning and development options include requiring:
  - the avoidance of cut and fill when preparing the building foundations
  - the maintenance of existing topography and drainage pattern
  - the retention of vegetation, particularly deep-rooted trees, that can lower the water table, bind the soil, filter nutrients, decrease runoff velocities, capture sediment and reduce the potential for dryland salinity.
  - stormwater retention techniques, such as permeable paving, pebble paths, infiltration trenches, soak-wells, lawn, garden areas and swales.
  - minimal impervious surfaces such as paved areas, roofs and concrete driveways.

(Commonwealth of Australia 2004).

Incorporation of these water conservation and efficiency measures will reduce the vulnerability of buildings to water resourcing issues (both supply and demand). The *Your Home Manual*, Chapter 2: 'Water Use', provides greater technical information for incorporating these features into residential dwellings (Commonwealth of Australia 2004).

### *New and existing commercial buildings*

Key water efficiency and conservation adaptation options for commercial buildings include:

**Methods for reducing potable water consumption of building occupants:**

- use of water saving tapware, fixture and fittings (including toilets and showers)
- use of greywater, blackwater or rainwater collection and re-use systems

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[3] WELS – Water Efficiency Labelling and Standards Scheme will be introduced from 1 July 2006. It applies national mandatory water efficiency labelling and minimum standards to household water-using products. Products currently covered by the scheme include: clothes-washing machines, dishwashers, flow controllers, toilet equipment, showers, tap equipment and urinal equipment.

**Installation of water sub-meters**

**Methods for reducing the consumption of potable water for landscape irrigation:**

- use of recycled rainwater, greywater or blackwater
- use of water-efficient irrigation system (subsoil drip systems and automatic timers etc)

**Methods for reducing the demand on potable water supplies and infrastructure due to water-based building cooling systems**

- designed to achieve 6 or better Cycles of Concentration, or the natural ventilation mode of a mixed mode system reduces the HVAC cooling water consumption by 50%
- use of non-potable water (aim for 90%).

(GBC Australia 2003)

### *New and existing commercial buildings*

For adapting commercial buildings for the impacts of more rain, the same options for stormwater control apply as per residential buildings, with particular emphasis on the reduction of impermeable surfaces, and on-site landscaping water control methods. Where the commercial site has no 'green' space or minimal surrounding land, attention should be placed on retention of rainwater on-site through use of rainwater collection systems, and where applicable the use of 'green roofs' to reduce roof runoff (also has benefits in reducing the 'heat island' effect, improving biodiversity and providing staff amenity).

### *Health and lifestyle needs*

In order to supplement mains water supplies, increasing numbers of households have been turning to some form of on-site water storage, and in recent years many local Councils have relaxed their opposition to (and some are now even encouraging) the installation of rain water storage tanks. However, consumers seem uncertain as to their appropriate use – some believe that they should remain filled until the water is needed for purposes for which mains water is restricted (e.g. topping up or refilling swimming pool; watering garden intensely), while others believe that they should be used regularly (and allowed to empty) in order to take advantage of the next deluge. In general, there seems to have been little uptake of on-site treatment and storage of grey water (e.g. from kitchens and laundries). Some regions of capital cities (e.g. north-west Sydney) are now being 'dual-piped' in order to receive treated grey water (e.g. from sewage treatment plants). Several sources have suggested that under-used swimming pools could be covered and equipped for this purpose.

With increasing drought and the possibility of extreme water restrictions, many sports and other recreational activities that are currently played, mainly outdoors, may need to move indoors. For example, due to water restrictions, dozens (possibly the majority) of ovals in Canberra have been closed to the public for safety reasons ('ground almost like concrete') and Sydney is thinking of the same action. Sports which have already been designed for, converted to, or modified for indoor play include cricket, soccer, tennis, basketball, netball, athletics, swimming and cycling. The popularity of these indoor sports would suggest that this move will continue.

### *Potential Code changes*

Potential areas for introducing water efficiency and conservation into the BCA include the following (for all residential and commercial building classes):

- Requirements for water saving tapware, fixtures and fittings (use of 5A conservation rating and labelling scheme or other water efficiency labelling scheme). (Refer to Standards Australia SAA MP64:2001: *Interim Manual of assessment procedures for water efficient products)*
- Requirements or standards developed for the installation of rainwater tanks (and guidance on use of the recovered water) in association with health authorities and Councils
- Requirements for the use of greywater and/or blackwater recovery and use technologies (including specifications on use of the recovered water) (NB: treated water must meet EPA regulations with respect to its intended use)
- Phasing out of evaporative or water cooling tower systems that use potable water supplies.

Note: it can be argued that requiring the installation of rainwater tanks is somewhat pointless in areas with very low rainfall (or in drought) as there is simply not enough rain to make collection worthwhile. In these circumstances, it may be preferable to require a greywater and/or blackwater recovery system as a means of reducing potable (mains) demand. However, as treated grey and blackwater must meet strict health requirements, potable demand is not necessarily reduced significantly (as grey and blackwater can then be only used for minimal non-potable uses). Clearly there are benefits in enabling grey and blackwater to be used for potable supply – however, well researched and tested systems are needed. Some manufacturers of grey and blackwater systems do claim to meet drinking water standards with their proprietary systems, but users are prevented from using the water as potable supply due to various regulations (especially in urban situations).

An integrated review of planning, development, building and health regulations is recommended in order to progress this issue.

## 9.3 More-intense tropical cyclones and storms

*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)*

### *New and existing residential buildings*

The main concerns with tropical cyclones and storms are the effects of extreme winds, coastal storm surges and driving rain. Wind loads on new buildings can be reduced by designing and building more aerodynamically efficient structures that assist in minimising wind loads, i.e. curved corners, minimising the overhang of eaves (though this type of alteration would be region-specific and need to be balanced with requirements to prevent driving rain and to reduce solar gain) (Sanders and Phillipson 2003). There are also additional construction and fixing requirements which are necessary to hold down roofs (edges of gable end roofs are susceptible to damage) against cyclone uplift wind forces. Note that greatly increasing the strength in only one area e.g. roof fasteners, may be counterproductive, as it may only change the mode of failure (i.e. the whole roof then lifts etc). Bracing in the roof, fixing of roof material and the connection of the roof to the walls are the key areas.

The need for maintenance of buildings to ensure the structural fixings have not worn, loosened or warped (from previous cyclones) or simply corroded overtime is largely unknown. Therefore, to date, there is not information to educate homeowners to check their homes and maintain them well. In areas like Darwin where houses may be 30-years old, and the structural fixings never check or maintained, the damage could be significant but relatively easy to fix if the appropriate information was known and disseminated. We recommend a general house condition survey be undertaken in the cyclonic regions to check the durability, effectiveness and maintenance required on houses to ensure they keep the designed strength to resist the wind pressures of cyclones. Research in this area has already begun at the Cyclone Testing Station, James Cook University, including Fatigue of Cladding and Risk Assessments (http://eng.jcu.edu.au/cts/research.htm).

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

To reduce the vulnerability of buildings to the effects of driving rain, good moisture management can be achieved through attention to (the 4Ds):

- Deflection (keeping water out in the first instance)
- Drainage (if water gets in, making sure it can drain out)
- Drying (allowing drying if materials get wet)
- Durability (withstanding the effects of getting wet).

Attention to the 4Ds is most relevant to timber framed and clad houses (common in older residential building stock across most sites in Australia and in newer buildings in Cairns, Darwin and Alice Springs). For new buildings, attention to detailing (see below) and the specification of a drainage cavity ameliorates most problems. Existing homes can be retrofitted by removing the weatherboards and adding a drainage cavity. This is a relatively difficult option as the windows may need adjusting as well.

Masonry veneer (timber framed, masonry clad) buildings (common in Brisbane, Gold Coast, Sydney, Canberra, Mildura, Coff's Harbour, Melbourne, Hobart and Adelaide) perform better with respect to moisture ingress as these have typically been built with a cavity (20 mm gap between the bricks and the timber framing), as it is recognised that bricks are porous and therefore do not prevent water entry.

For better detailing, the building elements that need to be considered are: roof edges, open decks, walls and joinery, retaining walls, floors, balconies, wall/roof junctions, and roofs. Figure 17 highlights these pressure points in a residential building.

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

### *New and existing commercial buildings*

As for houses, commercial buildings are not generally designed to *fully withstand* the effects of tropical cyclone wind speeds, and therefore would be expected to fail to some degree. Failure could be major structural damage or total collapse, or possibly partial or complete loss of cladding. A key adaptation option for new commercial buildings is to design the building over and above the specific wind loads (refer to AS/NZS 1170.2 Supp1:2002 and 1170.2:2002). For existing buildings, adaptation options include regular maintenance of external cladding (or replacement with more impact-resistant/durable claddings, including windows), stronger attachment of external fixtures and fittings (e.g. externally fitted services, signage etc).

### *Health and lifestyle needs*

The differences between the wet and dry seasons in much of tropical Australia are extreme. Both seasons are fairly predictable and there has been a perceived balance between them. Although many people choose to live in this climate (e.g. born and bred there), many others are required to live there (e.g. military and other government postings etc).

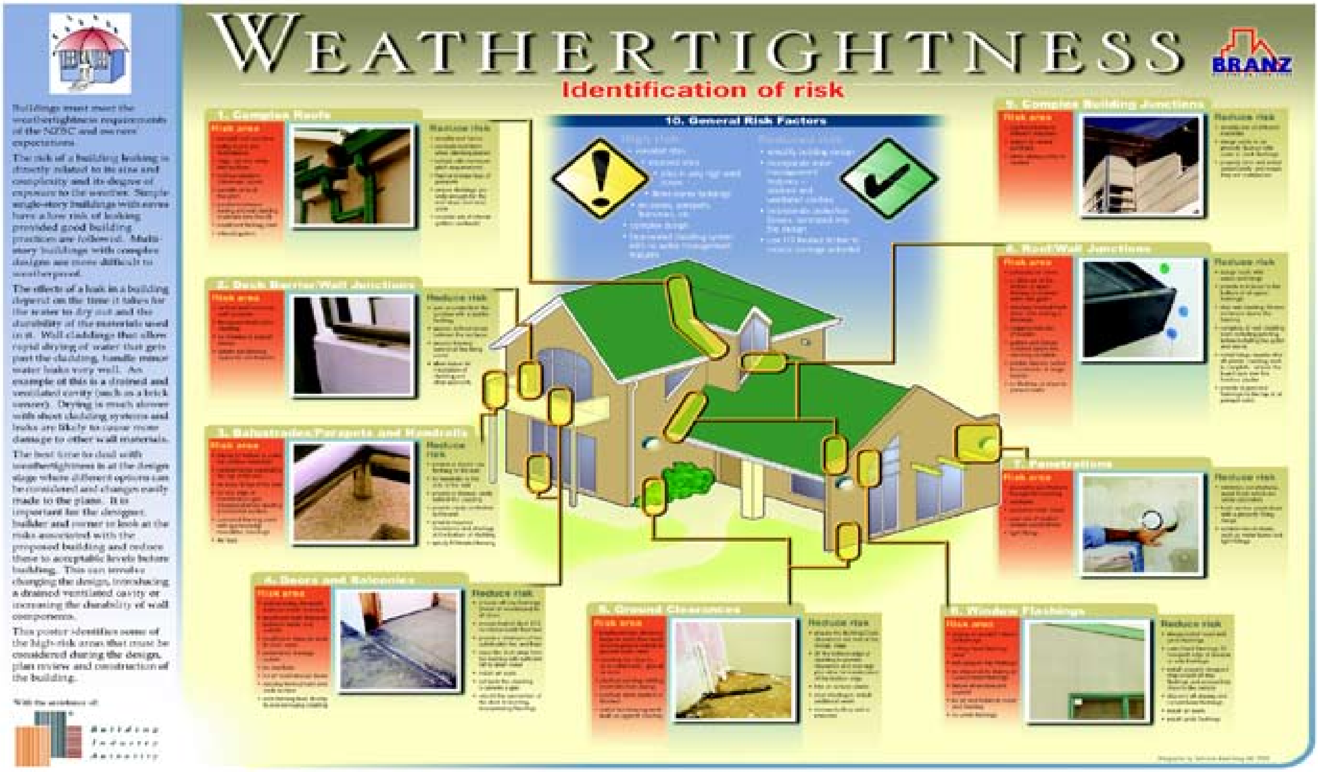


Figure 17: High-risk Areas for Water/Moisture Ingress (BRANZ 2003).

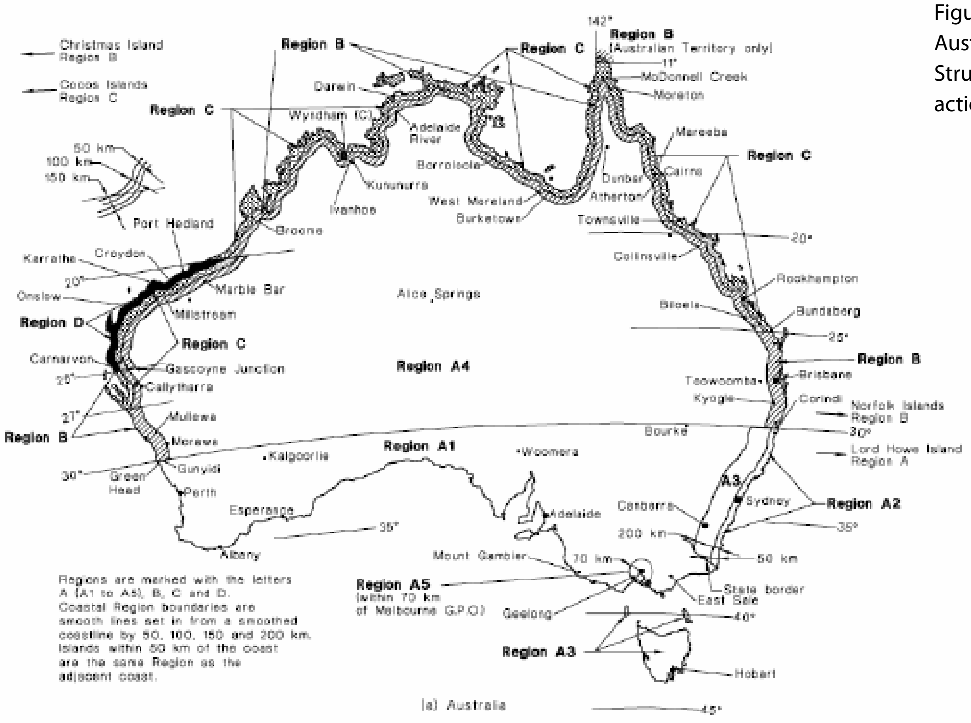
Without appropriate care and action, the effects of humidity and increased condensation that occurs during the wet season results in mould, damp slippery floor tiles, damage to furniture and pictures, and vermin infestation such as cockroaches, silverfish, dust mites and wood borers, with implications for both the health of occupants and building alike. Many people permanently close windows and most external doors to prevent more moisture getting in, restricting air exchange with the outside. This results in some people resorting to dehumidification either by mechanical or passive means, whereas others simply "live with the humidity". Both types "put up with" the wet season knowing that the (seen by many as ideal) dry season is coming. Any substantial increase in the nature and intensity of wet season conditions, and/or any disruption of dry season length or conditions, is likely to tip the balance for many people. Any significant increase in the intensity and/or frequency of storms and cyclones is also likely to substantially change perceptions of these areas.

### *Potential Code changes*

The BCA uses criteria that define the importance level of a building type and, from this, specifies the Annual Probability of Exceedance that the building design needs to meet in relation to withstanding wind pressure. The projected increases in wind speeds will not affect these Building Code requirements, but could impact on AS/NZS 1170.2:2002, AS 4055 and various material design standards (which are called up in the Building Code and set the design criteria for wind pressure).

AS/NZS 1170.2:2002 Section 3 provides Regional Wind Speeds and is used to calculate the gust wind speeds appropriate to the region in which a structure is constructed. Adjustment of the wind region map (see below) could incorporate wind speed projections and adjustments made to take climate change into account, where necessary. An example of another possible change would be to increase the depth of the "bands" to allow for tropical storms taking a wider path of going further inland.

The regional wind speeds given in Table 3.1 of AS/NZS 1170.2:2002 (see Table 10) are based on 3 second wind gust data ($V_R$). Adjusting this data for climate change has already begun, with recognition of the frequency of Level 5 cyclones crossing in Region D in recent years (1998–2002). The ultimate limit states wind speed for region C ($F_C$) includes an additional factor of 1.05 and for Region D ($F_D$) an additional factor of 1.1. These factors are in reality fudge factors and are still based on current data, not projected scenarios. The current regional wind speeds could be checked against projected (high and low) wind speeds to see how significant the difference is and the table adjusted accordingly. To do this, it would be necessary to have the projected wind speed data based on the 3 second gusts.



(a) Australia

FIGURE 3.1 (in part) WIND REGIONS

Figure 18: Wind Regions in Australia (AS/NZS 1170.2:2002 Structural Design Actions – Wind actions).

Table 10: Regional Wind Speeds (AS/NSZ 1170.2:2002 Structural Design Actions - Wind actions).

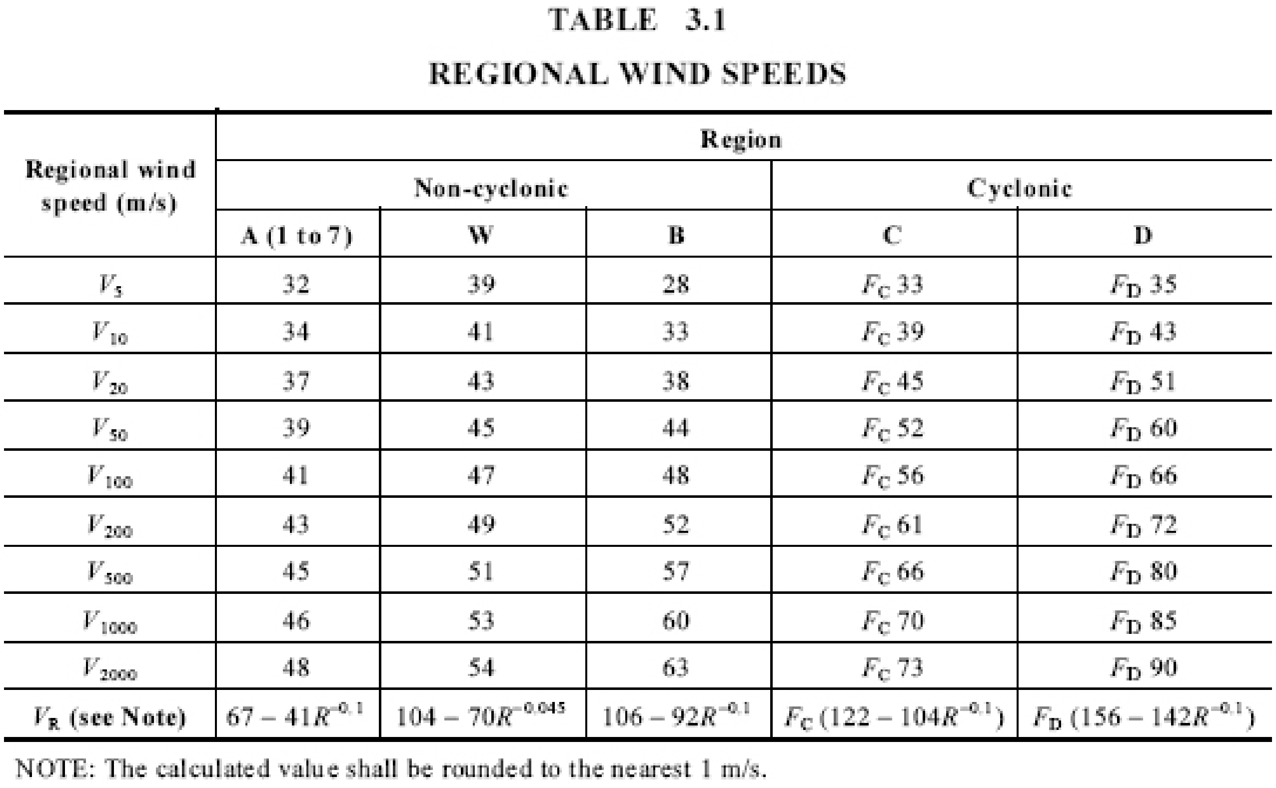


TABLE 3.1

REGIONAL WIND SPEEDS

| Regional wind speed (m/s) | Region | | | | |
|---|---|---|---|---|---|
| | Non-cyclonic | | | Cyclonic | |
| | A (1 to 7) | W | B | C | D |
| $V_5$ | 32 | 39 | 28 | $F_C$ 33 | $F_D$ 35 |
| $V_{10}$ | 34 | 41 | 33 | $F_C$ 39 | $F_D$ 43 |
| $V_{20}$ | 37 | 43 | 38 | $F_C$ 45 | $F_D$ 51 |
| $V_{50}$ | 39 | 45 | 44 | $F_C$ 52 | $F_D$ 60 |
| $V_{100}$ | 41 | 47 | 48 | $F_C$ 56 | $F_D$ 66 |
| $V_{200}$ | 43 | 49 | 52 | $F_C$ 61 | $F_D$ 72 |
| $V_{500}$ | 45 | 51 | 57 | $F_C$ 66 | $F_D$ 80 |
| $V_{1000}$ | 46 | 53 | 60 | $F_C$ 70 | $F_D$ 85 |
| $V_{2000}$ | 48 | 54 | 63 | $F_C$ 73 | $F_D$ 90 |
| $V_R$ (see Note) | $67 - 41R^{-0.1}$ | $104 - 70R^{-0.045}$ | $106 - 92R^{-0.1}$ | $F_C (122 - 104R^{-0.1})$ | $F_D (156 - 142R^{-0.1})$ |

NOTE: The calculated value shall be rounded to the nearest 1 m/s.

At the time of writing, there was no direct requirement for cyclone washers in the BCA, even though they or similar measures have been used in the northern States for many years. For buildings located in cyclonic regions, the Northern Territory has a State variation to the BCA which requires roof sheeting (and hence fixings, batten spacing etc) to comply with a particular test.

The predominant fixing method in both the Northern Territory and Western Australia is to use some form of cyclone assembly. This is not the case in Queensland, where roof sheeting is assessed against a different test.

Recent research into cyclonic events suggests that a third test – the Low High Low (LHL) test method – takes into account the cyclic nature of wind loads and better mimics cyclonic wind loads.

The ABCB has included the LHL test in the BCA, with effect from 1 May 2006, so that metal roof sheeting for all buildings in cyclonic regions – predominantly in Western Australia, the Northern Territory and Queensland – have the option of complying with the current or LHL test. After a transition period of 2 years, all metal roof sheeting will need to comply with the LHL test. The Northern Territory variation has been removed from the BCA. Whether the test requires the use of cyclone washers will depend on the type of roof sheeting being tested (Kelly, A.M., pers. comm. 31/5/05).

## 9.4 Decreased humidity

With decreases in humidity predicted, no specific building adaptation is needed for commercial or residential stock. However, any decreases in humidity will cause the following:

- increases the risk of bushfires (see Bushfires, Section 9.8) and
- reduction in the lag-time for corrosion of reinforced concrete as used in commercial buildings.

## 9.5 Increased and decreased radiation

With both increases and decreases in solar radiation predicted (in effect they cancel each other out), no specific building adaptation options can be identified. However, increases in radiation will have a direct impact on the rate of degradation of wood, cladding and sealants. Areas with decreased radiation will benefit from longer life of these materials. Changes in radiation will also have a direct impact on some of the opportunities identified (e.g. solar water heating, photovoltaics).

## 9.6 Coastal and inland flooding

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.

### *New and existing residential buildings*

There are a number of options for reducing the risk and impact of flooding. A key strategy to reducing flood problems is one of avoiding siting buildings on river flood plains and low-lying coastal areas in the first place (a critical planning and development issue).

Many options are available to reduce the flooding risk and damage potential when designing and constructing new buildings. In order of priority:

- avoid building on a flood-prone site[4]
- exceed minimum floor levels
- consider multi-storey construction
- design and construct buildings for flooding occurrences
- use water-resistant materials (see Table 11 below)
- design to ensure water can easily escape once flooding has subsided (especially for cellars and foundations)
- install essential, vulnerable equipment as high as possible
- the wider issue of designing access routes if flooding occurs and education about these routes (again there is a strong linkage with planning issues).

For existing buildings, the recommendations are similar to that of new buildings:

- raise or move the building
- building a second or multiple stories and using the lower storey as non-living or 'non-productive' space
- replacing cladding, flooring, and linings with water-resistant materials (see Table 11 below)
- moving services (hot water, meter board) above flood levels
- building a levee or flood wall around the building
- raising flood awareness and preparedness including access routes with building occupants.

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

The materials listed in Table 11 as water-resistant should withstand direct contact with flood waters for more than 72 hours, and require at most low cost cosmetic repair (such as painting).

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[4] Gaining a planning or building consent does not guarantee a site is not flood-prone.

Table 11: Water-resistance of some common building materials
(Camilleri 2001, adapted from FEMA, 1993).

| | Water resistant | Non-water-resistant |
|---|---|---|
| Insulation | Closed cell foam (polystyrene or polyurethane) | Fibreglass, mineral wool, wool, cellulose, foil |
| Floors | Concrete (bare or coated)<br>Floorboards, durable or treated timber<br>Concrete or clay tile | Particleboard, MDF, plywood[5]<br>Ceramic tile[6] |
| Walls | Fibre-cement<br>Concrete block<br>Durable or treated timber<br>PVC<br>Brick (glazed or faced) | Particleboard, plywood |
| Interior | Concrete block<br>Fibre-cement<br>Durable or treated timber | Plasterboard<br>Plywood<br>Hardboard<br>Softwood<br>Carpet or vinyl<br>Particleboard |

### *New and existing commercial buildings*

Commercial buildings are likely to be at greater risk of flooding than houses (mostly due to location, surrounded by impermeable surfaces, urban stormwater drainage systems overburdened, etc – especially in some CBDs) and therefore may suffer more damage than houses. On the other hand, there could be less damage as commercial buildings are more likely to be constructed of flood-resistant materials. Once a commercial building is flooded, a number of factors govern the extent and cost of the flooding damage. Adaptation measures for commercial buildings to flooding include:

- Use of water-resistant construction materials:
    - timber, particle-board and plasterboard (lightweight construction materials) require maintenance, repair or replacement after flooding, whereas concrete floors and walls (heavyweight construction) are often undamaged and can be cleaned quickly. Heavyweight construction is also more likely to be able to withstand water pressures in high flow, high flood level events.
- High(er) placement of vital equipment and services:
    - multi-storey buildings will usually only flood up to the ground floor (except in extreme flooding events with depths of around 3 m or more). However, services in office buildings (lifts, boilers, plant, switchboards, computer networks, telecommunications etc) are often on the ground floor or in the basement – so flooding to only the ground floor can paralyse a multi-storey building.
- Increased capacity stormwater drainage (or storage) systems on-site, including increased use of permeable surfaces.

(Camilleri 2001)

### *Health and lifestyle needs*

Flooding of buildings may be more frequent due to climate change, damaging furniture and other building contents, and possibly leading to structural problems. Contamination from sewage is also possible. In some places, if rainfall becomes much higher, then guttering, stormwater detention and land drainage systems will fail to cope with the added volumes of water (Willis 2001). These things have been happening at intervals already in various areas of Sydney, Melbourne and Canberra, and in particular where there has been increase in the population/dwelling density without an adequate upgrading of infrastructure. More frequent storms (depressions) will also cause increased structural damage to buildings. While reinforcement or retrofitting of new roofs is a possible solution for existing housing, many people may opt to move before such events affect them, or knock down and rebuild.

More extreme rainfall events and rises in sea-levels may require the development of new flood and stormwater strategies for low-lying suburbs. Some buildings in flood-prone areas could become uninsurable, or at least face massive increases in premiums. While one solution would be to avoid flood-prone land when planning and approving future property developments, these areas have become areas of choice by an increasing number of 'sea-changers' and others moving to coastal areas, especially to south-east Queensland (the Gold Coast-Brisbane-Sunshine Coast conurbation) where many of the coastal suburbs are in low-lying and reclaimed areas.

An increase in summer rainfall in tropical areas may relieve pressures on water resources. However, a decrease in rainfall in southern Australia would increase pressures on water resources, requiring a rethinking of public strategies, and resulting in major implications for the lifestyles on the population in terms of how, when and where they use water.

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[5] Untreated plywood is not water-resistant. It needs to be marine grade or treated to a similar level (i.e. the plywood has additives that prevent it breaking down when wet).

[6] The grouting used between the ceramic tiles is resistant to clean water flooding only if it has acid and alkali-resistant grout. Otherwise the system is not flood-resistant.

### *Potential Code changes*

Potential new Building Code provisions include the requirement for flood-resistant building materials (such as water-resistant materials and waterproof seals), stronger foundations, and elevated floor heights. Gutter and downpipe sizes, including stormwater control measures, are further areas where increased performance requirements could reduce building risk.

## 9.7 Hail events

*Decreased frequency of hail events in Melbourne, increased hail in Sydney*

### *New and existing residential buildings*

Hail events may decrease in Melbourne, but increase in Sydney. This shows that hailstorm scenarios are very location or site dependant. Also, there have been a limited number of studies in this particular area of climate change. However, because there is significant building damage

**Impact-resistant roofing materials**

**Steel roofs offer better protection in hailstorms than concrete, slate and terracotta tiles, according to new research by NRMA Insurance. Using a hail gun designed and created by NRMA Insurance, man-made hailstones were fired at corrugated steel sheets, and concrete, slate and terracotta tiles, to determine which roof materials are more likely to hold up against hail.**

**Robert McDonald, NRMA Insurance Head of Industry Research, said the release of the initial results of the hail gun project are aimed at educating the community on what roof materials perform better in a hailstorm, particularly for people designing and building a new home.**

**"Our preliminary research has found that corrugated steel performs best overall, holding up against hailstones up to 10 cm in diameter. While the steel sheets can be dented by smaller hailstones, they're not penetrated as easily as tiles so they're less likely to allow water into the house," he said.**

**"Concrete and new terracotta tiles also performed well, surviving the smaller hailstones and only cracking when 7 cm stones in diameter were projected from the hail gun. The worst performing were the old terracotta and old slate tiles, where 5 cm hailstones caused the tiles to crack," Mr McDonald said.**

**The roofing materials for the initial research were selected because they are commonly used in the community. The tests were conducted at 90°C to replicate a worse case scenario. The speeds varied from 100 km/h to 160 km/h.**

**Although the old slate tiles performed the same as the old terracotta tiles in the tests, slate is four times the cost to replace. Use of slate can also lead to delays, as it can be difficult to source.**

**"Roofing replacement costs vary depending on the material selected and the style, height and pitch of the roof. But if water gets into the roof, creating internal damage and destroying contents, repair and replacement costs can increase substantially," Mr McDonald added.**

**NRMA Insurance urges residents to check their roofs for cracks. "Following a hailstorm or heavy rain, many customers report water damage caused by leaking roofs. Most customers don't know they have cracked roof tiles until heavy rain hits. We recommend all residents organise to have their roofs checked as soon as possible while the weather is clear," he said.**

**The results of this research are timely, as already NSW has seen hailstorms this season. Although traditionally the storm season commences in October and hailstorms start around November, last month's hailstorms prove storms can happen anytime.**

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

http://www.nrma.com.au/pub/nrma/about_us/media_releases/20041013a.shtml accessed 06/08/05 and subsequent financial losses experienced in hail events, adaptation options have been included here. Options for reducing the vulnerability of buildings to hail events (and related storms) include:

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

### *New and existing commercial buildings*

Larger, multi-storey commercial buildings with typical concrete roof construction are less susceptible to hail impact damage. There is the possibility of glazing damage (depending on the angle of impact from the hail stones). The most vulnerable areas are externally fitted services or signage (e.g. air-conditioning systems on roofs). Adaptation options include the re-siting of these services or the addition of protective coverings. Similar to the advice given for residential buildings, commercial building managers should check for leaks after hail events.

### *Health and lifestyle needs*

Fry comments that "It is already clear that most roofs in places like Australia are not able to withstand the kinds of hailstorms that the country is already getting on a regular basis – the Sydney 'hailstones the size of tennis balls storm' of 1999 destroyed thousands of roofs (leading to a great deal of water damage) and was the most expensive claims event for the insurance industry in Australia's history (which includes the total levelling of Darwin by Cyclone Tracy in 1974)." (Fry 2001) There was also considerable damage to houses and disruption of traffic when a major hailstorm occurred in Brisbane (in 2005), dumping several centimetres of large hailstones in a matter of minutes (Unattributed 2005). Although it has been suggested that hail storms may decrease rather than increase, community perceptions may differ. Indeed, perceptions of an increase in the frequency and/or severity of these happenings are likely to have major implications for the current dwellers.

### *Potential Code changes*

Potential Code changes could include requirements for the use of impact-resistant building materials in vulnerable areas e.g. Sydney.

## 9.8 Increased risk of bushfires

*Increases in bushfire frequency and intensity across all of Australia*

### *New and existing residential buildings*

All houses in bushfire-prone areas are susceptible to bushfires, however the current Building Code provides sensible options for reducing fire risk. Adaptation options for houses built before the Code requirements should be based on the Code e.g. screening all portals with mesh. With the increase in fire intensity areas, bushfire zone areas may change (see Code changes below). In these areas, education of the maintenance needs to minimise the risk of fire should be carried out. Houses on small sites (i.e. close together) will increase the risk of fire spreading so in zoned areas, and with the increasing demands on the land, planning requirements to minimise this risk should be considered.

Domestic sprinkler systems are another possible option. However internal sprinkler systems can significantly damage the house contents. To date there have been no effective external systems due to unreliable activation methods and ineffective delivery. Also, the water shortages that are typically associated during this season make this a less feasible option unless water tanks are specifically installed for this purpose.

### *New and existing commercial buildings*

It is less likely commercial buildings will be in a bushfire-prone area because typically they are not close enough to vegetation to warrant concern. However for commercial buildings that fall into the category of being in a bushfire-prone area, similar adaptation options should be looked at including use of appropriate building materials that will resist embers, radiant heat and flame contact and minimising openings that will allow fire ingress (along with sprinkler systems).

### *Health and lifestyle needs*

There are obvious and significant risks to people who do not leave their homes (or workplaces) and surrounding areas during a bushfire, but choose to stay inside their homes (or do not have an option). With the increase in intensity of bushfires, it is likely the associated greater heat will have higher health risks than currently occur. Therefore the simple adaptation for health and safety is to have a well rehearsed fire safety evacuation plan to close up the home (so the fire cannot get into the house) and leave as quickly as possible. Whether to stay and defend or leave is a sensitive issue, but AS 3959 is written on the basis of the house providing a place of refuge during the passing of a bushfire and for occupants to leave immediately after. In any case, the matter is not so much about 'health and lifestyle' but more about life safety.

### *Potential Code changes*

There are limited potential Code additions or changes that have been identified due to the comprehensive requirements in Australian Standard AS3959-1999 *Construction of buildings in bushfire-prone areas*. However, the increased intensity of bushfires should be further investigated to determine if climate change increases the current fire risk levels. Each state should also consider the fire intensity increase when determining 'bushfire-prone' areas. The increase in frequency would have no impact on the Building Code or associated Standards.

## ISSUE FOUR
## "For existing buildings, consider possible benchmark levels for taking retrofit actions to accommodate the effects of climate change (including risks and costs of such actions)"

# 10. BENCHMARKING

## 10.1 Benchmark levels for retrofits

### *Residential buildings*

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

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

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

- the house should have a good chance of surviving until the climate change 'impact' occurs
- the climate change impact should be severe enough and thereafter persistent to justify the adaptation cost
- the house should have a worthwhile economic life for its occupants afterwards.

The key question is: when is it cost-effective to retrofit? Now or in 20, 30, 50 or 100 years?

Although it is building and context-specific, it is generally more costly and difficult to retrofit as a building ages, and therefore becomes less cost-effective as the building nears the end of its life. The longer it is left, the costlier it becomes to retrofit. Then, if the building is 'retired' earlier than it could have been, costs are also borne through the loss of income/utility and in the requirement of a new building to be built earlier etc. In other words, being reactive rather than proactive incurs expenses rather than deferring them.

### *Commercial buildings*

There is very little information on the average or expected lifetimes of commercial buildings. However, it is estimated that their lifetime would be at least 50 years (although determined more by economic life that physical age). Commercial fit-outs (interiors) have a significantly reduced lifetime; office churn is estimated at once in every 3-7 years.

Similar with residential buildings, knowing when to retrofit requires a comprehensive risk assessment process to be undertaken.

## 10.2 Adaptation case studies

The Charles Sturt University in Thurgoona (Albury) on the New South Wales–Victoria border is a good example of adaptation (of a series) of buildings to the dry climate of southeast Australia, a region that receives most of its rainfall in winter and spring (refer to http://www.csu.edu.au/division/marketing/tms/T101/T101p3.htm).

The designers made specific recognition of the climate when plans were developed for a formerly degraded (by land clearing and farming) site. The Student Pavilion (completed in 1996) became the prototype for other buildings on the site. It includes rammed earth walls, concrete floors for optimum solar capture, solar panels that collected heat, seasonal rainwater, and shaded windows framed with recycled plantation timber.

Lessons learned from the Pavilion process have allowed for improvements to be incorporated during the subsequent construction of other buildings and infrastructure on the campus (e.g. stormwater recycling; greywater treatment and re-use and composting toilets).

The Student Pavilion

The Gold Coast House in south-east Queensland is another good example where the designers deliberately chose to build for the local (sub-tropical) climate (where temperatures can go well over 38°C during summer) rather than opt for mechanical cooling. Thin-framed, movable glass walls forming a large part of the building fabric allow for unrestricted flow of cooling breezes (these walls are also designed to be resistant to tropical storms and cyclones). The outdoor verandah (a vernacular style for the region) and roof overhangs provide shade from summer sun. Concrete floors provide thermal mass for the cooler months, rainwater is collected and waste water is managed entirely on-site.

The Gold Coast House

(Refer to http://www.architectureweek.com/2003/0326/design_1-2.html)

The Gold Coast City Council has recently endorsed implementation of a 'sustainable housing code' as part of the city's planning initiatives for adapting to climate change (refer to http://www.goldcoast.qld.gov.au/t_std.asp?pid=4100). (O'Connell and Hargreaves 2004).

## 10.3 Identified Research Needs and Opportunities

Further investigation is necessary into a framework that allows climate change to be harmoniously incorporated into both land-use planning and building standards, so they work effectively together ensuring no 'gaps' in the building process. This is particularly important for both urban water use and flooding.

Encourage and support initiatives that are aimed at mainstreaming sustainable design and construction e.g. use of the *Your Home Manual*, HIA's Greensmart programme, etc.

Develop a similar risk index (as NZ's CCSI) to determine risk and benchmark levels for retrofitting and/or accelerating retirement of Australian residential and commercial building stock.

It may also be useful for the AGO to continue compiling case study information of what adaptation action has been done to date (with relevance to Australian building types).

**ISSUE FIVE**
**"Identify the opportunities that may come from climate change e.g. solar radiation (PV electricity generation or hot water), rainwater collection, etc"**

# 11. OPPORTUNITIES

This section identifies potential building-related opportunities (processes and/or products) as a result of key climate change pressures on Australia's building stock. While it is recognised that most of the opportunities identified also have mitigative benefits (i.e. also contribute to a reduction in greenhouse gases), the focus of the following information is on adaptive technologies and processes.

### *Building over-heating*

With hotter and drier days, there are health and safety issues for builders / contractors and other building personnel as a result of the construction process. In South Australia (as elsewhere across Australia), staff are required to cease work once outside (or inside) temperatures reach 36°C. With more very hot days predicted, work disruption is likely to increase, potentially increasing building delays and costs. This provides opportunities for different and improved construction practices that allow staff to keep working with extreme heat e.g:

- prefabrication and off-site construction
- provide shading and ventilation where appropriate
- manage delays through contractual agreements
- manage concrete placement to ensure the maximum strength and durability of concrete structures is maintained.

(CIRIA 2005)

For moderating internal temperatures in buildings (both residential and commercial), there are significant opportunities for the design of new super energy-efficient technologies for cooling, including those systems that use alternative (renewable) energy sources. Examples include:

- photovoltaic, solar, biomass, and wind-powered cooling technology
- co-generation technologies (including waste heat capture technology).

Other technologies including those that reduce solar cooling loads are:

- green roof and roof design technology
- high performance window films
- PV glazing
- low heat-producing lighting, equipment and plant.

For more detailed analysis of reduced space heating and water heating (including solar and photovoltaics) see Section 11.1 and Section 11.2.

### *Tropical cyclones, winds and intense storms*

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

- impact-resistant building materials, especially external claddings and glazing
- enhanced external finishes and claddings that repel / prevent water ingress
- better window designs e.g. increased thickness of glazing to reduce wind forces, or reduced panel sizes
- improved 'fixing' systems (roof to walls, walls to floors) e.g. stiffer structural framework sealants to reduce flexure in storms
- aerodynamic building designs that reduce deflection and resonance e.g. dynamic stabilisation systems, better foundation design
- better planning guidance to avoid 'wind tunnel' effect.

### *Flooding*

Many opportunities exist for new technologies to assist buildings cope with inland or coastal flooding. Most of these relate to either keeping water out, or capture and use of the water. Options include:

- more sophisticated rainwater collection and re-use technology
- water-resistant building materials (including salt water)
- roofing materials and design to cope with increased drainage loads, including sizing of external drainage systems, gutters and downpipes, and storage facilities
- better planning guidance, land-use management and site analysis techniques
- foundation design to better cope with subsidence and heave.

### *Bushfires*

Opportunities for dealing with bushfire impacts could include:

- fire-resistant building material technology
- better site planning and landscaping controls.

## 11.1 Reduced space heating

In all climates where there is space heating demand now, that demand is reduced. For homes which do not have space cooling, this represents an economic benefit and a reduction in GHG emissions. In the cases of under-heated homes, this also provides a winter health benefit through reduced depth and duration of under-heating.

These benefits, however, come at the cost of increased summer discomfort and hence these effects are dealt with primarily in combination of the effects on heating in winter and cooling (and/or heat stress) in summer in Section 8 above.

Reductions in space heating will also occur in other building classes and those for offices and for hospitals are analysed in detail. This benefit rarely comes without the detriment of increased cooling and hence it is considered in detail in the section above.

## 11.2 Water heating including solar water heating

**Methodology**

The methodology employed through this modelling process involved using a TRNSYS model, constructed for simulating thermosiphon solar hot water heating units. Models were constructed for each of the AS4234 Climate Zones using weather files containing temperature, diffuse irradiation, direct irradiation, wind speed and cloud cover parameters. Three models were constructed for each Climate Zone as follows;

- Current – uses current weather files together with water inlet temperatures and peak heating loads, as specified by AS4234
- Scenario 1 – uses 2070 (high) weather files together with water inlet temperatures and peak heating loads, as specified by AS4234
- Scenario 2 – uses 2070 (high) weather files, with water inlet temperatures increased by the same increment as in ambient air temperature and a proportional decrease in peak heating loads based on a lower required increase in water temperature and volumetric draw-off, for each respective zone, based on an assumption of the same end use patterns as today requiring an average end use temperature of 45°C.

Further conditions were specified for the solar water heater model. These are outlined below:

| | |
|---|---|
| Collector area | 4 $m^2$ |
| Collector type | Selective surface, low iron glass |
| Orientation | azimuth (zero) facing true North |
| Tilt collector | 25° |
| Heat loss coefficient | 9.576 W/K |
| Thermostat setting | 55°C |
| Auxiliary heating rate | 3.6 kW |
| Tank mode | Horizontal |
| Length of tank | 2.044 m |
| Height of tank | 0.45 m |
| Volume of tank | 315 L |

This model was simulated over 8,760 hours in each AS4234 Climate Zone, with annual results summarised for the total energy required to meet hot water heating demands, auxiliary energy required to meet hot water heating demands and $CO_2$ emissions which result from these consumption values.[7]

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[7] $CO_2$ emissions were calculated based on relevant State and Territory information provided by the AGO Factors and Methods Workbook 2004.

**Results**

Table 12: Current Climate Simulation Results.
Energy = delivered useful energy in the form of heated water
AUX = Auxiliary (i.e. bought) energy consumed by the system to deliver that useful energy

| CURRENT | | | | | |
|---|---|---|---|---|---|
| Climate Zone[8] | Location | Peak Load (MJ/24h) | Energy kWh/year | AUX kWh/year | $CO_2$ kg/year |
| 1 | Rockhampton | 30 | 2,751 | 189 | 200 |
| 2 | Alice Springs | 30 | 2,751 | 106 | 78 |
| 3 | Sydney | 38 | 3,486 | 787 | 829 |
| 4 | Melbourne | 42 | 3,853 | 1638 | 2,280 |

Table 13: AS4234 Peak Heating Load and Water Inlet Temperature Simulation Results (2070 scenario).

| SCENARIO 1 | | | | | | |
|---|---|---|---|---|---|---|
| 2070 High (with *current* cold water temperatures) | | | | | | |
| Climate Zone | Location | Peak Load (MJ/24h) | Energy kWh/year | AUX kWh/year | $CO_2$ kg/year | Change AUX % |
| 1 | Rockhampton | 30 | 2,751 | 64 | 68 | -66% |
| 2 | Alice Springs | 30 | 2,751 | 53 | 40 | -50% |
| 3 | Sydney | 38 | 3,486 | 463 | 488 | -41% |
| 4 | Melbourne | 42 | 3,853 | 1,195 | 1,663 | -27% |

Table 14: Climate with Adjusted Peak Heating Load and Water Inlet Temperatures (2070 Scenario).

| SCENARIO 2 | | | | | | |
|---|---|---|---|---|---|---|
| 2070 High (with increased cold water temperatures) | | | | | | |
| Climate Zone | Location | Peak Load (MJ/24h) | Energy kWh/year | AUX kWh/year | $CO_2$ kg/year | Change AUX % |
| 1 | Rockhampton | 21.3 | 1,961 | 20 | 21 | -89% |
| 2 | Alice Springs | 22.5 | 2,062 | 20 | 15 | -81% |
| 3 | Sydney | 30.4 | 2,769 | 282 | 297 | -64% |
| 4 | Melbourne | 35.28 | 3,228 | 948 | 1,319 | -42% |

Table 15: Estimated Impact on Conventional Water Heaters from Elevated Cold Water Temperatures.

| CONVENTIONAL WATER HEATERS | | | | | | |
|---|---|---|---|---|---|---|
| 2070 High (with increased cold water temperatures) | | | | | | |
| Climate Zone | Location | Current | | 2070 (high) | | |
| | | Peak Load (MJ/24h) | Energy kWh/year | Peak Load (MJ/24h) | Energy kWh/year | Change Energy % |
| 1 | Rockhampton | 30 | 2,751 | 21.3 | 1,961 | -29% |
| 2 | Alice Springs | 30 | 2,751 | 22.5 | 2,062 | -25% |
| 3 | Sydney | 38 | 3,486 | 30.4 | 2,769 | -21% |
| 4 | Melbourne | 42 | 3,853 | 35.28 | 3,228 | -16% |

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[8] The Climate Zones in AS 4234 do not coincide with those of the BCA, nor with NatHERS

### Conclusions

The inclusion of solar hot water heaters into building designs is likely to experience significant advantages in future climate scenarios. All AS 4234 Climate Zones are predicted to experience an increase in favourable conditions for producing solar hot water, resulting in a decrease in electrical (or gas) auxiliary energy required to meet the hot water demands. Scenario 1 results indicate that when comparing current auxiliary energy usage with estimates for 2070, the greatest percentage decrease in auxiliary energy use is for Zone 1. This shows a 66% decrease in auxiliary electrical consumption. For change in magnitude of auxiliary energy usage, Zone 4 has the largest value, with a reduction of 443 kWh/yr. Scenario 2 results lead to the conclusion that in 2070 even greater reductions in auxiliary energy usage will occur relative to current climatic conditions. These results predict an 89% decrease in auxiliary energy usage for Climate Zone 1. Climate Zones 3 and 4 are predicted to decrease the auxiliary energy consumption by 505 kWh/yr and 691 kWh/yr respectively.

With no allowance for the impact of higher ambient temperatures, but only for the impact of higher inlet and end-use mixing cold water temperatures, the estimated savings in water heater energy consumption for the standard end use consumption patterns ranged from 29% decrease in Zone 1 to a 16% decrease in Zone 4. This corresponds to a 790 kWh/year and a 625 kWh/year decrease in Zones 1 and 4 respectively.

## 11.3 Building integrated photovoltaics (BiPV)

The market for and production of photovoltaic (PV) systems, deriving solar power from the sun's energy to produce electricity, has grown by over 35% each year over the last decade into a US$5 billion global market . The dominant cell technology continues to be mono-crystalline silicon, with notable growth rates in multi-crystalline and amorphous silicon technologies. Each technology has particular operational characteristics under temperature and solar irradiation conditions.

While there have been significant advances in solar power system technologies, and this is likely to continue over the next 50 to 70 years, we can use the characteristics of the higher performance end of the currently available technologies to indicate what the impacts might be on PV performance under a changing climate.

To do this we have simulated Building Integrated Photovoltaics (BiPV) performance at major locations in Australia for an example building under current and forecast 2070 high warming climatic conditions.

### Methodology

The methodology involved using a BiPV simulation tool developed at University of NSW called BiPVsim. Current and high warming 2070 climates files with temperature, diffuse irradiation, direct irradiation, wind speed and cloud cover parameters were used to simulate 8,760 hours and these were summarised into monthly and annual performance outputs. For each location, the following conditions were specified:

| | |
|---|---|
| PV system area | 10 m$^2$ |
| Orientation | azimuth (zero) facing true north |
| Tilt of PV system | latitude angle (facing the sun at the equinoxes) |
| Inverter[9] | flat inverter response of 100% |
| Thermal resistivity[10] | 0.05°C/W/m$^2$ |

It was assumed that there was no obscuration (shading) of the PV system. A non-isotropic sky model (Perez, 1993) was used to calculate the amount of diffuse irradiation falling on the tilted PV panels. A glass encapsulation was selected with a refractive index of 1.46 which is representative of a typical panel. It is acknowledged that fluoropolymers are also used, but the level of detail and likely significance does not warrant differentiation in the simulation modelling.

To enable evaluation of different cell technologies, the two most significant cell technologies and attributes were used in the simulation process, assuming standard test conditions (STC) of 25°C and air mass 1.5:

| **Mono-Crystalline Silicon (m-Si)** | | |
|---|---|---|
| Efficiency | 12% | (at STC) |
| Temperature coefficient | 0.005 | (% lost efficiency each degree increase above STC) |

| **Amorphous Silicon (a-Si)** | | |
|---|---|---|
| Efficiency | 8% | (at STC) |
| Temperature coefficient | 0.001 | (% lost efficiency each degree increase above STC) |

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[9] An inverter is the device which converts the direct current (DC) electrical output of the PV panels into the alternating current (AC) used within homes and the electricity power grids.

[10] Any incident radiation which is transmitted through the encapsulant, but not converted to electricity, is assumed to contribute to heating the PV element. All heat is assumed to be dissipated by convective cooling to the surroundings. The thermal properties of the element are modelled by the thermal resistance (the reciprocal of the convection heat transfer coefficient) which can be estimated from operating data. For roof integrated modules this is taken as 0.05 oC/W/m2 after work from Schmid (1992) and De Gheselle et al (1997)

## Results

Table 16 presents the output results from the BiPV simulations.

Table 16: Impact of Mono-crystalline Silicon (m-Si) and Amorphous Silicon (a-Si)
(Monthly and Yearly Impact as a Percentage Change from Current to High 2070 Scenario for Three Key Locations of Australia).

| DARWIN | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m-Si | 5.7% | 6.2% | -2.9% | -3.1% | -3.1% | 8.0% | 7.3% | 7.0% | 5.7% | 6.4% | 6.9% | 5.6% | 4.4% |
| a-Si | 7.7% | 8.4% | -0.4% | -0.4% | -0.4% | 10.2% | 9.3% | 9.2% | 7.9% | 8.4% | 9.1% | 7.9% | 6.6% |

| SYDNEY | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m-Si | -3.1% | -2.9% | 2.8% | 3.7% | 3.5% | 6.4% | 6.5% | 7.0% | 6.7% | 6.7% | 7.1% | -3.1% | 3.2% |
| a-Si | -0.7% | -0.6% | 5.1% | 5.9% | 5.6% | 8.7% | 8.7% | 9.3% | 9.1% | 9.3% | 9.6% | -0.7% | 5.5% |

| MELBOURNE | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m-Si | 5.1% | 4.4% | 3.4% | 3.9% | 4.4% | 11.5% | 10.9% | 10.7% | 10.5% | 9.4% | 9.0% | 5.7% | 6.9% |
| a-Si | 7.2% | 6.6% | 5.5% | 5.8% | 6.0% | 12.8% | 12.1% | 12.3% | 11.9% | 11.3% | 11.3% | 7.8% | 8.8% |

## Conclusions

Building integrated photovoltaics (BiPV) are likely to face improved conditions for system performance in future climates. Mono-crystalline silicon cells will be impacted more by extreme temperatures during peak summer months, but gains during winter and spring months indicate a net gain in annual performance outputs for 2070 relative to current conditions. Summer impacts will be lessened in the advent of any increases in wind speed, although this effect cannot be modelled with currently available PV design tools. While it is hard to determine the significance of this, wind direction, the synchronous nature of increased wind speeds with increased temperatures and the thermal response of design integration options will all play a role. Amorphous silicon shows greater gains as it has the capacity to contend with higher ambient temperatures (i.e. a far lower temperature coefficient).

For new technologies to minimise the impact of climate change, encouragement and support of research into novel systems and technologies for the adaptation of residential and commercial buildings to climate change will be necessary. Based on information to date, it is unlikely market-led programmes will have a major impact on climate change.

## ISSUE SIX

**"Assess the financial costs of the various options identified for reducing the vulnerability of Australian residential and commercial buildings"**

## 14. FINANCIAL ASSESSMENT OF ADAPTATION OPTIONS

This chapter discusses the direct costs for three adaptations for housing:

- Building overheating
- Storm/ wind damage
- Bushfires

The adaptations are based on the scenarios of climate change discussed earlier, and the buildings have been redesigned to mitigate against the effects, using current practises. For overheating the enhanced thermal insulation levels in the energy modelling in Chapter 6 were used. To cost the measures to resist storm damage the Residential timber framed construction standard was used, and for bushfire attack, the Construction of buildings in bushfire–prone areas standard was used.

These adaptation options were selected because the study has shown all are likely to become an ever greater issue based on the climate change predictions and they are all referenced all called up in the BCA.

The financial analysis is limited mainly to stand alone houses, though some apartment buildings were costed for overheating adaptation. It is acknowledged that there will also be significant costs associated with adapting non-residential buildings. Due to the wide variety of non-residential buildings it is difficult to estimate a representative cost of adaptation, and they have been omitted from the cost analysis, apart from an estimate of over-heating mitigation costs in offices.

Costs are based on Rawlinsons, *Australian Construction Handbook 2004*, however they have been adjusted downward, as recommended in the draft RIS 2005-01[11]. Even with this base a large number of estimates on the building stock and occupant behaviour (for the building overheating estimates) were needed and therefore the results of this work should be taken as preliminary estimates, with more detailed work on costs and benefits required.

A summary of the estimated costs of adaptation for housing, per house and adaptation type, is provided in Table 17. This is based on adapting a new house so the cost for existing houses is likely to be greater. However, the number of variables with respect to housing stock and condition make it impossible to estimate with the information available for this study. The cost of insulation for the energy adaptation is based on the upgrades used for the energy modelling in Chapter 6. The wind and bush attack adaptation is based on the need to increase the severity level in a region. For example, a house may be located in a place that is not a bushfire-prone area.

Table 17: Costs of Adaptation per house.

**Cost per house for adaption options**
**(approximations derived from Table 19)**

**Energy Adaptation**
Energy upgrade cost (including double glazing and insulation)

| Climate Zone | House $ |
|---|---|
| Darwin | 6990 |
| Cairns | 7170 |
| Brisbane | 6650 |
| Gold Coast | 6650 |
| Alice Springs | 7170 |
| Mildura | 5700 |
| Adelaide | 6420 |
| Perth | 6460 |
| Sydney | 6260 |
| Coffs Harbour | 6560 |
| Melbourne | 0 |
| Canberra | 0 |
| Hobart | 0 |

**Storm/Wind adaptation**
Change in wind classification (increase on lower wind class)

| | Estimated cost $ per house (average) | | |
|---|---|---|---|
| | **N2→C1** | **C1→C2** | **C2→C3** |
| Timber floor | 3270 | 3940 | 5260 |
| Concrete floor | 2170 | 3040 | 3740 |

**Fire Attack Adaptation**
Change in bush fire attack level required.

| | Estimated cost $ per house (average) | | |
|---|---|---|---|
| | **O→L1** | **L1→L2** | **L2→L3** |
| Timber floor | 6360 | 180 | 3800 |
| Concrete floor | 5280 | 180 | 3800 |

---

[11] ABCB March 2005. Draft RIS 2005-01 Proposal to amend the BCA to include energy efficiency requirements for class 5 to 9 buildings.

However, climate change predictions show the increased temperatures in that location (with the vegetation type etc) will mean a higher risk, so the rating will go from 0 (not rated) to Level 1 requirements (0➛L1). The difference between the floor types was due to the different needs set out for timber and concrete flooring to meet both the wind and bush fire attack requirements in the BCA.

Table 18 shows a summary of the costs at a national level. The costs associated with the existing housing stock assume there will be no need to upgrade until 2030 due to climate change. This is because the existing housing stock baseline is largely un-quantified however, in reality the upgrades could (and in the case of insulation improvements are likely) to occur earlier than 2030. The total cost per year for new housing is significant at about $700 million.

The estimated direct building costs of adaptation are necessarily approximate, due to the assumptions required. For example, for over-heating the most cost-effective level of thermal insulation will depend on actual temperature increases, and in the following we have made an estimate based on the enhanced insulation levels assumed in the earlier Section 6, namely R5/R2/R2 (Ceiling / Walls / Floor) in Climate Zones 1 to 5. Similarly, the risk from bushfire and wind damage on housing is expected to increase, and the assumption is that the percentage of houses affected in the each risk category increases by 1% on average in the period after 2030.

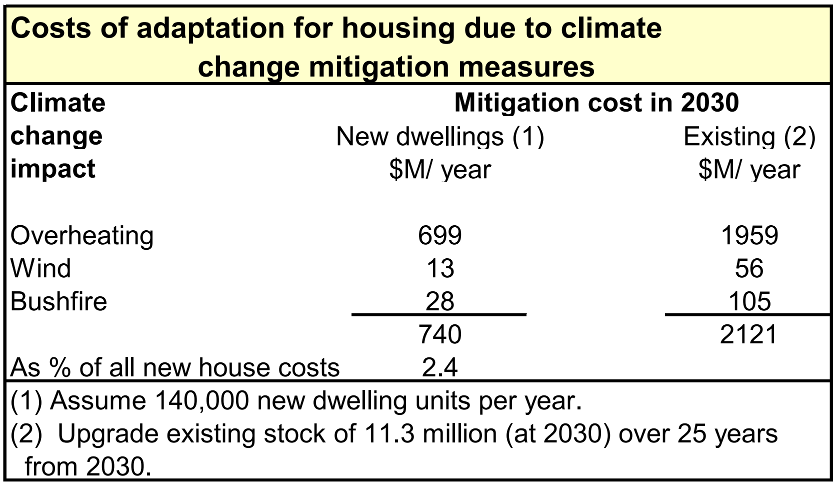
Without further work, it is difficult to know if these percentages are realistic, but the tables indicate for quite small increases in the risk categories there is a significant cost implication for both new housing, and retrofitting existing housing.

***Over-heating***

In Chapter 6, thermal modelling was carried out for various types of buildings. For housing, it is noted that in the cooler Climate Zones (Canberra, Melbourne and Hobart) the net amount of space conditioning energy required per dwelling unit is expected to reduce with time. Hence these

Climate Zones are omitted from the estimate of the cost of adaptation. The costs are shown in Table 19 below, and the assumptions are:

- New housing is insulated to R5/R2/R2 (Ceiling/ Walls/ Floor) in all Climate Zones 1 to 5.
- Bulk insulation costs were based on Rawlinson but reduced by 40%, as appears to have been done in the draft RIS 2005-01. Rawlinson does not have a rate for R5 insulation and an average of $14/ sqm was assumed.
- Existing housing is retrofitted after 2030 to the same level as new houses, using the same insulation as for new housing. This means that for existing framed houses the wall insulation is placed when either the cladding or wall linings are replaced, probably during remodelling. Solid wall houses are insulated with polystyrene sheets placed against the interior surface during remodelling, and finished with plaster or plasterboard. Ceiling insulation can be readily retrofitted, as can floor insulation for timber floor houses. For concrete slab houses, an edge layer of polystyrene would need to be retrofitted.
- All housing windows in Climate Zones 1 to 5 are upgraded to double glazed low-e windows, at a cost premium over plain single glazing of about $80 per sqm of window area.
- New and existing housing in Climate Zones 6 to 8 is not upgraded with insulation.



**Costs of adaptation for housing due to climate change mitigation measures**

| **Climate change impact** | **Mitigation cost in 2030**<br>New dwellings (1)<br>$M/ year | <br>Existing (2)<br>$M/ year |
|---|---|---|
| Overheating | 699 | 1959 |
| Wind | 13 | 56 |
| Bushfire | 28 | 105 |
| | 740 | 2121 |
| As % of all new house costs | 2.4 | |

(1) Assume 140,000 new dwelling units per year.
(2) Upgrade existing stock of 11.3 million (at 2030) over 25 years from 2030.

Table 18: National Costs of Adaptation.

### Housing cost for overheating adaptation

| | New dwellings | | Existing Dwellings (2) | | New dwelling Insulation | | Insulation upgrade cost (including double glazing) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Climate zone** | Average /yr to 2070 | | | | Current code | Assumed upgrade after 2030 | New house $ | All new dwellings | Existing dwellings (3) | All (4) existing |
| | (Number) | %(1) | (000) | % | Ceiling/wall/floor | | | $M/yr | (000) | $M |
| Darwin | 2100 | 1.5 | 41 | 0.9 | R1.5/R0.9 | R5/R2/R2 | 6988 | 15 | 102 | 712 |
| Cairns | 4200 | 3 | 49 | 1.1 | R1.5/R0.5 | R5/R2/R2 | 7168 | 30 | 122 | 872 |
| Brisbane | 21000 | 15 | 365 | 8.0 | R1.5/R0.5 | R5/R2/R2 | 6653 | 140 | 906 | 6031 |
| Gold Coast | 9800 | 7 | 17 | 0.4 | R1.5/R0.5 | R5/R2/R2 | 6653 | 65 | 42 | 281 |
| Alice Springs | 280 | 0.2 | 14 | 0.3 | R1.8/R0.9 | R5/R2/R2 | 7171 | 2 | 35 | 249 |
| Mildura | 420 | 0.3 | 23 | 0.5 | R2.6/R1.2 | R5/R2/R2 | 5695 | 2 | 57 | 325 |
| Adelaide | 12600 | 9 | 458 | 10.1 | R2.3/R0.9 | R5/R2/R2 | 6421 | 81 | 1137 | 7304 |
| Perth | 19600 | 14 | 552 | 12.1 | R2.3/R0.9 | R5/R2/R2 | 6459 | 127 | 1371 | 8854 |
| Sydney | 33600 | 24 | 1547 | 34.0 | R2.3/R0.9 | R5/R2/R2 | 6259 | 210 | 3842 | 24046 |
| Coffs Harbour | 4200 | 3 | 19 | 0.4 | R1.5/R0.9 | R5/R2/R2 | 6561 | 28 | 47 | 310 |
| Melbourne | 29400 | 21 | 1345 | 29.6 | R2.8/R1.2/foil | no change | 0 | 0 | 3340 | 0 |
| Canberra | 4100 | 1 | 37 | 0.8 | R3.4/R1.4/foil | no change | 0 | 0 | 96 | 0 |
| Hobart | 4100 | 1 | 83 | 1.8 | R3.4/R1.4/foil | no change | 0 | 0 | 206 | 0 |
| | 140,000 | 100 | 4550 | 100 | | | | 699 | 11300 | 48984 |

**New Dwellings**

| | |
|---|---|
| Average additional cost per new dwelling (including cost of insulation and double glazing) $= | 4996 |
| Total housing costs per year, assume 140,000 units/yr and $220,000 per unit, $ billion = | 30.8 |
| % increase in building costs to meet overheating adaptation = | 2.3 |

**Existing Dwellings**

| | |
|---|---|
| Cost to upgrade 11.3 million existing dwellings as 2030, $ billion = | 49.0 |
| Total insulation and double glazing retrofit cost per year for 25 years starting 2030 ($ million/yr) = | 1959 |

(1) Based on the population projections in Table 3.

(2) Number of dwelling units in the city or town from the 2001 census, used to obtain the % in the next column.

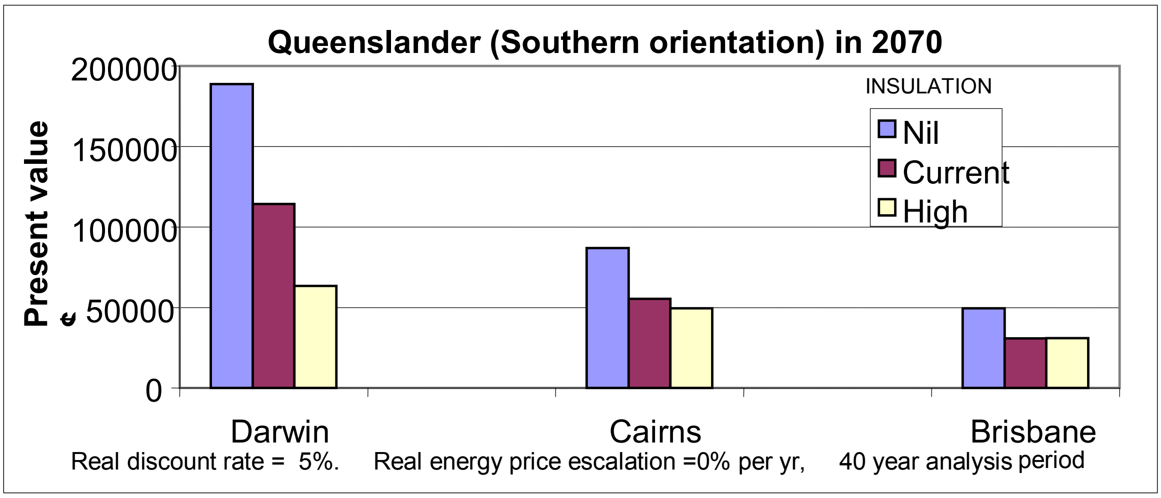
(3) Number of dwellings within the climate zone represented by the city or town. Total is 11.3 million dwelling units for all Australia by 2030.

(4) Retrofit assumes the same insulation and double glazing as for new dwellings.

Table 19: Housing Cost for Overheating Adaptation.

In accordance with the ABS forecasts in Table 5 and Table 6 the Queensland coastal regions increase their share of new housing to about 22%, from the current share of about 15%. The additional cost of the insulation and double glazing is approximately $0.7 billion per year. This assumes an average of 140,000 new dwelling units per year, and results in an average increase of about 2.3% per new dwelling - a significant portion of this cost results from the double glazing component. By 2030 another 3.5 million dwelling units will be constructed, giving a total housing stock of about 11.3 million units. These are all assumed to be upgraded after 2030, at a cost of approximately $2.0 billion per year, over the following 25 years. A significant portion of the cost results from the double glazing component therefore the cost would be significantly lower if double glazing was omitted from some regions. The current price premium for double glazing is about $120/sqm, according to Rawlinson, but we have used $80/ sqm, due to the observation that Rawlinson prices are generally on the high side, and the expectation that economies of scale will result in cost savings.

There will be considerable benefits in the upgrading of insulation, so the costs shown above are partly or completely off-set by energy cost savings, depending on the Climate Zone, and house type. Figure 19 shows the present values (PV) of the insulation and discounted energy use over a 40-year period for dwellings subject to 2070 climatic conditions. These figures are based on the energy use analysis in Section 6, Figure 6 and Figure 7. Many existing houses are uninsulated and are represented by the blue bars, the current Code requirements are the middle bars, and the enhanced insulation bars are the R5/R2/R2 plus double glazing case. For Darwin and Cairns the enhanced cases have a lower PV than the uninsulated or current code houses and hence have a net benefit. In Brisbane the enhanced case has a PV the same as that for the code insulation case, and so there is no financial penalty with additional insulation. In cooler climates the economics of enhanced insulation are unfavourable, however if double glazing was omitted (extra cost approximately $3,500 per house) the economics would probably be favourable, even though the energy saved would be lower. There is a need to investigate this further, using a wider range of insulation options and regions than was possible in this report. However it is already apparent that the costs of insulation to mitigate overheating will be substantially off-set by the energy savings.



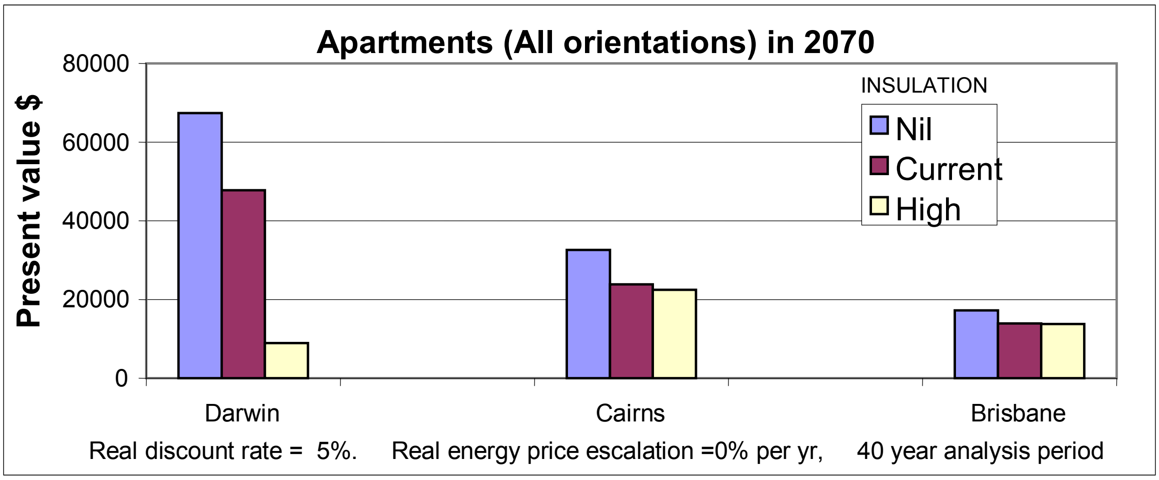
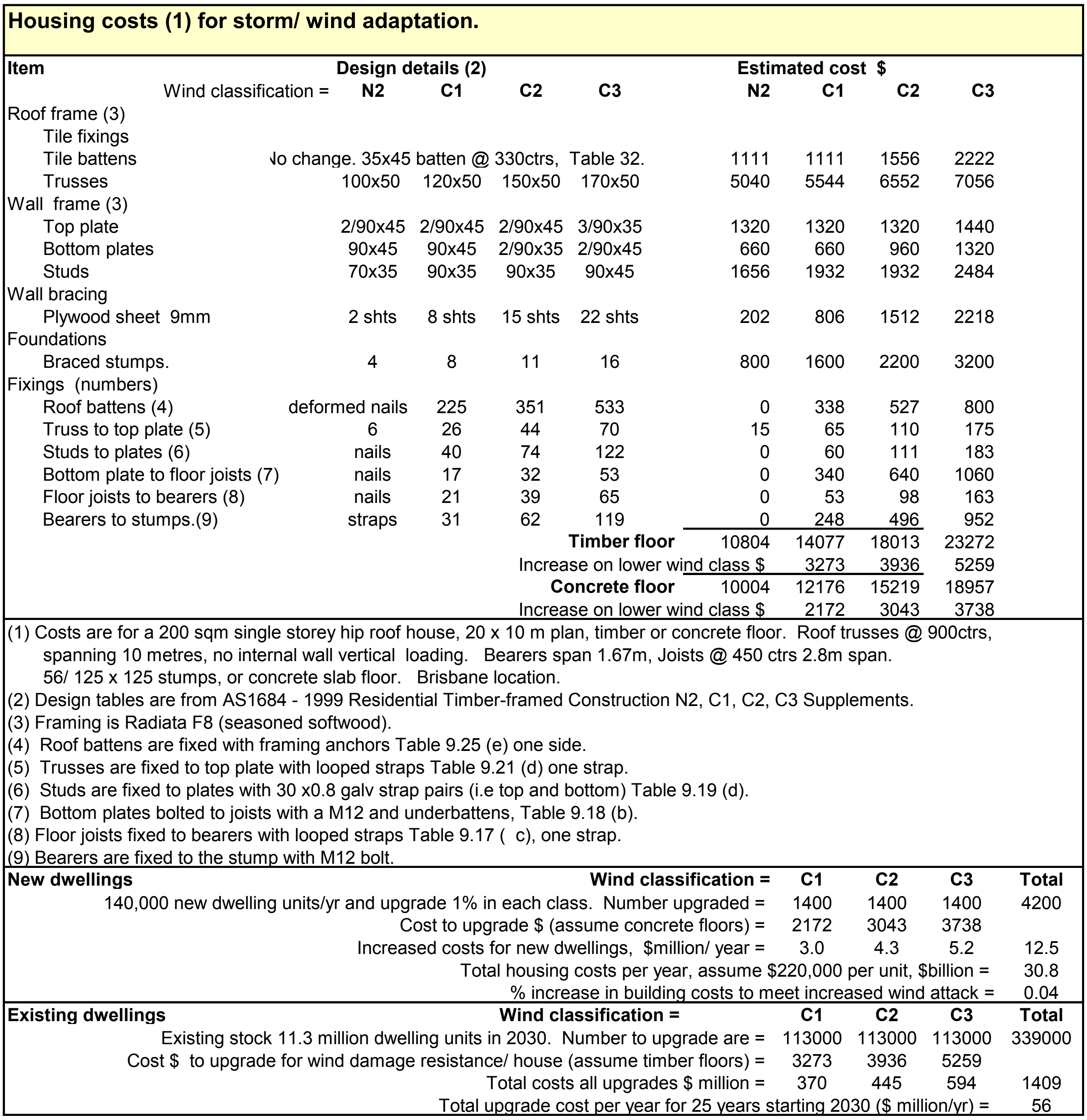


Figure 19: Present values (PV) of insulation and energy use over a 40-year period.

***Wind damage***

Peak winds are expected to become generally higher in most areas. The following assumes that the percentage of the total stock of dwellings in each of the cyclonic wind zones C1, C2 and C3 will increase by 1% on average by 2030, i.e. 3% more of the stock will be subject to cyclones compared to now.

Table 20 shows the costs of wind and cyclone resistant measures in new housing. For a standard 200 sqm single storey house on concrete slab these costs are between $10,000 to $19,000 per house, depending on the wind classification for the site. For existing houses it is assumed the retrofit costs are the same as for a new house because it is most likely to occur at a point where house maintenance is required so this becomes a possible option. Edica sinat



**Housing costs (1) for storm/ wind adaptation.**

| **Item** | **Design details (2)** | | | | **Estimated cost $** | | | |
|---|---|---|---|---|---|---|---|---|
| Wind classification = | **N2** | **C1** | **C2** | **C3** | **N2** | **C1** | **C2** | **C3** |
| Roof frame (3) | | | | | | | | |
| Tile fixings | | | | | | | | |
| Tile battens | No change. 35x45 batten @ 330ctrs, Table 32. | | | | 1111 | 1111 | 1556 | 2222 |
| Trusses | 100x50 | 120x50 | 150x50 | 170x50 | 5040 | 5544 | 6552 | 7056 |
| Wall frame (3) | | | | | | | | |
| Top plate | 2/90x45 | 2/90x45 | 2/90x45 | 3/90x35 | 1320 | 1320 | 1320 | 1440 |
| Bottom plates | 90x45 | 90x45 | 2/90x35 | 2/90x45 | 660 | 660 | 960 | 1320 |
| Studs | 70x35 | 90x35 | 90x35 | 90x45 | 1656 | 1932 | 1932 | 2484 |
| Wall bracing | | | | | | | | |
| Plywood sheet 9mm | 2 shts | 8 shts | 15 shts | 22 shts | 202 | 806 | 1512 | 2218 |
| Foundations | | | | | | | | |
| Braced stumps. | 4 | 8 | 11 | 16 | 800 | 1600 | 2200 | 3200 |
| Fixings (numbers) | | | | | | | | |
| Roof battens (4) | deformed nails | 225 | 351 | 533 | 0 | 338 | 527 | 800 |
| Truss to top plate (5) | 6 | 26 | 44 | 70 | 15 | 65 | 110 | 175 |
| Studs to plates (6) | nails | 40 | 74 | 122 | 0 | 60 | 111 | 183 |
| Bottom plate to floor joists (7) | nails | 17 | 32 | 53 | 0 | 340 | 640 | 1060 |
| Floor joists to bearers (8) | nails | 21 | 39 | 65 | 0 | 53 | 98 | 163 |
| Bearers to stumps.(9) | straps | 31 | 62 | 119 | 0 | 248 | 496 | 952 |
| | | | | **Timber floor** | 10804 | 14077 | 18013 | 23272 |
| | | | | Increase on lower wind class $ | | 3273 | 3936 | 5259 |
| | | | | **Concrete floor** | 10004 | 12176 | 15219 | 18957 |
| | | | | Increase on lower wind class $ | | 2172 | 3043 | 3738 |

(1) Costs are for a 200 sqm single storey hip roof house, 20 x 10 m plan, timber or concrete floor. Roof trusses @ 900ctrs, spanning 10 metres, no internal wall vertical loading. Bearers span 1.67m, Joists @ 450 ctrs 2.8m span. 56/ 125 x 125 stumps, or concrete slab floor. Brisbane location.
(2) Design tables are from AS1684 - 1999 Residential Timber-framed Construction N2, C1, C2, C3 Supplements.
(3) Framing is Radiata F8 (seasoned softwood).
(4) Roof battens are fixed with framing anchors Table 9.25 (e) one side.
(5) Trusses are fixed to top plate with looped straps Table 9.21 (d) one strap.
(6) Studs are fixed to plates with 30 x0.8 galv strap pairs (i.e top and bottom) Table 9.19 (d).
(7) Bottom plates bolted to joists with a M12 and underbattens, Table 9.18 (b).
(8) Floor joists fixed to bearers with looped straps Table 9.17 ( c), one strap.
(9) Bearers are fixed to the stump with M12 bolt.

| **New dwellings** | **Wind classification =** | **C1** | **C2** | **C3** | **Total** |
|---|---|---|---|---|---|
| | 140,000 new dwelling units/yr and upgrade 1% in each class. Number upgraded = | 1400 | 1400 | 1400 | 4200 |
| | Cost to upgrade $ (assume concrete floors) = | 2172 | 3043 | 3738 | |
| | Increased costs for new dwellings, $million/ year = | 3.0 | 4.3 | 5.2 | 12.5 |
| | Total housing costs per year, assume $220,000 per unit, $billion = | | | | 30.8 |
| | % increase in building costs to meet increased wind attack = | | | | 0.04 |

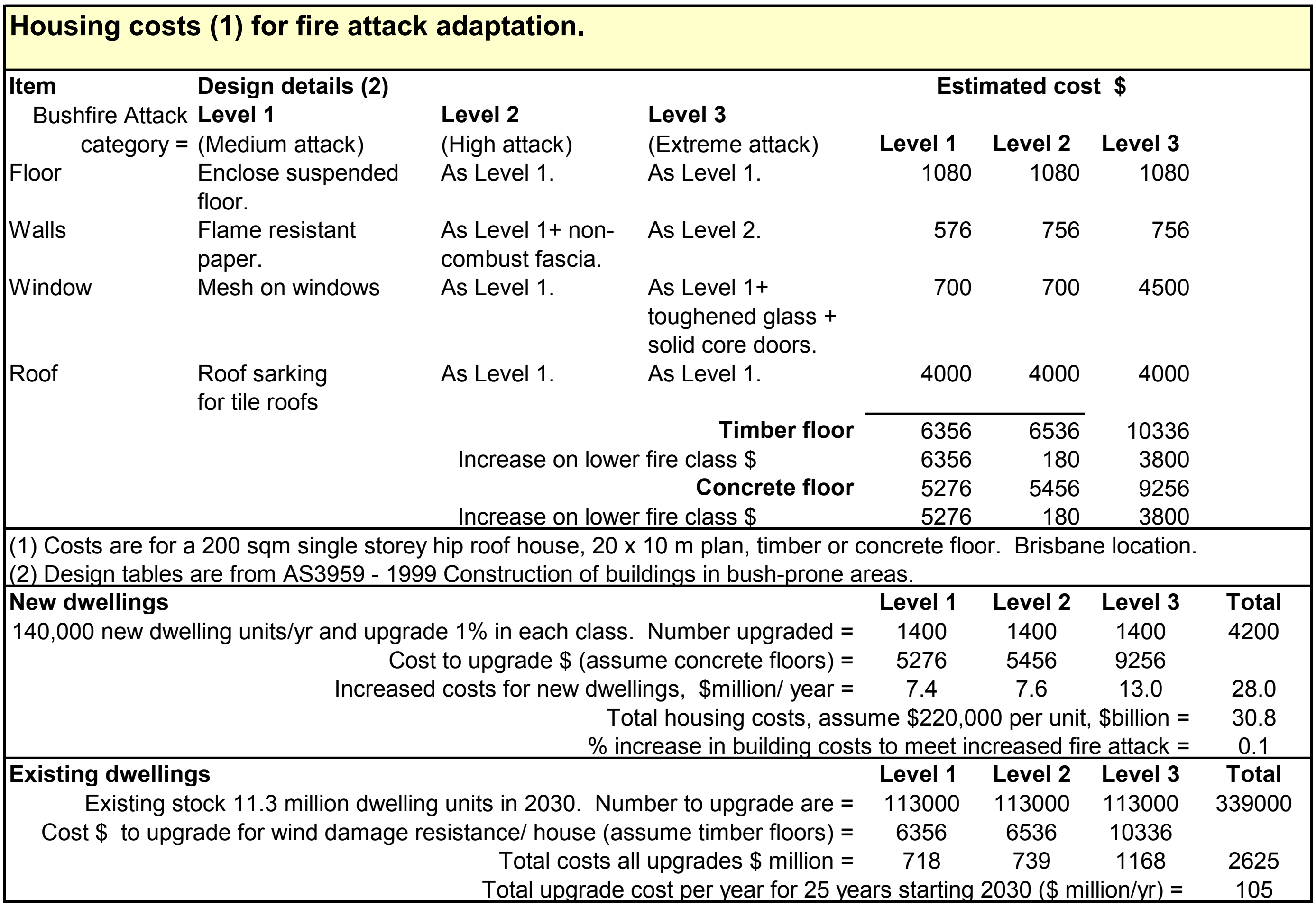
| **Existing dwellings** | **Wind classification =** | **C1** | **C2** | **C3** | **Total** |
|---|---|---|---|---|---|
| | Existing stock 11.3 million dwelling units in 2030. Number to upgrade are = | 113000 | 113000 | 113000 | 339000 |
| | Cost $ to upgrade for wind damage resistance/ house (assume timber floors) = | 3273 | 3936 | 5259 | |
| | Total costs all upgrades $ million = | 370 | 445 | 594 | 1409 |
| | Total upgrade cost per year for 25 years starting 2030 ($ million/yr) = | | | | 56 |

Table 20: Housing Costs for Storm/Wind Adaptation.

### *Bushfire*

The CSIRO estimates that the frequency of fires of a given intensity will approximately double in a moderate climate change scenario. It therefore seems likely that many more areas will be designated as bushfire risk areas by the local Councils. The current standard AS3959:1999 *Construction of buildings in bushfire-prone areas* determines the category of attack for the site solely in terms of vegetation density, building distance to vegetation and ground slope. The regulatory authorities may decide that the determination of risk behind the standard is no longer appropriate. For example, as wind gusts are expected to achieve high speeds the clearance distances in the standard may no longer be appropriate.

Given this, the assumption was made that the number of houses at risk in each of the three bushfire attack levels, as defined in the standard, increases by 1% on average after 2030. The costs effects are shown in Table 21.



**Housing costs (1) for fire attack adaptation.**

| Item | Design details (2) | | | Estimated cost $ | | |
|---|---|---|---|---|---|---|
| Bushfire Attack category = | Level 1 (Medium attack) | Level 2 (High attack) | Level 3 (Extreme attack) | Level 1 | Level 2 | Level 3 |
| Floor | Enclose suspended floor. | As Level 1. | As Level 1. | 1080 | 1080 | 1080 |
| Walls | Flame resistant paper. | As Level 1+ non-combust fascia. | As Level 2. | 576 | 756 | 756 |
| Window | Mesh on windows | As Level 1. | As Level 1+ toughened glass + solid core doors. | 700 | 700 | 4500 |
| Roof | Roof sarking for tile roofs | As Level 1. | As Level 1. | 4000 | 4000 | 4000 |
| | | | **Timber floor** | 6356 | 6536 | 10336 |
| | | | Increase on lower fire class $ | 6356 | 180 | 3800 |
| | | | **Concrete floor** | 5276 | 5456 | 9256 |
| | | | Increase on lower fire class $ | 5276 | 180 | 3800 |

(1) Costs are for a 200 sqm single storey hip roof house, 20 x 10 m plan, timber or concrete floor. Brisbane location.
(2) Design tables are from AS3959 - 1999 Construction of buildings in bush-prone areas.

| **New dwellings** | **Level 1** | **Level 2** | **Level 3** | **Total** |
|---|---|---|---|---|
| 140,000 new dwelling units/yr and upgrade 1% in each class. Number upgraded = | 1400 | 1400 | 1400 | 4200 |
| Cost to upgrade $ (assume concrete floors) = | 5276 | 5456 | 9256 | |
| Increased costs for new dwellings, $million/ year = | 7.4 | 7.6 | 13.0 | 28.0 |
| Total housing costs, assume $220,000 per unit, $billion = | | | | 30.8 |
| % increase in building costs to meet increased fire attack = | | | | 0.1 |

| **Existing dwellings** | **Level 1** | **Level 2** | **Level 3** | **Total** |
|---|---|---|---|---|
| Existing stock 11.3 million dwelling units in 2030. Number to upgrade are = | 113000 | 113000 | 113000 | 339000 |
| Cost $ to upgrade for wind damage resistance/ house (assume timber floors) = | 6356 | 6536 | 10336 | |
| Total costs all upgrades $ million = | 718 | 739 | 1168 | 2625 |
| Total upgrade cost per year for 25 years starting 2030 ($ million/yr) = | | | | 105 |

Table 21: Housing costs for Fire Attack Adaptation.

### Office buildings overheating

The indicative costs for the adaptation to over heating in office buildings are shown in Table 22. The costs are for chillers only, using data from Chapter 6 of this report, and the office has energy efficiency measures for the DTS case as set out in the Draft RIS 2005-01. The table indicates a quite small cost increase for the typical office building, of about 0.4%. Rather than increasing chiller capacity a more cost effective solution may be to increase the insulation of the external envelopment above the DTS level. The scope of this project did not allow this to be investigated and is work that should be done in the future.

**Office costs for overheating adaptation.**

| Climate zone | New office floor space per year (1) | | Existing office floor space (2) by 2050 | Net chiller costs to meet 2070 climate forecasts (3) | Net chiller costs New Offices | Net chiller costs Existing offices (4) |
|---|---|---|---|---|---|---|
| | (000 sqm) | % | (000 sqm) | $/sqm | $Million/ year | $Million/ year |
| 1 | 82 | 3.4 | 4890 | 9.4 | 0.8 | 2.3 |
| 2 | 370 | 15.4 | 22130 | 3.3 | 1.2 | 2.9 |
| 3 | 17 | 0.7 | 1010 | 5.7 | 0.1 | 0.2 |
| 4 | 74 | 3.1 | 4450 | 8.4 | 0.6 | 1.5 |
| 5 | 802 | 33.4 | 48000 | 7.2 | 5.8 | 13.8 |
| 6 | 948 | 39.5 | 56760 | 3 | 2.8 | 6.8 |
| 7 | 108 | 4.5 | 6470 | 1.5 | 0.2 | 0.4 |
| 8 | 1 | 0.04 | 60 | 0 | - | 0.0 |
| | 2,400 | 100.0 | 143700 | | 11.5 | 28.0 |

Value of new office space per year, assume $1200/sqm = 2,880 $ million

% increase in new office building costs = 0.4

(1) Based on Draft RIS 2005-01 Table B1, B3 and B4. Assume new and existing offices have the same regional distribution.
(2) Assume 2005 office stock is 84 million sqm and allow 1.2% per annum growth, as per the Draft RIS.
(3) Averages from Table 8 "Current costs of system components" and allows for boiler cost savings.
Assume the same costs for new and existing office chiller upgrades.
(4) Assume after 2050 the existing stock is upgraded over 20 years.

Table 22: Office Costs for Overheating

## 12.1 Identified research needs and opportunities

It is recommended that a methodology for assessing the costs and benefits of taking retrofit action (based on the assessment of risk / determination of the benchmark level) be developed.

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