Response strategies used to mitigate the effect of extreme weather on rural and remote housing in Australia

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Abstract. In the extreme climates of Australia, rural and remote locations have special site and dwelling requirements and therefore special design solutions. This can include construction constraints, bushfire risk, resource efficiency, comfort and respect for the surrounding environment and heritage. Existing regulations targeted at extreme weather impacts such as bushfire, flood, cyclones, and heatwaves often impact the design and material choices for rural and remote housing due to their exposed locations, including housing proposed for rebuild following damage resulting from an extreme weather event. These regulations also lead to increased costs and uncertainty about the suitability of rural land for construction, making it challenging for rebuilding communities in affected areas. Such well-intentioned regulations also create limitations on innovation through experimental / bespoke building design, such as; 1) novel solutions to extreme weather mitigation and resistance 2) material choices for construction; and 3) achievement of operational and embodied energy reductions.

Experimental buildings provide significant innovation benefits to industry as is often seen in the development of sustainable and high-performance buildings. This research examines the academic and industry knowledge of current design regulations for extreme weather events and implications for experimental and innovative design, highlighting the challenges for buildings to achieve increasing standards of environmental performance whilst ensuring resilience in the face of increasing extreme weather events, with a specific focus on rural communities. Case study analysis is used to provide an understanding of the focus and strategies used by different groups in different locations to address the impacts of extreme weather.

Keywords: Construction innovation; resilience; innovation; sustainability; emissions.
1. Introduction

Extreme weather events are part of a long-term trend of worsening extreme weather since the 1980s, both globally and in Australia. The last decade has presented the very worst of extremes as a result of human-induced climate change. Over the past several decades, heatwaves in Australia have increased in duration, frequency and intensity in many parts of the country; southern Australia has experienced a rainfall decline in the cooler months, heavy rainfall events have accounted for an increased proportion of total annual rainfall, and extreme fire weather days have increased at 24 out of 38 sites [1].

There is no simple definition of an extreme weather event, noting that some weather events can be classified separately as severe events, rare events, extreme events, or high impact events [2]. For the purposes of this research, we adopt the IPCC (2012) definition that extreme weather is “an occurrence of a value of a weather or climate variable beyond a threshold that lies near the end of the range of observations for the variable” [3]. Examples include very high / low temperatures, uncharacteristically heavy precipitation, and very high wind speeds. Extreme events usually occur only rarely, and they are noticeable because they are so different from the usual weather and climate, and because they are associated with adverse impacts on humans, infrastructure and ecosystems [4]. The spatio-temporal scale is a primary determinant of extreme weather events, defined by geographic location, and local geography. Seasonal variation amongst other factors [5] is an important determinant of extreme weather events. Despite geographic isolation, Australia is made up of many climates, but in consideration of extreme weather can be broadly separated into the tropical climate characterised by cyclone and flood, and the sub-tropical or temperate zones characterised by bushfire and heatwaves. Cyclone and bushfire are the deadliest in terms of lives lost, and along with flood represent the most significant economic impact. Heatwaves are not usually associated with the word ‘disaster’ but have a dramatic effect on health and wellbeing.

In Australia, regulations targeted at extreme weather impacts such as bushfire, flood, cyclones, and heatwaves have predominantly impacted the design (including structural integrity) and material choices for rural and remote housing due to their exposed locations, including new build or rebuild following damage resulting from an extreme weather event. However, such well-intentioned regulations create limitations on; 1) site-based design response and amenity, 2) material choices for construction; and 3) embodied energy. These regulations also lead to increased costs and uncertainty about the suitability of rural land for construction, making it challenging for rebuilding communities in affected areas. Rural and remote housing have considerable demands over urban residential projects as they are characterised by challenging sites, difficulty with delivery due to location, additional costs (such as transport and onsite labour) and a small population with limited trade workers. put greater demand on air conditioning and occupant comfort.

Despite extensive work on preparedness for extreme weather by governments, solutions by industry and research on impacts ex-post vary greatly according to the spatio-temporal variances by a number of different groups at different levels. there is no research that assembles the understanding of the different strategies in use by designers to mitigate against such disasters. Experimental buildings are often ahead of the regulations in the building industry, and this research captures this knowledge for the benefit of future building designs.
2. Background and Literature Review

The literature extensively covers the issues related to the impact of climate change on buildings [6] often considered inline with IPCC predictions for temperature and sea level rise. Climatic drivers of extreme weather are less well understood in terms of predictability [7] but it is generally accepted that extreme weather events will continue to increase. Macro climate change research is concerned with the appropriateness of the weather files and accuracy of building simulation, overheating risk and adaptation strategies and resilience.

![Schematic overview of climate change impact on buildings showing impacts of extreme weather events (highlighted) [8].](image)

Australian research on extreme weather impact on buildings and appropriate solutions are understandably location specific, and is focused on event specific conditions and solutions such as:

- cyclones, rebuilding, resilience
- flood: planning, structures and economic impacts
- bushfire: land use and assessing risks
- overheating: design considerations, health and wellbeing

Below is a summary of the extreme weather events in each type of impact:

### 2.1. Cyclone

In 1974 Cyclone Tracy caused 65 deaths and damaged 70 percent of Darwin homes. More recently, cyclones Vance (1999), Larry (2006) and Yasi (2011) showed that updated regulations and standards have resulted in much less building damage and consequent loss of life [9]. During Cyclone Yasi, for example, 12 per cent of older homes suffered severe roof damage, but only three per cent of newer homes [10]. Cyclones are categorised on a scale of 1 - 5, represented by wind speeds of 125km/h up to 280 km/h.
2.2. Flood

Often experienced in tandem with cyclones, both inland and coastal flooding present their own unique challenges to the built environment. Inland flooding is associated with heavy rainfall and vulnerability to the failure of infrastructure such as dams and local catchments [4]. Coastal flooding, as well as contributing to inland ‘storm surge’ flooding, presents a sustained challenge for those living within low-lying coastal areas in proximity to rising sea levels. In a built environment designed and built for the climate of the 20th century, Australian housing is “vulnerable and unprepared for the changes in climate that are likely to increase the intensity of coastal storms” [12]. There are many coastal flooding forecasting models being used to predict the range of impact on housing and infrastructure [13], and all forecast that in the lower range, tens of thousands of homes on Queensland's shoreline are at high risk of coastal flooding from sea level rise. At the higher end of this forecasting, the impact scales to hundreds of thousands of residential buildings exposed to the combined impact of inundation and shoreline recession [14]. This is of particular concern considering “most insurance policies do not cover actions of the sea. Insurers do not cover the future impact of climate change” [15].

2.3. Bushfire

Summer in Australia is synonymous with devastating bushfires, with the 2019 / 2020 summer being one of the worst seasons on record. By March 2020 Black Summer fires burnt almost 19 million hectares, destroyed over 3,000 houses, and killed 33 people [16]. The future looks set for more dramatic events, as stated by the CSIRO and BOM after the devastating 19/20 fires, “There has been an increase in extreme fire weather, and in the length of the fire season, across large parts of Australia since the 1950s, especially in southern Australia and it is predicted that both the south and east of Australia will experience a longer fire season and increase in the number of dangerous fire weather days.” [1].

2.4. Heatwave

Despite being a continent of extreme heat waves, there is currently no comprehensive requirement for overheating in Australian buildings, despite the extremes of the continent such as on 4 January 2020, where Penrith (New South Wales) was officially the hottest place on Earth at 48.9°C. [17]. In 2009 Victorian heatwave that began on the 27 January with daytime temperatures topping 43°C across 3 days, with night-time minimums of above 25°C [18]. Understandably the 2009 heatwaves coincided with catastrophic bushfires in Victoria. Although changes are progressively improving the National Construction Code (NCC) for energy efficiency, heat stress and thermal comfort is not explicitly included as a metric in the assessment of proposed designs, and the increase of building performance regulations has led to increased overheating, particularly in existing apartment buildings. This regulatory limitation is partially addressed by NCC 2019, which introduced a ‘cap’ on heating and cooling load per dwelling when calculating the energy performance. The Council enforced ‘Better Apartment Design Standards’ (BADS) introduced even more stringent cooling load limits, reflecting concern for overheating risks in apartments. Preceding the latest revision of NCC 2022, following a consultation process of 121 submissions on to updates of residential codes, an outcomes report was released by the ABCB identifying “An urgent need to respond to climate change, including protection from extreme heatwaves” [19] which demonstrates an understanding of the importance of the issue.
3. Case Study & Discussion

Case studies are appropriate to be used to test or generate theory and are particularly appropriate for areas where the research is still in its infancy, formative stages where there are no solid theoretical foundations. It is preferred when “how” or “why” questions are being posed [20]. According to [21], the case study research method represents an inductive approach that allows the in-depth study of individual cases (or innovations), which will provide a detailed understanding that would not be possible using more cross-sectional methods. It can include data from direct observation and systematic interviewing as well as from public and private archives. Any fact relevant to the stream of events describing the phenomenon is a potential datum in a case study, since context is important [22]. Of importance to this study, a critical case is used in order to generalise about innovations. The case study data is collected via content analysis [23].

This research analyses three groups responding to the issue to understand their strategies to mitigate the effect of extreme weather in Australian house design. This includes:

**Innovators** - designing solutions to achieve best practice. Innovators engage in rigorous testing, prototyping and research and development. They raise the benchmark for what is possible, creating the case for standards to move beyond minimum standards in an open conversation that engages the wider community. These innovative projects often connect to regulators through intermediaries such as insurers and government bodies.

**Insurers** - addressing risks related to housing damage and claims from extreme weather. Insurers are core to disaster recovery response and hold invaluable data and potential insight into both risk and recovery. They conduct their own research and development to advise and work directly with both regulatory bodies and innovators, directly contributing to the coordination of funding and mitigation efforts.

**Regulators** - addressing the appropriate minimum standards for extreme weather resilience. The regulatory system is a complex of policy makers and government bodies who are informed by a hierarchy of independent boards and advisory groups made up of state and local government representatives, technical experts, industry representatives, businesses, academics and community experts who are informed by research of innovators in these areas.

3.1. Case Study 1: Joost Bakker Fire Proof house, CSIRO

The Fireproof house was built by Joost Homes and was able to passed the worst-case CSIRO fire simulation of a major fire front. The unique design could withstand external temperatures of 1000°C, and maintain internally the air temperature only reach 40degC and internal surface temps reaching 55°C [24]. The design is also an exemplar of both innovative resilient combined with the rarer elements of sustainable design (green roof), non-toxic and recyclable materials, and challenges traditional construction methods and materials, using straw bale insulation set into a recyclable steel frame. Specifically for the project, Joost initiated the development and production of a fire-resistant, formaldehyde free plywood and charcoal embedded Magnesium Oxide (MgO) board that has 1/10 the carbon footprint of fibre cement sheet [25]. Embracing biomimicry principles allowed the plywood from sustainably harvested forests to use soy-based adhesives replacing formaldehyde as the glue that bonds the layers together. Dr. Li, a professor at Oregon State University’s College of Forestry, found that mussels secrete proteins known as byssal threads provide superior strength and extraordinary flexibility and discovered that soy proteins can be modified to perform similarly to byssal threads. And not only did they deliver phenomenal adhesion, they also offered exceptional water resistance. This breakthrough led to ‘PureBond’, proving that enhanced environmental quality and increased product
performance can go hand in hand” [26]. The Fireproof house demonstrated that an innovation need created by extreme weather could lead to innovative solutions.

3.2. Case Study 2: ONE House to Save Many -, CSIRO, Suncorp, James Cook University, Room 11 Architects

'One House' is a home specifically designed to protect against floods, fires, and cyclones in order to compare innovative strategies against a standard family home [27]. The experimental test facility allowed rigorous testing, including:

- Wind-driven debris and a roof section pressure demonstration simulating the effects of cyclonic wind
- A water ingress test to understand the vulnerable aspects of standard windows and doors in the event of wind driven rain and inundation
- A bushfire resilience test on a One House prototype measuring the impacts at different burnover levels using specialised simulated bushfire flame fronts.

The project collaboration responded to research that showed that homeowners prioritise aesthetics over the strength and protection of the home, and developed a number of key recommendations including, high performance mesh screens, dual water tanks for firefighting, electrical safety solutions for flooding, as well as design recommendations to provide strength and minimize risk. The project demonstrated best practice strategies, noting that “there’s an assumption that current building codes will fully protect you, and whilst they do protect life they don’t necessarily support building resilience into a building, and depending on when you built your home and how the code responded at that point in time.” [28].

3.3. Case Study 3: Insurance industry

Insurance companies have a responsibility to minimise harm to their clients and to provide financial returns. This has led to the identification of the need to assist homeowners before extreme weather impacts occur to minimise the payout, noting that in 2019/2020 the combination of all extreme weather related disaster cost $8.8 billion to the Australian GDP, and noted that without insurance some communities will never recover from disaster - This is especially the case in regional Australia, where there is increased risk of disasters and communities have a narrower economic base [29] (SGS Economics and Planning Pty Ltd 2020). As illustrated in the “One House” case study, insurance companies are already preemptively funding innovative designs to mitigate against extreme weather impacts that cause damage to buildings and properties.

Australia’s national insurance body, the Insurance council of Australia (ICA) has identified that while "at present no region in Australia is uninsurable… it is possible some regions may become difficult to insure in the future unless governments invest in appropriate physical mitigation and adaptation strategies. Implementation of stronger building codes, improved land-use planning and permanent physical mitigation measures, where necessary, will be key to ensuring an ‘Insurable Australia’." [15]. Tasked to raise the standards, the ICA is teaming with both innovators and regulators to move ahead of the next revision period for Australia’s building code revision, NCC 2022, on projects which will raise the bar for new developments and promoting more stringent standards for resilient design.

Teaming with an independent authority of sustainable buildings, the Insurance Council of Australia (ICA) and the Green Building Council of Australia (GBCA), created a new rating system for residential homes which goes beyond minimum standards to withstand natural disasters such as bushfires, flooding, and heat stress [30]. The worry of rising insurance premiums has also prompted the development of climate-ready home specification a locality of South Australia. The ‘Where we
Build, What we Build’ research project found that retrofitting housing stock across six regional local government areas in South Australia would translate into a net present value of $72 million. This research was conducted through heat and fire hazard mapping, comparing insurance industry data with Council data to assess the resilience of homes to natural hazards and risk exposure of specific housing archetypes. The resulting home specifications include detail materials, construction, planning climate hazard mapping information sheets that residents, organisations and local government can used for improving the climate resilience of new build and retrofit homes [31].

3.4. Case Study 4: Regulator perspective

Australian building standards have seen a now decades-long discussion amongst regulatory groups, discussing the pathway to introducing climate resilience [32, 33, 34, 35, 36]. The National Construction Code (NCC, or the Code) is a model code directed by two entities, the Building Ministers Forum and the Council of Australian Governments (COAG). The NCC is represented by the Building Code of Australia (BCA) – NCC Volumes 1 and 2; and Plumbing Code of Australia (PCA) – NCC Volume 3. These provide standards for extreme weather impacts related to settlements and infrastructure, emergency planning and response, insurance, and human health. Residential buildings and structures codes come under the domain of an Australian Building Codes Board (ABCB) which oversees the standards administration and development.

In 2019, as part of The Global Resiliency Dialogue, the ABCB participated in a global survey with government and non-governmental stakeholders from eight countries to assess how climate-based risks are considered within their national building codes and standards. The surveys concluded that none of the participating countries, including Australia, addressed future risk [37]. So, while the Australian Standards are adequate to preserve life, they do not address resilience. Australia’s building standards relating to effects of extreme weather are produced by an independent, non-governmental organisation, Standards Australia, which utilises committees of technical experts, businesses, academics, government bodies and representatives and community experts to develop, assess and review changes.

The NCC provisions (2019) has numerous provisions related to the design for extreme weather impacts such as Specification B1.2, ‘Design of buildings in cyclonic areas’ which contains requirements for the design of buildings in cyclonic areas in addition to the requirements of Australian Standard AS/NZS 1170.2. This chain of command illustrates how the NCC interprets standards as regulation for the building industry, each of which is independently adopted by States and Territories. Since 2014 the ABCB has worked towards addressing a number of impacts of extreme weather events including to:

- Comprehensively review and consider the impacts of extreme weather events in relation to all relevant new regulatory initiatives;
- Investigate climate related natural hazard events as they occur to determine whether the NCC scope and provisions are adequate;
- Liaise with the planning, building, industry and insurance sectors, to improve the relationship between building and planning and to explore ways of better defining responsibilities, especially in high hazard areas.

The case study analysis demonstrates considerable efforts by all groups but with different strategies to mitigate impacts from extreme weather for rural housing, with a focused effort by the innovators on practical solutions, a community level effort by insurers who have a vested interest in reducing the scale of damage to houses from extreme weather events, and by the regulators attempting to define the requirements of new or rebuild construction projects to save lives and minimise damage. It is reassuring to see that in most cases, even if at the high level, the groups with mitigation strategies are communicating in order to achieve the common goal.
4. Conclusion

New housing projects always exist somewhere between the minimum standards of regulation and the best practice innovation of designers, suppliers and builders. At present the regulatory aspects of managing extreme weather appear to be lagging due to previously identified challenges, the need for robust consistent data, government/community support, and affordability. Much like sustainability initiatives that are a response to climate change, extreme weather responses are required to achieve a balancing act that is part way between the efforts of the innovators, insurers and regulations.

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