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Review

Housing Design for Health in a Changing Climate for Remote Indigenous Communities in Semi-Arid Australia

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Abstract: Architecture can be very influential in enabling health and wellbeing in the residential built environment. In arid regions, health-supportive design would consider major environmental hazards, such as heat and dust, as well as social and cultural factors that influence household size and composition. Under current and projected conditions, the effects of climate change will increase, presenting opportunities and challenges to architects to demonstrate and deliver best practice in climate-appropriate and culturally appropriate housing design. This paper brings together a multidisciplinary team of researchers to identify the current and future needs for tropical semi-arid zone design with a focus on Indigenous communities in northern Central Australia. In a narrative review of the literature and exploratory fieldwork, current and projected impacts of climate change on housing, health, energy systems and behavioural practices are explored in a holistic way. Our findings demonstrate the growing awareness of climate-related issues for remote Indigenous housing but also the lack of place-based studies that might inform adaptation strategies. Overwhelmingly, there is limited understanding of local lived experiences that may be highly significant for developing resilience in a changing climate. Consideration of the beliefs, values and practices of Indigenous people will be integral to design solutions.

Keywords: sustainable aboriginal housing; indigenous health and wellbeing; crowding; semi-arid Australia; energy justice; climate change

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1. Introduction

Countries of the Global North, including Australia, are disproportionately heavy emitters of greenhouse gases contributing to human-induced climate change, whereas the countries of the Global South disproportionately endure the resulting negative impacts [1]. Within Australia, as in other high-income countries, social inequality between groups based on gender and ethnicity, as well as remoteness can exacerbate the detrimental effects. Reports have clearly shown that some Indigenous Australians (the authors acknowledge that there is a range of preferred terminology for the First Peoples of Australia, including First Nations Peoples, Indigenous Peoples, and Aboriginal and Torres Strait Islander Peoples. As per the preference of our two Indigenous co-authors, Burgen and Frank, we henceforth respectfully use the term 'Indigenous Australians' when referring to wider Australia, but 'Aboriginal people' when speaking specifically of the Barkly region) have already been experiencing significant adverse effects, particularly in remote communities [2,3]. Low-emission energy generation options (e.g., solar panels, electric transport, wind turbines) that have been the focus of mitigation and adaptive responses in Australia can inadvertently overlook disadvantage and create further injustice [4,5].

Architecture can be instrumental for enabling health and wellbeing in the residential built environment, typically flagged in climate change policy around choice of infrastructure. However, there is often very little detail on how the integrated design of all components can contribute to better outcomes for residents. In semi-arid regions, health-supportive design (our term, informed by [6]) should consider major environmental hazards of heat and dust, as well as social, economic and cultural factors that influence household size, composition and behaviours. Under current and projected conditions, the effects of climate change will intensify, presenting both opportunities and challenges to government housing agencies and architects to demonstrate and deliver best practice, in both 'climate-appropriate' and culturally appropriate housing design.

This paper brings together a multidisciplinary team of researchers to identify more fully the current and future needs for arid zone design with a focus on Indigenous communities in northern Central Australia. The authors draw on their expertise within architecture, engineering, anthropology, health science, medicine and education, as well as lived experience to inform a holistic approach to the nexus of housing, health and design for climate. For some of the authors it is a continuation of related research on housing and health in the Barkly region of the Northern Territory (NT) (see [6]). In a narrative review of the literature, the current and projected impacts of climate change on housing, health, energy systems and behavioural practices are explored in a holistic way. Our Indigenous co-authors provide a first-hand set of observations and perspectives on how climate change has been affecting Indigenous residents of Tennant Creek, in the Barkly region.

Our research seeks to add to the growing awareness of climate-related issues for remote Indigenous housing, and offset the lack of place-based multidisciplinary studies that inform adaptation strategies. Overwhelmingly, there is limited understanding of local lived experiences that may be highly significant for developing resilience in a changing climate. Consideration of the beliefs, values and practices of Indigenous people will be integral to design solutions.

Research Aims and Methodology

This research aims to inform best practice housing design and management to strengthen resilience and sustainability in the context of climate change. Using a holistic approach from a multidisciplinary team, the research explored important research topics around adaptive design responses for semi-arid housing for remote Australia, focusing on Indigenous communities in Australia's Barkly region (Figure 1). The topics include climate change in semi-arid Central Australia, housing, health and infectious diseases in the Barkly region, Aboriginal housing practices, government response, energy systems and infrastructure and design.

The authors undertook a review of the literature to examine supportive housing design for Indigenous Australians in the study location. The topics under investigation broadly correlated with their disciplinary focus and research experience including architecture, social anthropology, public health, thermal physics and design, and sustainable energy system science. In the search for an appropriate design that could be resistant to the effects of climate change, one of the authors applied climate software, 'Climate Consultant V6.0' to climatic records of Tennant Creek. Analysis of the data was informed and supplemented by several informal ethnographic field discussions in Tennant Creek led by the Indigenous authors.

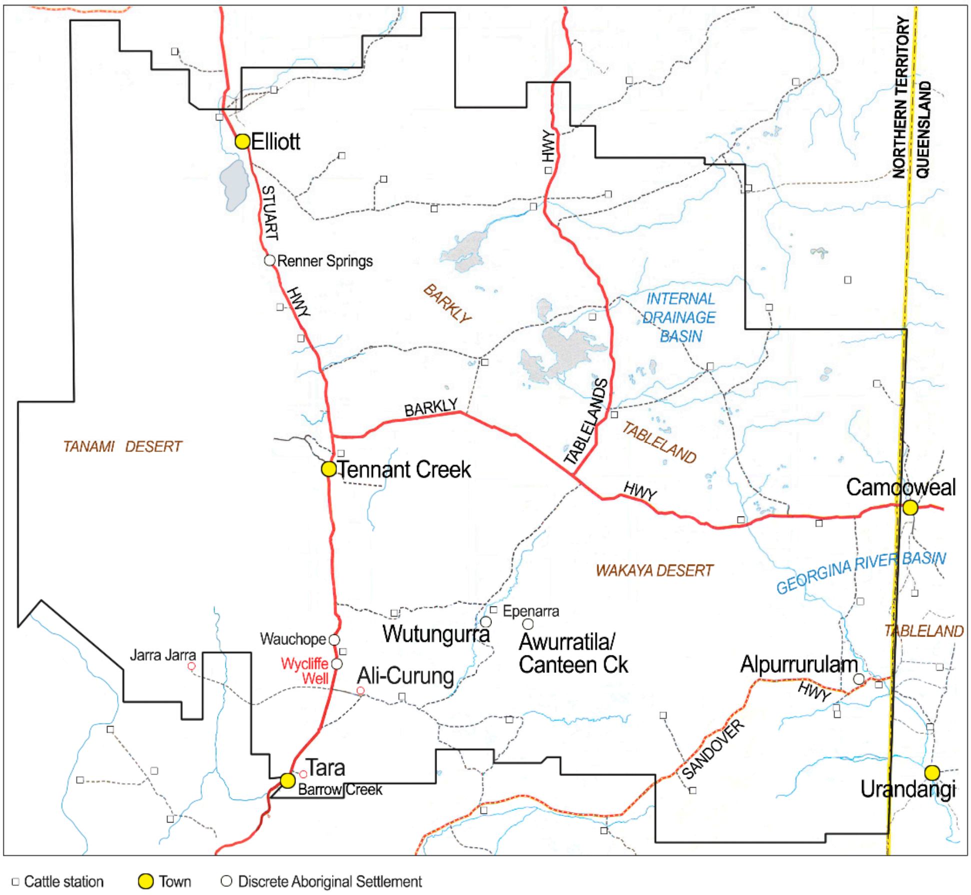

Figure 1. Map of Barkly region showing main centres of Aboriginal population in larger font (smaller outstations not shown).

Five key themes emerged from the investigation of the research topics, as follows:

Theme 1: Challenges of remote living for Indigenous people
Theme 2: Improved housing is needed for better health
Theme 3: Widespread government inaction (and failure to provide appropriate housing)
Theme 4: Supportive design has cultural, technological and health components
Theme 5: Importance of energy efficiency and energy justice.

2. Theme 1: Challenges of Remote Living for Indigenous People

2.1. Living with Climate Change in Semi-Arid Northern Central Australia

As the driest inhabited continent, Australia is highly vulnerable to the impacts of global warming. The global average temperature has risen 1.1 °C since 1910 [7] and Australia has warmed on average by 1.4 °C (since national records began in 1910 [8]). Evidence suggests that the increasing temperature has led in recent times to more frequent and intense heatwaves, unpredictable rainfall, droughts, bushfires, cyclones, storms and flooding including the catastrophic 2019–2020 bushfires in south-eastern Australia, when the national mean temperature was 1.52 °C above average [9]. For semi-arid northern Central Australia, there are predictions of water scarcity and increased desertification during the 21st century [10,11]. As in other parts of Australia, increased droughts together with bushfires are likely to increase the number of 'dust days' particularly in summer months [12].

The current study focuses specifically on the town of Tennant Creek and the Barkly Tableland in Australia's Barkly region (Figure 1). Tennant Creek and the Barkly Tableland are in the centre of the Northern Territory in Australia—between 18 and 20 degrees south and from 134 to 138 degrees east and, in climatic terms, are described as dry, with a mild winter and a hot dry summer [13]. Tennant Creek, the largest town in this area, has recorded a warm annual average temperature of 25.5 °C, with winter minimum temperatures typically remaining above 10 °C. In contrast, the period from beginning December through to end March has an average maximum temperature of 36.6 °C, and, as noted above, Tennant Creek experiences an average of 140.5 days above 35 °C and 28.2 days above 40 °C each year. During summer, overnight minimum temperatures average 23.8 °C and provide little relief from the daytime heat [14]. Relative humidity remains low throughout the year, occasionally reaching above 50% in January and February and falling to the 20–30% range over the winter months.

Using past climatic records and the analysis software 'Climate Consultant V6.0 (Developed by University of California, Los Angeles Energy Design Tools Group)', it is possible to plot on a psychrometric chart the long-term average daily maximum and minimum temperatures and humidity for Tennant Creek between December and March, and overlay a thermal comfort zone based on a 90% acceptance rate (under ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) 55-2004) by people wearing typical summer clothes. This analysis indicates that the largest part of the December—March period is either too hot, too humid or both too hot and too humid for comfort, and that well-designed shelter or mechanical cooling will be required for comfort and long-term health of people living in this area.

Similarly, using the same software (and similar assumptions), the long-term average daily maximum and minimum temperatures can be plotted for Tennant Creek in June and July, alongside a thermal comfort zone. This analysis shows that while there are many days with comfortable conditions some of the time, most nights are too cool for comfort and that suitable shelter or other heating will be required for comfort and long-term health.

Of the climatic factors, successive days of very high temperatures are likely to be the most significant. In the study area, Tennant Creek currently averages more than 140 days per year with a maximum temperature above 35 °C each year, and a significant number of these correlate with high overnight temperatures. Climate change modelling by CSIRO suggests that there are likely to be an additional 5–70 days above 35 °C each year by 2030 and an additional 26–130 days each year by 2070 [15]. This substantial increase in both daytime and night-time temperatures undermines the effectiveness of high thermal mass passive design strategies which are often recommended for climates like that of Tennant Creek and the region.

2.2. The Nature of Infectious Diseases in the Barkly Region

Preventable, hygiene-related infectious diseases are regularly recorded at the Anyinginyi Health clinic in Tennant Creek. Memmott et al. [6] analysed clinic data between February 2017 and May 2019, and reported that over half of the total infectious disease diagnoses (from most frequent) were skin (boils, sores, scabies and school sores), respiratory (upper and lower respiratory tract), and ear, nose and throat infections (middle ear/otitis media, tonsillitis, ear canal and pharyngitis/strep throat).

Specifically focusing on skin, preventable infections often involve streptococcal and staphylococcal bacteria. The Northern Territory Government's health department states that 'most people who come in contact with GAS (Group A Streptococcal bacteria, common cause of skin infection) will not develop invasive GAS disease . . . those most at risk are Indigenous people, people living in poor hygienic and crowded conditions, people with chronic illnesses . . .' [16]. However, these 'risk categories' are well-represented in remote community infection records. Thomas et al. [17] (p. 752) reported that 'Indigenous Australians, particularly those living in remote communities, are among those most at risk for skin and soft tissue infections and resulting complications'. Their research from two remote Northern Territory communities found 75 percent of patients in retrospective health records during the 2014 calendar year presented with a skin condition [17]. Community-associated methicillin-resistant Staphylococcus aureus (MRSA) was also reported in high rates in Indigenous populations in the Northern Territory, with demonstrated increases in resistance between 1993 and 2012 [18]. High ubiquity of MRSA in Northern Territory communities across all age groups was found in 2017 records [19], creating challenges for effective antibiotic treatment. Such acute and recurrent infections can provide the antecedent conditions for acute rheumatic disease and subsequent rheumatic heart disease [17].

2.3. Factors Affecting Remote Indigenous Housing in Australia

Several studies have linked expected rising temperatures to the future liveability of the remote inland regions in Australia with questions on current policy and funding settings and whether housing and infrastructure will be able to adequately protect against the harsher conditions. These studies have pointed to the probably detrimental effects on health and safety, particularly for the elderly, children and Indigenous people [20–22]. In a climate change scenario, the cost of increased energy demand has also been flagged as a significant threat for low-income households already experiencing vulnerabilities [23]. Strategies to mitigate these effects of climate change can be challenging for Indigenous communities. Despite their demonstrable resilience to living in harsh environmental conditions, they may be less likely to relocate to more liveable climates because of their historical and cultural connections to their lands and kin.

2.4. Crowding and Mobility

It is well established that crowding exists in remote Indigenous housing; however, the level of crowding has been disputed due to some uncertainty around metrics and in understandings of Indigenous mobility [24]. The ABS measure of overcrowding is based on the Canadian National Occupancy Standard, a density model which determines the number of bedrooms needed to achieve suitable housing. In public housing, Indigenous households (defined as a household with at least one Indigenous person) have higher rates of crowding (9%) compared to all households (4%), and crowding is proportionately highest in remote regions [25]. In the most recent Census, Tennant Creek had 250 Aboriginal and Torres Strait Islander households (33.2%) that required one or two extra bedrooms [26,27]. The ABS provides a disclaimer that crowding may be under-reported by tenants because of fear of repercussions with authorities (tenancy providers; children's services) [28]. This view of potential underreporting is supported by studies of crowding in Tennant Creek and other remote locations [6,28,29].

From a psychological stress perspective [30] it may be that crowding exists in terms of density, but it may or may not be stressful. The desire to live together can override stressful impacts of crowding. A shortage of appropriate rental housing compels large, often multigenerational and extended, families to live in houses designed for a single nuclear family, and certainly not for multiple families. Grandparents and other family members play an important role in Indigenous childrearing practices, for example, and their presence is generally preferred despite potential stressors from crowding. Nevertheless, better designed spaces may be preferable and more equitable for the residents of a large household.

A common cause of crowding is the accommodation of visiting family members and the cultural obligation to provide this support [31]. Crowding is the consequence of the need to regularly and frequently renew social connections through face-to-face contact as tradition dictates [32]. In Central and Northern Australia, regional mobility is a significant driver of crowding. Aboriginal people move between remote communities and regional centres to visit family but they also travel for medical reasons, court attendance, recreational events, funerals and various social/cultural gatherings as well as family crises.

Climate change may impact on mobility and crowding as people respond to more frequent and extreme weather events. After Cyclone Yasi in 2011, many travelled from remote communities in the Barkly region to Alice Springs and Tennant Creek, where they remained with family for extended periods [28], and more recently, floods in Central Australia [33] stranded people away from their usual places of residence [34,35]. It has also been hypothesized that current poorly thermally performing houses and landscaping forces people to crowd indoors in hot weather, amplifying conditions for spread of infectious disease and other illnesses of overcrowding such as Rheumatic Heart Disease [36].

Visitors intending overnight stays typically find accommodation in households of their relatives and friends who reside in the town. While households may readily absorb short-term stays, extended stays can lead to problems (associated with crowding). A householder with visitors can feel constrained and conflicted about moving them on because of personal and cultural obligations to look after kin [31], with respect to 'demand sharing' [37] and tenancy rules that do not allow visitors [38]. When the need is prolonged, the visitor/s may effectively be homeless, cycling between known supportive households and adding to crowding pressures, or eventually being forced into sub-standard housing and homelessness. In remote and regional Australia, the long waiting lists for housing are a continuing barrier to suitable housing for low-income families [39].

The people who reside in a particular house on any given night may vary in terms of where they sleep or even if they sleep in that house. This applies particularly to children who may routinely stay in a relative's care for one or more nights, or when a senior woman moves temporarily with her dependents to her kin's house to help care for family members (child/other dependent) [40]. The phenomenon resonates with traditional Aboriginal sleeping arrangements that are 'an expression of the current state of interpersonal relations' that can change with each day's happenings, as described for women at Yuendumu in Central Australia [41].

Environmental health perspectives suggest that co-sleeping/bed-sharing (with accompanying transmission of diseases by skin contact and respiratory emissions) is manifestly an aspect of crowding and needs to be addressed, notably by more housing [42]. Sensitive communication is required as co-sleeping is a continuing practice for many households corresponding with traditional values of immediacy and intimacy [41,43]. An increase in available housing would not necessarily eliminate bed-sharing; however, better design, as well as educational initiatives, could allow this practice to continue with fewer health risks, e.g., infectious skin diseases.

Strong household heads manage nocturnal crowding through sleeping arrangements, taking into consideration various social, cultural and physical preferences including special needs. Places are allocated strategically for a smooth-running household, e.g., household head in main living area for surveillance purposes, and adolescents separated by gender and away from younger siblings. Spaces designed for flexibility in size and function (e.g., to expand in response to increase in numbers of people) could greatly assist.

3. Theme 2: Improved Housing Is Needed for Better Health

3.1. Improving Health and Reducing the Likelihood of Infectious Diseases

Government and academic publications have emphasised the importance of functional housing to support resident health and prevent diseases [44–46]. The range of environmental health functions in the home have been described as the 'Nine Healthy Living Practices' (HLPs) and include the appropriate infrastructure ('health hardware') to wash people, clothing and bedding, store food and medications, minimise crowding and maintain a comfortable temperature [47,48].

In Tennant Creek in the Barkly region, recent documentation indicates that the HLPs are not being attained. Data from 2019 found unintended crowding in CLA and remote community houses due to insufficient housing stock, with households of up to 23 residents in two- and three-bedroom homes [6]. There was associated damage through overuse of health hardware, such as washing machines, hot water and air conditioning [6]. Linked to crowding was a higher than average incidence of preventable hygiene-related infections, including skin, respiratory, and ear, nose and throat infections [6].

Intensifying climatic conditions are projected to act as stressors on the current health situation for residents in remote communities [49]. In the Barkly region, current and projected increases in extreme hot days and a reduction in water security and energy security will further exacerbate the ability for residents to maintain HLPs and their associated health and wellbeing [50,51]. This could further raise gastrointestinal health risks from heat-related contamination of surface-sourced drinking water supplies [50]. The installation of air conditioning to protect against hotter weather and the associated requirement to close windows during use could have possible unintended outcomes of increasing the risk of airborne infections, such as Strep A bacteria and COVID [52].

3.2. A Critical Housing-Related Health Issue: Dust Impact

Among many broad impacts, sand and dust storms cause a range of economic and human health problems [53]. Damage to infrastructure (including houses) and communication and power systems can be extensive, requiring increased costs for maintenance and renewal, and in turn can negatively impact on human health as people spend more time in a hazardous environment.

In Australia, sand and dust storms are relatively small and in low concentration on a world scale and occur mainly over the eastern half of the continent; however, studies have indicated that the Barkly Tableland has relatively high concentrations on certain days, particularly in Spring (Sept–Nov) [53,54]. Some climate change scenarios for Central Australia show that the conditions will be hotter and drier [55] and so places like Alice Springs and Tennant Creek would likely experience more droughts and bushfires, and, depending on other variables including wind, the number of days with high concentrations of dust could increase.

Dust phenomena are well known to Aboriginal people in the Barkly region. Patricia Frank Narrurlu (Warumungu) (p.c. to Paul Memmott 29/11/22) differentiates three types, albeit all having similar impacts. First there is the summertime whirlywind (aka 'willy-willy' and marlarnpurru in Warumungu) of which there are two or three passing through Tennant Creek in those six hotter months. Although only having a narrow path, any house in the path of such a whirlywind will receive a strong impact of wind, dust and debris. Second is the 'Barkly breeze', the nickname for the strong cold winter winds that blow across the Barkly Tableland from north-east or east to west intermittently through winter, bringing the impact of wind-borne dust for periods of days in regular cycles (see Figure 2). And third, dust storms proper which tend to happen about once in the early part of the year, and are the most intense. Such a storm arrives as a huge bank of skyward sand coming from one of the surrounding deserts, and has a set of storm characteristics accompanying it, these being lightning and thunder and possibly some limited rainfall. Clarissa Burgen (Waanyi) has spoken of massive dust storms lasting 5 to 10 min being pushed ahead of a cloud burst of rain storms. These storms leave thick layers of powdered dust outside and reach inside through any gaps or openings of the house, and can cause additional respiratory issues for many Aboriginal people.

For many decades, there has existed a gap in the Australian design literature on designing for dust despite the knowledge of architects (p.c. to P. Memmott c1988) from Tangentyere Council, a local Aboriginal organisation in Alice Springs. They have described the infiltration of fine sand particles into houses even when fully closed up and penetrating through all cracks and crevices under strong wind pressure on a house, so much so that the contents of drawers and cupboards can be found to be covered in dust despite being closed. Another key problem is the accumulation of dust in house fittings, fixtures and furnishings that have moving components whose functioning will be severely compromised; including sliding door and window tracks, roof vents, hinges, fans, computers, garage doors, etc. In turn, dust accumulation in window surrounds may facilitate water penetration during heavy rain.

The renowned 'Housing for Health' Guide (B7.1) from Healthabitat [56] is one key reference on "Reducing the health impacts of dust". This document asserts most wind-borne dust is conveyed within one metre of the ground, although it is probable this is only relevant to the second category above (strong winter winds). Nevertheless, a design recommendation that follows from this is the provision of low windbreaks around houses, especially on windward sides, such as walls, hedges or earth berms. The addition of trees to reduce wind speed and to block higher wind-borne dust would assist in the case of the whirlywind and dust storm categories above. The covering of the bare ground for open areas and around houses is another obvious design response, whether with lawn, paving, concrete or gravel, including barriers in open spaces to reduce vehicle-generated dust from unregulated internal community roads or 'shortcuts'.

Figure 2. "This is what I saw just before 9 am driving into Tingkarli, sick people live here like other CLAs [Community Living Areas; formerly known as 'town camps'], how can we ever close the gap when our people are expected to live like this. Its sickening to me. We need to advocate for dust suppression in the CLAs or figure out how this can be addressed moving forward. (Its not only Tingkarli but all the other CLAs are the same today whole the wind is blowing so hard)". (Tennant Creek Community Leader Linda Turner (Warlmanpa) p.c., 24/8/22 email) (Tennant Creek Community leader Linda Turner (Warlmanpa), August 2022).

Health impacts can result from dust-borne animal faeces and other bacteria on roofs which are later washed into rainwater tanks, and from dust damage to health hardware including reduction of the efficiency of solar panels for water heating due to dust films, and the failure of washing machines due to dust build-up within moving components [56]. A serious omission in this Guide, however, is the air-borne transmission of bacteria and irritating particles causing eye health problems including trachoma, a major cause of preventable blindness that remains active in some Indigenous communities in remote Australia but is kept under control through a consistent public health program [57]. Functioning health hardware to keep the face clean is critical to the program. Another omission is recommendations for the design of walls, roofs, windows, and doors to minimise dust penetration. This set of design techniques requires expert practice input [56].

Geoff Barker of PM + D Architects in Western Australia is one of the most experienced practitioners in designing houses to prevent dust entry. He recommends the following:

> *For windows, one must specify high-quality fabric seals, preferably multi-layered felt; and avoid materials that get hard and brittle with weathering. Window frames need to be of very rigid materials that will not deflect under the pressure of strong wind pressure, with felt strips sealing between the frame and the jambs, head and sill. Replacement of*

window seals needs to be factored into maintenance regimes if performance deteriorates over time. . . (Personal communication with Geoff Barker, Perth 5 February 2024)

He adds that glass louvres are ineffective in preventing dust entry, as they will deflect in strong winds allowing ingress; and "bottom of doors should be fixed with a dense brush seal, and a memory foam-seal strip or closed-cell, air-seal strip with adhesive on one side, should be stuck around jambs and head of doors" (Ibid).

4. Theme 3: Widespread Government Inaction (And Failure to Provide Appropriate Housing)

The lack of appropriate housing and the poor state of social housing stock have been documented for remote Indigenous communities in Australia for many years [58–60]. Successive governments have failed to adequately address the ongoing housing needs of different cultural groups and their geographic and climatic circumstances regarding design and materials, and have demonstrated a lack of understanding and commitment to challenging aspects of maintenance and appropriate technology to extend the lifespan and resilience of housing stock [21,61,62].

Climate change scenarios for remote Australia point to increased impacts on housing fabric, but there is also the need for internal and external design adjustments to support people in remote living. The ongoing failure to address Indigenous housing disadvantage cannot be blamed on a lack of design-related solutions. Continuing under-investment by governments in social housing has resulted in lengthy periods of poor living standards, particularly for Indigenous people in remote and very remote regions, an unjust outcome which is indicative of systemic racism, and which manifests across a range of policy areas [63,64]. Mobility and crowding are often seen as Indigenous practices that cause housing problems, but some mobility (and crowding) is caused by return to residential locations of prior displacement initiated by government policy [65]. Our exploration of the social and cultural dynamics of crowding provides a more nuanced understanding of Indigenous housing practices, and how potential effects might be addressed in the context of climate change. In remote and very remote households, crowding is a significant problem [66,67] and is increasingly associated with poor health [6].

This broad review of projected climate and living conditions indicates a complex problem nexus in addressing the design and management of living environments in Central Australia. Whereas passive house design can achieve outcomes of comfort for some of the year, summer and winter weather extremes will continue to demand different house design attributes, combined with the need for some mechanical cooling and heating. However, the latter brings energy costs which may not be affordable to disadvantaged Indigenous households, especially during high demand when household size expands with visitors. Additionally, such high densities, when combined with inadequate house maintenance, may also exacerbate health and wellbeing issues. What knowledge bases and cultural factors need to be understood in navigating this multi-dimensioned set of challenges?

The NT Climate Change Response: Towards 2050 (2020) [45] suggests that the NT Government plans to act constructively to counter the increased risks of heat due to climate change for residents of social housing. The document suggests that the Territory Government will also ensure that public housing policies and strategies incorporate green building design into new social housing, with opportunities to incorporate passive cooling approaches in remote locations.

Yet it must be said that the record of Australian governments (both State and Federal) on promises around remote Indigenous housing is disappointing. The lack of affordable, safe and sustainable housing is 'out of control' in remote communities, including in the Barkly region [68]. For example, at the time of writing, an Aboriginal woman in Tennant Creek had caught media attention as she sweltered in extreme heat conditions in sub-standard housing, worried that her situation would not improve for a very long time as a result of long waiting lists for housing in the town [69]. While Aboriginal residents call for better sealed doors and windows and air conditioners in order to withstand the high temperatures, the politicians refer to their building programs that are only very slowly adding to housing supply.

High temperatures are readily associated with the Central Australian climate; however, thermal comfort in the tropical semi-arid zone requires attention to both effective heating and cooling strategies (as discussed below in 'Theme 4: Supportive Design').

5. Theme 4: Supportive Design Has Cultural, Technological and Health Components

Australia's National Construction Code (NCC) assigns Tennant Creek and the Barkly Tableland as Climate Zone 3, for which the thermal design requirements include minimum roof (insulation with a minimum R value of 3.5 must be included in light-coloured roofs of standard construction which do not have reflective insulation. Increased R values may be required depending on roof colour [Table 13.2.3d of 2022 Housing Provisions Standard]) and wall (insulation with a minimum R value of 1.5 must be added to external concrete block walls, and increased R values may be required for lightweight walls, depending on wall height, wall colour and extent of roof overhang [Table 13.2.5e and Table 13.2.5f of 2022 Housing Provisions Standard]) insulation for housing. Additionally, there are limits on the size and type of windows based on a dwelling's area, orientation and extent of shading, and on the type of glass and frame used in the window [70].

The NCC requires all new dwellings in Climate Zone 3 to meet minimum building fabric requirements to resist both heat gain in summer and heat loss in winter. However, the NCC standards do not in themselves result in the acceptable thermal comfort of the resident. Whilst the NCC's minimum building fabric requirements are explicitly oriented towards reducing the energy required to heat and cool a building [71], its regulations assume that occupants have access to the energy and appliances needed to further heat and cool their dwelling in order to achieve total thermal comfort ([72] p. 2). This unreliable assumption is addressed below.

5.1. Exploring Passive Thermal Design Potential for Winter

One of the co-authors has studied appropriate thermal comfort and low-energy-use heating and cooling to compare several passive house design strategies for summer and winter throughout the Barkly region, using psychrometric chart analyses. This determines the extent of predicted thermal comfort that would be achieved by employing passive solar gain (capturing and storing the sun's warmth inside the dwelling) in both a high thermal mass dwelling and a low thermal mass dwelling, as well as by internal heat gain (capturing and storing the heat given off by occupants and generated by cooking and other appliances). In dwelling design terms, passive solar gain would require windows oriented and shaded to restrict direct sunlight into the dwelling only during the colder months, while the internal heat gain strategy would involve creating an airtight building environment to seal warmth internally, as well as high-performance doors (well sealed) and windows that reduce heat loss through the glass (either double-glazing, low emissivity glass and/or non-metallic frames).

In the study region, passive solar gain in a high thermal mass dwelling at first looks to be the best strategy in winter, as it covers the complete range of expected temperatures and humidity over the colder months. This combination of passive thermal mass strategies achieves thermal comfort for the great majority of the non-summer months and would require only that dwellings be well-oriented with respect to the sun, have high thermal mass elements, such as a concrete slab on ground or masonry walls which are insulated from the sun (for example, reverse brick veneer or concrete blockwork clad on the outside) and a relatively small number of well-positioned windows to admit winter sun to the dwelling. In such a case, additional heating from an appliance would not be needed.

However, for the summer months, different strategies would be required to reduce the impact of the extreme heat. Analysis (the relevant data in the form of graphs is available as Supplementary Materials: Figure S1−S9) showed that neither reliance on existing winds (the software algorithm uses local windspeed and direction data to assess the cooling potential of ventilation strategies) nor fan-forced ventilation could successfully cope with expected Barkly conditions in summer, as simply moving hot outside air through a dwelling is not likely to result in a cooler dwelling. Analysis also graphed the extended comfort zone due to both evaporative cooling (evaporative cooling involves fan-forcing hot, dry external air over water-saturated pads. The cooled air, which can be 8 °C or more colder than outside air, is blown into the dwelling. Evaporative cooling requires either mechanical air extraction or some windows to be left partially open to remove stale and humid air) and 'two-stage' (two-stage evaporation cooling uses a pre-cooler, high efficiency water pads and more efficient motors to deliver a greater volume of cooler air than standard evaporative coolers) evaporative cooling. These strategies are more successful than regular ventilation through windows, but neither one can successfully create thermal comfort during the hottest months of the year (additionally, these passive design strategies depend on a reliable supply of water for evaporation. The dry climate of the Barkly region may not support water use in this manner for some locations (e.g., outstations)).

A third analysis using a psychrometric chart graphed the extended comfort zone from high thermal mass design strategies and high thermal mass design with night purging of day-time energy gains (either by ventilation or ducted cooling). High thermal mass strategies appear to be more successful at addressing the summer conditions in the Barkly region, but they must be used cautiously when high overnight temperatures occur in summer. There are certain months when even the minimum temperatures are above the comfort zone in the Barkly region and this is likely to overwhelm the thermal mass in a dwelling and simply result in a dwelling that never cools down. Once overheated, a high thermal mass building will require a lot of energy to reduce temperatures back to a comfortable level. So, for places like Tennant Creek, where substantial parts of the year are very hot and no passive design strategies result in thermal comfort, the only reliable solution from December to March, and in particular during January and February, is air conditioning (air conditioning is the process of extracting heat and moisture from air through compression cycles of refrigerant chemicals. Cool and dry air is then blown into a dwelling while excess heat and moisture are vented to the outside).

The high thermal mass strategy will use familiar construction materials for Indigenous residents, such as concrete and bricks (although potentially in unfamiliar ways, e.g., use of reverse brick veneer), and typically requires most of the construction work to be done on site. High thermal mass strategies require some level of householder knowledge about when to open the building up to gain or shed heat and when to close it down to trap heat or cool inside, which occupants may need to learn in order to get the best performance from their dwelling.

5.2. Comparison of High Thermal Mass Strategy to the Lightweight Tightly-Sealed Envelope Strategy

Psychrometric chart analysis also showed the impact of a lightweight, tightly-sealed building envelope with evaporative cooling introduced through ducts and exhaust air mechanically ventilated. This combination of strategies would require additional insulation in the roof, walls and floor of the dwelling, higher-quality glass and window frames as well as effective seals on doors and windows to reduce heat transfer, as well as a relatively simple evaporative cooler and systems of ducts to distribute cool and moist air throughout the building. This approach may also require the use of an air tightness layer for additional control of air and heat movement through the envelope. This strategy successfully provides thermal comfort in the majority of hours between April and November, although it is significantly less successful at managing the coldest hours than the high thermal mass strategy. As noted, though, closing windows can reduce ventilation and thus increase circulation and sharing of indoor air, thus increasing the risk of airborne infection. Lightweight, tightly-sealed buildings are less prone to overheating over successive very hot summer days, and when they do overheat they are easier to bring back into a comfortable temperature than high thermal mass buildings, either by natural ventilation or by using air conditioning. A lightweight, tightly-sealed building will also be more dustproof, or at least more dust-resistant than a high thermal mass building which requires ventilation from the outside air to effectively control summer temperature. A downside is that the lightweight, tightly-sealed strategy may involve the use of unfamiliar materials (building wraps, double glazing, door seals, ducted evaporative coolers) which could be difficult for remote community residents to maintain or replace. However, lightweight, tightly-sealed construction has the potential to be pre-fabricated, which may save costs and/or increase building fabric quality.

5.3. The Need for Supportive Housing Design and Management for Healthy Living Practices (HLPs)

Housing situations with unintended crowding and poorly maintained health hardware can limit the ability for households to prevent infection transmission and perform HLPs [73]. As noted above, acute infections can contribute to later chronic conditions, including ear infections and subsequent hearing impairment, trachoma eye infections and subsequent sight impairments, and skin infections and subsequent rheumatic heart disease and chronic kidney disease [17,73,74]. Therefore, housing design clearly influences the health and wellbeing of residents [6]. Health-protective housing design in remote Australian communities requires health hardware to enable HLPS, both regular proactive and responsive repair and maintenance, as well as new housing [21].

Furthermore, health-protective housing requires appropriate provisions against future projected climate risks [21]. For Central Australia, a key current and projected climatic change comprises extreme heat periods that are commencing earlier than previous records and with more consecutive hot days [21]. For example, in the Northern Territory, the town of Katherine had 56 days over 40 °C (above the average of 6 days) in 2019, and Tennant Creek had 28 days in one month above 40 °C in 2018 [75].

5.4. Householder Support for Better Health

Three existing and proven housing initiatives that protect the health of householders in remote Australia are regular house repairs and maintenance, 'survey-fixes' of health hardware, and public health referrals from health clinics. Memmott et al. [6] described the historical and contemporary experience of social housing residents in homes with unintended crowding due to insufficient housing supply, delays to repairs potentially due to remoteness, and staff turnover in housing services. These aspects indicate the need for new and maintained housing infrastructure. In addition, comprehensive audits of housing functionality followed by immediate repairs to enable Health Living Practices (the HLPs encompass the capacity to effectively perform a range of functions in a home including the ingress of water and the egress of liquid waste, washing human bodies, clothes and bedding, storing food safely, minimisation of dust with associated bacteria, and minimisation of risk of traumatic injury [47]) can be undertaken through 'survey fixes', such as provided in the Healthabitat model [76,77]. Building in referrals from clinicians to supportive public health service interventions can provide a longer-term prevention of hygiene-related infections. Anyinginyi Health's Kalpa Purru Wirranjarlki—Public Health team, for example, deliver both preventative and reactive environmental health support in homes. This unit works both in collaboration with other Anyinginyi services, including family support and medical care, as well as with external agencies [78].

5.5. Summary of House Design Findings

If considering thermal comfort during only the colder months (April–November), the high thermal mass strategy appears more successful than the lightweight, tightly-sealed approach. The high thermal mass strategy is better able to manage both the colder nights and warmer daytime temperatures in this period.

However, during the hotter months of summer (December–March), lightweight, tightly-sealed houses will be less prone to overheating over successive very hot days, and when they do overheat they will be faster to return to a comfortable temperature than high thermal mass designs, whether by natural ventilation or by using air conditioning. As the Barkly region currently experiences extremes of both day- and night-time temperature in summer, the probability of overheating is high. When the predicted increases in day- and night-time temperatures due to climate change are considered, this probability becomes almost a certainty.

For this reason, the lightweight, tightly-sealed approach appears to be generally more suitable for the Barkly region than high thermal mass strategies. Nevertheless, due to the extreme day- and night-time summer heat in the Barkly region, lightweight, tightly-sealed buildings are not likely to provide thermal comfort year-round without mechanical cooling of some kind. Air conditioning systems can provide a high degree of thermal comfort to occupants throughout the summer months, but these systems only make sense where electricity supplies are reliable and affordable, and where there are good opportunities to service and re-gas the equipment. However, without regular maintenance, air conditioning systems are likely to fail and leave dwellings uninhabitable during summer. Where electricity supplies are not reliable, or where opportunities to service these systems are poor, evaporative cooling systems could be used in their place. Evaporative cooling systems are significantly less complex than air conditioning systems and use substantially less power, making them appear more suited to some remote locations. But in the Barkly region, evaporative coolers are considered inferior due to their inability to cool air sufficiently in very hot humid conditions, coupled with the corrosive nature of water supplies which continually clog the mats and cause the motors to break down, needing replacement. (Personal communication with Tony Miles, Chairman of Julalikari Council Aboriginal Corporation (JCAC), 12 February 24, Natalie Fraser, Department of Territory Families, Housing and Communities, 14 February 24, Tracey Muckton, JCAC, 14 February 24 and Norm Frank, resident and JCAC board member).

5.6. Norms around Air-Conditioning and Outside Living Spaces

Any solution for the Barkly region must factor in the pre-existing aspirations, norms and values of the Aboriginal householders concerning house technology. Recent fieldwork in Tennant Creek by some of the authors found that there were widespread views by householders, as well as public servants and board members in housing agencies, that the standard evaporative coolers were largely non-functional for the more extreme weather conditions, as well as being prone to regular breakdown due to calcium in the bore water. Thermal house conditions using evaporative coolers in summer were said to be 'intolerable'. Disadvantaged Aboriginal residents are well aware that the town norm amongst employed townspeople is for split-system air conditioning units and so aspire to the same standard as being equitable for all.

Depending on needs, both indoor and outdoor spaces are used in which sleeping spaces extend beyond bedrooms to living rooms, verandas and outdoor spaces.

In many communities, a preference for outdoor living is evident in the use of yards for sleeping, cooking and socialising [79,80]. In crowded houses with inefficient and unworkable energy systems, yard use may be indicative of energy poverty and injustice that calls for a holistic policy approach. With appropriate treatments directed towards greater thermal comfort, outdoor spaces around houses could be a significant area of design development with a view to managing more extreme climatic conditions. Landscaping for shade as well as warmth from wintertime sun on walls can reduce energy consumption and achieve thermal comfort providing positive gains towards efficiency and reduced costs combined with culturally acceptable housing behaviour. Outdoor living and visitor spaces can work well in functioning households with serviceable health hardware. Pressure from day visitors and also prepaid power disconnections are significant issues regarding social and thermal comfort that can disrupt these strategies [51,79].

We could conclude at this point that an optimisation in the Barkly region, then, would be a lightweight passive design house that provides comfort for most of the seasonal year, augmented with split-system air conditioning units in a few rooms for use only during periods of extremes of cold, heat and humidity. There are two important caveats to this assertion. First, this solution ideally needs an energy literacy education package for householders, concerning the economic need to confine the use of the split-system units to the periods of extreme temperatures. Second, a plan needs to be developed by all stakeholders for low-income households to receive solar power technology on their roofs with battery storage, to generally alleviate poverty as well as fossil fuel energy usage, but specifically to minimise the power cost of running split-system air conditioning units.

6. Theme 5: Importance of Energy Efficiency and Energy Justice

Transition to renewable sources of energy is slowly underway in parts of remote regional Australia despite limited national policy co-ordination. Over the last decade, a range of government and non-government entities have connected Indigenous communities to off-grid power with varying levels of access and support.

In the Northern Territory, power to households is supplied through the grid in larger centres and in smaller centres and remote communities through a range of supply sources including solar, diesel, hybrid solar and diesel generators, grid, and some (14%) had no power. In 2019, the Solar Energy Transformation Program (SETuP), a federally-funded (ARENA) NT government-delivered subsidiary, set up 10 MW solar microgrids in 25 remote Indigenous communities, about half of them in Central Australia. However, many smaller remote communities have continued to rely on diesel generation [81], including in the Barkly region. This represents a significantly higher cost burden for those people both now and in the future given the increasing effects of climate change. Strong arguments exist for a 'just approach' to a renewable energy transition that would bring development opportunities to support better living conditions for Indigenous people, including in housing, particularly since many communities hold title to their land [82].

For residents in social housing, two aspects of energy access loom large on a daily basis: the use of power cards and potential disconnections.

6.1. Power Cards

Dwellings in many Indigenous communities in the Northern Territory are fitted with pre-payment electricity meters, in contrast to their relative absence in capital city or non-Indigenous households in Australia. Indigenous households do not typically have a choice whether to pre-pay or post-pay for electricity [50]. Pre-payment meters are purported to enable households to keep closer control of electricity bills, and to better cater for greater occupancy fluctuations, e.g., visitors can more directly contribute to the electricity costs of their hosts who are less likely to fall into arrears, and in turn, electricity retailers save on reduced debt recovery costs [83]. On the other hand, pre-payment customers pay a higher tariff per unit consumed than billed customers, given the supply charge (standing charge) is incorporated into the kilowatt hour charge [84]. Pre-payment customers in Australia experience far higher disconnection rates compared to billed customers [66,83]. Those with limited technical literacy and/or mobility can be disadvantaged if they cannot go online to top-up or easily visit a shop. Disconnections are particularly problematic during heatwaves or during COVID-19 lockdowns (where households without power would move in with those with power), leading to calls for a moratorium on disconnections during exceptional circumstances [85,86]. Convenience stores in remote areas can run short of power card types or preferred denominations [87], and power costs per kilowatt hour are higher for pre-paid vs. billed customers, because network supply charges are necessarily bundled into consumption charges.

6.2. Disconnections

A 2021 study found 91% of all pre-paid Indigenous households in a sample of the Northern Territory experienced at least one disconnection event and 74% were disconnected at least 10 times, during the 2017–2018 financial year [88]. This is in contrast with 1% of non-pre-paid households [88]. The probability of disconnection events was found to be higher on hot (34–40 degree maximums) and cold (0–10 degree minimums) days. When considered alongside the demonstrable thermal inadequacy of housing stock, disconnection can be dangerous to health [50]. In general, there are relatively few published accounts of Indigenous residents' personal lived experiences of pre-payment and involuntary disconnections, and further work is necessary to better incorporate more First Nations voices in this ongoing debate [84,85,89].

6.3. Towards a First Nations Definition of Energy Literacy

Energy literacy is a widely used, but poorly defined concept referring to knowledge of energy systems and appliances and people's knowledge of the consumption of domestic appliances, and grounded in Western constructs of energy [90]. Studies highlight that the term 'literacy' (whether 'energy literacy', 'privacy literacy' or 'financial literacy') is itself contestable in respect of marginalised populations, given such language implicitly places the onus of responsible energy management back onto the customer [91]. Understanding of energy in remote communities is often mixed, where energy literacy is generally low, but may be very high among certain individuals such as household heads who understand the cost implications of different appliances and practices and seek to regulate behaviour accordingly [92]. Widespread over-crowding in Indigenous housing [72] makes controlling door opening and hence retaining cool/warmth difficult. Indigenous-led understandings of how to improve energy literacy are lacking, whereas the Manymak Energy Efficiency project in Arnhem Land emphasizes the importance and benefits of Indigenous-led co-design of energy use visualisations and energy budgeting technology and resources to overcome linguistic diversity [92].

Given the above conceptual differences between remote Indigenous and Western contexts, we would argue that much has to be done to effectively incorporate energy literacy as part of efforts to improve the thermal performance of housing stock, and to address issues of over-crowding and energy injustice issues, not least the structural barriers faced by Indigenous Australians to installing rooftop solar [93].

7. Discussion and Conclusions: Building Resilience

The significance of our investigations relates to the challenges and opportunities for building Indigenous resilience through supportive housing in a changing climate. In its Sixth Assessment Report, the Intergovernmental Panel on climate change advocated that policy makers "scale up practice and infrastructure to enhance resilience" with specific reference to building (and infrastructure) and associated fields including design, construction, and use of building and energy systems as significant for mitigation and adaptation [94]. The report highlighted the role of long-term planning and the need to consider the vulnerabilities of low-income communities to avoid unnecessary financial and other stress. Our findings suggest that relevant knowledge and technical expertise is available to support appropriate building, infrastructure and energy systems and to develop strategies to reduce potential risks for health and well-being; however, the policy responses to mandate appropriate housing for climate change in regional and remote Indigenous communities appear to be absent [21].

While potential solutions may be available and widely applicable, they have not been tested for different locations and specific groups. More research needs to be done. It is critical that remote Indigenous communities are involved in the various stages of design and implementation so that their economic and environmental needs, and social and cultural practices, can be taken into account. Evidence needs to be collected on both the successful and failed experiments of imposed housing designs. An affordable energy system and a rigorous maintenance program are necessary to sustain healthy living conditions, but housing conditions can deteriorate significantly and community resilience may be undermined when there is lack of engagement from the local community [61,95], and conversely, enhanced by appropriate consultation [96]. With our focus on Indigenous people in the Barkly region, we reflect further on the significance of local, place-based conditions and how an inclusive integrated approach can facilitate better housing design.

An unexplored design approach for thermal comfort in the Barkly region that should be the subject of future field research and economic feasibility analysis would be a house with a combination of room types, employing both mass construction techniques and lightweight construction techniques. This would, on the surface, appear to be excessively expensive, implying the need for a much larger floor area than the normal standard house; however, the initial outlay on construction might be off-set in the long-term life of the house in energy savings.

The upgrading of existing housing stock to perform better in climatic extremes is probably a better economic strategy than building new ones within the very restricted government budgets of recent decades. Unfortunately, space does not permit the authors to expand this analysis into strategies for such retrofitting on existing homes whose designs and materials are quite diverse.

7.1. Challenges and Opportunities

The role of supportive housing in prevention of ill-health and disease is well documented [3,6,49,97], including the health impacts of inappropriate housing that cannot support healthy indoor environments [21]. The severity of environmental hazards (heat and dust discussed above) can vary depending on season and location, and Barkly climate change scenarios predict more days of extreme heat in hotter months. Health impacts can arise directly from thermal discomfort and from exposure to airborne dust, and indirectly via the effects on health hardware. Houses will require appropriate health hardware (h/w, washing machine, etc.) to support healthy living practices that take into account the attributes of the local conditions of a changing climate as well as remoteness. Even though Tennant Creek lies within an NT government Building Control Area, most Indigenous communities do not [98]. In this unregulated environment, it is important that the standards set out in the National Indigenous Housing Guide be updated and implemented in a changing climate, particularly as the needs of remote residents are currently not being met [99].

Challenges of construction and energy systems in very remote locations due to supply costs and lack of service reliability influenced our assessment that a lightweight, tightly-sealed design supported by evaporative cooling or air conditioning is an appropriate approach. However, this design would not be without challenges. Evaporative cooling draws large amounts of water, and water scarcity is characteristic of remote arid and semi-arid Australia, seasonally and through droughts. Most water is also heavily mineralised causing continued costs for repairs and maintenance of evaporative cooling systems. (Also, when these systems are dry and then restarted, they blow mineralised silt into the home which has been sitting in the ducting and unit itself.) Taking into consideration the predictions for more very hot days and increasing periods of water scarcity due to rainfall variability and increased evaporation, there needs to be planning around use of water so that there is sufficient water for household systems and to support healthy living practices. An integrated approach to water level monitoring (e.g., in bores), storage and testing is required that includes community involvement instead of control by centralised government bodies. Local residents need to become skilled in these areas, for without agency, individual and community resilience cannot build effectively.

While it is understood that air conditioning will be required for the hottest days in order to achieve thermal comfort, windows and doors need to be well sealed in order to efficiently achieve desired cooling. In a crowded household, doors (and windows) are opened and closed much more frequently in any given period, and as a result, operational efficiency may be compromised, and energy use and costs increased, which is challenging for households dependent on power cards. Households in transition to greater energy literacy may be unfairly penalised by the financial burden. Moreover, a recent study suggested that prolonged use of air conditioning may be physiologically maladaptive, particularly in very hot regions, and so it may be important to look at socio-cultural practices that have been protective mechanisms in the past [29], including well-ventilated, deep shade to keep cool, wind protection and access to sun for warming [100]. Passive cooling of houses is consistent with this approach and would be workable for flexible households.

7.2. Reduced Support by Governments

Indigenous Australians have demonstrated resilience in harsh living environments, with poverty and in substandard and insecure housing. Increasingly, social housing in remote Australia has proven inadequate and poorly maintained with a high level of conditionality, including for Aboriginal people in the Barkly region [38]. The overarching challenges have come from insufficient and uncoordinated government funding due to the complexity around sharing of responsibility between state and federal bodies. Recent decades have seen gradual withdrawal of support for homelands and remote communities and substantial allocation of funds for social housing in towns and regional centres [62,101].

People do not want to leave their Country but there is little support to remain, despite the evidence for benefits to health and well-being [102,103]. Governments encourage movement away from remote communities and homelands with inferior infrastructure that cannot ameliorate effects of climate change. This policy and program trajectory presents an ongoing challenge to communities who want to remain on Country and away from larger population centres. The extra imposition of climate change factors means that already difficult living circumstances are exacerbated and healthy housing choices are limited. With longer periods of water scarcity and high temperatures predicted, housing in homelands (with or without retrofitting) may be unliveable for periods. Residents would most likely move out to live with relatives in larger communities for a period of time, and crowding would likely increase as a result of these 'climate refugees' [104].

It is important that planners and policy makers resist the 'victim-blaming' by political conservatives who view mobility and visitations in the light of anti-social behaviour [105]. Instead, there needs to be recognition of Indigenous people's right to choose aspects of living that may not fit neatly into mainstream housing behavioural norms, as well as a need to understand the importance of attachment to Country and kin, and of travel in order to be with kin and Country. Indigenous people strengthen their social and environmental resilience and their ability to cope with change through family networks [31,40,106].

Crowding does need to be offset by the priority provision of increased numbers of houses in annual government budgets, as well as improved design initiatives. Current design standards (free-standing dwelling with bedrooms grouped together, kitchen and living rooms adjacent with bathroom/laundry, etc.) are not conducive to accommodating extra people into households in appropriate ways (i.e., incongruences occur). Flexibility is a key design criterion for both interiors and exteriors, e.g., modular spaces that can open/expand and close/contract space for different numbers of people for sleeping or social gathering.

7.3. Design Challenges in External Domiciliary Spaces

Use of yards offers significant opportunities for climate-appropriate and culturally sustainable living in a changing climate. Use of space around the house is an underexplored and under-resourced concept in design of housing for Indigenous communities [78]. With careful attention to temperature variability, movement of sun and prevailing winds, it is possible to incorporate shade structures (eaves, awnings), windbreaks and plantings to significantly enhance the liveability of a house.

Prior consultation with local knowledge holders combined with specialist knowledge of architects, planners and landscape architects would be essential to achieve best design outcomes compatible with community expectations. Yard design, if included at planning and procurement stages of housing, often does not survive the full process, resulting in lost opportunities for supportive design. Apart from the advantages of achieving thermal comfort through the use of outdoor spaces (discussed above), there are social, cultural, economic and ecological reasons for landscaping according to local preferences [79].

Stronger push is needed for programs that include climate change-ready houses and their surrounding space that can respond to the increasing need for protection from sun radiation, wind (dust) and rain (flooding). Through community and home improvement programs, local residents can contribute to the creation of parks, shade corridors, mobility stops, and microclimate housing shade areas as well as land care improvements and protected areas for native plant and animal species, all of which assist in wider dust suppression. Similar developments in yards can enhance liveability and reinforce cultural practices that often occur outdoors around homes, including social gatherings to commemorate life events.

7.4. Healthy Living Practices and Better Understanding of Disease Transmission

Health-protective housing is necessary in order to achieve healthy living practices that in turn require appropriate provisions against future projected climate risks. The provision of health hardware is fundamental to people's ability to live well in a house and to reduce the impacts of infectious diseases. Transmission of disease can occur with human-to-human contact that can be managed, pending awareness of symptoms and of how the spread can occur. Health promotion strategies are required to raise awareness about healthy living practices through local Indigenous health organisations that can disseminate appropriate information and coordinate programs. People are empowered when they understand more about how disease spreads and indeed how they may be influencing the transmission to their family. Community involvement in the information-sharing process can increase program effectiveness and reduce aspects of ill-health.

7.5. Energy Literacy and Managing Energy Use

Almost a decade ago, a report [28] on Aboriginal responses to climate change in the semi-arid Georgina River region of north-west Queensland, to the immediate east of the study area, called for increased involvement in decision-making and delivery of services that would incorporate local knowledge, culture and expertise. As governments become increasingly aware of renewable energy sources, there is a greater sense of urgency for Indigenous communities to learn about energy technology that can enhance their community access to more affordable power [50]. Community workshops around energy supply and management, and programs to increase local employment in housing construction and services would entail up-skilling, and bring a sense of agency to the community and improve adaptive capacity.

7.6. Household Education and Capacity Building

Successful adaptation to climate change must include a focus on householder education around healthy living practices, with better understandings of disease transmission and energy literacy. As policy makers and settlement planners become more aware of how governments are failing Indigenous people in preparation for the effects of climate change, they may consider appropriate local solutions that offer hope to people for a brighter future living on their land. Participation in community programs led by local Indigenous organisations can help build individual and community resilience.

7.7. Key Findings and Implications: Concluding Remarks

Our investigations have covered a wide range of topics from different disciplinary perspectives to set out the challenges and opportunities that exist for change that might establish supportive housing in the remote tropical semi-arid Barkly region. While the research had a regional focus, our conclusions may have broader application to other Indigenous Australian communities in Central Australia, and beyond. Following are some implications for practice in the Barkly region indicated by our findings—Table 1 below.

Table 1. Key findings of the paper and their design implications.

Key Findings	Design Implications
Current housing cannot provide thermal comfort during periods of high temperatures in the semi-arid tropical Barkly region.	Lightweight, tightly-sealed design with ducted evaporative cooling (a/c on hottest days).
Dust (and fine sand) is an under-researched environmental hazard for remote housing.	Tightly-sealed windows and doors made of durable materials.
Healthy living practices require supportive design attributes.	Interior and exterior of houses, including yards, need appropriate 'health hardware' and spaces for sleeping, washing, cooking and socializing.
Indigenous social and cultural practices around housing are not facilitated by housing in remote regions.	Supportive design includes flexible spaces to accommodate visitors appropriately according to age, gender, marital status, etc.
Governments need a better understanding of social and cultural practices including mobility and crowding, and appropriate spatial configuration in housing.	Supportive design includes flexible spaces to accommodate large families/visitors appropriately according to age, gender, marital status and kinship.
Adaptable and efficient energy systems are required to meet current and future needs in climate change.	Best practice requires consultative co-design, by government (planners, housing managers) with local communities, of housing and its energy systems.

8. Conclusions

From a multidisciplinary perspective, there are many areas of policy and practice to be considered in order to address the current and foreseeable issues for remote Indigenous communities. With the backing of housing and health advocates, planners, architects and community organisations, building codes and design practices can adapt in ways to better support healthy housing in the context of climate challenges. Co-ordination of public policy that addresses the social determinants of health and the role of housing under a changing climate is required. Policy and practice must operate together to collect information about the housing, energy and health needs of local communities and to develop plans that can respond to the challenges of climate change.

It is important to remember that current vulnerabilities of remote Indigenous communities stem from multifactorial preconditions of trauma and displacement related to the processes of colonisation. While we cannot expect profound changes in people's future ability to cope with the severity of climate change until the structural causes of inequality are comprehensively addressed, major up-scaling and improvements in the design and management of supportive housing can be transformative. Architecture and design offer a pathway to begin this comprehensive and health-protective approach.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/architecture4030041/s1, Figure S1: Three-dimensional graph of annual average temperatures and thermal comfort in Tennant Creek. Figure S2: Psychrometric chart showing thermal comfort zone against conditions in Tennant Creek in June and July. Figure S3: Psychrometric chart showing expanded thermal comfort zone from passive solar gain design strategies in winter, for low and high thermal mass dwellings, against daily conditions in Tennant Creek in June and July. Figure S4: Psychrometric chart showing expanded thermal comfort zone from a high thermal mass design strategy, against daily conditions in Tennant Creek from April to November. Figure S5: Psychrometric chart showing expanded thermal comfort zone from tightly-sealed building envelope design strategies against conditions in Tennant Creek from April to November. Figure S6: Psychrometric chart showing thermal comfort zone against conditions in Tennant Creek from December to March. Figure S7: Psychrometric chart showing the expanded thermal comfort zone from natural ventilation design strategies, against conditions in Tennant Creek from December to March. Figure S8: Psychrometric chart showing the expanded thermal comfort zone from evaporative cooling, against conditions in Tennant Creek from December to March. Figure S9: Psychrometric chart showing the expanded thermal comfort zone from night-purged high thermal mass design strategies, against conditions in Tennant Creek from December to March.

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