

Heat stress resistant residential design in Australia

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Cover image. Whitmore Square Affordable Eco-Housing, Adelaide, by Troppo (Image: Troppo)

Abstract

In Australia, heatwaves are the deadliest natural hazard and a major driver of peak electricity demand and blackouts. Heatwaves are exacerbated by urban heat island effects in cities, and becoming more common due to climate change. Keeping Australian homes cool while reducing the demand for air conditioning is a key challenge. A further concern is that increased building energy efficiency – assessed based on annual thermal load – can decrease a building's heat stress resistance.

This note outlines strategies for heat stress resistant residential building design and construction. It discusses the integration of heat stress resistant measures in current Australian building standards and provides recommendations on the assessment of buildings' heat stress resistance.

Impacts of heatwaves in Australia

Heatwaves are not just the deadliest natural hazard in Australia (Coates et al. 2014), they substantially decrease productivity and economic activity (Zander et al. 2015). Heatwaves drive peak electricity demand caused by air conditioning (Australian Electricity Market Operator 2011), which can lead to blackouts (Reeves et al. 2010; Energy Supply Association of Australia 2015). The disproportionately high peak demand places pressure on the grid and is responsible for soaring electricity prices (Dickinson, Parham & Nathan 2010) and energy poverty.

Energy poverty refers to people who cannot afford to run their heating and cooling appliances to ensure healthy indoor temperatures year-round.

Air conditioning is not the ultimate solution for many reasons. Non-renewable powered air conditioners increase carbon emissions. Residential cooling consumption is projected to account for 35% of the total heating and cooling needs of buildings by 2050 (Santamouris 2016). This ratio was only 4% in 2010.

Air conditioning based on heat rejection expels waste heat outside, while cooling down the indoor environment, contributing to the urban heat island effect (UHIE) (Gartland 2008). In addition to that, the more we use air conditioning, the more we demand it (Hatvani-Kovacs et al. 2016; Kim et al. 2017).

Urban Heat Island Effect (UHIE) is the discernible temperature difference between cities and surrounding rural regions caused by the excess level of urbanisation (Gartland 2008). The main causes of the UHIE include the high thermal mass and low reflectivity of urban materials, decreased vegetation, dense urban forms and waste heat generated by humans.

It is a common belief that buildings can protect us from excess heat. However, recent studies point out a significant proportion of the population is exposed to indoor heat stress (Coates et al. 2014; Salagnac 2007). During heatwaves, indoor conditions can be worse than the outdoor environment (Chan et al. 2001).

In some cases, recently constructed energy efficient buildings can overheat more than older less efficient buildings. This is due to the high level

of airtightness and insulation without sufficient ventilation and shading (Pyrgou et al. 2017; Ren, Wang & Chen 2014; Dengel & Swainson 2012). A representative survey in Adelaide underpinned the magnitude of the problem: only one-quarter of householders reported that their home coped well with heatwaves. Two out of ten respondents had health issues during heatwaves, even though more than nine out of ten residents had access to air conditioning (Hatvani-Kovacs et al. 2016).

This note aims to:

- assist architects and designers to understand the impact of design and construction practices on the performance of residential buildings during heatwaves, and
- provide strategies and assessment tools to design energy efficient buildings which should not fail their occupants during heatwaves.

Heat stress resistant residential building design

Heat stress refers to conditions when the combination of prolonged high temperatures and humidity has a quantifiable impact on human productivity and health beyond substantial discomfort.

The built environment can influence both indoor and outdoor temperatures and decrease our exposure to heat (Zuo et al. 2014). In many cases, however, building design amplifies the already extreme outdoor temperatures.

One of the reasons is that heat stress resistant and energy efficient design are not the same and can even contradict each other if misinterpreted. An energy efficient building is often defined by its low annual thermal energy load, considering the sum of its heating and cooling requirements. However, this does not guarantee that the heating and cooling consumption is proportional. Disproportionally meeting heating and cooling needs can lead to energy efficient buildings that perform poorly in either winter or summer.

Energy efficient design often by definition refers to a reduction in the annual energy consumption of a building without considering the impact on heating and cooling loads separately.

Heat stress resistant design creates an indoor thermal environment that is comfortable and safe even during heatwaves.

There are two approaches to heat stress resistant design:

1. **For air-conditioned buildings** – heat stress resistant design minimises the peak cooling demand and annual cooling energy required to maintain a healthy and comfortable indoor environment with air conditioning.
2. **For non-air-conditioned buildings** – the design aims to decrease the number of indoor hours with discomfort without the use of air conditioning even during heatwaves. This approach requires more focus on passive cooling design techniques and the acceptance of a wider indoor temperature band by the occupants (Daniel, Williamson and Soebarto, 2017).

Considering current Australian building conventions, the following recommendations focus on minimising, though not necessarily eliminating, the demand for air conditioning. Nevertheless, it is possible to build homes without air conditioning that are resilient to the harsh Australian summer.

Climate responsive design elements

Before the first design sketch, considering the local microclimatic characteristics is the most determinant step. Temperature, wind, humidity and solar radiation are all important weather elements influencing human thermal comfort (Candido 2011). The Nationwide House Energy Rating Scheme (NatHERS) differentiates local climates across the capital metropolitan regions.

However, local microclimate variability can be substantial. Local heatwave maps that depict the microclimatic differences should be integrated into the design process where such maps are available.

Unfortunately, studies undertaken in Australia on heatwave vulnerability mapping are rarely publicly available longer than a few years after the completion of the research project (Loughnan et al. 2013).

Passive design features

Heat stress resistance can be most easily enhanced by the implementation of passive design features that do not require energy (Figure 1).

Orientation and shading

Inappropriate orientation and lack of shading are often the main causes of overheating (Wong & Chen 2009; Roaf 2001; Porritt et al. 2013). In contrast, excess heat gain can be avoided with an orientation designed for climate and an optimised layout. The Girasole house in Canberra (Figure 2) provides a unique solution to optimising orientation and shading with a fully rotatable building operated by a touchscreen panel.

Shading can be provided by eaves, shading devices or vegetation. Wide eaves and horizontal pergolas to block summer sun but allow the penetration of winter sun are the most practical on the northern facade. Vertical shading is the best choice on the eastern and western facades (McGee & Reardon 2013).

External, adjustable devices are the most efficient solutions, along with deciduous trees that can allow access to winter sun while still limiting summer heat gain (Figure 3). It is important to note that over shading can be counterproductive to energy saving in climates with considerable heating demand.

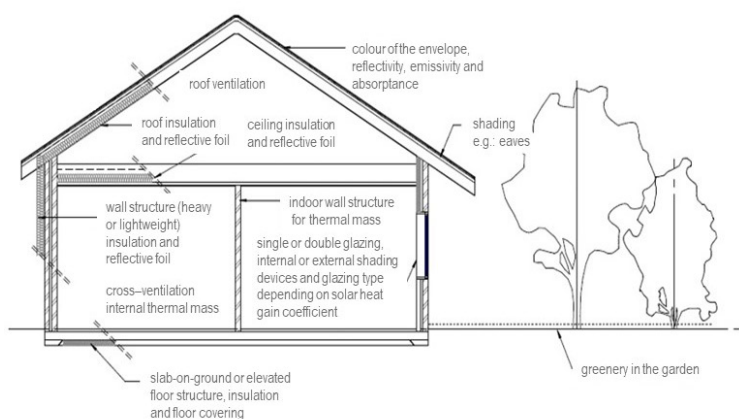


Figure 1. Passive heat stress resistant design features (Source: Author)



Figure 2. Girasole rotating solar house, Canberra, by dna architects [Source: Liz Eve for Inhabitat, CC BY-NC-ND 2.0]



Figure 3. Anadara multi-storey residential building with movable shading and pergolas with vine by fjmt, Barangaroo South, Sydney [Source: Author]

Greenery

In addition to providing shade, the benefits of greenery include reduced stormwater runoff and air pollution, and increased recreational space and biodiversity (Planet Ark 2014; Zhou & Rana 2012).

Reduced stormwater run-off enables the natural circulation of water. Rainwater can be absorbed by vegetation and soil and released back to the air through evapotranspiration. This process of evaporation and transpiration efficiently decreases ambient air temperatures during the hottest part of the day, particularly in drier regions (Han, Chen & Wang 2016). The potential cooling effect of greenery is significant, reducing transmitted solar radiation by up to 20% (Figure 4).

Increasing the intensity and coverage of greenery has multiple benefits. In the climate of Melbourne, increasing the city-wide green coverage by between 15% and 33% can decrease indoor air temperatures, and consequently, the mortality rate can drop by between 5% and 28% during heatwaves (Chen et al. 2014).

Building envelope

In Australian detached homes, roofs, followed by windows are the main drivers of heat gain (Mosher, McGee & Dick 2002). Both bulk and reflective insulations - the latter coupled with an appropriate air gap - effectively block heat flow through the envelope (Saman et al. 2013; Barnett et al. 2013).

However, insulation can be occasionally counterproductive to both cooling and total annual energy demand. Inappropriate insulation without a whole-building design can include excess wall insulation, depending on the orientation (Porritt et al. 2013); slab insulation in already insulated buildings located in temperate or hot climates (Ren, Wang & Chen 2014), and triple glazing compared to double glazing without shading (Rahman, Rasul & Khan 2010). These examples show that design measures need to consider the whole building.

Reflective foil is recommended to be used with a lighter roof colour. In a single-storey six-star home, this design measure could cut the annual cooling requirement by up to 44% in Adelaide and 49% in Sydney (Saman et al. 2013). The reduction of the cooling load, without increasing the annual energy demand, was confirmed throughout the mainland capital cities of Australia. The only exception is Hobart where the increase in heating needs would outweigh the benefit in cooling. The

positive impact of light roof colour across Australia was even more significant when the researchers accounted for climate change.

Cool roofs include both roof materials and coatings designed with increased thermal reflectance and emittance compared to traditional roofs (City of Melbourne 2012).

Painting roofs white is the cheapest and easiest solution. Cool roofs are one step up in technology; they reflect and emit more heat than traditional materials (Osmond & Sharifi 2017).

Cool roofs are often mistakenly considered counterproductive in Melbourne, however, an independent Melbourne study concluded their year-round efficiency in almost all project types (Hes 2012).

A roof colour's level of reflectivity can be defined by albedo value or solar absorptance. As a rule of thumb, the lighter the colour, the more heat is reflected back to the atmosphere. High emissivity - the ability of the material to dissipate heat - can also help to reduce overall heat gain. For example, tiles dissipate heat and perform better than metals (Barnett et al. 2013). Nevertheless, the colour of the roof is the single most effective way of reducing summer heat gain (Barnett et al. 2013). Just switching from a dark to light roof colour in low, medium and high-rise buildings was found to reduce the number of hours with unsafe indoor thermal conditions by 29% in Mt Isa, Queensland and 95% in Canberra (Barnett et al. 2013).

The potential impact of roof colour and material selection on solar reflectance and emittance is summarised in Figure 5.

Windows are the other primary source of excess heat gain (Mosher, McGee & Dick 2002). This heat gain can be reduced by appropriate selection of the frame - choose PVC, wood or thermally broken aluminium. To decrease heat gain through the glazing, install low-e double glazing with a reduced solar heat gain coefficient (SHGC) value and argon (or krypton) gas (Ren, Wang & Chen 2014). Keep in mind that a low SHGC can be counterproductive in colder climates by reducing winter solar heat gain.

Low-e coatings reduce heat emitted through the glazing. Therefore, their installation on the correct side of the glass panes is crucial. In a design aiming to reduce winter heat loss, the low-e coating should be placed on the external side of the inner glass. In a design with excessive summer heat gain, the low-e coating should be placed on the internal side of the outer glass pane (Turner 2018).

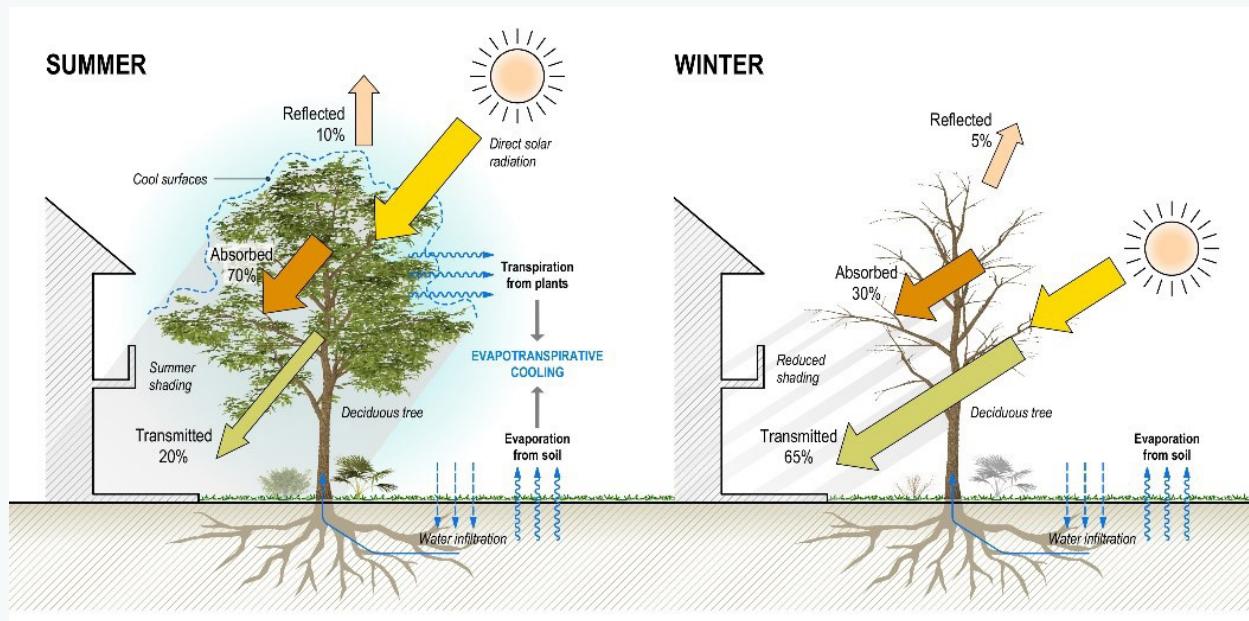


Figure 4. Cooling effect of a tree on a sunny day in summer and winter (Source: Osmond & Sharifi 2017)

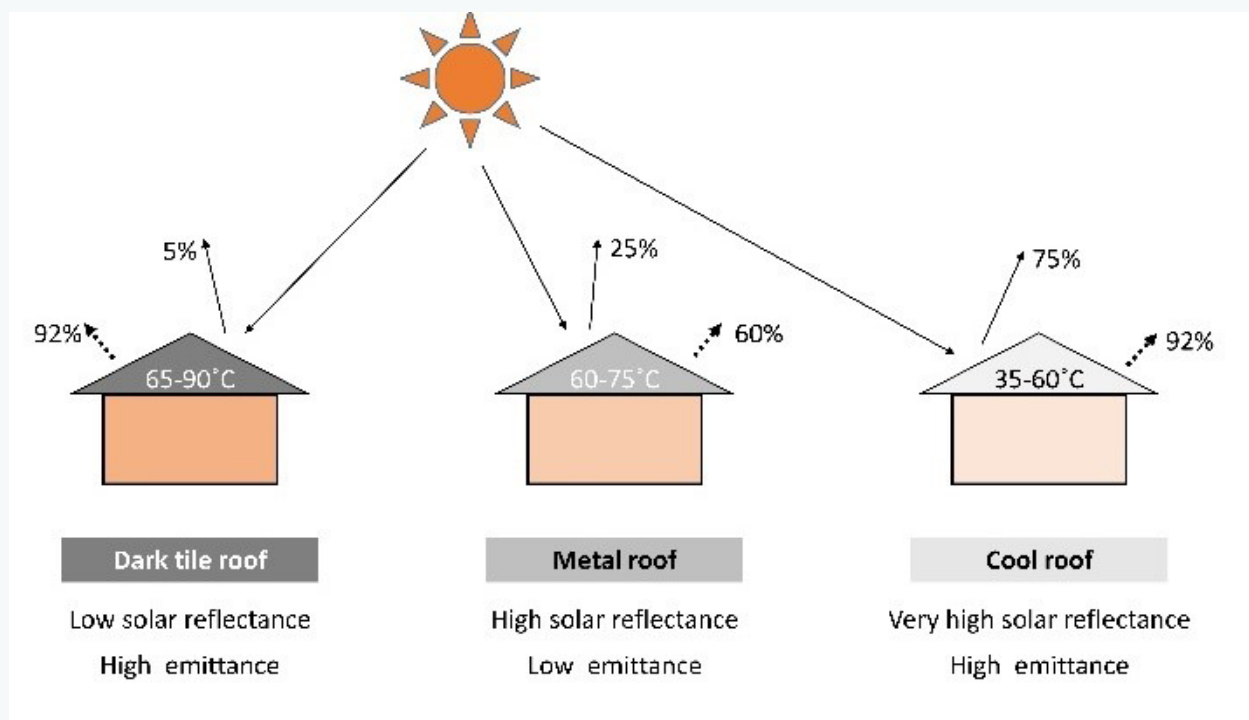


Figure 5. The impact of colour and material on solar reflectance and emittance (Source: C. Bartesaghi Koc in Osmond and Sharifi, 2017)

Earth coupling and thermal mass

Earth coupling, which utilises the cooling and heating capacity of the earth, is an efficient passive design strategy in most temperate climates of Australia (Reardon 2013). In the coldest regions of Australia, slab insulation is necessary to minimise winter heat loss. In contrast, in warmer climates, an elevated structure can help to eliminate summer cooling requirements by cross-ventilation under the elevated floor (Wong & Chen 2009).

In homes with a high level of insulation, even the selection of the floor coverings can have an impact on indoor thermal comfort. Ceramic floor coverings on uninsulated slabs on ground can further decrease the cooling load without increasing the annual energy demand in Adelaide (Karimpour et al. 2015).

Increasing thermal mass is an effective tool to maintain a comfortable indoor temperature over the year in temperate climates (Gregory et al. 2008), especially when coupled with night-time ventilation. Thermal mass can include the use of brick internal walls and reverse brick veneer walls, as well as alternative solutions such as water in an internal pool or phase-changing materials. However, thermal mass can be detrimental in bedrooms and during prolonged heatwaves (McLeod, Hopfe & Kwan 2013).

To effectively utilise thermal mass, a considerable difference between day and night-time temperatures is necessary. Therefore, in tropical climates with a low level of temperature fluctuation, light-weight structures are often more appropriate combined with single-room depths for good cross ventilation (Hampton 2010). In contrast, in colder climates, wider building depth can help to keep the house cool even during the hottest heatwaves. The combination of the two structures is also an opportunity. A lightweight structure built for the bedrooms can increase the efficiency of either the natural night-time ventilation or mechanical cooling.

Cool retreats

Design plays a vital role in occupants' behaviour choice. Before the availability of air conditioning, traditional adaptation techniques were used. In the 19th century, verandahs with insect screens provided shading and a buffer zone between indoors and outdoors. Verandahs were also used for sleeping during warm nights (Lewis 1997). Early settlers used the basement of the building as a cool refuge during heatwaves (Pikusa 1986). This

solution is similar to the vernacular buildings built in much hotter climates such as central Iran (Roaf, Crichton & Nicol 2009).

Based on the same concept, Palmer et al. (2013) proposed the cool retreat in Australia: a highly-insulated, southern or central part of the building is used and air-conditioned as a refuge from extreme heat stress. Cool retreats can dramatically decrease cooling demand during heatwaves in Adelaide, Richmond (NSW) and Amberley (Queensland), assuming changes in occupancy behaviours (Palmer et al. 2013).

To create a cool retreat, the internal building zones are organised to use only the coolest room of the building during heatwaves, such as the southern or central part of the building. Although basement cool retreats are the most efficient, they are rarely feasible in Australian homes. A central location is only recommended if comfortable indoor thermal conditions can be maintained for a prolonged period during heatwaves. An alternative location is next to an internal patio if available, as shown in Figure 6.

The selected room must be isolatable from the adjacent rooms with doors. Increased internal thermal mass, extra insulation of both internal and external perimeter walls and roof are important to deflect heat gain. If some of the walls are external, low-e double glazing, light wall and roof colours and increased shading are highly recommended.

The room function should primarily allow night-time use with the option to extend its use to daytime. If air conditioning is installed, it should be separately controlled for that specific space to minimise energy use and maximise efficiency. To ensure continuous electricity supply, even during blackouts, power backup fuelled by a solar panel and a small-scale battery is preferable.

Cool retreats can also be effective in other climates. A recent study investigating the impact of cool retreats during heatwaves considered five different detached home designs across NSW, Queensland and South Australia. In the tropical climate of Queensland, with hot wet summers and warm winters, a cool retreat can reduce the cooling requirement during heatwaves by up to 91% (Saman et al., 2013).

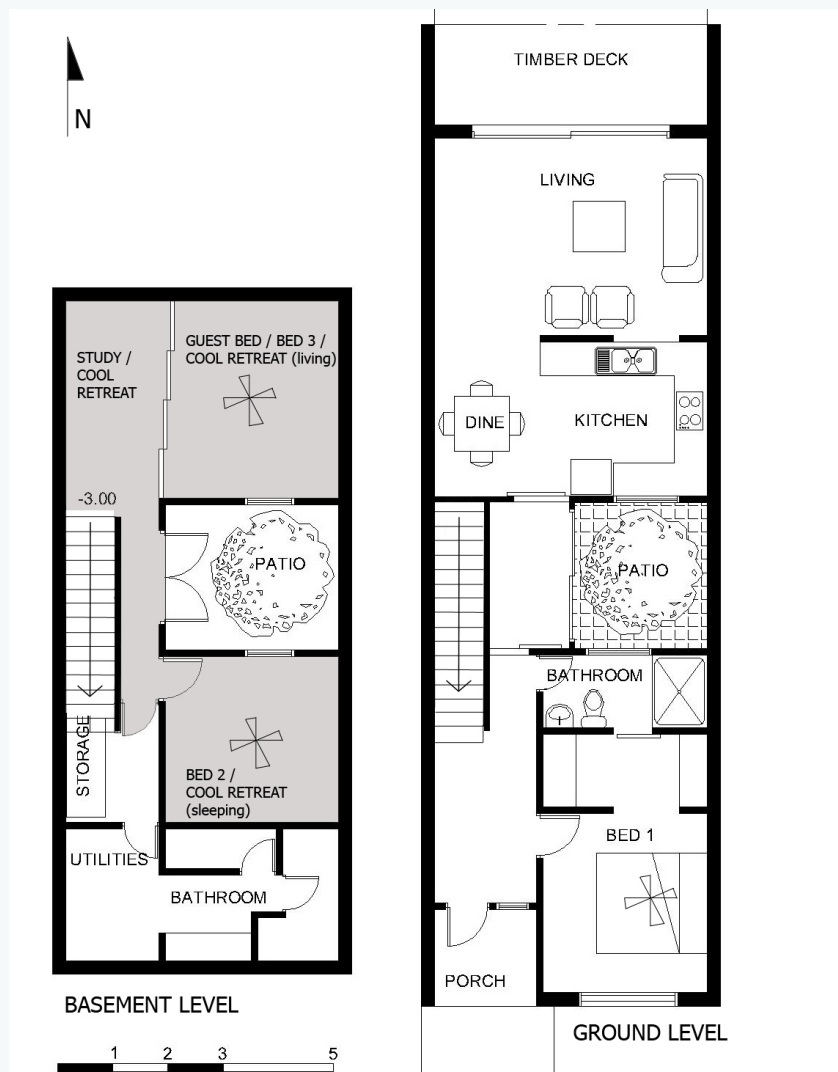


Figure 6. Sample layout for cool retreat (Source: Palmer et al., 2013)

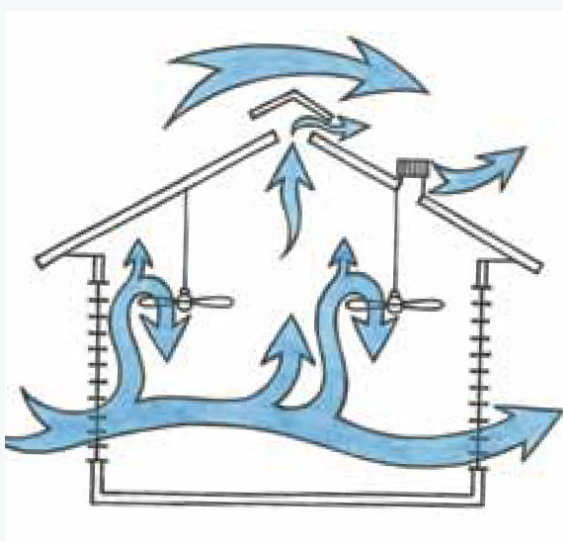


Figure 7. Ideal use of fan positions close to openings (Source: Beagley, 2011, for COOLmob, illustrator Sally Heinrich)

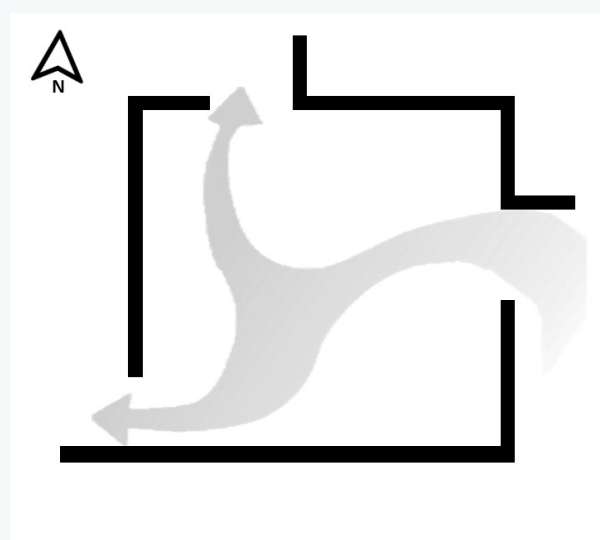


Figure 8. Plan of wing wall directing cool air into the home from the windward side and pulling out warm air on the downwind sides (Image: Author)

Natural or mechanical ventilation

Optimised orientation and layout can give access to natural ventilation, utilising the cooling power of summer breezes and night-time ventilation (Aynsley 2014). Night purge can be helpful during summer nights in the lead up to heatwaves to minimise heat stored in the building structure.

Night purge ventilation occurs when windows, doors and openings are opened at night to flush out the warm air and reduce the heat stored in the thermal mass of the building.

The decrease in the size of backyards (Planet Ark 2013) and spaces between buildings in recent decades have reduced the cooling potential of green spaces. The decreased distance between neighbours further limits natural ventilation. Although natural ventilation is widely underutilised (Miller 2014), it is not always efficient. During the most extreme heatwaves and in the tropics, it is limited by high night-time temperatures. Home security and privacy concerns can also be barriers to natural ventilation along with increased pollution and noise.

Natural ventilation has multiple benefits. Beyond the reduced energy demand, the number of people dissatisfied with their thermal comfort is significantly higher in air-conditioned buildings than in naturally-ventilated ones (Candido et al. 2010). Natural ventilation supports occupants' tolerance levels and resilience. In contrast, air-conditioned buildings raise people's expectations of thermal comfort beyond the negative economic and environmental burdens.

Occupants are still more likely to turn on their air conditioners than open windows (Willand, Ridley & Pears 2016). The ideal operation of windows relies on an understanding of the characteristics of the home and the local microclimate, which occupants are rarely fully aware of (Miller 2014).

NatHERS' fundamental assumption on the frequency of the opening of windows and doors for natural ventilation is often compromised (Ambrose et al. 2013). Changes introduced since the National Construction Code (NCC) 2016 cause further restrictions; namely first-floor window openings are limited to 125 mm to avoid the potential falling risk of small children (Jensen, Cadorel & Chu 2017).

A further challenge is that the design of air conditioners has been underregulated prior to the very recently issued AS/NZS5141 standard on

'Residential heating and cooling systems'. The lack of regulation has led to oversized systems installed in energy efficient buildings due to the risk-averse nature of suppliers and designers. Oversized units run far less efficiently than units correctly sized for the particular space (Saman et al. 2013; US Environmental Protection Agency 2005).

Coefficient of performance (COP) measures the ratio of output thermal power and the input electrical power of the cooling or heating system. The higher the COP the more efficient the system is.

The efficiency of air conditioners is measured in the coefficient of performance (COP). During heatwaves, the COP can be significantly worse than expected (Saman et al. 2013; Santamouris et al. 2001).

An alternative to refrigeration-based air conditioners is evaporative coolers, applicable in the drier areas of Australia. Evaporative coolers can perform ten times more efficiently, defined by the COP, than reverse-cycle air conditioners (Saman et al. 2013; Sustainability Victoria 2019). Fans can be another low-energy alternative, lifting the maximum tolerable indoor air temperature by 3–4°C (Jay et al. 2015) (See Figure 7).

Natural and low energy ventilation techniques that minimise or do not require occupants' interactions can make a significant difference. These include ground cooling systems, solar chimneys, wind towers, hybrid systems using both natural and mechanical systems, and ceiling fans (Prelgauskas 2018; Santamouris et al. 2007).

For example, a wind tower installed in a four-storey residential building in Sydney can reduce the indoor temperatures on average by 1.1°C in the warmer months of the year (Sadeghi et al. 2017). A home designed for stack ventilation utilises the advantage of cross ventilation, the rise of warm air and the suction effect of wind. High or raked roof and ceilings encourage warm air to rise.

Smart purge systems are a hybrid solution. They automatically start or cease the natural ventilation, depending on the indoor and outdoor conditions and the occupants' thermal comfort. They can also communicate with the air conditioning system (Clarke 2018).

Heat recovery mechanical systems can also reduce cooling needs while maintaining comfortable indoor temperatures (Parry 2014). A heat exchanger pre-cools or pre-heats the incoming fresh air, utilising the temperature difference between the indoor air exhausted from the building and the incoming air from outdoors.

The use of photovoltaic panels and small-scale batteries can shift the timing of and reduce residential peak electricity demand driven by air conditioning (Energy Supply Association of Australia 2012; SA Power Networks 2012). With the revolution of small-scale batteries and the price drop of solar panels, these are readily available tools to reduce peak cooling demand without putting stress on the electricity grid.

Design in the tropics

Traditional building practices allowed buildings to work with their local climates. Vernacular design in the Australian tropics and subtropics includes features such as a light elevated wooden structure, wide eaves and shading, large openings for cross ventilation, fans, light wall and roof colours and increased surrounding vegetation (Figure 9).

Such design relies on optimum natural ventilation throughout the day. Building professionals have repeatedly raised concerns that the NCC's increasing requirement for energy efficiency will create unwanted reliance on insulation and air conditioning in tropical building design.

A recent study pointed out that occupants in Darwin can tolerate high indoor temperatures

beyond the regulatory indoor thermal comfort bands. The reasons include the neglected cooling effect of natural air movement in regulatory simulation software (Daniel et al. 2015) and human acclimatisation.

However, one can argue that with the increasing number of heatwaves and a generally warming climate, indoor thermal conditions in such homes can become unsafe without air conditioning (Miller 2014). A recent study commissioned by the Department for the Environment and Energy concluded that although the NatHERS software could be fine-tuned for tropical climates, the software-estimated star rating still rewards traditional tropical design elements such as natural air ventilation, large openings and shading (Tony Issaacs Consulting 2017).

Tropical climates unarguably pose different challenges for architects and designers. Excess solar gain and relatively warmer nights limit the effectiveness of night-time natural ventilation. In the early design stage for any climate, the decision has to be made whether a building will be naturally ventilated, air-conditioned or a combination of the two. Introducing air conditioning efficiently in a naturally ventilated building can be done only through a combination of insulation, decreasing openings and increasing airtightness (Reardon



Figure 9 Stradbroke House, South Stradbroke Island, Queensland, by Tim Bennetton Architects in association with Gabriel Poole (Image: Mindi Cooke)

2013). This decision is specifically important in tropical climates.

In the tropics, reflective insulation and light wall and roof colours are even more efficient tools to reduce unwanted heat gain, compared to temperate climates. Passive design features adopted to increase natural ventilation include wing walls and whirly birds. Wing walls create a natural breeze that redirects cool air into the home and draws out the hot air with the pressure difference created (Beagley 2011) (Figure 8).

Whirly birds roof ventilators, widely used in attics and rooms with secondary functions, allow warm air to escape through the roof due to the pressure difference.

Keeping buildings cool can also be supported by false walls or facade elements (Beagley 2011). False walls create a naturally ventilated air gap placing an additional facade or cladding element before the wall. This solution provides both additional shading to the envelope and a natural cooling effect by the air circulating between the false wall and the facade walls.

Combination of heat stress resistant design elements

A recent study demonstrated how different designs can result in an extremely heating or cooling dominant home under the same NatHERS star (Hatvani-Kovacs et al. 2017). Transferring a home from cooling to heating dominance means changing the house’s primary energy needs from cooling into heating.

Adopting design changes from Figure 10, the cooling load of a six-star detached home with average floor size in Adelaide could be halved. The cooling loads of a seven- and eight-star home were reduced to almost one-quarter and more than one-fifth respectively. A moderate combination of the design features listed would be enough to achieve a home comfortable during both summer and winter. However, it should be noted that if all changes are implemented, it will change the home from a cooling-dominant to a heating-dominant one.

Design changes to reduce the cooling load		
In a six-star home	In a seven-star home	In an eight-star home
application of light-coloured metal instead of dark tiles on the roof	application of light-coloured metal instead of dark tiles on the roof	application of light-coloured tiles instead of dark-coloured metal on the roof
installation of reflective foils in the roof cavity	installation of reflective foils in the roof cavity	installation of reflective foils in the roof cavity
replacing internal plasterboard walls with brick	replacing internal plasterboard walls with brick	replacing R3.5 external brick veneer walls with R3.5 reverse brick veneer walls
installing external shutters/shading in the west-facing bedroom	installing external shutters/shading in the west-facing bedroom	installing external shutters/shading in all rooms
selecting windows with a lower SHGC (single-glazed)	selecting windows with a lower SHGC (double-glazed with argon gas filling)	selecting windows with a lower SHGC, (double-glazed with argon gas filling and thermally broken frame
	building a slab-on-ground structure without under-slab insulation	building a slab-on-ground structure without under-slab insulation
		replacing all internal floor coverings with ceramic tiles or exposed slab to utilise thermal mass

Figure 10. Design features to reduce the cooling load in a detached home in Adelaide, South Australia (Source: Author). Note: Adoption of all features for a given star rating will change a cooling-dominant home into a heating-dominant one.

Figure 10 demonstrates that heat resistant design features should be used only in the context of the whole buildings' energy balance. For example, a window with low solar heat gain might compromise the heat gain of a temperate climate home, resulting in extra heating demand during winter.

A representative survey from Adelaide found residents in homes with a higher number of heat stress resistant features, specifically with roof and wall insulation and double-glazing, had fewer health issues during heatwaves than those living in homes without these features (Hatvani-Kovacs et al. 2016).

Retrofitting is also effective in multi-storey residential buildings. A recent Melbourne study showed that the number of hours with overheating in a twenty-storey residential block can be reduced by 85% with a combined retrofit. The project included the installation of external insulation, painting the walls a light colour and increasing natural ventilation (Jensen, Cadorel & Chu 2017).

The primary intention of passive heat stress resistant design features is to decrease exposure to heat. These features can also indirectly mitigate heatwaves via reduced waste heat and carbon emissions, to a varying degree. For example, the application of materials with high solar reflectance in the built environment, such as reflective roofs, can simultaneously save energy, increase thermal comfort, mitigate UHIEs and cut carbon emissions (Cotana et al. 2014).

Heat stress resistance in the Australian building standards

Homes built since the introduction of a minimum six-star NatHERS rating can still underperform during heatwaves (Willand, Ridley & Pears 2016). This is because the NCC only encourages overall energy efficiency but not necessarily heat stress resistance (Willand, Ridley & Pears 2016; Ren, Wang & Chen 2014; Hatvani-Kovacs et al. 2017).

As of the time of writing, the current energy-efficiency measures of the NatHERS cannot necessarily ensure lower cooling energy consumption, reduce relative peak demand or prevent overheating during heatwaves in new homes (Hatvani-Kovacs et al. 2017). In addition, a high star rated home can have decreased heat stress resistance and increased reliance on air conditioning during heatwaves compared to a traditional, double-brick home.

Figure 11 graphs the annual cooling and total energy loads of a single-storey detached home with average floor size in Sydney for different design variations. In all versions, the floor plan and orientation remained unchanged. An uninsulated double-brick design version could still outperform a BASIX-compliant new design of 5.6 stars in summer before the most recent amendment was issued in July 2017. Such an overreliance on air conditioning can present a public health hazard should a blackout occur or for those who are energy poor.

BASIX strengthened their separate minimum heating and cooling thresholds in July 2017, (NSW Department of Planning and Environment 2016). However, under these new thresholds, the minimum-compliant cooling-dominant home with 5.6 stars, modelled in the earlier discussed study from Hatvani-Kovacs et al. (2017) would fail.

A recent Melbourne study simulated the design of six apartment buildings, such as low and high-rise, old and new, and minimum standards and best practice (Jewell 2018). The researchers found that all designs failed against the minimum overheating requirements of four international high-performing building standards, including the Passivhaus standard, France's green building standard (Norme Française Haute Qualité Environnementale), the UK's Chartered Institution of Building Services Engineers guide and the US's American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard.

These issues have recently been recognised by the Australian Building Codes Board (Australian Building Codes Board 2018). New thresholds have been introduced for separate heating and cooling loads in the NCC 2019. These thresholds are still lenient because they eliminate only the most extreme designs, ruling out the 5% most cooling-dominant (and heating-dominant) homes with 5.5, 5 and 6 stars.

Similar and proportional thresholds should be defined for higher star levels of the NatHERS, beyond the current scope of both the NCC and BASIX.

The next section outlines best practice recommendations for architects, building designers and building energy assessors on how to evaluate the heat stress resistance of a design.

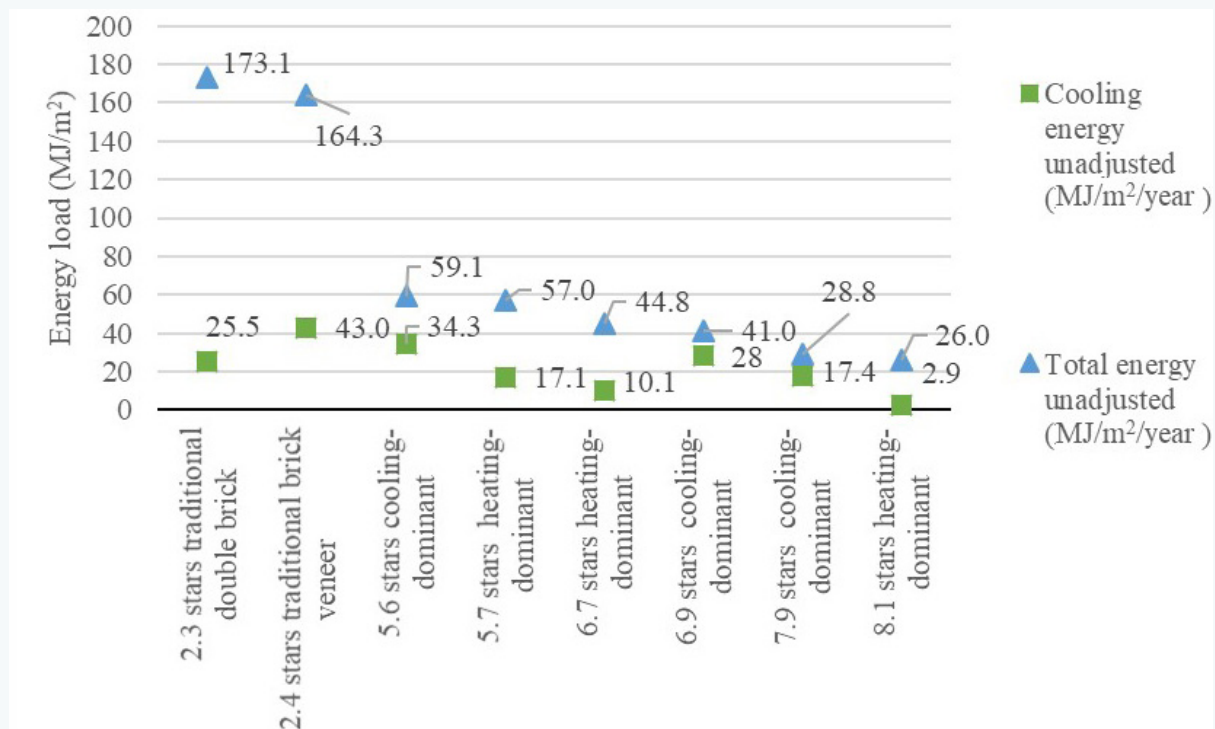


Figure 11. Total annual energy and cooling energy loads of design options in Sydney (Source: Hatvani-Kovacs et al. 2017)

Using building energy simulation to increase heat stress resistance

Beyond following the design strategies discussed earlier, additional steps can be taken during building energy simulation to provide appropriate heat stress resistant design.

Apply the proposed heating and cooling thresholds of the NCC 2019 to new construction.

The annual cooling load is reported by the NatHERS simulation software. The ratio of the heating and cooling thresholds defined by the NCC 2019 public draft for 6-star homes is publicly available (Australian Building Codes Board 2018, p. 73 Appendix B). For buildings with a higher star rating, the ratio of the thresholds can be proportionally calculated and applied.

Consider the impact of design changes on peak demand. AccuRate, the most widely used NatHERS-accredited building energy simulation software, calculates the hourly peak load demand. However, it assumes that the capacity of the cooling system is infinite. More realistic peak demand can be calculated from the three-hourly running mean of the 'txt' file generated by AccuRate. The calculated peak demand is more representative of the capacity of a real cooling system (Saman et al. 2013).

Use the rating software to calculate the number of hours with discomfort during the hottest part of the year. For this calculation, run the free-running mode of the software instead of the regulatory mode. Thermal discomfort occurs when indoor temperatures exceed an internal temperature threshold. The indoor temperatures can be resourced as a 'txt' file from the AccuRate simulation, similarly to the peak demand data series. Ask your energy rater to provide this information for you at the sketch design stage, to enable easy implementation of the changes.

Free-running mode is an energy simulation mode when no mechanical heating or cooling is used.

For indoor temperature thresholds, the easiest option is to apply the NatHERS static thermostat setpoints (Department of Environment and Energy 2012, p. 26 Appendix B2).

An alternative path is to adopt the adaptive comfort model (Candido 2011) calculated based on the ASHRAE standard (ASHRAE 2016). The adaptive comfort model, initially designed for commercial buildings, was preliminarily validated for residential mixed-mode ventilated buildings in Adelaide, Brisbane and Sydney (Saman et al. 2013). Another study from Adelaide and Darwin found that temperatures even above the adaptive comfort model thresholds can be tolerated by many occupants (Daniel, Williamson & Soebarto 2017).

Adaptive comfort model utilises the human adaptive capacity allowing a wider indoor temperature range in proportion with the outdoor temperature. For example, during heatwaves, indoor thermostat setpoints can be set as high as 28°C.

Based on the calculation of the ASHRAE 55 standard, assuming that 80% of the occupants are satisfied with the indoor temperature, the upper limit of neutral temperatures can be calculated as below, where $T_{outdoor}$ is the average monthly local temperature:

$$T_{ACM} = 0.31 * T_{outdoor} + 21.3$$

The overall goal is to keep indoor temperatures under the selected threshold values in most of the hottest weeks of the typical meteorological year (TMY). Note that weather extremes, such as heatwaves, are only present in the TMY to a limited extent.

For the assessment of indoor thermal discomfort, either living rooms or bedrooms are recommended with the highest exposure to heat gain. Mostly these are located on the second floor under the roof, facing north or west or lacking shading. Internal night-time temperatures for bedrooms are of particular concern, considering the impacts

of minimum temperatures on sleep deprivation (Anderson et al. 2013).

Monitor indoor temperatures not just on the hottest days but the succeeding ones. The development and validation of a recent heatwave intensity metric, the 'excess heat factor', demonstrated that human adaptation capacity can be more exhausted during a longer heatwave. This is not surprising if we think about sleep deprivation, our general exhaustion caused by a long period of heat and the accumulated heat stored in the built environment (Nairn & Fawcett 2015).

Figure 12 is an example of the assessment of indoor overheating in a bedroom of a single-storey detached home with average floor size in Adelaide. Multiple temperature thresholds were adopted, including the fixed thermostat setpoint of AccuRate, the adaptive comfort model and overlapping days with the highest health risk. Health risk was calculated with the excess heat factor.

Unfortunately, even the heating-dominant six-star home repeatedly exceeds the indoor temperature thresholds. This result indicates that a six-star home cannot really cope well with heatwaves unless it is air-conditioned. Still, the number of hours with discomfort are much fewer than in a cooling-dominant home.

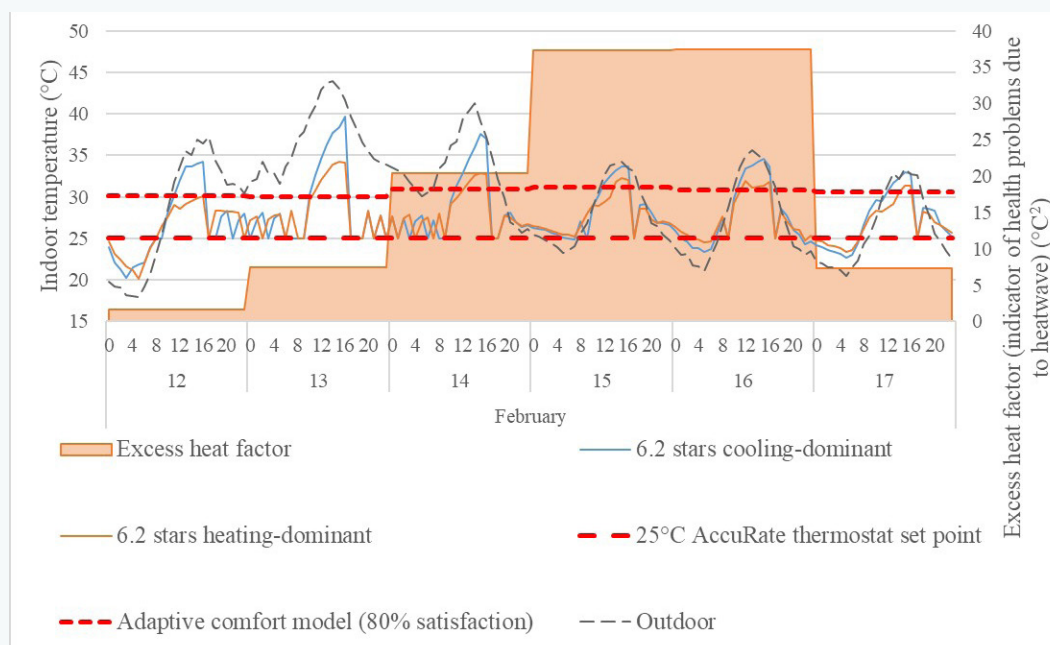


Figure 12. Overheating analysis of a north-facing bedroom during a medium heatwave period in Adelaide [Source: Hatvani-Kovacs et al. 2017]. Note: The solid orange line represents the indoor temperatures simulated in a 6-star heating-dominant home compared to the solid blue line, representing the 6-star cooling dominant home. The metric of the excess heat factor is °C², and measured on the secondary vertical axis, referring to days with higher heat related health risks.

Heat stress resistance in the construction phase

Australian residential building energy-efficiency standards are ineffective compared to leading jurisdictions internationally (Moore, Berry & Moyse 2017). However, this is in part due to a lack of enforcement of the NCC in the construction phase. Non-compliance is a major issue in delivering homes which are energy efficient and heat stress resistant as much in their as-built form as in the design phase (Berry et al. 2014; Department of State Development – Government of South Australia 2014).

NatHERS' building energy simulation underrepresents the level of overheating because of the ignored real-world factors that affect building energy use. Typical non-compliance issues include thermal bridges, compromised airtightness, substitution and omission of insulation specified, and the use of poor quality ducting in the case of ducted air conditioning (Department of State Development – Government of South Australia 2014; Saman et al. 2013). Thermal bridges include missing insulation in the roof because of recessed downlights and exhaust fans (Figure 13). Non-compliance issues can dramatically reduce the overall performance of buildings.

Airtightness helps to reduce unintended air leakage from and into the house through cracks and gaps in the building envelope.

A further problem is that thermal bridging caused by studs (Figure 14) is not addressed by the NCC (Kenna & Boland 2017). For example, insulation in the roof cavity is installed between timber frames with compression of the material. The wooden studs cause structural thermal bridges beyond the

compression of the insulation (McGregor 2012). These thermal bridges cause the designed R2 and R3 values of the bulk insulation to drop back to R 1.2 and R1.4 after installation (Belusko et al. 2010).

Such negative impacts of thermal bridges on R3 roof insulation in detached homes increase the annual cooling load by 34% even in Melbourne (Saman et al. 2013). These figures are obviously higher in warmer climates. One solution is to install batt insulation between the framing and roll out a blanket insulation in the opposite direction.

The primary responsibility to ensure that the building is built as per the design is the builders'. However, without adequate checking processes required by building certifiers, appropriate guidance from architects and building designers is also essential. Such an approach would require a paradigm shift with more engagement of the architects and building designers in the construction phase.

Conclusion

Architects and building designers can make a substantial difference in future residential building stock by implementing heat stress resistant strategies such as those discussed. The integration of a building energy simulation, to evaluate not just the overall star rating but the heat stress resistance of new homes and renovations, is recommended from the initial design phase.

Builders have an immense role in the execution of the design and to comply with the technical documentation in each phase of the construction. While appropriate policies are not in place, heat stress resistant design is voluntary. Policymakers have the largest impact on ensuring more heat stress-resistant homes are designed and built for the future.

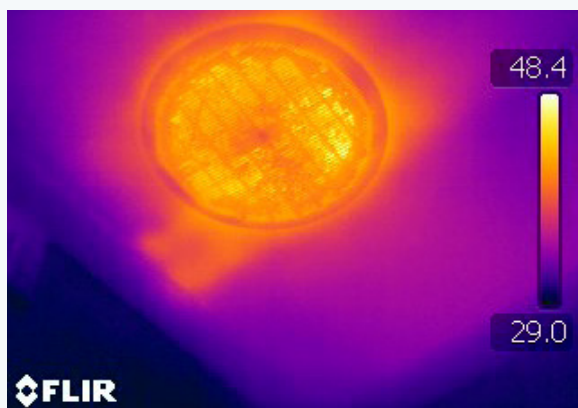


Figure 13. Insulation gap caused by the installation of a recessed downlight (Source: Author)

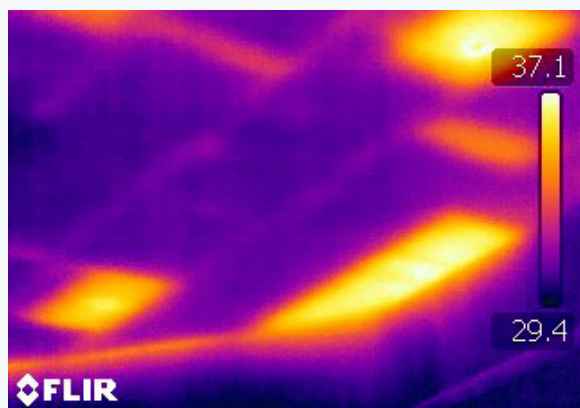


Figure 14. Patchy installation of roof insulation with thermal bridges caused by the wooden studs (Source: Author)

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