Optimising Building Affordability and Operational Costs – A Case Study of the Parallel Design Philosophies in the Use of Cool roofs in Australia.

Jamie Adams[1], Robert Scott[1], Rui Yan[2]

Abstract

In 2006, the Building Code of Australia (BCA) introduced energy efficiency requirements for new Class 2 to 9 buildings. Over time, the regulatory approach has been to increase the energy efficiency requirements. This has led to the development of products designed to improve the thermal performance of the building envelope. This paper examines one of these products, cool roofing.

In considering the design philosophies in the use of cool roof technology, two alternate frameworks are possible; to improve a building's energy efficiency or to deliver construction cost benefits. Particularly at a time when building costs are achieving great focus, understanding these frameworks provides additional options for optimising the design of the roof to deliver the best combination of energy efficiency, operating and capital costs of a building.

It is shown that, for the case study building, the cool roof is able to deliver economic benefit in most environments in Australia. The philosophy of improved energy efficiency is shown to have an attractive economic pay back in most climates, while the philosophy of efficient building construction leads to immediate capital savings. In both cases, there is the additional benefit of reducing the urban heat island effect.

Keywords: cool roofing, solar reflectance, energy efficiency, construction cost.

1. Introduction

Cool roofs are characterised by having high solar reflectance and high thermal emittance (Akbari and Levinson, 2008). The coolest roofs are typically white; however technology has been developed to provide high solar reflectance products where colour is required, referred to as cool colours. Cool roofs provide a range of benefits, including energy efficiency of buildings, human comfort and reduction in the urban heat island effect (VanCuren, 2012). Whilst cool roofs are also often promoted on the basis of reducing urban heat, including through credits in green rating tools (LEEDUser, 2012) the principle focus of this paper is upon energy efficiency of buildings.

---

[1] BlueScope Steel.
[2] University of Wollongong.

A primary benefit of cool roofing is its ability to reduce the heat transferred to the building below, and as a consequence reducing the building's cooling load. Many factors influence the savings from cool roofing, however high savings are typically achieved for single or 2 storey buildings that have high cooling demand. High cooling demand is typical of buildings in either a warm climate, predominant daytime only occupation or a high internal load. Retail buildings, which are the focus of this study, can provide all three of these situations in combination, and therefore have some of the highest levels of cooling demand of any building typology.

The major design philosophy of using a cool roof has been to improve building energy efficiency. An alternative approach is the philosophy of using a cool roof to deliver equivalent energy efficiency to a nominal roof design, and deliver construction cost benefits. These two distinct design philosophies are considered for a case study retail building.

2. Literature on potential of cool roofing

Numerous studies demonstrate that cool roofs can significantly reduce energy costs, particularly for single storey buildings in warm climates. For example, Akbari et al. (2004) documented that 72Wh/m^2/day (52%) air conditioning energy saving was achieved by replacing an existing dark roof (solar absorptance, α=0.79) with a cool roof (α=0.2) for a retail building located in Sacramento California during summer. Bhatia et al. (2011) demonstrated, based on a calibrated simulation, that an office building (663 m^2) in a cold climate in India (Shillong) can still achieve valuable savings from a cool roof, with annual savings of 4586 kWh or an average saving of 19 Wh/m^2/day. Parker et al. (1998) reported average mid-summer cooling energy savings of 19% in Florida by lowering the roof's solar absorptance by painting them white based on measurement of 11 homes. Similar results have also been found in other residential building studies where white metal roofing has been used (Parker et al., 2002, Chasar, 2005).

A cool roof primarily saves cooling energy by reducing solar heat gain into a building (Mechanism 1 and 2 in Figure 1). For some buildings further savings are achieved due to reduced heating of the cooling system (Mechanism 3 in Figure 1). This is true for buildings where the duct system is located in the attic, upon or just beneath the roof and/or has a roof-mounted Heating Ventilation and Air Conditioning (HVAC) system. Further, for cool roofs where the HVAC inlet is on the roof, the air intake temperature is lower than for standard roofs (Mechanism 4 in Figure 1). Carter (2011) proposed that this is a key factor in explaining why current simulation software underestimates the energy saving potential of cool roofs. Whilst the impact of solar heat gain transferred to the building below is usually accounted for (Mechanism 1 and 2), other factors associated with a cool roof's impact upon a cooling system are not (Mechanism 3 and 4).

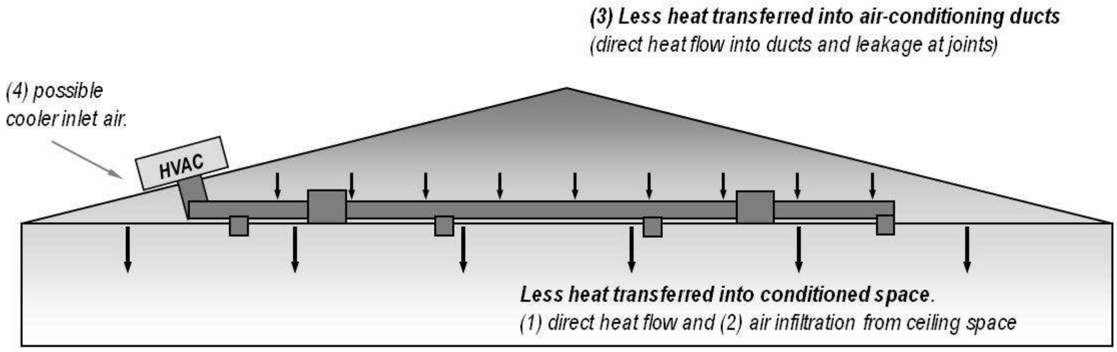


Figure 1: Cool roof impacts upon a building and its cooling system.

Gentle, Aguilar and Smith (2011) demonstrated that for certain buildings, where a cool roof is used, an optimum level of insulation can be determined. Similarly, Carter (2011) showed that the air temperatures around cool roofs lead to an improvement in the operation of the conditioning equipment in warm climates.

Given the current software limitations, this paper only considers the primary saving potential of a cool roof as a result of solar heat gain transferred to the building below (Mechanism 1 and 2). Further investigation is required to better understand the value of other factors influencing cool roof savings, in particular the impact of a cooler roof upon cooling systems (Mechanisms 3 and 4).

3. Modelling methodology

3.1 Simulation software

The building simulation conducted for this paper uses the DesignBuilder interface, which uses EnergyPlus simulation software.

3.2 Building constuction

The building modelled in this paper is a rectangular store with flat roof of size 40m×50m×5m (W×L×H) and set with its 50m side facing to the north (Figure 2). The glazing ratio of the north façade is 12% and the other three facades have no glazing. The building geometry was chosen to resemble a medium sized retail building, such as a supermarket.

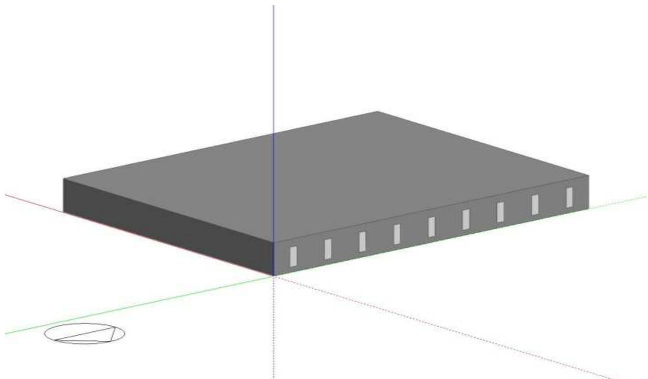


Figure 2: Overview of the building modelled.

The reference building fabric wall and roof layers used in the building model and corresponding total R-value are shown in Table 1. The insulation levels and surface properties are based on the National Construction Code (NCC) BCA 2012 Volume 1 Section JV3 (Australian Building Codes Board, 2012).

The study includes comparison of two forms of roofing against the reference roof, a white prepainted steel roof and a resin coated aluminium/zinc (AZ150) roof, referred herein as a cool roof and a bare metal roof. The assumed cool roof and bare metal roof solar absorptance are 0.23 and 0.35, respectively, and thermal emittance are 0.87 and 0.3, respectively. The Cool Roof Rating Council (2009) contains typical values for cool roof and bare metal roof products. The solar absorptance used in modelling were increased by 0.05 to 0.28 and 0.40, respectively, to allow for weathering as required by Section JV3 (Australian Building Codes Board, 2012).

Table 1: Reference building construction

Construction	Wall	Roof
Layer 1	BRICKWORK outer leaf (100mm, k=0.84)	Metal Deck (0.42mm, k=48)
Layer 2	Concrete Block Medium (100mm, k=1.35)	Air Gap (30mm, R=0.18)
Layer 3	Glass Wool (84mm, k=0.037)	Glass Wool (20mm, k=0.007)
Layer 4	Air Gap (10mm, R=0.18)	Plasterboard (10mm, k=0.4)
Layer 5	Plasterboard (10mm, k=0.4)	N/A
Base Solar Absorptance	0.6	0.7
Thermal Emittance	0.9	0.85
Total R-Value	2.838 $m^2.^{o}K/W$	3.202 $m^2.^{o}K/W$

Note: k is thermal conductivity in W/m.ºK,
R-Value is thermal resistance in m^2.ºK/W.

3.3 Internal loads

Internal loads heat a building, which can be beneficial in cold climates and deleterious in warm or hot climates. Internal loads in retail buildings include occupancy, lighting and equipment. This paper includes consideration of a high and a mid range internal load case.

The high internal load case is in line with the Green Star Retail Centre Energy Modelling Guidelines (Green Building Council of Australia, 2009), and is summarised in Table 2. Such high internal loads may exist in a supermarket as a result of refrigeration equipment within the building. The equipment load in these Guidelines is higher than the default value in Specification JV for a retail building of 5W/m^2 (Australian Building Codes Board, 2012). A set of lower internal loads was also modelled (as shown in Table 2) with reduced loads for both equipment and lighting. A daytime building operation schedule was assumed for both internal load cases based on the Green Star Retail Building Guidelines (Green Building Council of Australia, 2009).

Table 2: Assumed internal loads

	High Internal Load	Mid Range Internal Load
Occupancy m^2/person	4	4
Metabolic Rate (Sensible) W/person	70	70
Metabolic Rate (latent) W/person	60	60
Total Lighting Load (W/m^2)	20	14
Equipment Load (W/m^2)	40	5

Note: As EnergyPlus/DesignBuilder defines metabolic rate based on human behaviour, light office work/standing/walking was selected instead of defining it as W/person.

3.4 HVAC assumptions

The following assumptions were made for modelling of the HVAC system and based on default software values and BCA Sec J5.4 (Australian Building Codes Board, 2012): a Co-efficient of Performance of 2.7; a 5% distribution loss; cooling and heating setpoint of 22ºC and 24ºC respectively; and mechanical ventilation of 2.5 $l/s.m^2$.

3.5 Scope

The variables considered in this paper were chosen to allow investigation of the influence of insulation levels when cool and non-cool roofs are used for a typical retail building located in different climate regions of Australia.

The variables considered include:

- Roof type: Comparisons between the reference building roof (Table 1), with a cool roof and a bare metal roof.
- Climate: Seven locations (Darwin, Brisbane, Tenant Creek, Kalgoorlie–Boulder, Perth, Melbourne and Hobart) representing all of Australia's BCA climate zones except for alpine (Zones 1 to 7).
- Internal load: A high and a mid range internal load case.
- Roof insulation level: Roof insulation total R-Values ranging from R0.18 for an uninsulated roof up to R4.2. A total R-Value of R4.2 is the highest BCA minimum requirement for climate zones 1 to 7 (Table 3).

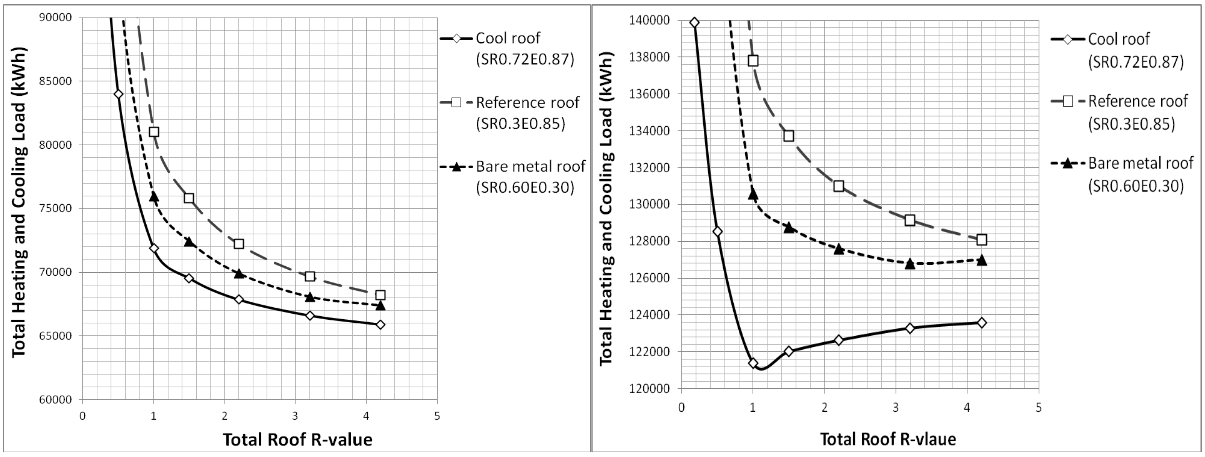
Table 3: BCA minimum prescriptive roof Total R-Value requirements (Australian Building Codes Board, 2012)

Climate Zone	1 to 5	6	7	8
Direction of Heat Flow	Downwards		Upwards	
Roof solar absorptance value of not more than 0.4	3.2	3.2	3.7	4.8
Roof solar absorptance value of more than 0.4 but not more than 0.6	3.7	3.2	3.7	4.8
Roof solar absorptance value of more than 0.6	4.2	3.2	3.7	4.8

4. Results and discussion

4.1 General

Modelling was completed to determine the annual heating and cooling energy demand (thermal load) for each climate, roof type, insulation and internal load. The data was plotted comparing the thermal load for different roofing products at different insulation levels. An example is shown in Figure 3, which charts the results for Perth (climate zone 5) for mid range (Figure 3a) and high (Figure 3b) internal load cases. It is clear from this that increasing insulation creates a diminishing benefit, and in the case of a high internal load, the increased insulation can increase rather than decrease the building's thermal load.

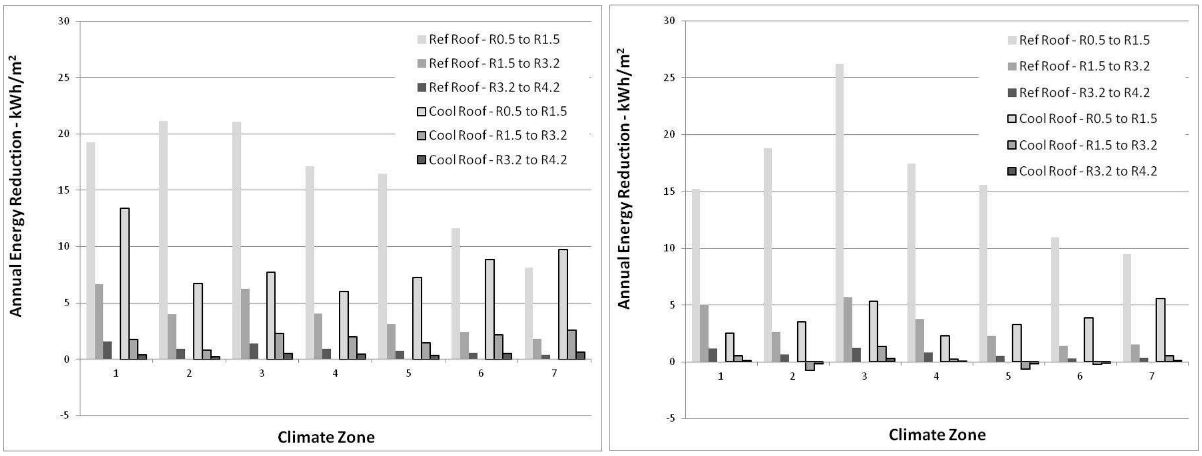


(a) mid range internal load ***b) high internal load***

Figure 3 Annual thermal load – Perth (Zone 5)

This type of thermal load curve applied in all seven climate regions modelled. For all climates the building's thermal loads were found to reduce dramatically up to an insulation level of about R1 to R1.5, highlighting the significant benefit of modest insulation (see Figure 4). There is less incremental benefit from greater levels of insulation. Under certain conditions additional insulation reduces the energy efficiency of a cool roof building (Figures 3b and 4b). Insulation acts to slow heat moving through the building fabric. There is a trade-off in the value of additional insulation between reducing the solar load coming in through the roof, and impeding the ability for the heat (due to internal loads or gains through the façade) to escape the building. The results show that for cool roofs on buildings with high internal loads and in temperate climates that have high night cooling potential (zones 2, 5 and 6) that an optimum level of insulation exists. For each of these climate zones, Figure 4b shows a decrease in annual energy reduction as insulation is increased from R1.5 to R3.2, i.e. the higher level of insulation led to greater energy load.

For more thermally absorbent roofs, the results show there is still a benefit in additional insulation, albeit smaller, as its value in limiting the solar load through the fabric is greater than the negative impact of impeding the ability for heat to escape the building.



(a) mid range internal load *b) high internal load*

Figure 4 Value of insulation to reduce thermal load

This finding that, in certain circumstances, a minima in thermal load can occur at an optimum rather than maximum level of insulation is in agreement with the work of other researchers. A number of studies have found that under certain conditions insulation did not improve walling performance (Johnson, 1997, Barkaszi and Parker, 1995, Masoso and Grobler, 2008), whilst research at UTS has shown that for certain buildings, where a cool roof is used, an optimum level of roof insulation can be determined (Gentle, Aguilar and Smith, 2011).

4.2 Financial consideration of the cool roof benefits

This section examines the modelled outcomes of two distinct design philosophies, using a cool roof to either increase a building's energy efficiency or deliver construction cost benefits. The merits of bare metal roofing are also considered.

4.2.1 Using a cool roof to increase energy efficiency

As already discussed, the traditional approach to use of cool roof technology in buildings has been to reduce the heat transmitted into the building, improving building comfort or when conditioned create operational savings. Whilst not considered here, improved energy efficiency can also lead to higher building ratings, such as NABERS, that may improve capital values and or rental yields.

For R3.2 roof insulation, the maximum saving was 13 Wh/m^2/d or 6.5% (and a peak cooling load reduction of 8 W/m^2) in changing from a roof solar absorptance of 0.70 to 0.28. This is lower than savings discussed in the real building studies (19 and 72 Wh/m^2/d) in Section 2, again indicating that modelled cool roof savings may be underestimated relative to real world performance.

The operational financial savings from a cool roof can often provide payback of the extra cost for appropriate buildings. However, this will depend on several factors:

- Cool roofing costs can vary widely from around \$2/m^2 for cool pre-finished roofing products to more than \$20/m^2 for some post applied solutions (US EPA, 2012).

- Energy tariffs also vary widely, and can include combination of cost components of consumption, peak demand, time of use and fixed daily charges.

Cool roofs can provide benefit through reduced consumption, reduced peak demand and savings tend to coincide with the higher time of use tariffs. For simplicity assuming a single consumption tariff of 28 c/kWh with the conservative modelling results, the cool roof saving is predicted to be up to $1.33/m^2/year.[3] In addition, potential also exist to scale down the size of the cooling equipment creating an additional upfront saving of around $2.40/m^2 assuming equipment cost at $300/kW (The Centre for International Economics, 2009).

These predicted savings are based on the change in solar absorptance of 0.42 in this study. Linear interpolation of the relative solar absorptance of similar products will provide a reasonable estimate to assess the operational saving and payback period for alternative solar absorptance products.

4.2.2 Using a cool roof to deliver construction cost benefits

A cool roof can be used to deliver construction cost benefits for a new building required to meet BCA energy efficiency requirements. This approach involves the use of BCA Section JV3 (Australian Building Codes Board, 2012), which recognises that comparable energy efficiency of a reference roof can be achieved at a lower insulation level with a cool roof.

In the cases of high internal loads, it is possible that the cool roof may deliver an improved energy efficiency outcome (and lower operating costs) as well as lower capital costs, for those situations where there is a minima in the thermal load curve for cool roofs (see Figure 3(b) and climate zones 2, 5 and 6 in Figure 4(b)).

BCA Section JV3 allows verification of a ‘proposed building’ by modelling that shows the performance to be as good as, or better than, a ‘reference building’. The ‘reference building’ is required to be equivalent in most respects to the ‘proposed building’ but include some mandatory prescriptive features. The ‘reference building’ must have a roof solar absorptance of 0.7 and prescriptive insulation levels as per Table 3. For the building modelled in this study, an insulation level for the cool roof was determined that provides equivalent performance to the building as the reference roof with prescriptive insulation levels, thereby meeting the BCA Section JV3 performance requirement. The equivalent R-value for each climate zone and internal load case is contained in Table 4. Again, this is solely based on Mechanisms 1 and 2 in Figure 1, and does not take into account the additional unmodelled benefits of Mechanisms 3 and 4.

---

[3] A $1.33/m^2 saving is determined on the basis of 28 c/kWh with an average daily saving of 13 Wh/m^2 (365x0.013x0.28). Example electricity rates for small to medium business can be found at:
http://www.originenergy.com.au/976/Energy-Price-Fact-Sheets?
http://www.qenergy.com.au/docs/default-document-library/ausgrid_price-fact-sheet_nsw_freedom-biz.pdf?
http://www.momentumenergy.com.au/system/files/documents/PPIS/01102012-PPIS-SmilePower-SME-NSW.pdf

Table 4: Cool roof Total R-Value required for equivalence to reference building

Zone	Location	Reference Roof	Cool Roof Internal Load	
			High	Mid Range
1	Darwin	4.2	0.50	0.93
2	Brisbane	4.2	0.50	0.95
3	Tenant Creek	4.2	1.00	1.56
4	Kalgoorlie–Boulder	4.2	0.50	2.12
5	Perth	4.2	0.53	2.06
6	Melbourne	3.2	0.74	3.12
7	Hobart	3.7	1.14	>3.7

Table 4 indicates that replacing the reference roof with a cool roof on the modelled building leads to the potential to:

- In all high internal load cases, reduce the total insulation requirement to under R1.5.
- For mid range internal loads,
  - in climate zones 1-5, reduce the total insulation requirement to around R1.5 to R2, and
  - for the cooler climates of zones 6 and 7 (Melbourne and Hobart), the cool roof does not substantially alter the insulation requirement[4].

The simulation results highlight that many retail buildings can reduce roof insulation levels when cool roofing is used, by using the verification method of BCA JV3, rather than using the prescriptive deemed to satisfy approach. The reduced insulation requirement has the potential to drive construction cost savings through thinner insulation and avoiding the need for roof raiser systems that are often used for commercial roofing to limit squashing of insulation between the roof and safety mesh. The construction cost savings attributable to being able to use thinner blanket and foil insulation is about $2/m^2 for a 25mm reduction (≈R0.5 reduction) in thickness (Cordell, 2012). The removal of the need for a roof raiser system has the potential to save significantly more than the insulation saving (>$10/m^2)[5].

4.3 Relative performance of bare metal roofing

Bare metal roofing, which is often used for commercial roofing, was modelled to understand its relative performance. The results of this study have shown that the heating and cooling energy load of the building with a bare metal roof lies typically between the cool roof and the reference roof, although closer to the reference roof for the warmer climate zones and high internal loads (Figure 3). The exceptions are for the cooler climates of Melbourne and Hobart with mid range internal load.

---

[4] Had the model been capable of incorporating the benefit created by cool roofs, as discussed in Section 2, a reduced insulation requirement may have also been achieved for these cooler climates.

[5] Cost estimate from unpublished industry survey.

The insulation required using a bare metal roof to provide equivalent performance to the reference building in accordance with BCA Section JV3 is provided in Table 5. These results show that the ability to significantly reduce insulation using a bare metal roof is likely to be quite limited. Further, bare metallic coated steel is known to weather more than pre-painted steel (Cool Roof Rating Council, 2012) leading to poorer relative long term performance of the bare metal roof than considered here.

Table 5: Bare metal roof Total R-Value required for equivalence to reference building

Zone	Location	Reference Roof	Cool Roof	
			Internal Load	
			High	Mid Range
1	Darwin	4.2	3.77	3.43
2	Brisbane	4.2	2.13	2.88
3	Tenant Creek	4.2	3.60	3.68
4	Kalgoorlie–Boulder	4.2	3.18	3.53
5	Perth	4.2	1.93	3.12
6	Melbourne	3.2	2.05	2.81
7	Hobart	3.7	2.61	3.43

5. Conclusion

This case study has modelled the impact of cool roofing on heating and cooling a retail building with different levels of insulation and internal load, based on the two first two mechanisms for cool roof performance articulated in Figure 1. The results demonstrate the value of the two distinct design philosophies aimed at creating energy efficiency improvements or construction cost benefits of using cool roofing for a retail building.

The results show that, for the building modelled, a cool roof increases the energy efficiency of the building. Noting that the additional benefits of Mechanisms 3 and 4 are not included, for the retail building considered an operational saving of up to $1.33/m^2/year was determined on the basis of a solar absorptance change of 0.42. The operational financial savings provided economic payback of the extra cost of cool roofing products.

The alternative approach in this paper has shown that in most climates of Australia for the retail building considered, a cool roof can allow thinner roof insulation creating reduced need for roof raisers, potentially providing a lower total construction cost. Where the retail building also has high internal loads, in some climates, both reduced insulation was possible with an increase in energy efficiency thereby also delivering operational savings.

The case study has highlighted the importance of the relationship between internal loads in buildings and insulation, particularly for cool roofs. For high internal loads in the retail building studied, for some climates, there was an optimal insulation level beyond which additional insulation increased energy loads for cool roofing.

This paper has considered the savings attributable to cool roofing from models rather than real building studies, and notes the reasons that modelling often under predicts the observed benefits. This risks underselling the appreciable benefits of cool roofs and the benefits to the carbon footprint and energy efficiency they can deliver to the built environment. Further investigation is required to address these inadequacies and ensure that models more accurately account for the full range of benefits. The final set of benefits around the mitigation of urban heat island at a precinct level needs additional quantification, though this is more readily dealt with in precinct models rather than individual building models.

References

Akbari H and Levinson R (2008) *Evolution of Cool-Roof Standards in the US,* Advances in Building Energy Research, **2**: 1-32

Akbari H, Levinson R and Rainer L (2004) *Monitoring the energy-use effects of cool roofs on California commercial buildings*, Energy and Buildings, Vol. 37, pp1007-1016.

Australian Building Codes Board (2012) *National Construction Code, Building Code of Australia, Volume 1*, Australian Building Codes Board, Canberra, ACT.

Barkaszi S and Parker DS (1995) *Florida Exterior Wall Insulation Field Test: Final Report*, FSEC-CR-868-95, Florida Solar Energy Center (available online http://www.fsec.ucf.edu/en/publications/html/FSEC-CR-868-95/index.htm accessed Oct 2012]).

Bhatia A, Mathur J and Garg V (2011) *Calibrated simulation for estimating energy savings by the use of cool roof in five Indian climatic zones*, J. Renewable Sustainable Energy 3, 023108.

Carter TG (2011) *Issues and solutions to more realistically simulate conventional and cool roofs*, 12th Conference of International Building Performance Simulation Association, 14-16 November 2011, Sydney, Australia.

Chasar D (2005) *Metal Roof Retrofit on a Hurricane Damaged Home*, Building America Partnership for Improved Residential Construction (available online http://www.ba-pirc.org/casestud/hdh_roof/index.htm accessed Oct 2012]).

Cool Roof Rating Council (2012) *Product directory of properties for new and exposed samples* (available online - http://www.coolroofs.org/products/search.php accessed Oct 2012)

Cordell (2012) *Cordell's building cost guide. Commercial and industrial. New South Wales,* Cordell Building Publications, NSW.

Gentle AR, Aguilar JLC and Smith GB (2011) *Optimized cool roofs: Integrating albedo and thermal emittance with R-value*, Solar Energy Materials & Solar Cells 95.

Green Building Council of Australia (2009) *Green Star - Retail Centre v1 Energy Calculator Guide*, Green Building Council of Australia (available online http://www.gbca.org.au/uploads/221/1757/Green Star - Retail Centre v1 Energy Calculator Guide (2009)_170409.pdf accessed Oct 2012]).

Johnson D (1997) *When Wall Insulation Doesn't Save*, Home Energy Magazine Online May/June 1997 (available online http://www.homeenergy.org/show/article/nav/walls/page/4/id/1293 accessed Oct 2012]).

LEEDuser (2012) *NC-v2.2 SSc7.2: Heat Island Effect—Roof* (available online http://www.leeduser.com/credit/NC-v2.2/SSc7.2 [accessed Oct 2012])

Masoso OT and Grobler L (2008) *A new and innovative look at anti-insulation behaviour in building energy*, Energy and Buildings 40 pp1889–1894.

Parker D, Huang Y, Konopacki S, Gartland L, Sherwin J and Gu L (1998) *Measured and Simulated Performance of Reflective Roofing Systems in Residential Buildings*, *ASHRAE Transactions*, Vol. 104.

Parker D, Sonne J and Sherwin J (2002) *Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida*, Proceeding of ACEEE 2002 Summer Study, American Council for an Energy Efficient Economy.

The Centre for International Economics (2009) *Proposal to revise energy efficiency requirements of the Building Code of Australia for commercial buildings (Class 3 and 5 to 9 buildings)*, The Centre for International Economics, Canberra, ACT.

US EPA (2005) *Increase Insulation: Building Envelope Improvements, EnergyStar Fact Sheet,* US Environment Protection Agency and Department of Energy (available online http://www.energystar.gov/ia/home_improvement/home_sealing/IncreaseInsulationFS_2005.pdf accessed Oct 2012]).

US EPA (2012) *Cool Roofs* Environment Protection Agency (available online http://www.epa.gov/hiri/mitigation/coolroofs.htm accessed Oct 2012]).

VanCuren, R. (2012) *The radiative forcing benefits of "cool roof" construction in California: quantifying the climate impacts of building albedo modification,* Climatic Change, **112**:1071–1083