INDUSTRIAL
ROOF
COATINGS

# THERMOBOND

## Heat Reflective Coating

## REPORT

# THERMOBOND HRC
Heat Reflective Coating
# REPORT

## Product Information – Thermobond HRC Heat Reflective Coating

**American ASTM Test Methods and comments from PositivEnergy Commission.**

On September 15th, 2003, PRI Asphalt Technologies Inc. of 6408 Badger Drive, Tampa, Florida, conducted tests on four samples of **Thermobond HRC,** comprising 2 White and 2 Beige samples. The objective was to ascertain these samples' solar reflectance and emittance properties. The test samples were provided by Uni-Glaze, located at 17927 Ida Drive, Los Gatos, California, which serves as the primary distributor of **Thermobond HRC** in the United States of America. The comprehensive test results are appended herewith. Below is a concise overview of the findings: -

The tests were executed in compliance with ASTM C 1549, the standard test method for determining Solar Reflectance, and ASTM C 1371, the standard test method for determining Infrared Emittance. Both methodologies are officially recognised by the Cool Roof Rating Council (CRRC) as accepted means of determining these crucial properties.

**Solar Reflectance** quantifies the amount of visible light and heat reflected by a surface. Typically, a high-quality white commercial paint would yield a reflectance rate of approximately 82-84%, with some white coatings exhibiting values as low as 70% or even lower. Notably, the result of 88% for white **Thermobond HRC** stands as an exceptional achievement. Similarly, the solar reflectance outcomes for the beige samples were commendable, registering at 79.5%.

**Emittance** measures a material's capacity to emit heat in the form of Infrared radiation. An exceedingly high emittance rating would reach 0.90 or 90%, while a low emittance rating would hover around 0.06 or 6%. Once more, the emittance results for both white and beige Thermobond HRC, at 0.88 or 88%, are outstanding.

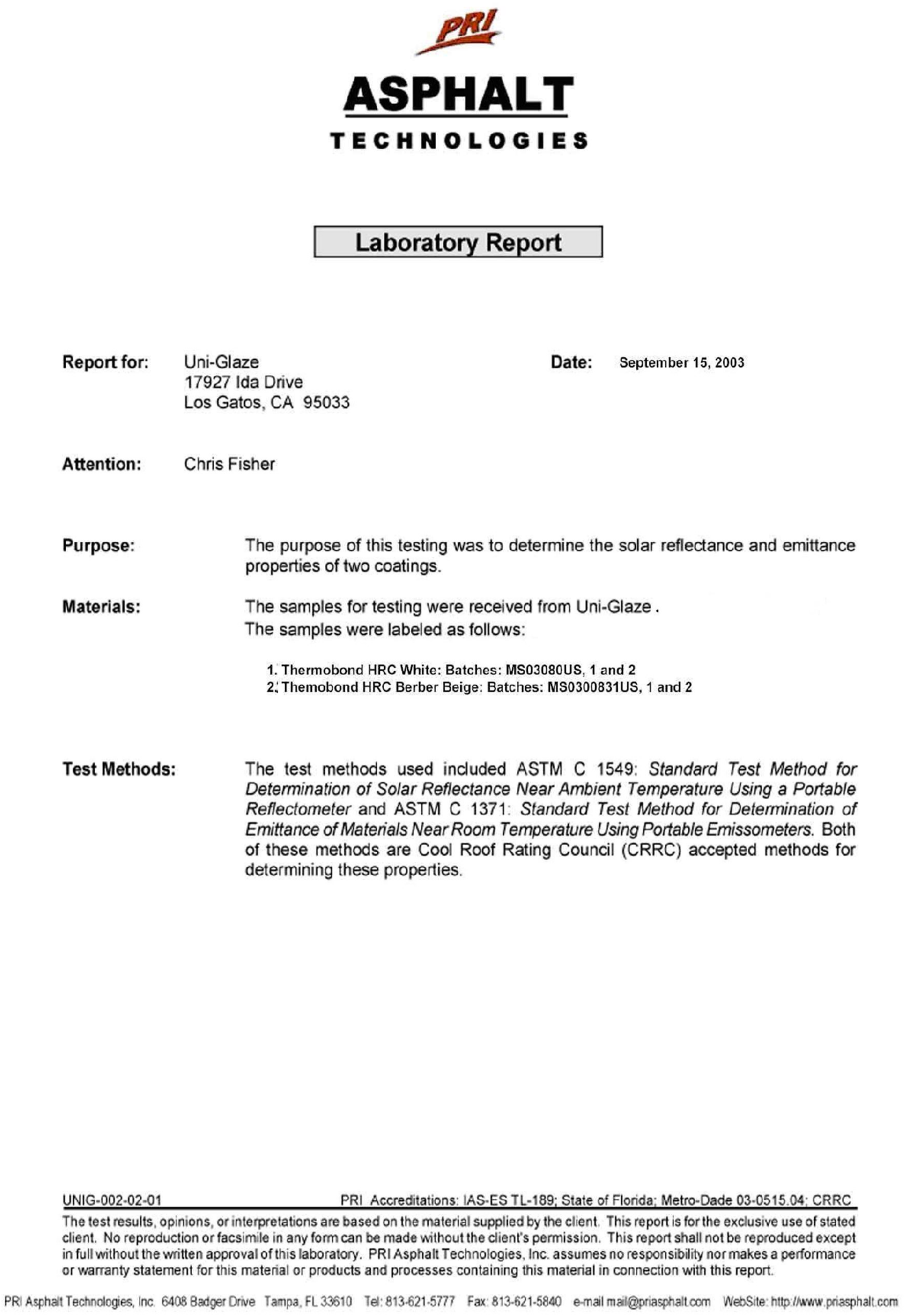
**Solar Reflective Index (SRI)** represents the real measure for assessing a coating's performance as a heat-reflecting system. This innovative system was pioneered by Dr. Paul Berdahl of the Lawrence Berkeley Institute at the University of California. The SRI takes into account the product's solar reflectivity, its infrared emittance, and any resultant temperature fluctuations.

Calculated according to ASTM E 1980 (Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces), it provides a relative value compared to a standard black-and-white surface. The standard black surface is presumed to possess a solar reflectance of 5% and thermal emittance of 90%, while the standard white surface boasts a solar reflectance of 80% and thermal emittance of 90%.

Dr Lisa Gartland, Director of Positive Energy in Oakland, California, wrote in her email of September 18th, 2003, that…
*".… Your white product performs better than the standard white surface, so it has an SRI value higher than 100. Your brown* (beige) *products also perform very well.…"* Dr Gartland calculated the SRI for our white Thermobond HRC to be 110.5 and the beige to be 98.9.

Dr Gartland also stated that *"… The State of California is considering defining a cool roof as one with a solar reflectance of 70% or higher and a thermal emittanceof 75% or higher, for an SRI of 82.5 or higher.…"*

It is worth noting that Thermobond HRC, available in both white and beige variants, significantly surpasses the prerequisites for an effective heat-reflective coating.



PRI

**ASPHALT**
**TECHNOLOGIES**

## Laboratory Report

**Report for:** Uni-Glaze
17927 Ida Drive
Los Gatos, CA 95033

**Date:** September 15, 2003

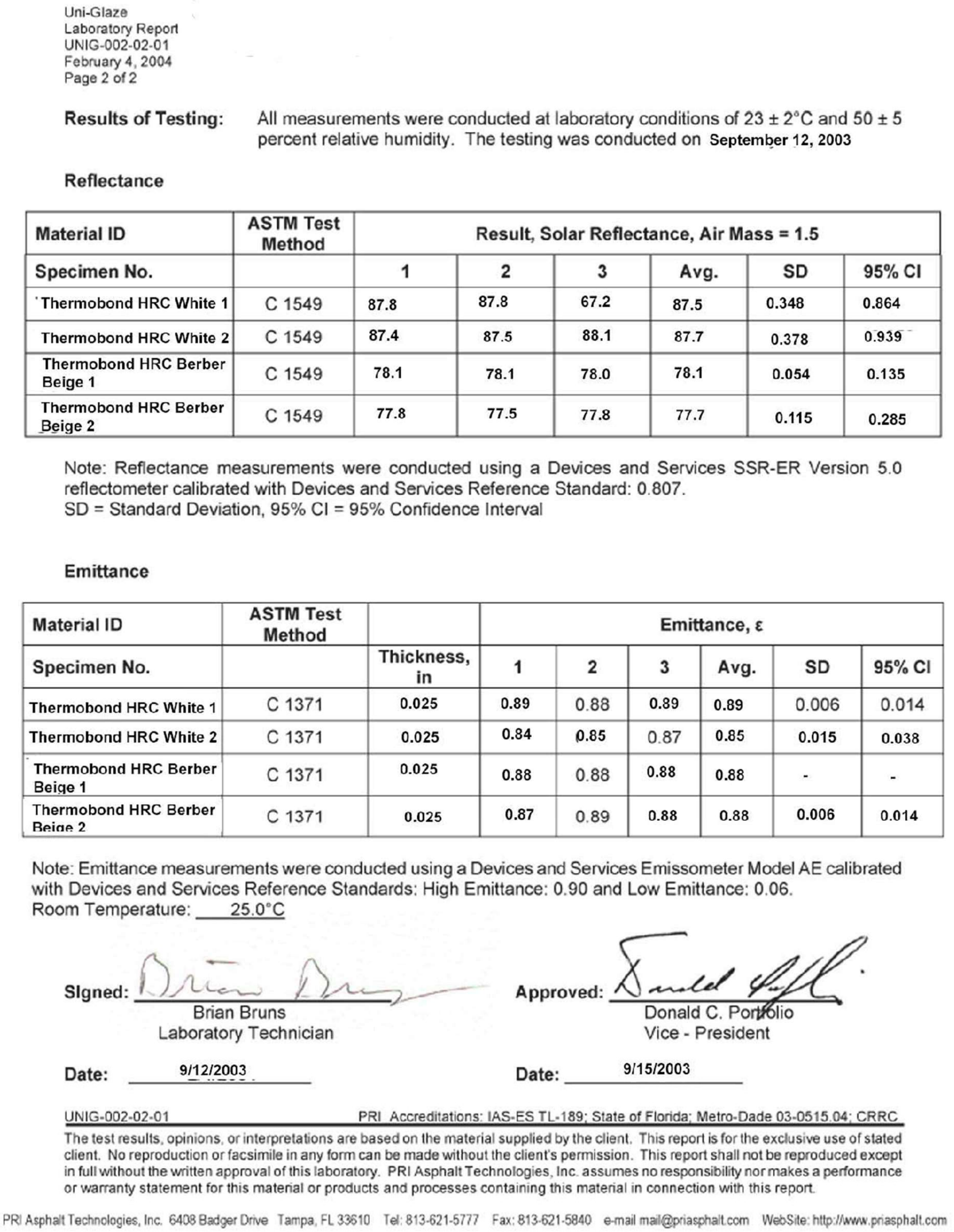
**Attention:** Chris Fisher

**Purpose:** The purpose of this testing was to determine the solar reflectance and emittance properties of two coatings.

**Materials:** The samples for testing were received from Uni-Glaze .
The samples were labeled as follows:

1. Thermobond HRC White: Batches: MS03080US, 1 and 2
2. Themobond HRC Berber Beige: Batches: MS0300831US, 1 and 2

**Test Methods:** The test methods used included ASTM C 1549: *Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Reflectometer* and ASTM C 1371: *Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers.* Both of these methods are Cool Roof Rating Council (CRRC) accepted methods for determining these properties.



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**Results of Testing:** All measurements were conducted at laboratory conditions of 23 ± 2°C and 50 ± 5 percent relative humidity. The testing was conducted on September 12, 2003

**Reflectance**

| Material ID | ASTM Test Method | Result, Solar Reflectance, Air Mass = 1.5 | | | | | |
|---|---|---|---|---|---|---|---|
| **Specimen No.** | | **1** | **2** | **3** | **Avg.** | **SD** | **95% CI** |
| Thermobond HRC White 1 | C 1549 | 87.8 | 87.8 | 67.2 | 87.5 | 0.348 | 0.864 |
| Thermobond HRC White 2 | C 1549 | 87.4 | 87.5 | 88.1 | 87.7 | 0.378 | 0.939 |
| Thermobond HRC Berber Beige 1 | C 1549 | 78.1 | 78.1 | 78.0 | 78.1 | 0.054 | 0.135 |
| Thermobond HRC Berber Beige 2 | C 1549 | 77.8 | 77.5 | 77.8 | 77.7 | 0.115 | 0.285 |

Note: Reflectance measurements were conducted using a Devices and Services SSR-ER Version 5.0 reflectometer calibrated with Devices and Services Reference Standard: 0.807.
SD = Standard Deviation, 95% CI = 95% Confidence Interval

**Emittance**

| Material ID | ASTM Test Method | | Emittance, ε | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Specimen No.** | | **Thickness, in** | **1** | **2** | **3** | **Avg.** | **SD** | **95% CI** |
| Thermobond HRC White 1 | C 1371 | 0.025 | 0.89 | 0.88 | 0.89 | 0.89 | 0.006 | 0.014 |
| Thermobond HRC White 2 | C 1371 | 0.025 | 0.84 | 0.85 | 0.87 | 0.85 | 0.015 | 0.038 |
| Thermobond HRC Berber Beige 1 | C 1371 | 0.025 | 0.88 | 0.88 | 0.88 | 0.88 | - | - |
| Thermobond HRC Berber Beige 2 | C 1371 | 0.025 | 0.87 | 0.89 | 0.88 | 0.88 | 0.006 | 0.014 |

Note: Emittance measurements were conducted using a Devices and Services Emissometer Model AE calibrated with Devices and Services Reference Standards: High Emittance: 0.90 and Low Emittance: 0.06.
Room Temperature: 25.0°C

Signed: Brian Bruns
Brian Bruns
Laboratory Technician

Approved:
Donald C. Portfolio
Vice - President

Date: 9/12/2003

Date: 9/15/2003

UNIG-002-02-01 PRI Accreditations: IAS-ES TL-189; State of Florida; Metro-Dade 03-0515.04; CRRC

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## ‘Cool Roofs’ Project Queensland - Phase One Report

# PHASE ONE REPORT:

# DESKTOP LITERATURE REVIEW

# AND

# RECOMMENDATIONS FOR FIELD TRIAL METHODOLOGY

Prepared by
Dr Wendy Miller, Senior Research Fellow Glenn Crompton, Research Associate

School of Chemistry, Physics and Mechanical Engineering Science and Engineering Faculty
Queensland University of Technology Brisbane Queensland Australia

## Executive Summary

This report represents Phase 1 of the ‘cool roof’ Activity Agreement between Queensland University of Technology, Ergon Energy Corporation Limited, StrongGuard and SmartGrid.

The purpose of Phase 1 was to: -

1. collect and collate existing (quality) literature on ‘Cool Roof’ coatings with an emphasis on energy impacts,
2. identify gaps in current research, and
3. make recommendations as to the scope and nature of the field trial.

### Report Structure

The first part of this report provides an overview of published academic and industry research reports relating to cool roofs in four key areas:

a) product chemistry and standards
b) product performance over time
c) product impact, especially in terms of cooling energy savings (kWh) and cooling demand savings (kW)
d) product inclusion in building regulations.

It concludes with a summary of key gaps in the research literature.

The second part of this report outlines the research methodology for the field testing of ‘Cool Roof’ coatings in a tropical environment in Australia and the quantification of possible benefits for the electricity network in this particular region. This framework utilises the experiences of researchers recorded in the literature and follows internationally accepted measurement and verification protocols.

### 'Cool Roof' Parameters

In the context of this project, a ‘‘Cool Roof’ ' is defined as a roof that, owing to its optical and infrared characteristics, typically conferred by specialised coatings, maintains a temperature at or near ambient levels during sunny conditions. Specialised roof coatings are discerned by their solar Reflectance, thermal emittance, and/or solar reflectance index (a composite of the two). On an international scale, the precise stipulations for the minimum requirements of these parameters necessary to classify a roof as 'cool' are contingent upon regional regulatory mandates or market-driven energy efficiency initiatives.

These criteria, in turn, seem to be rooted in the local climate conditions (e.g., the need for space cooling), the architectural characteristics of buildings within the region (e.g., the energy efficiency of building envelopes and construction types), and the desired objectives (e.g., the extent of desired reductions in cooling demand and/or peak demand, improvement in internal comfort levels in non-air-conditioned spaces, or mitigation of the urban heat island effect).

## Benefits of Cool Roofs – International Studies

‘Cool Roofs’ are reported to have various advantages, encompassing reduced energy consumption and peak demand, monetary savings, enhanced thermal comfort in and around buildings, prolonged roof lifespan, and improved urban environmental quality. The indicative energy benefits for diverse building types in the United States are presented in Table 1 below, utilising correct temperature units.

## Table 1: Indicative Energy Benefits for a range of building types in the US

| Location | Building Type | Reduction in cooling energy (kWh) | Reduction in peak demand |
|---|---|---|---|
| Florida, California, Texas, Sacramento | Retail | 2-52%<br>(A Californian estimate of 6-15 kWh/m2 of conditioned area/year; for a particular retail building type) | 0.65W – 3.8W/m2<br>(A Californian estimate for a particular retail building type of 2.9-5.8 W/m2 (12:00 – 17:00)) |
| California | Cold storage facility (group of 4 buildings) | 3-4% (summer)<br>4.5 – 7.4 kWh/m2 of conditioned area/year | 3.9- 6.6 W/m2 (12:00 – 17:00) |
| California, Mississippi | Commercial (offices) | 12-26% | |
| Florida | Residential | 19% average | 135W/$m^2$ |
| Florida California | Schools | 17-25% (summer)<br>3-6 kWh/$m^2$ of conditioned area/year | 6.0W/$m^2$<br>2.6-3.8 W/$m^2$ (12:00 – 17:00) |

Additional benefits, beyond the reduction in cooling energy and peak demand, have also been reported. As an example, changing the solar Reflectance of residential roofs from a typical dark roof (solar Reflectance <0.2) to a high-performance ‘Cool Roof’ (solar Reflectance>0.7) has resulted in:

Significant reduction in roof surface, under-surface, and roof cavity temperatures. Post-coating temperatures are much closer to ambient air temperature.

- Reduction in maximum internal air temperatures
- Changes in air-conditioner load profile and coefficient of performance (COP)
- Reduction or elimination of low air-conditioning use during shoulder seasons (average air temperatures 21 – 25oC)
- Shifts in average time of daily peak energy use.
- Higher peak energy savings on hot summer days (>30oC) compared with average summer days.

Results from a Florida field study of residential houses is of particular interest to Queensland because of similarities in summer climate (high temperatures and relative humidity), similar roofing materials (tiles and metal) and the high incidence of existing homes (43%), which have no insulation. Simulated energy savings for residential dwellings for various warm climates are shown in Table 2.

For buildings with roof-mounted air-conditioners (e.g., retail buildings), the efficiency of the air-conditioners (COP) improves due to the reduced air temperature above the ‘Cool Roof’.

## Table 2: Simulated residential cooling load reductions for selected cities, with thermostat setpoint of 26°C

| | | Cooling load (kWh/m2) | % decrease in cooling load between base case and (SR = 0.6 and 0.85) |
|---|---|---|---|
| Location | Latitude | Base case (SR = 0.2) | |
| Mexico City | 19.19 | 9.0 | 75 - 93 |
| Abu Dhabi | 24.3 | 265.4 | 11 - 18 |
| Riyadh | 24.5 | 179.1 | 14 - 22 |
| Miami | 25.59 | 117.7 | 22 - 35 |
| Johannesburg | -26.17 | 38 | 43 - 65 |
| New Delhi | 28.16 | 158.9 | 14 - 23 |
| Sydney | -33.46 | 37.7 | 35 - 55 |

There is an increasing body of work that seeks to establish the benefits of ‘Cool Roof’ coatings at an urban scale through the reduction in the average albedo of urban environments. This is modelled to decrease the urban heat island effect, possibly resulting in a 2-3% reduction in utility summer load for each degree decrease in urban air temperature.

‘Cool roofs’ are mandated in the California building regulations for all building types in all climate zones. This is a major part of their energy efficiency and climate change initiatives.

## Benefits of 'Cool Roofs' - Australian Studies

For almost 20 years, Thermobond HRC has been used as a solution for heat and electricity cost reduction throughout Australia on numerous building types, such as shopping centres, universities, schools and air-conditioned warehouses. Thermobond can be applied to anything that would benefit from reduced temperatures because of direct sunlight.

Thermobond HRC operates on three levels: solar reflectivity, very high heat emissivity and membrane thickness. This means Thermobond HRC does not allow the passage of heat from the sun to reach the substrate it has been installed on.

The benefits outlined by the limited number of Australian studies include:

- Sydney: peak cooling loads could be reduced by factors of 2.5% – 3.5% by increasing the Solar Reflectance of existing residential roofs, regardless of total roof insulation levels.
- Melbourne: reduction in the temperature of roof surface, attic space and internal spaces. Cool roof coatings would have the greatest benefit for modern houses with unvented roof spaces and ceiling insulation, and for older, poorly insulated homes. A 3% reduction in cooling load is indicated for commercial buildings and a 17% improvement in internal thermal comfort conditions for un-conditioned industrial buildings.
- Adelaide: 23% reduction in median daily maximum power demand; internal temperatures more moderate and divergent from external ambient temperature; overall cooling energy consumption reduction of 21.3%; peak reduction 15.2% and off-peak reduction 26.2%.

## Key Variables

These benefits, however, cannot be assumed to apply to other climatic and cultural contexts. There are key variables that impact the extent of measurable energy benefits attributable to 'Cool Roof' coatings:

- Climate: solar radiation (including UV), rainfall, wind speed, atmospheric pollution
- Roof: material, profile, pitch, surface roughness, surface coating thickness, solar reflectance and thermal emittance
- Building: type, form, materials, thermal efficiency, insulation levels, the ratio of the roof-to-wall area
- Building occupancy
- Cooling equipment: efficiency, air duct location, sizing, thermostat setting
- Electricity: peak demand time, electricity prices
- Urban density and extent of urban heat island effect

### Research Gaps

There is no published literature on field studies in Queensland quantifying the effects (including thermal comfort and energy consumption and demand) of 'Cool Roof' coatings on different building typologies.

No literature exists on the possible impact of atmospheric and environmental pollution levels on long-term solar Reflectance of roof coatings in tropical and subtropical Australia (i.e., there have been no long-term ageing studies for roof coatings and typical roof structures in Queensland). This is outside the scope of the proposed field trial but should be considered a complementary project.

### Field Trial Methodology

The field trial aims to validate the energy (kWh) and demand (kW) reduction performance of 'Cool Roof' coatings for various building typologies in Queensland. The methodology is consistent with the International Performance Measurement and Verification Protocol and published scientific methodologies. A range of building types will be monitored during the field trial: residential (two detached houses in Townsville and Four townhouses in Moranbah); educational (one building at James Cook University, Townsville and One administrative building and one dining hall at Cathedral School in Townsville) and retail (one shopping centre in Brisbane). An 'experiment and control' methodology will be used for the townhouses, whilst all other buildings will use historical data for trial comparisons.

Historical and field study data (temperature, energy, environmental, building, occupant) will be analysed. Computer simulation tools (BersPro 4.1 and IES) will be utilised to model the coatings' effects.

## Purpose Of Review

This desktop review represents Phase 1 of the 'Cool Roof' Activity Agreement between Queensland University of Technology, Ergon Energy Corporation Limited, StrongGuard and SmartGrid.

To ensure the quality and credibility of information on claims of energy savings resulting from 'Cool Roof' coatings, peer-reviewed research papers were searched on the topic and published in high-ranking research journals. Over fifty articles were identified as relevant to this review's purpose.

Several thesis and industry reports have been added to this collection. Industry association websites and manufacturers' websites have not been included in this review, although they may obtain helpful information to the reader. The Cool Roofs Rating Council (www.coolroofs.org) is particularly worth mentioning.

## Definitions

Before we begin with the literature, it is crucial to ensure that all readers share a common understanding of the key terminology that will be used throughout this report.

| | |
|---|---|
| Albedo | The fraction of incident short-wave (visible and infrared) radiation reflected from a surface averaged across the entire incident spectrum.<br>(Compare with solar Reflectance). |
| Convection coefficient | A measure of the quantity of heat transferred through convection. |
| Solar Absorptance ($A_{sol}$) | The ratio of the solar radiation absorbed by the surface compared with that absorbed by a black body (a perfectly absorbing body) at the same temperature. For example, white paint has a typical absorptance of 0.3, black paint 0.9, oxidised galvanised iron 0.8 [2]. Some of the heat a roof absorbs will be transferred into the building (Figure 1). |
| Solar Reflectance ($R_{sol}$) | The fraction of solar radiation (0.3 – 2.5 microns) from a single incidence angle that a surface reflects. Sunlight that is not reflected is absorbed as heat. Solar Reflectance is measured on a scale of 0 to 1.For example, a surface that reflects 55% of sunlight has a solar reflectance of 0.55. Most dark roof materials reflect 5 to 20% of incoming sunlight, while light-coloured roof materials typically reflect 55% to 90% [3]. Refer to Figure 1. |
| Solar Reflectance Index (SRI) | A calculation based on the combination of solar Reflectance and thermal emittance values. The higher the SRI, the cooler the roof will be in the sun. For example, a clean black roof could have an SRI of 0, while a clean white roof could have an SRI of 100. Dark roofs usually have an SRI of less than 20 [3]. Calculation of the SRI is defined in the ASTM E1980 Standard Test Method (2001). |
| Thermal Conductance | The heat transfer from an interior surface to an exterior surface. It is similar to thermal transmittance but calculated from the surface temperature as opposed to the internal or external air films. |
| Thermal Emittance (TE) | The fraction of heat that is re-radiated from a material to its surroundings. Thermal emittance describes how efficiently a surface cools itself by emitting thermal (infrared) radiation (4-80 microns). Thermal emittance is measured on a scale of 0 to 1, where a value of 1 indicates a perfectly efficient emitter. [3] For example, white paint has a typical emittance of 0.9, black paint of 0.85, oxidised galvanised iron 0.28 [2].<br>1. White paint: Typically has a thermal emittance value close to 0.9 or even higher. White surfaces are efficient emitters of thermal radiation, which helps them cool down by radiating heat effectively.<br>2. Black paint: Typically has a lower thermal emittance compared to white surfaces. Depending on the specific type of black paint, it may have a thermal emittance value closer to 0.85 or lower.<br>These values can vary somewhat depending on the specific formulation of the paint or coating. Still, white surfaces are generally more efficient at emitting thermal radiation than black surfaces, which is why they tend to have higher thermal emittance values. Refer to Figures 1 and 2. |

| | |
|---|---|
| Thermal Resistance<br>(R-value) | The resistance to heat flow between two surfaces at different temperatures [2]. The R-value is typically used to rate insulation materials or building envelope properties, indicating how resistive the material/wall/roof is to the flow of heat. For example, ceiling insulation with a high R-value (e.g., R4) will have a higher resistance to heat transfer from the roof cavity into internal spaces compared to insulation with a low R-value (e.g., R1). |
| Thermal Transmittance<br>(U value) | The reciprocal of thermal resistance. Calculated as the rate of heat transmission from the internal air film adjacent to an interior surface to the external air film of an exterior surface [4]. |

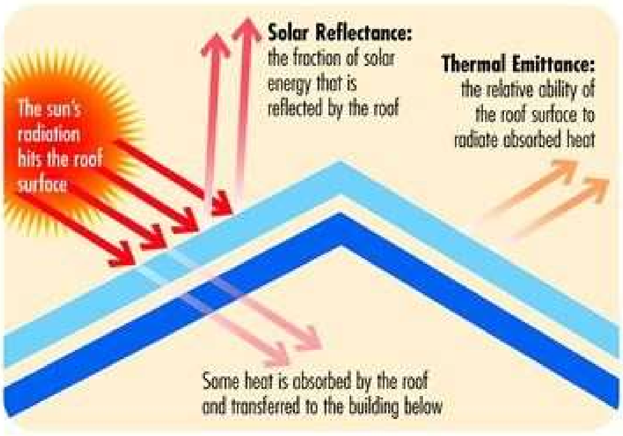


FIGURE 1: SIMPLISTIC VIEW OF EFFECT OF SOLAR RADIATION ON A ROOF SURFACE (SOURCE: 'COOL ROOF' RATING COUNCIL)

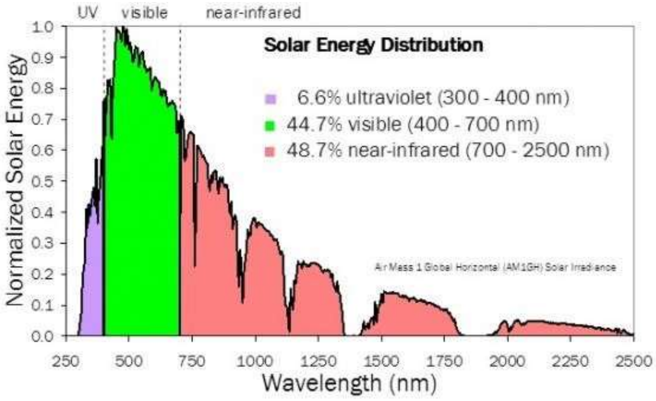


FIGURE 2: SOLAR ENERGY DISTRIBUTION (SOURCE: LAWRENCE BERKLEY LABORATORIES)

## Introduction To 'Cool Roofs'

In this project, a cool roof is defined as a roof that, because of its optical and infrared properties, usually imparted by special coatings, remains at or near ambient temperature under sunny conditions. Special roof coatings are identified by their Solar Reflectance and Thermal emittance. A combination of these two factors is used to calculate a surface's solar reflectance index. A third key attribute is a cool roof's ability to maintain the high reflectance and emittance characteristics over the product lifespan.

Cool Roofs are reported to have multiple benefits, including reductions in energy consumption and peak demand, monetary savings, increased thermal comfort in and around buildings, extended roof life, and enhanced urban environmental quality. The extent of these benefits, however, is reported to vary with climate and season, building type and materials, electricity pricing, heating and cooling equipment utilised, and building occupancy.

This report has two main functions. First, this report provides an overview of what published academic and industry research reports say about cool roofs. Second, this report outlines the research framework to field test cool roof coatings in a tropical environment in Australia and quantify their benefits for this particular climate zone. This framework utilises the experiences of researchers recorded in the literature and follows internationally accepted measurement and verification protocols.

## Literature Findings

The literature reviewed falls broadly into four main categories: product chemistry and standards, product performance over time, product impact, and product regulation. Each of these categories impacts energy savings potential. Key findings are therefore presented in the following pages under these key headings.

## 'Cool Roofs' Physics and Chemistry

Because of its large surface area and exposure to solar radiation, the roof is the key building structure that allows or controls heat flow into internal spaces. Limiting the roof temperature is essential to limiting overall heat transfer and allowing any insulation installed in the roof space to perform effectively. The R-value, i.e., the thermal conductivity of insulation, is defined at (and measured at) 24ºC. Still, it decreases with higher temperatures because the thermal conductivity of air increases with temperature, and the radiant transfer within insulation is higher with increases in temperature (e.g., 15% higher heat transfer with an increase of 17ºC) [5].

The reported value of cool roof coatings is on their role in limiting the flow of heat through the roof. The heat flow system through a roof is scientifically complex, but in essence, the energy balance of a roof is determined by four key elements: incoming solar energy, reflected solar energy, absorbed solar energy and heat transfer via radiation, convection, and conduction (Figure 3). In addition, heat flow through the roof is impacted by the roof structure (insulations, air spaces, etc.) and internal and external temperatures [6, 7].

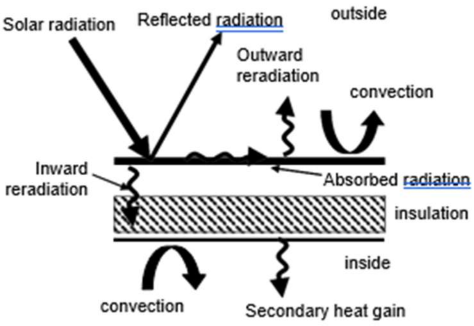


FIGURE 3: COMPONENTS OF HEAT TRANSFER FOR A ROOF [5]

Light-coloured roofing has been used in buildings in many hot regions of the world for a long time, providing a cooler internal space for human comfort. Modern 'cool roof' coatings use advanced chemistry to increase the external surface solar reflectance and infrared emittance (enhancing radiative cooling). Both reduce the temperature of the building exterior, which reduces heat flow through the building envelope to interior spaces.

Early chemistry analysis showed that the best surface cooling effects were gained from materials with high values in solar Reflectance, thermal emittance and convection coefficient but that the solar Reflectance was (and still is) dependent on materials, surface roughness and paint pigment impurities [8, 9].

Cool roofing technology 'aims to deliver products that keep buildings cool regardless of colour.' [10]. Enhanced chemistry has led to the development of non-white near-infrared- reflective (NIR) coatings that may satisfy aesthetic needs for roof coatings in colours other than white or light colours. Levinson et al conducted comparative studies of buildings with standard-coloured roofs and equivalent coloured NIR coatings [11], reporting absolute reductions in roof surface temperature, roof cavity temperature and ceiling heat-flux (heat transfer from the roof cavity through the ceiling to the internal space).

Table 1 shows the comparative solar reflectance values of various coloured paints and their 'cool roof' equivalents.

(These are indicative values only, as each specific product will have slightly varying values). Levinson's study also reported that roof-level wind speed also had an impact on reducing roof surface and roof cavity temperature; hence, projected energy savings from NIR coatings would be lower in areas with a high wind speed (possibly higher than 1.5 – 2m/s).

An Italian field tested on NIR cool coloured coatings, compared with colour-matched conventional pigment coatings [13], measured lower surface temperatures in summer (1.6 -10.2°C) for all NIR coatings (compared with their equivalent standard pigment). The surface temperature differences were attributed predominantly to differences in solar reflectance (between standard and NIR pigmented coatings) and decreased with lower solar radiation (i.e., the differences were less in cooler months).

Different authorities use different standards to define a 'cool roof' under regulatory and guideline requirements. Main USA standard definitions of 'cool roofs', in terms of Solar Reflectance Index (SRI), Solar Reflectance (SR) and Thermal Emissivity (TE), are shown in the table below:

INDICATIVE SOLAR REFLECTANCE OF STANDARD ROOF COLOURS AND NIR COATINGS

| Colour | Standard solar Reflectance | Reflectance of NIR coating [11] | Italian technical standards[12] |
|---|---|---|---|
| White | 0.75 | 0.90 | High reflectance 0.9 |
| Sand / Dune | 0.35 | 0.80 | Light colours 0.7 |
| Terracotta | 0.33 | 0.48 | Intermediate colours 0.4 |
| Gray | 0.21 | 0.44 | |
| Chocolate | 0.12 | 0.41 | Dark colours 0.1 |
| Dark Green | 0.17 | 0.46 | |
| Dark Blue | 0.19 | 0.44 | |
| Black | 0.04 | 0.41 | |

VARIATIONS IN QUANTIFICATION OF 'COOL ROOFS' IN DIFFERENT USA JURISDICTIONS [3]

| Roof type | California Energy Commission | | US Green Building Council LEED program | EnergyStar® |
|---|---|---|---|---|
| | SR + TE | SRI<br>(3yr aged) | SRI<br>(3yr aged) | SR only<br>(aged) |
| Low sloped ≤9.5° or2:12 | 0.55+ 0.75 | 64 | ≥78 | 0.5 |
| Steep sloped >9.5° or 2:12 | 0.20 + 0.75 | 16 | ≥29 | 0.15 |

This table shows four important points:

1. No exact definition exists for a 'cool roof': some variance exists between different regulatory zones.
2. Roofs can qualify as 'cool' by meeting or exceeding the minimum requirements for Rsol and/or TE or by meeting or exceeding the SRI requirements. This allows much flexibility regarding the relative thermal emittance and solar reflectance ratio.
3. Cool roof requirements are higher for low-sloped versus steep-sloped roofs because of solar radiation and heat transfer differences due to roof pitch.
4. The measured Rsol and TE are affected by aging (refer to the next section for more details). Therefore, it is important to know whether quoted performance figures refer to initial (new) materials or aged (typically three-year) materials. This information is shown on products certified by the Cool Roof Rating Council, the reference standard in the USA (Figure 4).

CRRC
COOL ROOF RATING COUNCIL ®

| | Initial | Weathered |
|---|---|---|
| **Solar Reflectance** | **0.00** | **Pending** |
| **Thermal Emittance** | **0.00** | **Pending** |

Rated Product ID Number ____
Licensed Seller ID Number ____
Classification Production Line

Cool Roof Rating Council ratings are determined for a fixed set of conditions, and may not be appropriate for determining seasonal energy performance. The actual effect of solar reflectance and thermal emittance on building performance may vary.

Manufacturer of product stipulates that these ratings were determined in accordance with the applicable Cool Roof Rating Council procedures.

FIGURE 4: PRODUCT LABEL - COOL ROOF RATING COUNCIL USA

## 'Cool Roof' Maintenance and Weatherisation

Long-term benefits of cool roofing products can be compromised if there is a loss in solar Reflectance in the first few years of service. Solar Reflectance can be affected by UV radiation, atmospheric pollution, microbial growths, acid rain, temperature cycling (sunlight and sudden storms), moisture penetration, condensation, wind, hail, and freezing [14]. Some of these effects may be temporary (e.g., surface accumulations that are soluble in rain and therefore wash off), whilst others may induce chemical changes in the roof material, resulting in permanent alteration of the albedo [15]. Berdahl, as reported by [16], indicates that the properties of the coating material itself can determine the ability of deposited soot to adhere to the roof, resisting washout by rain. It is also important to note that the albedo measurements between individual roofs will always vary, depending on substrate roughness and condition, the coating thickness, and the environmental variations mentioned above [15].

In the mid-1990s, Bretz et al. measured an average decrease in albedo of 15% in the first year, with a much slower rate of decline in subsequent years. To account for this decline, the cooling effects modelling incorporated a 20% degradation factor after the first year [15]. The most recent publication on weatherisation studied the long-term effects of environmental exposure at seven California sites [14]. White-painted samples showed a 4-23% loss in solar Reflectance over the first year, with the worst performance in desert-like areas (higher dust environment and less rainfall for self-cleaning).

After an additional eight months of weathering, samples across all sites regained most of their solar Reflectance (average SR loss 6% from starting value) due to a combination of rainfall and wind, or wind only. Darker-coloured samples did not show the same seasonal variation as lighter colours because their solar Reflectance is half that of white-painted materials, and dust particles tend to lighten darker pigments, slightly increasing their solar Reflectance. The degradation in solar Reflectance in the cool coatings was no more than that observed in the similarly coloured standard coatings (i.e., cool roof coatings did not perform worse than standard roof coatings).

The Roof slope was shown to be important in some environments and for roofs with an initial solar reflectance exceeding 0.50. Evidence appears to suggest that in areas of high environmental soiling (e.g., dry, dusty environments or urban/industrial environments), a higher roof slope (over 18 degrees or more) may assist with self-cleaning (through rain and or wind). Overall, the study suggests that reflectance changes are cyclic with the onset of wet seasons. Key environmental contaminants included road dust, soil, rock debris (calcium, aluminium, silicon, potassium, titanium, iron, barium), sulphur (e.g., from coal power plant), and anthropogenic elements. (vanadium, chromium, nickel, zinc, lead); organic compounds; and elemental carbons (e.g., soot and vehicle exhaust).

A more recent assessment of the long-term solar reflectance performance of cool roof coatings was conducted on commonly used roof coverings in Turkey [17]. This study, measuring only the aging effects of UV radiation, reports no significant degradation in performance after one year for tiles (clay, ceramic, and concrete) and bituminous shingles.

In the Queensland context, the evaluation of energy savings would need to consider the relative atmospheric/environmental pollution levels that could adversely impact the solar Reflectance and, hence, estimated energy savings.

## 'Cool Roofs' Impacts – Simulated and Measured

For more than two decades, researchers have conducted extensive investigations into the effects of reflective roof coatings on the urban environment, building occupants, and electricity networks. These studies have involved a combination of modelling exercises and field experiments. It is imperative to take into account the advancements in roof coating chemistry that have occurred from the 1990s to the present day when analysing early field findings associated with white reflective paints.

One of the earliest field trials (1991,1992, California) involved a house and two school bungalows, measuring building characteristics, electricity and microclimatic conditions before and after changing the roof coating [18]. (School buildings were measured during occupied and unoccupied periods). Cooling energy savings accruable over a summer season were estimated by correlating air conditioner use with daily average temperatures. At the school, cooling energy use savings of 40-50% were measured (depending on the previous roof type), with a reduction in peak cooling power in the order of 0.6kW. Overall energy savings for cooling during an entire summer were estimated at 23% (assuming air-conditioning only during school days and a cooling setpoint of 25.5ºC).

Changing the albedo of the house roof from 0.18 to 0.73 resulted in cooling energy savings amounting to 2.2 kilowatt-hours per day, along with a reduction of 0.6 kilowatts in peak cooling demand. The study also revealed that the previously observed low air-conditioning usage during "shoulder seasons," characterised by average air temperatures between 21.6oC and 25oC, was eliminated. Furthermore, cooling energy savings of up to 80% were estimated for the hottest months. A notable finding was that the simulation tool used for modelling the buildings, specifically the DOR-2.1E building energy program, underestimated peak power savings. Field measurements indicated higher energy savings, shifts in the average time of the daily peak energy usage, and evidence suggesting that peak cooling energy savings could be even higher (10-20%) on scorching summer days with daily averages exceeding 30oC compared to the peak savings on typical summer days with averages between 21.6oC and 25oC.

Another field test around the same period involved nine residential buildings in Florida [5], increasing the roof reflectivity on average from 0.20 to 0.66. The homes indicated a range of roof construction types and materials and homes with and without insulation.

Infrared thermography was utilised to help understand the effect of roof coatings on heat gains through the roof structure. Local meteorological conditions, interior and building temperatures, and air conditioner use were monitored for three weeks before and after roof coatings. Roof surface temperatures (shingle roof) were near 30oC lower after coating. Electricity savings (kWh/day) from air conditioner use averaged 19% (range 2-43%), with a utility peak demand (5-6pm) average reduction of 22% (0.427kW)

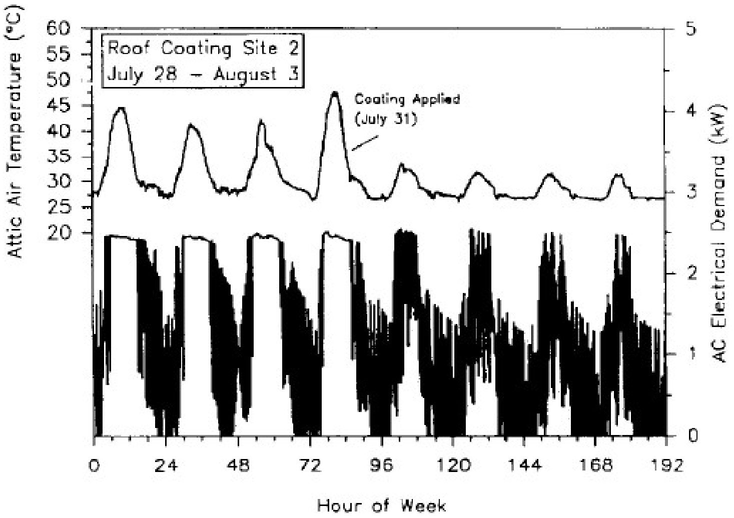
For example, one of the houses had a flat roof structure that did not allow for insulation and an undersized air conditioner that ran continuously at maximum power (2300W) for seven hours each afternoon to try to reach the thermostat set point. The reflective roof coating dramatically reduced the roof cavity (attic) temperature, significantly changing the air conditioner load profile (Figure 3).

Key factors that impacted on the energy reductions in these Florida homes included*:*
ceiling insulation level (higher savings in uninsulated roofs, but savings in insulated roofs as well, due to enhanced insulation performance due to reduced roof space temperature)
difference between before and after roof solar reflectance
air duct system location (higher efficiency of air conditioner with lower roof temperature) and air conditioner sizing.

Note that the air-conditioner thermostat settings would also impact energy reductions.

The relevance of this field study to Queensland is particularly noteworthy due to similarities in the summer climate (characterised by high temperatures and relative humidity), comparable roofing materials (tiles and metal), and the prevalence of existing homes (accounting for 43%) that lack insulation [19].

FIGURE 5: INTERACTION BETWEEN ROOF CAVITY TEMPERATURE AND AIR-CONDITIONER CYCLING [5]



Simulations of residential and commercial buildings, using prototypical buildings with light-coloured (reflective) and dark-coloured (absorptive) roofs, were conducted in the USA in the late 1990s [20]. The prototype buildings included old and new single-family residences, offices, retail stores, schools, health facilities and grocery stores.

Base case roof albedos were estimated from digitised photography of several cities, and savings were estimated for eleven metropolitan statistical areas based on assumptions of building type and age for each statistical area.

Existing roof albedos were typically about 0.20, and an improvement to 0.60 was feasible (accounting for the weatherisation of new coatings with an albedo of 0.70 or higher). Three building types were identified as accounting for over 93% of total air-conditioned roof area and 90% of the U.S. national electricity and net savings: old residences (55%), old and new offices and retail stores (25%) and new residences (15%).

The greatest energy and peak demand reductions were in the hottest climate zones. Simulations for Miami, for example, indicated an estimated annual cooling saving of 259kWh per 1000 ft2 (93m2) of the roof area of air-conditioned residential buildings, with an estimated peak demand saving of 135W.

Akbari [21] summarised field study findings of the effect of applying high albedo roof coatings to buildings in the latter half of the 1990s and early 2000s (Table 3). His study, in 2000, involving small telecommunications equipment buildings that required year-round air-conditioning to maintain equipment performance, revealed dramatic reductions in the temperature of the roof surface, under surface and attic space, reducing these temperatures closer to ambient conditions (surface albedo changed from 0.26 to 0.72).

No incremental costs were attributed to the roof coatings as roofs are prefabricated. The need to balance roof reflectivity and roof insulation was noted for buildings with high internal heat loads.

**Table 3: Field Study Results from Warm U.S. Climates**

| Location | Building Type/number | Reduction in cooling energy (kWh) | Reduction in peak demand |
|---|---|---|---|
| California | Commercial / 2 | 12-18% | |
| Florida | Residential / 11 | 19% average | 1.5 – 7.7W/m2 |
| Florida | Retail / 7 | 25% | 0.65W/m2 |
| Texas | Large Retail / 1 | 11% | 3.8W/m2 |
| Sacramento | Office / 1 | 17% | |
| Sacramento | Museum / 1 | 26% | |
| Sacramento | Hospice / 1 | 39% | |
| Mississippi | Office / 1 | 22% | |
| California | Medical offices /2 | 13-18% | 2.4-3.3W/m2 |
| California | Retail store / 1 | 2% | 1.6W/m2 |
| Florida | Residential / 1 | 17% | |
| Florida | School / 1 | 25% | 6.0W/m2 |
| Sacramento* | Retail store / 1 | 52% (estimated) for two summer months | Average peak demand (12:00 – 17:00) 10W/m2 conditioned area (T-afternoon>38ºC) |
| San Diego* | Elementary school / 1 | 17-18% (estimated) for two summer months | Average peak demand (10:00 – 16:00) 5W/m2 conditioned area (T-afternoon>32ºC) |
| Fresno*<br>*Daily peak surface temperatures were reduced by 33-42K. | Cold storage facility (group of 4 buildings) | 3-4% (summer months) | Measured reduction in peak demand (12:00 – 18:00) 5-6W/m2 conditioned area (T-afternoon>38ºC) |

Based on the measured and estimated energy and peak demand savings of the commercial buildings in California (Table 3, locations marked *), Akbari et al. estimated savings for similar buildings in all sixteen of California's climate zones

**Table 4: Estimated Energy Impacts of 'Cool Roofs' in California Commercial Buildings**

| Building type | The range of estimated energy savings | The range of estimated peak demand impacts |
|---|---|---|
| Similar retail stores | 6-15 kWh/m2 of conditioned area/year | 2.9-5.8 W/m2 (12:00 – 17:00) |
| Similar school buildings | 3-6 kWh/m2 of conditioned area/year | 2.6-3.8 W/m2 (12:00 – 17:00) |
| Similar cold storage buildings | 4.5 – 7.4 kWh/m2 of conditioned area/year | 3.9- 6.6 W/m2 (12:00 – 17:00) |

In the early 2000s, the focus moved from the impact of high albedo roofs on single buildings to the impact on urban environments, specifically as one of a range of strategies to reduce the heat-island effect. The high percentage of solar-absorbing surfaces in urban environments (e.g., building roofs, pavements, and roads) leads to elevated air temperatures in urban environments during summer (compared with rural and parkland environments) (Figure 6).

The heat-island effect negatively impacts the thermal performance of buildings (higher heat penetration), increases the demand for air-conditioning to maintain occupant comfort, reduces the efficiency of air-conditioner operation, and strains electricity supply infrastructure [1].

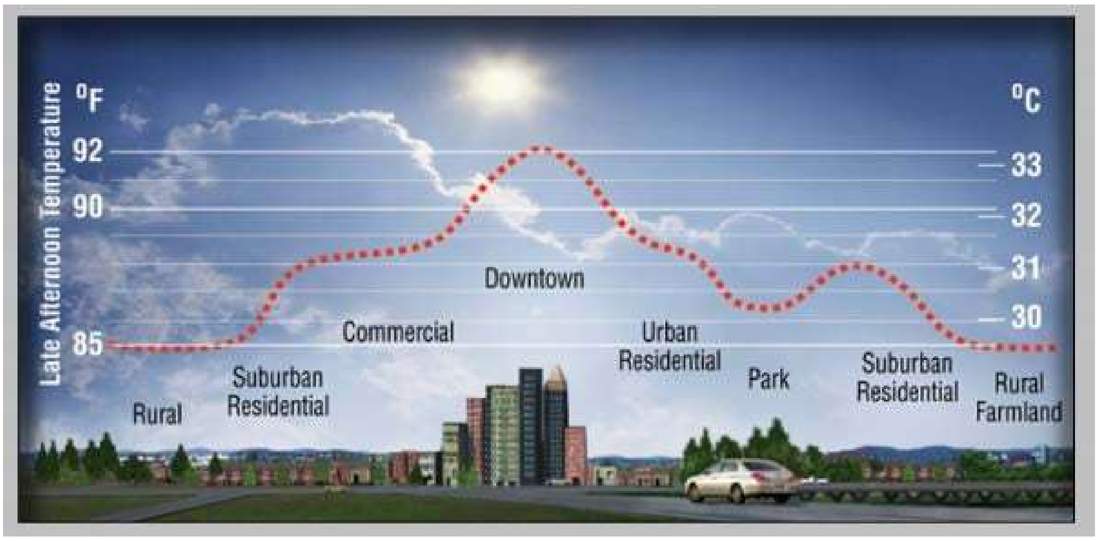


FIGURE 6: URBAN HEAT ISLAND EFFECT IN AMERICAN URBAN ENVIRONMENTS (LAWRENCE BERKLEY LABORATORIES)

In a similar study to that conducted for 11 U.S. statistical areas mentioned previously, a simulated study in Toronto [22] showed the following contributions to total potential annual energy savings from heat-island reduction (HIR) strategies: residential sector 59%, offices 13% and retail stores 28%. Cool roofs contributed to 20% of the savings (which were attributable to other HIR strategies such as shade trees (30%), wind shielding of trees (37%) and ambient cooling by trees and reflective surfaces (12%)).

In this report, Akbari notes that savings potentials for cool roofs should be considered conservative as field tests had shown that the simulation tool utilised (DOE-2) underestimates the cooling energy saving potential of cool roof coatings by as much as a factor of two. Another report by Akbari [24] argues that increasing the urban albedo by 0.05 (0.10) results in a temperature decrease of about 1 K (2K) (global temperature) in about 20 years – based on the simulation tool UVic ESCM that calculates the long-term effect of surface albedo modification, combined with an increase in atmospheric CO2 on global temperature.

Parker [5] highlights research that indicates the potential benefits of increasing urban albedo, such as a 2-3% reduction in utility summer load for each degree decrease in urban air temperature.
Both cool roofs and green roofs are apparent strategies for reducing the urban heat island effect and increasing human thermal comfort in urban environments [25]. Whilst pointing out that solar albedo and the released latent heat are the key variables that

determine the mitigation potential of the systems, Santamouris lists four categories of parameters that need to be fully understood to define performance comparisons between cool roofs and green roofs correctly:

1. Climatological variables (solar radiation intensity; ambient temperature and temperature differential with roof surface; ambient humidity; wind speed and atmospheric turbulence; and precipitation)
2. Optical variables (albedo to solar radiation and emissivity of the roofing system)
3. Thermal variables (thermal capacity of the roofs, total U value, and overall heat transfer coefficient)
4. Hydrological variables (relevant to green roofs)

His literature review of comparative assessments of cool roofs (albedo 0.6 and 0.8) and green roofs came to the following conclusions:

- A cool roof reflectance greater than 0.7 presents a higher heat island mitigation potential than green roofs during the peak period.
- Climate plays an especially significant role in the mitigation potential. Reflective roofs present an important advantage in sunny climates, while vegetative roofs deliver higher benefits in moderate and cold climates.
- The weatherisation of cool roofs needs to be taken into account.
- Reflective or green roofs installed in high-rise buildings have limited climatic and mitigation potential (as the roof area to building volume ratio is very small)

The insulation value of the total roof structure is an important factor in calculating the benefits of cool roof coatings, as recognised in ANSI/ASHRAE Standard 90.20-2004 and explored by various researchers [7, 26]. In the Queensland context, it is important to note that regulatory requirements for building insulation did not commence until 2003, that the benefits of insulation in modifying the internal temperature is poorly understood, and that insulation continues to be poorly installed [27, 28].

Past and present poor practices in maximising the thermal performance of building envelopes would indicate that cool roof coatings have a vital role in minimising heat gains and, hence, reducing electrical cooling loads to meet comfort needs.

Because potential savings depend on the variables of climate and building characteristics, there has been a growth in both field studies and simulation studies to estimate the potential savings of cool roofs in various countries. A significant study attempted to compare the effect of cool roof materials on residential energy loads in 27 countries with different climatic conditions [1].

TRNSYS was the tool used for the simulations, with meteorological data from the METENORM database. A base case building (100m2, single storey, flat roof, 3 m height, glazing 13.2% of wall area) was not intended to be representative of housing in each climatic zone but valuable for comparative purposes across zones.

Results, representative of locations with similar latitudes to Queensland, are presented in Table 5. As well as reductions in cooling loads, the study showed the benefits of enhanced occupant comfort (assuming non-conditioned buildings). Increasing solar Reflectance by 0.4 reduced the maximum internal temperature by 0.8 – $2^{o}$C , whilst a solar reflectance of 0.85 reduced the maximum internal temperature by 1.2 – $3.7^{o}$.

An additional energy benefit of cool roof coatings is the increased co-efficient of performance (COP) of roof-mounted air conditioner plants due to the lower air temperatures resulting from the cool coatings [29].

## Table 5: Simulated Residential Cooling Load Reductions for Selected Cities

TABLE 5: SIMULATED RESIDENTIAL COOLING LOAD REDUCTIONS FOR SELECTED CITIES, WITH THERMOSTAT SET POINT OF 26ºC (EXTRACTS FROM [1])

**Cooling load (kWh/m2)**

| **Location** | Latitude | Base case (SR = 0.2) | Increased albedo #1 (SR = 0.6) | Increased albedo #2 (SR = 0.85) | % decreasein cooling load between base case and #1 | % decreasein cooling load between base case and #2 |
|---|---|---|---|---|---|---|
| **Mexico City** | 19.19 | 9.0 | 2.2 | 0.6 | 75 | 93 |
| **Abu Dhabi** | 24.3 | 265.4 | 236.0 | 217.0 | 11 | 18 |
| **Riyadh** | 24.5 | 179.1 | 154.8 | 139.5 | 14 | 22 |
| **Miami** | 25.59 | 117.7 | 92.4 | 76.7 | 22 | 35 |
| **Johannesburg** | -26.17 | 38 | 21.7 | 13.2 | 43 | 65 |
| **New Delhi** | 28.16 | 158.9 | 136.8 | 122.7 | 14 | 23 |
| **Sydney** | -33.46 | 37.7 | 24.3 | 16.8 | 35 | 55 |

The effect of U-value on the overall energy savings was also calculated for five locations. If a roof is well insulated, the heat transfer between the roof surface and the interior space should be limited; therefore, any changes to the roof surface temperature would have little effect on internal temperatures and, thus, energy loads.

Increasing roof solar reflectance has higher benefits, in terms of energy savings potential, in buildings with poor insulation levels. Figure 5 shows the effect of U-value on the net energy savings resulting from changing the roof reflectance from 0.2 to 0.6.

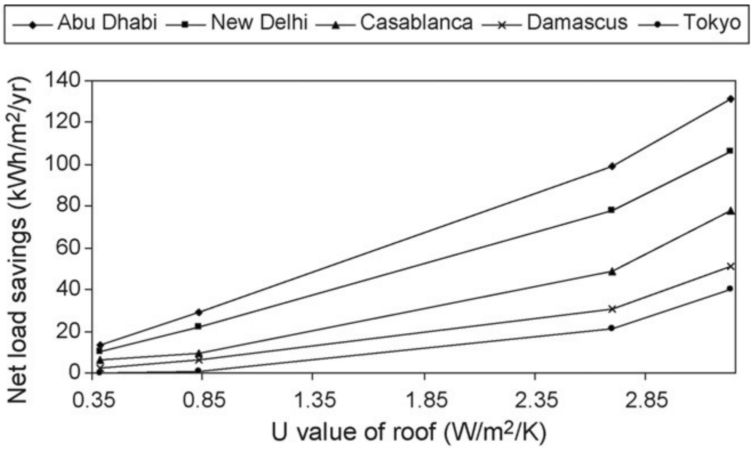


FIGURE 7: EFFECT OF U VALUE ON NET ELECTRICITY LOAD SAVINGS [1]

This does not mean, however, that the energy savings potential in well-insulated buildings in hot climates is not significant. Analysis of the effect of insulation levels for the Sydney climate demonstrated that peak cooling loads could be reduced by factors of 2.5 – 3.5 by increasing solar Reflectance of existing residential roofs, regardless of total roof insulation levels (R0.5, R1.63 and R 3.06) (figures 8 and 9) [7].

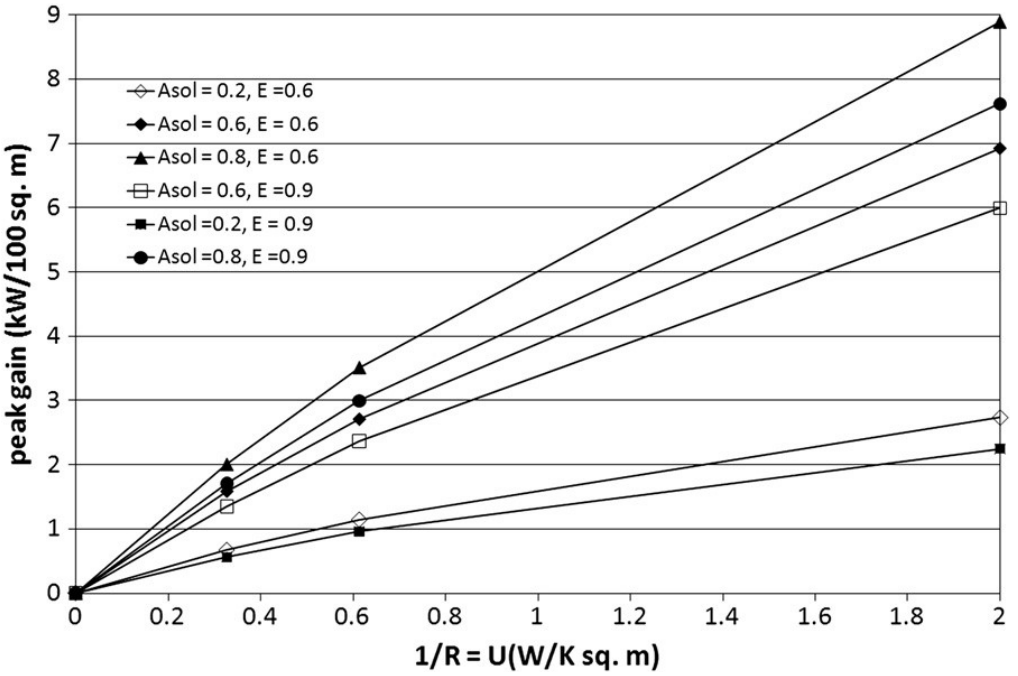


FIGURE 8: PEAK HEAT GAIN IN KW PER 100M2 OF ROOF [7]

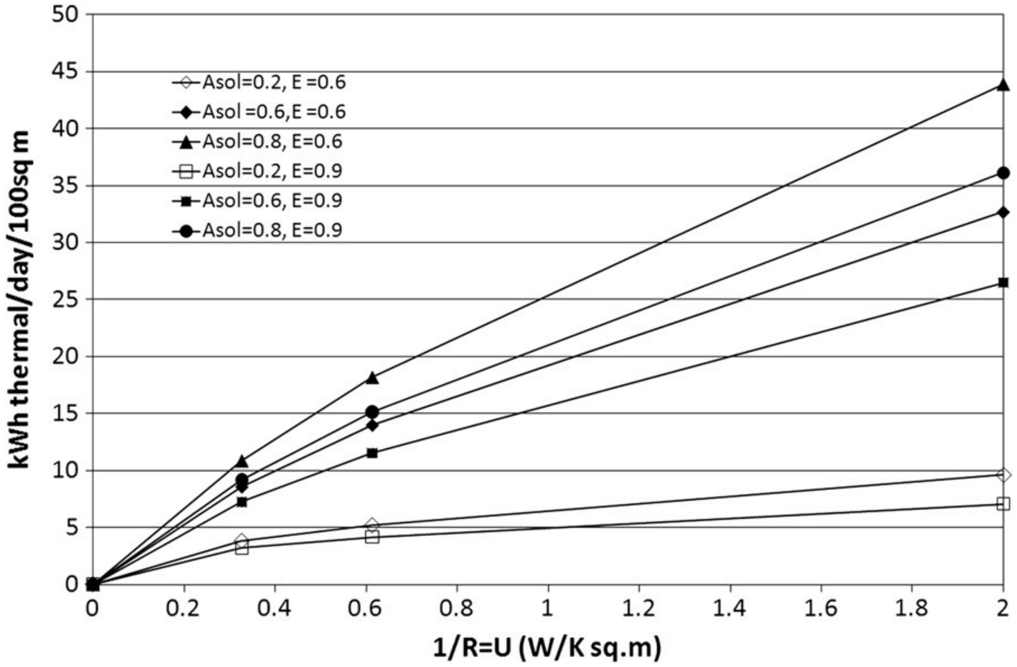


FIGURE 9: DAILY AVERAGE COOLING LOAD PER 100M2 OVER 6 MONTHS [7]

## Table 6: Summary of Various International Studies

Table 6 outlines a number of other studies reporting on energy savings for different building typologies and the application of measured results into broader impact models.

| Country | Summary |
|---|---|
| India [30] | Metropolitan Hyderabad, commercial buildings. Measured annual energy savings from roof whitening of previously black roofs ranged from 20 to 22 kWh/m2 of roof area, corresponding to a cooling energy use reduction of 14 - 26%. The application of white coatings to uncoated concrete roofs resulted in annual savings of 13 - 14 kWh/m2 of roof area, corresponding to cooling energy savings of 10 - 19%. The annual direct CO2 reductions associated with the reduced cooling energy use were estimated to be 11 - 12 kg CO2/m2 of flat roof area. |
| Greece [31] | Schools. A decrease in internal temperature 2.8°C. Reduction of annual cooling load by 40%. |
| Spain [16] | Residential buildings with flat roofs. Methodology used to calculate annual savings for Andalusia and other provinces. |
| Sicily [32] and Mediterranean region [33] | Large building on a school campus. Monitored data used to calibrate a building model to simulate/evaluate building performance with a number of variants for southern Europe climates. Studies look at energy savings (demand and peak) and indoor comfort. |
| France [34] | Low-rise public housing without an active system. Results will be projected for various construction typologies in different climatic regions. Links with EU cool roof project. |
| Global [25] | When only cool roofs are considered, the analysis of the existing data shows that the expected depression rate of the average urban ambient temperature varies between 0.1 and 0.33 K per 0.1 increase of the roof's albedo with a mean value close to 0.2 K. |
| General [35] | Looks at a mesoscale assessment model for solar reflective roofs. |

Limited studies have been conducted in the Australian context. Several studies are briefly discussed below.

## 'Cool Roofs' City of Melbourne Study

This study [36] used both computer simulation and field-testing methodologies to quantify the effect of high-reflectivity roof coatings on various insulation levels, shading levels, and roof pitches in the Melbourne climate. The field tests utilised small buildings (off-ground lightweight construction to 1991 building standards) to measure various coatings' temperature impacts compared with a non-coated 'control' building. Primary data collected included indoorand outdoor temperature, roof surface temperature, reflectivity in horizontal and vertical planes and solar radiation. Computer modelling (TRNSYS) was used to model the effects for a 'typical' residential, commercial, and industrial building under different parameters (insulation level, percentage shading and roof pitch).

The two key measured results of cool roof buildings compared to the control building related to:

1) Internal Temperature
    - Reduction in internal temperature by 2-3°C in the warmest part of the day in summer, with no significant difference in temperature in winter.
    - Lower indoor temperatures during the night in summer (providing some evidence of the ability of the coating product to assist in the shedding of heat to the atmosphere)
2) Roof surface temperature
    - Significant reduction in roof surface temperature (warm to touch, rather than untouchable), with summer surface temperatures up to 30°C lower than non-cool roof (zinc alum 68°C)

The key simulated results, as applied to a base case residential building design to meet current building regulations, relate to:

1. **Attic space temperature**
   - Attic space temperatures in summer were almost 20 degrees cooler, assuming insulation (R2.5) is on the ceiling. There is a different impact (less effect) if theinsulation is located under the roof (above the roof space). No modelling was done of insulation in both locations.
   - The report asserts that this means that cool roof coatings would have the greatest benefit, in the Melbourne climate, for modern houses with unvented roof spaces and ceiling insulation and for older, poorly insulated homes.

2. **Internal temperatures**
   - A reduction in internal temperatures is dependent on the level of insulation. No benefit (from cool roof coatings) was attributable to housing that meets current construction standards of R2.5 insulation level in the roof structure.

3. **Roof pitches** (0, 4.8, 20 and 50)
   - At current building standards (requiring R2.5 insulation in roof structure), there was no benefit or penalty for the various roof pitches.
   - Steeper roofs showed greater benefits of cool coatings, though it was not considered significant for this heating-dominated climate.
   - Increasing the roof pitch resulted in higher heating energy, regardless of roof coating.

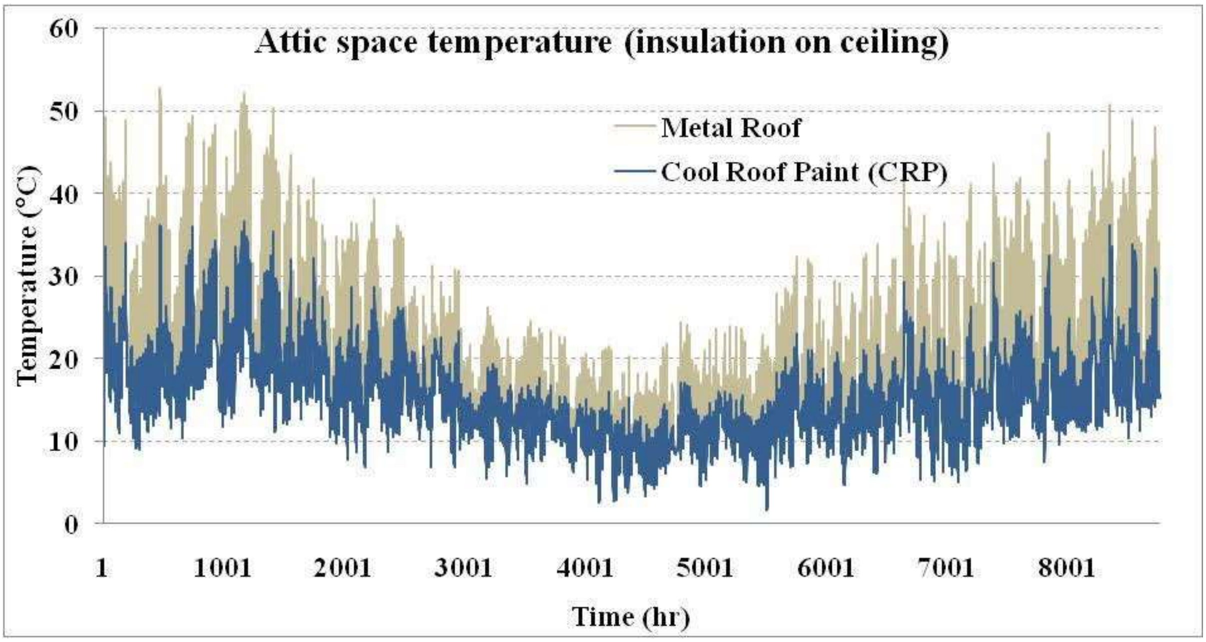
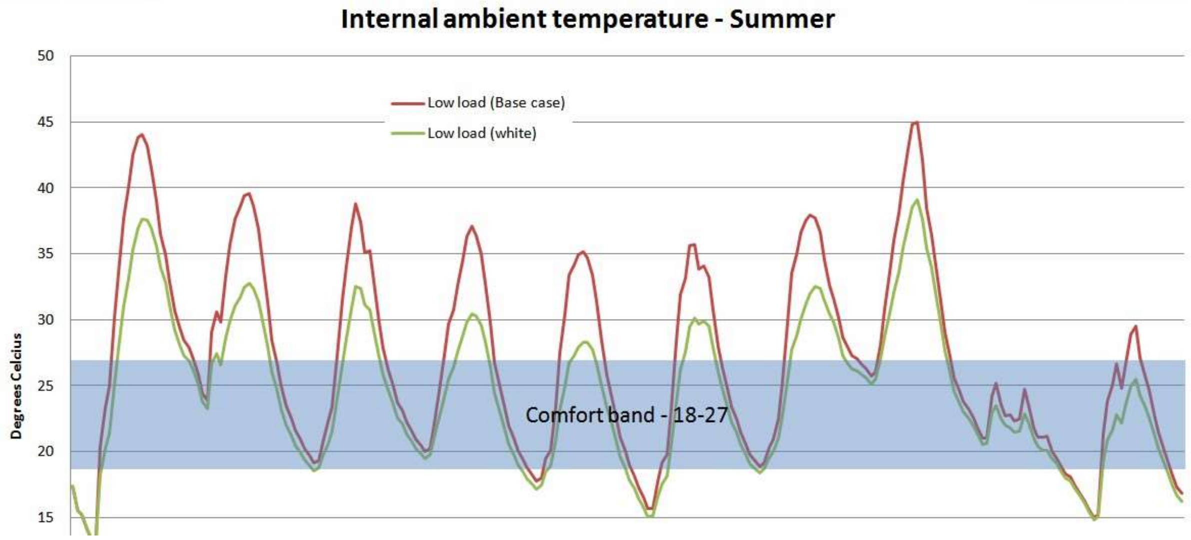


FIGURE 10: ANNUAL ROOF CAVITY TEMPERATURES MELBOURNE

Computer modelling extended to typical commercial and industrial buildings. Commercial buildings (with a limited floor height) showed a 3% reduction in summer cooling load.

The simulation of an industrial building concentrated on indoor thermal comfort, as these buildings are frequently not conditioned (and not insulated). Figure 11 shows the difference in simulated internal temperatures between a base-case industrial building (no insulation and poor thermal performance) and a similar building with reflective coatings.

FIGURE 11: SIMULATED INDUSTRIAL BUILDING INTERNAL TEMPERATURE - SUMMER



## South Australia Demand Side Management Trial No 26

This trial [10] involved a residential townhouse with a flat unpainted zinc aluminium roof during 2007 - 2008. Prior to coating the roof, the external and internal ambient temperatures were logged at 30-minute intervals, along with power demand. Minimums, maximums, and median values were computed for daily and 30-minute interval readings.

Correlations were drawn between maximum daily electricity demand and maximum daily external ambient temperature. The house was monitored for 49 days post-coating the roof with a NIR light tone paint (solar Reflectance not reported). A 23% reduction in median daily maximum power demand was recorded.

Internal temperatures post-painting were more divergent to external temperatures than previously (i.e., the internal temperatures did not rise as much or as quickly as the external temperatures on hot days). An overall reduction in energy consumption for cooling of 21.3% was reported, along with a peak reduction of 15.2% and an off-peak reduction of 26.2%. A payback period of 1.48 years was estimated based on the roof coating cost versus the savings from reduced demand.

These results, however, should be treated with caution as there are no details given of house construction materials (e.g., R-value of the roof), the period of time was very short, and many uncontrolled variables could have impacted the results.

## James Cook University Modelling for North America

This study [26] analyses the effect of solar Reflectance on building heat gain from a roof in Townsville. Because of the tropical climate, the study focused on the downward heat flow from the roof, caused by the temperature differential between outside and inside temperatures and solar radiation absorbed on the roof surface.

In tropical regions, the daytime heat flow due to the outside-inside air temperature difference is typically in the order of 5 K, while the heat flow due to solar radiation absorption on the roof surface is in the order of 20K.

Several assumptions were included in this study (based on derived data):

- In Australia, roof colours were divided into dark ($R_{sol}$ - 0.1), medium ($R_{sol}$ - 0.3) and light ($R_{sol}$ – 0.5) colours, resulting in an average $R_{sol}$ of 0.3.
- The average annual daily radiation on a horizontal surface in tropical regions in Australia (latitude <23.5$^{O}$C) is 21.5 MJ/m2.
- The heat transfer coefficient is 25 W/m2 K (assuming a wind speed of 3 m/s).

The study showed that increasing solar Reflectance from 0.3 to 0.6 reduces the average downward heat transfer from the roof by about 33% in an air-conditioned building and 43% for a non-air-conditioned building in north Australia.

## Reef HQ Aquarium

Reef HQ Aquarium is part of the Great Barrier Reef Marine Park Authority. The aquarium has 2000 m2 of exhibition and office space. Main energy uses are space cooling, aquarium water cooling (4 million litres, requiring constant cooling in summer) and water pumping. Annual energy consumption (2005/6) was 2.4 GWh.

As an energy efficiency initiative, the roof of the building was coated with a reflective coating in early 2012. No details are provided regarding the roof's solar Reflectance and thermal emittance before and after coating. The roof surface temperature prior to coating was 57°C, and after coating, 31°C. No further data is available on this project at this time. Still, it is understood that Ergon is a partner in this project and should be able to access appropriate energy data as the project progresses.

http://www.ehp.qld.gov.au/ecobiz/network/previous-forums/transcripts/aug-2012-hvac.html#sasha_thyer_reef_hq_aquarium)

## 'Cool Roofs' and Building Regulations

As the effect of reflective roofs had been simulated and field tested in the U.S. since the late 1980s, particularly in California and Florida, cool roof requirements entered into regulatory codes in California in 2001. A cost-benefit argument for the inclusion of prescriptive requirements for cool roofs for non-residential buildings with low-sloped roofs was presented by the Lawrence Berkley Laboratory (LBL) in 2004 [37].

The benefits of cool roofs were cited to be decreased electricity use for cooling (3.2kWh/m2) and cooling power demand (2.1W/m2), as well as reduced cooling equipment capacity requirements. Broader society benefits cited included lower ambient air temperature (i.e., reduced heat-island effect), resulting in increased human comfort.

The cost-effectiveness was estimated based on five key parameters: decrease in cooling electricity consumption, potential increase in heating energy consumption (in winter months), net present value of net energy savings, savings from down-sizing of cooling equipment, and cost premium of a cool roof. Time of use pricing and peak demand charges were not considered (at that time). As defined by the Lawrence Berkley Laboratory (LBL), cool roofs are those with a minimum solar reflectance of 0.70 and a minimum thermal emittance of 0.75.

A summary of the development of standards and current U.S. building regulations and policies was provided this year by Akbari [24] (Table 7). There are two main approaches to increasing the utilisation of cool roof coatings to enhance the energy-efficiency of buildings: the regulatory,top-down approach of mandating and prescribing requirements within building energy-efficiency standards and the market-driven, bottom-up approach of crediting the use of cool roofs.

According to Akbari, this latter approach may allow more flexibility in building design and could be energy neutral (no reduction in energy demand) whilst possibly still reducing peak demand, improving air quality, and reducing upfront building costs.

Note that the highest regulated standard currently is in California (2008), which prescribes minimum performance standards (solar Reflectance and thermal emittance) for all residential and non-residential roofs. The development of cool roof standards and regulations [24, 38] indicates the level of confidence in the product.

The inclusion of cool roof requirements in building regulations impacts the rate of diffusion of the technology into the built environment and allows the built environment to play a more active role in energy infrastructure management.

There are no roof reflectance requirements in the Construction Code of Australia; however, there is a requirement for darker-coloured roofs to compensate for additional heating load by incorporating higher insulation levels in some climate zones.

**Table 7: 'Cool Roof 'Standards, Building Codes, Rating and Labelling Programs in the USA**

| **Standards, codes, labelling programs** | **Remarks** |
|---|---|
| ASHRAE Standard 90.1-2007 | Prescribes cool materials for low-sloped roofs on non-residential buildings in some U.S. climate zones. |
| ASHRAE Standard 90.1-2004 and 1999 | Offer credits for cool materials for low-sloped roofs on non-residential buildings in some U.S. climate zones. |
| ASHRAE Standard 90.2-2004 | Offer credits for cool materials for all roofs on non-residential buildings in some U.S. climate zones. |
| California Title 24 Standards 2008 | Prescribes cool materials for all roofs on residential and non-residential buildings in California by climate zone. |
| California Title 24 Standards 2005 | Prescribes cool materials for low-sloped roofs on residential and non-residential buildings in California by climate zone. |
| California Title 24 Standards 2001 | Offers credits for cool materials for all roofs on residential buildings in California by climate zone. |
| International Energy Conservation Code 2003 | Allows commercial buildings to comply with the 2003 IECC by satisfying the requirements of ASHRAE Standard 90.1. |
| Chicago, IL Energy Conservation Code | Prescribes a minimum solar reflectance and thermal emittance for low-sloped roofs. |
| Florida code 2004 | Prescribes cool materials for all roofs on non-residential buildings that are the same as those in ASHRAE Standard 90.1-2004. |
| Hawaii | In 2001, 2002, and 2005, respectively, the counties of Honolulu, Kauai, and Maui adopted cool-roof credits for commercial and high-rise residential buildings based on ASHRAE Standard 90.1-1999. |
| U.S. EPA Energy Star TM label | Requires that low-sloped roofing products have initial and three-year-aged solar reflectances not less than 0.65 and 0.50, respectively. Steep-sloped roofing products must have initial and three-year-aged solar reflectances not less than 0.25 and 0.15, respectively. |
| LEED Green Building Rating Scheme | Assigns one rating point for the use of a cool roof in its Sustainable Sites Credit. |
| Cool Roof Rating Council<br>http://www.coolroofs.org/StandardReview.html | Develops accurate and credible methods for evaluating and labelling solar Reflectance and thermal emittance roofing products. |

## Gaps In Current Research

The desktop review has revealed the following gaps in knowledge about cool roofs and their impact on energy demand:

1. There is no published literature on field studies in Queensland quantifying the effects (including thermal comfort and energy consumption and demand) of cool roof coatings on different building typologies.

2. No literature exists on the possible impact of atmospheric and environmental pollution levels on long-term solar Reflectance of roof coatings in tropical and subtropical Australia (i.e., there have been no long-term ageing studies for roof coatings and typical roof structures in Queensland). This is outside the scope of the proposed field trial but should be considered a complementary project.

## International Performance Measurement & Verification Protocol (IPMVP)

To ensure confidence in the results of the Cool Roofs field trial, it is considered necessary that the methodology undertaken complies with the key steps of the IPMVP: in particular, that energy demand savings are calculated by comparing energy use before and after the implementation of the specific intervention (i.e. the coating of the roofs). These steps should include:

1. Design Intent: description of the intended intervention and expected outcomes.
2. Baseline data: gathering and recording relevant data prior to intervention.
3. Intervention design: methods for implementing the intervention and demonstrating achievement of the design intent.
4. M&V plan: defining equipment, terminology, processes, and methodologies to measure,verify and simulate savings.
5. Equipment selection and installation: select, purchase, install and test measurement equipment, and inspect and revise operating procedures if necessary.
6. Data gathering: record selected data for the post-intervention period (consistent with baseline data).
7. Data analysis: compute and report savings over a defined period.
8. Data verification: obtain independent verification of savings by comparing results with the plan and the objectives.

## Methodology For Cool Roofs Field Trial

The primary purpose of the Cool Roof field trial is stated in the activity agreement. Schedule 1 of the agreement outlines the scope of the activity. The project has two phases, which may be conducted concurrently (as the tasks between the two phases can be interdependent).

The purpose of Phase 1 is to:

- Review current literature and research on cool roof coatings to understand energy performance impacts and
- Conduct high-level financial modelling of the Cool Roof financial proposition.

The purpose of Phase 2 is to:

- Undertake small-scale field trials to validate the energy (kWh) and demand (kW) reduction performance of roof coatings and
- Create a performance model in a format suitable for input into Ergon Energy's network impact modelling.

The intent of the field trial is to measure the changes in the air-conditioning demand profile following the application of a reflective roof coating. The trial will include residential, commercial, and industrial sites. The effect of changed air-conditioning requirements will impact electricity consumption. To quantify this magnitude, baseline energy consumption is established for a building before applying a reflective roof coating.The same process is repeated after the reflective coating is applied.

The main steps in the project are:

- ✓ Pre-coating baseline energy consumption is established.
- ✓ Reflective roof coating is applied.
- ✓ Post-coating energy consumption measured.
- ✓ An analysis is conducted on changes in electricity consumption, especially peak demand, before and after coating.

## Base Line Data

Baseline data is required to analyse energy performance before and after roof coating and to compare similar building types with subtle differences (e.g., residential buildings in the same region with and without insulation). Historical data is recorded to establish baseline conditions for each building in the field trial. Where possible, this will include:

- Energy consumption and demand profiles (12 months where possible)
- Occupancy type/density/periods
- Internal temperatures where possible
- Internal space conditions: air-conditioning plant specifications, COP, condition, thermal set point, thermal comfort strategies of occupants
- Building characteristics: age, floor area, window-to-wall area, materials, insulation levels, conditioned floor area.
- Local weather station data

## Table 8: Site-Specific Baseline Data for Study Sites

| Site Name | Baseline Data Available |
|---|---|
| **Cathedral School** | Level 2 energy audit conducted in 2010 |
| **James Cook University** | Comprehensive BMS, EMS and on-site weather station data |
| **Townsville Residential** | Two houses with 6-9 months of internal and external temperature data |

## Intervention Design

The field study will use a 'before and after' experimental design for residential, educational, and commercial buildings in Townsville and an 'experiment and control' design for residential buildings in Moranbah. These two design approaches will enable the isolation of the effects of the cool roof coatings.

Following discussions within the project alliance, the following buildings have been selected to participate in the field trial:

### Table 9: Study Site Information

| Building Type | Site details |
|---|---|
| **Residential:** | Two existing houses in Townsville<br>Four townhouses are due to be erected in Moranbah (same orientation; Two 'end' townhouses and two 'middle' townhouses) |
| **Educational:** | Two buildings at Cathedral School (dining hall and main administration)<br>One building at James Cook University (Building #34, 'TESAG') |
| **Retail:** | One or two buildings[1] (Woolworths)<br>Arndale Shopping Centre (Brisbane) |

The design intent is to obtain owner consent to coat the roofs of the nominated buildings with a specific cool roof coating and measure the impacts that the coating has on building temperatures, energy consumption and energy load.

The scope of the current project is limited to data gathering and analysis to establish the impact of a 'Cool Roofs' program in the specific geographic regions selected.

Electricity consumption information will be collected before and after roof coating, and results for the specific sites reported on.

The reporting of the data gathering and subsequent analysis will relate directly to the sites measured .Individual site results may be used to give an indicative impact on the greater electricity network; however, this will involve some high-level assumptions.

Any high-level network impact calculations will be based upon clearly documented assumptions, e.g., that residential dwelling roofs are one-third each – light, medium and dark-coloured.

The results can be extrapolated for more accurate analysis as inputs to a network performance model. This project will not extend to network performance modelling other than to provide outputs to be used as inputs to the network model.

## Equipment Selection and Installation

Based on the desktop review, general field study and scientific knowledge, Table 10 was devised to identify the core information needs of the project, the data required to meet those needs, and the equipment required to obtain the data.

Following discussions and agreement at a project meeting in October 2012, the responsibilities for procuring and installing the main equipment fell to QUT (temperature sensing) and Ergon (Interval meters on all AC circuits / or building sub-boards as appropriate).

### Table 10: Field Trial Core Questions, Data Needs and Equipment

| What do we need to know? | What data do we need for this? | How can this data be collected? (equipment andtest standards) |
|---|---|---|
| Heat gain and loss from theroof [7] | Solar albedo Thermal emittance<br>Sub-roof R-value (U-value = 1/R) | BOM weather station data Product information and Laboratory testing QUT<br>Building plans |
| Effect of coating on internalheat reduction and heat retention (delta Tin/Tout) | Tout – 30-minute intervals before and after trial<br>Tin – 30-minute intervals before and after trial<br>Roof heat flux W/m2 (Peak and average; over different time periods) Roof and building characteristics (external surface, insulation, internal surface, air gaps, attic air movement) | Building plans Temperature sensors Visual inspection Thermal imaging Building simulation. |
| Correlation between Toutand power demand (max,min, median daily, and for specific time periods) | Tout – 30-minute intervals before and after trial<br>Power Demand at 30-minute intervals | Ibutton temperature sensors Interval meter on main circuitHistorical data from Ergon |
| Effect of coating on energy consumption | Energy consumption (at intervals of30 minutes, daily, specific periods e.g., school days / non-school days) | Interval meter on main circuit Historical electricity bills |
| Effect of coating on AC usage / AC efficiency | Energy consumption at 30-minute intervals<br>Roof surface temperature | Interval meter on AC circuit or individual AC units |
| Impact of emittance roof temperature [16] | Solar Reflectance Thermal Emittance<br>T roofsurface | Ibutton temperature sensor |
| Impact of solar radiation on reflective coating | Solar radiation (average daily) | BOM weather station data |
| Impact on local climate onsolar Reflectance and comfort | Seasonal and annual climatic conditions; daily weather observations; expected future climate conditions | BOM weather station data |
| Effects of climatic soiling onsolar Reflectance and<br>infrared emittance [16] | Contaminant swabs Solar Reflectance<br>Thermal Emittance | Roof sample mounted in exposure rack/frame.This is NOT part of the field study. |

## Data Gathering

Based on meeting discussions, the time period nominated by Ergon for the field trial was four months, representing a peak summer from December 2012 – March 2013. Timeframes have had to be flexible due to delays in contractual arrangements with participating building owners.

### Temperature

Temperature data will be recorded on-site from Maxim Ibutton temperature sensors. Sensor placement will vary due to access at each site but will include spaces such as:

### Ambient outside temperature

- Outside on roof material
- Roof space
- Internal ceiling
- Various internal room temperatures with different uses (living space, bedroom, etc.)

### Other Climate

- T, RH, Wind, Insolation (from on-site or nearest BOM weather station)

### Electricity

Electricity information is available from a variety of sources, such as:

- Interval meters on the air conditioner circuit/s where possible
- Historical billing information
- Energy audits
- BMS data

| Site | Temperature sensors | Electricity meters |
|---|---|---|
| **Residential Houses** | Installed Feb / April 2012 | No meters on the AC yet |
| **Cathedral School** | Installed November 2012 | Installed January 2013 |
| **JCU** | Installed January 10th 2013 | BMS / EMS |
| **Moranbah Townhouses** | Waiting for advice from the manufacturer on when the buildings will be delivered | |

## Data Analysis

First, a baseline 'business as usual' air-conditioning load for each building will be established. Variation from this baseline will be assessed to determine the magnitude of the change in energy consumption (or the magnitude of the change in internal temperature).

**Temperature**
External roof surface and internal roof space temperatures are expected to reduce after the coating is applied. Temperature data should enable analysis of heat flow through the roof structure.

Internal room temperatures in conditioned spaces will be analysed to confirm the thermostat setpoints and system operation have not changed throughout the trial. If the same internal room temperatures are maintained throughout the study, less cooling energy is expected to be required to achieve this.

For times when internal space may not be conditioned, temperature data will be analysed to determine the impact of the roof coating on internal temperatures. For school and residential buildings, previous studies would indicate the possibility of changes to the need for air conditioning.

**Changes in air-conditioning demand**

Generally, changes in air-conditioning demand will be observed in a reduction in electricity consumption when air-conditioning is needed.

In the case of JCU, electricity consumption reduction will be seen during the overnight chilling process. The advanced Energy Management System at JCU will provide information relating to the thermal load in the monitored building.

**Other factors**

Where available, other factors will be used to match equivalent days more confidently for the 'before and after' comparison. For example, days with similar ambient temperatures will be compared and with similar wind speeds if this data is readily available.

Different methods of calculating savings and extrapolating wider savings across the network will be utilised to ensure valid results (i.e., not due to differences in weather).

## Data Verification

### Computer Simulations

Data collected during the project will be verified in a number of ways. The buildings monitored during the trial will also be simulated using building modelling software. The software uses climate data for the local region and produces an expected energy consumption profile to maintain specific internal conditions.

- *BERS Pro 4.2*

Building Energy Rating Scheme2 is accredited residential energy rating software under the National House Energy Rating Scheme. It is the predominant software tool used for rating residential dwellings in Queensland. As well as calculating the thermal performance of the building envelope, this version of the software also enables input of specific air conditioner efficiencies and usage profiles to develop electricity load profiles for space cooling.

- *IES-VE*

IES-VE3 is a building simulation package designed to simulate many aspects of a building's overall performance in many aspects, one of which is energy.
IES-VE is generally suited to larger commercial developments than BERS and can produce far more complex outputs.

To verify results, computer modelling results of the actual buildings being monitored will be backed by real data, or vice versa.

### Results comparison with previous research

The results from this trial will be compared to the results achieved in similar previous research described in the first section of the document.

Changes in thermal load and energy consumption are expected to be in the same order of magnitude as previous work, with some differences due to specific building characteristics and climate.

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## CERTIFICATE OF COMPLIANCE

**CERTIFICATE OF COMPLIANCE**

CLIENT CERTIFICATE NO: 34105-21075

ISSUE DATE: September 24th, 2007

**REPORT REFERENCES**: Oak Ridge National Laboratories CA Report 6527, Asphalt Technologies Tempe Florida Lab Report(s)15/03,4/04

**Product Description:** Thermobond HRC (Heat Reflectant Coating)

**Product Use:** Heat Reflectant Barrier for walls, roofs, and poly, steel and concrete pipelines. Substitute and Augment for Insulation in Zones 1 & 2 to prevent Heat Gain.

This is to certify that representative samples of: Industrial Roof Coatings' Thermobond HRC (Heat Reflectant Coating) has been investigated by PCS in accordance with the following standards:
ORNL Report 6527 test of 24 Heat Reflectant Membranes using standards ASTM C-177(Thermal Conductivity) and ASTM C-1045 (Thermal Transmission) results of K value-0.0454, Heat Flux Reduction 13,500BTU/SqFt or R22 (imperial)
metric R = 0.176 of imperial R-value.
Current CRRC standard for Cool Coatings: Solar Reflectance -70%>; Thermal Emittance-75%>; SRI 82.5>
(a correlation between Solar reflectance and infrared emission).

The products, based on the results of Industrial Roof Coatings' Thermobond HRC product tested at Asphalt Technologies
ASTM C 1549 (Solar Reflectance); 20=poor 90=excellent
Thermobond HRC White- 87.8; Thermobond HRC Pastels-78.1:
ASTM C 1371(InfraRed Emittance) 20%=poor 90%=excellent
Thermobond HRC White- 89%; Thermobond HRC Pastels-88%.
SRI (Solar Reflective Index- a correlation between Solar reflectance and Infra-Red Emittance)
Standard Scale 0-100 20=poor 100>=excellent
Thermobond HRC White- 110.5; Thermobond HRC Pastels-98.9.
meets the results as determined by ORNL Report 6527 being- K value-0.0454, Heat Flux Reduction 13,500BTU/SqFt.

**Subject to the following conditions:**
Thermobond Heat Reflective Coating (HRC) Technical and Specification Guide inclusive of Application Instructions, Dry Film Thickness and Colour limitations.

By Mark W Slater
Managing Director LTSC SCAA