Cool Roofs:

City of Melbourne

Research Report

September 2011

The University of Melbourne

Contents

Introduction

This research and associated fact sheet has been commissioned by the City of Melbourne to provide direction to consumers about the use of “Cool” or “White” roof paints (hereafter referred to as Cool Roof Paint (CRP), that have a significant higher reflectivity and emissivity when compared with normal roof materials and coatings.

There is currently available a number of products that can be applied to a variety of new and existing roof types to reduce primarily heat gain (reflection) through the surface of the roof and also in some cases to improve heat lost to the atmosphere (emissivity). These products vary widely in their application approach and performance.

Background

A cool roof is one that reflects the sun’s heat and emits absorbed radiation back into the atmosphere at a higher rate than standard materials. Cool roof performance may be achieved with additives to the base material, or by applying a CRP. These types of roofs literally stay cooler,thus reducing the amount of heat held and transferred to the building below, keeping the building a cooler and more constant temperature.

A simple analogy is putting your hand on a white piece of metal out in the sun or a black piece of metal, or feeling warmer in a black jumper compared to a white jumper. And there are times when it is desirable to absorb more heat, and this will be discussed in relation to building typologies.

It is important to note that with modern technology, CRP’s need not be white. There are many CRP products which use darker-coloured pigments that have increased reflectivity in the near infrared (non-visible) portion of the solar spectrum. With these technologies there are roofs that come in a wide variety of colours and still maintain a high solar reflectance. It is generally accepted however that a darker roof will never be as reflective as a light coloured roof.

Terminology

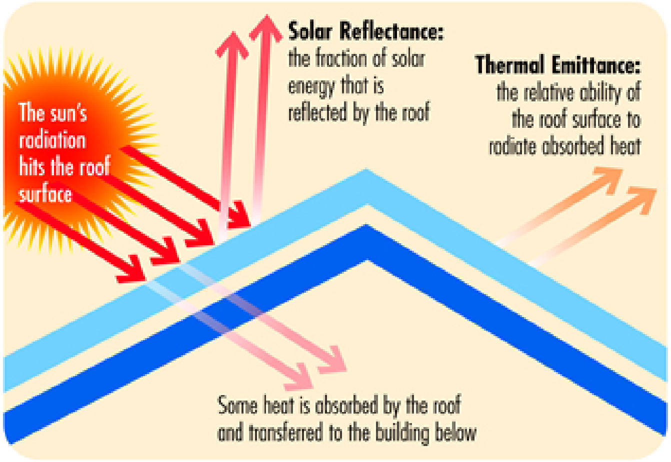


Figure 1 Cool roof diagram courtesy www.coolroof.org

The two basic characteristics that determine the 'coolness' of a roof are solar reflectance (SR) and thermal emittance (TE). Both properties are rated on a scale from 0 to 1, where 1 is the 100% reflection of solar radiation (most reflective) or 100% emission of heat (most emissive).

Understanding the language of cool roof properties

Solar Reflectance:

Solar Reflectance is the ability of a material to reflect solar radiation (light, infrared and UV).

Typical Albedo Values:	Fresh snow	Earth Average	Charcoal
	0.9	0.3	0.04

Table 1: Understanding solar reflectance values

Thermal Emittance:

Thermal Emmittance is a measure of the ability of the material to both absorb and re-radiate heat into the atmosphere.

Typical thermal Emmittance Values:	Metal roof	White Roof
	0.8	0.21

Table 2: Understanding thermal emittance values

Solar Reflectance Index:

The characteristics of cool roof properties have been combined into one single value known as the Solar Reflectance Index (SRI). The SRI value combines both the reflectivity value and emittance value as a measure of a coating's overall ability to reject solar heat. The calculation has a specific calculation that must be followed.

It is defined such that a standard black (reflectance 0.05, emittance 0.90) is 0 and a standard white (reflectance 0.80, emittance 0.90) is 100.

The SRI method is not used in this study as it is expensive and more difficult to determine the effect of the solar reflectance and thermal emittance individually for the products tested

What are the benefits of a cool roof?

There are numerous benefits in having a cool roof:

- Reducing your utility bills associated with air conditioning
- Due to lower use lower maintenance requirements for the air conditioning system
- Increasing occupant comfort and potential to avoid installing an air conditioner where not already installed
- Decreasing the size and prolonging the life of your air conditioning system
- Lowering roof maintenance costs and extending roof life, avoiding reroofing costs and reducing solid waste
- Assist your building in meeting building codes – Section J
- Mitigating your community's Urban Heat Island Effect
- Maintaining aesthetics with a roof that performs and looks good
- Increase ecological sustainability factor, or make your building “greener”

A cool roof can significantly reduce your cooling energy costs and increase your comfort level by reducing temperature fluctuations inside your home. There are times where a cool roof is undesirable – such as a domestic dwelling that requires predominately heating. This type of building may have an increased heating need with the use of a CRP.

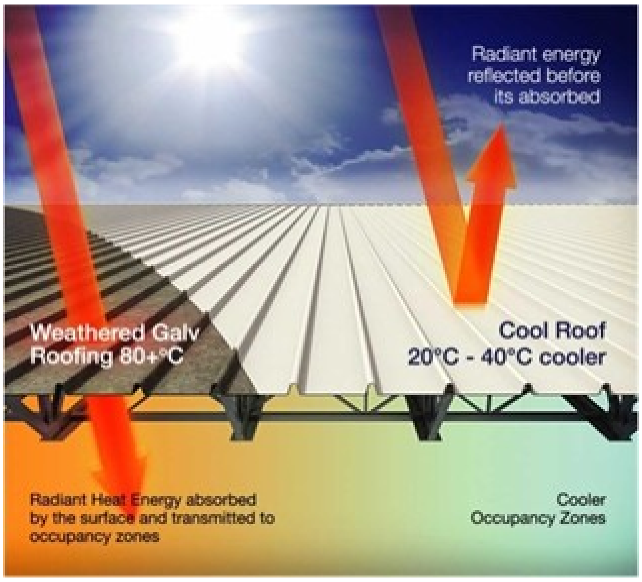


Figure 2: Image courtesy www.coolroofcommercial.com

Literature review

As interest in climate change and the urban heat island effect grows, so too does the interest in the use of both vegetation and “cool” building materials to reduce the impact of both climate issues. As there is extensive research completed on the topics of both Urban Heat Island and Cool Roof products, this literature review is separated for ease of understanding.

Urban Heat Island

The urban heat island (UHI) effect refers to the phenomenon of a metropolitan or built up area which is significantly warmer than its surrounding areas. In some cases, it causes average urban daytime air temperatures of typically 5.6°Chigher than the surrounding rural areas in summer (Akbari, Menon & Rosenfeld 2009).When looking over the long term, downtown Los Angeles has been measured to be 2.5° Kelvin warmer than in the 1930’s, which equates to 1 – 1.5 GWe more electricity to cool in summer, costing an extra $100 Million per year (Akbari 2008). Surface air temperatures elevated by at least 1°C compared with surrounding areas have been observed in New York City for more than a century (Gaffin et al. 2008).

The urban heat island effect can be detected throughout the year, but it is of particular public policy concern during the summer, because higher surface air temperature is associated with increases in electricity demand for air conditioning, air pollution, and heat stress-related mortality and illness (Rosenfeld et al. 1995; Nowak et al. 2000; Sailor et al. 2002; Hogrefe et al. 2004). According to the U.S. Centre for Disease Control and Prevention, more Americans over the past 20 years were killed by heat than by hurricanes, lightning, tornadoes, floods, and earthquakes combined. Within a five-day period, the 1995 Chicago heat wave killed between 525 and 726 people (Akbari2008). As such, the Urban Heat Island effect is a very real and serious problem facing developed areas.

In areas that suffer from the UHI effect, the temperature difference is usually larger at night than during the day, and is most apparent when winds are weak as the result of the thermal lag of the heavyweight products such as roads, concrete bricks and other construction materials and low albedo surfaces that make up these types of areas, which, are a significant percentage according to an Akbari et al estimate (2003), the roof surface area alone in four U.S. cities varies from 20 percent (low density city) to 60 percent (high density city).

The UHI effect decreases air quality by increasing the production of pollutants such as ozone (Taha et al. 1994), and UHI’s are associated with changes to local weather patterns including rainfall and pressure systems. Monthly rainfall is greater downwind of cities, partially due to the UHI. Increases in heat within urban centers increases the length of growing seasons, and decreases the occurrence of weak tornadoes.

Mitigation of the urban heat island effect can be accomplished through the use of green roofs and the use of CRPs or lighter surfaces in urban areas, which reflect more sunlight and absorb less heat. Despite concerns raised about its possible contribution to global warming, comparisons between urban and rural areas show that the urban heat island effects have little influence on global mean temperature trends.[Peterson 1999)]

The UHI effect is primarily caused by the storage of solar energy received from the sun (radiation) by the heavyweight mass elements that make up the buildings, roads and pavements of our cities. This leads to night time re-radiation of heat from these materials which lead to night-time warming. The lack of evapotranspiration (for example through lack of vegetation) in urban areas is also a significant cause – vegetation maintains a significantly lower temperature than most common building materials when exposed to the sunshine. Mitigation of the UHI effect can also be improved by the use of cool materials that are characterized by high solar reflectance and infrared emittance values (Synnefa et al 2008).The properties of surface materials commonly used in urban areas for pavement and roofs, such as concrete and asphalt, have significantly different thermal properties (including heat capacity and thermal conductivity) and surface radiative properties (albedo and emissivity) than both the cool materials and also the surrounding rural areas. This causes a change in the energy balance of the urban area, often leading to higher temperatures than surrounding rural areas.[Oke, 1982]

In terms of a solution, increased vegetation, higher albedo surfaces and higher albedo pavements are cited as the main opportunities, Rosenzweig et al (2009) found that that the influence of vegetation on urban climate is more important than the influence of the albedo of built surfaces, and that although planting street trees citywide has only half the impact of high-albedo surfaces, it involves planting trees in 7% of the city's area, as compared to raising the albedo of 48% of the city's surfaces. It must be acknowledged that vegetation cannot be used in every situation and high albedo coatings will have a significant impact in reducing the UHI effect when used appropriately.

Local thermal effects – micro heat islands

During a typical sunny day, there is approximately 1 kW/m^2 of solar radiation on a roofs surface, and between 20 percent and 95 percent of this radiation is absorbed based on the different roof colours (Suehrcke, Peterson & Selby 2008). This massive heat load affects the microclimate around a building or in cities, and is heavily influenced by the incident solar radiation on the building envelope as well as the level of vegetation in the area. The thermal or long wave radiation reradiated from building surfaces affects air temperature, relative humidity and wind speed (Prado and Ferraira, 2004).

Cool roof studies and measurements

There have been several studies using both field measurement and computer simulations that document the energy savings from increasing the solar reflectance properties of buildings, combined with an increased thermal emittance. It is now widely accepted that the higher reflectivity a roof colour is, the lower solar energy is absorbed and the lower surface temperature will be (Kiehl & Trenberth 2010).

Akbari and Konopacki (2005) have calculated the cooling energy savings due to the application of heat island mitigation strategies (application of cool materials and increase in vegetation cover) for 240 regions in the United States. It was found that for residential buildings the cooling energy savings vary between 12% and 25%, for office buildings between 5% and 18%, and for commercial (retail stores) buildings between 7% and 17%.

In a 2001 study by Konopacki and Akbari, the Lawrence Berkeley National Laboratory (LBNL) measured and calculated the reduction in peak energy demand associated with a cool roof’s surface reflectivity. They found that, compared to the original black rubber roofing membrane on the Texas retail building studied, a retrofitted vinyl membrane delivered an average decrease of 24 °C in surface temperature, an 11 percent decrease in aggregate air conditioning energy consumption, and a corresponding 14 percent drop in peak hour demand. The average daily summertime temperature of the black roof surface was 75 °C, but once retrofitted with a white reflective surface, it measured 52 °C. Without considering any tax benefits or other utility charges, annual energy expenditures were reduced by $7,200 or $0.07/sq. ft.

Other relevant field studies in California and Florida have demonstrated direct cooling-energy savings in excess of 20% upon raising the solar reflectance of a roof to 0.6 from a prior value of 0.1-0.2. Energy savings are particularly pronounced in older houses that have little or no attic insulation, especially if the attic contains air distribution ducts for ducted heating and cooling. Akbari et al. observed cooling energy savings of 46% and peak power savings of 20%) achieved by increasing the roof reflectance of two identical portable classrooms in Sacramento, California. Konopacki et al documented measured energy savings of 12-18% in two commercial buildings in California. In a large retail store in Austin, Texas, Konopacki and Akbari documented measured energy savings of 12%. (Akbari 2008)

Product Description

The products used in the study included:

- Thermoshield
- SkyCool*
- Staycool
- Dulux Infracool^.

*Skycool was not used in the computer modeling
^Dulux Infracool was not used in the field tests

Other products not studied included:

- Thermilate
- Colorbond Coolmax
- Coolpaints.com.au
- Nutech
- Solacoat
- solar-cool
- Heat reflective paint.

The following information is a summary of the information provided by the relevant manufacturer (website).

Thermoshield (from website)

Thermoshield is a NASA-inspired, water-based emulsion of high grade acrylic resins, that contains millions of hollow ceramic particles. The dead air space provided by these particles creates a high thermally reflective shield, resulting in up to 75% of incoming heat being reflected directly back, thereby reducing internal building temperatures by up to 45%. Additionally, Thermoshield has an ultraviolet resistance of 96%, a solar reflectance of over 80%, and an emissivity of 90%, making it almost as effective as a mirror.

The application of Thermoshield is very much like that of paint. The surface should be cleaned and generally prepared, and then two coats of Thermoshield are sprayed on. Once applied the coating chemically converts any iron oxide (rust) present into iron sulphate, thereby preventing continued corrosion. It will also seal and waterproof the roof. The heat barrier formed will also eliminate up to 80% of destructive thermal shock i.e. the movement of various roofing materials against each other, which is a major cause of roof degradation and water leakage.

The colours available include all the universal tints, but must be restricted to the first shade of pastel on any colour chart.

Figure 3: Thermosheild

Keeping buildings and people comfortable – a typical use of Thermoshield

Figure 4: Thermosheild

And keeping canines comfortable - one of the more unusual uses of Thermoshield

SkyCool (from website)

SkyCool is a specialized thermal coating that is applied to the exterior of metal roofs, which is designed to combat heat build-up in industrial and commercial buildings. It does this firstly by preventing excess heat from the sun from entering the building, and secondly, by increasing the emittance of some of the internal heat. Observations have confirmed constant internal sub-roof temperature decreases of 20 to 40°C, resulting in work areas being around 14°C below ambient in the peak of summer, and energy savings averaging around 40-50% for large commercial buildings.

The application of SkyCool will result in a number of important benefits that include:

- Large drop in internal temperature, like that experienced by a shopping complex in Melbourne.
- Substantial and very cost-effective reduction in air conditioning power consumption.
- Greater efficiency & life from existing air conditioning plant through reduced peak loads.
- Significant contribution to the environment through large reductions in greenhouse gas generation resulting from the power saved.

- A more productive work environment without the expense of air conditioning.
- Increased value in the building whether it is conditioned or not.

In turn, the roof is protected from:

- thermal shock due to varying sun load
- corrosion from atmospheric contaminants
- precipitation – as a weather sealant.

The product is environmentally safe and convenient to apply so there is no interruption to business within the building

SkyCool has so far been used for a wide variety industrial and commercial applications, including airports, banks, schools, shopping centres, supermarkets and warehouse, to name a few.

Figure 5: Skycool

Application of SkyCool to Melbourne Airport has resulted in energy savings of 30-40%, and an estimated reduction of 40,000 tonnes of greenhouse gases.

EPA Staycool

EPA Staycool does not have a lot of marketing for this product, as it is an additive in the roof protective membrane coatings. The performance data that we have been given suggests it is most similar to other products in the study in terms of outright performance, however it must be noted that the products are very different and are likely to perform differently as a result.

Dulux Infracool (from website)

The Dulux infracool product differs from the others in two ways: 1) it is partly aimed at the residential market, and 2) because it is available in a range of colours

InfraCool Heat Reflective Coatings (from website)

“We are committed to continually improving the environmental footprint and sustainability of our products. InfraCOOL Technology reflects and emits both the visible or "coloured" light and invisible Infrared light which accounts for over 50% of the sun's total light energy to provide a much cooler building surface. A cooler surface means less heat penetration resulting in cooler accupancy zones which lowers the use of energy- translating in cost savings and reduced associated greenhouse gas emissions.”

For commercial properties, the product estimates that the surfaces can be 20-40°C cooler translating into cooler occupancy zones, lowering cooling energy demand and thus delivery cost and energy emission savings.

For residential properties (from website), “It doesn't have to be WHITE to be COOL - InfraCOOL Technology maximises reflection of infra-red radiation, so even dark colours can be made cooler. InfraCOOL Charcoal, for example can be up to 16ºC cooler than conventionally formulated Charcoal without changing the visual colour.”

Colorbond CoolMax (from website)

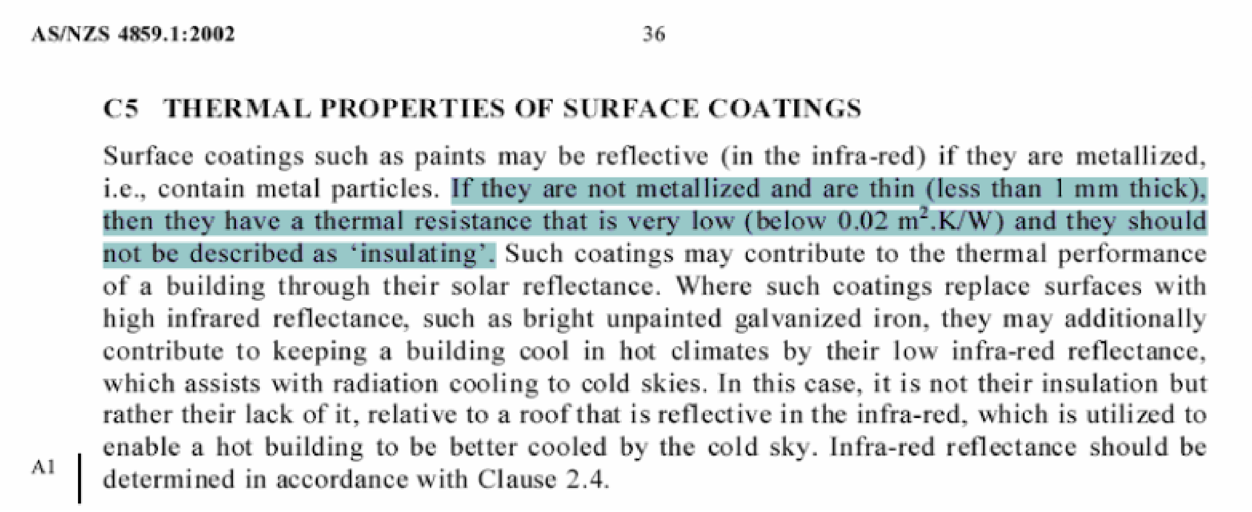
The ColorBond product is not in the study but is an interesting product to compare because the cool technology is applied during production

ColorBond CoolMax is from the Bluescope Steel range which is designed to reduce energy costs by up to 7.5% compared with the some of the company’s other products. It delivers this performance through having a comparatively high solar reflectance of 0.77 (a value of 0.0 indicates that a surface absorbs all solar radiation, and a value of 1.0 represents all is reflected). Additionally, it is able to maintain this by having an excellent resistance to dirt retention, with studies showing sites that retain 95%of their initial solar reflectance after a decade.

The Issue of R-values

It became apparent that most of the products interpreted the benefit of their products as having and “equivalent” R-value. Because reflective paint coverings have only a very low “real” R-value benefit to the properties of the roof on which they are painted (see below), this was identified as potentially being very confusing to consumers.

CRP’s have a very low direct R-value but the marketing of the products make an “equivalent” r-value by comparing the temperature reduction of a building that uses CRP to a building that does not use CRP but has an increased R-value.



AS/NZS 4859.1:2002 36

C5 THERMAL PROPERTIES OF SURFACE COATINGS

Surface coatings such as paints may be reflective (in the infra-red) if they are metallized, i.e., contain metal particles. If they are not metallized and are thin (less than 1 mm thick), then they have a thermal resistance that is very low (below 0.02 m^2.K/W) and they should not be described as 'insulating'. Such coatings may contribute to the thermal performance of a building through their solar reflectance. Where such coatings replace surfaces with high infrared reflectance, such as bright unpainted galvanized iron, they may additionally contribute to keeping a building cool in hot climates by their low infra-red reflectance, which assists with radiation cooling to cold skies. In this case, it is not their insulation but rather their lack of it, relative to a roof that is reflective in the infra-red, which is utilized to enable a hot building to be better cooled by the cold sky. Infra-red reflectance should be determined in accordance with Clause 2.4.

A1

Figure 6: Australian Standards for surface coatings

Methodology

This study is based on two concurrent testing methodologies. The first is a full-scale installation of three single room buildings (and one 1/3 scale building) at the University of Melbourne's Burnley campus in Melbourne, Australia. Two of the full scale buildings and the 1/3 scale building are painted with proprietary reflective white roof paint (CRP), and the third building is left unpainted as a control.

The second method is a computer simulation of the physical experiment using the TRNSYS software package. While these methods are run concurrently, precedents set by Akbrai et al. suggest that simulated and measured data is not likely to be directly relative but rather implicit of trends and indications (Akbari 1997).We will aim to compare and integrate the two methodologies in order to establish an effective predictive model for future scenarios.

The site for this study located in Eastern metropolitan Melbourne with coordinates37°48′49″S, 144°57′47″E. The moderate oceanic climate results in significant residential heating and cooling loads throughout the year and is an ideal climate for passive design principles. Among the simplest of these principles is roof surface albedo which has the potential to provide significant reductions in cooling energy demand and peak loads through cooling months.

The test buildings are of a lightweight construction typical of Australian housing and insulation levels are indicative of the 1991 minimum building standards (approx R1.0 walls and R0.82 ceilings), which would have been in place at the time of construction. The un-insulated timber floors and the absence of weather strips to doors resulted in an assumed infiltration rate of approximately 2air changes per hour (ACH). The doors and windows were always closed with the exception of those times access was required for installation and maintenance of equipment. Blinds were installed to North facing windows in order to mitigate misleading sensor output affected by glare and direct solar gain.

Study limitations

This study is limited in scope as follows:

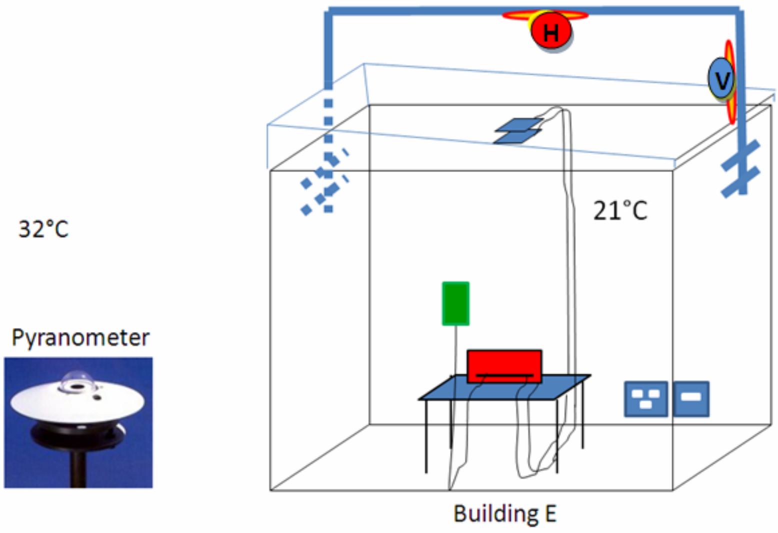
- The study does not accurately cover a complete summer period due to timing of the monitoring, additionally, the study was conducted in a year that was cooler than average with less sunshine hours.
- The study monitored small buildings – this in some cases limits the ability to upscale the results due to the differences in roof to wall area ratios.
- The study only tests 3 products in the field with one additional product in the computer modelling. Other products and brands are therefore not accounted for in the results.
- Computer modelling is inherently limited to specific assumptions about internal gains, occupancy profiles and other variables that were required to be fixed as static.
- The results of this study do not easily translate to likely performance or energy savings for other, more specialised types of buildings, such as educational, airports, retail etc.

Methodology – Site Measurements

The field study of the products was conducted at the Melbourne University Burnley Horticultural campus where 3 “full-size” (10.43m^2) sheds, (1 control and 2 white roof sheds - Staycool and Skycool) were monitored along with a scale model building (approx 1m^2) using the Thermoshield product.

Data will be collected at Burnley on three of the paints including, heat transfer into the roof and room, ambient temperature (dry bulb and wet bulb) thermal comfort – humidity, radiant temperature and air movement and radiation from the roof – horizontal and vertical.

.


Heat flux sensors (blue) to measure the thermal load and transfer of heat into buildings through roof, sensors to monitor the radiation into the environment (pyranometer) through the roof (yellow circle) and ambient comfort conditions (temp and humidity) monitored in the buildings (green). These will be connected to a logger (red) which will be connected to the internet.

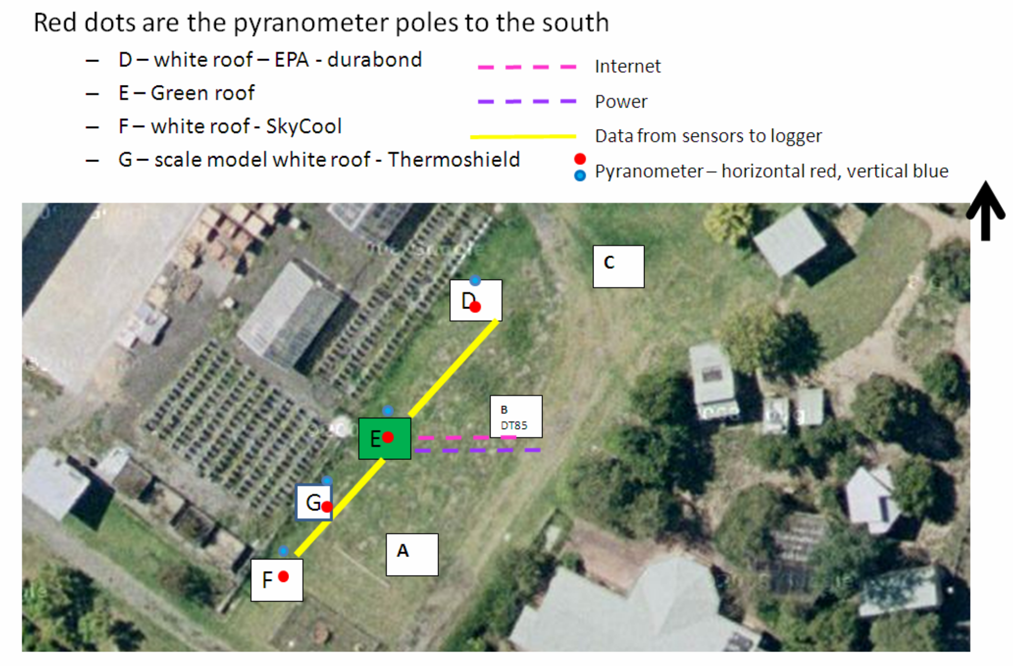


Figure 7: Building and Site plan for field tests

Field Data Logging

The data collected in this field test is extensive and extends beyond that which is specifically required to quantify the effects of the CRP's. It provided a valuable opportunity to collect thorough surface property and environmental data over an extended period of time from which future research could draw upon. This additional data was useful in verifying results and identifying anomalies in data or building performance.

Two means of data collection were used in this field test; a DataTaker DT85 data logger with two CEM20 expansion modules, and a Hobo weather station. The bulk of the data was recorded using the DT85 data logger, which was logging continuously at 20-second intervals. The data logger was located in the control building (building B) for part of the field test but was relocated to a near by building in order to eliminate the need for regular access to building B which would influence results. The primary data collection was of the indoor and outdoor temperatures, roof surface temperatures and reflection both in the horizontal and vertical planes. Additional data was logged including the solar radiation received.

Once the data logging was set in place there were no changes to the test buildings or the logging equipment for the duration of the study

This data was then used to verify the computer model which was used to extend the results to commercial and industrial buildings with different heating and cooling requirements. Sensitivity analysis was done around benefits dependent on roof paint colour, levels of insulation, percentage shading and pitch, the table below summarises the options.

Option	Sensitivity range	Factor
Roof paint colour	based on available products	Total energy use based on

Roof paint colour	based on available products	Total energy use based on properties
Insulation levels	R1.5/R2.5/R3.5/R4/R4.5/R5	Heat transfer through the roof
Percentage of shading	0%-20%-50%-70%-100%	Percentage shaded
Pitch	5%, 20%	Percentage of incident

Table4: Modeling parameters

Methodology–Computer Simulation

TRNSYS 16 (Klein et al. 2006) was used for all the simulations. Base case building (Appendix A) layers defined by Table 1 was simulated initially. Other parameters are listed in Table 2. Typical Metrological Year data for Melbourne developed by Morrison & Litvak (1999) was used. The simulated hourly internal temperatures and roof temperatures were compared with the experimental data to validate the model developed for this study.

Layers	Material	Thickness (mm) or R value
Wall layers	Masonite	6
	Mineral Wool	50
	Particle Board	9
Roof layers	Masonite	5
	Mineral Wool	50
	Reflective layer	R = 0.08
	Air Gap	40
	Corrugated iron	1
Floor layers	Carpet and underlay	12
	Particle Board	20
Door layers	Particle Board	32
Windows	Glass	4

Table 5: building parameters

Description	Parameters	Unit
Roof reflectivity	0.8	-
Outdoor air infiltration rate	2	ACH
Ventilation rate	0	ACH

Internal load	0	W
Thermostat setting for cooling	24	°C
Thermostat setting for heating	21	°C
Night setback for heating	18 (11 pm – 6 am)	°C
Beginning of heating season	3240 (16 May)	hr
End of heating season	6192 (15 September)	hr
Beginning of cooling season	8016 (1 December)	hr
End of cooling season	1416 (28 February)	hr

Table 6: Settings

Figures8 and 9 show the graphical caparisons and Figures10 and 11show the correlation for the 1-10 January 2011. The relationship between measured and simulated values was tested by Root Mean Square Error (RMSE), Mean Bias Error (MBE) and Correlation Coefficient (CC) (see Appendix B). Table 3 shows the statistical parameters. The correlation coefficients found for internal and roof temperatures are 0.985 and 0.970. The model developedfor the simulation is found to be acceptable for the study

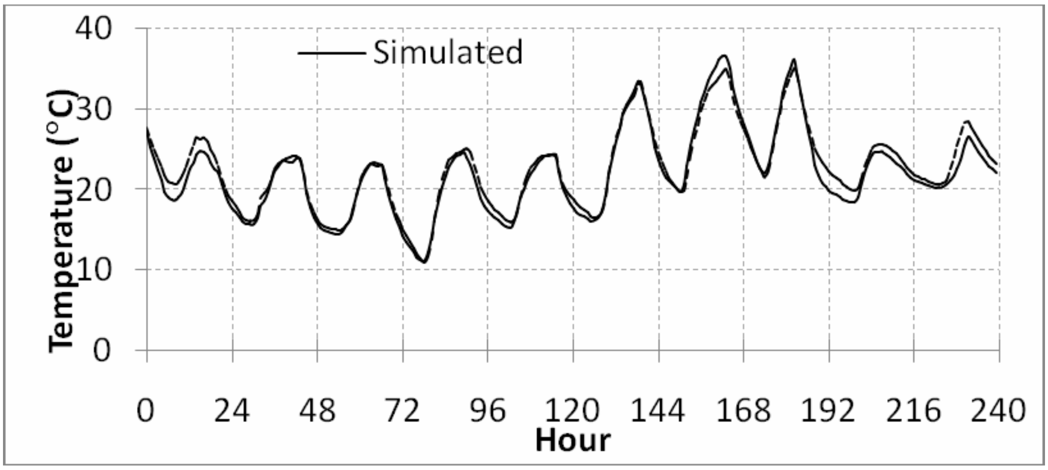


Figure 8: simulation internal temperatures

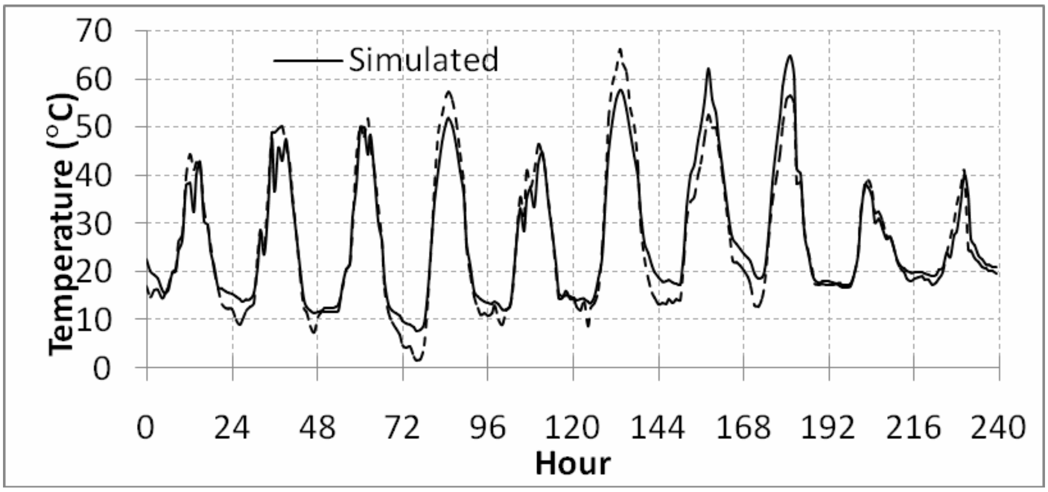


Figure 9: Simulation roof temperatures

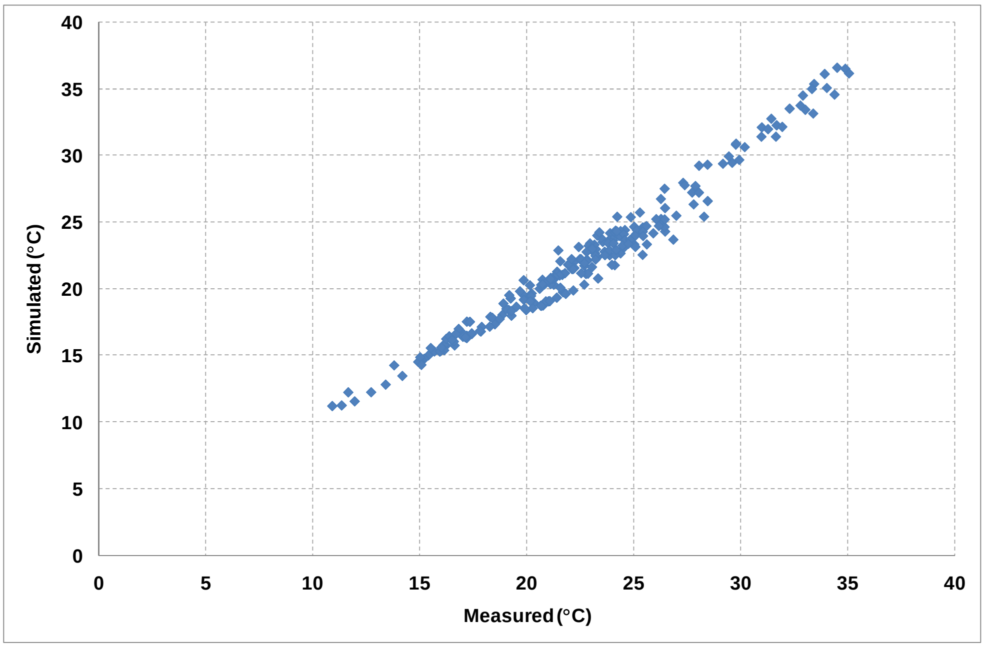


Figure 10: Measured vs simulated internal temperatures

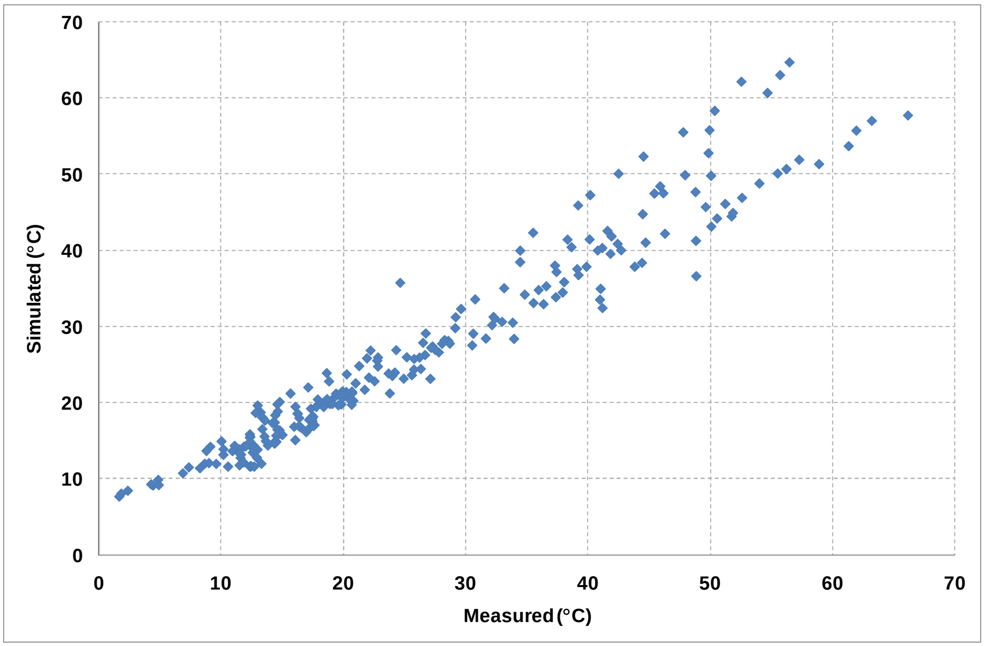


Figure 11: Measured vs simulated roof temperatures

	Internal temperature	Roof temperature
Root Mean Square Error (RMSE)	1.082 (°C)	3.705 (°C)
Mean Bias Error (MBE)	– 0.553 (°C)	0.755 (°C)
Correlation Coefficient (CC)	0.985	0.970

Table 7: Statistical parameters

By using the validated TRNSYS model the following were investigated:

- Effect of roof paint reflectivity on cooling and heating load
- Effect of roof paint with highest reflectivity on various insulation levels
- Effect of roof paint with highest reflectivity on various shading levels
- Effect of roof paint with highest reflectivity on various roof pitches

Field Results

The results of the onsite measurements conducted between December 2010 and July 2011 (ongoing) have been separated into a summer (January 1 – 14) and winter (April 23 – 8th May, 2nd – 16th June for Reflection) data sets. These sets are the most suitable for analysis for a number of reasons (e.g. the control building is air-conditioned making comparisons difficult, sensors being added or changed during the study) and allow a closer look at the performance of the tested products.

Indoor Temperatures

The summer indoor temperature profiles suggest that the CRP product test buildings maintain a 2 or 3 degree lower internal temperature compared with the control building at the warmest part of the day. This visible difference is most obvious during the warmest parts of the day, however a similar effect can be seen overnight also. The main source of difference seen in the indoor temperatures of these test buildings would be the solar radiation.

Figure 12: Summer Indoor Temperature (11 days)

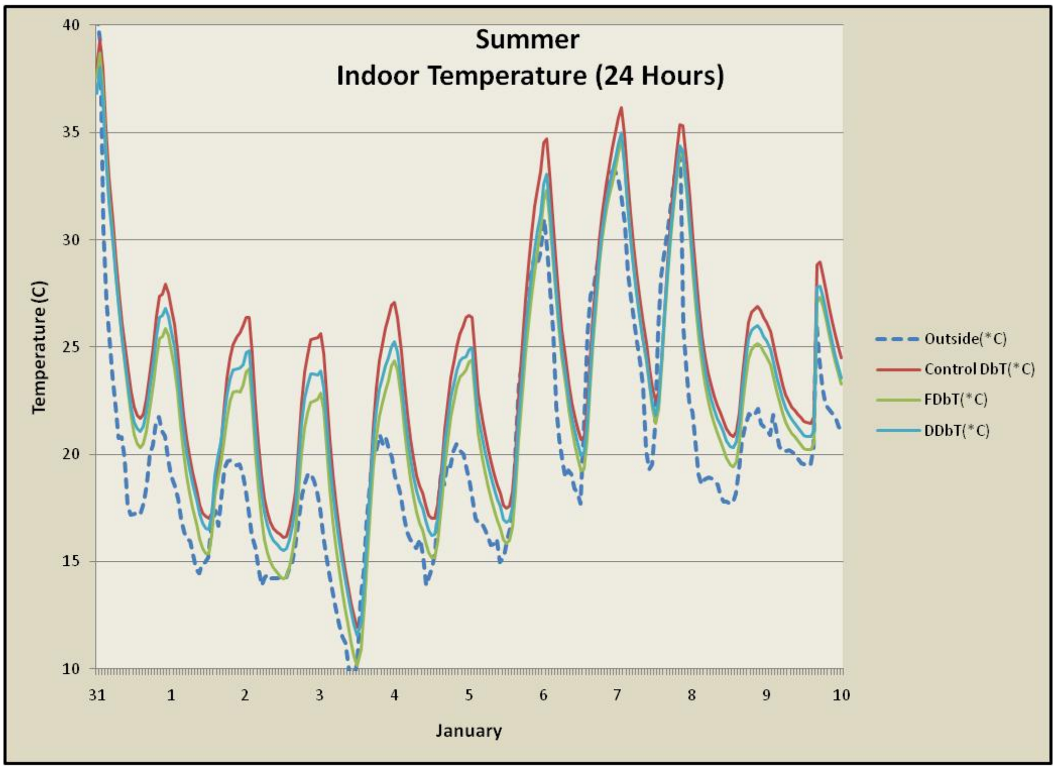
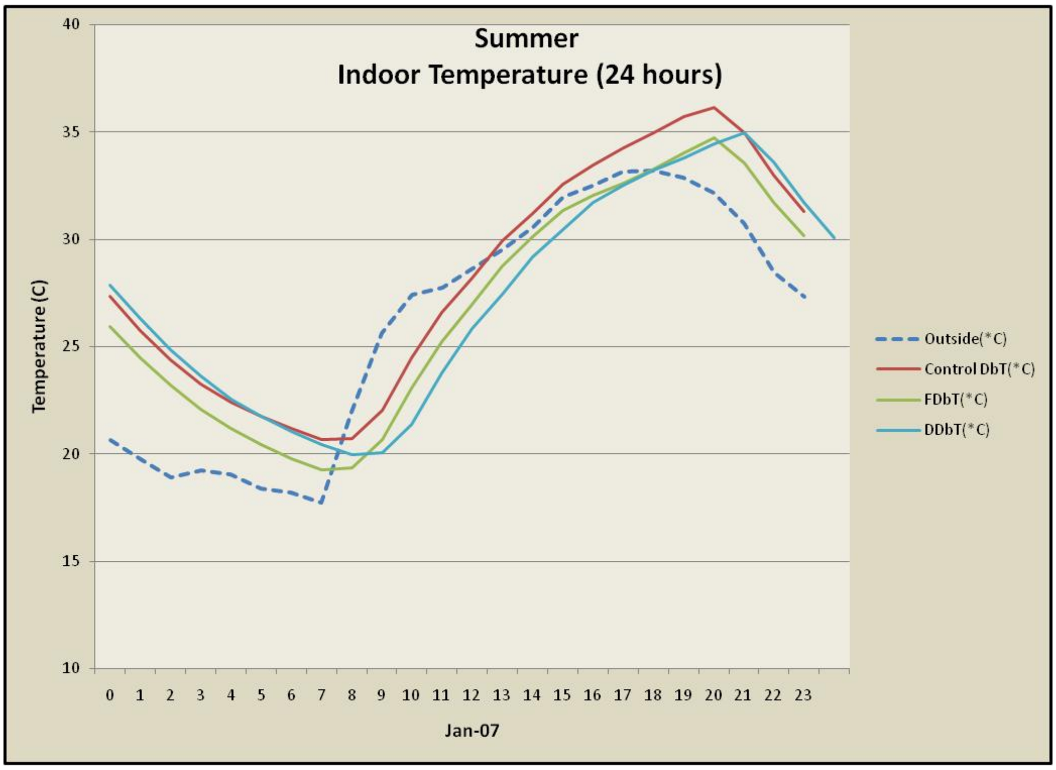


Figure 13: Summer Indoor temperature (24 hours)



The day time winter indoor temperature profiles for the test buildings do not show any significant difference to the control building. This is most likely due to the lower solar radiation at this time, and therefore conducted heat gains and losses are a more significant factor in determining indoor temperatures.

The night time temperatures of the test buildings show a lower temperature reading through the night. This supports the notion that these products assist with the extraction of heat from within the building to the atmosphere (related to the thermal emittance of the materials).

It is worth noting that both the computer simulations and the field results support the suggestion that the insulation used in the ceiling / roof cavity is negating the majority of the effect on indoor temperature of these products in the field study. As such, a building that does not have bulk insulation would get a greater benefit from the use of these products.

Figure 14: Winter indoor Temperature (14 Days)

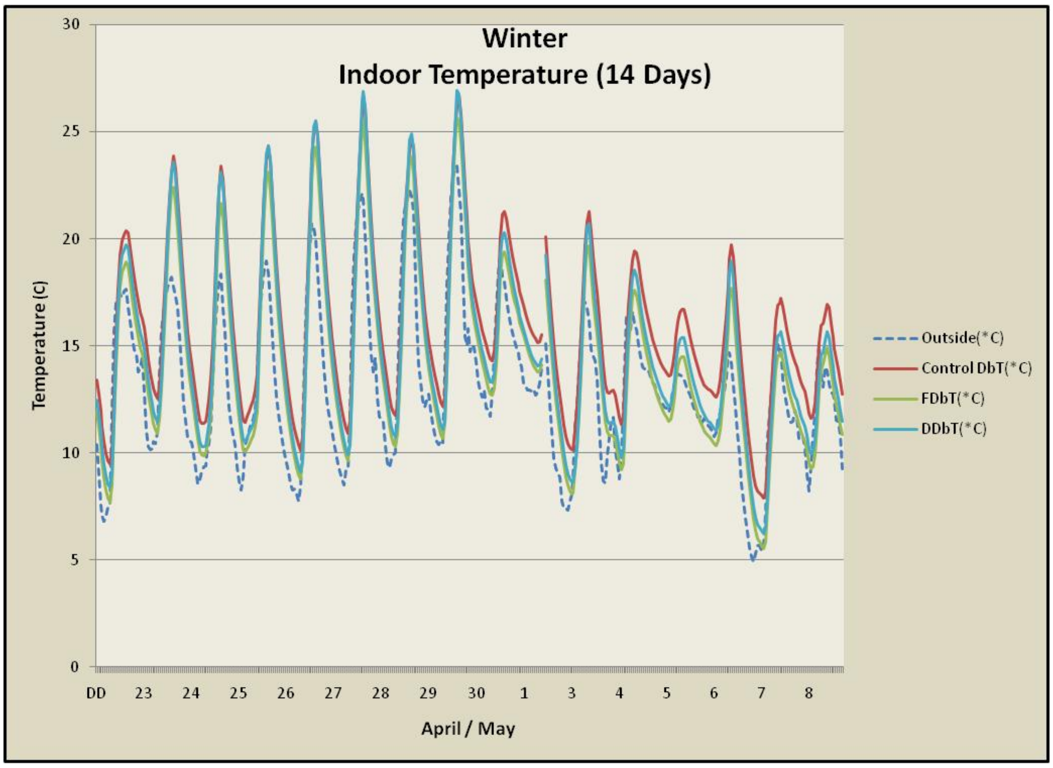
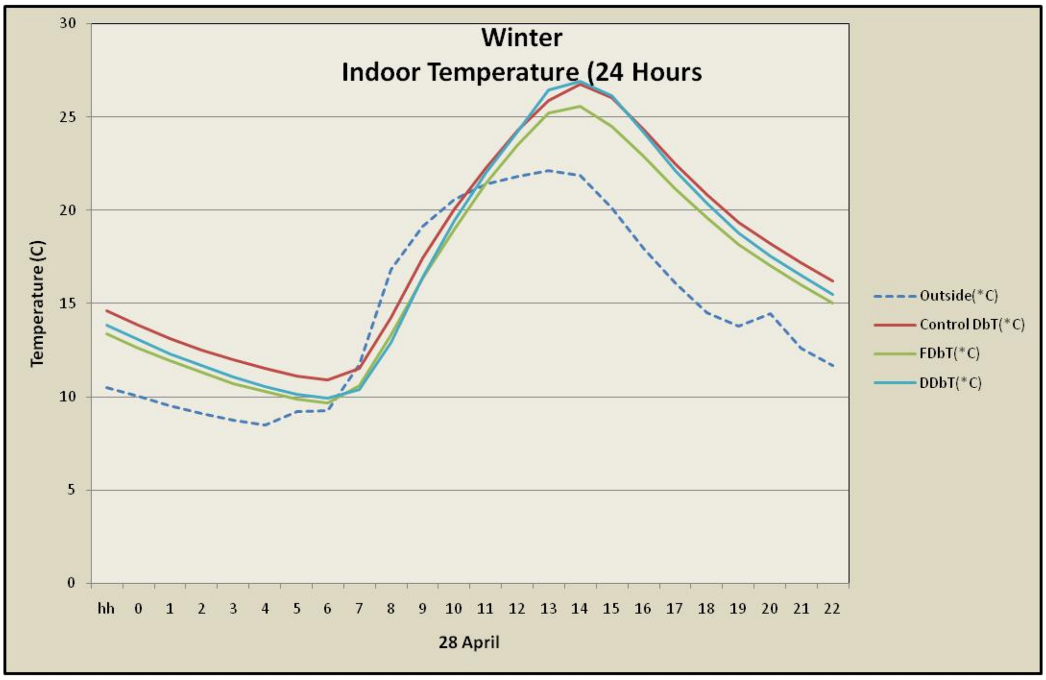


Figure 15: Winter Indoor Temperatures (24 hours)



It is clear that the products are reducing both daytime (summer) and night-time (winter) temperatures.

Roof Surface Temperatures (external)

The roof temperatures results refer to the outside temperature of the roof surface. The results show that CRP's significantly reduce the surface temperature and make the difference between being too hot to touch and being warm to touch.

Figure 16: Summer Roof Temperatures (14 days)

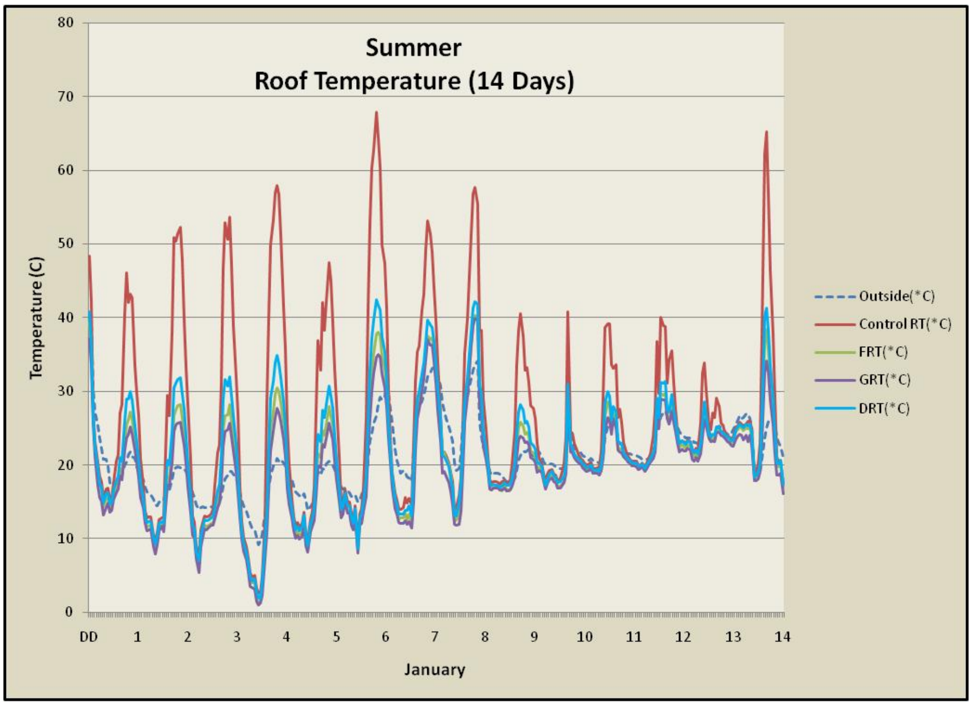
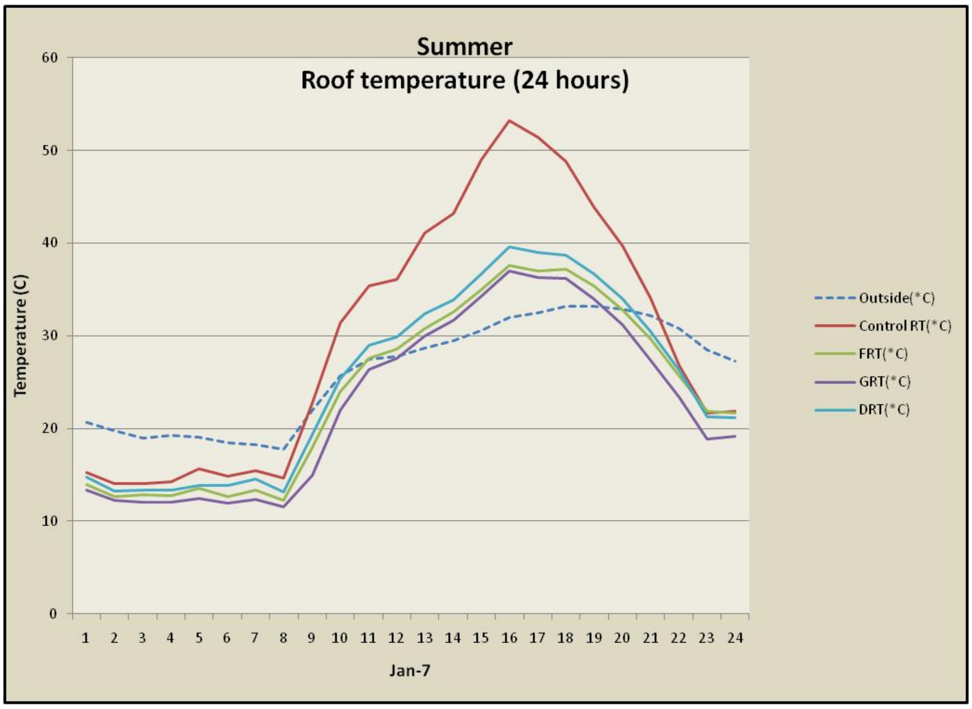


Figure 17: Summer Roof Temperature (24 hours)



The summer roof temperature profile shows a clear difference of up to approximately 30 degrees. As can be seen on the 6th January the control roof (zincalume) reaches 68° C whilst the coolest roof is 35° C – this supports the suggestion that a “normal” roof is too hot to touch whilst the CRP roofs are consistent below 40° C.

Figure 18: Winter Roof Temperature (14 Days)

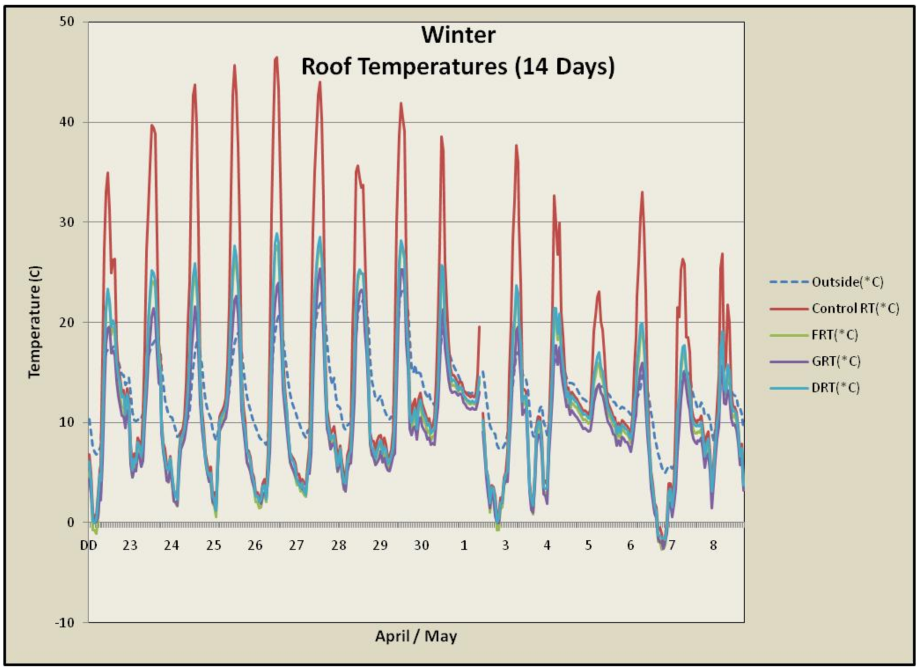
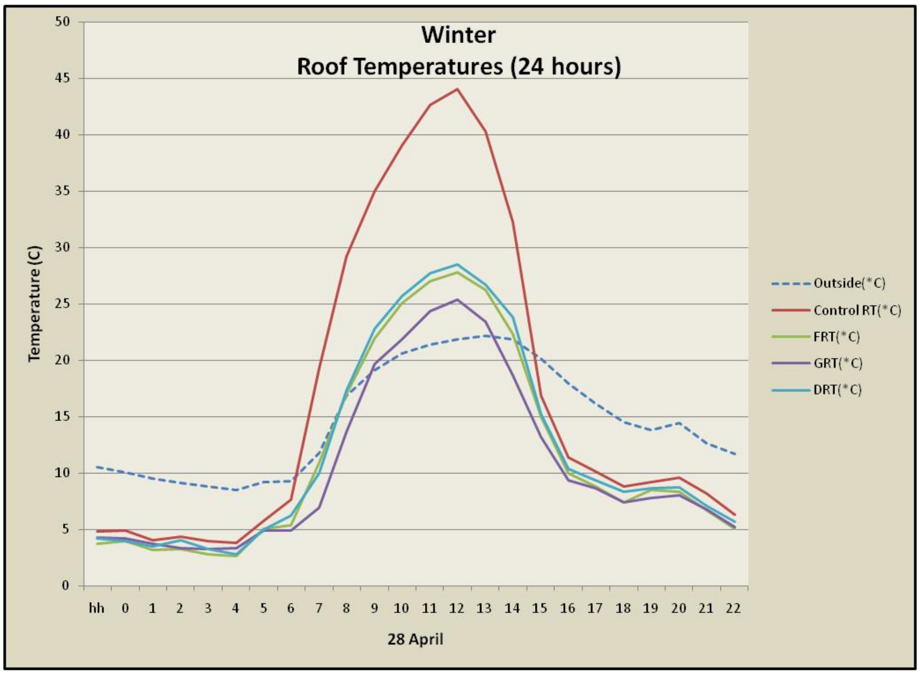


Figure 19: Winter Roof Temperature (24 Hours)



The winter roof temperature results demonstrate a similar temperature reduction which suggests that although the roof surface temperatures are lower in general, the CRP roofs still provide a temperature reduction that is comparable with the summer results. Consistent with previous findings and product literature, the CRP products are reducing radiant heat into buildings.

Roof Reflectivity

The horizontal solar radiation reflected was measured and shown below, comparing the roof types. We measured both horizontal radiation, that is going straight up into the air and vertical; that is deflected down the slope of the roof (Figure 20 insert). It was found that the horizontal and total reflection were very similar for roofs with low slopes such as these, and thus this single measure was used, that is the vertical component is a very small component of the total.

Figure 20: Summer Reflectivity (14 Days), insert difference between horizontal re-radiation or reflection of solar energy measured by the pyranometers and vertical re-radiation.

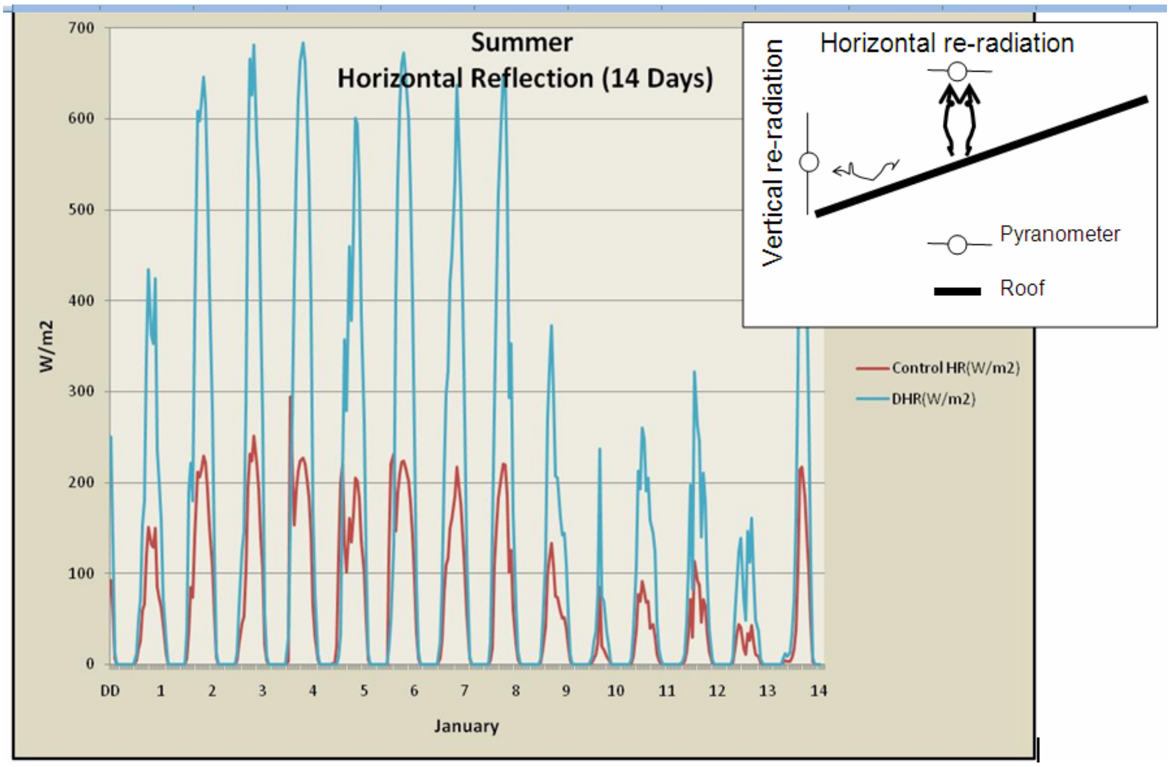


Figure 21: Summer Horizontal Reflectivity (24hours)

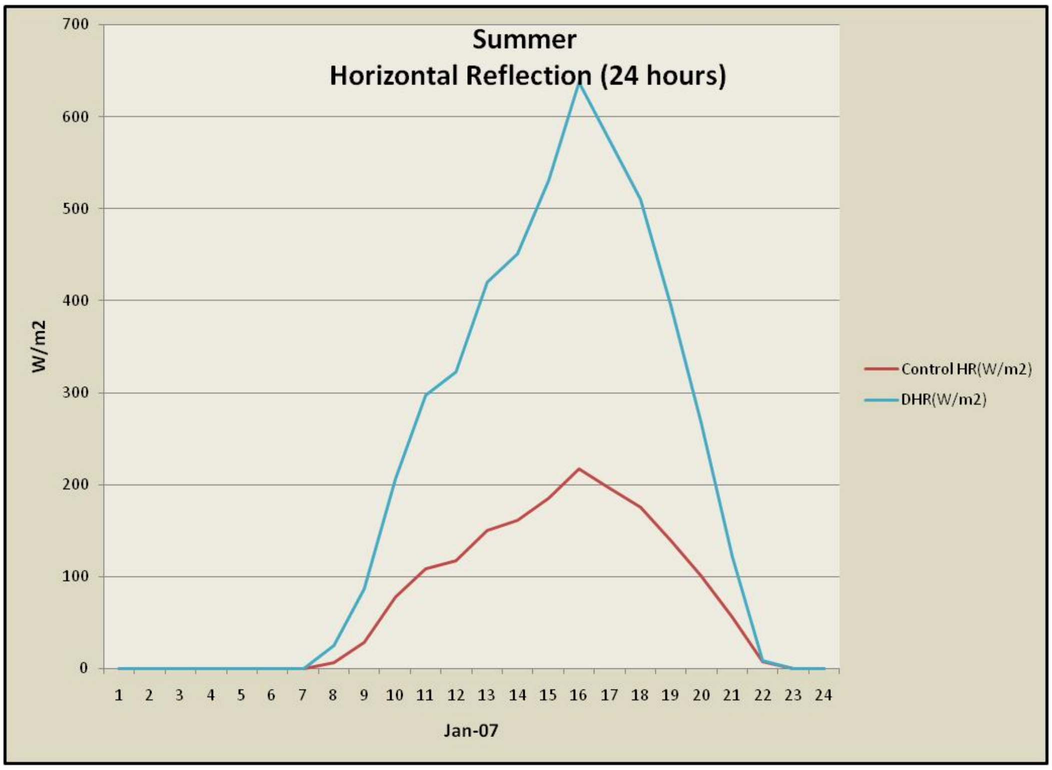
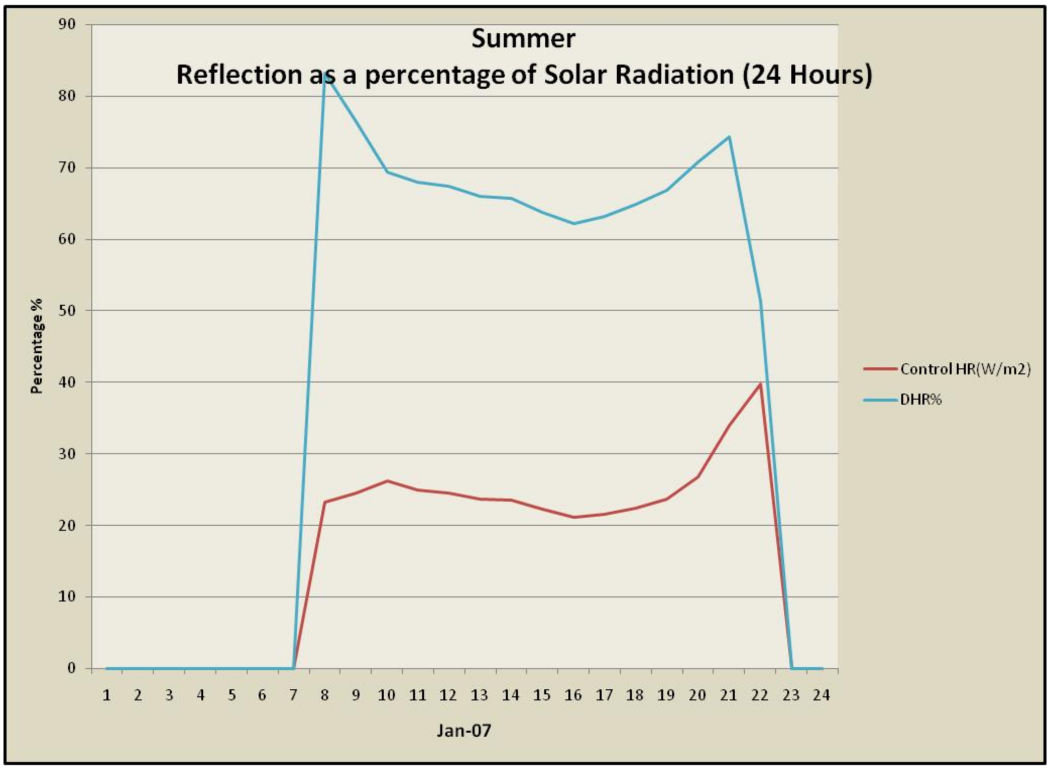


Figure 22: Summer horizontal Reflection as a percentage of radiation recieved (24 hours)



The summer results for reflectivity demonstrate a three – fold increase in reflectance from the CRP product tested above.

Figure 23: Winter Horizontal Reflection (14 Days)

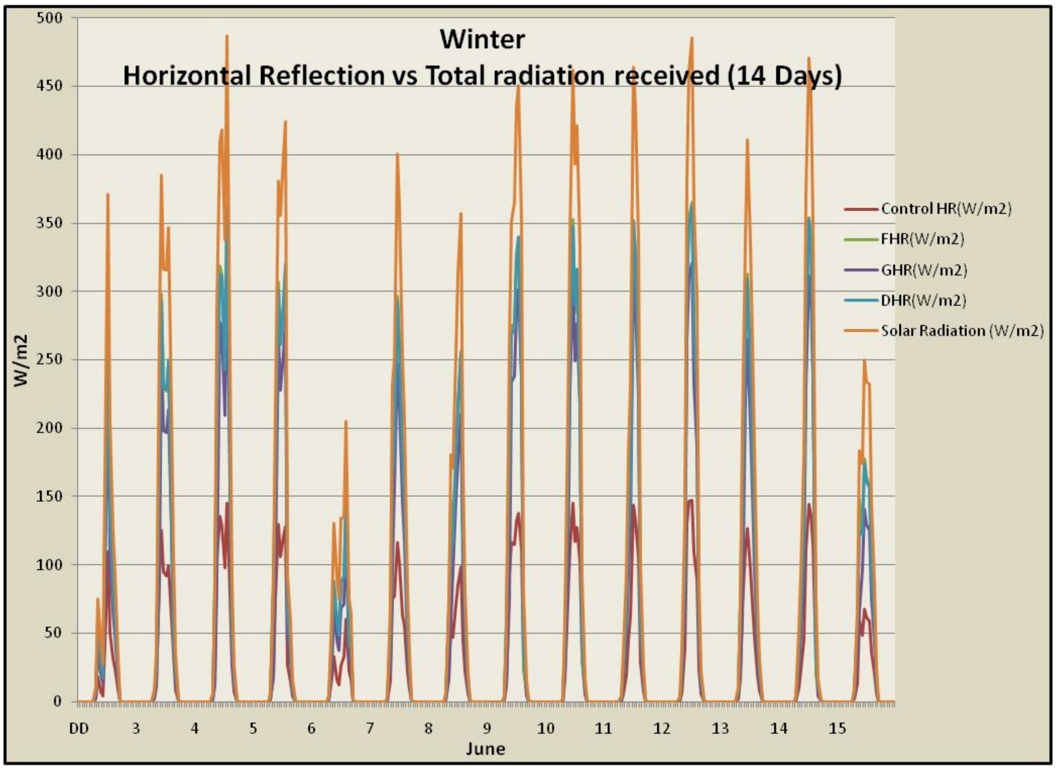


Figure 24: Winter Horizontal Reflection (24 hours)

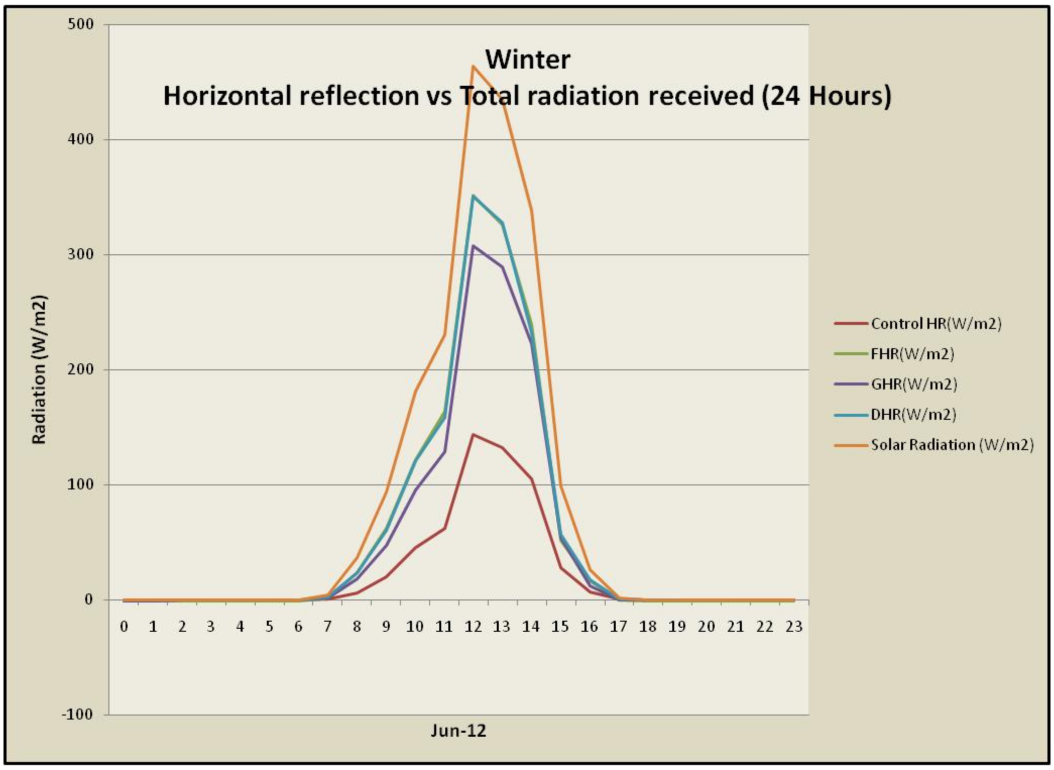
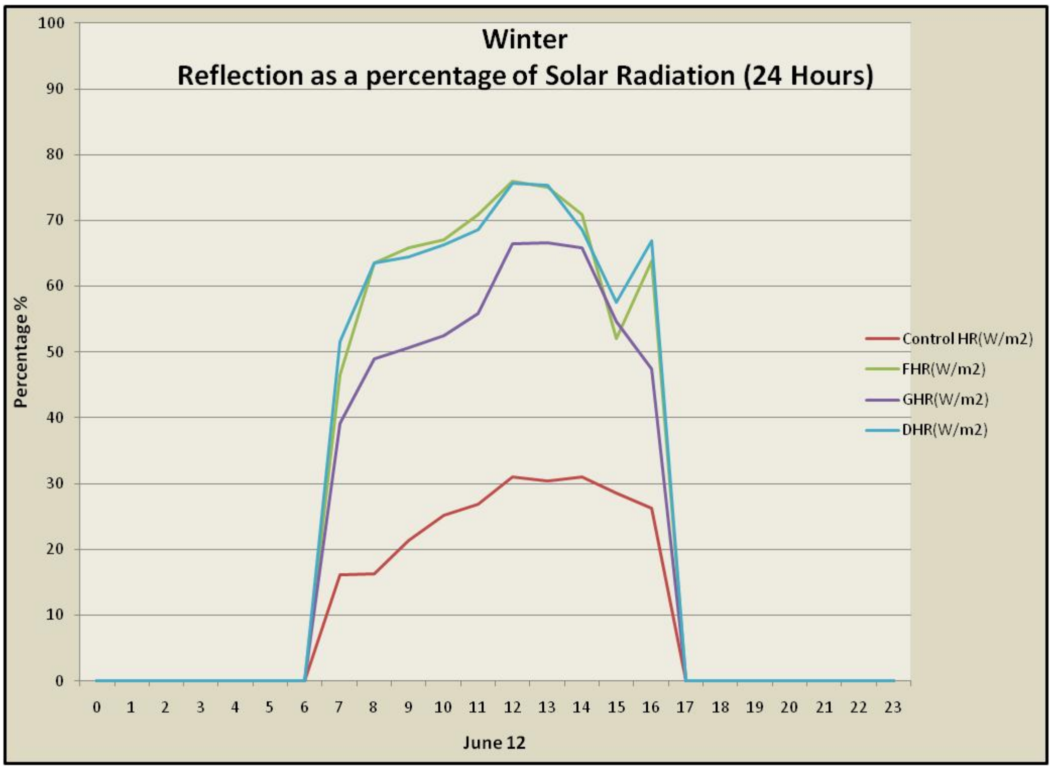


Figure 25: Winter reflection as a percentage (24 hours)



The control building is unfortunately absent from the winter results however it is possible to compare the 3 CRP roofs. This outcome suggests that two products are similar in performance (and with similar properties and specifications).

Product G, although very high performing, has properties that are designed for insulating and reflective benefits. As such in this study this product is about 10% less effective in reflecting heat than the products designed purely for reflectance.

Field Results Summary

The field testing demonstrates a clear benefit of the CRP products in reducing indoor temperatures, reducing roof surface temperatures and increasing the reflection of heat and light. The reduction of indoor temperatures is heavily influenced by the amount of insulation in the ceiling – this was not demonstrated however it is consistent with the simulation findings (see below)

Simulation Results

Field Test Buildings – modelling for total energy use

The results of the simulation show that for all white roof paints there is a benefit annually of between 0.88 and 1.53 MJ/m^2. So for an average 200m^2 home this would be equal to between 176-306 MJ per year. This represents only a small improvement for this type of building (total energy use in this example being 7,300MJ, this represents a 4.2% benefit).The predominant reason is the effectiveness of the insulation, see the sensitivity study carried out below.

Savings in energy				
Type of roof paint	Absorptance	Heating energy (MJ/m^2)	Cooling energy (MJ/m^2)	Total energy (MJ/m^2)
DI-white	0.21	-9.91	11.43	1.52
Product G	0.21	-9.91	11.43	1.52
DI-cream	0.34	-8.22	9.05	0.83
Product D	0.4	-7.03	7.91	0.88
DI-Terracotta	0.62	-3.24	3.65	0.41
DI-charcoal	0.76	-0.71	0.84	0.13
Base case	0.8	0.00	0.00	0.00
Product F	0.25	-9.19	10.72	1.53

Table 8: Energy Savings

Field Test Buildings – modelling for variation to R-value

From the simulation using the field test buildings it shows that an increase in R-values reduces the benefit of the paint on heating and cooling energy. When there is no insulation, then there is a benefit in using the CRP's(for an average 200m^2 house this would be 800MJ, but given BCA standard for insulation added under deemed to satisfy of R2.5, the benefit is 0). This means that from an energy saving perspective the CRP's will impact existing housing with lower or zero insulation, but will not benefit new housing with standard insulation levels. It is worth noting that there will be an impact on the urban heat island effect due to lower heat build up.

Savings in energy MJ/m^2)			
R value	Heating	Cooling	Total
Base case (R=0.82)	-9.9	11.4	1.5
0.0	-13.8	18.0	4.2
1.5	-7.7	8.5	0.8
2.5	-6.2	6.1	-0.1
3.5	-4.0	4.7	0.7
5.0	-4.1	3.3	-0.8

Table 9: Insulation energy savings

The table above shows that the modelling assumption is based around a Ceiling R-value of R2.5 – hence the R2.5 saving is zero (0)

Field Test Buildings – modelling for variation to roof pitch

From the simulation using the field test buildings, with an increase in roof pitch with a fixed R-value of 2.5,there is no benefit from the application of CRP on total energy use. This is due to the effectiveness of the insulation, as discussed above.

Savings in energy MJ/m^2			
Roof pitch	**Heating**	**Cooling**	**Total**
0.0	-6.2	6.1	-0.1
4.8	-6.2	6.1	-0.1
20.0	-6.5	6.4	-0.1
50.0	-8.7	8.7	0.0

Table 10: Roof pitch energy savings

Yet when comparing the heating and cooling energy requirements, it is clear that increased roof pitch leads to a higher heating energy, irrespective of the paint on the roof.

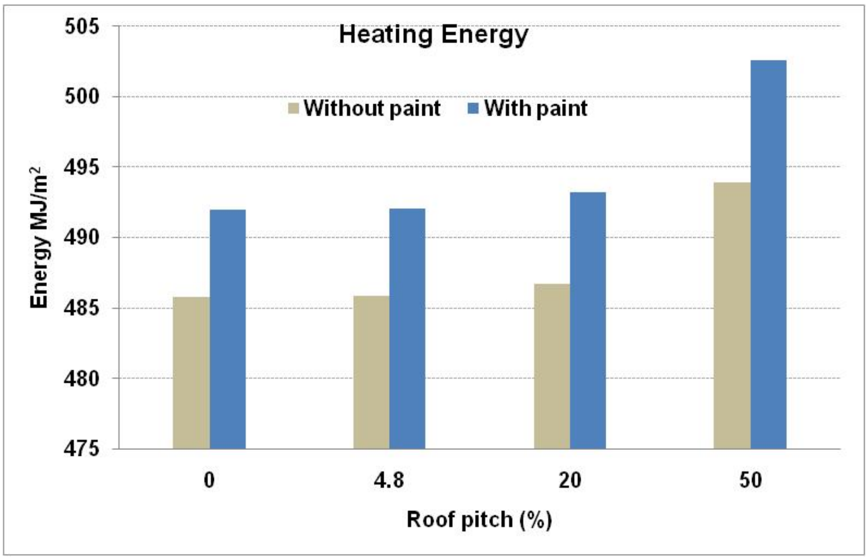


Figure 26: Heating energy with roof pitch

For cooling energy, the steeper the roof slope the greater the benefit of the CRP. This therefore concludes from this simulation that it makes sense to paint sloped roofs if artificial cooling is used.

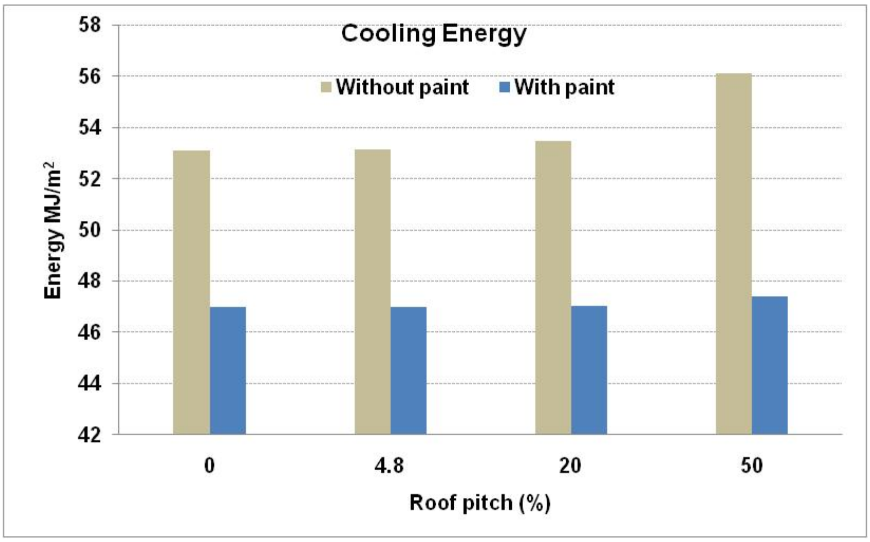


Figure 27: Cooling energy with roof pitch

However, given the assumptions of the model, and that cooling is such a small percentage (~10%) of the total energy use for residential projects– roof slope is not a significant factor in deciding to paint an insulated residential roof with CRP.

Again these results do not discuss the urban heat island effect only the internal temperature factors. For the urban heat island effect there would be less build up in the city and therefore less cooling required.

Field Test Buildings – modelling for variation to shading of the roof surface

From the simulation using the field test buildings, it shows that an increase in shading of the roof with a fixed R-value of 2.5 there is no net benefit from the application of CRP. This isbe because of the effectiveness of the insulation, the initial sensitivity test for this is shown above.

Savings in energy MJ/m^2			
Shading %	**Heating**	**Cooling**	**Total**
0.0	-6.2	6.1	-0.1
20.0	-4.9	4.8	-0.1
50.0	-3.2	3.0	-0.2
70.0	-2.0	1.8	-0.2

Table 11: Energy savings with shading

In Winter, more shading requires more heating and this reduces the benefit from the paint.

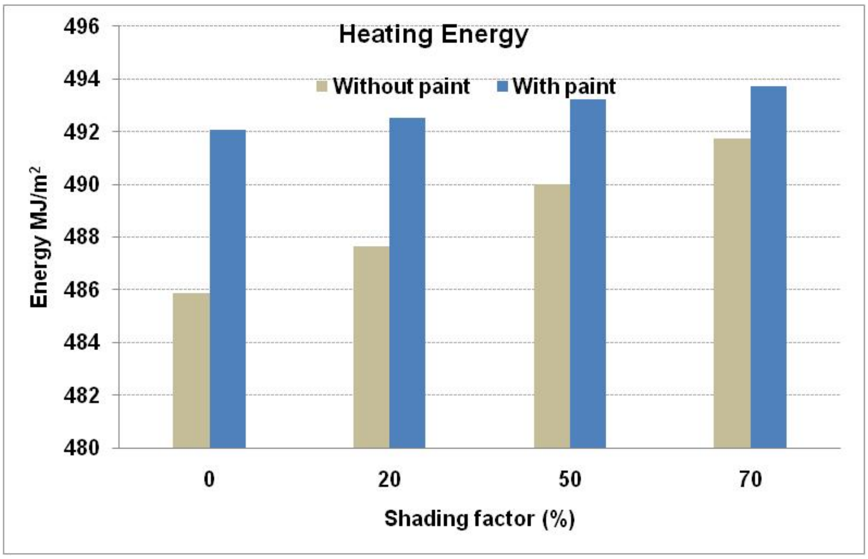


Figure 28: Heating energy with shading factor

In summer, shading requires less cooling and reduces the benefit from the paint.

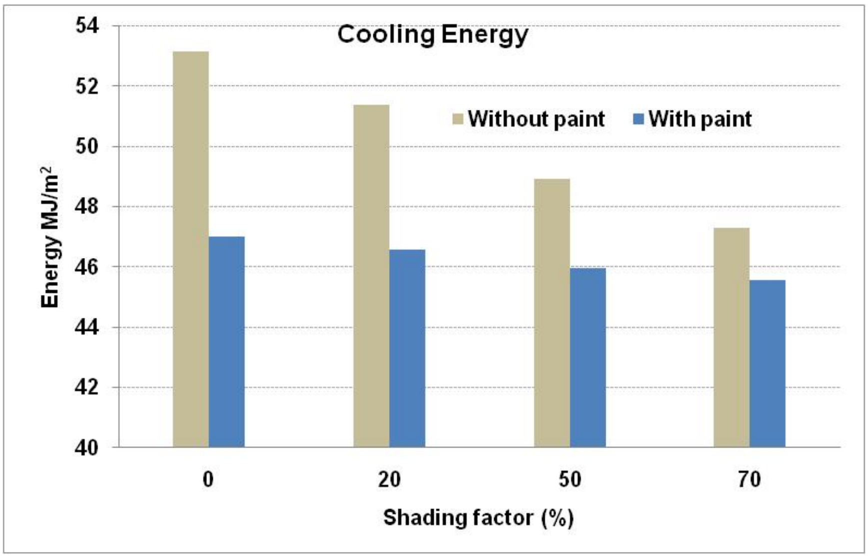


Figure 29: Cooling energy with shading factor

In summary, in both scenarios the shading reduces the benefit of the paint.

Again these results do not discuss the urban heat island effect only the internal temperature factors. For the urban heat island effect there would be less build up in the city and therefore less cooling required.

Sample Building Modeling – residential variation of insulation location in roof space

Across the year, the difference between using a CRP and not using a CRP can result in an increased roofspace temperature of up to 18.5oC (assuming R2.5 insulation fitted to the ceiling). This is illustrated below – it can be seen that summer roof space temperatures increase from the 20 – 30oC range with the use of CRP products to in excess of 45 degrees.

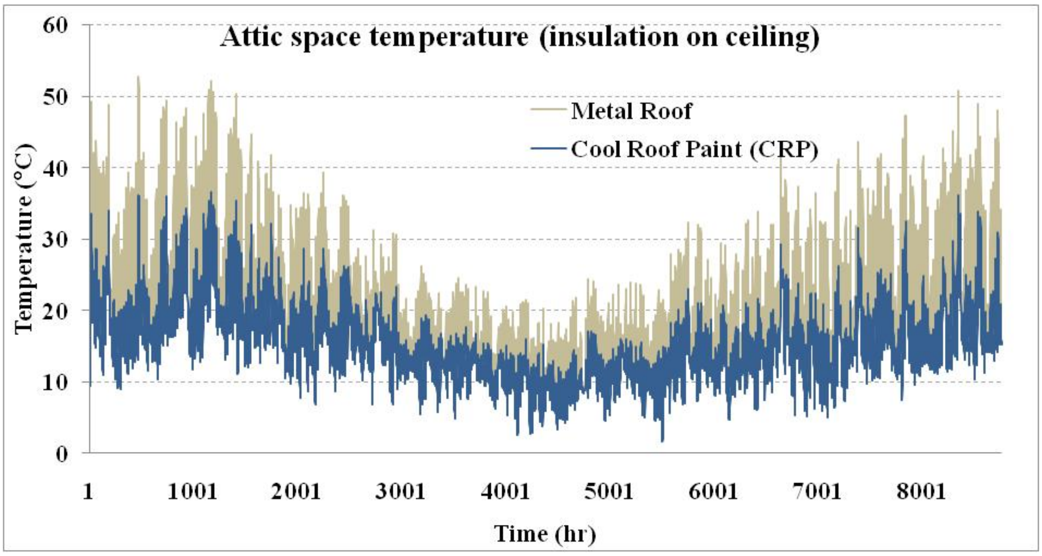


Figure 30: Attic temperature with insulation on ceiling

If the insulation is moved from on the ceiling to under the roof (i.e. from being between the roof space and the habitable room to being between the roof and the roo fspace), it dramatically reduces the roof space temperatures to the point where the effect of the CRP is much less significant.

In other words, houses with an unvented attic roof space and insulation only on the ceiling will get a significant benefit from the CRP's, as roof space temperatures will otherwise reach up to 50°C, which will act to slowly heat the habitable spaces below.

Houses with vented roof spaces, or insulation under the roof material (insulated sarking, air cell or similar) will receive less benefit from the use of CRP's as the heat is not getting into the roof space.

It should be noted that this component of the research is not accounting for the difference in the amount of cooling vs. heating required for a residential dwelling which skews dramatically in favour of the heating conditions for the Melbourne climate. Both graphs show that for a large part of the heating season the roof space is below the typical indoor comfort temperature range (and therefore would be drawing heat out of the habitable space) and thus these houses would respond better to higher roofspace temperatures (i.e. a darker roof).

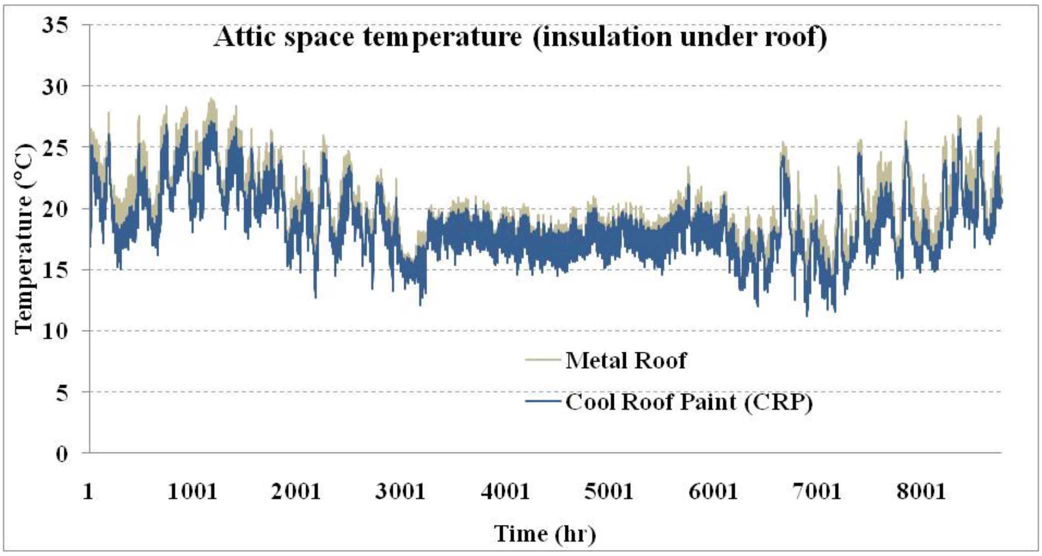


Figure 31: Attic temperature with insulation under roof

The above results demonstrate that the CRPs are effective in reducing summer heat build up in buildings with attic roof spaces. This is an excellent outcome for both air-conditioning energy use as well as a reduced contribution to the Urban Heat Island effect.

Sample Building Simulation – Commercial and Residential Heating and Cooling Energy

To investigate the impact of the CRP products on different building types, a commercial, residential and industrial building were modelled. This approach was designed to continue the study beyond the field test buildings to more “real world” examples (specifications of which can be found in the appendices).

Why test different building typologies?

Commercial buildings have a day time occupancy profile, a much higher cooling load and unique building dimensions (often tall with a low roof area). Residential buildings have predominantly night time occupancy, a higher heating requirement, relatively high levels of insulation, and a total roof to floor area that is greater than the commercial building. Finally, the industrial buildings tend to have longer or 24 hour occupancy, are not conditioned, have large roofs compared to total floor area (i.e. be one story with large footprints).

The residential buildings showed little benefit from the CRP’s, as shown by the simulation and results of the field test buildings, the typical insulation levels are overpowering the effects of the CRP’s or other variations. This result is also found with the computer modelling where the energy savings in both summer and winter show no effect from the use of CRP resulting in a total zero effect. Older un-insulated buildings receive a positive benefit from the CRP’s

The commercial building showed a small benefit to cooling load (3%) by using the CRP. This of course is dependent on the proportions of the building, its usage, construction, and other specifics. It is noted that the literature showed studies that found a benefit of up to 20% of the CRP’s.

Structure	Absorptance	Annual (MJ)		Average (MJ/m^2)		total MJ m2	total MJ savings per m2
		Heating	Cooling	Heating	Cooling		
Commercial base case	0.8	155876	308979	50.9	101.0	151.9	
Commercial_thermoshield	0.21	159036	299504	52.0	97.9	149.8	2.1
Residential base case	0.8	13102	2280	99.7	17.3	117.1	
Residential_thermoshield	0.21	13102	2280	99.7	17.3	117.1	0.0

Table 12: Heating and cooling total energy

Sample building simulation – effect of height of a commercial building

The above results used a four storey office building. Given many buildings are significantly taller than this; a simulation was run on different height buildings, all with the same properties.

Storeys	Absorptance	Annual (MJ)		Average (MJ/m^2)		Savings (%)				
		Heating	Cooling	Heating	Cooling	Heating	Cooling	Total MJ	MJ difference	MJ per m2
4	0.8	155876	308979	51	101	-2.03	3.07	464855		
	0.21	159036	299504	52	98			458540	6315	2.1
10	0.8	437128	782338	57	102	-1.54	1.86	1219466		
	0.21	443873	767823	58	100			1211695	7770	1.0
20	0.8	905881	1571270	59	103	-1.40	1.46	2477150		
	0.21	918601	1548354	60	101			2466955	10195	0.7
30	0.8	1374633	2360201	60	103	-1.36	1.33	3734835		
	0.21	1393329	2328886	61	101			3722215	12620	0.5

Table 13: Effect of height of building

The above table shows that the lower building (four storeys) receives the greatest benefit from the CRP, and the tallest building receives the least benefit from the CRP.

Sample Building Simulation – industrial internal temperature profile

Because the industrial building does not use energy for heating or cooling, the analysis was instead made on internal comfort conditions. Although this approach results in a direct comparison of performance of with and without CRP, it is more difficult to assign a cost saving to the use of the products.

The results show that both the CRP and base case roofs result in buildings are uncomfortable at times, but that the CRP building maintained a significantly lower internal temperature during these times. To illustrate this, as can be seen from the graph below, on a day when the base case building internal temperature approach 40 degrees, the CRP building maintained approximately 33 degrees. This represents a difference of 7 degrees or approximately 17% cooler conditions.

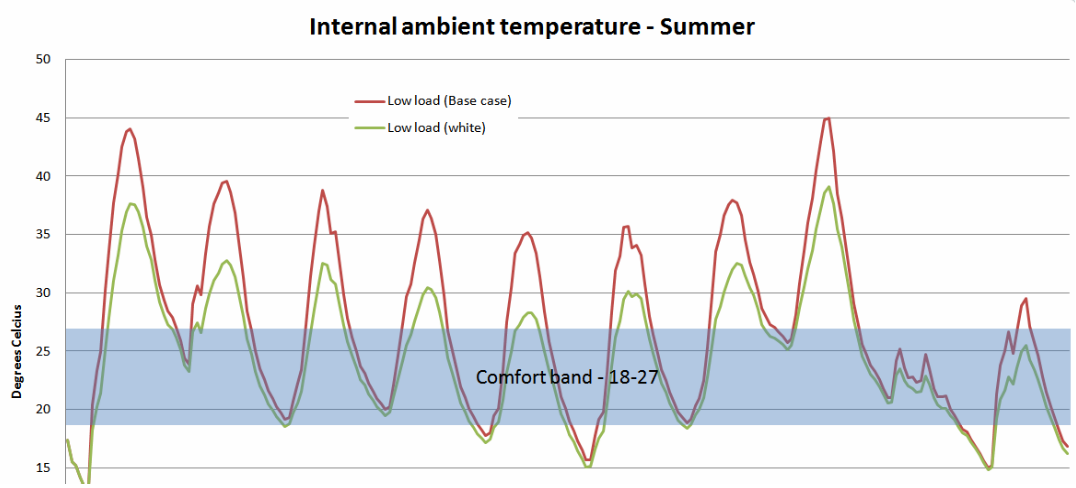


Figure 32: Industrial internal temperature - summer

In winter neither building is comfortable due to the lack of insulation and gap sealing, nor in this case the CRP is keeping the indoor temperature down, below comfort temperatures in some conditions.

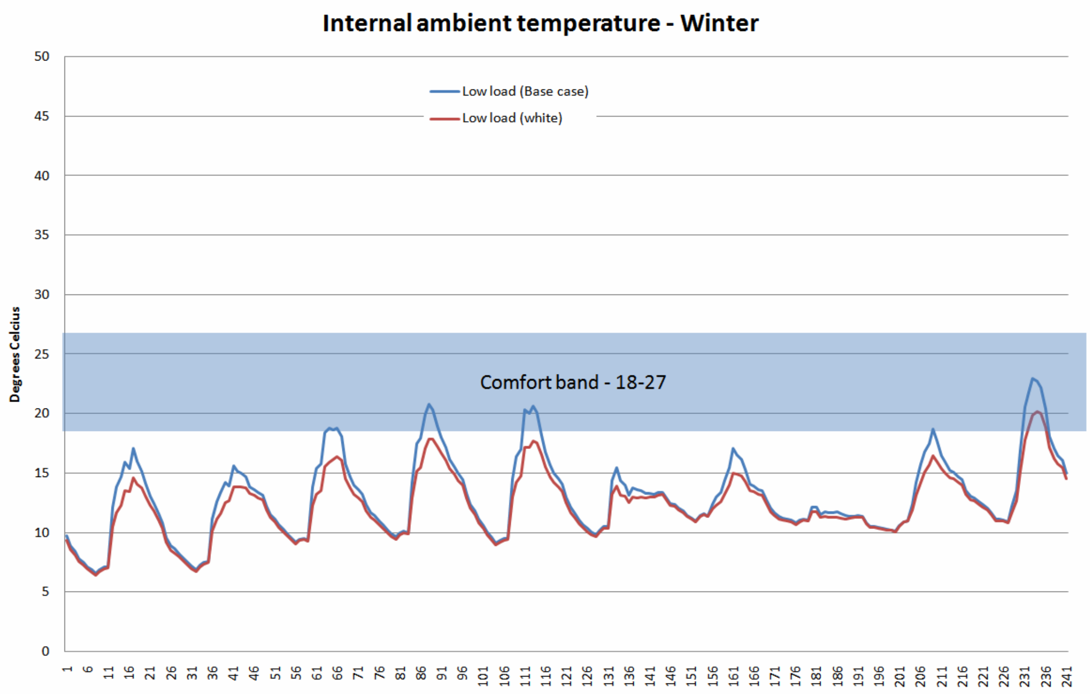


Figure 33: Industrial internal temperature - winter

Sample Building Simulation – Industrial Energy Use profile

Although the testing on the industrial style building assumes there is no heating and cooling, but rather an impact on the level of comfort between the CRP and Non-CRP models, it is of interest to draw comparisons of the energy use if the spaces were heated and cooled to quantify the benefits of the CRP.

The modelling for the industrial building was completed using two internal load profiles:

1) A high load profile – 100W/m^2 – representing a process style building such as manufacturing

2) A Low load profile – 10W/m^2 – representing a storage style building, such as a warehouse

Type of load	Absorptance	Annual (MJ)		Average (MJ/m^2)		Total
		Heating	Cooling	Heating	Cooling	
High load - Metal	0.80	156989	465382	157	465	622
High load - CRP	0.21	192756	185890	193	186	379
Low load - Metal	0.80	365014	266729	365	267	632
Low Load - CRP	0.21	467956	80260	468	80	548

Table 14: Industrial energy savings

The results show in the above table demonstrate that cooling energy for both scenarios is significantly reduced (59% reduction high load, 70% low load), but that heating energy is increased (18.6% high load, 22% Low load).

It is important to remember that these figures are heavily biased by the fact that the industrial building model assumed zero insulation and very poor thermal performance and as such very high cooling energy figures are easily influenced by the improvement given by the CRP. As has been demonstrated previously, if this building were to be heated and cooled in real life it would be required to have a minimum of R1.8 wall insulation and R3.2 ceiling insulation, which would significantly decrease the effect of the CRP seen here. This again supports the idea that CRP products are best suited to older and/or uninsulated buildings.

The following table represents the number of hours outside the comfort zone, which determines the number of hours that cooling or heating would be required. This is different to the above results which show the total demand, this represents the amount of time that external conditioning is required. For example, day 1 may require 8 hours of cooling with a total demand of 200MJ. Day two may require 10 hours of cooling with only 100MJ.

No of hrs outside comfort zone (<18 and >27)		
Type of load	**Absorptance**	**hrs**
High load - Metal	0.8	5136
High load - CRP	0.21	4655
Low load - Metal	0.8	5360
Low Load - CRP	0.21	5361

Table 15: Industrial – hours outside of comfort zone

It can be seen here that the high load scenario receives a 9% reduction in hours outside the comfort zone compared with standard roofing products, whilst the low load scenario receives no benefit. This is due to the fact that uninsulated CRP products reduce the heat gained from the sun in winter, as well as reducing the heat gain in summer. This has an overall effect of making summer more tolerable (less hours above comfort) but winter less tolerable (more hours below comfort temps)

This result is consistent with the internal temperature modelling results.

Conclusions

Extensive field testing in conjunction with detailed computer modelling have demonstrated that the both methodologies are suitable to determine the effectiveness of CRP products on a range of building typologies. Our computer modelling validation studies have been very accurate in replicating the effects seen in the field tests.

From this it is concluded that computer simulation is an appropriate methodology to study the effects and benefits of CRP products on a variety of buildings without the need to replicate it in full scale. This means that a “calculator” type approach for consumers to consider the benefits of these products would be effective.

The field tests and computer simulation both have shown that CRP products are highly effective at reflecting solar radiation and lowering roof surface temperatures, when compared with a standard metal roof material. Both testing methodologies also have demonstrated that the products reduce indoor temperatures of the test buildings both during the day and at night-time. This supports the claims of manufacturers that the products are effective at reflecting radiation AND emitting heat at night time. Furthermore, these results are fairly consistent between the summer and winter seasons. The single drawback of these products has been shown to be this heat reduction consistency between seasons as it is not particularly well suited to the Melbourne heating climate.

The computer simulation results tested the effect of roof pitch, roof shading, roof insulation levels, and the location of the insulation in the ceiling cavity. It is clear from the results that the level of insulation specified in the model had a very significant effect on the results, and far outweighed the significance of all of the other variables. Despite this result, it was clear that the other tested variables do have an effect on the results as would be expected, and a more significant effect would be seen if the test building was modelled with no ceiling insulation.

For a typical residential building, the simulation showed that a standard attic space temperature profile would vary greatly based on the location of the insulation. If the insulation is located on the ceiling (below roof space - as is the case with most residential buildings at this time) the attic space would be up to 18.5 degrees cooler with the use of CRP. If the insulation is located under the roof (above the roof space) the CRP’s have only a minor impact on the temperature of the roof space.

When extending the computer simulation of the CRP’s to a typical commercial and industrial building, again the importance of ceiling insulation to the results became apparent. It was demonstrated that a commercial building in Melbourne could benefit by approximately 3% in terms of cooling energy reductions – it is expected that much higher savings would be achieved depending on the building age, construction and location, as found in the literature review. This result suggests that many older office style buildings would benefit from the use of these products.

Uninsulated, un-conditioned industrial buildings also can benefit from these products, with the results showing that depending on the internal temperature load, a significant reduction in indoor temperature can be achieved. Conversely, in an industrial building that has a low internal gain profile, such as a warehouse or similar, the products had the effect of improving the comfort (indoor temperature) in the summer months and reducing the comfort in the winter months, leading to a net zero benefit.

It is clear from the results of this study that buildings with high cooling loads and minimal insulation will received significant benefits with the use of CRP's. Buildings without a significant cooling load, and with typical insulation levels (e.g. residential buildings) can benefit from these products, but will be sensitive to roof pitch, shading and of course the level of ceiling insulation.

References

Literature Review

Akbari, H. (2003). Measured energy savings from the application of reflective roofs in two small nonresidential buildings. *Energy.*Vol 28*.* Issue 9, 953-967.

Akbari H, and Konopacki, S. (2005).Calculating energy saving potentials of heat-island reduction strategies, *Energy Policy* vol 33, no 6, pp721 – 756

Akbari (2008) Saving Energy and Improving Energy in Urban Heat Islands. *Physics of Sustainability, Using energy efficiently and producing it renewably.*

Akbari, H. Menon & Rosenfeld (2009) *Global Cooling: increasing world-wide albedos to offset CO2 Climate Change* 94:275 – 286

Gaffin, S., and Coauthors (2008) *Variations in New York City's urban heat island strength over time and space.* Theor. Appl. Climatol., 94, 1-11.

Hogrefe C, Lynn B, Civerolo K, Ku JY, Rosenthal J, Rosenzweig C, Goldberg R, Gaffin S, Knowlton K, Kinney PL (2004a) *Simulating changes in regional air pollution over the eastern United States due to changes in global and regional climate and emissions*. J Geophys Res D – Atmospheres 109:1–13

Konopacki, AkbariH., GartlandL., and RainerL., (1998) *Demonstration of Energy Savings of Cool Roofs, Lawrence Berkeley National Laboratory Report* LBNL-40673. Berkeley, CA,

Konopacki, S.J., and AkbariH. (2001). *Measured Energy Savings and Demand Reduction from a Reflective Roof Membrane on a Large Retail Store in Austin*. Lawrence Berkeley National Laboratory Report No.LBNL-47149, Berkeley, CA.

Nowak, D. J.,. Civerolo K. L,. Trivikrama Rao, S. Sistla G.,. Luley C. J, and. Crane D. E,(2000): *A modeling study of the impact of urban trees on ozone.* Atmos. Environ., 34, 1601-1613.

Oke T. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society* 108: 1–24.

Peterson, T. Gallo, K. Lawrimore,J.; Owen T. Huang, A. McKittrick, D. (1999). Global rural temperature trends. *Geophysical Research Letters* 26 (3): 329–332.

Prado R., Ferreira, F. (2005) *Measurement of albedo and analysis of its influence the surface temperature of building roof materials*, Building System Laboratory of Escola Politécnica at University of São Paulo, São Paulo, Brazil

Rosenfeld, A., AkbariH., BretzS., FishmanB., KurnD., SailorD., and TahaH., (1995): *Mitigation of urban heat islands: Material, utility programs, updates*. Energy Build., 22, 255– 265.

Rosenzweig, C., Solecki, W.D., Parshall, L., Lynn, B., Cox. J., Goldberg, R. Hodges, S., Gaffin, S., Slosberg, R.B., Savio, P., Dunstan, F. and Watson, M. (2009).*Mitigating New York City's heat island*. Bulletin of the American Meteorological Society 90: 1297-1312

Sailor, D., KalksteinL. S., and WongE., (2002): *Alleviating heat-related mortality through urban heat island mitigation.* Bull. Amer. Meteor. Soc, 83, 663-664.

Suehrcke, H. Peterson E, Selby N (2008) *Effect of roof solar reflectance on the building heat gain in a hot climate,* Energy and Buildings 40 2224–223

Synnefa et al (2008) On the use of Cool Materials as a Heat Island Mitigation Strategy. *Journal of Applied Meteorological and Climatology American Meteorological Society.*

Taha, H., (1994): Meteorological and photochemical simulations of the South Coast Air Basin. *Analysis of Energy Efficiency of Air Quality in the South Coast Air Basin* - Phase II, LBL- 35728, H. Taha, Ed., Lawrence Berkeley Laboratory, 161– 218.

Simulation Methodology

Klein, SA, Beckman, WA, Mitchell, JW, Duffe, JA, Duffe, NA, Freeman, TL, Mitchell, JC, Braun, JE, Evans, BL, Kumar, JP, Urban, RE, Fiksel, A, Thornton, JW, Blair, NJ, Williams, PM, Bradley, DE, McDowell, TP, Kummert, M & Arias, DA 2006, TRNSYS 16: a *Transient System Simulation Program*, University of Wisconsin-Madison, WI, USA.

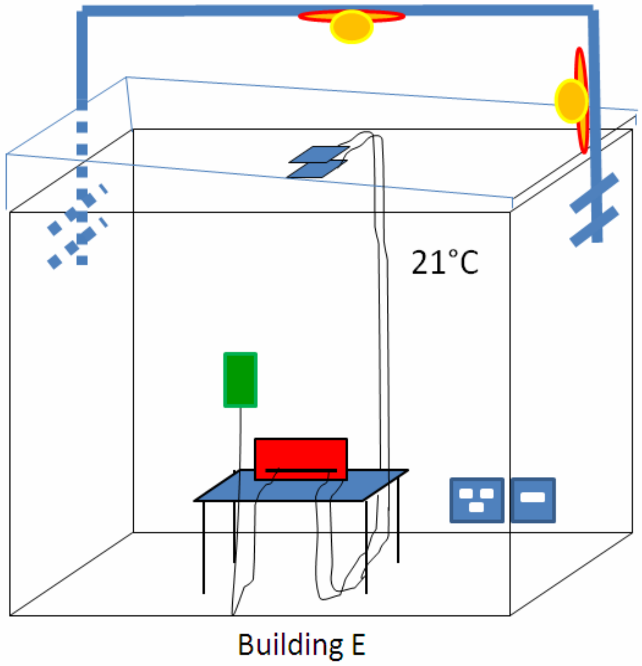
Morrison, GL & Litvak, A, (1999), Condensed *Solar Radiation Data Base for Australia,* 1/1999, 1999: Solar Thermal Energy Laboratory, University of New South Wales, Sydney, Australia.

Iqbal, M. (1983). *An Introduction to Solar Radiation*, Academic Press, Canada.

Appendix A:

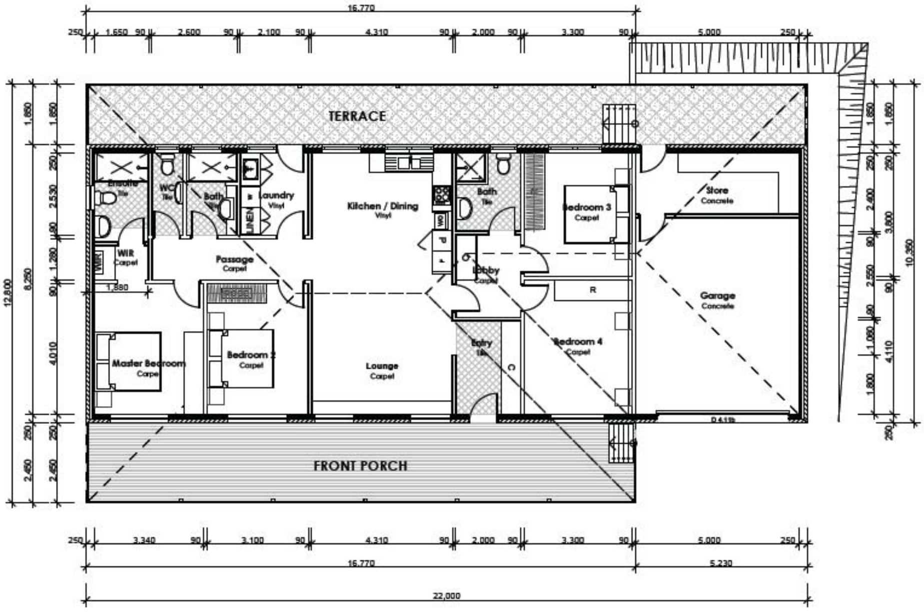
Sketch of the base case building

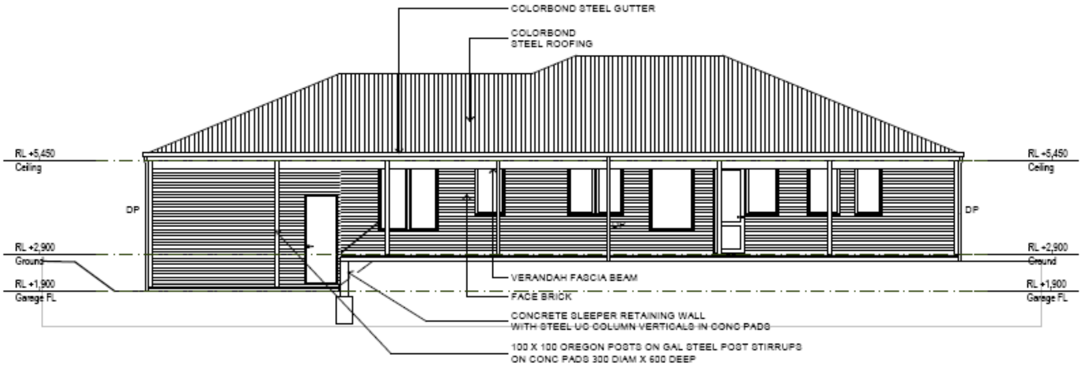
Heat flux sensors (blue) to measure the thermal load and transfer of heat into buildings through roof, sensors to monitor the radiation into the environment (pyranometer) through the roof (yellow circle) and ambient comfort conditions (temp and humidity) monitored in the buildings (green). These will be connected to a logger (red) which will be connected to the internet.



Appendix B:

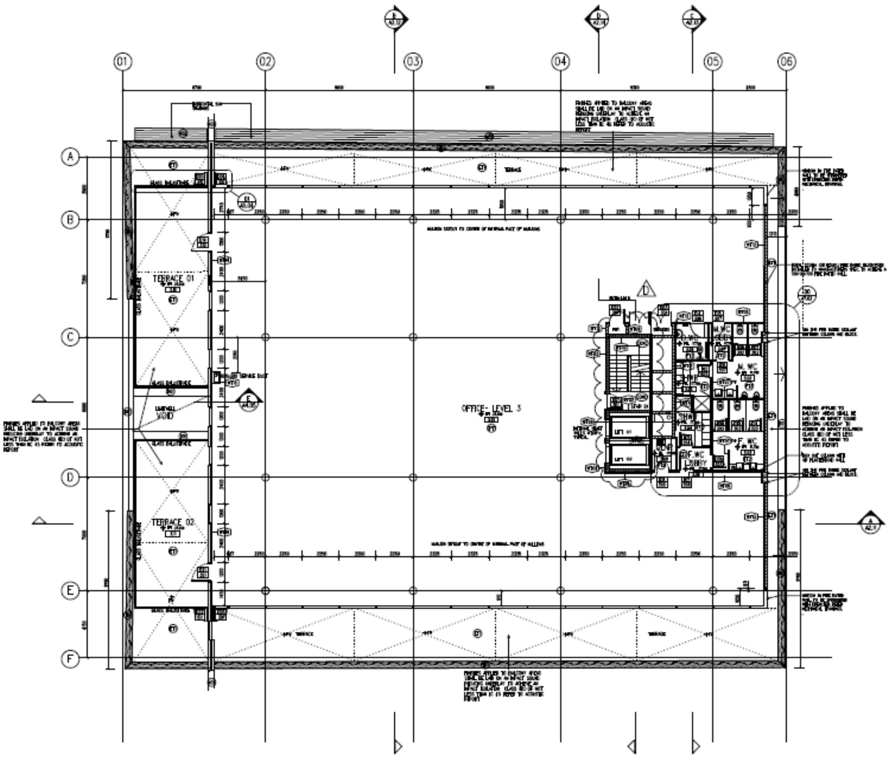
Drawing files of the typical residential building used in modelling





Appendix C:

Sketch of the typical commercial building



Building type used for commercial building model

Appendix D:

Image of the typical industrial building

Building type used for Industrial building model

Appendix E

Assumptions of area for the modelled buildings

Residential building

Zone	Wall	Dimension	Area (m^2)
Conditioned space	Floor & Ceiling	16.43 x 8.00	131.44
	North East wall	16.43 x 2.55	41.90
	South East wall	8.50 x 2.55	21.67
	South West wall	16.43 x 2.55	41.90
	North West wall (adjacent to garage)	8.50 x 2.55	21.67
	North East windows	1.2 m height	14.04
	South West windows	1.2 m height	9.75
	Door on NE wall	1.2 x 2.2	2.64
	Door on SW wall	1.2 x 2.2	2.64
	Eaves board on NE wall	16.43 x 2.45	40.25
	Eaves board on SW wall	16.43 x 1.85	30.39
Garage	Floor & Ceiling	5.00 x 8.00	40.00
	North East wall	5.00 x 2.55	3.78
	South East wall (adjacent to conditioned space)	8.50 x 2.55	21.67
	South West wall	5.00 x 2.55	10.11
	North West wall	8.50 x 2.55	21.67
	Door on NE	4.00 x 2.24	8.97
	Door on SW	1.2 x 2.2	2.64
Attic	North East roof (22.48°)		118.62
	South East roof (22.31°)		43.03
	South West roof (22.48°)		98.22

	North West roof (22.31°)		28.06

Residential building materials

Layers	Material	Thickness (mm)
Room floor	Carpet	5
	Tile	5
	Concrete	100
Garage floor	Concrete	100
Ceiling	Plaster board	15
	Mineral wool	150
Outside wall	Plaster board	15
	Mineral wool	150
	Air gap	40
	Bricks	100
Internal wall	Particle board	15
	Mineral wool	150
	Particle board	15
Roof	Masonite	5
	Air	40
	Corrugated iron	1
Door	Particle board	32
Window	Glass	5

Other parameters for the residential building

Description	Parameters	Unit
Outdoor air infiltration rate	0.2	ACH
Ventilation rate	0.2	ACH
Person, seated at rest	5	-
Computer	3 nos x 140	W
Artificial lighting	10	W m^{-2}

Lighting schedule (ON)	6 – 11 pm	-
Thermostat setting for cooling	24	°C
Thermostat setting for heating	21	°C
Night setback for heating	18 (11 pm – 6 am)	°C
Beginning of heating season	3240 (16 May)	hr
End of heating season	6192 (15 September)	hr
Beginning of cooling season	8016 (1 December)	hr
End of cooling season	1416 (28 February)	hr

Commercial building

Zone	Wall	Dimension	Area (m^2)
Ground, 1st and 2nd floor	Floor & Ceiling	32.69 x 25.79	843.00
	North wall	32.69 x 3	98.06
	East wall	25.79 x 3	77.37
	South wall	32.69 x 3	98.06
	West wall	25.79 x 3	77.37
	Windows on North and South walls	32.69 x 1.2	39.22
3rd floor	Floor & roof	50 x 20	843.00
	North wall	32.69 x 3	98.06
	East wall	25.79 x 3	77.37
	South wall	32.69 x 3	98.06
	West wall	25.79 x 3	77.37
	Windows on North and South walls	32.69 x 1.2	39.22
	Horizontal roof	32.69 x 25.79	843.00
	Eaves board on North wall	32.69 x 3.85	125.86
	Eaves board on south wall	32.69 x 3.00	98.07

Commercial building Materials

Layers	Material	Thickness (mm)
Ground floor	Carpet	5
	Tile	5
	Concrete	100
Ceiling (ground, 1st and 2nd floor)	Plaster board	5
	Concrete	100
	Tile	5
	Carpet	5
Roof	Plaster board	5
	Mineral wool	150
	Concrete	100
Outside wall	Plaster board	15
	Mineral wool	150
	Concrete	100
Internal wall	Particle board	15
	Mineral wool	150
	Particle board	15
Window	Glass	5

Other parameters for the commercial building

Description	Parameters	Unit
Outdoor air infiltration rate	0.6	ACH
Ventilation rate	1	ACH
Person, seated light work	240	-
Computer	240 nos x 140	W
Artificial lighting	10	W m^{-2}
Lighting schedule (ON)	8 am – 6 pm	-
Thermostat setting for cooling	24	°C
Thermostat setting for heating	21	°C
Heating & cooling (ON only weekdays)	7:30 am – 5:30 pm	-

Industrial building

Zone	Wall	Dimension	Area (m^2)
Internal space	Floor	50 x 20	1000.00
	North wall	50 x 4	200.00
	East wall	20 x 4	80.00
	South wall	50 x 4	200.00
	West wall	20 x 4	80.00
	North roof (30° slope)	50 x 11.55	577.50
	East roof (vertical)	10 x 5.68	56.80
	South roof (30° slope)	50 x 11.55	577.50
	West roof (vertical)	10 x 5.68	56.80
	Sky light (on North and South roofs at 30° slope)	0.9 m width	62.37

Industrial building Materials

Layers	Material	Thickness (mm)
Floor	Heavy concrete	100
Roof	Masonite	5
	Air	40
	Corrugated iron	2
Outside wall	Masonite	5
	Air	40
	Corrugated iron	2
Skylight	Polycarbonate (assumed to have similar transmissivity as plain glass)	2

Other parameters for the industrial building

Description	Parameters	Unit
Outdoor air infiltration rate	0.6	ACH

Ventilation rate	0.5	ACH
Person, heavy work	33	-
Artificial lighting	10	W m^{-2}
Lighting schedule (ON)	6 am – 10 pm	-
Equipment cooling load	10 & 100	W m^{-2}

Appendix F:

Method of comparison of simulated and measured results (Iqbal 1983)

Root Mean Square Error (RMSE)

$$RMSE = \left(\left(\sum (Y_i - X_i)^2\right)/n\right)^{0.5}$$

Mean Bias Error (MBE)

$$MBE = \left(\sum (\mathrm{Y_i} - X_i)\right)/n$$

Correlation Coefficient (CC)

$$CC = \frac{\sum \left((Y_i - Y_{mean})(X_i - X_{mean})\right)}{\left(\left(\sum (Y_i - Y_{mean})^2\right)\left(\sum (X_i - X_{mean})^2\right)\right)^{0.5}}$$

Where X_i - i^{th} measured value

Y_i - i^{th} simulated value

X_{mean} - measured mean value

Y_{mean} - simulated mean value

n - number of observations

Appendix G:

Current Programs using CRP

It is interesting to review the current research and requirements for CRP around the world.

International Programs

Across the U.S. Federal Government

The United States Department of Energy has announced a series of initiatives to more broadly implement cool roof technologies on DOE facilities and buildings across the country. DOE will install a cool roof, whenever cost effective over the lifetime of the roof, during construction of a new roof or the replacement of an old one at a DOE facility.

DOE Cool Roof Calculator http://www.ornl.gov/sci/roofs%2Bwalls/facts/CoolCalcEnergy.htm

US Energy Star

A roof product qualifying for the Energy Star label under its Roof Products Program must have an initial solar reflectivity of at least 0.65, and weathered reflectance of at least 0.50, in accordance with EPA testing procedures.

EPA Cool Roof Calculator http://www.roofcalc.com

Cool Roof Rating Council

The Cool Roof Rating Council (CRRC) is an independent, non-profit organization that maintains a third-party rating system for radiative properties of roof surfacing materials.CRRC has created an extensive database and rating system for all types of roofing products. www.coolroof.org

CRRC's rating program allows manufacturers and sellers to appropriately label their roofing products according to specific CRRC measured properties. The program does not, however, specify minimum requirements for solar reflectance or thermal emittance.

Green Globes

To qualify for a Green globe rating category B-2 Ecological impacts, roofing materials must have a solar reflectance of at least .65 and thermal emittance of at least .90. As many as 10 points may be awarded for 1-100 percent roof coverage with either vegetation or highly reflective materials or both.

LEED

In the area of roofing, to receive LEED Sustainable Sites Credit 7.2, at least 75% of the surface of a roof must use materials having a Solar Reflective Index (SRI) of at least 78. This criterion may also be met by installing a vegetated roof for at least 50% of the roof area, or installing a high albedo and vegetated roof that, in combination, meets this formula: (Area of SRI Roof/0.75)+(Area of vegetated roof/0.5) = Total Roof Area.

Cool Roofs Europe

There is a number of Cool roof related organizations in Europe, with Cool Roofs Europe being central to all of the cool roof activity in the region. This European Union backed organisation aims to create and implement an Action Plan for the cool roofs in EU. Although the organization is well organized and well run, there is a lack of specific rating, design and quality control based on information from the site. It would appear be more designed to provide information to consumers should they be interested. http://www.coolroofs-eu.eu/

Australian requirements for a CRP product

In the local scene, the Australian Building Code now has an allowance for a cool roof, which basically equates to the northern Australian climate having a reduced R-value requirement for the ceiling with the use of cool roof products. This is an excellent introduction to the market as to the benefit of using such products and it is likely the BCA will increase its requirements around this type of performance as the BCA progresses.

Table J1.3a ROOFS AND CEILINGS - MINIMUM TOTAL R-VALUE FOR EACH CLIMATE ZONE

Climate zone	1, 2 and 3	4, 5 and 6	7	8
Direction of heat flow	Downwards		Upwards	
Minimum Total R-Value for a roof or ceiling with a roof upper surface solar absorptance value of not more than 0.5	3.2	3.2	3.7	4.8
Minimum Total R-Value for a roof or ceiling with a roof upper surface solar absorptance value of more than 0.5 but not more than 0.6	3.7	3.2	3.7	4.8
Minimum Total R-Value for a roof or ceiling with a roof upper surface solar absorptance value of more than 0.6	4.2	3.2	3.7	4.8

Table 3 BCA requirements for roof absorptance

*It should be noted that solar absorptance is a measure of the ability of a material or coating to absorb heat. It is the opposite of the reflectance – although not in a direct mathematical way.