TECHLINE4

FOR THE CONSTRUCTION INDUSTRY

Reducing Over-heating in Buildings by Use of Cool Reflective Roof Coatings (CRRCs)

ABSTRACT

Cool Reflective Roof Coatings (CRRC's) were introduced into the United States in the 1980`s with the aim of reducing the amount of solar energy absorbed by buildings and the build-up of heat in urban environments (the Urban Heat Island effect). The coatings have a high level of solar reflectivity (SR) which serves to reflect solar radiation away from the roof whilst their high heat emissivity (TE) means they readily release any energy they absorb: such coatings have been shown to renew and prolong waterproof coverings for flat and low-slope roofs.

Two case studies demonstrate how a CRRC reduces heat penetration into a building, thereby reducing energy usage in air-conditioning. The first study, conducted by the University of Southern Mississippi in the late 1980s, found that with the use of CRRC energy consumption for summer-time cooling was reduced by 21.9% and that for winter-time heating by 4%; pay-back time for the coating was just two years.

The second study was conducted by the Energy Co-ordinating Agency (ECA) of Philadelphia from 2001 to 2003 and focused on three hundred and seventy five dwellings (mainly row houses). It found that those dwellings equipped with an air-conditioning system consumed less energy when CRRC was applied whilst in those without air-conditioning the indoor temperature was reduced.

The most critical constituent of a CRRC is the white pigment which provides solar reflectivity and the binder which contains and protects the pigment; together they provide a protective film which adheres to the roof covering. The most critical properties of the binder film – such as elasticity, adhesion, durability, UV-resistance, water ponding and dirt pick-up resistance – are discussed. Different binders will be presented that were developed and tailored to meet the critical requirements and application to different roof substrates.

In the following, results of the studies will be looked at in detail as well as results of various property and long term performance tests will be presented.

INTRODUCTION

Sustainability and improved living standards are targets for most governments world-wide; many western countries (especially the European Community) are also focused on reducing carbon dioxide (CO_2) emissions as a way to reduce global warming.

The most significant single contribution to meeting those targets is a reduction in the amount of energy used to control the internal temperature of buildings, particularly dwellings. In cold regions the application of thermal insulation in order to conserve heat can be most effective in reducing energy demand whereas in warmer regions it can be more rewarding to adopt measures which mitigate the effects of solar radiation and thus help to maintain lower internal temperatures.

The application of a reflective roof coating is just such a measure; not only does it reduce internal temperatures, it also protects the roof against climatic elements: provided it can retain its physical characteristics over the long term a CRRC helps to prolong the service life of the roof to which it is applied. Various studies have shown that CRRC based on Dow binders, which can be formulated to meet the specific performance requirements of different roof covering materials, work very well in practice. The referenced studies have been conducted by Rohm and Haas over many years – a specialty chemical company which has been acquired by The Dow Chemical Company in 2009. When references are made to a product, we encourage you to read Dow Construction Chemicals' Technical Data Sheets (TDS) available on **www.dowcc.eu**.

CASE STUDIES

Work in our company to develop CRRCs began in 1981, initial experiments being conducted on two "Bird Houses" (**Figure 1**) which were designed to simulate simple forms of building construction used in dwellings. The pitched roofs of these "Bird Houses" were covered with dark asphaltic shingles, one being left exposed the other coated with a white reflective coating. In each unit we recorded internal and roof surface temperatures as a function of solar radiation. As anticipated, both internal and roof surface temperatures were significantly lower in the unit with CRRC; these results encouraged us to undertake further detailed scientific studies.

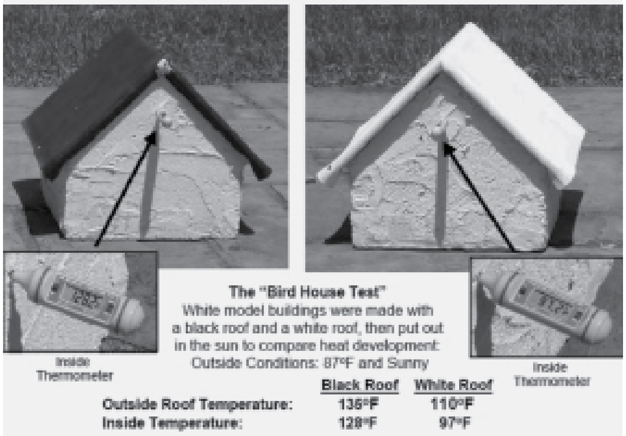

Figure 1: Bird houses for evaluation of effect of reflective roof coatings

Southern Mississippi 1985

One of the earliest scientific studies of the effects of CRRCs was conducted in collaboration with the University of Southern Mississippi, The Mississippi Power Company and Rohm and Haas; it began in September 1985 and data was logged for one year to cover a full weathering/solar season. Three similar buildings (Figure 2) were constructed on the Hattiesburg Campus of the University; they were of nearly identical construction, with a brick external wall cladding to a timber frame, lined internally with gypsum board. Buildings 1 and 2 were insulated above ceiling with 10cm of glass mineral wool whilst Building 3 was insulated in accordance with the "Good Cents" programme of the Mississippi Power Company. All three buildings incorporated areas of flat roof which were waterproofed with smooth black asphalt; that to Building 2 only was treated with a white reflective coating based on a pure acrylic binder. (Construction details are given in **Table 1**).

Figure 2: House type used for the study

Construction Material	Building 1 Control	Building 2 Rohm and Haas	Building 3 "Good Cents"
Ceiling	R 11 4" Batt Glass mineral wool	R 11 4" Batt Glass mineral wool	R 30 10" Batt Glass mineral wool
Walls	No Insulation	No Insulation	Perlite R2.85 1.5 Ure R11.7
Windows	Single Glass Standard	Single Glass Standard	Double Glass Tight Fit
Doors	Wood Door Standard	Wood Door Standard	Metal Insulation Weather Strip
Foundation	No Insulation	No Insulation	1.5" Ins. R11.7 Perimeter

Table 1: Building Specifications

The internal temperature of all three buildings was maintained at 24°C by means of a heat pump which provided heating or cooling as required by the external climate conditions. Over the course of the one-year-trial we recorded, at 15 minute intervals inside and outside air temperatures, relative humidity, solar radiation, wind velocity and energy consumption for heating or cooling.

As anticipated, the energy consumption of Building 2 and Building 3 was lower than that of the control Building 1 as shown in **Table 2**.

	Building 1 Control	Building 2 Rohm and Haas	Building 3 "Good Cents"
Energy Demand Summer	100 %	78.1 %	70.2 %
Energy Demand in Winter	100 %	96.0 %	57.9 %
Pay back time of investment	–	2.07 years	3.05 years
Return on investment	–	48.3 %	32.8 %

Table 2: Energy demand relatively to the control building and financial pay back.

It can be seen that the energy consumption of Building 2 – on which the reflective roof coating had been applied – was 21.9% lower than that of the control house during the summer and - perhaps surprisingly – 4.0% lower in the winter. It had been expected that the heat energy absorbed by the black roof would contribute to winter time heating of the building. Whilst that was found to be true during daylight hours, the black roof also acted as a radiator of energy during the night: in addition, any positive heating contribution from a black roof during winter time was minimized by the effects of low sun angle, greater cloud cover and snow.

The energy consumption of Building 3 was 29.8% lower than that of the control house during the summer and 42.1% lower in the winter, doubtless as a result of the better standard of thermal insulation reducing heat loss through the building fabric. However, the difference in summer time performance between Buildings 2 and 3 (-21.9% vs. -29.8%) was less than expected. We believe this was due to the effect of the CRRC which resulted in a lower temperature in the waterproof asphalt and in the roof beneath it which, combined with the lesser thermal insulation at ceiling level, allowed more rapid dissipation of heat from the interior during the hours of darkness.

Philadelphia 2001 – 2003

Following the case study at the University of Southern Mississippi, several further studies of the effects of CRRCs were conducted on various building types (Offices, Storage, Assembly, Dwellings etc.) in different climatic regions for the purpose of assessing the potential for CRRCs – in conjunction with thermal insulation – to moderate internal temperatures and so reduce energy consumption.

A study (Blasnik 2004) of the Cool Homes Programme of Philadelphia's Energy Co-ordinating Agency (ECA), which ran from 2001 to 2003, in addition to measuring energy savings, sought to evaluate how CRRCs might mitigate the heatrelated health risks faced by low-income senior citizens in urban housing. Kalkstein had reported (1993) that excessive heat influences mortality rates in cities, with people aged 65 and over being more affected. Mortality rates increase exponentially when temperature rises above 33-34°C because, the surface temperature of the human body being normally 33-34°C, if the ambient temperature is above that level efficient body cooling is not possible and critical maximum body temperature is reached. Other factors, including relative humidity (RH) also have an impact (Kalkstein, Vailmont 1987) but the human body can more readily acclimatize to high levels of relative humidity than it can to heat. In Philadelphia, hot weather-related mortality for all age groups was reported as 2.7 per 100,000 but for those aged 65 and above the rate rose to 16.5 (Chestnut 1998).

The ECA programme, which was aimed at improving the quality of life and reducing mortalities, included 375 senior citizen households, mainly in row houses; of those 90% were fitted with CRRC and 66% had insulation at the ceiling line. The occupants were instructed in how best to keep indoor temperature low during hot weather.

It was found that 20% of roofs in the programme suffered water penetration which could have affected adversely the performance of any thermal insulation; those roofs were repaired before the CRRC was applied. It should be noted that the CRRC, by keeping the asphalt waterproofing cool, prolongs the service life of the roof, the coating also acts as an additional water resistant layer.

On examining data at the conclusion of the test period we found that, in those dwellings with air-conditioning and a CRRC roof, energy consumption was reduced by a third, from 1,736 to 1,178 kWh/year whilst in dwellings with a CRRC roof but no air-conditioning the peak ceiling level temperature had been reduced by 2-3°C. Such reduction in internal temperature, which could contribute to a reduction in heat-related mortality rates, is of particular interest in the light of heat-related deaths in Chicago and Philadelphia (i.e. > 100 heat related deaths in Philadelphia during the summer of 2003) and in Europe during 2000-2008.

Our calculations show that either thermal insulation or the application of a CRRC has a huge impact on the heat balance of a building and on its energy demands; a relatively small additional improvement in performance will be achieved by the combined use of both insulation and a CRRC. It should be noted that thermal insulation at ceiling level is of particular value in reducing energy usage during the winter heating season.

Other programmes have subsequently been run by the ECA including one called "The Coolest Block" in which residents in Philadelphia row-houses were encouraged to compete for an energy up-grade for their entire block. The up-grade included installation of thermal insulation, a CRRC and draught-sealing to doors and windows. It was sponsored by The Dow Chemical Company which provided elastomeric roof coatings binder and finished coating based on our specified formulation. The Dow Foundation provided funds for labor and installation of the RHOPLEX™ coatings, GREAT STUFF™ and STYROFOAM™ products for the project.

Other Studies

Several other studies have been undertaken both before and after the Philadelphia study; without exception they all show that energy savings can be achieved by use of a CRRC. Discussion continues as to the relative merits of using both thermal insulation and CRRCs in combination but it apparently much depends upon whether or not winter heating is used which, of course, depends upon the climate zone in which the building is located.

> Levinson et al.(2005) <
reviewed the results of various previous studies and analyzed the most common roof constructions. He considered the various options for low-slope roofs, both with CRRC and without, calculated energy savings and costs and extrapolated those savings via a model for California.

> Akbari et al (2005) <
investigated the impact of a CRRC on the energy demand of a retail store, an elementary school and a fruit-packing facility comprising three separate buildings. Savings, similar to those for dwellings, were recorded in all those buildings: the savings for each building type were extrapolated to the 16 different climate zones of California.

> Akbari et al.(2006) <
studied the impact on solar reflectance of cleaning procedures over a period of ten years. Results showed wide variation in performance but it was evident that professional cleaning with a detergent can ensure the reflectance value of a coating is maintained at close to its initial value for the life of the roof.

> Suehrcke et al.(2008) <
analyzed heat flow and balance in hot climates where no winter heating is used. Different colours of roof coating were ranked according to their thermal effect and the effects of weathering and ageing on solar reflectance were evaluated.

> Jo et al.(2010) <
reports on a study which involved measuring internal temperature and energy used for cooling a large commercial building constructed in 1972. In this study one half of the 13,400m^2 roof was treated with a CRRC the other half being left untreated. A comparison of the cooling energy consumption for the two halves of the building clearly showed that application of the CRRC had resulted in a reduction of 24kWh/m^2 per year which equated to a reduction of carbon dioxide emissions of 174 MT a year, roughly the same amount as would be consumed by a mid-size European car driven over one million kilometres.

COOL REFLECTIVE ROOF COATINGS

Initial attempts to paint a roof with a reflective coating used standard emulsion paint, such as is widely used on walls both indoors and outdoors, but results were less than satisfactory: the coating cracked and peeled off. This was found to be due to poor elongation and adhesion properties of the emulsion paint which meant it was unable to withstand the mechanical and thermal stresses to which it was subjected when exposed on a roof. In order to overcome those problems an emulsion was formulated with very soft polymers which gave excellent elongation properties but was found to collect surface dirt and so loose the surface whiteness which is essential for a high level of solar reflectance. Manufacturers therefore developed new polymers which combine excellent elongation properties with good adhesion and resistance to dirt pick-up.

Characteristics of Cool Reflective Roof Coatings

The performance characteristics of a CRRC are closer to those of an elastomeric waterproof membrane than to those of an emulsion paint. It is most important that a roof coating be able to withstand mechanical and thermal stresses whilst remaining adhered to the roof surface without allowing significant water penetration, even under ponding. Whilst in a perfect world one formulation of coating would suit all types of roofing material, in practice it is necessary to tailor the CRRC to the surface on which it is to be applied. With that in mind Dow enables manufacturers to design specifically to suit various new substrates including asphalt and polyurethane foam as well as weathered substrates such as asphalt, polyvinyl chloride (PVC) and single ply polymer membranes like ethylene propylene diene monomer (EPDM) and Thermoplastic PolyOlefin (TPO).

A CRRC is applied by spray or roller; normal drying time at 20°C and 50% relative humidity is 24 hours and dry thickness is between 500 and 750 microns (some ten times thicker than a coat of emulsion paint). Temperature and relative humidity during application are important: at less than 5°C both adhesion and durability of the coating will not be sufficient; low temperature and high humidity will both increase the drying time which will increase the risk of damage to the coating should rain fall before it is properly dry.

The main components of a CRRC are the emulsion polymer (also called latex or binder) with a solids content of 50-55%; the pigment (usually titanium oxide but may be zinc oxide) and the filler (mainly calcium carbonate). Other components, used in concentrations below 1% and referred to as additives, include dispersants – to aid even distribution; de-foaming agent – to prevent foaming of the coating; biocide -to prevent growth of micro-organisms in the product during storage and thickener – to adjust viscosity of the coating. Up to 4% of a coalescing agent may also be added; these are high boiling temperature organic solvents which evaporate slowly from the applied coating and normally help film formation of the polymer. Coalescent is not only required for film formation but is used to increase wet edge and open time of the coating. Table 3 shows the percentages of the main components in a typical CRRC.

	Parts (w/w)
Pigment	4 … 9 %
Filler	25 … 40%
Polymer (wet, 55% solids)	38 … 52 %
Polymer (based on solids)	21 … 29 %

Table 3: Composition of a CRRC (main components)

The % Pigment Volume Concentration (PVC) of a CRRC (the ratio of pigment and fillers to all components remaining in the dried film) is of critical importance; it should be not less than 30% and not more than 45%. If the PVC falls significantly above the maximum 45% PVC critical level then the volume of binder is insufficient to cover all the pigment and fillers. The result is that the binder serves only to glue them together and will not form a continuous non-porous film because of air voids and porosity in the dried film. It is essential that pores in the coating be avoided if resistance to water penetration is to be achieved.

Properties of a CRRC

The critical properties of a CRRC are its elasticity – allowing it to follow thermally-induced movements on the roof; adhesion to the substrate and durability-retention of its performance characteristics for the lifetime of the roof; those properties are now considered in more detail.

Elasticity

Solar radiation can raise roof-top temperature to 80°C and above whilst on a winter night it can be as low as -30°C: to withstand the stresses created by such a wide variation in temperature a CRRC must possess outstanding flexibility and elongation.

Elasticity of a coating film is measured by tensile test. The coating film is fixed in two clamps. One clamp is moved with a certain speed and elongates the coating film. The elongation in per cent of the initial width between the two clamps and the force that is necessary to elongate the film is measured. The tensile strength is calculated from the force divided by the area of the cross-section of the film. Usually the maximum tensile strength and the corresponding elongation are reported. Once the maximum tensile strength of a CRRC film is reached its structure is irreversibly changed.

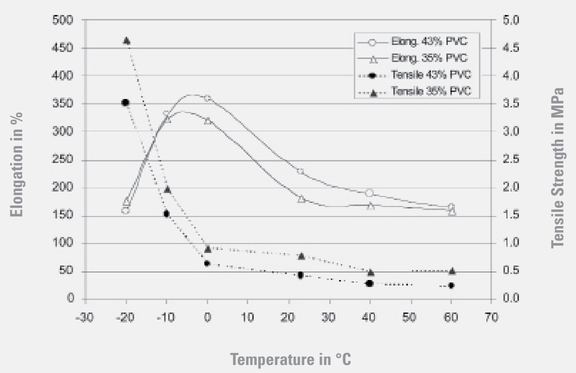

Figure 3: Elongation and tensile strength of CRRC, 1mm dry film, non-aged with 43% PVC and 35% PVC at different temperatures, binder: PRIMAL™ EC-1791 E.

Figure 3 shows the elongation and tensile strengths of two CRRC films at various temperatures; one sample with 43% the other with 35% PVC, both with PRIMAL™ EC-1791E binder. It can be seen that tensile strength is high for both samples at low temperature, falling sharply as temperature increases to 0°C and then remaining virtually constant. Elongation increases from a minimum of 150% at low temperature to reach maximum at 0°C, it then returns to its original value as temperature increases further. The decrease in tensile strength can be explained by the increased movement of molecules in the polymer which becomes softer at higher temperatures, requiring less force to elongate the film.

Elongation of the binder increases with initial rise in temperature but at around 0˚C the effect of other components outweighs the increased flexibility of the binder. Elongation remains above 150% which is more than adequate for a roof coating.

Durability

A roof coating must be durable and must retain its performance characteristics for the life of the roof. Coatings have been tested by accelerated artificial weathering and by outdoor exposure at different locations to obtain results for a variety of climates. Whilst artificial weathering tests can give good early indication of a membrane`s performance over time, only long term outdoor exposure can give accurate results for a given climate. Outdoor exposure test have been carried out in Philadelphia (USA) over a four year period; test panels were arranged horizontally to simulate a typical flat roof and elongation and tensile strength were measured across a range of temperatures from -18 to +24˚C (as the tensile strength test is destructive each data point was taken from a different sample).

Elongation at -18˚C did not change over the 4 years but at +24˚C it dropped during year 1 then remained constant. A similar change has been noted in accelerated weathering tests and is believed to be due to an initial leaching out of water-soluble components in the formulation. Tensile strength at +24˚C is constant and at -18˚C a slight increase in strength was observed. Thus the CRRC formulated from PRIMAL™ EC-1791 E has been shown to retain excellent elongation over the whole temperature range over an extended period of time.

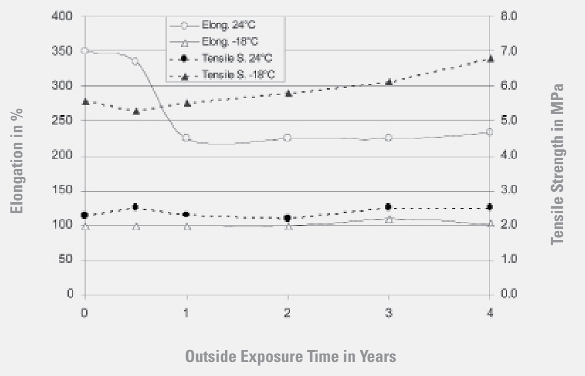

Figure 4: Elongation and tensile strength of CRRC, 1mm dry film, 43% PVC after outside exposure (horizontal), binder: PRIMAL™ EC-1791 E.

Good elongation without good adhesion to the substrate is, of course, without value in real terms so, in addition to tensile strength measurements, we also measured the force needed to peel the coating from the substrate at intervals during the test period; Table 4 lists the adhesion of the test material to polyurethane (PU) foam and to weathered asphalt. Fluctuations in the results are due to the fact that adhesion of the coating to the substrate was greater than cohesion of the substrate material itself.

Exposure time (years)	Adhesion on PU foam (% of initial)	Adhesion on Asphalt (% of initial)
0	100*	100*
0.5	80*	92*
1	94*	100*
2	100*	100*
3	100*	96*
4	100*	92*

Table 4: Peel-off adhesion of a CRRC, binder: EC-1791 43% PVC after outside exposure (horizontal). * failure in substrate

Binders

Different binders have been, and continue to be, developed to meet the specific requirements of various applications to different substrates in different climate zones. PRIMAL™ EC-1791 E was one of the first binders developed for use in CRRCs. Coatings incorporating this product could be applied to a wide range of substrates and, after drying of the coating, provided good adhesion, flexibility, durability and resistance to dirt pick-up: the product is still widely used as the binder for CRRCs. However, even a good product can be improved or modified to meet particular requirements.

CRRCs normally contain in excess of 30% water which must evaporate to allow the membrane to dry out and achieve its final adhesion strength. Drying out normally requires one day at 20˚C and 50% relative humidity but, if temperature is low and/or humidity is high, water evaporation is slowed down and it takes longer to reach a fully dried film with acceptable adhesion which can leave the coating susceptible to wash-out should rain occur before full drying is achieved. In order to allow the coating to be applied even when rain within 24 hours is likely, we introduced into the chemistry a new technology which we call "Quick Set". PRIMAL™ EC-1791 QSE – a product that incorporates Quick Set technology – helps retain all the performance characteristics of the original whilst additionally offering higher wash-out resistance of the fresh applied coating compared to one without this technology.

Newly applied asphalt is the most difficult substrate in terms of adhesion of a CRRC because it is extremely hydrophobic so that coatings applied to it will often develop blistering and loss of adhesion. To overcome this it was necessary to develop a new binder which would be compatible with new asphalt whilst retaining full functionality of the coating. LIPACRYL™ MB-3640, which was introduced to the market some years ago, fulfilled those requirements. Figure 5 illustrates how well a coating formulated with LIPACRYL™ MB-3640 adheres to fresh asphalt: to the right of the illustration, its performance is compared with that of a standard coating. This product, specially designed for application to fresh asphalt, does however not have such good adhesion to other substrates.

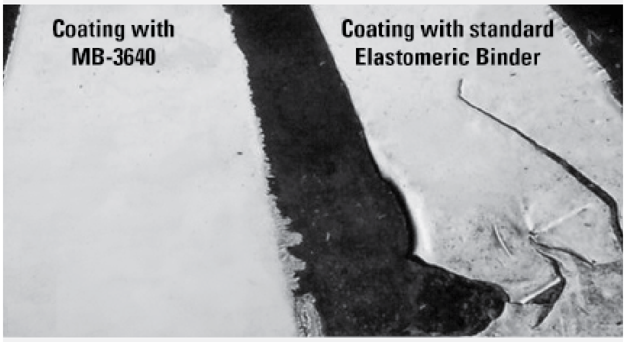

Figure 5: Adhesion of a CRRC based on LIPACRYL™ MB-3640 on fresh asphalt compared with a standard CRRC after 2 weeks water immersion

CONCLUSION

Numerous studies have shown that the use of a white reflective roof covering (CRRC) helps achieve substantial savings in the energy used to air-condition buildings and also to reduce the internal temperature of buildings in which no air-conditioning is installed. Because most energy is today produced with CO_2 emitting technologies, reduced energy usage results in a reduction of CO_2 emmissions and so contributes towards the EU target of 20% reduction in such emmissions by 2020. The use of a CRRC will also help to maintain a ceiling-level temperature at or below 33-34°C which will significantly reduce heat-related mortality, especially amongst the elderly.

CRRCs, and the Binders used in their composition, have now been in use for more than twenty years during which time experience shows they not only maintain their physical characteristics but also can extend the life to renewal of roof surfaces to which they are applied, thus contributing to the overall level of sustainability.