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A Short Review on Energy Conservation in Buildings Using Roof Coating Materials for Hot and Dry Climates

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Abstract:

Hot and dry climatic regions are known by very high solar radiation levels, high ambient temperatures and relatively low specific humidity. The roof surface of the building is always exposed to Sun directly for the longest duration in hot and dry regions to the intense perpendicular solar heat radiations. Solar radiation is a significant mode of heat transfer through the building roof. Solar radiation heat the roof which in turn re-radiates the heat onto the ceiling and finally on to the room occupants. Most of the roofs in the world are of dark colour. In summer, the surface of a black roof can increase in temperature as much as 65 to 90 ˚ C. At higher roof temperatures the deterioration of roofing materials starts and leads to increased roof maintenance costs, and high levels of roofing waste directed to landfills. The best way to reduce this is with the help of radiant barriers such as light coloured metallic or non metallic surfaces which have high solar reflectance and a high emittance to redirect the radiations back to the environment. Due to this, the heat transfer from the roof surface to the ceiling will become negligible. By blocking the solar radiations, the building conditioning is largely mitigated because heating and cooling usually use largest portion of energy in buildings. Low temperature roofs benefit the environment and public health by reducing greenhouse gas emissions by conserving energy for air conditioning; therefore less CO_2 is emitted from power plant. In the present paper various approaches to redirect the solar radiations by using different roof coating materials from the roof, their relative benefits in terms of energy and cost savings has been discussed at length.

Keywords: Energy conservation, radiation, roof surface solar energy, surface coating

1.0 Introduction:

Solar radiation is a significant mode of heat transfer through the building roof. Solar radiation will heat the roof which in turn re-radiates the heat on to the ceiling and finally on to the room occupants (SETS Manual, 2007). The roof surface of the building is always exposed to Sun directly for the longest duration to the intense perpendicular solar heat radiations as shown in Fig. 1. As heat addition increases, the temperature of roof continuously rises as shown in Fig. 2. The heat stored in the roofing material is transmitted slowly through the roof into the rooms. Due to large thermal mass of roof, this phenomenon of heat transfer continues even after the sunsets. Using some coating materials at top of the roof surface, which has both high solar reflectance and a high emittance (rejecting heat back to the environment) which can reduce heat transfer to the rooms directly and further can reduce the heat storage in roof material (Moe, 2010; Architecture Energy, 2011). Due to coating, the room will remain cooler during summer and warmer in winter as compared to outside This will reduce the cooling load and hence energy consumption by air conditioners and room coolers. To maximize cooling energy savings, high-albedo roof coatings should have high solar reflectance (both in the visible and near-infrared bands), have high infrared emittance and maintain these properties for the service life of the coating (Sarah E, *et al*, 2011).

Hot and dry climatic regions are known by very high solar radiation levels, high ambient temperatures and relatively low specific humidity. According to a recent code of Bureau of Indian Standards, Hot & Dry means, monthly average temperature remains greater than 30 ˚C and relative humidity lower than 55%. Climate has a major effect on the energy consumption and performance of the building (Report, 2005). Reflective roof coatings applied to roofs to reduce solar heat, especially in areas with hot, sunny weather for a longer part of the year. Because they can reduce surface temperatures up to 45°C, these products also have a big impact on cooling costs (Report on urban heat island, 2007). A flat roof coating can extend the life of a roof because it lowers the roof temperature. Concrete roof tiles have a defined 'lifespan' which tends to be around

25-35 years depending on the style and mixture of the concrete used. After this time the surface deteriorates year on year and creates the need to change the tiles. It can also lead to additional energy savings as the temperature is reduced (Joanne D, 2010).

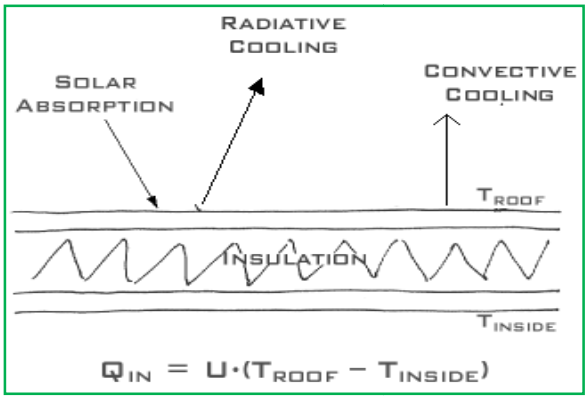

Fig 1: Mode of Heat Transfer of Solar Heat

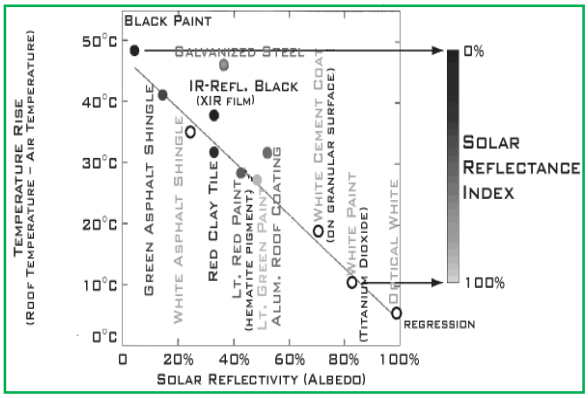

Fig 2: Solar Reflectivity v/s Temperature Rise Occupants

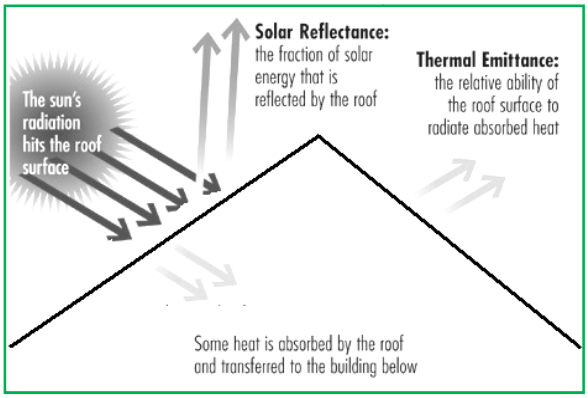

Fig 3: Heat Transfer, Reflectance and Emittance of Solar Energy

The Lawrence Berkeley Laboratory in California estimates that reflective roof coatings can save homeowners a minimum of 25% in energy usage. Another advantage of reflective roof coatings is that they contain ultraviolet blocking pigments (Report on energy efficiency, 1997; John C. *et al*, 1996). Because ultraviolet rays increases the life of a roof considerably up to 15 years. This is especially true in buildings with low slope or flat roofs, which tend to absorb sun energy at a higher rate than slanted roofs. Since roof maintenance accounts for more than 80% of a building's total maintenance cost, any product that can extend roof life will result in substantial money savings (Report, 2009). Since 1998, the Cool Roof Rating Council, or CRRC, provides Energy Star labelling to roofing products that pass their quality tests. Because roof coatings tend to lose their reflectance properties over time due to dust and dew, regular maintenance, in the form of reapplications or cleanings, is a must (Report on cool colour roofing material, 2006). Roof coatings are designed to protect the roof from moisture or to add an insulating barrier between the roof and interior of a building for energy savings. There are acrylic and metal-based coatings and each is good for a particular kind of building and purpose (Report, 2004). Reflective roof coatings act like mirrors, reflecting the solar radiation back into space. To rate the level of reflective-ness of different products, manufacturers have come up with a classifying system such as bright-white paint are the most effective, with a solar reflectance of 85%. Applying roof coatings is easy. Almost anyone can apply a roof coating like a professional. Roof coating includes a process of cleaning, treating, repair and coating to enhance the performance and the look of the roof whilst adding a breathable, waterproof coating (Report on air quality management, 2009).

The two basic characteristics that determine the performance of a cool roof are solar reflectance and thermal emittance. Both properties are rated on a scale from 0 to 1, where 1 is the most reflective (Draft of USAID ECO III, 2007). Although there is no industry-wide definition of a coated roof, the EPA's Energy Star Roof Products Program has established a minimum standard, requiring that good coating roof products have an initial reflectance of at least 0.65, and a reflectance of at least 0.5 after three years of weathering (Report on building energy efficiency, 2007). By contrast, conventional asphalt roofs have a reflectivity of between 0.06 and 0.26, resulting in large amounts of heat transfer into the building's interior (Fact sheet for low slope roofs, 2001). The solar reflectance and thermal emittance of a roof is shown in Fig. 3.

2.0 Major Benefits of Roof Coating:

2.1 Increased lifespan of roofing materials: Coated roofs do not experience thermal cyclic loading as much as conventional roofs. Thermal cyclic loads can deteriorate the bond between shingles and asphalt, potentially causing premature failure.

2.2 Energy savings: According to the U.S. Department of Energy, some reflective roof products can lower roof surface temperature even up to 100 ˚C and can reduce peak cooling demand by as much as 15%. However, coated roofs may result in increased heating costs during the winter, but this increase is greatly outweighed in hot and dry climatic areas where major energy savings achieved during summer and winter is very short and mild;

***2.3 Reduction of the 'heat island' effect*:** This is the tendency for metropolitan highly populated areas to be warmer than their surroundings due to the large amount of building materials that retain heat. Studies have shown that this phenomenon increases the risk of death during heat waves in summer and decreases air quality by increasing the production of pollutants at higher temperatures, such as ozone and NO_2. Cooler air in metropolitan cities slows down the formation of smog, beyond reducing cooling energy needs and emission production.

***2.4 Lower peak electrical demand*:** The peak energy load an electric utility experiences in late afternoons around 3 'O clock in summer as businesses and residences turn up their air conditioners instantaneously, is reduced by the implementation of reflective roofs.

2.5 Roof coatings reduce the roofing materials produced: Used and thrown away if cool coatings are used to increase roof life this waste can be greatly reduced and the energy and materials needed to produce new roofing can be conserved.

***2.6 Roof coatings reduce air pollution*:** Direct reductions in air pollution generated from power plants result when less energy is used to cool a buildings.

3.0 Roof Coating Materials:

Roof coatings can be divided into two categories: field-applied and factory-applied. Field-applied coatings are applied directly onto the roof surface, either on a new roof assembly or over an existing roof surface. Factory-applied coatings are applied during the manufacturing process. Examples of factory-applied coatings include coatings applied to metal, and glazes that are applied to tiles. Roof coatings fall into two general categories i.e. elastomeric-based and bituminous-based products (Anderson R.W, *et al*, 2001).

The base materials for elastomeric-based coatings include acrylics, Hypalon, neoprene, silicone, and urethane and hybrid materials. These coatings are compatible with most types of roofing systems but appear to be used most widely on single-ply, spray-applied polyurethane foam, and metal roofing systems. Elastomeric also can be used on most built-up and modified bitumen systems. Bituminous-based coatings are manufactured to be compatible with either asphalt or coal-tar built-up roofing systems or with modified bitumen membranes. These coatings also are used as a cost-efficient material to prolong the life of metal roofing.

3.1 Elastomeric-based Coatings:

Elastomeric-based coatings includes Acrylic which is suitable for all types of roofs including metal, modified bitumen, single ply, and polyurethane foam and can reflect up to 90% of total thermal radiations (Ronen L, *et al*, 2005). Due to effective reflective properties, cooling load in buildings reduces significantly. Elastomeric also can be used on most built-up and modified bitumen systems (CASE study, 2000).

3.2 Salient Features:

1. It reduces daily thermal expansion and contraction of metal roofing due to lower temperature. . By using an insulating paint even when the temperature is low outside the heat within the building will not be lost as easily through the sheet metal roof.
2. It contains very strong rust inhibitive pigments and fungicides.
3. It has excellent reflective properties which help to reduce cooling costs. This is due to the fact that the majority of heat reflective metal roof paint coverings will also act as an insulator. It also prevents premature degradation.
4. Very good adhesive properties on substrates. Superior resistance to pick-up dirt and helps in staying white for longer time and maintains its reflectivity. This will continue until the roof needs another coating, which can be anything up to 15 years. As this type of paint lasts so long it is seen as a wise investment for buildings that have previously had large cooling and heating bills.
5. Easy to use, easy clean up, non-toxic and VOC compliant water based coating.

3.3 Procedure:

Before coating, it is must that the roof and roof membrane should be examined carefully (surface material) for cracks, tears, blisters, evidence of pounding, exposed foam, and open seams. If already coated, evaluate the condition of the coating. Before coating the surface has to be cleaned properly. Serious roofing problems should always be referred to a qualified roofer for repair before attempting any coating. If possible, the roof surface shall be cleaned with forced water. No dirt or prior coating residues shall be available. Any existing coating must be checked for good adhesion. Liquid Acrylic is available in market which is ready to use. Thinning is not required or recommended. Use good quality brush for applying on the cleaned surface. If small hole sprayer is available than at approximately 3000 psi spraying shall be done. A coating job can often be completed over a two-day weekend in warm weather. Dry, sunny weather over 70° C is ideal. Avoid periods of very cold nights when dew and frost can be a problem

Table 1: Technical Specifications of Elastomeric-based and Bituminous-based Coatings

Parameter	Elastomeric-based Coatings	Bituminous-based Coatings
Colour	White or any custom colour	Brown
Viscosity	6,000 - 8,000cps	2000-15000 cps
Density in kg/m^3	1178	1160
pH	> 8	>7
Percent solids by Volume	68%+/- 2%	70%
Percent Solids by Weight	60% ± 2%	66%
Hardness, Shore A	45	45
Tensile Strength at Max Stress	400 ±50 p.s.i.	600 psi
% Elongation at Break	315	32.7
Permeability	3.5 perms	
Coverage	2 gallons per 100 sq.ft. yields 20 dry mils	Good
Recommended Coverage	Two to four gallons per 100 sq ft depending on surface	Good
Minimum Surface Application Temperature	45°F.	Hot
Drying Time	3 hours	12 hours
Packaging	5 gallon buckets, 50 gallon drums.	Bulk
Energy Star Solar Reflectance	Initial Solar Reflectance = 0.89 Solar Reflectance after 3 years = 0.82	-

3.4 Bituminous-based Coatings:

Roof reflective coatings are the most common solution to cool existing roofs. They comprise elastomeric white roof and acrylic coatings, aluminium coatings, polyurethane foam coatings, bitumen, synthetic rubber. Bituminous-based coatings are manufactured to be compatible with either asphalt or coal-tar built-up roofing systems or with modified bitumen membranes. These coatings are also used as a cost-efficient material to prolong the life of metal roofing. Leaks in modified bitumen roofs are difficult to isolate and a seamless roof coating system is a cost effective solution. A reflective coating applied within five years of installation can extend the service life of the membrane by 10 or more years (Smythe J, *et al*). In summary, roofs are applied with sheets to make them reflect the sun radiations in order to keep building's interior cooler and more energy-efficient, which is especially important during summer months and in warmer climate.

4.0 Procedure of Applying Roof Coating:

4.1 Inspection: Before applying any coating, inspect the roof to look for signs of wear, cracks, uneven bumps and debris. If the roof is old or cracked, then you will have to address these issues before applying the coating. Older roofs in need of replacement should not be coated because the coating will cause difficulty when replacing the roof. Roof coatings will also not work as effectively on roofs with cracks or other damage (Lexis coating, 2008).

4.2 Cleaning: A roof coating is basically a type of paint, which means that the surface will need to be cleaned before the coating will be able to stick to the roof. A pressure washer is the best way to get rid of dirt and other contaminants on the roof. Pressure washers should not be used on gravel roofs because it will cause stones to come loose and ruin the surface of the roof. Gravel roofs should be cleaned with brushes and a cleaning detergent that will not damage the adhesive (Anderson R.W *et al*, 1993).

4.3 Preparation: When the roof has dried from the cleaning it should be inspected once more. Any cracks or damages that are visible should be repaired before applying the roof coating. This is usually done with roofing putty or tar. The putty will provide a drier surface to paint over. If tar is used it will bubble during hot days which can damage the roof coating. Any loose shingles or paper can be nailed back into place. Fix any leaks in the roof before proceeding to the coating stage. Allow any repairs to dry for 24 hours in the warm sun before proceeding.

4.4 Painting: The easiest way to apply roof coating to a flat roof is with a roller. The easiest way to apply roof coating to shingled or rocky roofs is with a paint sprayer. If you choose the roller method, use a wide roller for faster coverage. Roll the coating over the roof like you are painting a wall. Allow each coat to dry for four to six hours before applying a second coat. Generally, two to three coats will be enough to add effective coverage to the roof. If you use the sprayer method, only apply the paint on a low-wind day. Tape off areas of the roof that you do not want to paint. Keep the sprayer close to the roof. It is necessary to apply four to five coats with a sprayer.

5.0 Conclusions:

On the Basis of exhaustive literature review following salient conclusions has been drawn:

1. Coatings can help in protecting the roof from ultraviolet and infrared heat degradation.
2. The heat shock that accompanies diurnal swings in temperatures has a debilitating effect on watertight seals, flashings, rubber roofing and asphalt.
3. Coatings that reflect the sun's UV rays and infrared radiation reduce absorbed heat and prolong roofing life.
4. Coatings that reflect heat can also help protect against another kind of shock — the one from opening the monthly energy bill. Particularly for flat-roofed or low-sloped buildings with air-conditioning ducts that run through the plenum, roof coatings can substantially reduce summertime cooling costs; that's all the more true if the plenum space is un-insulated.
5. It has been noticed that the energy savings of up to 70% in hot and dry conditions which prevails for most of the time particularly in western Rajasthan. If conditions are moderate, energy savings from applying a reflective roof coating could range anywhere from 20% to 50%.

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