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Cool Roofs, a Solution to Reduce the Effects of Heat Islands

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Abstract- **Nowadays heat islands are one the major topics in building designing. Heat islands bring about a number of detrimental effects including climate change, increased energy consumption, greenhouse gas emission, reduced water quality and human health threats. Any of these threats are going to become problems for now and future mankind. The roof surfaces of buildings in urban areas are one of the major surfaces that absorb sunlight and raise the temperature of cities through producing heat islands. One way of reducing such harmful effects is pay attention to materials used in roof surfaces so as to bring about a considerable decrease in urban heat islands. Using these materials which named in this paper, can build a roof called *cool roof*. It is one easy way to gain the goal. Roofing a building by these materials to achieve cool roof could pave the way for a more sustainable architecture. This paper attempts to introduce cool roofs as one of the three proposed strategies of reducing heat islands by a comparative and analytical study on heat islands and their damaging effects. A comprehensive table showing various materials that can create cool roofs is provided.**

Keywords: Urban Heat Islands, Cool Roof, Albido, Energy Calculators

I. INTRODUCTION

Urban climate is greatly influenced by those processes that constitute urban life and work. Expansion of cities and increased construction activities has led to climate change in cities. Direct involvement of human beings is one of the known factors which increases urban temperature compared to those of the surrounding areas. Buildings, roads, and urban infrastructures have taken the place of green spaces and open areas. Such factors make cities warmer than their surrounding areas (2-4 degrees) which consequently create heat islands. Domestic heating systems, air pollution along with the use of inefficient materials like asphalt which absorbs sunlight, are some of the most influential factors in the creation of heat islands which in turn bring about unpleasant conditions for the citizens. The study and analysis of the effects of heat islands will ultimately enable us to reduce them and offer solutions to decrease urban temperatures. Paying attention to urban surfaces such as roofs, sidewalks, streets and roads plays a major role in reducing heat islands. The present study, first, intends to briefly elaborate on urban heat islands and then offers a definition of cool roofs and finally presents materials that could make cool roofs in a comprehensive table.

II. URBAN HEAT ISLANDS

A heat island is an urban surface which is warmer than its surrounding rural areas. This phenomenon was first explained by Luke Haward in 1810. The appearance and growth of cities changed the face of the earth. Buildings, roads, and other urban infrastructures have taken the place of areas with vegetation. [1] The surfaces which used to be wet and permeable are now impervious and dry. These changes made urban areas warmer than the suburbs and created islands with a higher temperature.

Urban surfaces are warm during the day and night; however, during the day, with the radiation of intense sunlight, their temperature rise considerably. Under such circumstances, urban surfaces become warmer than the surrounding temperature. Urban temperature is up to 12 degrees warmer than the temperature of non-urban areas, particularly after the sunset. Roofs, floors, and exposed surfaces absorb most of the sun radiation and change it into heat. On a warm and sunny summer day, such surfaces can become 27 to 50 degrees warmer than the surrounding areas. [2] The temperature in the shade and vegetated areas is closer to the air temperature. The difference in temperature is usually greater during the night than the day. This difference is also more noticeable when it is slightly windy. Heat islands are detectable in both winter and summer. The main reason behind the formation of heat islands is the change in land surfaces due to urban developments. The growth of populated areas creates more surfaces which has a direct impact on

the average temperature. Apart from this impact on the temperature, heat islands can slightly affect the climate by giving rise to changes in local wind patterns, cloud and fog formation, and variation in humidity and precipitation. [1]

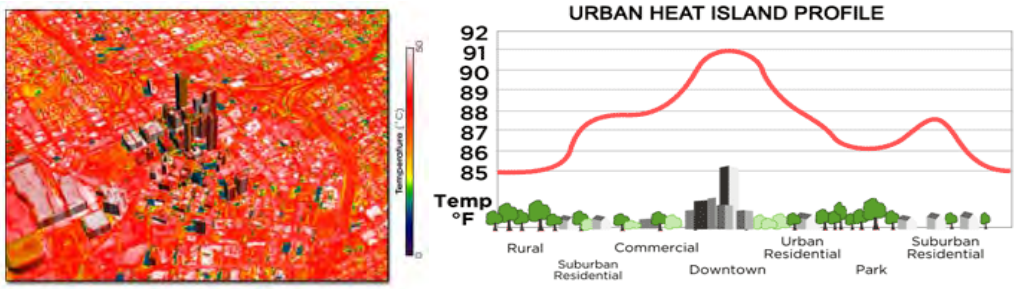

Figure 1: City of Atlanta in America, this image shows the extent to which urban areas are warmer than the suburbs.

Some of the other negative effects of heat islands are as follows:

The increase in the consumption of energy: Higher temperature in summer is accompanied with an increase in the demand for energy for cooling purposes. Such an increase puts more pressure on grid during peak power consumption. Heat islands are responsible for 5 to 10 percent of peak electricity demand for domestic cooling purposes. [3]

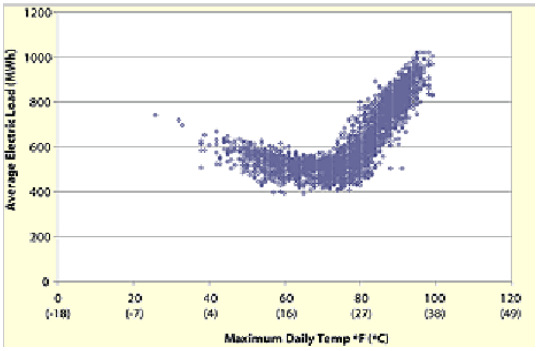

Figure 2: Diagram showing the demand for electricity in the city of New Orleans in the year 2002.

The increase in greenhouse emission and air pollution: Sun, as the only source of heat outside the earth, emits short-wave visible rays and ultraviolet radiation to the earth. Approximately 25% of the sun's radiation is absorbed by the atmosphere and another 25% is reflected by the upper level clouds back into the space. The earth absorbs the rest of solar radiations and becomes warm. The earth radiates a significant amount of energy received from the sun back to the outer space. But since the earth is much cooler than the sun, the energy reflected back to the space is much weaker. According to Stefan-Boltzmann's law, such rays are radiated in the form of infrared (heat) rays.

Greenhouse gases such as water vapor, carbon dioxide, methane and nitrous oxide, capture radiated infrared rays from the earth's surface. Earth's atmosphere acts like the greenhouse glass, allowing the short-wavelength rays enter but stopping long-wavelength rays from leaving.

This process increases the temperature of the atmosphere and is called the greenhouse effect. The earth's temperature (having an average degree of 15 centigrade) is 33 degrees warmer when encircled by the atmosphere. [3] Having said this, it could be inferred that the increase in energy demands generally increases air pollution and greenhouse emissions caused by power plants.

Health threats: heat islands can have a direct and indirect impact on the health and social welfare of the citizens. Polluted warmer days and nights are more likely to cause general discomfort, respiratory problems, fatigue, heat stroke and heat casualties. Just in America almost 1000 people annually die of intense heat. [3]

Deterioration of water quality: hot surfaces and roofs transfer the excess heat to the flood drainage pipes and increase the temperature of the water. This warmer water flows into streams, rivers, lakes, and ponds. Rapid temperature changes can endanger aquatic ecosystems. In order to reduce such negative effects, many countries have adopted four main strategies whose effectiveness depends on factors which might or might not be under the control of human beings. These include climatic conditions of the region, topography, geology, etc. As for the rest, it is recommended that urban designers and organizers follow efficient energy saving strategies in landscaping, land use, and building materials. Urban heat island reduction strategies include:

- Increasing trees and vegetation
- Installing green roofs
- Installing cool roofs
- Using cool floors

Using any of these strategies or a combination of them will reduce air pollution, environmental contamination, greenhouse emissions, energy consumption, solid waste production, and heat casualties. Furthermore, improving the quality of water and controlling floods will result in the protection of living creatures and greater durability of surfaces which in turn cuts back on maintenance. [4] The owners of buildings and their residents can also enjoy a plethora of financial benefits. Using cool surfaces could be regarded as a comprehensive strategy to reduce weather temperature which in turn significantly reduces the adverse effects mentioned above.

As it was noted earlier, roofs and floors are exposed to sunlight more than other urban structures and which make them considerably hotter. According to the radiation distribution diagram, a large portion of the radiation spectrum consists of infrared radiation which turns into heat once it hits roofs and floors. On a sunny summer day, such surfaces can become by 27 to 50 degrees warmer compared to their surrounding areas. The most effective way to prevent such a phenomenon is to reflect more sunlight back to the space. [1]

III. COOL ROOFS

In an urban area, approximately 25% of surfaces are roofs and almost 90% of them are dark colored. Many of the existing roofs absorb a great amount of sunlight into the building and reflect only about 10 to 20 %. Temperature of dark roofs can rise from 50 to 80 degrees. [5] The effects of this phenomenon include:

- More energy demand for cooling devices during the peak energy consumption
- An increase in the costs of energy
- Reduction of residents' comfort and welfare
- Increase of air pollution due to urban heat islands
- Acceleration of roofing material erosion

Figure 3: Thermal diagram of Chicago City hall. On a typical day, the green roof of the City Hall is about 40 degrees cooler than the surrounding areas.

Cool roof is considered to mitigate such negative effects because instead of transferring the heat into the building, it reflects the sunlight back to the space and keeps the temperature of the building stable. "Cool World Program" is the basis of such studies which is planned by the department of heat island at Technologies of Environmental Energy Union at Lawrence Berkeley National Laboratory and the University of California in 1980. In the 1990s, manufacturing various products related to cool roofs in different residential,

industrial, and commercial fields greatly flourished. In 2001, products and companies associated with cool roofs were granted different quality awards. From the very same year, cool roof award qualification became a criterion based on which LEED quality award was granted. Also, in order to encourage people, some countries like the United States have allocated financial credits to those families who wish to change their roofs. Since then a variety of laboratory and research projects have been carried out to achieve the main objective of reducing harmful effects of heat islands. [1]

IV. Advantages of Cool Roofs

Using cool roofs in buildings has a lot of direct and indirect advantages. Direct advantages concerns short-term immediate and noticeable effects. For instance, by installing cool roofs, heat absorption of a building immediately lessens because their temperature can only rise 5 to 14 degrees. Other direct advantages may include: reducing the costs of ventilation and cooling systems and maximizing their durability; reducing roofs maintenance costs and increasing their durability; preventing roof reconstruction and reducing solid waste and finally creating beautiful roofs which are quite efficient. Indirect benefits on the other hand, are those which appear in the long run. Reducing the negative effects of urban heat islands and global warming, reducing greenhouse emissions and pollution, increasing residents' comfort, ecology sustainability by transforming a house into a green house, and finally saving about 7 to 15% energy for future use during summer all refer to indirect advantages. [5]

In an article published in the Journal of Climate Change by Berkeley Lab in 2009, it was stated that reconstruction of roofs, floors, and streets with cool roofing materials decreases carbon dioxide emissions (which is the result of global warming) by 44 billion ton meters (1 ton meter=1000 kg). Furthermore, the replacement of conventional roofs with cool ones, and the use of reflective materials or even white coat of paint reduce 20-30 percent of energy consumption in cooling systems and lower the temperature of summer days as well. An investigation conducted in Texas in 2001 yielded surprising results according to which replacement of black rubber roofing material with white vinyl cover led to 23 degree temperature reduction of the roof (from 75 to 52 degrees)and 11% reduction of energy consumption in cooling systems. [1] Another similar study in the same year revealed that replacing conventional roofs with cool roofs and using plants in a metropolis like Toronto in Canada saved up to 11 billion dollars in energy costs.

Figure 4: different roofs using cool roofing materials (such as clay and metal covers) to have maximum sunlight reflection.

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V. The Degree of Roofs Coolness

The more reflective the roof, the cooler it will be. Basically coolness is measured by two components: Solar Reflectance and Thermal Emittance, both of which are graded from 0 to 1 or expressed in percentage. Combining these two characteristics, Green

Building Association of America introduced Solar Reflectance Index, which shows the degree a surface is warmed in the sunlight and indicates the impacts of emission and reflection of sunrays on the surface temperature. [6] Solar Reflectance Index is measured on the scale of 0 to 100.

Different kinds of cool roofs:

- Roofs with essentially cool roofing materials; roofing materials are inherently reflective. For instance asphalt roofs reflect only about 6 to 26% of sunlight while thermoplastic white vinyl roofs reflect about 80% of sunlight and release 70% heat. [6]
- Roofs with cool covers; one way to convert conventional roofs to cool ones is using roofs covers which has energy label.
- Green roofs; growing plants on roofs.

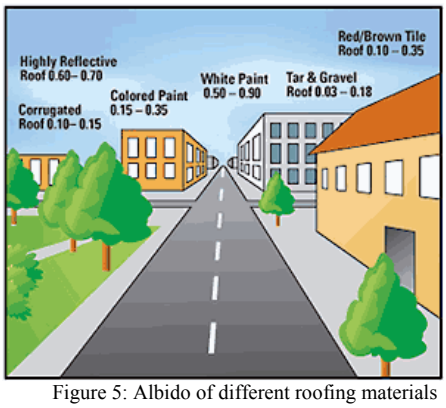

Figure 5: Albido of different roofing materials

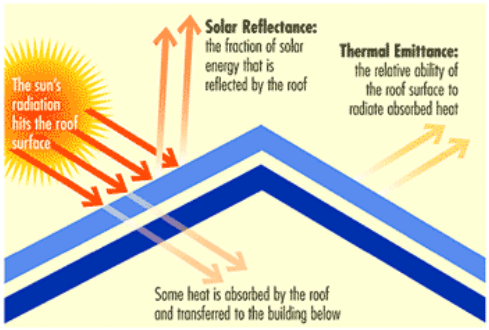

Figure 6: Radiation diagram on the surface of the roof

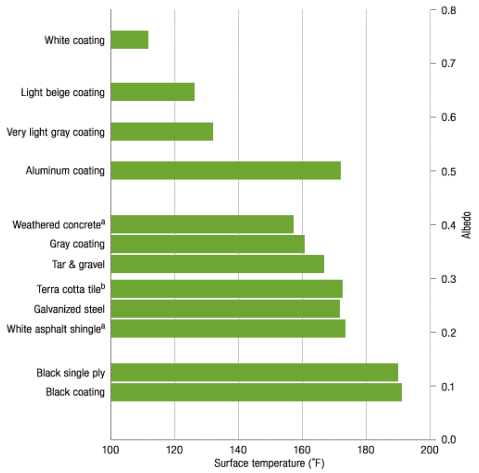

Figure 7: surface temperature of different material

Figure 8: Different types of cool roofs and green roofs

VI. Energy Calculators

In order to choose appropriate roofing materials, two programs of 'Cool Roof Calculator Program of America's Energy Department' and 'Cool Roof Calculator of America's Environmental Protection Agency' provide online information regarding the area, climate, and the required amount of energy consumption. Detailed knowledge of these two items is quite necessary in selecting the best and most efficient roofing materials. In addition, 'Star Energy' roof measurement calculator not only examines the materials to have this quality but also estimates the expenses in terms of the size of the building and its location. To help people choose the right roofing products which will eventually lead to building sustainable buildings, particular plans (using cool roofs is one of them) have been regulated to promote this objective. Among them receiving these awards can be pointed out:

Energy Star is a label which is designed by DOE and EPA to reduce greenhouse gas emissions.

LEED (GBS) is a rating system of organizing energy and environmental design which is given on behalf of America's Green Building. LEED is a standard mark to highlight sustainable buildings and material selection in designing buildings.

GREEN GLOBES is a system in Canada and America to establish standards of energy consumption in buildings, comparing it with statistics and EPA BREEAM index. It is a method to design sustainable buildings and determine standards for building construction in Europe.

VII. Introducing Roofing Materials

Cool Roof Rating Council (CRRC) has developed accurate methods for evaluating and labeling solar reflectance and thermal emittance of roofing products. CRRC provides online information regarding 850 construction products and the companies offering them. The following points are considered to be necessary by CRRC in order to determine appropriate products:

- Climate: in cold climate, cool roofs are not basically different from each other, but it is better to use green roofs.
- Sustainability issues: recycling materials, reusing, durability, the amount of toxic materials, etc.
- Slope: gradual or light slope (less than 2%) reflectance 25%, steep slope (more than 2%)reflectance 65%
- Objectives: saving energy and fulfilling environmental requirements
- Project location
- Aesthetic issues

Figure 8: Concrete tiles with high Albido, roofs made of modified bitumen, a shingle combined with asphalt.

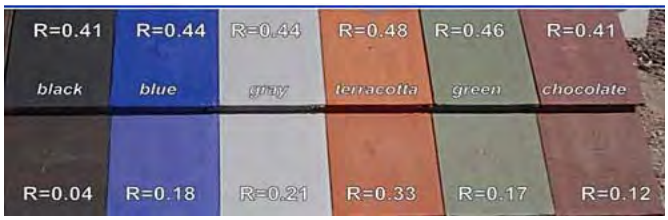

Figure 9: Clay tiles with former colors (on top) and modified pigments (at the bottom), their reflectance is significantly different.

Construction industry offers a great variety of products. Some companies, apart from offering new products, introduce current popular products with new formulas to the market; such as different kinds of concrete, clay, cement, or metal tiles, paper-based insulation, elastomeric cover (polymer with elastic feature), and various roof covers made up of recyclable natural materials. White is not the only color for cool roofs. Berkeley Laboratory and Oak Ridge lab has developed pigments that have reflective properties. Roofing materials are generally classified into three main categories: different types of roof construction materials, roof covers, and color. [7] The following table shows materials which are extensively used in cool roofs.

Table 1: Introducing cool roofs materials

Type of material	***Name of Material***	***Features***
Roofing materials	Asphalt shingles	Combined layers of asphalt with natural wool and fiberglass which are placed in the intended location with high heat and light emission. The final layer can be made of silicone with tiny pigments.
	Roof foam	Factory types, with hard solid panels and reflective covers ready to be installed.
		Another type which is installed in the intended place. Liquid is sprayed on roofs and it will get hard after sometime.
	Metal	As shingles and planks plus different types of fillers and connections in different colors and textures.
	Modified bitumen	Modified bitumen with plastic and layers of fortifying materials and reflective covers.
Final roof cover	White covers	White covers having transparent polymeric materials such as acrylic and pigments such as titanium dioxide which makes them opaque and reflective.
	Colored cover	Covers with colored ting which are reflective. Such colors can be dark too, but they are mainly bright colors like lemon yellow and have herbal fibers.
	Aluminum cover	Sheets of aluminum brought from the factory to be placed on the asphalt roofs.
Final roof cover	Shingle, plank, and tiles	Different roofing materials placed on each other such as bitumen boards which are cheap and easy to use. They have different forms, colors and textures which can reflect sunlight and emit heat.
	Polymeric planks	Building materials in which its polymeric materials are made of bituminous hydrocarbon materials and industrial plastics such as EPMD and polymers such as PVC and poly phenylene
	Single-layer cover	Prefabricated plates made of rubber polymers for roofs with steep or light slopes which are pasted on the roofs with special glues.
	Flexible single-layer cover	Such as EPDM, welding is not used to fill the empty spaces; cement is used instead.

	Soft one-layer cover	Such as PVC and TPO which are very flexible plates, a combination of polymeric plastics. Heat melts the empty holes inside the roofing plates. They are reflective and have fortifying layer for greater durability.
Color	Acrylic colors	In white and various dark and light colors to increase reflectance and heat emission of different dark colors using new compositions.

VIII. CONCLUSION

Global warming and urban heat islands should be taken seriously. The solutions and suggestions offered by different organizations and institutions across the world point to the degree this problem is causing apprehension and drawing attentions. Thus cool roofing materials as an efficient and simple strategy need to be considered more vigorously. Cool roofing material is an appropriate way of economizing and saving energy. With the every-day advances in building and construction technologies, it is advisable to pay more attention to the manufacturing of various roofing materials, and coating paints so as to highlight the importance of these manufactures for the owners as well as those involved in construction of buildings.

Monitoring the quality of such manufactures is also of importance. Unfortunately, this monitoring is somehow usually neglected in some countries. Any failure and negligence on the part of authorities and urban policy-makers in this respect is unacceptable and unjustifiable, as the world is making great progress in this field. It is also incumbent on the related scholars and academicians to take serious actions vis-à-vis the points raised in this study including the impact of urban heat islands. It is also recommended that executive and planning organizations like the municipality and civil engineering organization, as key role players, follow the example of other countries and establish an evaluation procedure mechanism in order to access the quality of products and construction plans with the aim of achieving the highest world standards. Only after fulfilling the necessary requirements can the manufacturers and planners be granted the world recognized quality awards. Last but not least, those who are inclined to use cool roofing materials can be given incentives including the reduction of municipal taxes, and of expenses through gratuitous financial aids.

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