Cool Roofs, Cooler Cities: Reducing Energy Consumption and the Heat Island Effect in Urban Settings through Roof Design.

Albino Marsetti (student) and Masato R. Nakamura (advisor)
Department of Mechanical Engineering and Industrial Design Technology
New York City College of Technology (City Tech), City University of New York (CUNY)
300 Jay Street, Brooklyn, NY 11201

Abstract

Heat reduction on rooftops by current passive roof cooling technology is investigated in order to find design solutions for urban energy usage. Cities represent two-thirds of global energy consumption. This proportion is expected to grow to almost three-quarters, by the year 2030. [1] Given this staggering statistic, increasing attention is being focused on design solutions for reductions in urban energy usage. In this study a new passive roof cooling unit is developed in order to reduce the consumption of cooling energy, and mitigate the heat island effect in the urban environment.

Research Methods

Our research is an investigation of roof cooling technology published in peer reviewed engineering and architectural journals. We have made a distinct effort to identify “passive” designs which do not require additional energy or effort to mitigate urban heat absorption. Our proposed experiment unifies common characteristics from several different passive experiments.

Background

The heat island effect occurs in urban environments where dark surfaces absorb solar radiation which in turn can make the temperature of the urban environment 1.8 to 5.4° F warmer than surrounding rural areas. In the evening, the difference can be as high as 22°F. [2]

By simply replacing black roof surfaces with white elastomeric coatings or membranes the temperature of a roof surface can be reduced by as much as 55°F [3]. More of the sun’s radiation is reflected back to the atmosphere reducing absorption and heat transfer to interior spaces[4]. Since 2010, New York City’s “Cool Roofs” program has used volunteer labor, to cover 3,688,672 ft² of roof with white coating. [5] It is estimated that the potential global CO2 reduction that could be achieved by painting rooftops is 24 Gt.[6]

Passive Cooling Designs

Early Persian designs of passive cooling systems include domed roofs and windcatchers. M Hadavand et al. show that a vaulted roof maintains lower interior temperatures than their flat counterparts. [8] Exploiting the prevailing wind is an important factor in early Persian architectural cooling. [9]

Evaporation appears as one of the earliest cooling strategies and has been explored in many iterations. For example: rooftop ponds, evaporation chambers, sprinklers, and irrigation.[10][11][12] Evaporative cooling is one of the important characteristics of the “green roof”.

The green roof is a concept that has been gaining in popularity. A secondary benefit is mitigation of runoff. We would not classify the green roof as a strictly passive system since it requires regular maintenance as a garden would. However, it must be identified as it provides the most energy benefit. The green roof can reduce the heat loss rate by 34% in the winter and lower the heat gain rate by 84% in the summer.[13]

Phase change materials (PCMs) are among the newest elements being considered for incorporation into roof design. PCMs are materials which “melt” at a specific temperature and absorb tremendous amounts of heat. Specific heat increases more than 100 times during phase change, and is stored until surrounding temperatures decrease. Heat flux at the indoor space can be reduced as much as 39%.[14]

Shade as an Obvious Strategy

One study suggests that the shade created by the simple installation of rooftop solar panels can reduce cooling costs by 38%. [15]

Sakai, S. et al. propose a roof comprised of fractal shapes which block 100 % of sunlight from one direction. This design seeks to replicate the shade of trees which allows heat to be swept away by air currents. Surface of the fractal roof was 30-65% cooler than a flat roof. [16]

The cavity roof is proposed by Susanti L., et al., which demonstrated a reduction in temperatures of the surface underneath the roof. In air conditioning mode, The cavity roof showed the possibility for 48% cooling load savings over a single roof. Equivalent interior temperatures could be achieved at an operating thermostat temperature 7.6° C higher than in the single roof structure. [17]

Discussion/Conclusion

Some common characteristics emerge throughout much of the research and knowledge about the transfer of heat between the roof of a building and its interior. There is consensus that engineered white surfaces absorb less solar radiation. Insulation is perhaps the most important factor in mitigating heat transfer to interior spaces, though additional reductions can be achieved by providing a ventilated space wherein heat transfer is mitigated. The green roof appears to provide the most energy benefits, though other considerations must be made regarding roof design, and vegetation maintenance.

Future Work

We are proposing a simple passive method for reducing heat transfer from a rooftop. The unit is a lightweight, 16 gauge louvered white metal panel 2ft x 2 ft with detachable base which can be deployed on any flat roof. The modular design allows for installation around existing roof features. The panel reflects sunlight and creates a cavity above the roof which is naturally ventilated by the prevailing wind. The light weight and modular design allows for installation without the need for structural modification of an existing roof. Our initial research will be performed in a laboratory in the spring and continued in the field in summer.

References