Mechanical Engineering Doctoral Defense

The importance of radiative properties of rooftop materials in affecting building thermal performance and the resulting impact on urban climates

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Abstract

A well-insulated dark conventional rooftop can be hotter than any other urban surface, including pavements. Since rooftops cover around 20 – 25% of most urban areas, their role in the urban heat island effect is significant. In general, buildings exchange heat with the surroundings in three ways: heat release from the cooling/heating system, air exchange associated with exfiltration and relief air, and heat transfer between the building envelope and surroundings. Several recent studies show that the building envelope generates more heat release into the environment than any other building component.Current advancements in material science have enabled the development of materials and coatings with very high solar reflectance and thermal emissivity, and that can alter their radiative properties based on surface temperature. This dissertation is an effort to quantify the impact of recent developments in such technologies on urban air. The current study addresses three specific unresolved topics: 1) the relative importance of rooftop solar reflectance and thermal emissivity, 2) the role of rooftop radiative properties in different climates, and 3) the impact of temperature-adaptive exterior materials/coatings on building energy savings and urban cooling. The findings from this study show that the use of rooftop materials with solar reflectance above 0.9 maintain the surface temperature below ambient air temperature most of the time, even when the materials have conventional thermal emissivity (0.9). This research has demonstrated that for hot cities, rooftops with high solar reflectance and thermal emittance maximize building energy savings and always cool the surrounding air. For moderate climate regions, high solar reflectance and low thermal emittance result in the greatest building energy cost savings. This combination of radiative properties cools the air during the daytime and warms it at night. Finally, this research found that temperature-adaptive materials could play a significant role in reducing utility costs for poorly insulated buildings, but that they heat the surrounding air in the winter, irrespective of the rooftop insulation. Through the detailed analysis of building façade radiative properties, this dissertation offers climate-specific design guidance that can be used to simultaneously optimize energy costs while minimizing adverse warming of the surrounding environment.

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