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Modeling impacts of roof reflectivity, integrated photovoltaic panels and green roof systems on sensible heat flux into the urban environment

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ABSTRACT

This study presents results of a modeling effort to explore the role that sustainable roofing technologies play in impacting the rooftop energy balance, and the resultant net sensible heat flux into the urban atmosphere with a focus on the summertime urban heat island. The model has been validated using data from a field experiment conducted in Portland Oregon. Roofing technologies explored include control dark membrane roof, a highly reflective (cool) roof, a vegetated green roof, and photovoltaic (PV) panels elevated above various base roofs. Energy balance models were developed, validated with experimental measurements, and then used to estimate sensible fluxes in cities located in six climate zones across the US.

On average the black roof and black roof with PV have the highest peak daily sensible flux to the environment, ranging from 331 to 405 W/m^2. The addition of PV panels to a black roof had a negligible effect on the peak flux, but decreased the total flux by an average of 11%. Replacing a black roof with a white or green roof resulted in a substantial decrease in the total sensible flux. Results indicate that if a black membrane roof is replaced by a PV-covered white or a PV-covered green roof the corresponding reduction in total sensible flux is on the order of 50%. The methodology developed for this analysis provides a foundation for evaluating the relative impacts of roof design choices on the urban climate and should prove useful in guiding urban heat island mitigation efforts.

1. Background

Rooftops are playing an increasingly important role in urban sustainability efforts. Various roofing technologies have been promoted for reducing stormwater runoff, generating electricity, reducing building energy consumption, or mitigating the urban heat island (UHI). While some prior research has explored the efficacy of such technologies, these studies are typically limited to a single technology or a specific location (climate). They also tend to lack a quantitative connection between the rooftop surface energy balance and the urban climate system.

1.1. Context and previous work

For several decades now research has been conducted into the use of cool roof (high solar reflective or high "albedo") technologies both for building energy savings and urban heat island mitigation [1–5]. Cool roofs provide an alternative to dark asphalt, black membrane, or rock ballasted roofs. Due to their high albedo, cool roofs absorb less incoming solar radiation than comparable roofs with greater solar absorptivities. As a result, cool roofs maintain a lower surface temperature which can reduce heat transfer into the building, as well as into the urban environment. In some climates there may be a slight winter penalty associated with cool roofs, but this is typically outweighed by the summer benefit, and can also be negated if the roof is covered with snow in the winter [6]. After initial installation of a green roof, the accumulation of dirt can affect the albedo of a roof. The roof pitch, location and climate all influence the degree to which albedo is impacted by weatherization. It has been shown that most of the weathering occurs during the first year after roof installation, with albedo decreases averaging 0.15. If the roof is washed, the albedo can be restored to within 90% of its original value [6]. The typical albedo of an unweathered membrane roof ranges from 0.06 (dark black) to 0.83 (high albedo white) [7].

Measurements in various climates have shown that white roofs can reduce rooftop temperatures 20–42 °C as compared to dark roofs [8–10]. In one of the early studies of cool roofing, researchers used building energy simulation of prototypical buildings across 11 US metropolitan areas to evaluate the potential energy savings of highly reflective roofing [11]. In extrapolating their results to the

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