

Subambient Colored Radiative Cooling Using Photoluminescence

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Extended Abstract

Passive radiative cooling (PRC) has emerged as a promising and eco-friendly cooling technology for achieving carbon neutrality as it directs thermal radiation toward the cryogenic Universe (~ 2.7 K) [1]. However, the glaring white appearance of conventional PRC raises significant aesthetic concerns and create thermal/visual discomfort in urban environments [2]. Realizing vibrant and angle-insensitive colors with multifunctionality and subambient cooling performance, without relying on super-whiteness, remains a formidable challenge [3].

In this study, we present a photoluminescence-based aesthetic composite (PLAC) for addressing the long-standing trade-off between the intertwined optical, chromatic, cooling, comfort, and functional challenges of colored PRC for urban skins. By leveraging the light conversion properties of rare-earth-doped phosphors, the PLAC achieves vivid, customizable, and angle-insensitive colors (green, yellow, and red) with moderate whiteness, while maintaining high cooling efficiency, overcoming the intrinsic limitations of conventional, light-scattering-based super-white PRC systems. To enable precise optimization, we further introduce a standardized spectro-fluorescence-photometry methodology that effectively decouples the light conversion and scattering processes, establishing an analytical tool that has been critically lacking in this field. After optimizing the interplay between light conversion, optical properties, and chromatic performances, the PLACs exhibited effective spectral reflectance exceeding 100% and, especially, a peak reflectance over 140% at emission wavelength regions. Even with a moderate overall solar reflectance of $\sim 90\%$, the PLACs demonstrated remarkable subambient temperature reduction up to 3.9°C and net cooling power up to 40.7 W/m^2 during outdoor field tests. These results unequivocally highlight the immense potential of cooling power recovery through light conversion, effectively circumventing the traditional reliance on the whiteness of reflective substrates or matrices. In addition to the cooling capacity and aesthetic enhancement, we, for the first time, provide comprehensive assessments of the impact of whiteness on the urban environment using quantitative indicators including Mean Radiant Temperature (MRT), the Universal Thermal Climate Index (UTCI), and Daylight Glare Probability (DGP). We demonstrate that the PLACs significantly mitigate the negative thermal and visual impacts of super-white PRC materials on urban microclimates. Specifically, the moderate whiteness of the PLAC reduces MRT by up to 9.3°C and decreases thermal and visual discomfort in urban canyons, predominantly through the reduction of excessive shortwave reflection. Beyond these exceptional aesthetics and cooling performance, the PLACs further showcase outstanding compatibility with diverse substrates, excellent mechanical flexibility, long-term durability, and robust hydrophobicity, highlighting their potential for scalable deployment in urban infrastructure. Collectively, these attributes and innovations position PLACs as a transformative solution for practical deployment in the rapidly growing PRC market, paving the way for a more vibrant, energy-efficient, and environmentally comfortable residential urban landscape. Furthermore, the light conversion strategy establishes a novel paradigm for thermal management, energy harvesting, and energy transfer technologies.

References

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