Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

Enhancing Cooling Efficiency Using Parabolic Reflectors in Radiative Cooling Systems

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Abstract

Passive radiative coolers (RCs) work by naturally emitting heat as infrared radiation within the 8–13 µm range, over which the earth's atmosphere allows radiation to escape freely into outer space. Recent improvements in RC materials and design have made this technology an affordable and scalable means to reduce cooling needs. RCs primarily cool through sky-facing surfaces, while earth-facing surfaces remain unutilized. The use of parabolic trough reflectors beneath the RC can mitigate these limitations and enhance cooling performance by directing radiation emitted by the RC towards a parabolic mirror for reflection, while also reducing the impact of incoming atmospheric radiation. Monte Carlo Ray Tracing methods are employed to investigate the effects of the RC structure and the parabolic trough geometry on the cooling performance, The evaluation is based on the angular distribution of RC-emitted rays relative to the zenith direction. The study examines the effects of the tubular RC's diameter and length, as well as the reflector's height, length, and focal length, on redistributing the angular distribution of RC-emitted radiation to enhance cooling power. Furthermore, the impacts of convective heat transfer from the environment and solar absorption on the cooling performance of RCs are analyzed. This research is the first to provide a full set of comprehensive results on how RC materials perform when combined with parabolic trough reflectors. The results demonstrate that incorporating an underlying parabolic trough reflector can significantly enhance the cooling performance of RCs. Previous studies have predicted at most a twofold enhancement in cooling performance. Specifically, this research demonstrates that incorporating a reflector enhances cooling power by up to 2.2 times compared to configurations without it. Additionally, the results indicate that variations in tubular RC length and diameter impact the cooling power differently, despite both changes leading to the same cross-sectional area along the tube. These findings provide valuable insights for optimizing RC systems to achieve enhanced sub-ambient cooling performance.