2024 Asia and Pacific Mathematical Contest in Modeling

Problem B

Modeling and Optimization of Radiative Cooling Technology

Global industrialization and population growth have led to a continuous increase in energy consumption. Although the proportion of supply from clean energy sources such as solar, wind, and nuclear power has risen, petroleum and other liquid fuels remain the world's largest source of energy supply. This has led to the exacerbation of the urban heat island effect and the greenhouse effect.

According to the Stefan-Boltzmann Law, objects at higher temperatures radiate more power than objects at lower temperatures. Under the condition of an average Earth surface temperature of 15°C, most thermal radiation from objects on the Earth's surface occurs within the infrared spectral range. Consequently, scientists have proposed a technology known as Passive Daytime Radiative Cooling (PDRC). This technology is based on the principle: the high transmittance of infrared radiation through the 8-13 μm "atmospheric transparency window" and the thermal radiation energy exchange that occurs due to temperature differences. Without consuming any energy, an object on the Earth's surface can directly emit its thermal radiation energy into the cold expanse of outer space, thus spontaneously lowering its temperature, potentially even below the ambient temperature.

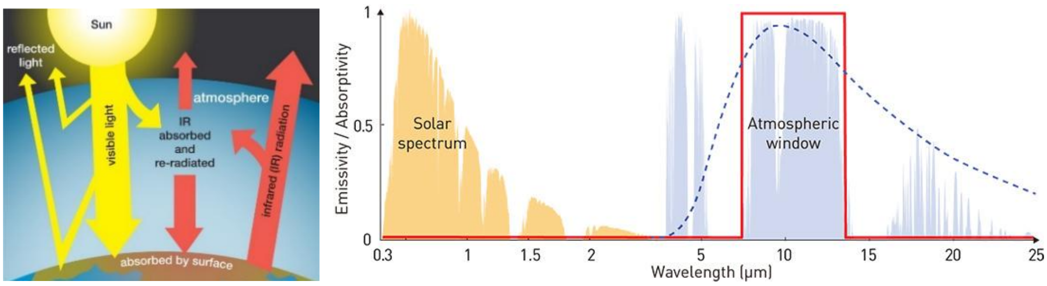

Figure 1 Radiative Cooling Technology

Compared to other cooling technologies, radiative cooling requires no energy input while simultaneously reducing overall energy consumption, creating a virtuous cycle of energy savings. This is of great significance for achieving renewable energy development and carbon neutrality goals. The technology shows immense application potential in fields such as energy-efficient buildings, solar cells, personal thermal management, power plant condensers, and power generation and water harvesting. However, radiative cooling technology still faces several challenges on its path toward large-scale practical application. These challenges primarily lie in the need to optimize the spectral emission properties of materials, as well as complex fabrication processes and high production costs. Current research indicates that polydimethylsiloxane (PDMS) thin film is a material that possesses both ultra-high transmittance in the visible spectrum and high emissivity in the "atmospheric window" band, making it highly suitable for application in radiative cooling technology. Information on the refractive index of materials can be found on relevant websites (e.g., https://refractiveindex.info/).

1.Please establish a suitable mathematical model to study the emissivity of PDMS thin films as a function of wavelength for different film thicknesses.

2.Please establish a suitable evaluation model to assess the radiative cooling performance of PDMS thin films of varying thicknesses. Based on your findings, provide some recommendations related to the advancement and application of radiative cooling technology.

3.Please select suitable materials to form a multilayer film structure in conjunction with PDMS. Incorporating an optimization design algorithm, perform an optimization of the material selection and layer thickness for each layer within the multilayer structure.

4.Please perform a comprehensive optimal design of the radiative cooling materials and structures to achieve the best possible radiative cooling performance. Following the design, conduct an evaluation of the feasibility and cost of the resulting radiative cooling product.

References：

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