Simulation and Experimental Exploration of Radiative Cooling

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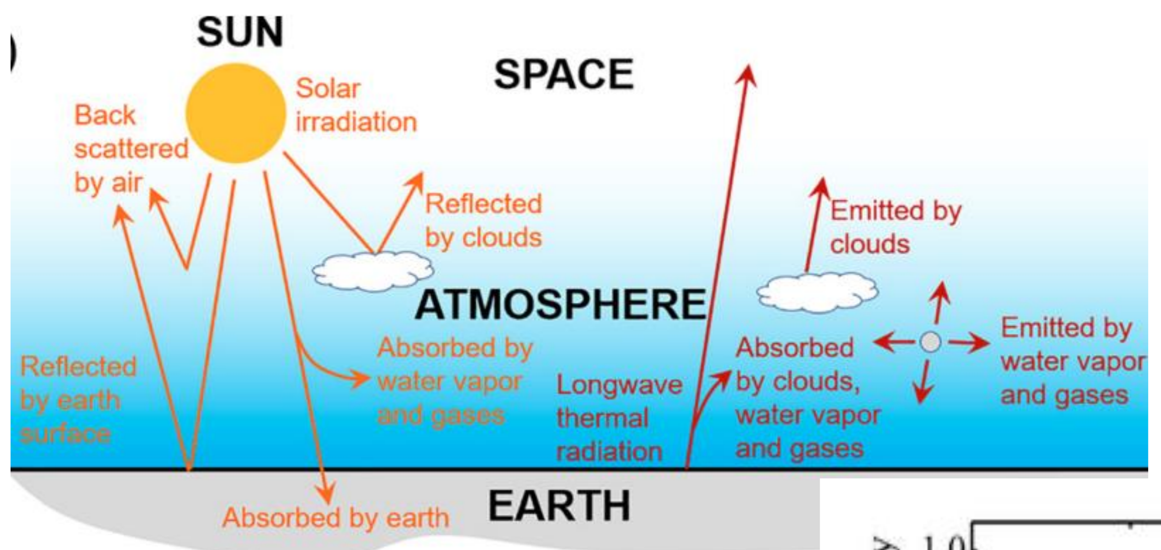
INTRODUCTION

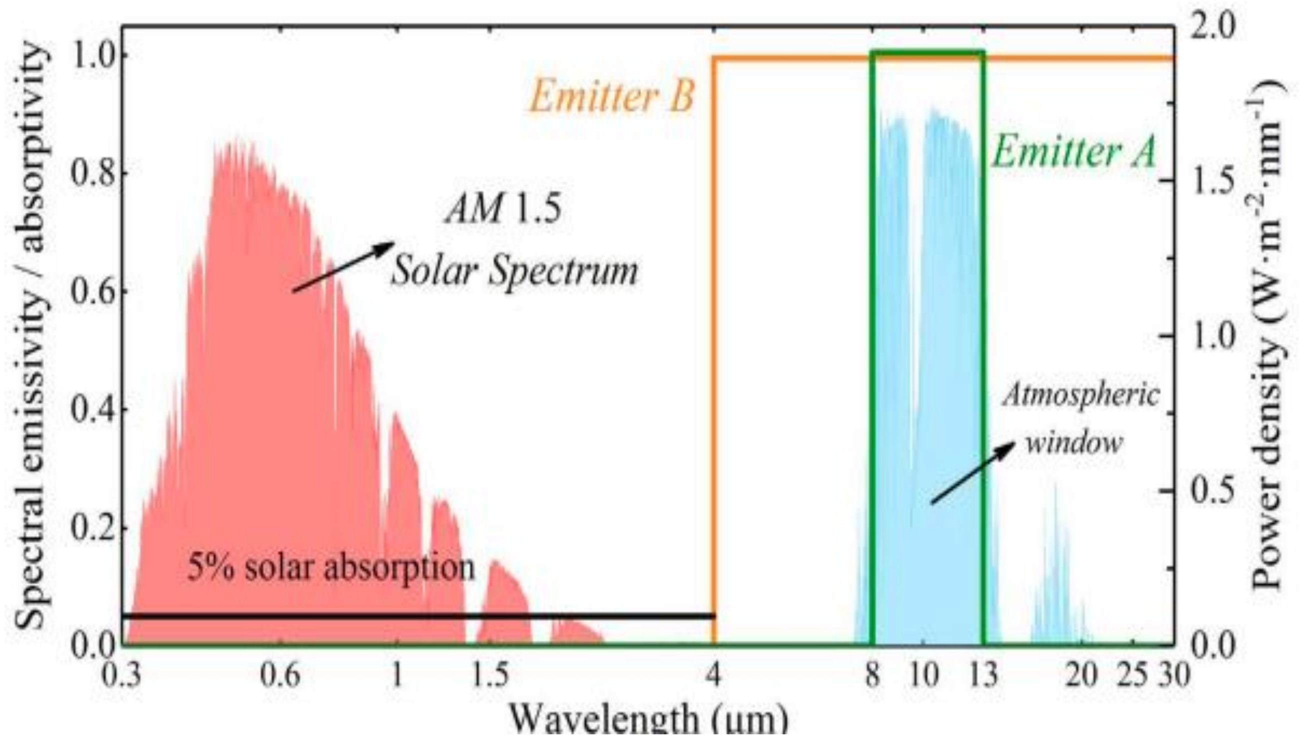
The radiative cooling effect is a phenomenon where an object radiating energy at a certain wavelength towards a clear sky decreases its temperature by sending the energy through the atmosphere and into space. This allows for an object to be cooled down without any energy consumption. If an object has high emission in this range, then it has the capacity for radiative cooling [1,2].



Radiative Cooling Representation [2] (Fig. 1)

Advances in materials now make possible radiative coolers that reflect most sunlight while retaining high emission in the atmospheric window. These innovations could be used to increase solar energy efficiency or cool buildings [4].

The idea of the radiative cooling mathematical model is to design a tool that allows us to estimate the radiative cooling potential of many objects and surfaces. An experiment using a nighttime radiative cooler is planned to be compared to the model to verify its accuracy.



Solar Spectrum and Atmospheric Window [2] (Fig. 2)

MATERIALS & METHODS

This research was conducted in two steps, the creation of the model, then the testing of the model.

The model presented in [1, 2] was adopted and implemented in MATLAB. Each equation was modeled in a function using MATLAB. The model was tested at night with a radiative cooler constructed using a design from [5], which collected data that was entered into the program [6]. The model was also compared to data calculated in [4].

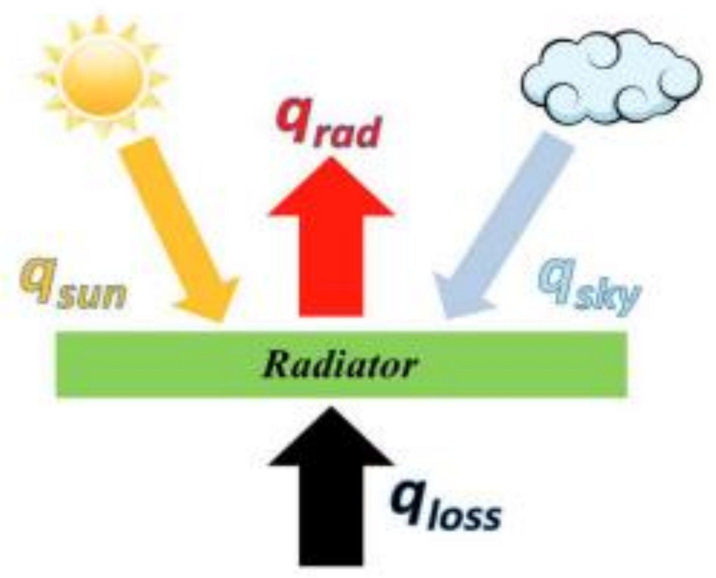
Variables

I_{BB}- Spectral Irradiance of Blackbody

ε_{film}- Emissivity of Cooler T - Temperature λ – Wavelength θ - Sky Angle

I_{solar}- Spectral Irradiance of Sun φ - Sun Angle

ε_{atm}- Emissivity of Atmosphere ; h_{air} - Heat Transfer Coefficient



Radiative Cooling Components Representation [1] (Fig. 3)

The model was created with the following equations:

Total cooling achieved from the effect:

$$P_{cooling} = P_{rad} - P_{sun} - P_{sky} - P_{conv+cond}$$

Energy emitted as radiation by the cooler:

$$P_{rad} = 2\pi \int_0^{\pi/2} \int_0^{\infty} I_{BB}(T,\lambda)\varepsilon_{film}(\lambda,\theta)\sin(\theta)\cos(\theta)d\lambda d\theta$$

Solar energy absorbed by the emitter:

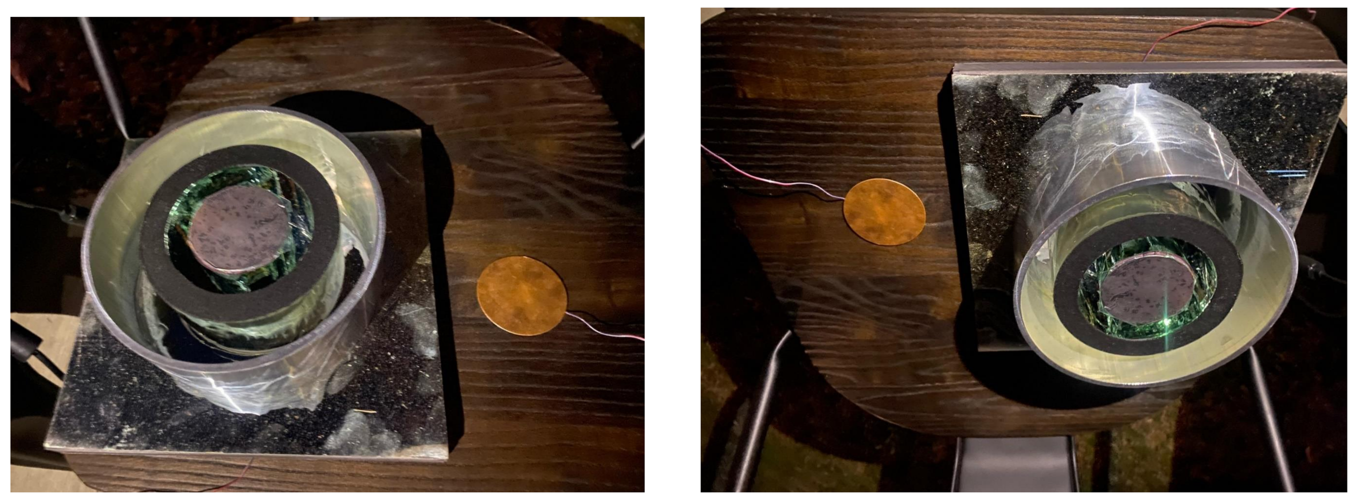
$$P_{sun} = \cos(\varphi)\int_0^{\infty} \varepsilon_{film}(\lambda,\varphi)I_{solar}(\lambda)d\lambda$$

Emitted radiation energy absorbed by the atmosphere:

$$P_{atm}(T_{amb}) = 2\pi \int_0^{\pi/2} \int_0^{\infty} I_{BB}(T_{amb},\lambda)\varepsilon_{film}(\lambda,\theta)\varepsilon_{atm}(\lambda,\theta)\sin(\theta)\cos(\theta)d\lambda d\theta$$

Energy gained or lost from conduction and convection:

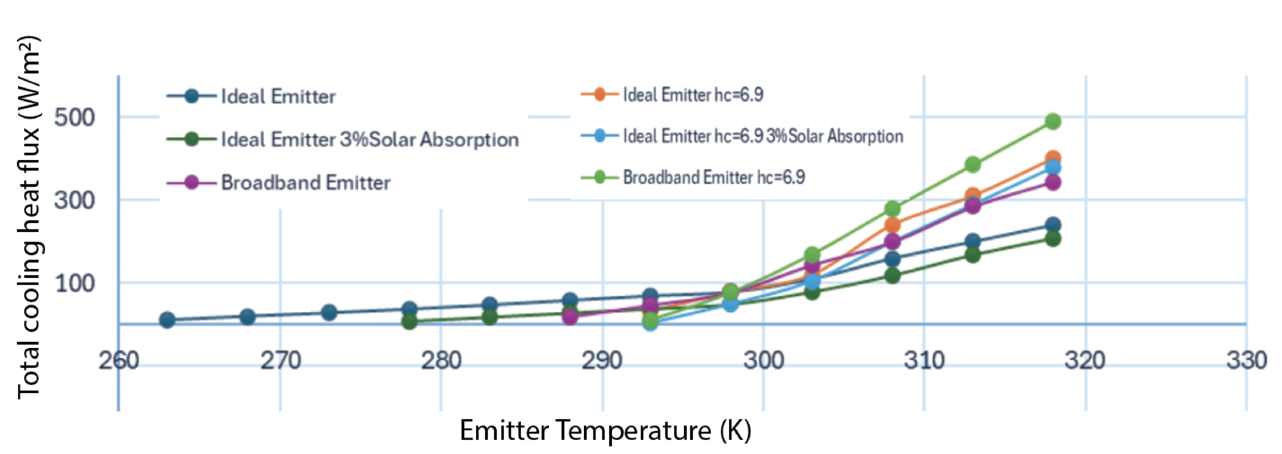
$$P_{cond+conv} = (T - T_{atm})h_{air}$$



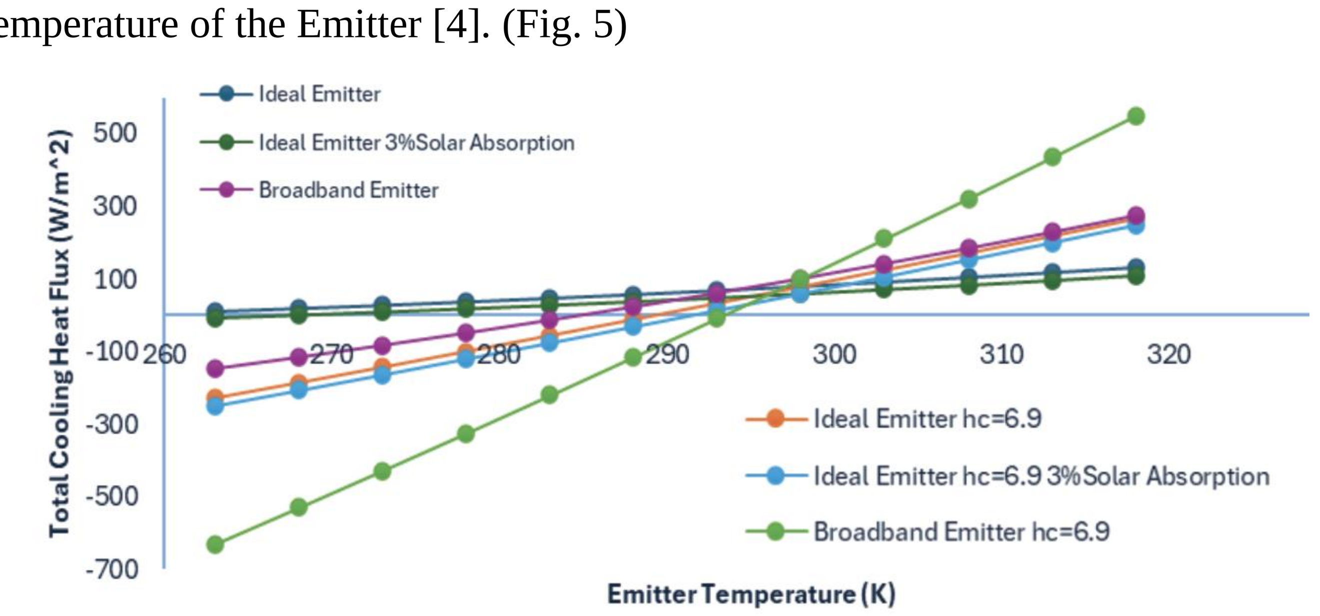
Radiative Cooler Experiment (Fig. 4)

This model is an important first step towards an accurate representation of the radiative cooling effect. Once an accurate base model is created it would be beneficial to create a more complex model that accounts for humidity and cloud cover as these factors significantly hinder the radiative cooling effect [3].

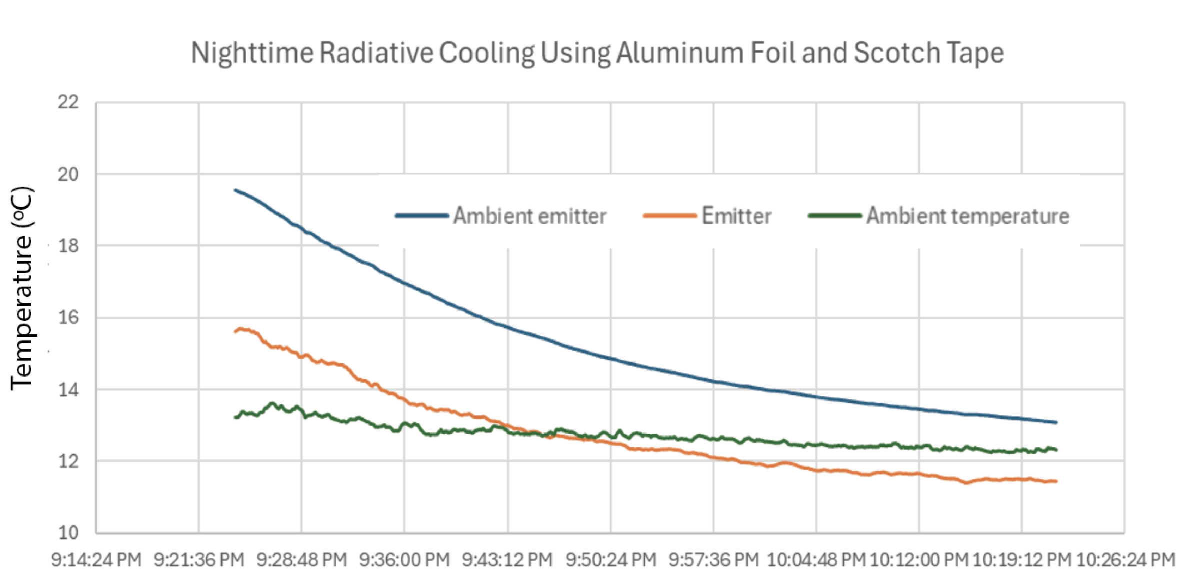
RESULTS



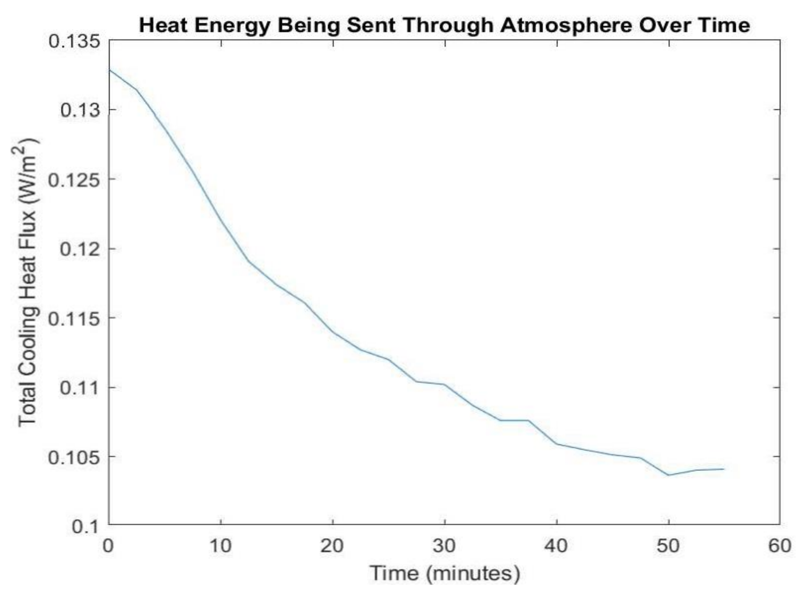
Calculated Total Cooling Heat Flux Of Different Emitter Designs Based On Temperature of the Emitter [4]. (Fig. 5)



Modeled Total Cooling Heat Flux Of Different Emitter Designs Based On Temperature of the Emitter. (Fig. 6)



Data represented in this table was taken at night for one hour using a design limiting cooling loss. (Fig. 7)



Cooling heat flux calculated using the created model and measured data. (Fig. 8)

CONCLUSIONS

This project attempts to create a computer program that will function as a model for the radiative cooling effect. The program is to be used when assessing a surface's potential as a radiative cooler. Currently the model shows that surfaces with little emissivity outside of the atmospheric window are better suited for sub ambient radiative cooling, while surfaces like the broadband model are efficient at cooling a surface at temperatures above the surroundings (Fig. 5). This lines up with previous research and is a good early sign for the model [1].

The program produces graphs comparable to those from measured and calculated data. The lines created by the model are more linear than other data which means there is still work to be done, but the model shows promise. In the future its application could help to make radiative cooling more accessible and as a result reduce energy use spent on cooling.

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