Radiative Cooling Properties in Cellulose Materials

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Abstract: Radiative cooling properties in certain materials have the potential to reduce the urban heat island effect if applied at scale. An ideal passively cooling material should exhibit properties such that they are simultaneously high in solar reflectance whilst being effective at longwave infrared heat transfer through the atmospheric infrared window. Such properties effectively allow the material to cool passively without consuming electricity. Here, we explore the passive cooling capabilities of various cellulose composites by improving upon an existing experimental setup to determine their cooling power more reliably.

Introduction: We want to test the cooling power of various material composites consisting of a polydimethylsiloxane (PDMS) base combined with various additional polymers, namely; cellulose (C), cellulose acetate (CA), and ethyl cellulose (EC). Our setup works by measuring the temperature of a sample material (serving as a control), the ambient temperature of the environment, and a second sample of the same material that will be heated back up to ambient temperature (assuming the material possesses passive cooling capabilities). By comparing the control and ambient sample temperatures, we can determine the temperature difference, while the heated sample allows us to assess the cooling power of the chosen material.

Goals:

1) Refine the experimental setup used to test the cooling power of a given material.
2) Use this experimental setup to find a PDMS cellulose composite that demonstrates the best radiative cooling properties.

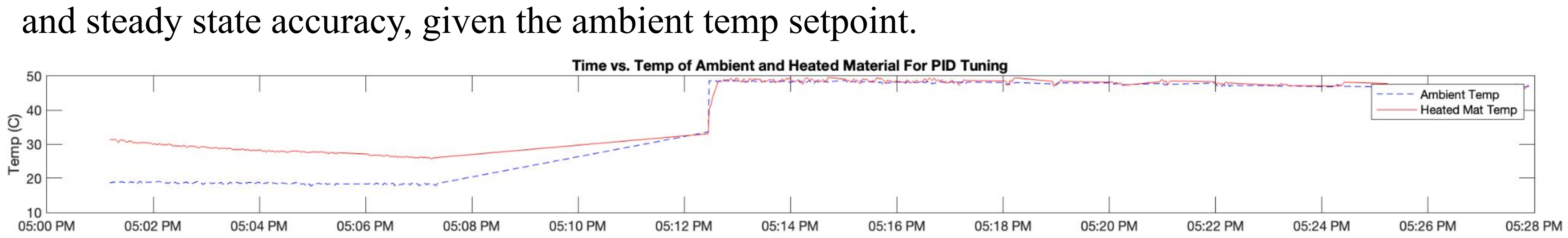
Methods:

Experimental Setup:

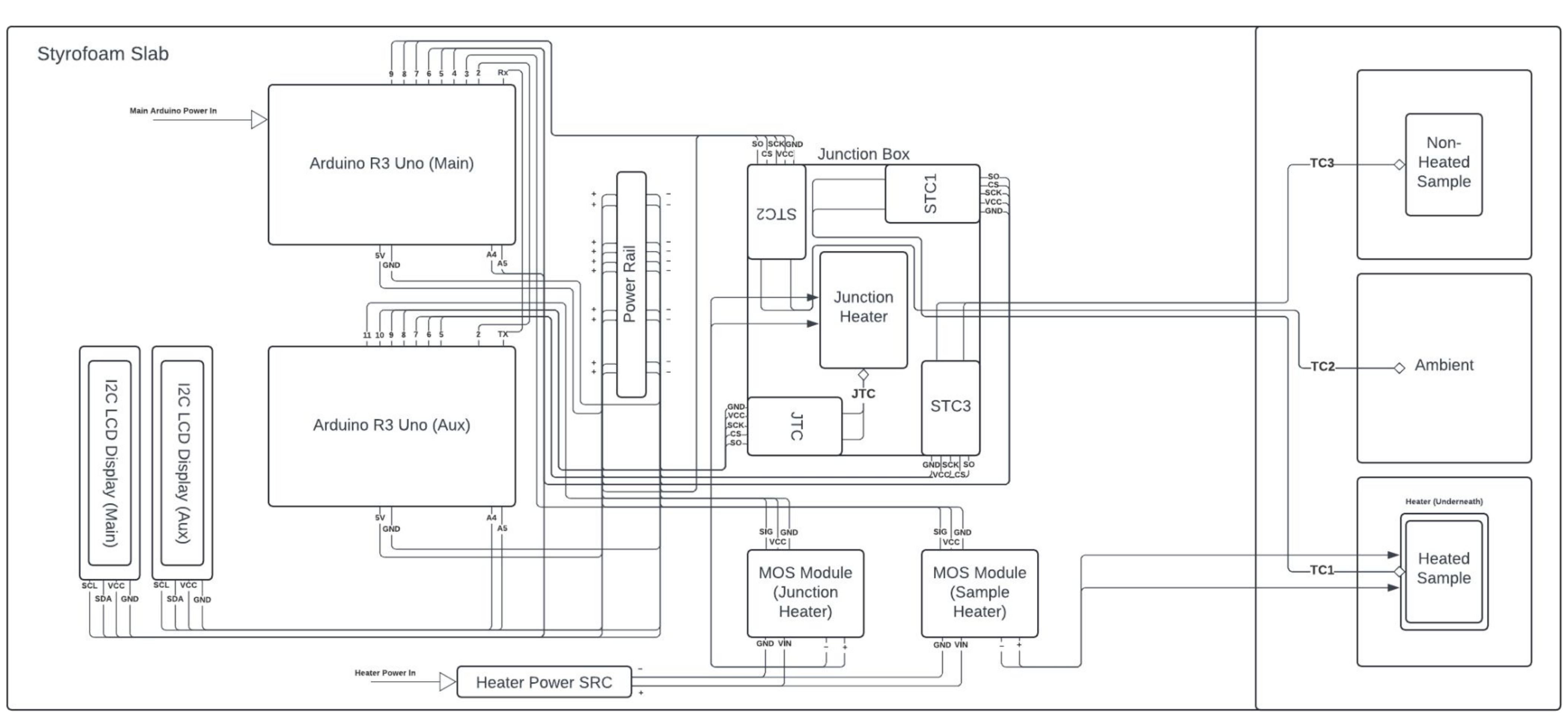
- Used four MAX6675 K-type thermocouples to measure temps at four locations: bare sample (sample 2), heated sample (sample 1), ambient temp, and thermocouple junctions.
- Two PID controlled heaters maintained sample 2 at ambient temp and thermocouple junctions at constant temperature.
- Data logging of three temperatures done with Arduino Uno R3 SD card shield attached to main board with an I2C LCD display.
- Thermocouple junctions placed in a thermally insulated box and heated at constant temp, controlled and monitored through an auxiliary Arduino Uno R3 board and another I2C LCD display.

Procedures:

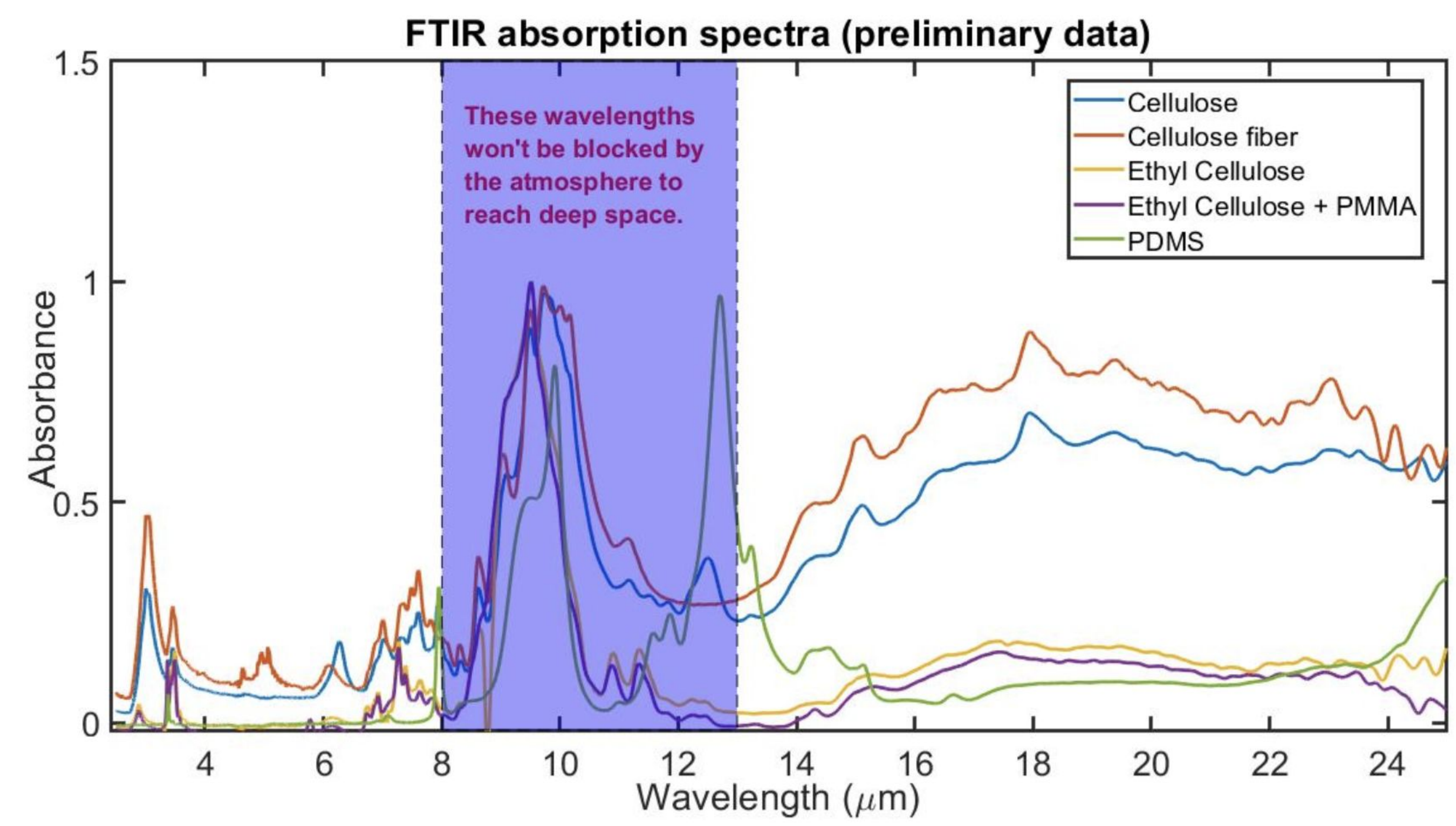
- Thermocouples were calibrated using an ice-water bath (0°C) for low point and boiling water (100°C) for high point.
- Intermediate points at 25, 50, and 75°C were used.
- For each thermocouple, actual vs. sensor temp values were recorded and regression lines were fitted.
- PID values tuned by logging sample 1 temp on a plot to gauge response time, level of overshooting, and steady state accuracy, given the ambient temp setpoint.



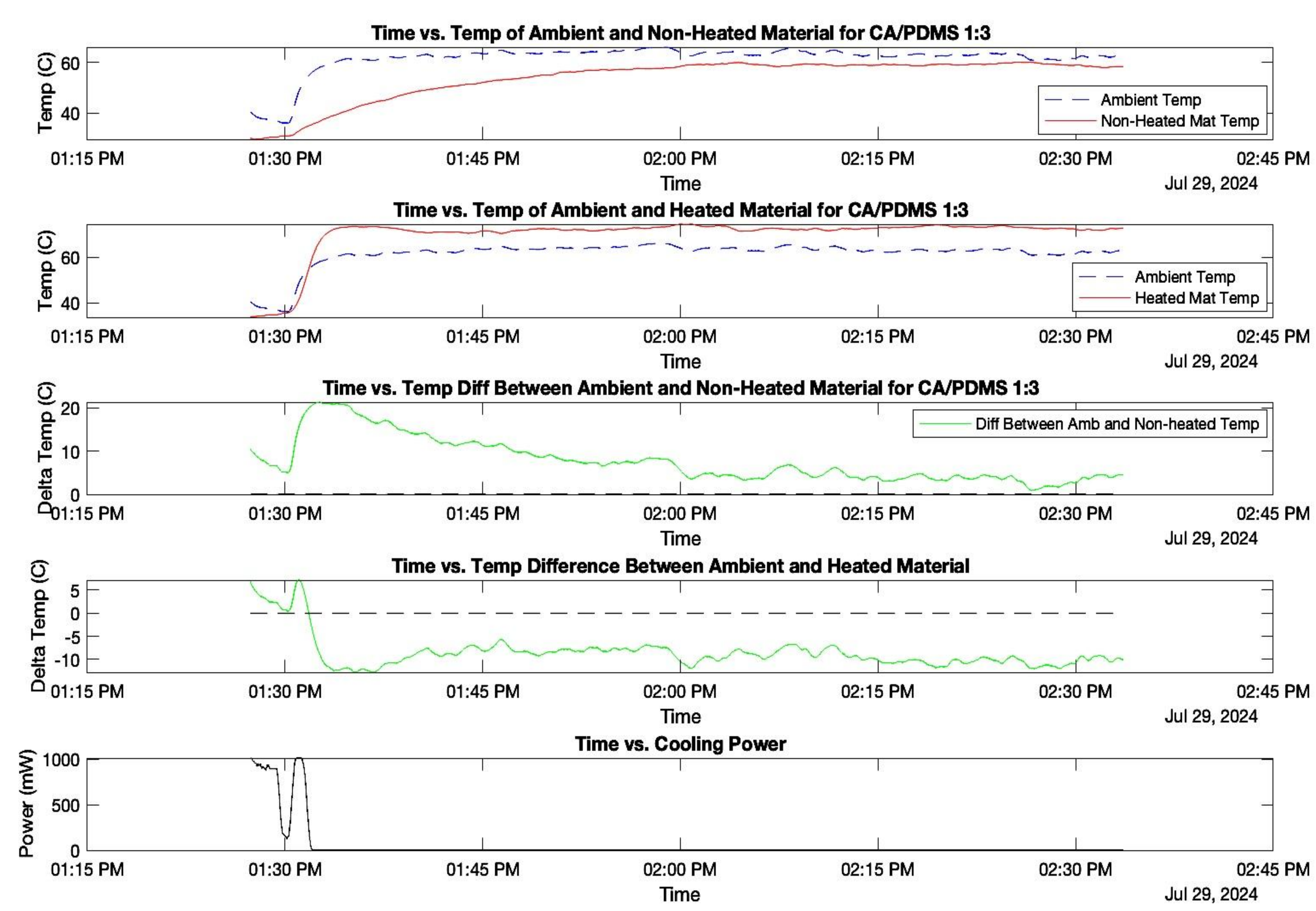
Schematic of Experiment:



Hypothesis: The terrestrial atmosphere absorbs most infrared wavelengths but is known to be transparent in the 8-13 µm window. We postulate that, using a PDMS cellulose base material, when combined with various materials such as that of cellulose (C), cellulose acetate (CA), ethyl cellulose (EC), or methyl cellulose (MC) at varying ratios, will exhibit a significant improvement in passive cooling power capabilities, by enhancing the base material's ability to both reflect solar radiation as well as emitting the absorbed surrounding heat in the environment through the 8-13 µm window.



Results:



Conclusion:

- Under 1 hour of direct sunlight exposure, the use of cellulose acetate and PDMS, in a 1:3 ratio, resulted in a temperature difference of around 5°C between the temperature of the ambient environment and the non-heated sample after settling down.
- The heated material temperature overshot the ambient environment temperature and consistently remained above it, showing that the heater response time was too fast, which led to the material not being able to cool down afterwards. Some more PID tuning is necessary to resolve this.

References:

Zhao, Dongliang, et al. "Radiative Sky Cooling: Fundamental Principles, materials, and applications." Applied Physics Reviews, vol. 6, no. 2, 16 Apr. 2019, https://doi.org/10.1063/1.5087281.