# Designing, Manufacturing, and Testing New Low-Cost Temperature Sensor Assemblies

BROWN Institute at Brown for Environment & Society

Eshan Alam - Advisors: Professor Meredith Hastings and Sol Cooperdock

LAIDLAW SCHOLARS

*Class of 2029*
*Mechanical Engineering*

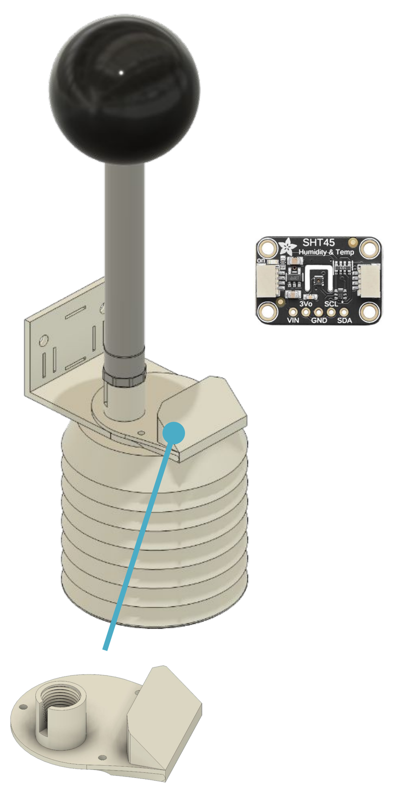
## Introduction

The **Breathe Providence Project utilizes a network of over 25 low-cost sensors to monitor Providence's air quality.** Currently, the project uses sensors such as the BEACO$_2$N node which can track metrics like CO, $CO_2$, $NO_x$, $O_3$, and $PM_{2.5}$ alongside meteorological data, the project delivers actionable insights tailored to community priorities for residents and policymakers alike.

Following recent requests from local officials for reliable, highly localized climate data, **the project's sensor engineering side has set focus on developing and integrating low-cost temperature sensors built entirely in-house.**

*Above: BEACO$_2$N Node station on the roof of the Rockefeller Library looking over the city of Providence*

## New Temperature Sensor Assemblies



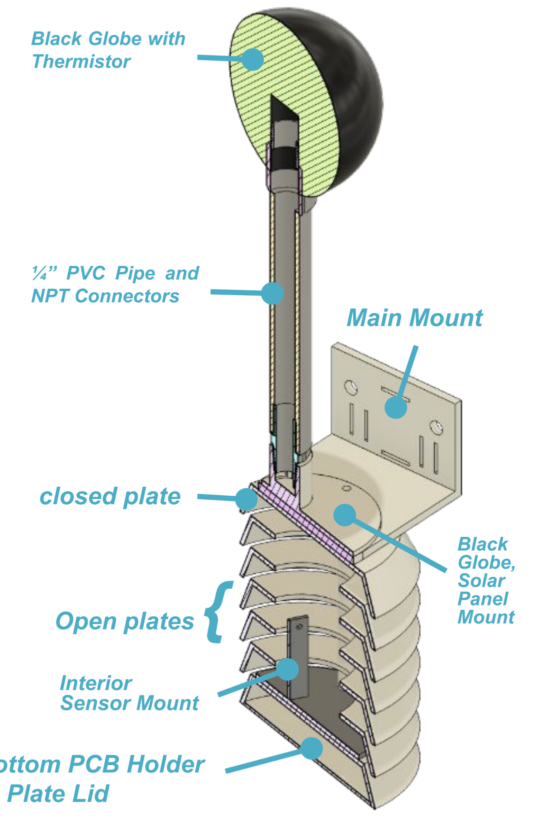
*Above: SHT-45 Module, CAD Rendition of Our New assembly, and CAD of New mount part*

Currently, we have decided to test primarily inexpensive Arduino-friendly modules such as the SHT-45 that can measure both temperature and humidity or such or our sensors. We are pursuing two main metrics:

- **Ambient Air Temperature** - measured by standard outdoor thermometers
- **"Black Globe" Temperature** - representing immediate sunlight temperature

These metrics can then be used to calculate the **Natural "Wet Bulb"** and **"Wet Bulb Globe" temperatures**, which are both used to determine the safety of outdoor conditions for certain activities.

To expand our Stevenson Radiation Shield CAD design, **we created a new mount for a "black globe" housing an inexpensive thermistor** to measure direct sunlight temperature. The assembled hardware was then installed on a testing rig on the roof of Brown's DEEPS Lincoln Field building for July testing:

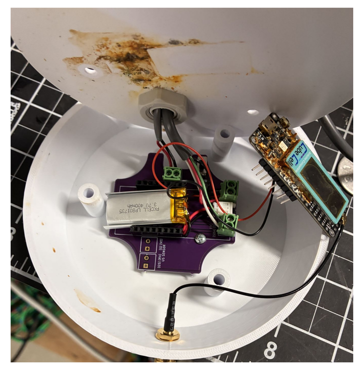



*Above: Cross-sectional labelled view of the new assembly*
*Right: Array of sensor set up on Lincoln Field; Three in-house shields and one Industry-made reference by Davis Instruments*

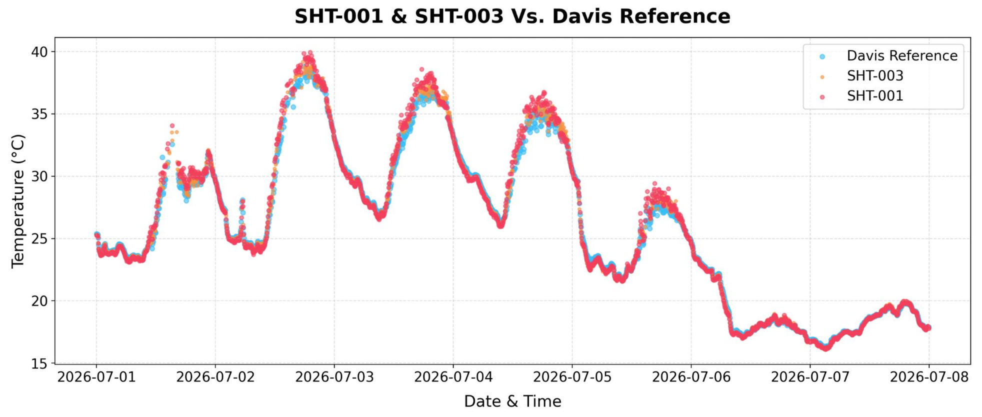
## Initial Testing Approach & Challenges

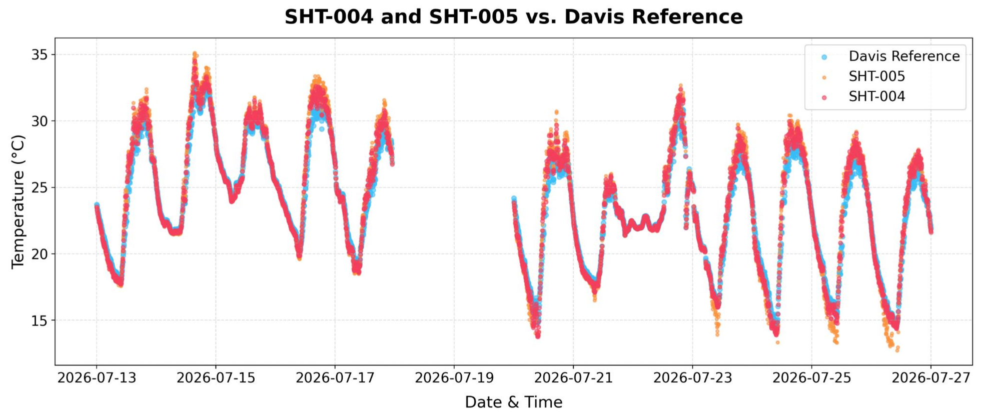
To evaluate our design against the reference Davis MET shield, we deployed five SHT-45 configurations on Lincoln Field in July:

- **SHT-001 & SHT-003 -** Two SHT-45's inside our standard in-house shields (deployed July 1).
- **SHT-004** - SHT-45 with our new black globe assembly (deployed July 6–8).
- **SHT-005** - SHT-45 with a thermistor inside the shield itself rather than a globe (deployed July 6–8).
- **Davis SHT-45** - Placed inside a Davis Industries MET shield to serve as our baseline reference.



*Above: Water-damaged SHT-003 with original back plate*

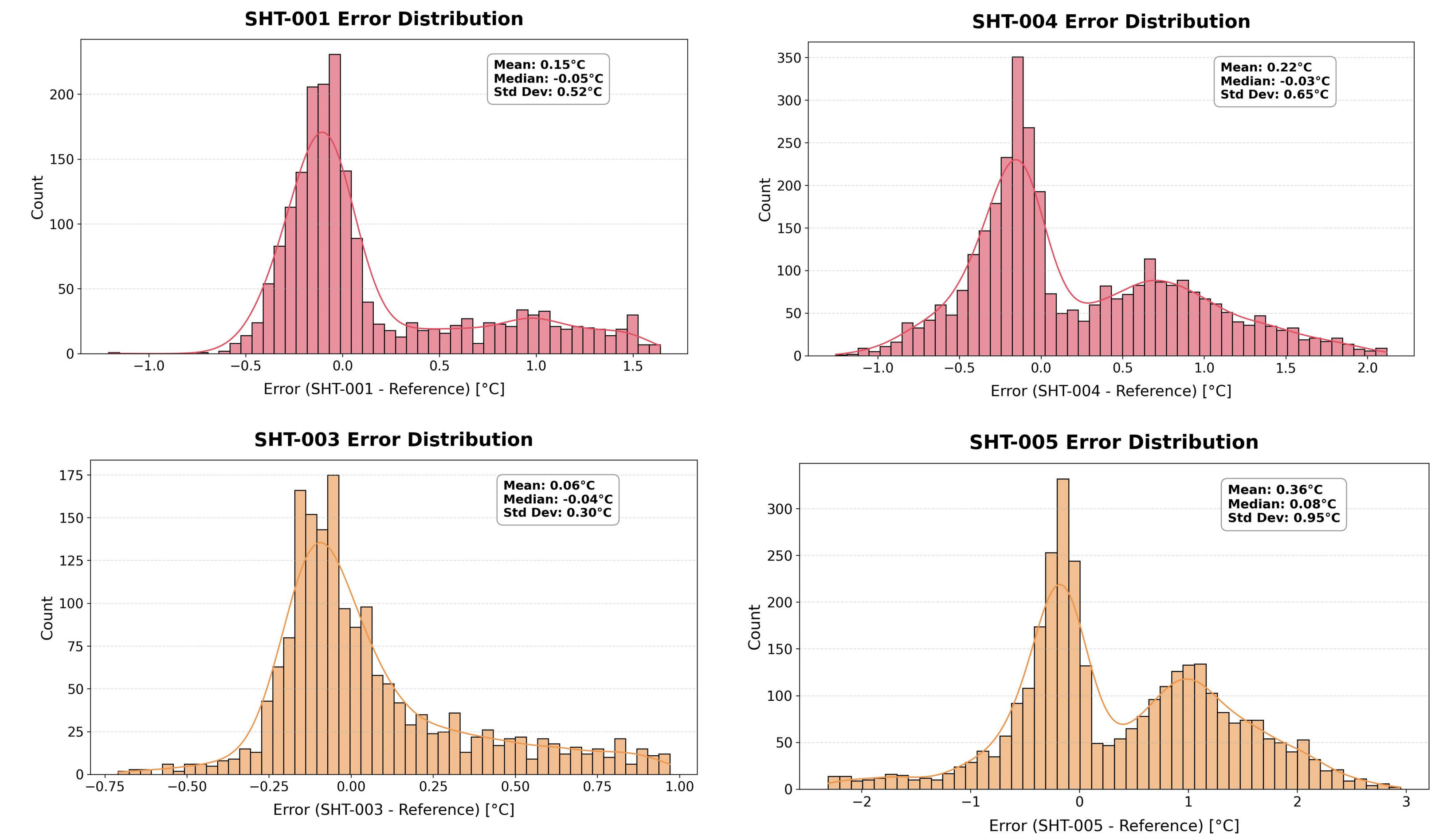



Within just one week, **SHT-001 and SHT-003 failed due to water infiltration,** exposing the first necessary change to our design. Despite this and a brief two-day network outage, **we successfully gathered extensive July data from SHT-004 and SHT-005, alongside the first week from SHT-001 and SHT-003.** The raw data shows a strong coherent trend

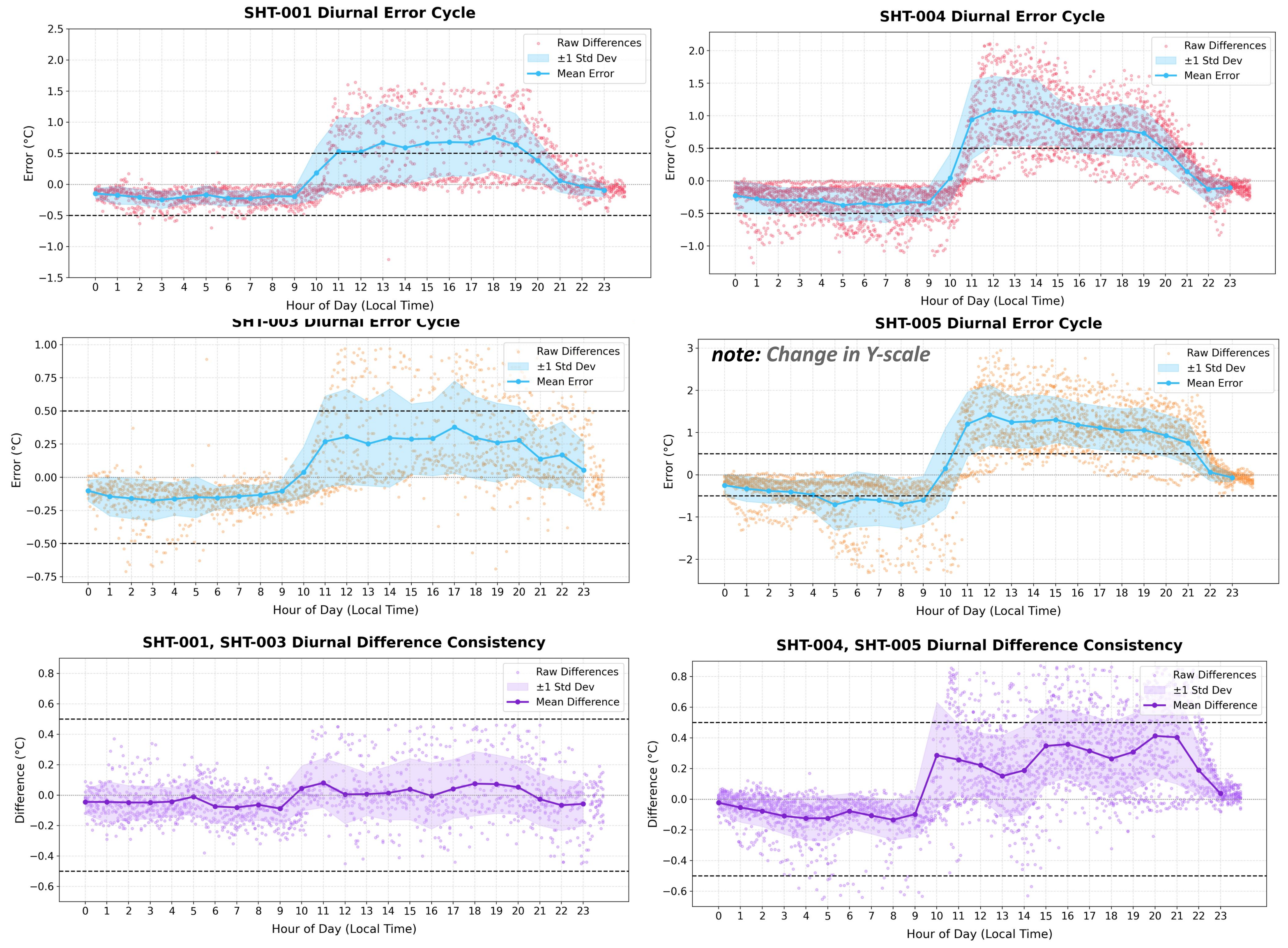
## Difference Distributions

While all the sensors in our shields visually are coherent and seem to follow the same trend of the davis shields, **looking close at the distributions of the differences between our sensors and the Davis Reference reveals the differences are highly variable, not consistent, and are not normal with a clear right skew as shown below:**




## Diurnal Cycle Analysis

**The shapes of the difference distributions imply that the temperature difference between our sensors and the reference may change based on the outdoor temperature itself.** A closer look at the 24-hour diurnal cycle distributions of all the differences:

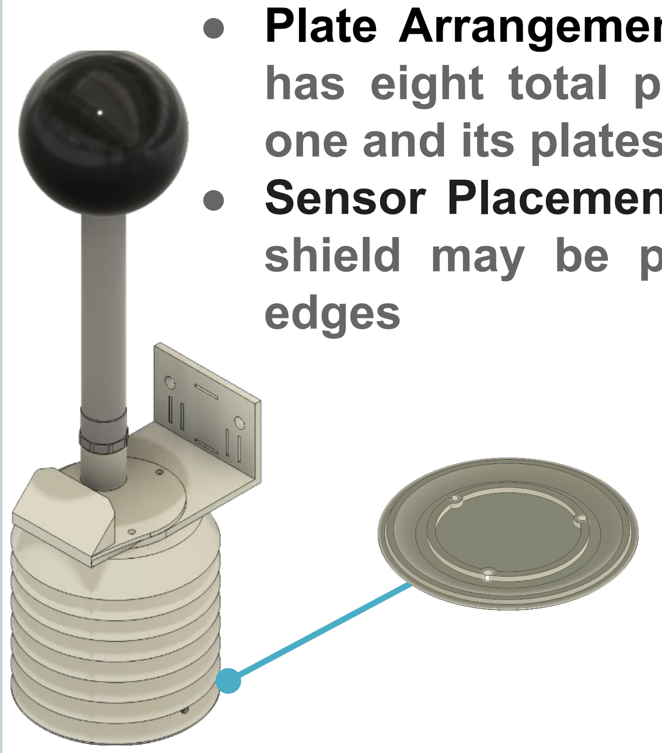



Looking above at these cycles shows how the differences, even between our own sensors, **tend to increase and become more unstable during peak daytime, surpassing our acceptable difference range of 0.5℃.**

## Takeaways & Future Changes

When looking at all the plots and the distributions, **the data implies that our sensor shields may expose the sensors to more heat than they should, hence the greater temperature differences. Alternatively, the shield itself may itself be trapping more heat within than it should.** Nevertheless, some key changes to consider in improving the shield design will include:

- **Plate Arrangement & Thickness** - The Davis Reference has eight total plates and three top plates rather than one and its plates are somewhat thinner
- **Sensor Placement in the Shield** - The mount inside the shield may be placing the sensor too close to outer edges



*Above: New Assembly Draft and New Bottom plate design*

Currently, while testing these shields, **we created a new design that accommodates an extra top plate to combat heating issues as well as a new bottom lid to combat water issues.** Fortunately, **the new bottom plate has shown to be successful in outside tests at Lincoln Field.**