# Wireless Sensors for Investment Casting Shell Data Acquisition

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INVESTMENT CASTING
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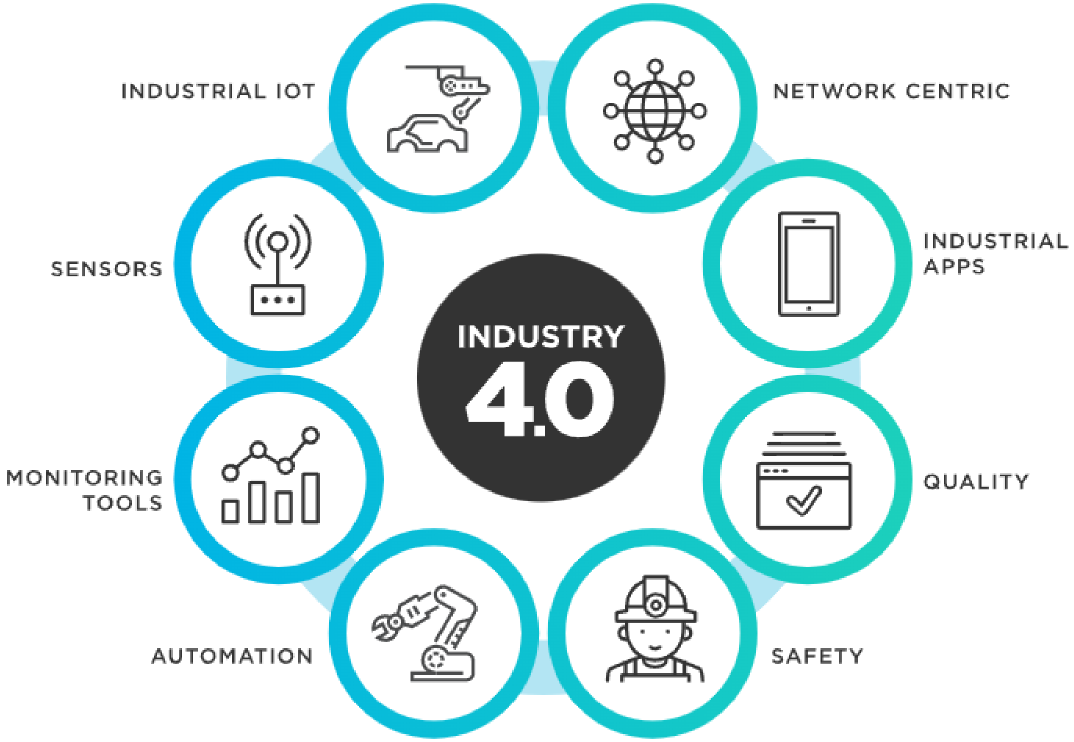
# Introduction – Industry 4.0

- Sensors for Data Acquisition and the Internet of Things.
- Allows for remote monitoring of industrial processes.
- Provides tools necessary for data driven decision making.
  - Automation



# How long should I dry shells for?

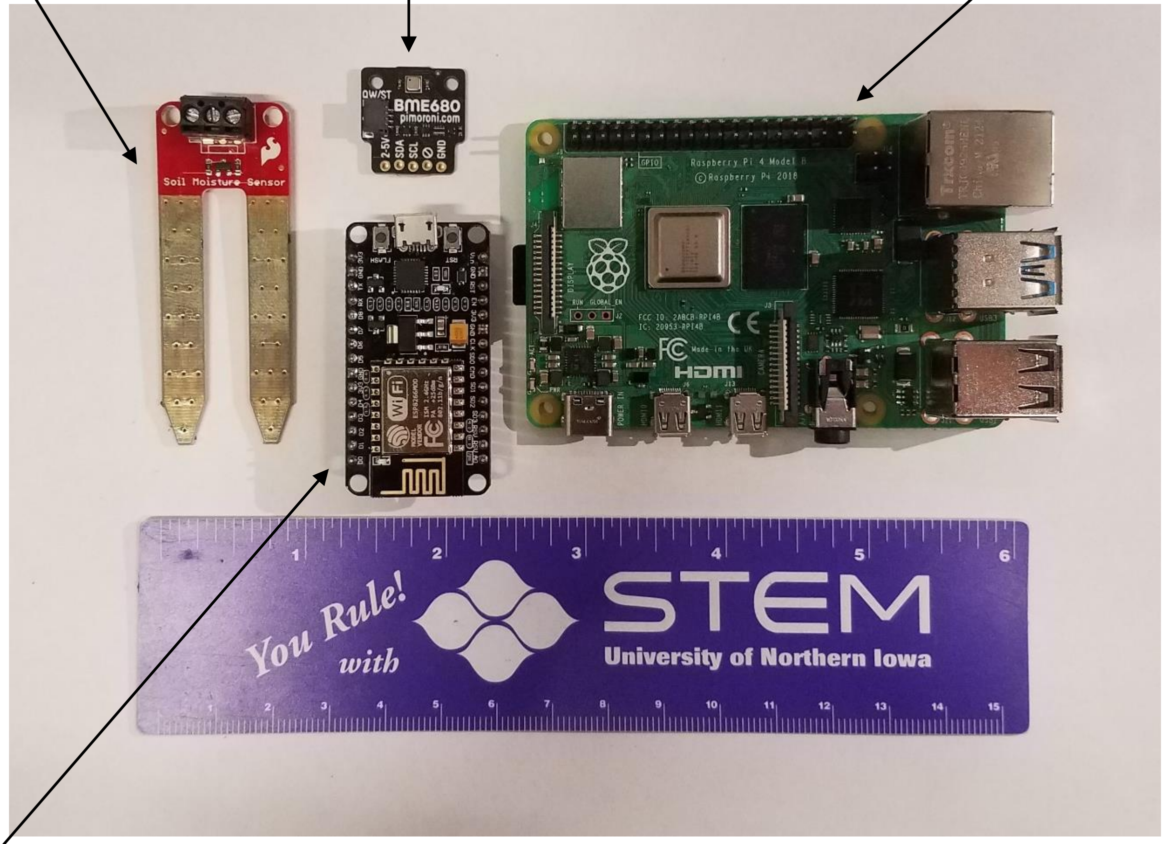
"It depends"

- Slurry Composition / Properties
- Shell Layer #
- Temperature
- Humidity
- Etc.

To automate at the highest level of productivity, robots need smart data and static rules.

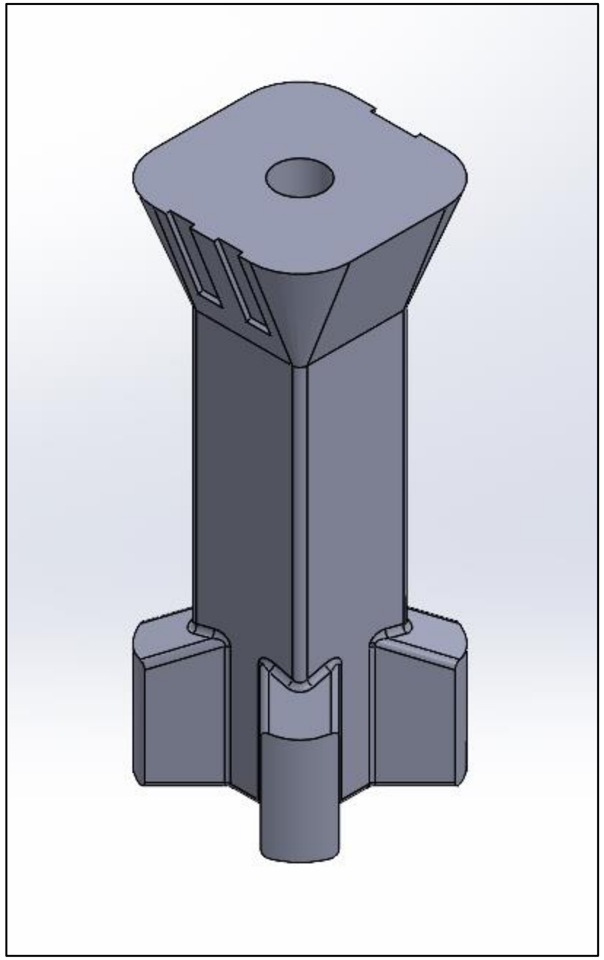
# Sensor Technology

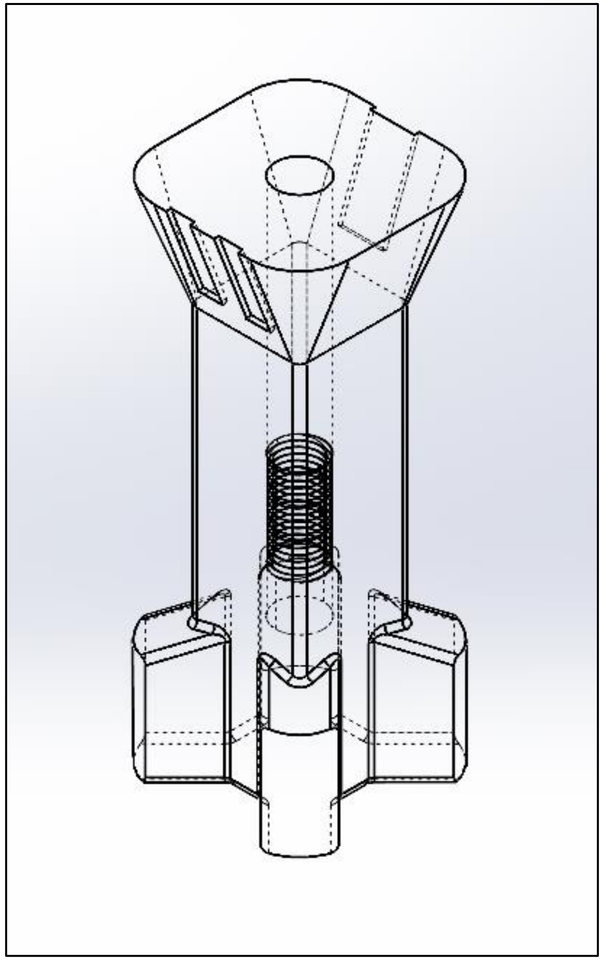
- **The testing setup utilized a battery powered NodeMCU, which was connected to the soil moisture sensor through a direct analog port. The environmental sensor was connected by $i^2c$.**
- **This study utilized a 5000 mAh battery. With shown components, battery life per charge was ~160 hours.**
- **The NodeMCU serves as the data acquisition unit, which is connected to the raspberry pi via Wi-fi.**
- **Further, the raspberry pi acts as the data storage device and can receive data from multiple nodes.**



# Experimental Methodology

- Test geometry development
  - Grooves for sensor mounting
  - Internal threads for handling purposes
- Printed by the University's VX1000 unit in polymethyl methacrylate (PMMA) powder.

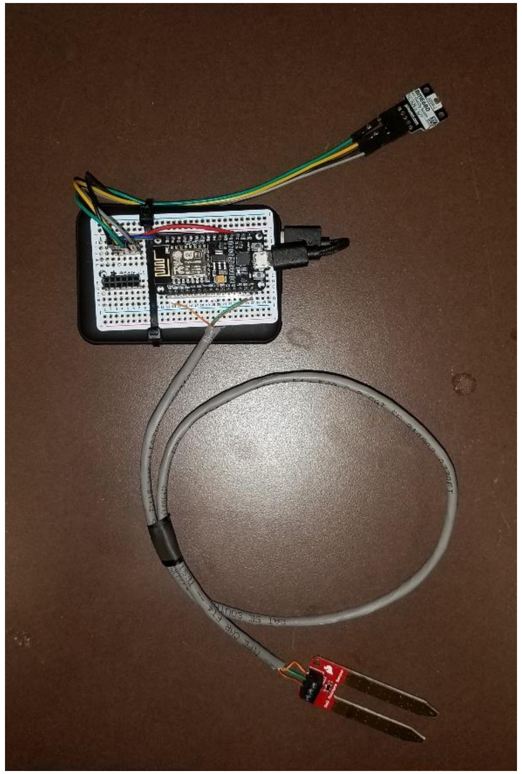



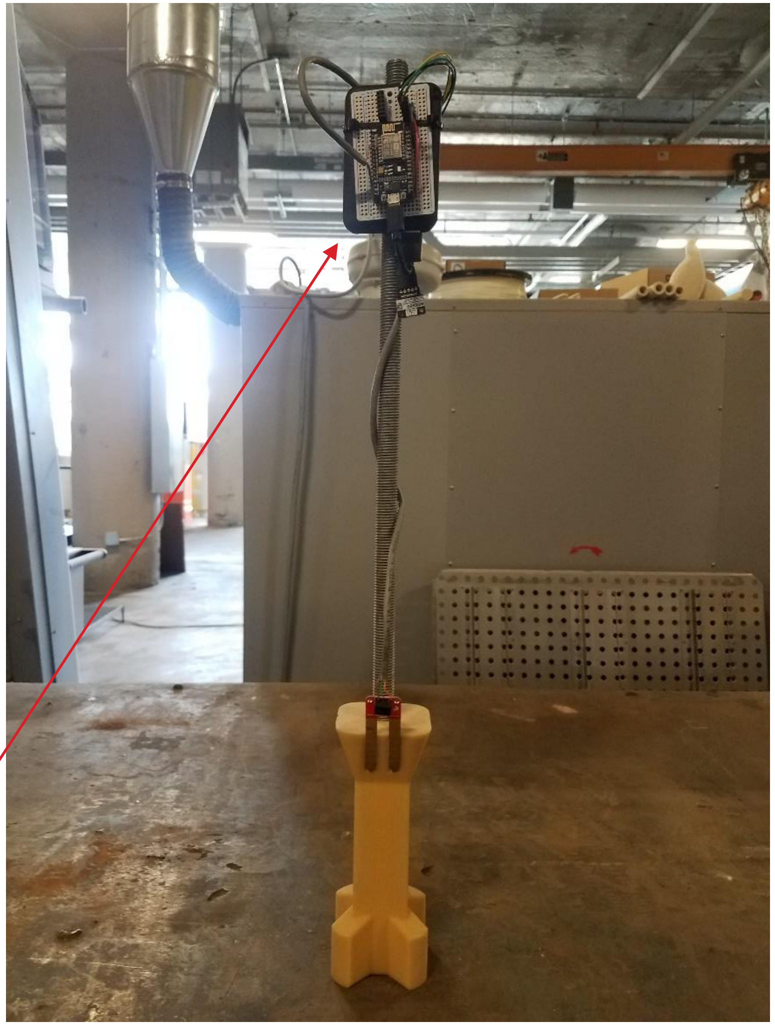


# Specimen Preparation

- After printing, the specimens were placed in a convection oven at 55°C for 30 minutes to cure.
- After removal, the specimens were plunged into molten wax to seal the surface porosity.

# Sensor Mounting and Connection to NodeMCU





5000 mAh battery

# Shell Building Sequence

| Shell Building Step | Stucco |
|---|---|
| Prime Coat | Zircon Sand |
| Intermediate Coat | 100 - 140 Mesh Fused Silica |
| Backup Coat 1 | 30 - 50 Mesh Fused Silica |
| Backup Coat 2 | 30 - 50 Mesh Fused Silica |
| Backup Coat 3 | 30 - 50 Mesh Fused Silica |
| Backup Coat 4 | 30 - 50 Mesh Fused Silica |
| Seal Coat | N/A |

## Slurry Properties

### Primary Slurry

- Colloidal Silica Binder with Fused Silica Powder
- 2:1 Solids:Binder Ratio
- Controlled by #5 Zahn Cup
  - 25-35s range

### Backup Slurry

- Colloidal Silica Binder with Fused Silica Powder
- 2:1 Solids:Binder Ratio
- Controlled by #4 Zahn Cup
  - 12-14s range

| Mesh | % Retained | |
|---|---|---|
| | Primary Solids | Backup Solids |
| 30 | 0 | 0 |
| 50 | 0 | 0 - 0.5 |
| 60 | 0 | 0 |
| 80 | 0 - 0.5 | 0 |
| 100 | 0 - 0.5 | 4 - 12 |
| 140 | 0 - 4 | 7 - 13 |
| 200 | 3 - 9 | 10 - 15 |
| 325 | 13 - 20 | 14 - 20 |
| Pan | 69 - 81 | 45 - 55 |

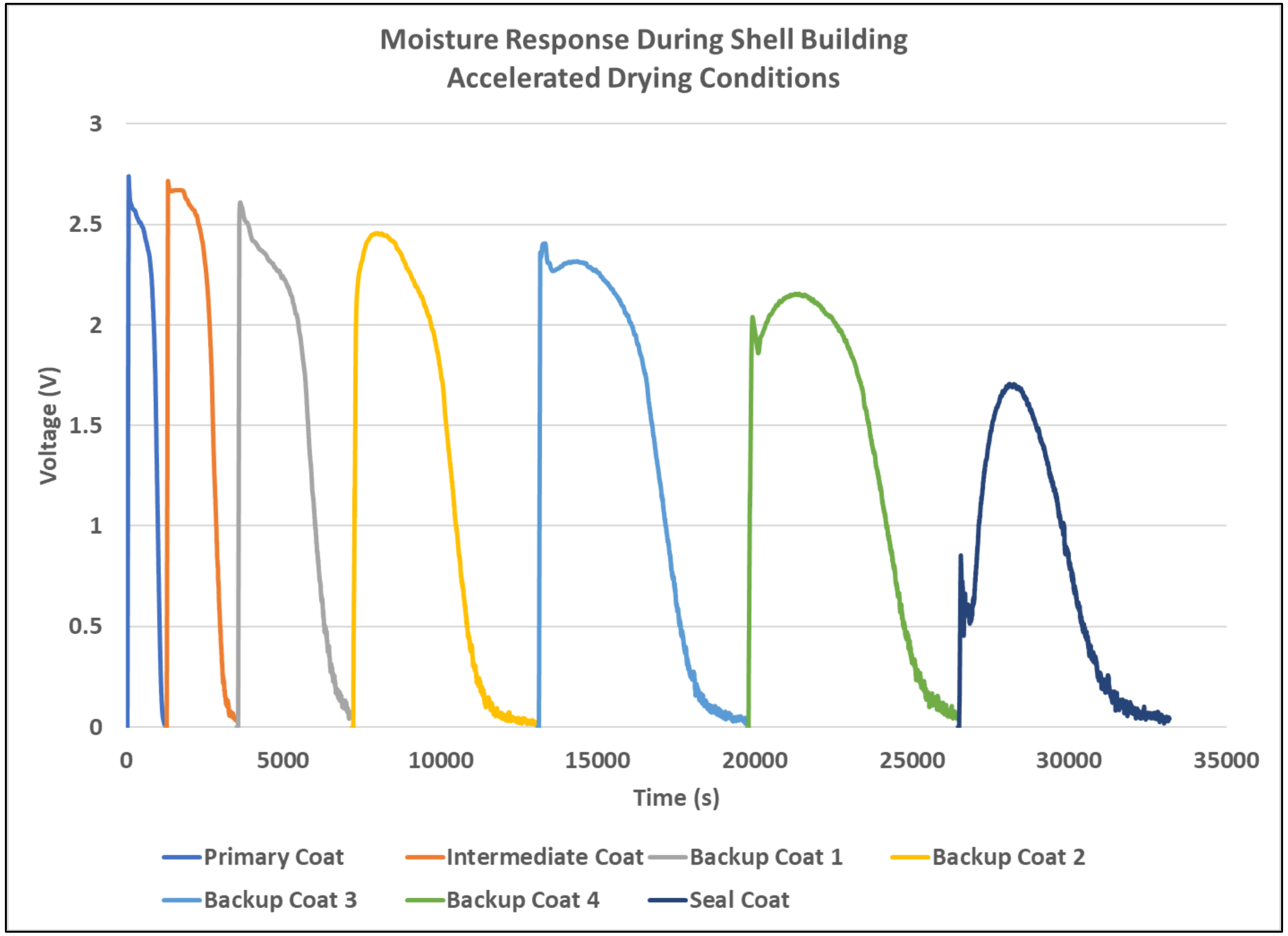
# Drying Treatments

- Accelerated Drying Conditions
  - Temperature Range: 40 - 42°C
  - Humidity Range: 11 - 14%

- Ambient Drying Conditions
  - Temperature Range: 20 – 23°C
  - Humidity Range: 14 – 19%

# Accelerated Drying Conditions
# Moisture Sensor Response

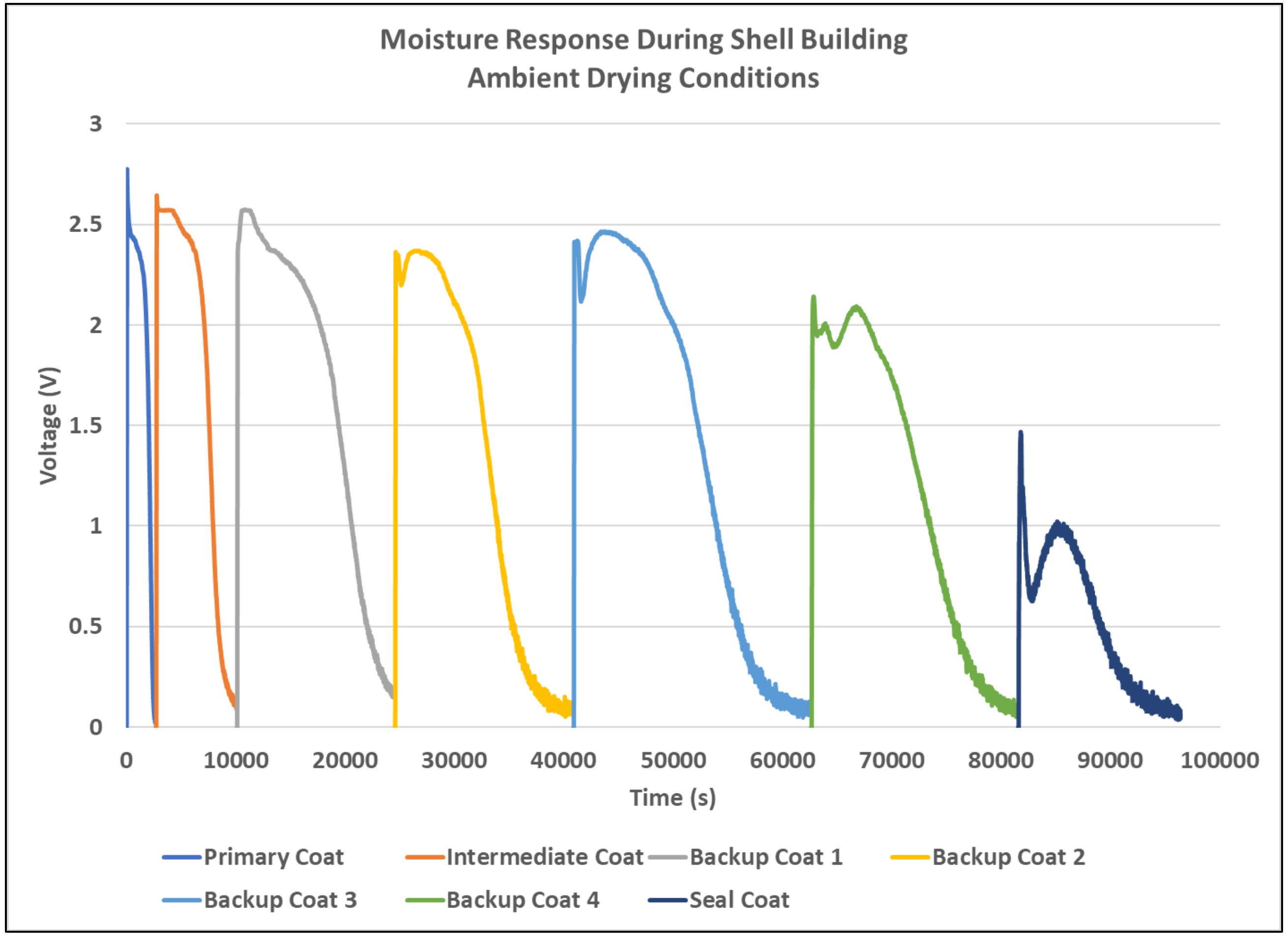
- The voltage response from the moisture sensor increases when in contact with the slurry.
- Over time, the voltage reading decreased and eventually settled at 0V, meaning the shell layer was completely dried.
- Subsequent layers generally took longer periods of time for the voltage reading to return to a constant value.
- Total drying time: 33,182s (9.2 hours)



# Ambient Drying Conditions
# Moisture Sensor Response

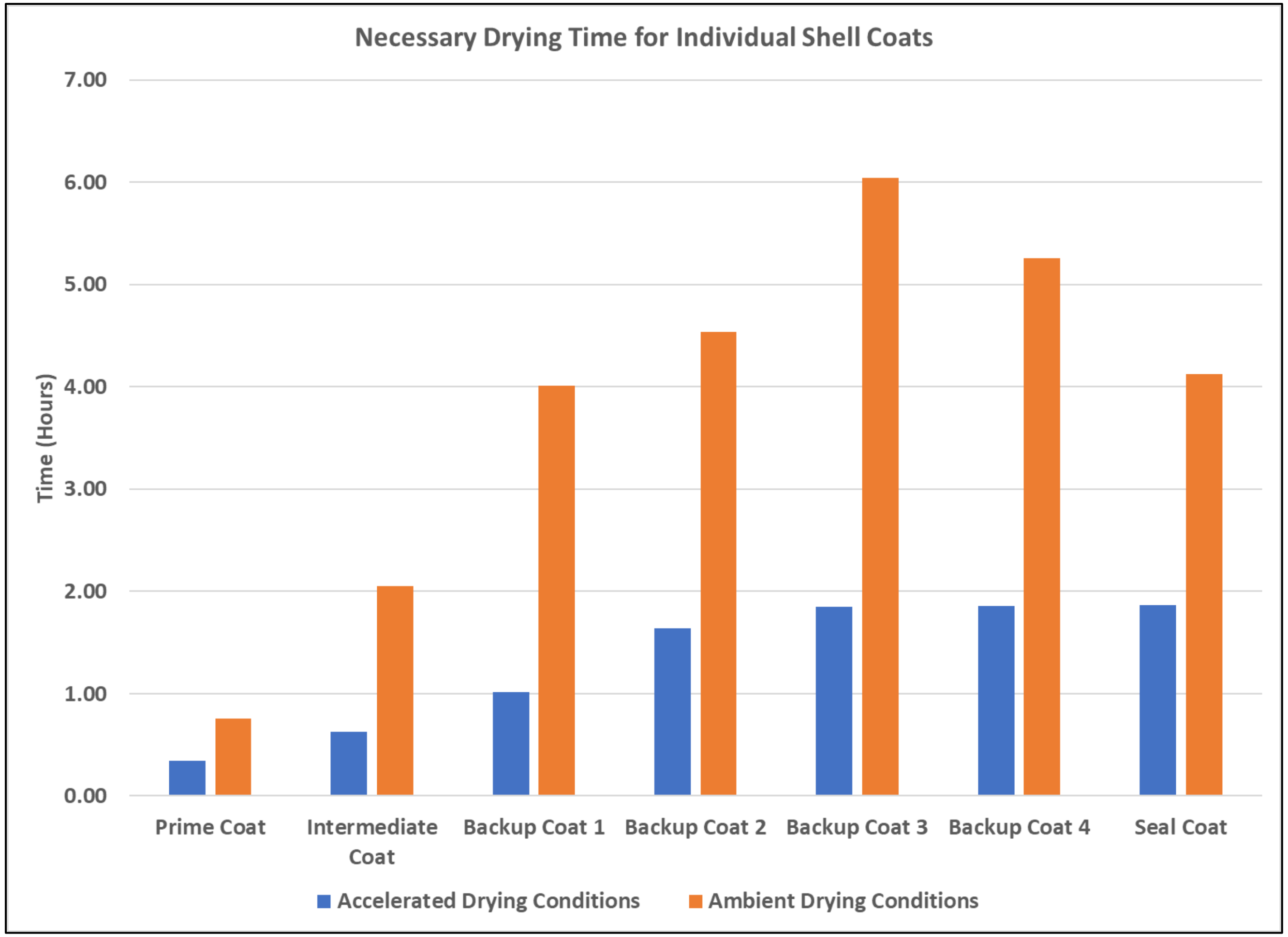
- Similar trend was observed. However, the time necessary to dry was (intuitively) much longer than the heated shell.

- Total time: 96,396s (26.8 hours)
  - ~3x longer than the other shell.



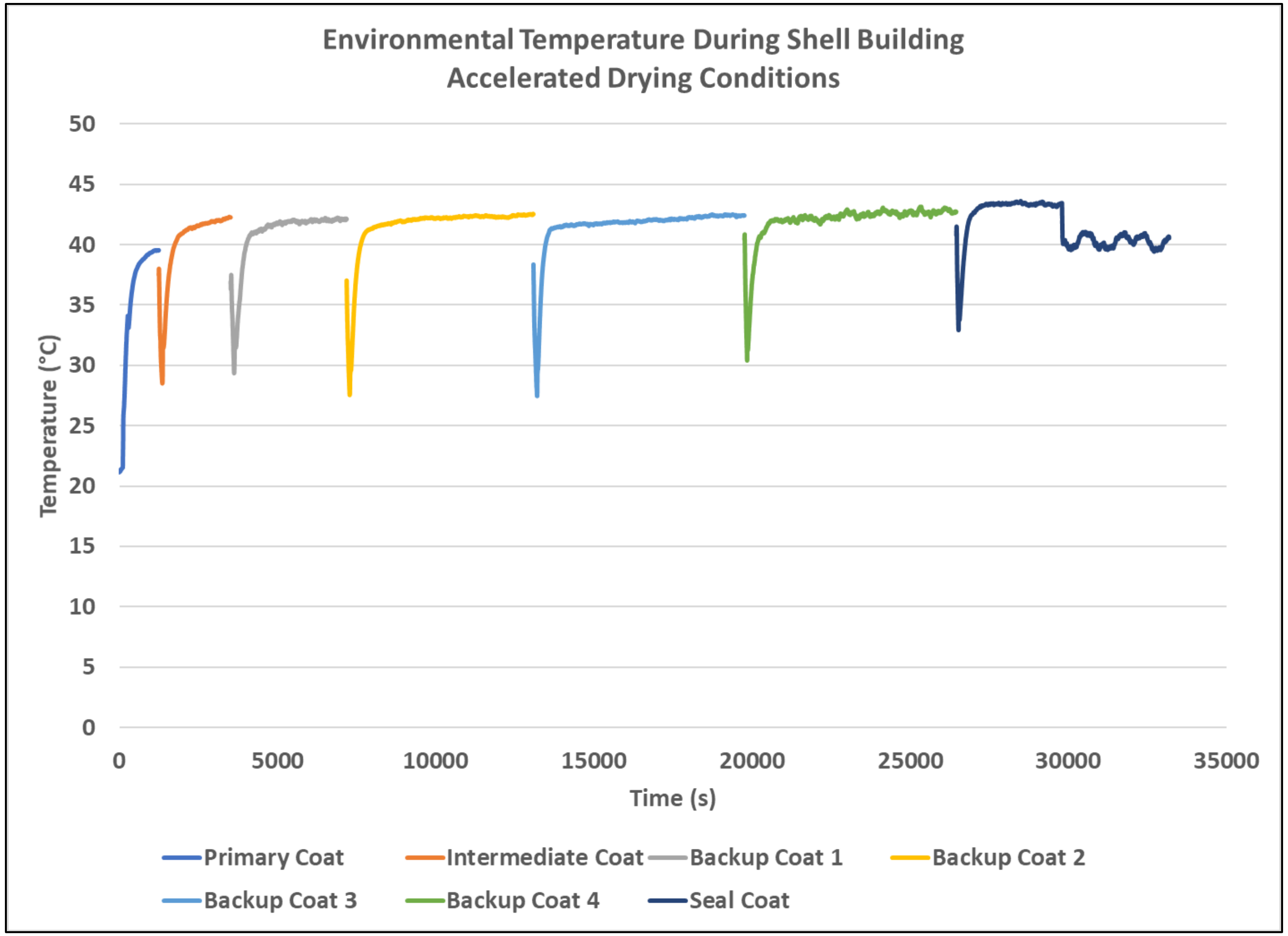
# Individual Shell Cycle Drying Times

| Shell Building Step | Time to Dry (hr) | |
|---|---|---|
| | Accelerated | Ambient |
| Prime Coat | 0.3 | 0.8 |
| Intermediate Coat | 0.6 | 2.1 |
| Backup Coat 1 | 1.0 | 4.0 |
| Backup Coat 2 | 1.6 | 4.5 |
| Backup Coat 3 | 1.9 | 6.0 |
| Backup Coat 4 | 1.9 | 5.3 |
| Seal Coat | 1.9 | 4.1 |
| ***Total*** | ***9.2*** | ***26.8*** |



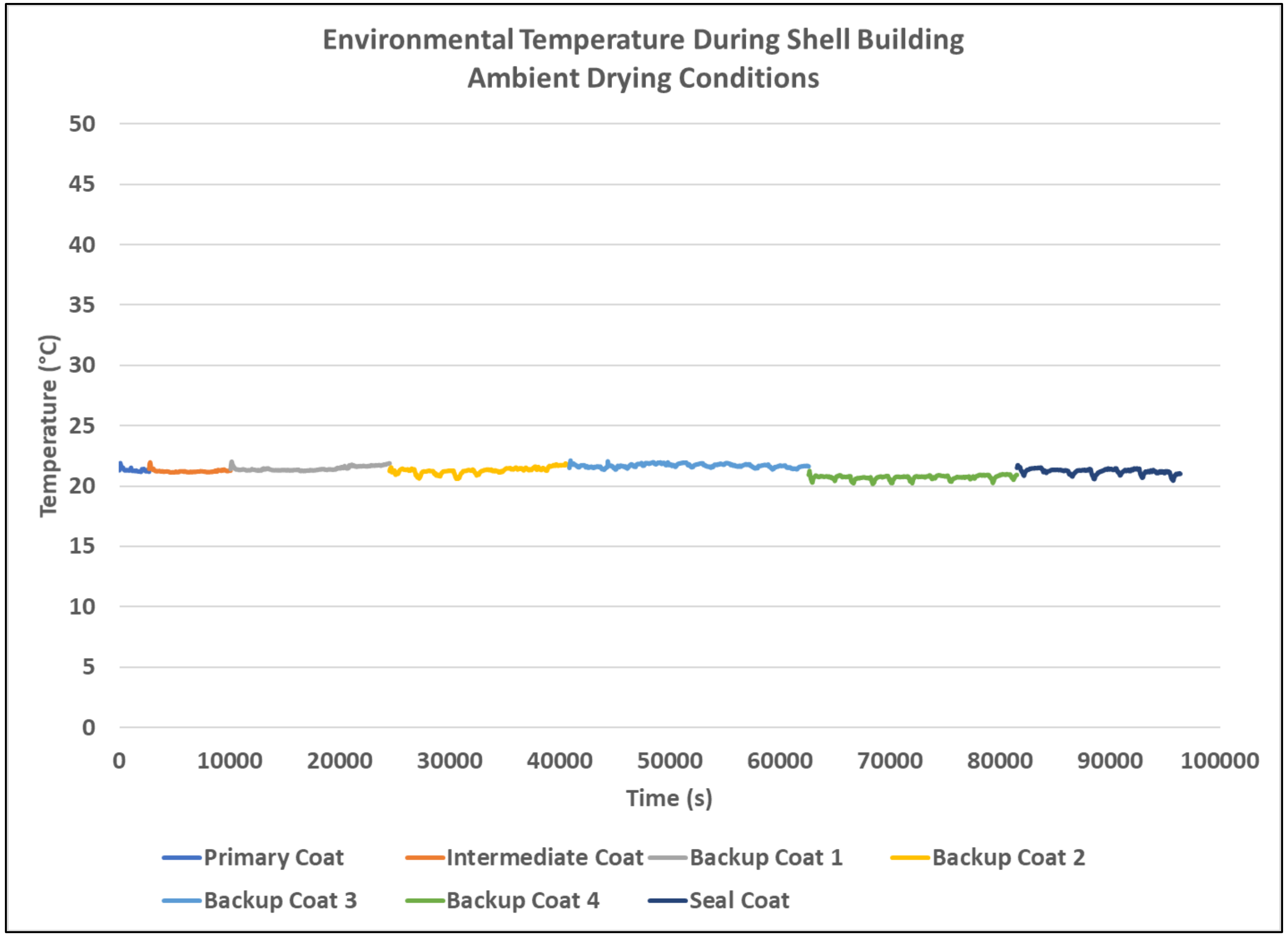
# Accelerated Drying Conditions Temperature

- The shell cooled rapidly during the time it was removed from the drying chamber. This was during the dipping and stuccoing process.
- It quickly heated to the desired temperature (~40°C) once placed in the drying chamber.
- The drop in temperature during the seal coat was due to an opening and incomplete closing of the drying chamber doors.



# Ambient Drying Conditions Temperature

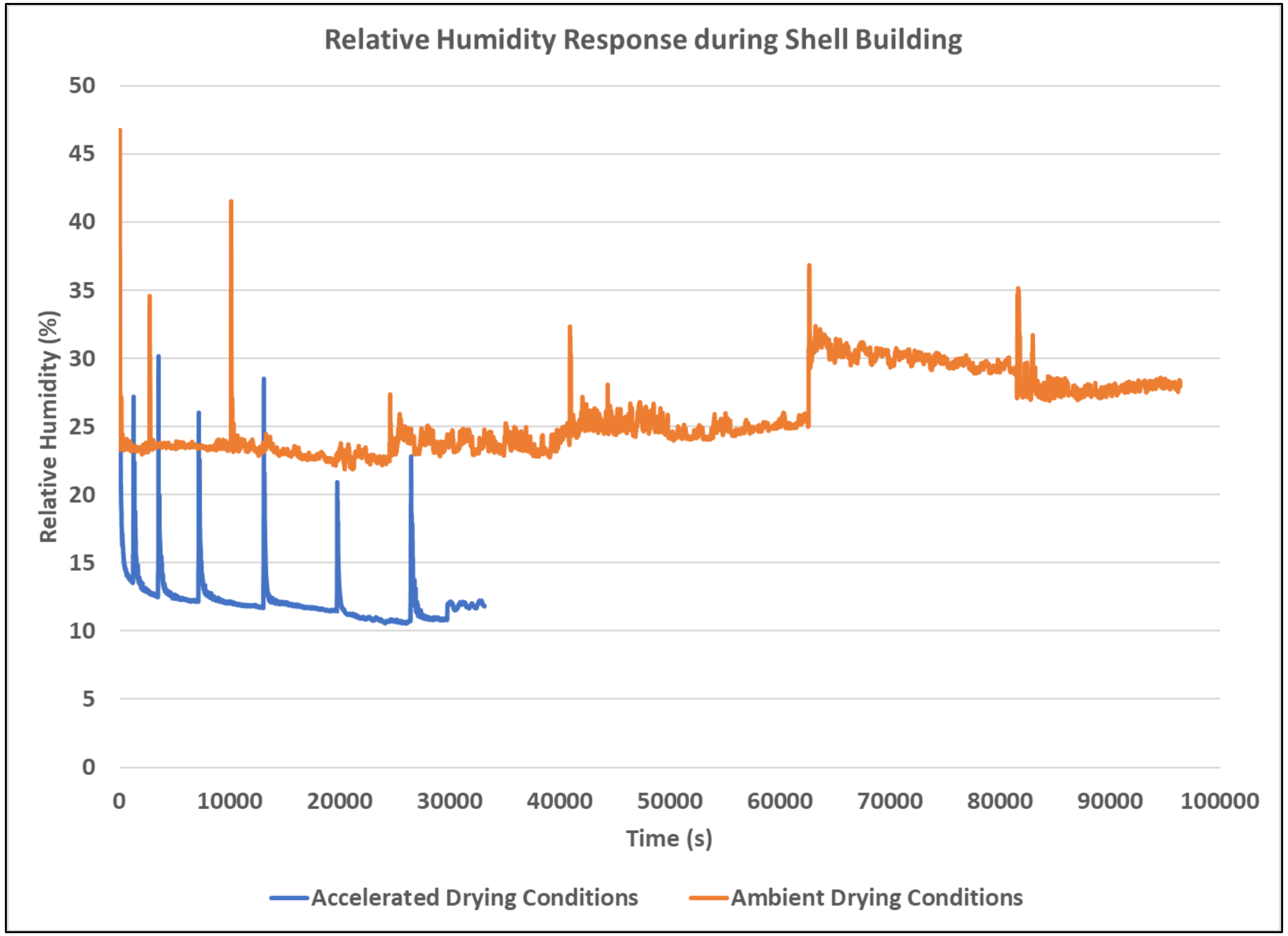
- Over the course of the shell building cycle, the environmental temperature stayed constant.
- As expected, this caused the shell to dry significantly slower than the other shell.



# Relative Humidity Comparison

The relative humidity within the heated chamber was lower than the shop floor. One may assume that this indicates a 'drier' environment, however, this is relative (not absolute) humidity.

The increased capacity due to higher air temperature allows for more absorption of water vapor.

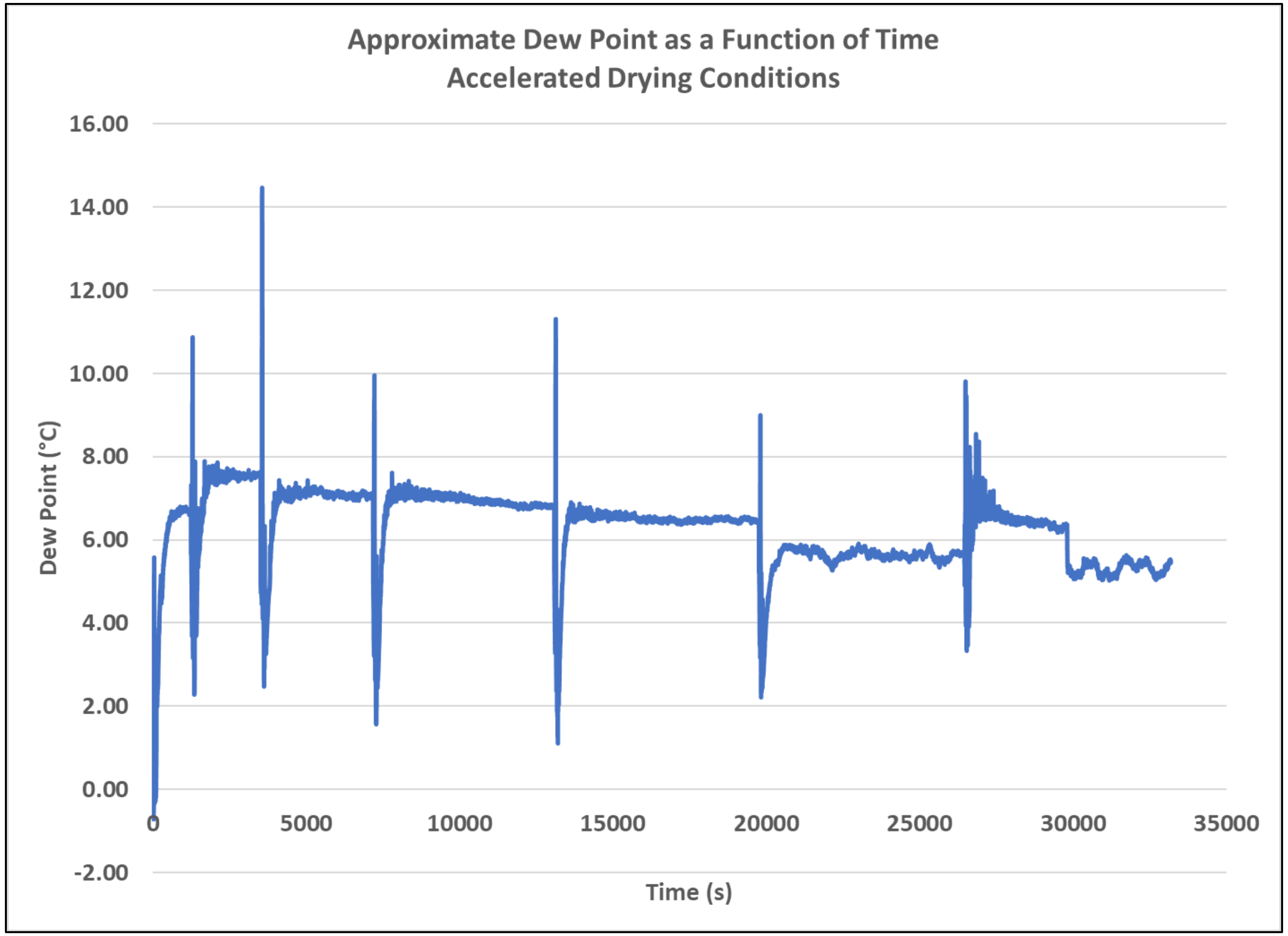


# Accelerated Drying Conditions Dew Point

**The presence of water vapor in air directly influences the dew point.**

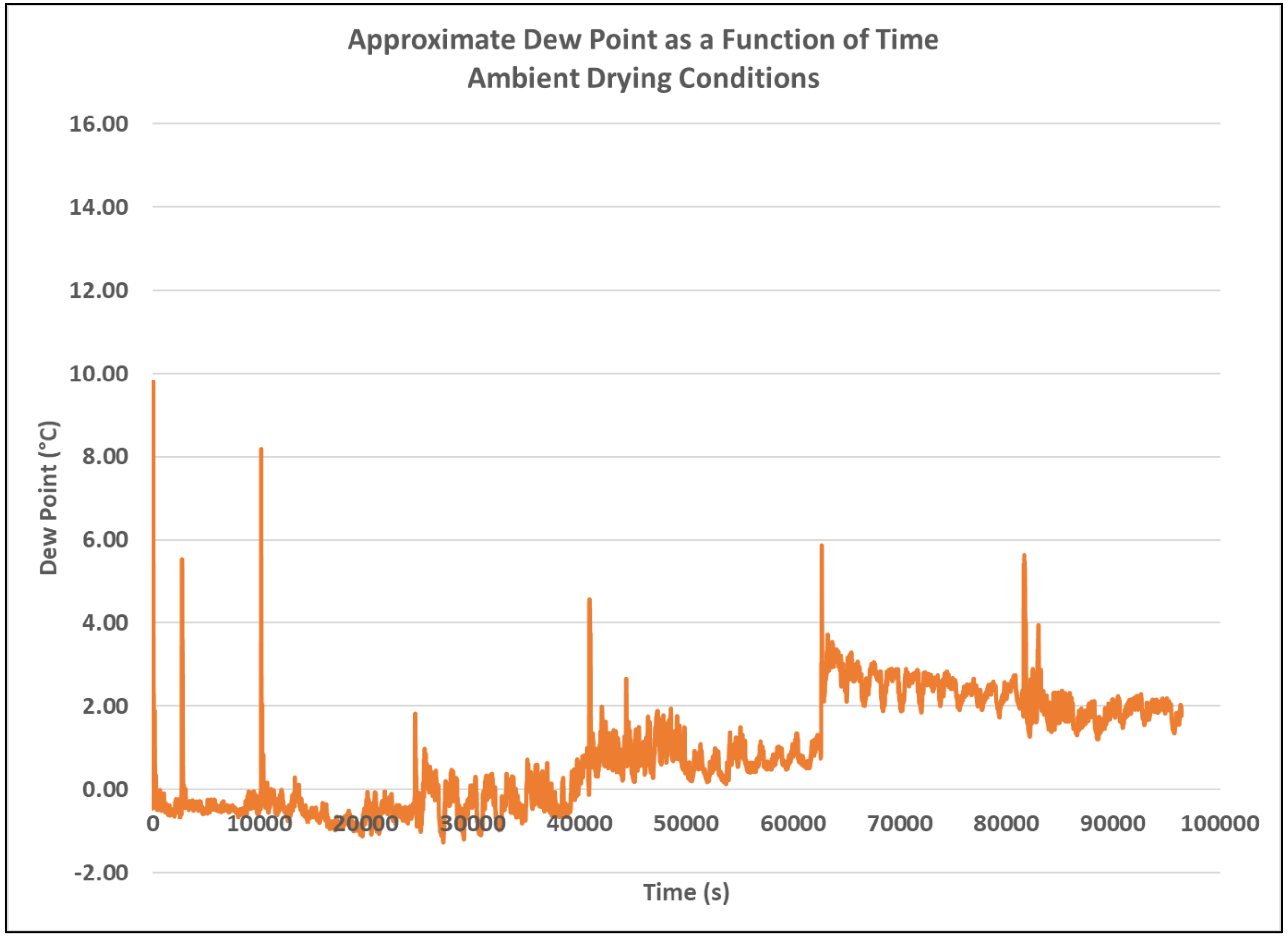
**Dew point and relative humidity are not identical. Relative humidity measures the amount of water vapor related to the capacity in air. Dew point is a measure of total moisture present.**

**High dew points indicate higher presence of water vapor in the air.**



# Ambient Drying Conditions
# Dew Point

The ambient shell had a lower dew point, meaning that less water vapor was present in the air during drying.



## Conclusions

- Real time monitoring of shell moisture allows for the optimization of shell integrity, productivity, and energy costs.
- The sensor being in direct contact with both the expendable pattern surface and the slurry layers didn't interfere with shell building.
- Dashboarding and manual data analysis are limitations in the current state.
- This particular strategy with low-cost sensors may not be the final solution, but can assist with introducing operating foundries to the IIoT.

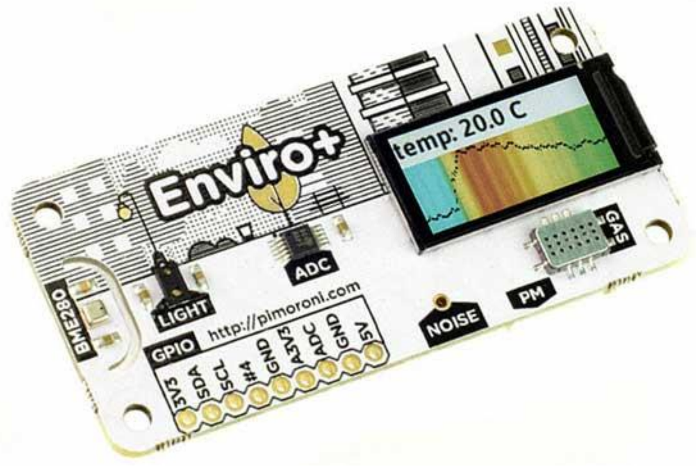
# Future Research Opportunities

- Measurement of green & fired modulus of rupture to relate shell properties to various drying profiles.
  - This provides measurable feedback to the acquired data.

- Other sensor applications:
  - Vibration
    - Predictive maintenance of wear components
  - Equipment power consumption
    - Furnaces, blast machines
  - RPM of slurry tanks

- Further exploration of the IC process using sensors.
  - Emissions measurement during pattern removal?





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