Indoor Soil Deposition Chamber: Validation of Anti-Soiling Coating Claims

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Objective

- **Problem:** Soiling = Transmission loss = Production loss = Revenue loss

- **Solution:** Reduce soiling loss using anti-soiling coatings or remove soiling using various cost-effective cleaning techniques.

- **Objective:** Develop a standardized technique to quantitatively determine the effectiveness of anti-soiling coatings.

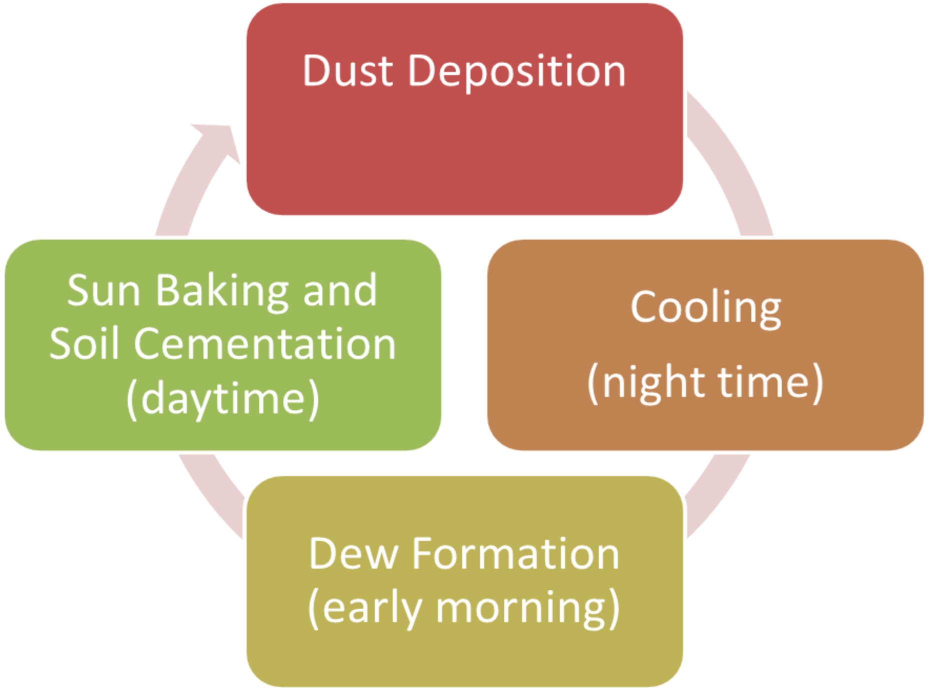
Indoor Artificial Soil Deposition Chamber - *why is it needed?*

- To determine the effectiveness of anti-soiling coatings or cleaning techniques so the vendor claims can be quantitatively validated.

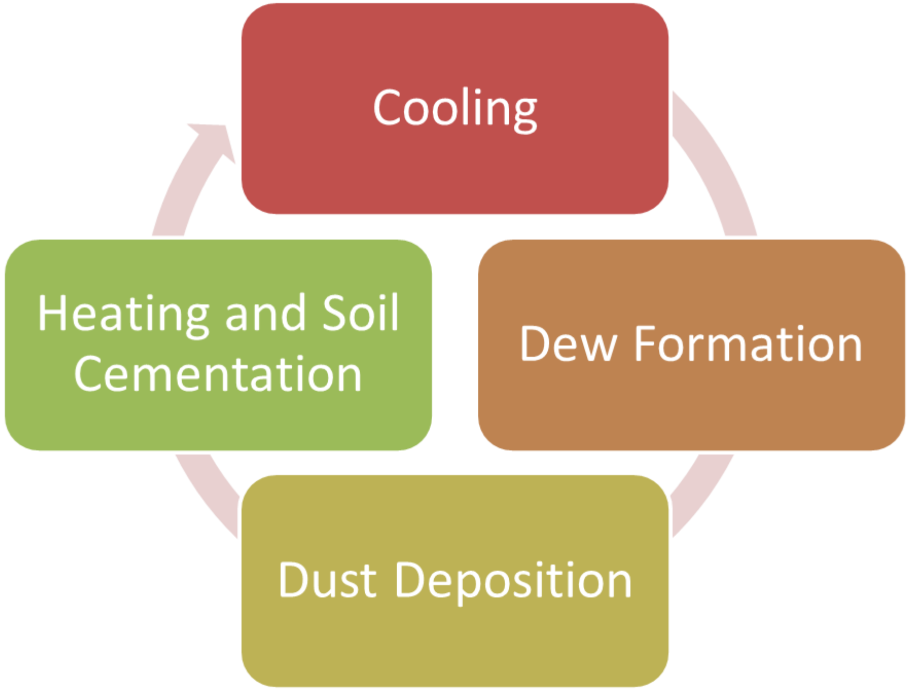
- To standardize the artificial soil deposition conditions simulating natural soiling conditions and sequence (standardization requires repeatable deposition within a lab and reproducible deposition between the labs) so a national or an international standard can be developed.

Presentation Scope

Natural Soiling Cycle



Artificial Soiling Cycle

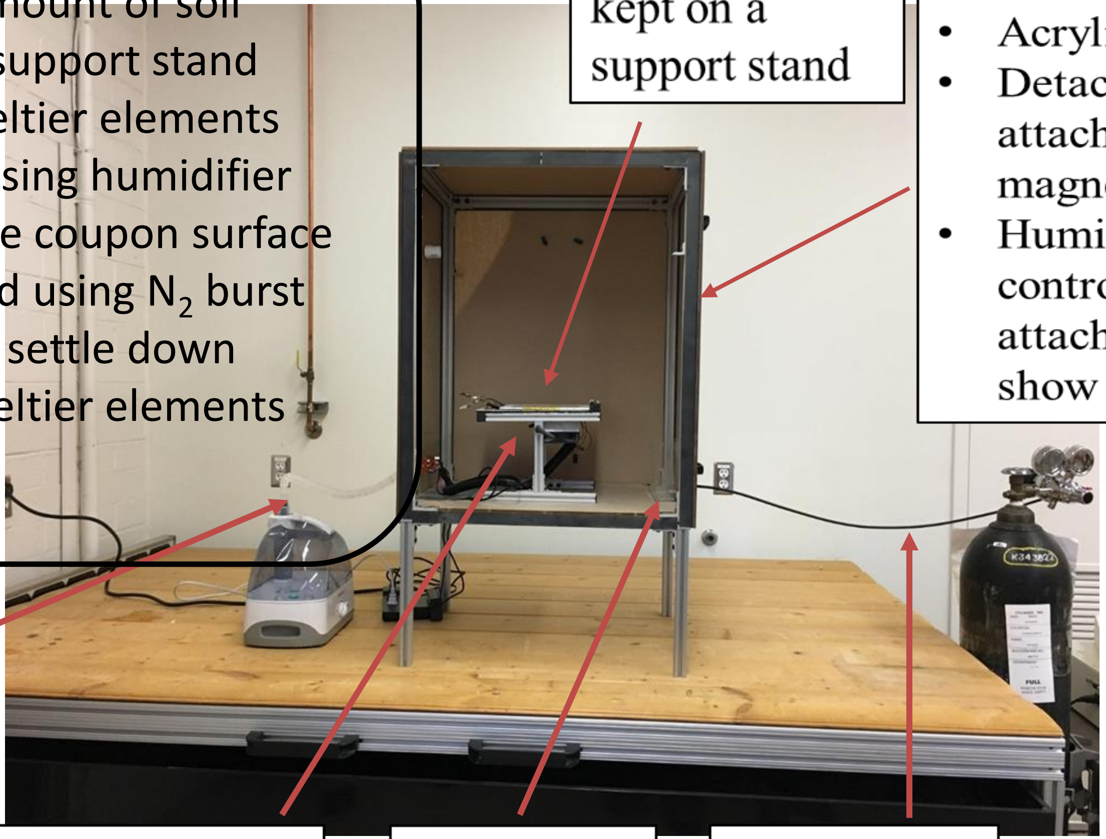


- Surface coating
  - ✓ Uncoated
  - ✓ AS coated
- Characterizations
  - ✓ Optical
  - ✓ Electrical
- Cleaning
  - ✓ Wind
  - ✓ Rain

One-chamber Soil Deposition Method

PROCESS SEQUENCE

- Place the required amount of soil
- Place PV coupon on support stand
- Cool coupon using Peltier elements
- Introduce humidify using humidifier
- Dew formation on the coupon surface
- Generate a dust cloud using N_2 burst
- Wait for the cloud to settle down
- Bake coupon using Peltier elements
- Repeat the cycle



Clean coupon kept on a support stand

- 3 x 2 x 2 ft chamber
- Acrylic (1/4”)
- Detachable / attachable walls with magnetic strips
- Humidity/temperature controller and sensor attached on a wall (not show here)

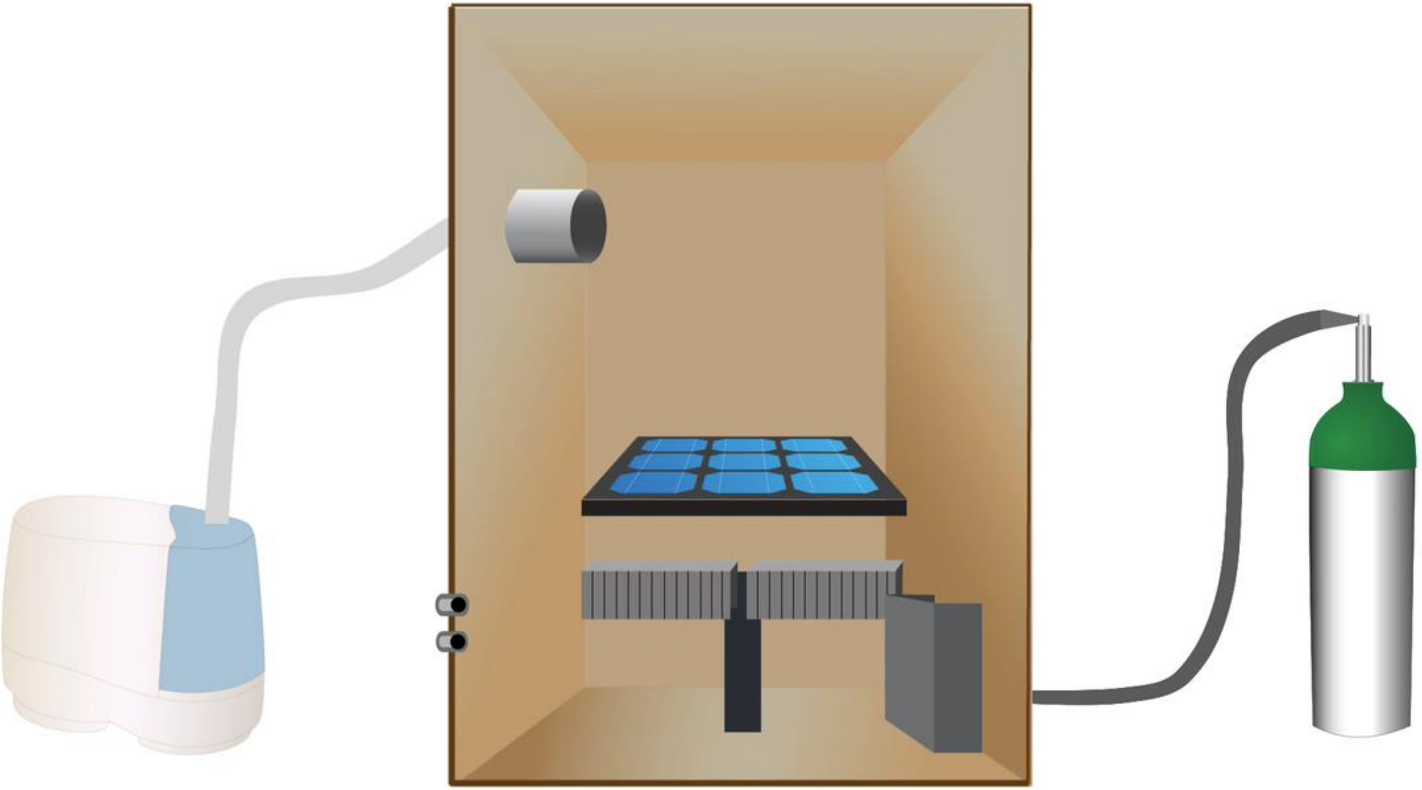
Humidifier hose sending humidified air

Thermoelectric cooling & heating

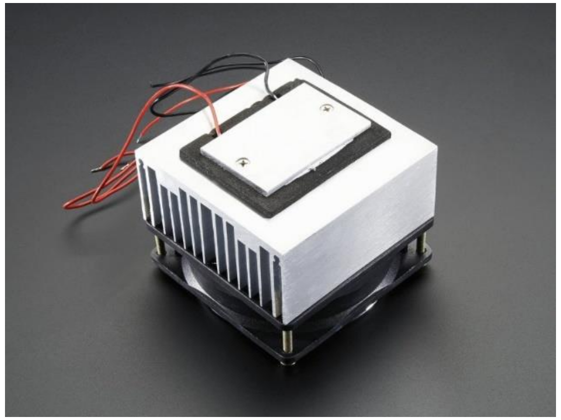
Soil dispensing chamber

Compressed N_2 cylinder tubing

Soiling Station Animation



Components Used in the One-Chamber Method

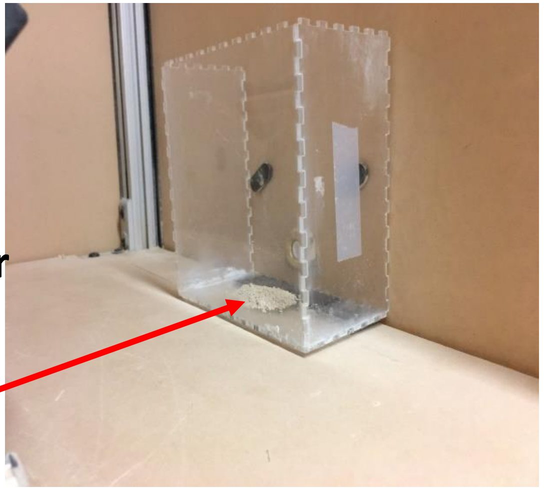


Adafruit - Thermoelectric Cooler/Heater Assembly (12V/5A)

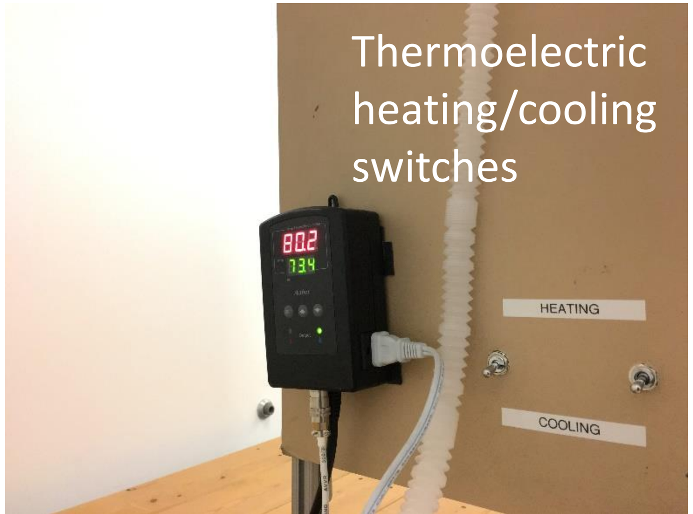
Auber Humidity controller

Walgreens cool mist humidifier

Detachable / attachable soil dispersion chamber



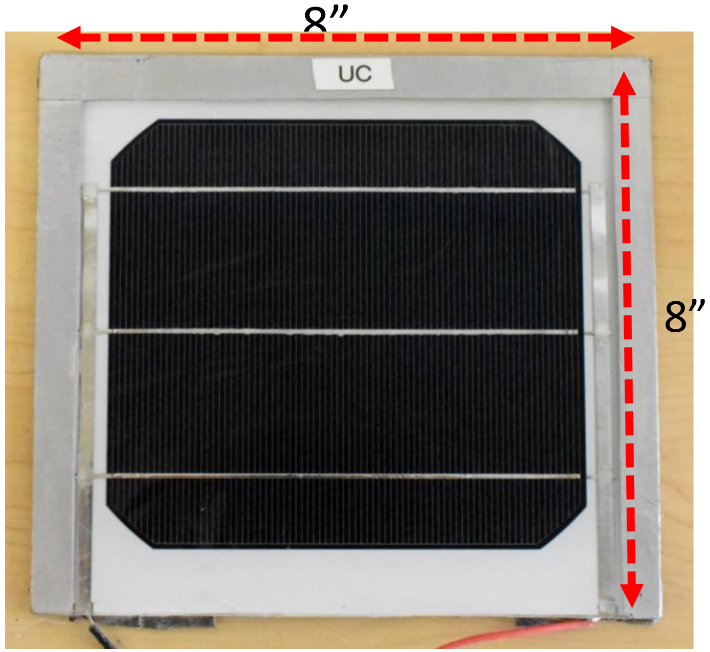
2 g soil sample

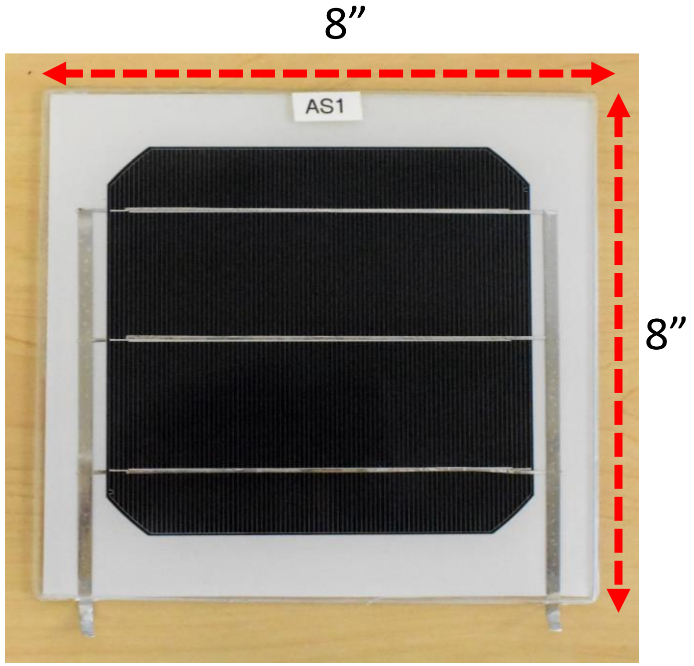


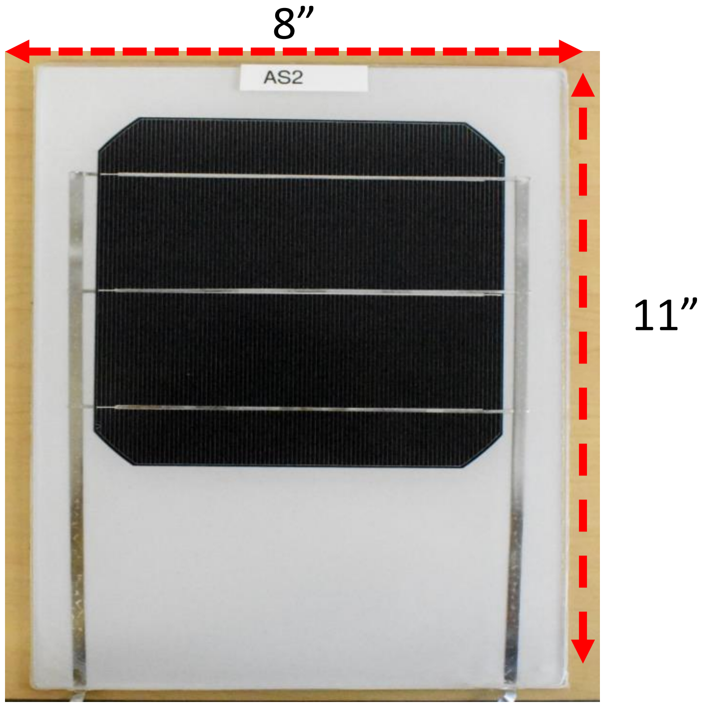
Thermoelectric heating/cooling switches

Test Modules

- Three 1-cell modules were fabricated at ASU-Photovoltaic Reliability Laboratory.
- One module (AS1) was shipped to the anti-soiling (AS) coating manufacturer who coated the 1-cell module with their AS coating.
- Anti-soiling coating liquid was purchased from manufacturer 2 and was coated on the second 1-cell module (AS2) using a paint roller. This roller is commercially used to apply coatings on glass.
- The third 1-cell module (UC) was the reference uncoated module.



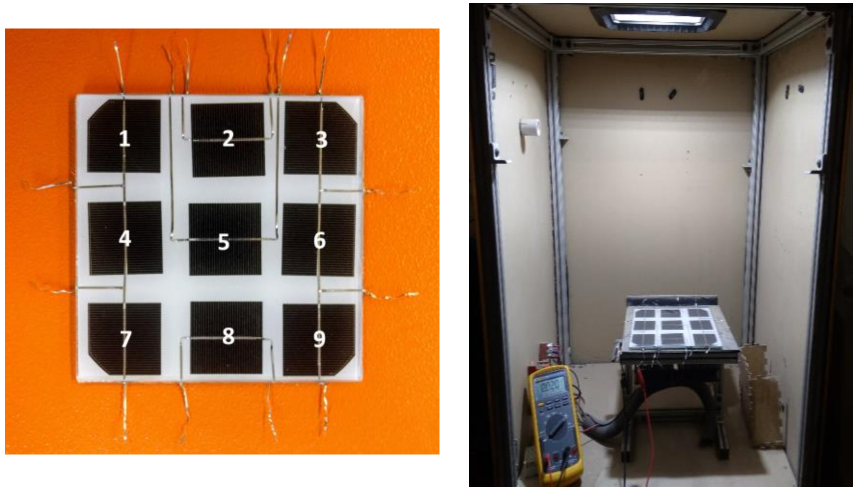




Typical Testing Sequence

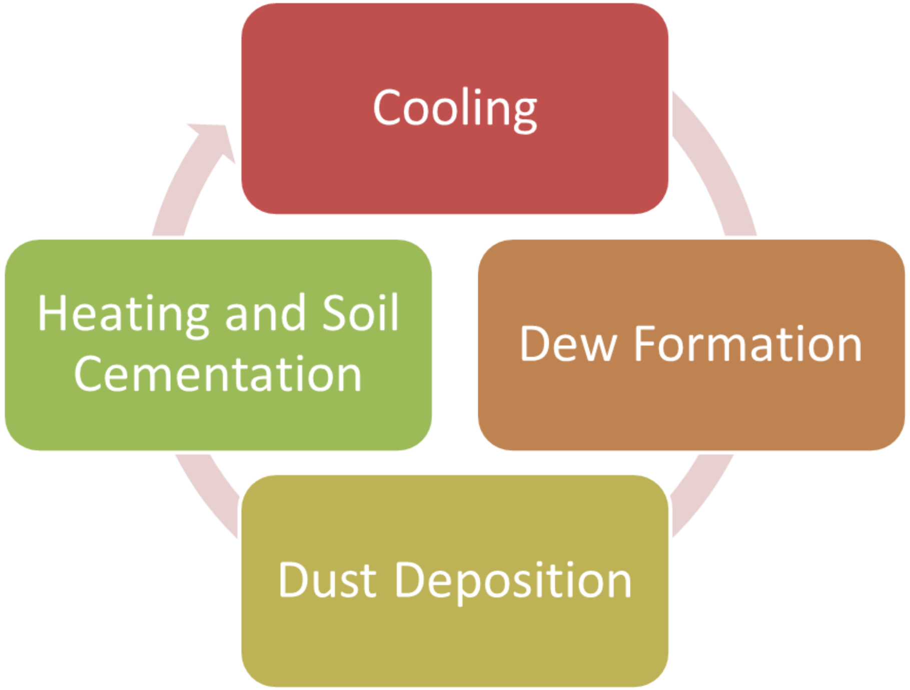
- Soiling loss is measured through %T loss using Isc loss
- Soiling uniformity is measured using Isc losses of 9 individual cells laminated in a single module
- The indoor soiling chamber is used to deposit soil on the three 1-cell modules. The modules are placed flat at 0° tilt during soil deposition.
- Three layers of soil (**3 cycles**) are deposited on the surface of 1-cell modules for each trial in this study. 2 g of **AZ reference dust** is used in each deposition cycle.
- Isc of the module was measured in-situ after each cycle. Weight of the module was also recorded with precision of 0.001 g **(1 mg)** after every cycle.

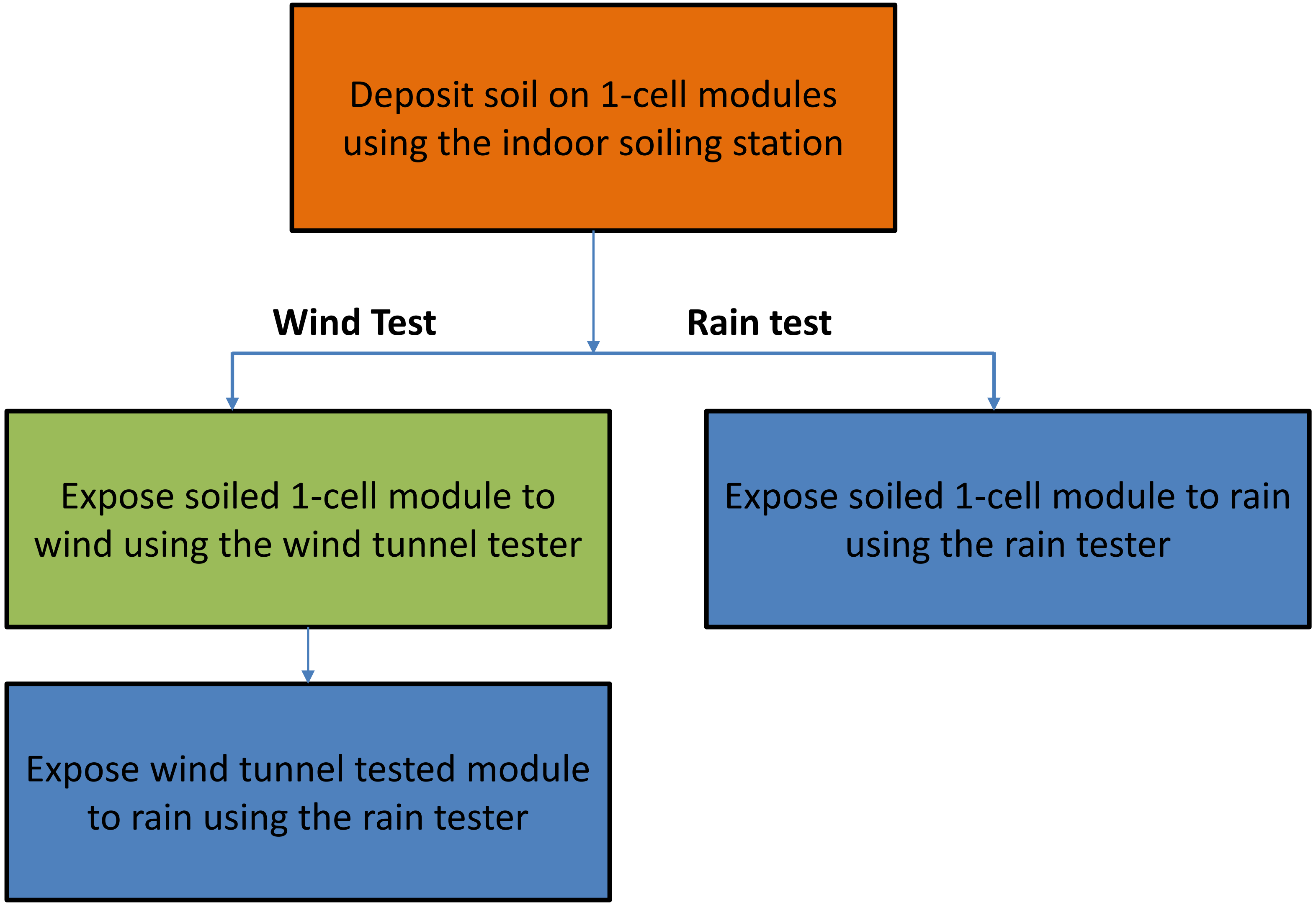
In-situ Transmittance (Isc) Measurement



In-situ Soiling Uniformity (Isc) Measurement

Indoor Soiling Cycle

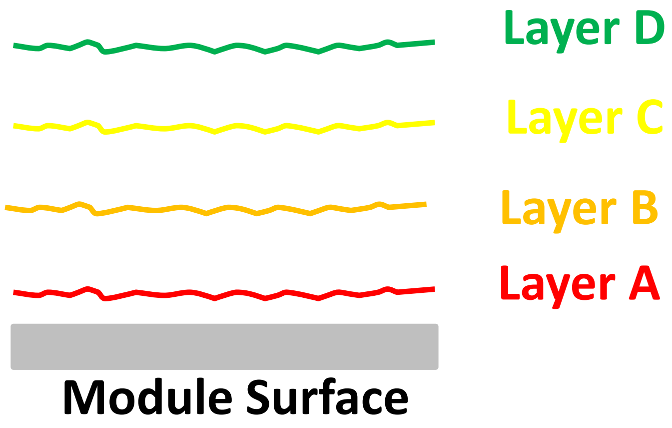




Adhesion of Soil Layers

Soil deposited on PV module surface can be classified into three or four distinct layers:

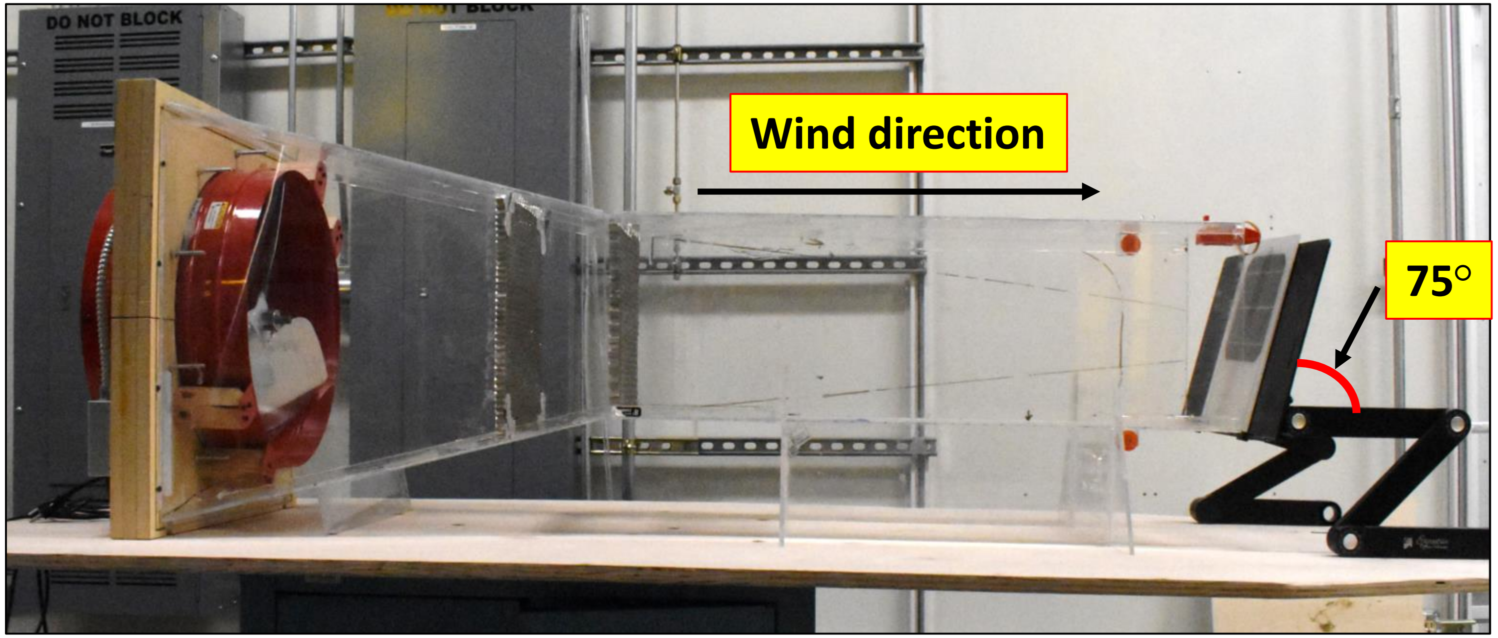
A. First layer of soil, **Layer A**, is cemented (chemically bonded) to the surface of PV module and is extremely hard to remove by rain or wind*
B. Second layer of soil, **Layer B**, can be removed by rain but is resistant to high speed wind.
C. Third layer of soil, **Layer C**, is loosely bound and can be cleaned by rain and high speed wind.
D. Fourth layer of soil, **Layer D**, is the weakest bonded layer and can be removed by moderate wind (or gravity by tilting the module vertically).



**Reference: Surface Soiling: Theoretical Mechanisms and Evaluation of Low-Soiling Coatings, Edward F. Cuddihy, Jet Propulsion Laboratory, 1983*

Wind Tunnel Testing

- The soiled modules are placed on a stand fixed at **75° tilt** with the module facing the wind, so that the wind completely covers the module surface.
- An open-circuit sub-sonic wind tunnel is used in this study. The wind velocity can be varied between **5 m/s and 11 m/s.**
- The wind velocity can be changed using a dial in the wind tunnel tester and the velocity was also verified using a handheld anemometer.

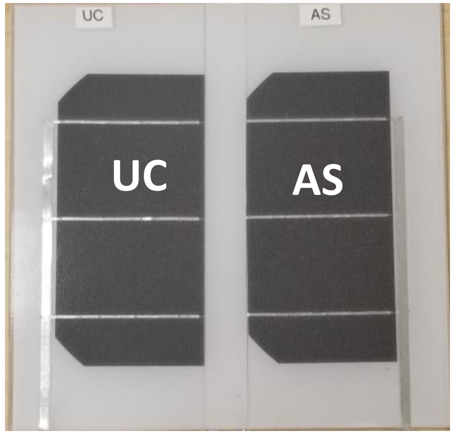


Rain test

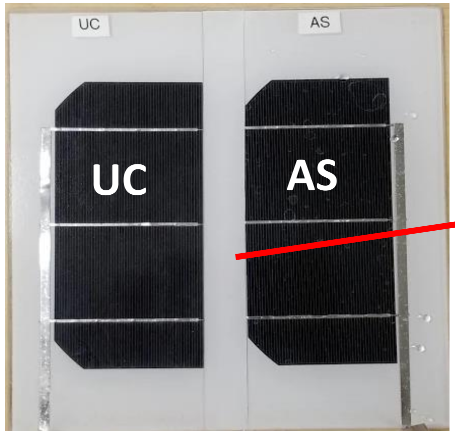
Approach 1 (not good):

UL 1703 water spray nozzle

- The soiled module is placed on the stand. The distance between the module and the center of the nozzle is 3 ft.
- The water jet pressure in this experiment is set to be 0.5 psi.
- The valve is opened and the soiled modules are exposed to “rain”. Water also collects in the beaker and when water reaches a specified level in the beaker (1mm, 5mm and 10mm), the valve is closed.
- Even at 0.5 psi, the intensity of “rain” is high. 1 mm rain is collected in 25 seconds. In case of a light rain, 1 mm might take much longer to collect.



Before 1mm rain



After 1mm rain

Rain test

Approach 2 (yet to be implemented):

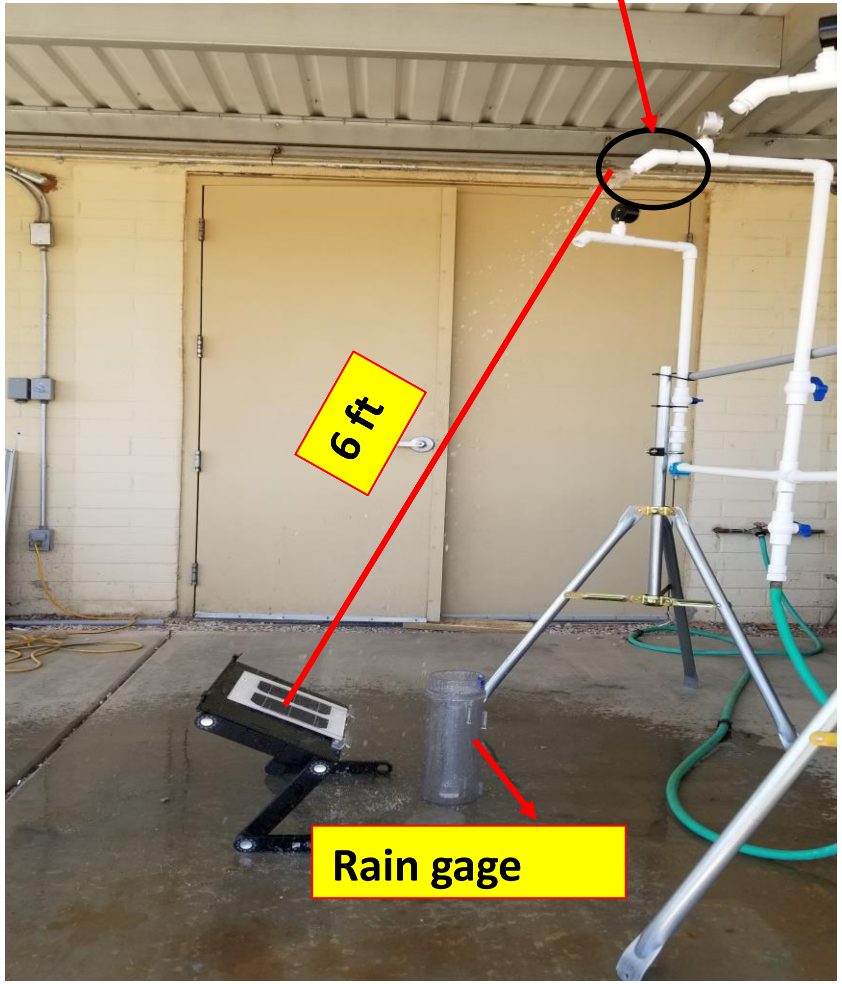
- The distance between the center of the nozzle to the module to be set at 6 ft.
- The current nozzles are to be replaced by 1/8 HH-5 full jet nozzles (Spraying Systems Co.; *spray.com*)
- Rain gage is used to measure the rain amount.
- At 10 psi, we would obtain a **2 inch/h rain** (1 min and 10 seconds for 1 mm rain) with droplet size of around 4 mm.
- By varying the inlet pressure, different rain intensities and droplet sizes can be obtained. Light Rain, Heavy Rain, Fog conditions can be simulated.

IN MICRONS

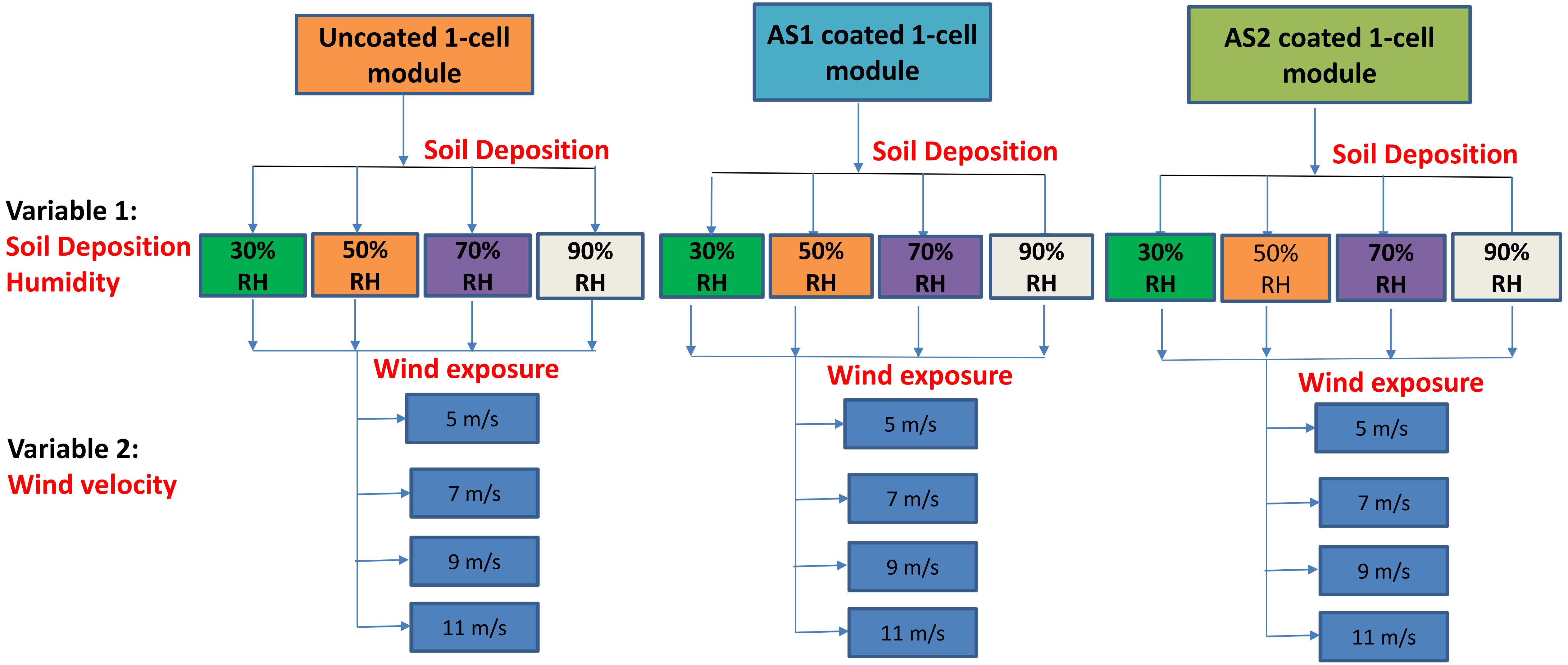
FOG	LIGHT RAIN	MODERATE RAIN	INTENSE/HEAVY RAIN
10 to 100	100 to 500	500 to 1000	1000 to 5000
VERY SMALL	SMALL	MEDIUM	LARGE

spray.com

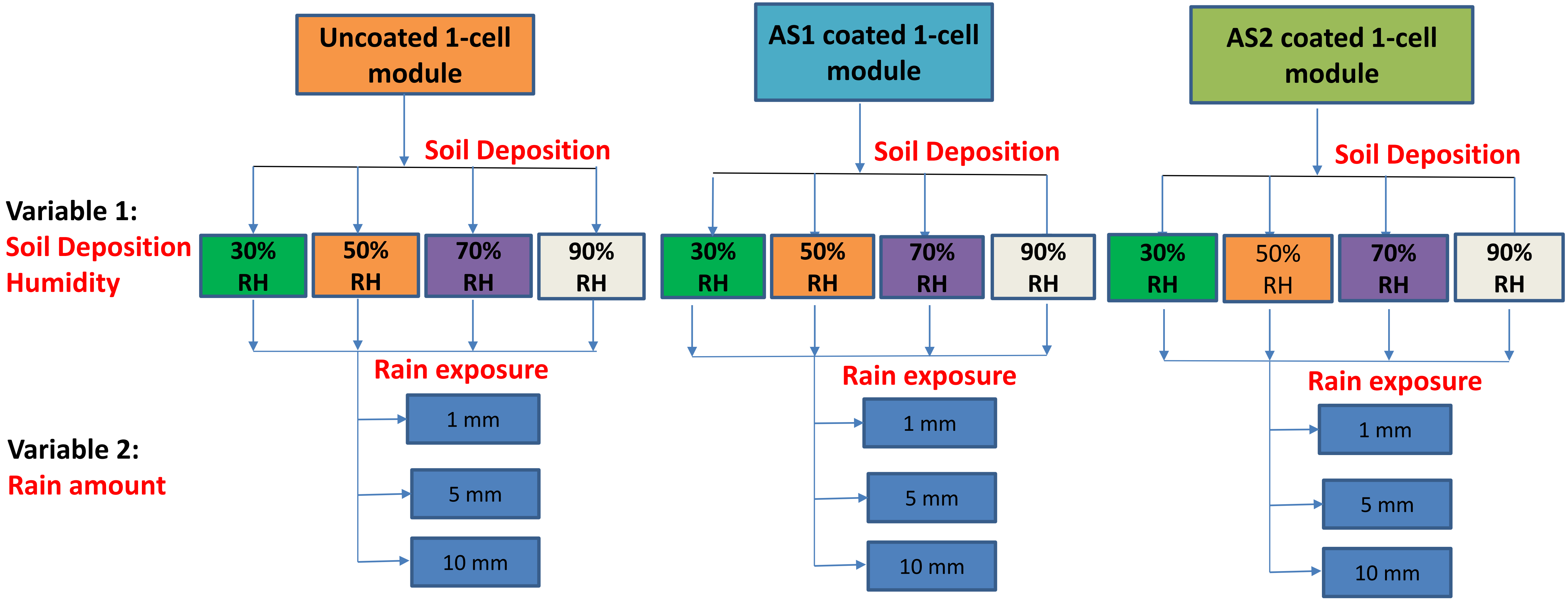
1/8 HH-5 full jet spray nozzle to be installed



Design of Experiments: Wind Test

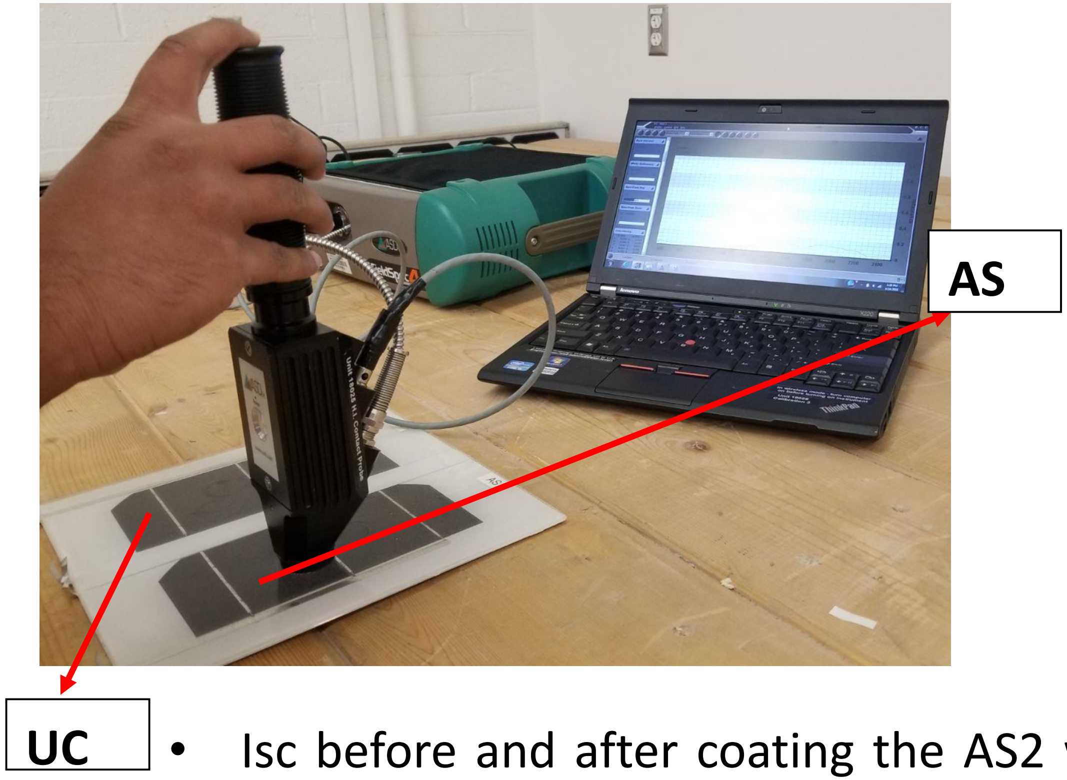


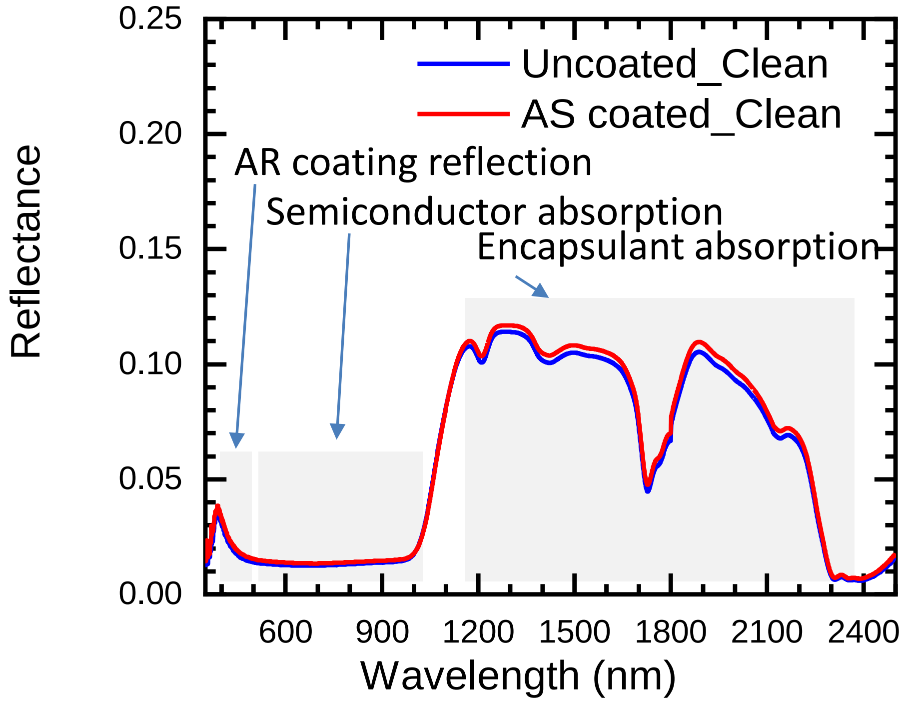
Design of Experiment: Rain test



Reflectance of clean AS coated and uncoated split-cell module

- A split-cell monocrystalline module was fabricated with one half coated with anti-soiling coating and the other half was uncoated.

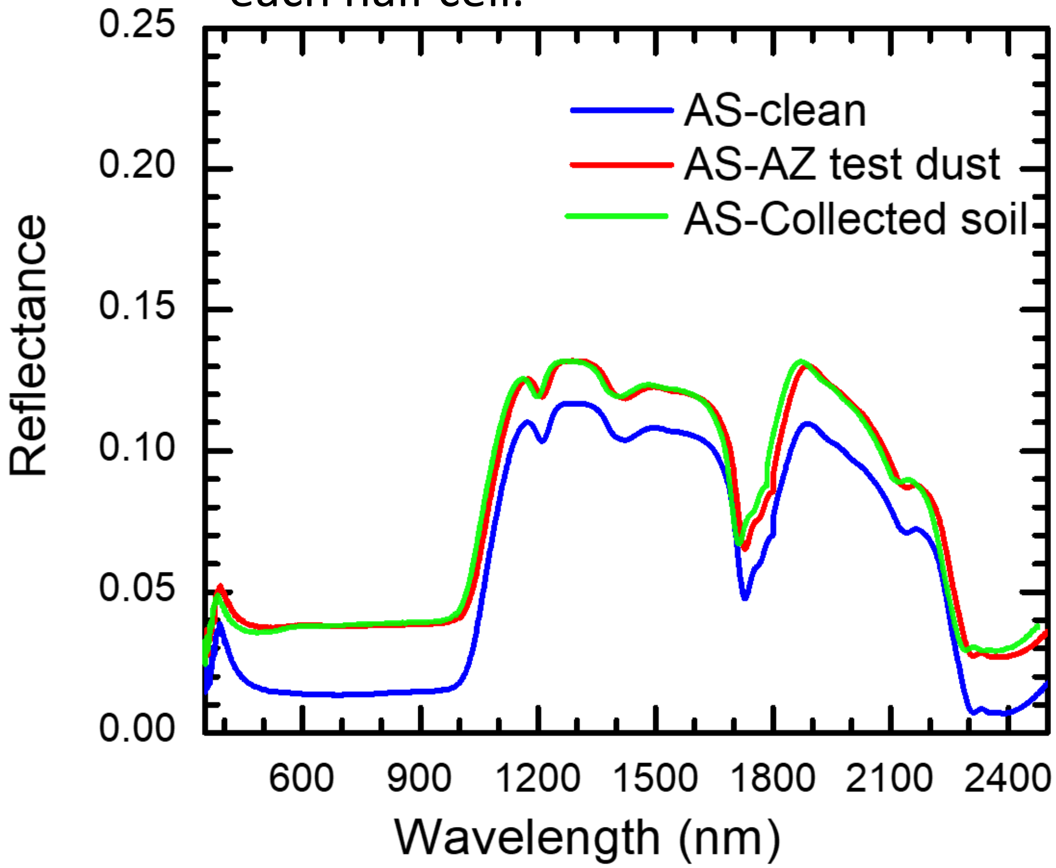


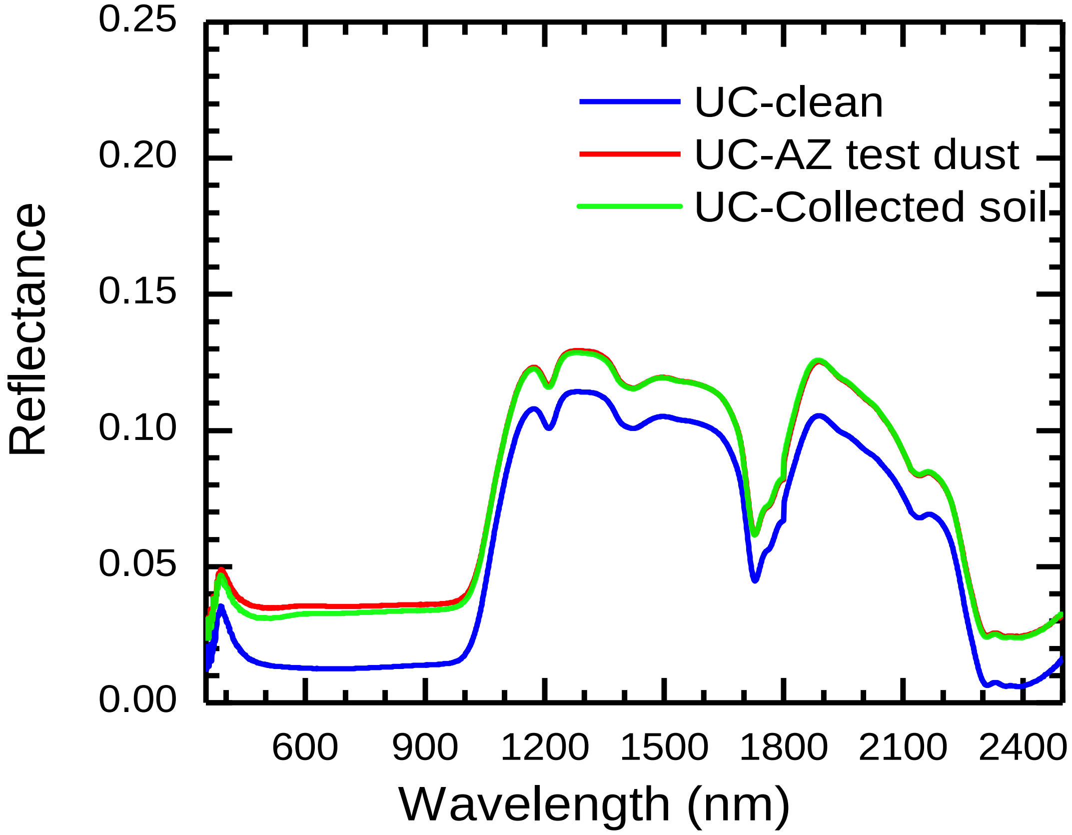


- Isc before and after coating the AS2 was measured using the **in-situ Isc measurement** setup in the indoor soiling chamber. The transmission loss was determined to be **0.6 %.**
- The transmittance loss for **AS1** was calculated in a similar fashion to be **0.62 %.**

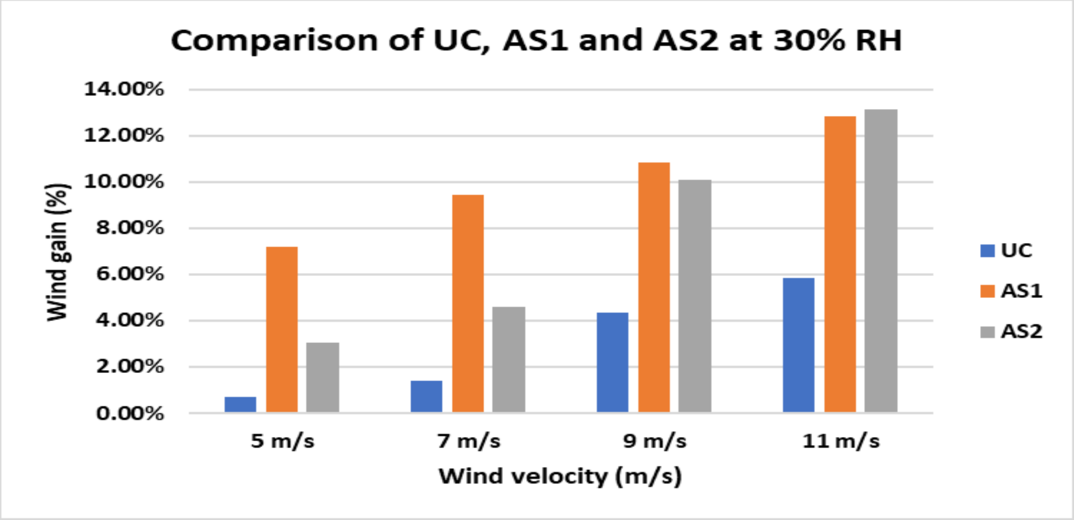
Reflectance Measurements

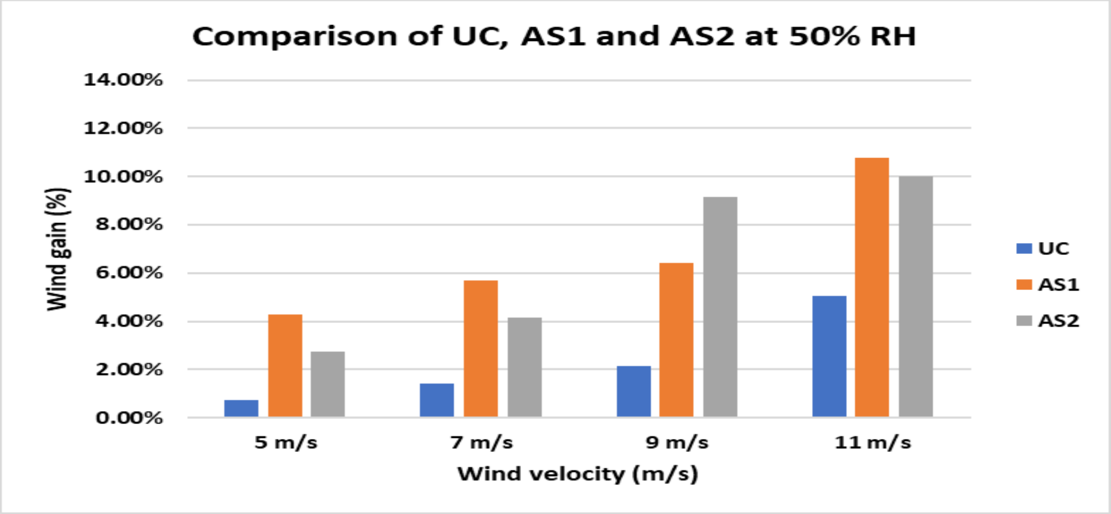
- 3 g of AZ test dust and fielded PV array surface collected soil samples were used to deposit soil on the split-cell module and the reflectance measurements were taken at the center of each half cell.

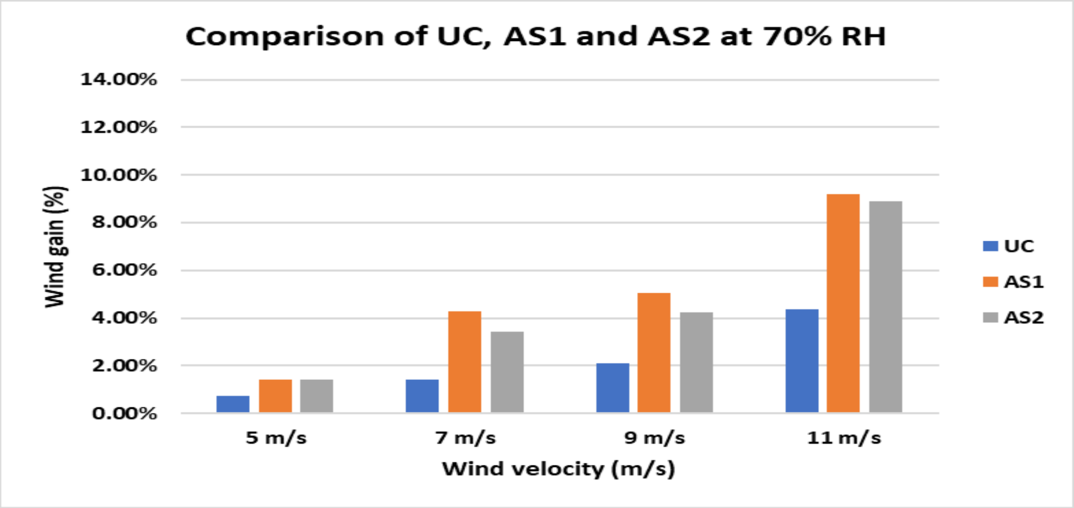


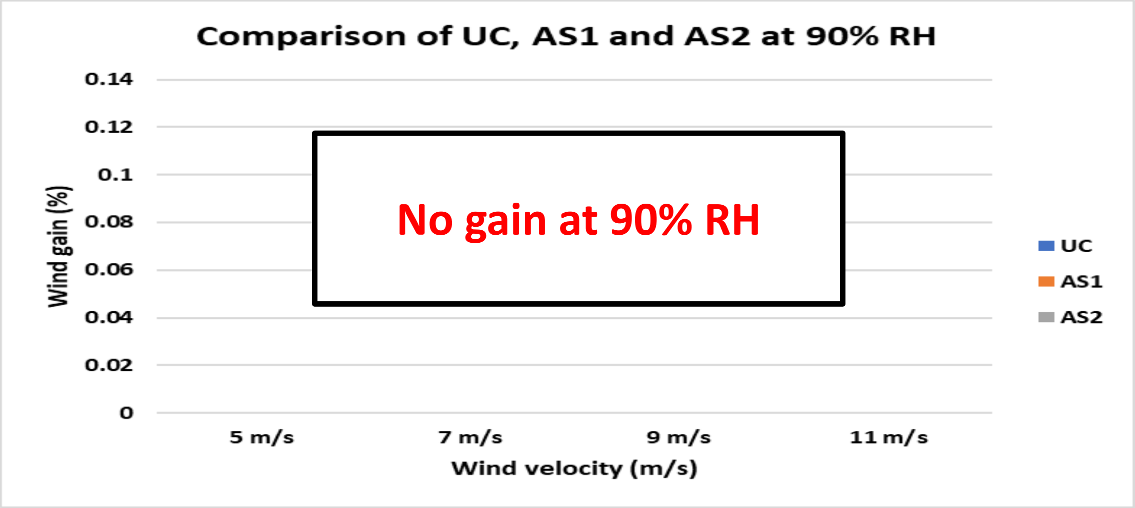


Wind gain comparison of UC, AS1 and AS2 modules after 6 minutes of wind exposure



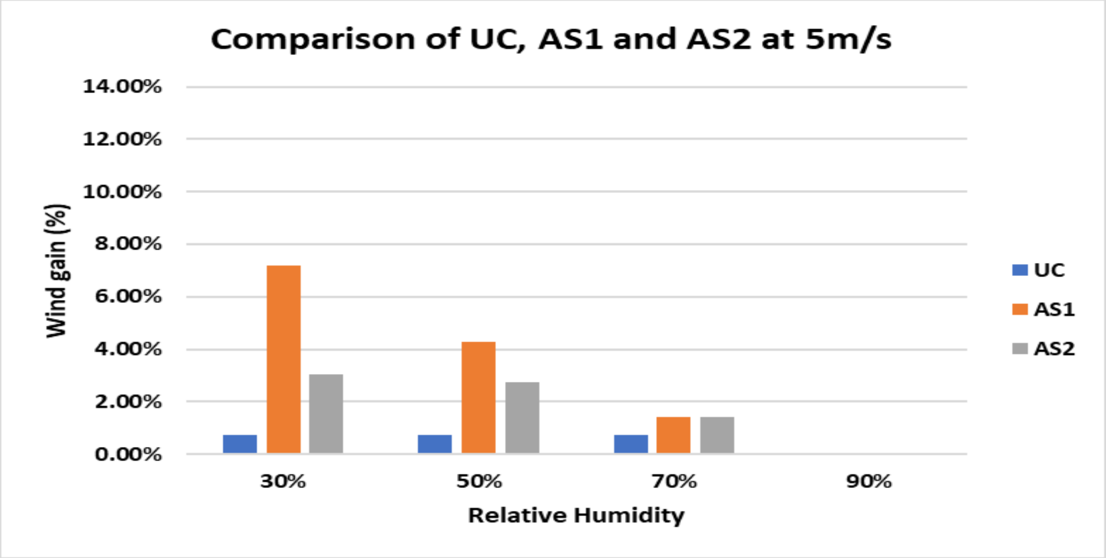


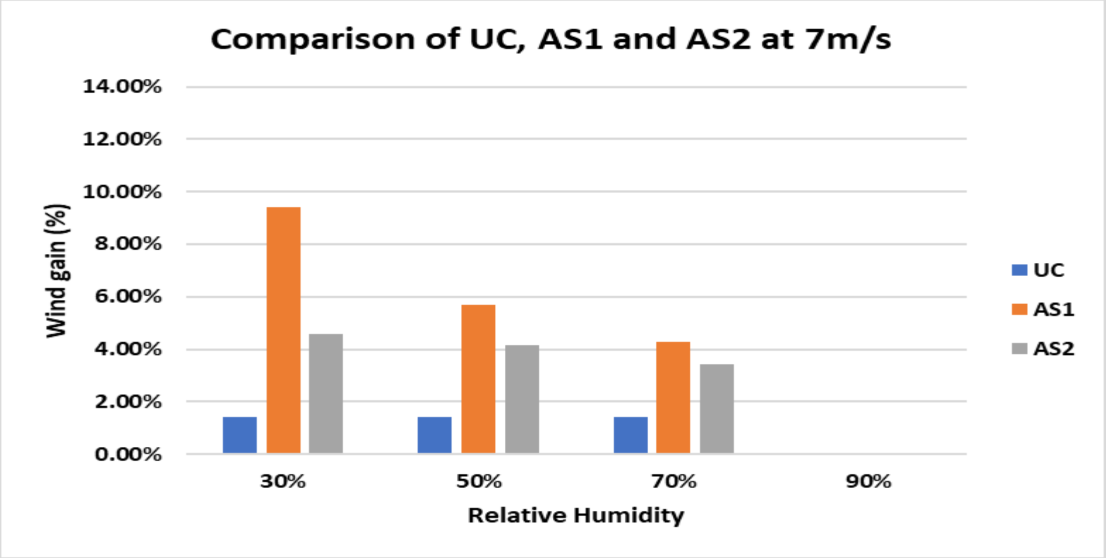


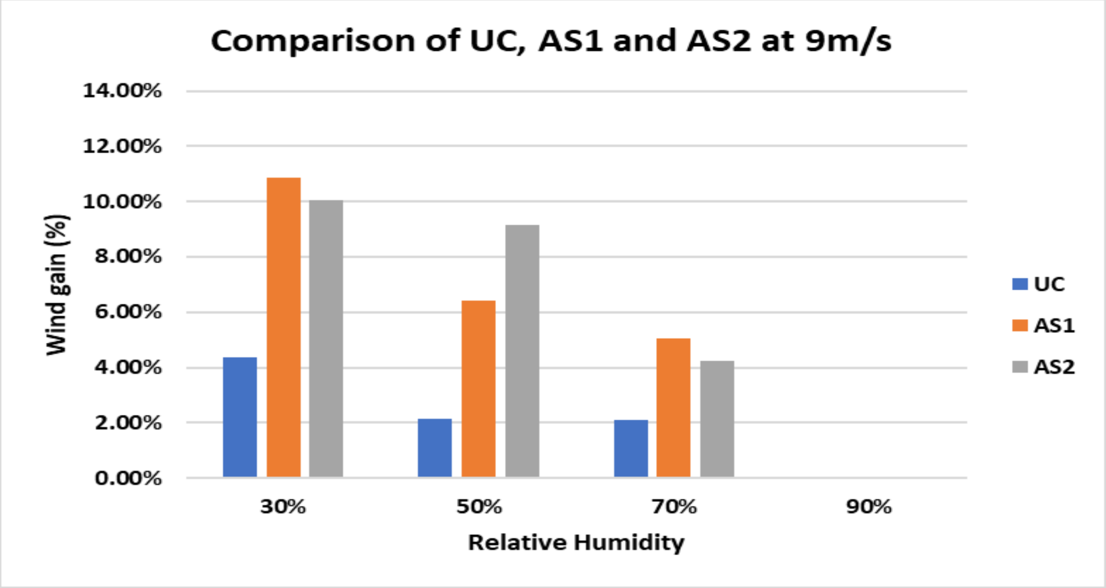


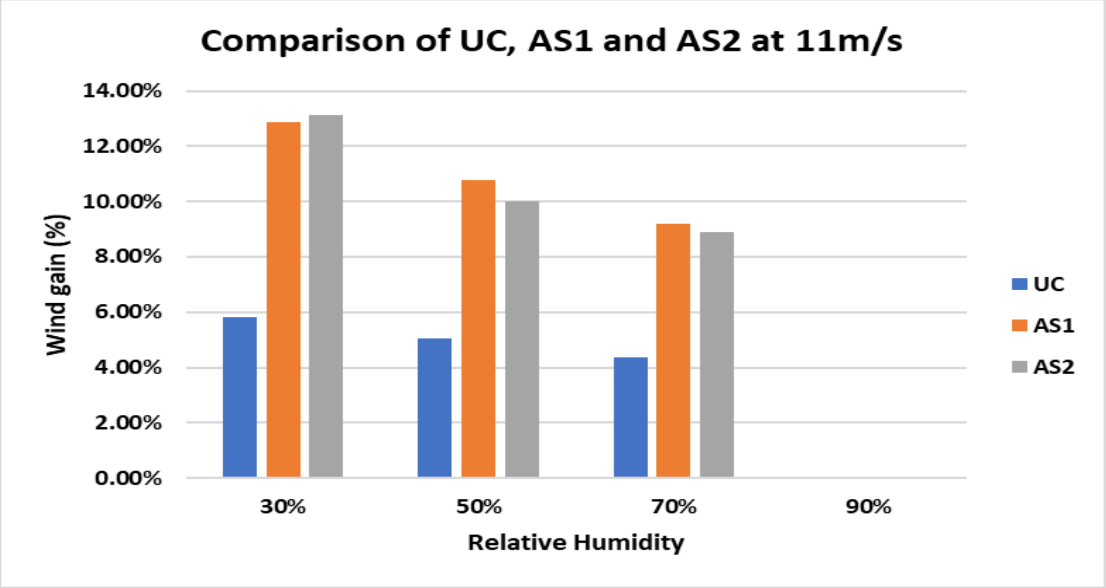
$$Wind\ gain\ (\%) = \frac{(Isc\ after\ wind\ exposure - Isc\ of\ soiled\ module)}{Isc\ of\ soiled\ module} * 100$$

Wind gain comparison of UC, AS1 and AS2 modules after 6 minutes of wind exposure









Summary

- An optimized soil deposition chamber is developed to validate the claims related to anti-soiling coatings and cleaning techniques.
- Test setups related to wind cleaning and rain cleaning have been explored.
- Wind gain dramatically decreases as the humidity during deposition increases
- No reflectance difference is practically observed between the Arizona road dust and the collected soil from module surface installed in Arizona
- A repeatable standard operating procedure (SOP) is being developed. This SOP may be converted into a national or an international test standard.