Evaporative Cooling System for PV Panels

GROUP 14

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MOTIVATION

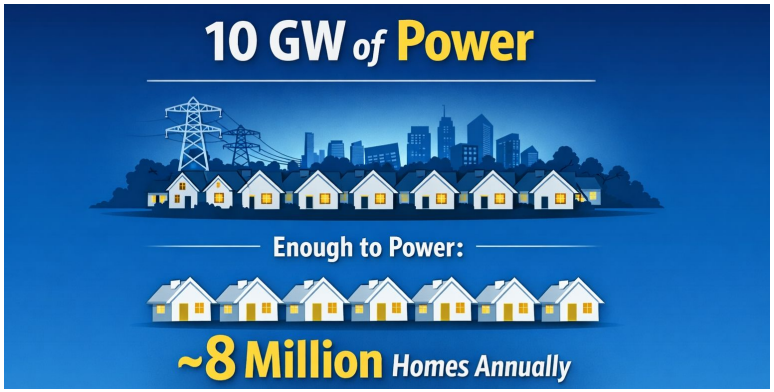
Thermal Loss

- 0.45% efficiency lost / °C above 25 °C
- Typical panel temp: 55–70 °C
- **12 - 22 % power loss**

Dust / Soiling Loss

- Moderate(urban): 2–15%
- Heavy(desert): 20–30%
- **10% average annual loss**

Conservative Total Loss Estimate = 25%



Globally equates to approximately 500 GWs of Equivalent Solar Power Loss Annually.

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CONTROL OBJECTIVE

- Limit peak operating temperature under solar heating
- Reduce cumulative efficiency loss during high-irradiance periods

Panel Temperature = Solar Heating − Evaporative Cooling

Control Variable

Solar panel surface temperature

Disturbance

Solar heat input (Uncontrolled thermal energy from irradiation)

Control Input

Evaporative misting rate (Heat removal via phase-change cooling)

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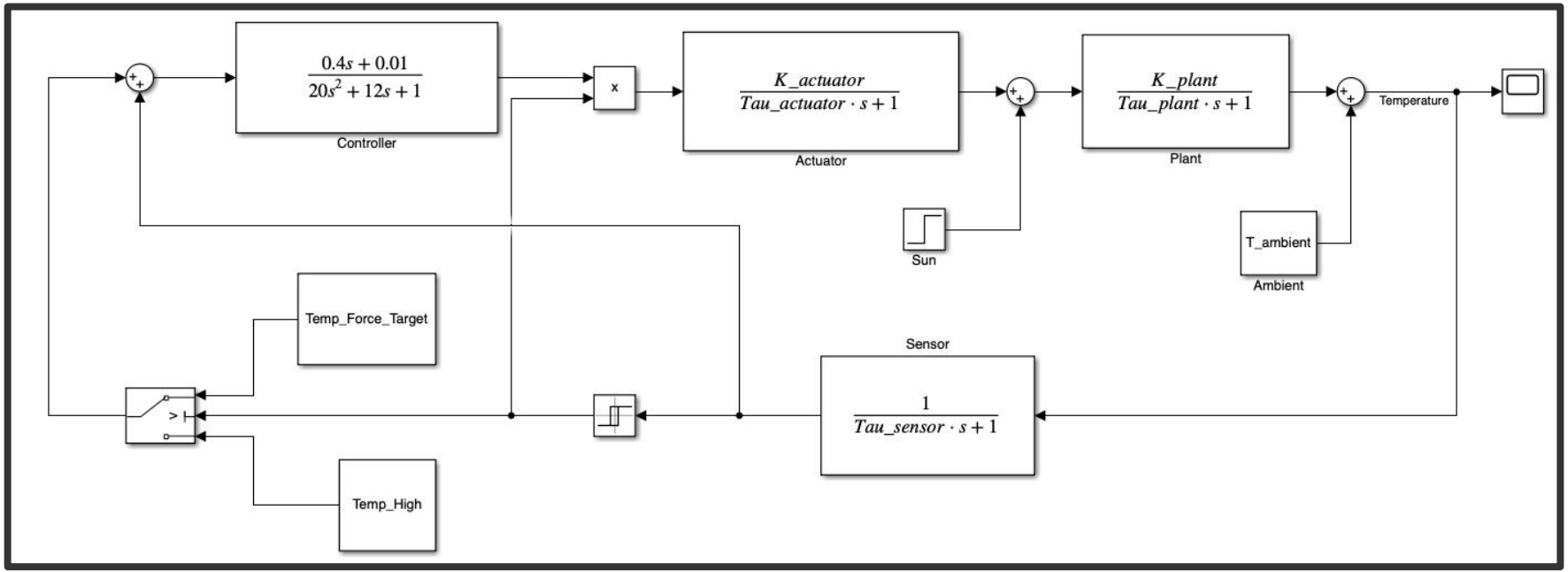
CL SIMULINK CONTROL MODEL



Plant G(s)

$$\frac{K\_plant}{Tau\_plant \cdot s + 1}$$

NYU 3inx5in mini PV cell

Sensor H(s)

$$\frac{1}{Tau\_sensor \cdot s + 1}$$

10k NTC Thermistor

Actuator A(s)

$$\frac{K\_actuator}{Tau\_actuator \cdot s + 1}$$

Foam Mister x2

SYSTEM PARAMETERS

Block	Parameter	Meaning	Value
Actuator	K_Actuator	Cooling gain from mister	-1400
	Tau_actuator	Pump / mister response time	5 s
Plant	K_plant	Cooling effectiveness (normalized)	0.025
	Tau_plant	Panel thermal time constant	400 s
Sensor	Tau_sensor	Thermistor thermal lag	2 s
Environment	T_ambient	Ambient air temperature	26 °C
Reference	Temp_Force_Target	Target panel temperature	41 °C
Supervisory Logic	Temp_High	High-temperature threshold	44 °C

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System parameters were experimentally obtained/ inferred from multiple full setup runs by observing heating and cooling transients, and represented as effective first-order dynamics in the model.

CONTROLLER DESIGN AND ANALYSIS

$$\frac{0.4s + 0.01}{20s^2 + 12s + 1}$$

2nd order compensator for a slow thermal system

- Second-Order Controller
- High-Frequency Noise Filtering
- Stability Augmentation
- Smooth Control Action

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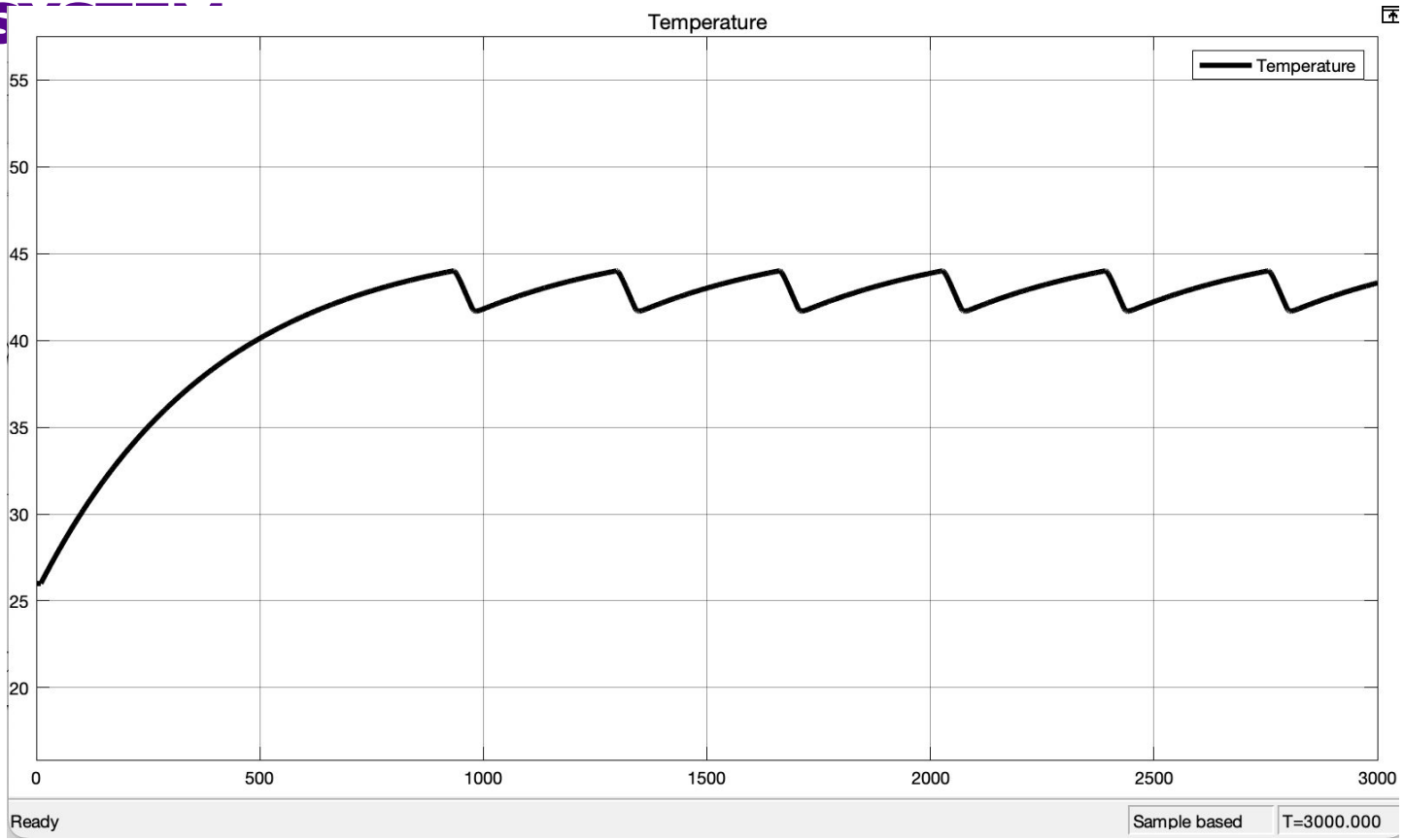
TEMPERATURE SCOPE OF SIMULINK SYSTEM



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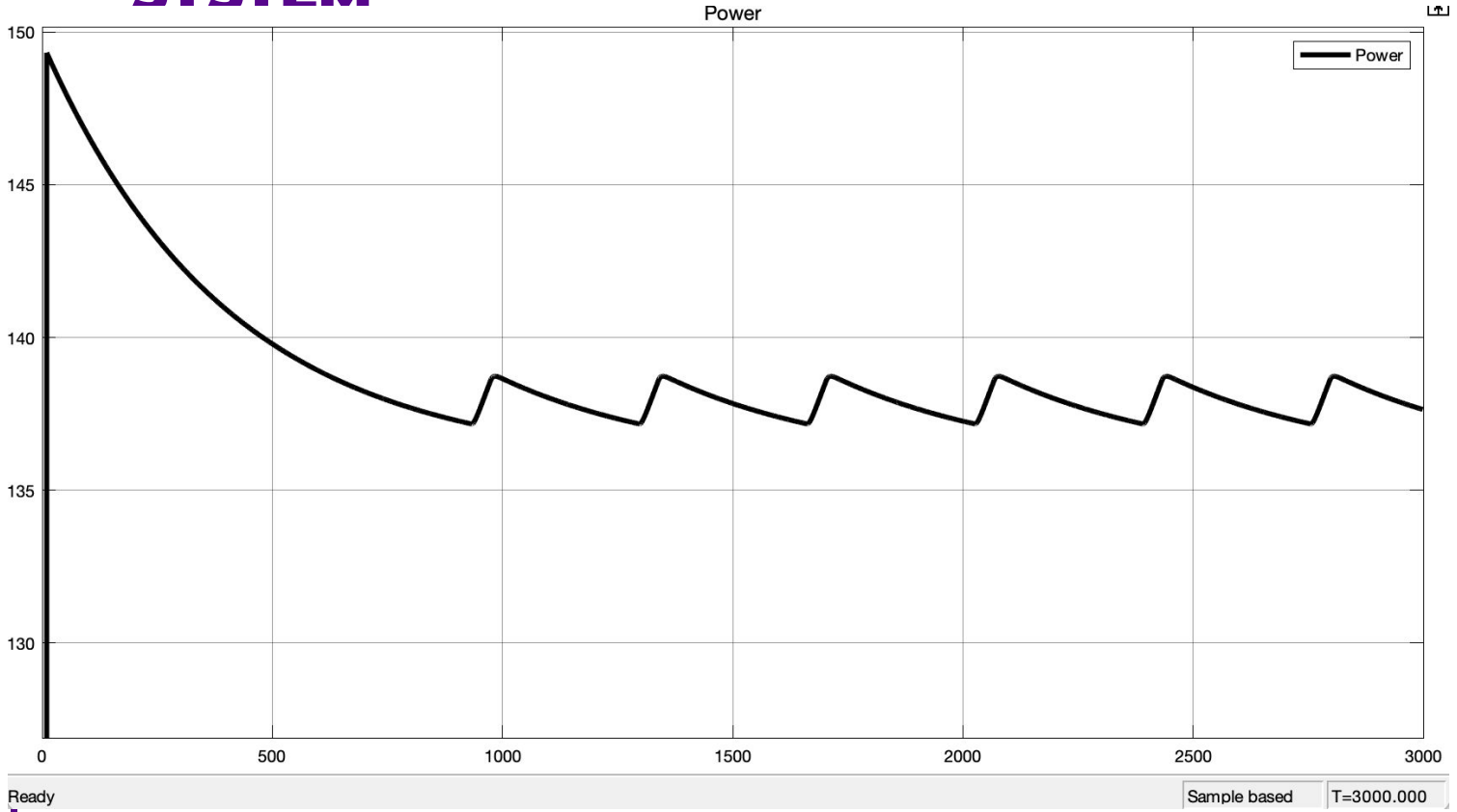
POWER SCOPE OF SIMULINK SYSTEM



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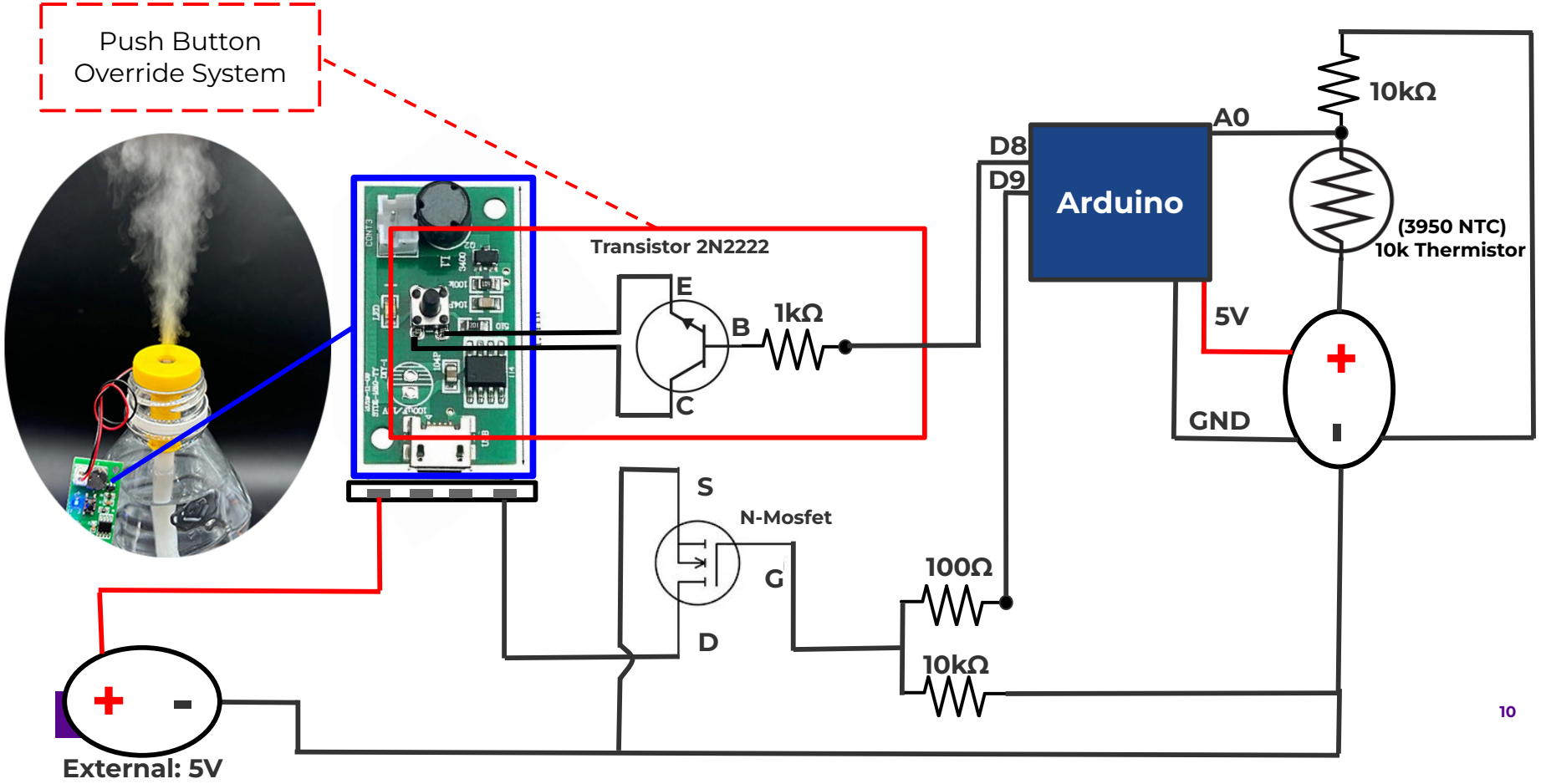
TEMPERATURE+MIST SYSTEM HARDWARE INTEGRATION



SOLAR OUTPUT SYSTEM HARDWARE INTEGRATION

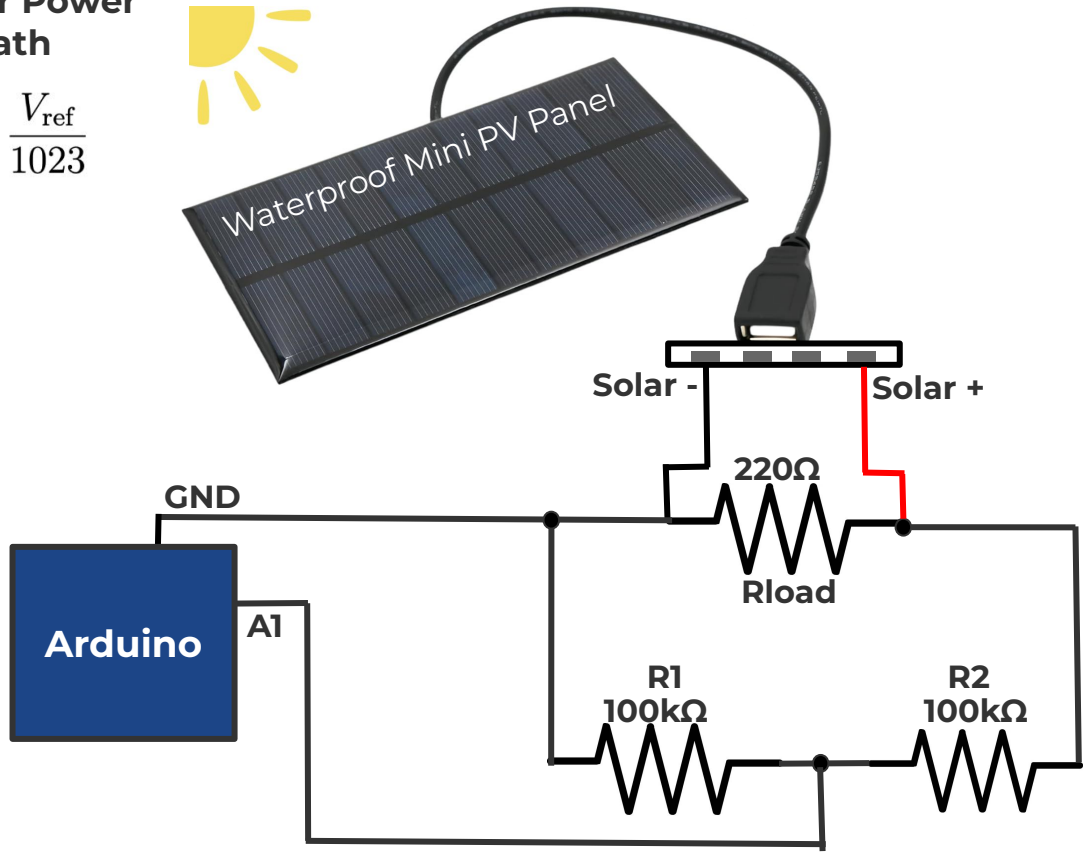
Voltage Divider Power Output Math

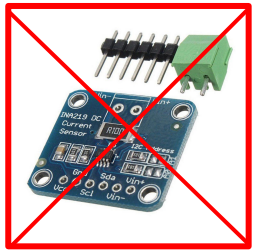
$$V_{A1} = \text{ADC} \cdot \frac{V_{\text{ref}}}{1023}$$

$$V_{\text{panel}} = 2V_{A1}$$

$$I_{\text{panel}} = \frac{V_{\text{panel}}}{220}$$

$$P_{\text{panel}} = \frac{V_{\text{panel}}^2}{220}$$

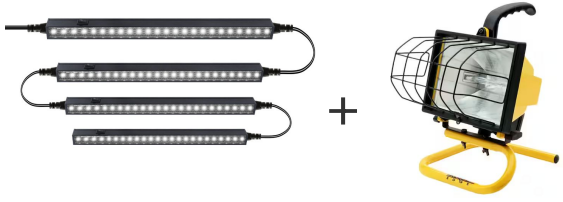




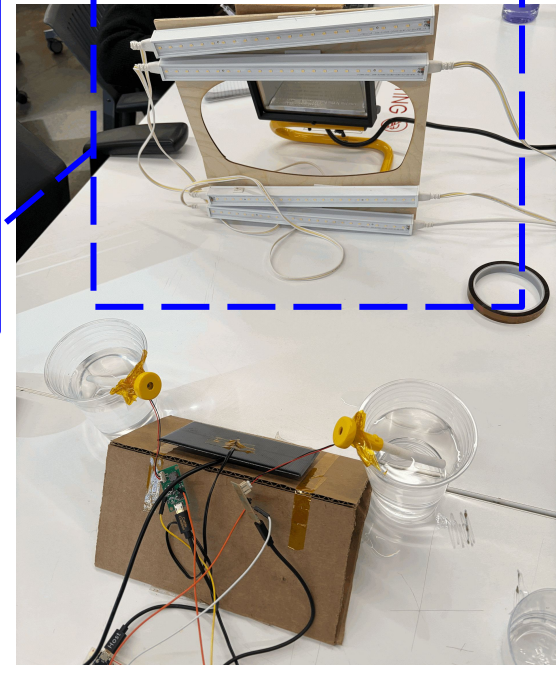
Defective Sensor:
INA219 (Power Monitoring)

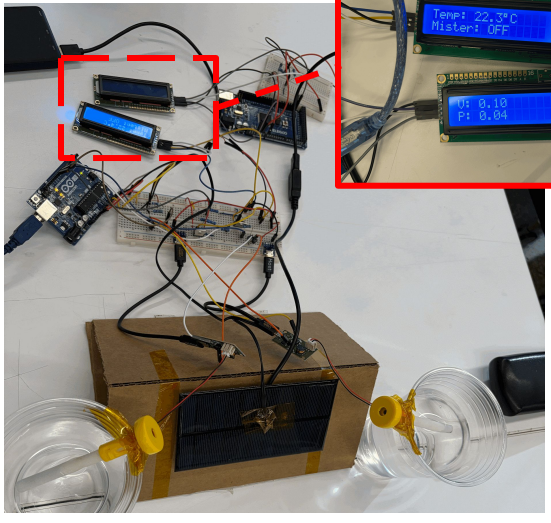
PHYSICAL SETUP

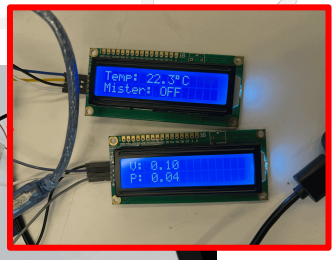
Emulating solar irradiance indoors

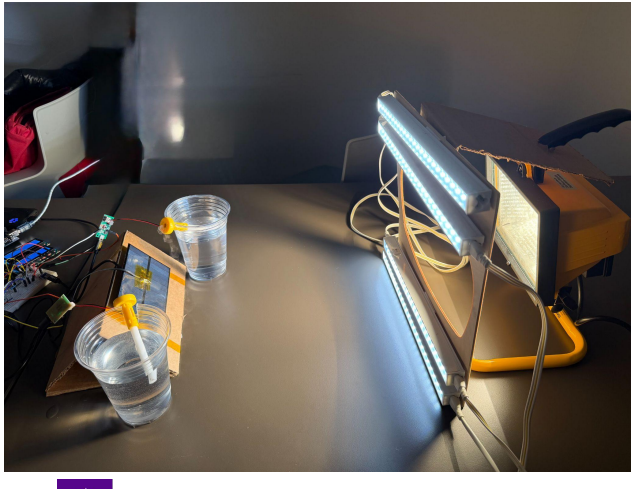


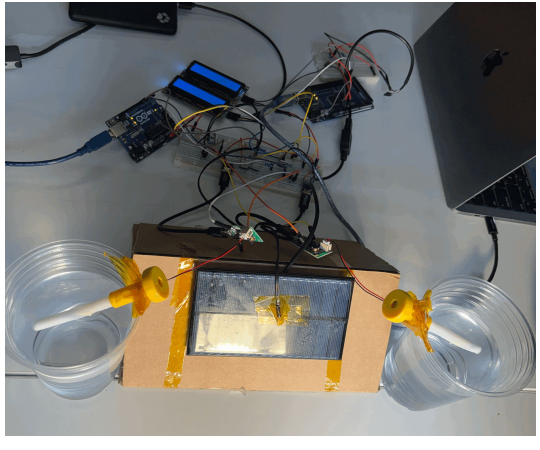
Spectral+Thermal Requirements











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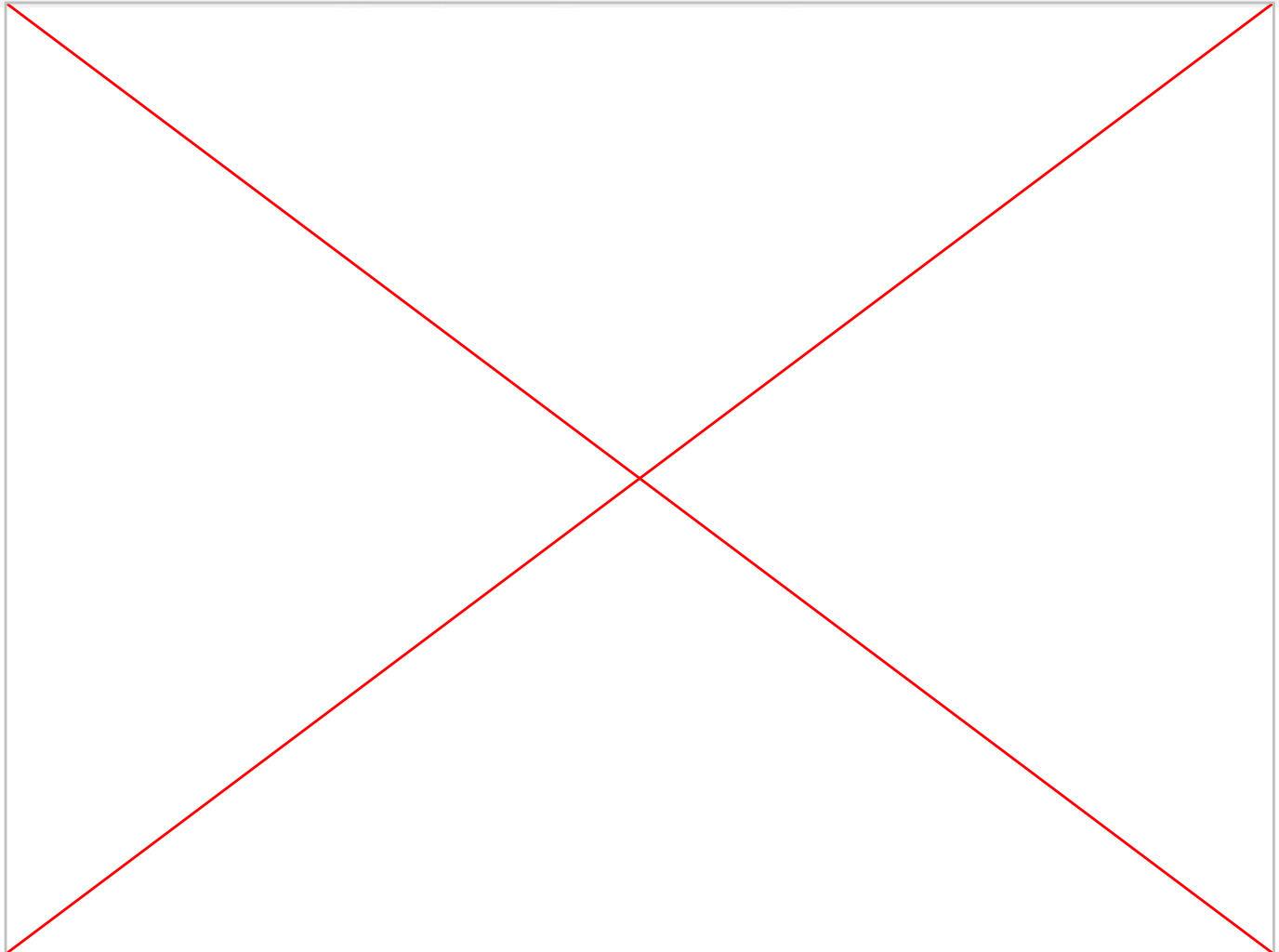
Demonstration Thresholds

Mister on: 44.0 C

Mister off: 41.0 C

Demo



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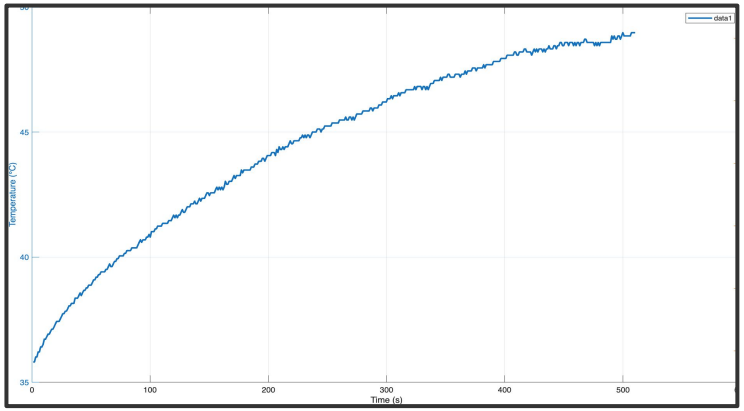
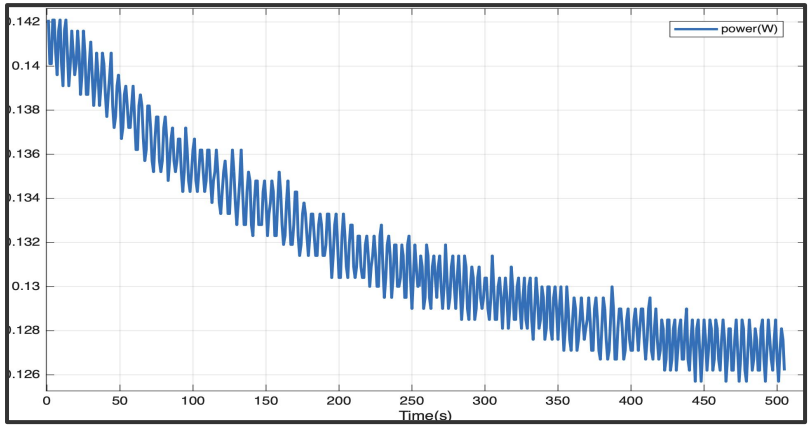
Results

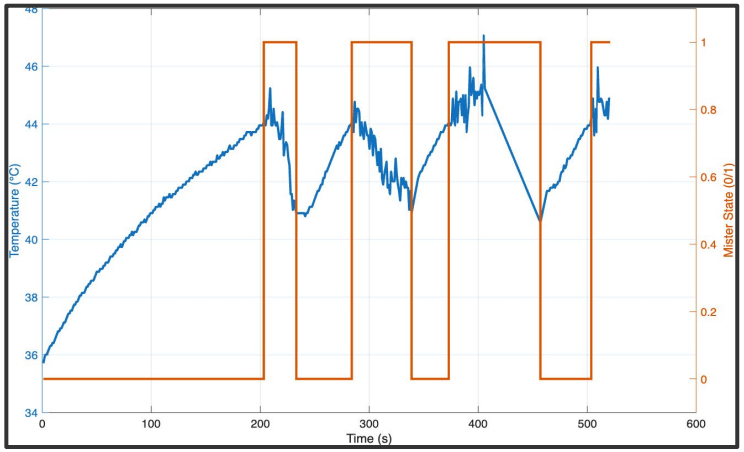
Temperature(°C)

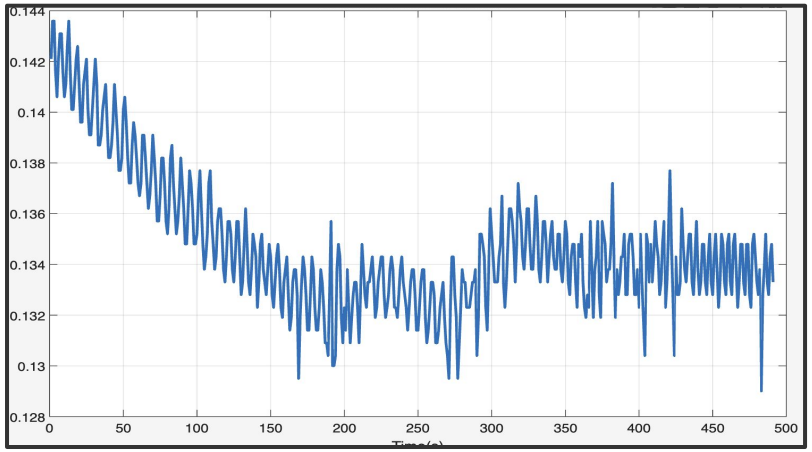


Power(mW)



Control





Empirical

Are we energy positive?

No!

Net energy balance:
Energy cost of misters> Energy gained from evaporative cooling
Net energy expenditure = 1900J

Key limitations:

- Scale Mismatch
- Lower Irradiance test conditions
- Non-linear mist distribution
- Power measurement through voltage divider
- Un-optimal thermistor placement
- Binary Actuation

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Future Steps

Upgrade architecture to high fidelity MIMO system

- Inputs: Mist pulse frequency, backside air flow, coolant temperature for liquid cooling
- Outputs:PV efficiency, water consumption, system reliability
- Environmental Adaptations: Wind and ambient temperature estimation

Explore alternative cooling modalities

- Pneumatic blower(better at dealing with dust)
- Backside liquid cooling pipes
- Hybrid mist+ airflow system for maximum heat transfer

Scale and create field-deployable system

- Scale to larger panel area or a multi-panel array
- Long duration outdoor testing under real irradiance cycles
- Weatherproof packaging
- Water management and filtration
- Autonomous scheduling and safety interlocks
- Validate efficiency gains

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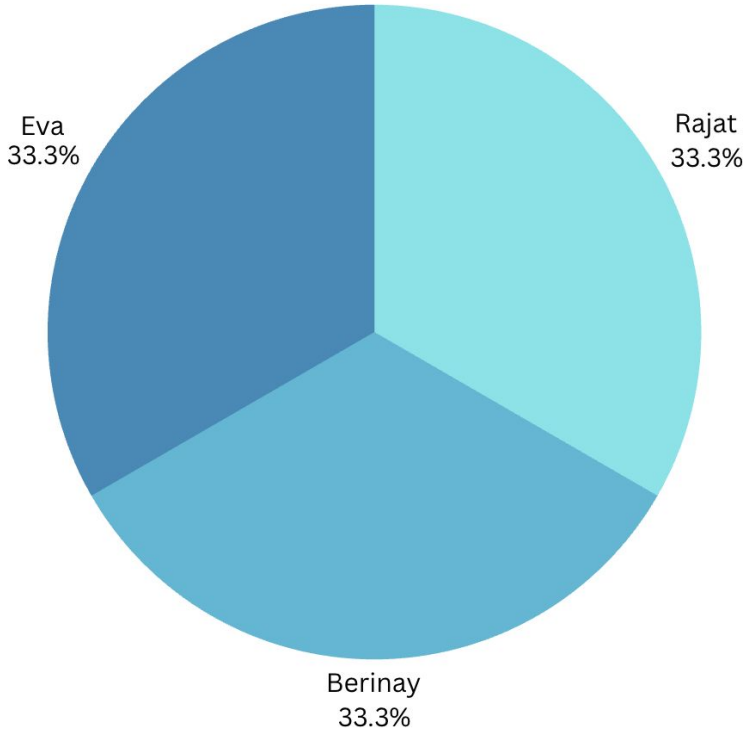
Contribution



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THANK YOU

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