Lab of Applied MultiPhase Thermal Engineering

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Thermal Study of a Valve Regulated Lead-Acid Batteries and Electronics Chamber used in Stand-Alone Street Lighting Applications

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COMSOL CONFERENCE
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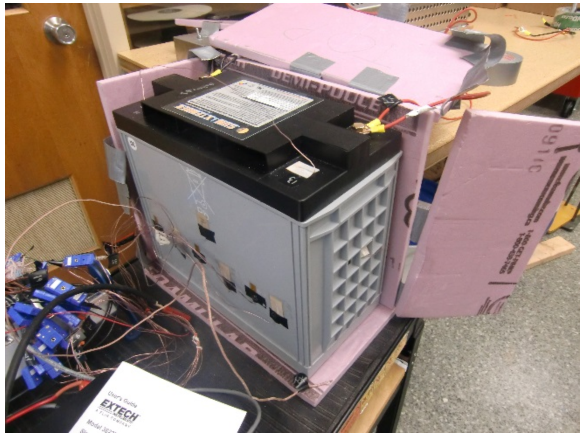
Research Rationale

- 6 month research grant with PoleCo ltd.
- They design and supply grid-independent street lighting systems.
- All of their power derived from renewable sources using small wind turbines, solar panels, or a combination of the two.
- Power stored in on-board rechargeable Valve Regulated Lead Acid (VRLA) batteries.
- VRLA batteries are particularly vulnerable to higher operating temperature; when receiving a float charge at a temperature 10°C above intended operating temperature, the battery life will be cut in half[1].

1. D. Berndt, Valve-regulated Lead-acid Batteries, *Journal of Power Sources*, **100**, 29-46 (2001)

Research Objective

- Determine the thermal behaviour of VRLA batteries under various charging and discharging conditions and ambient temperature;
- Using COMSOL Multiphysics, determine the amount of heat generated during battery operation – validated with experiments;
- Model and validate the entire battery enclosure, including the impact of the charge controller.



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1st Type of **Experiments:** Battery

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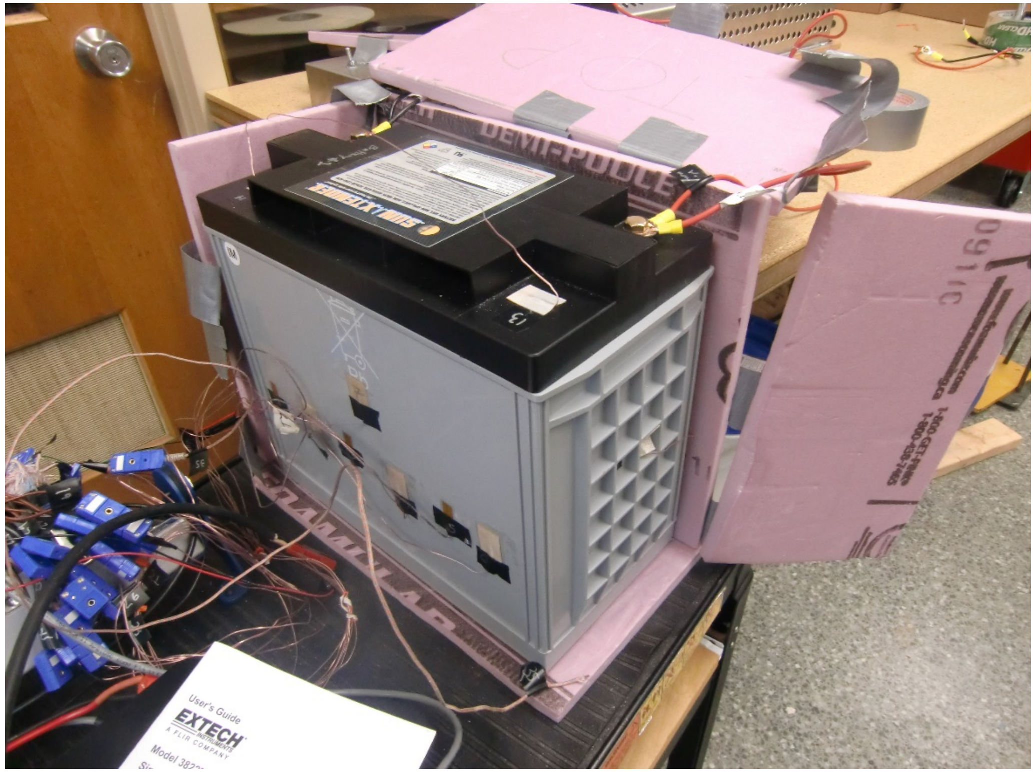
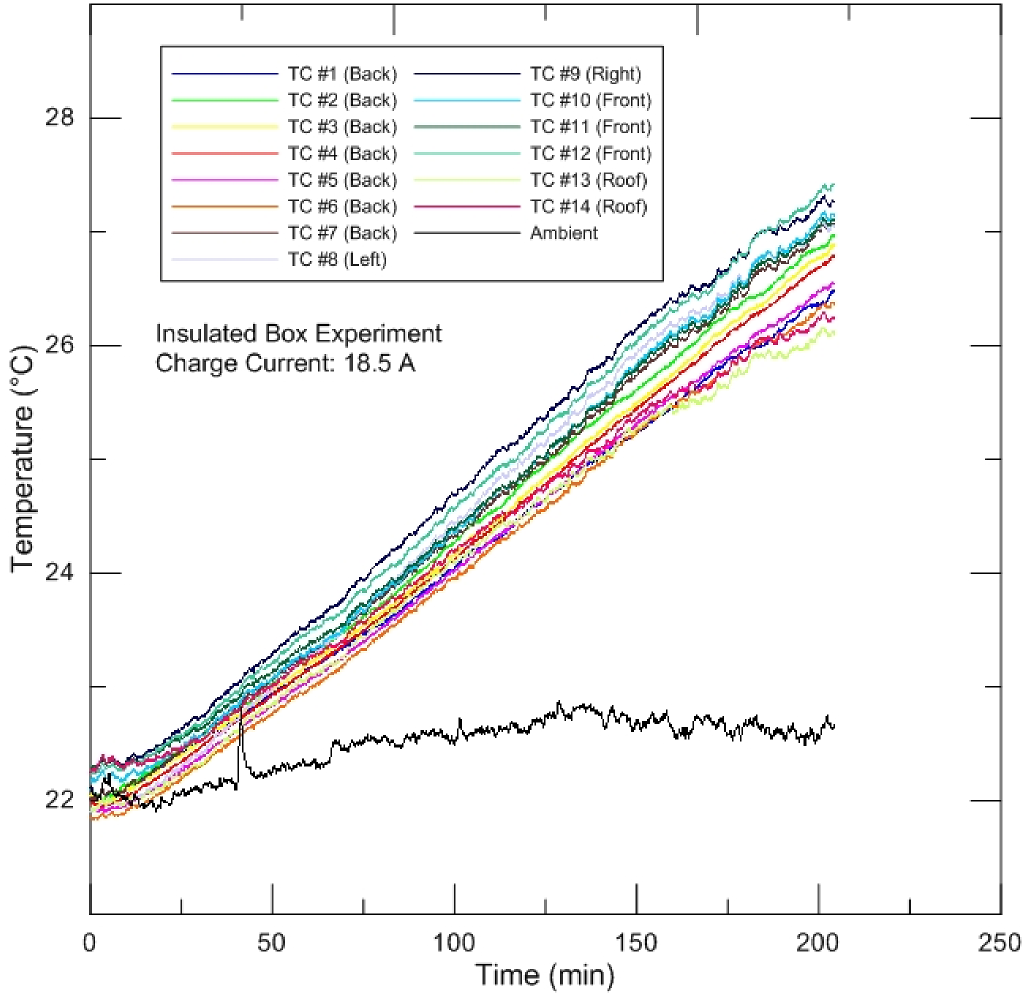
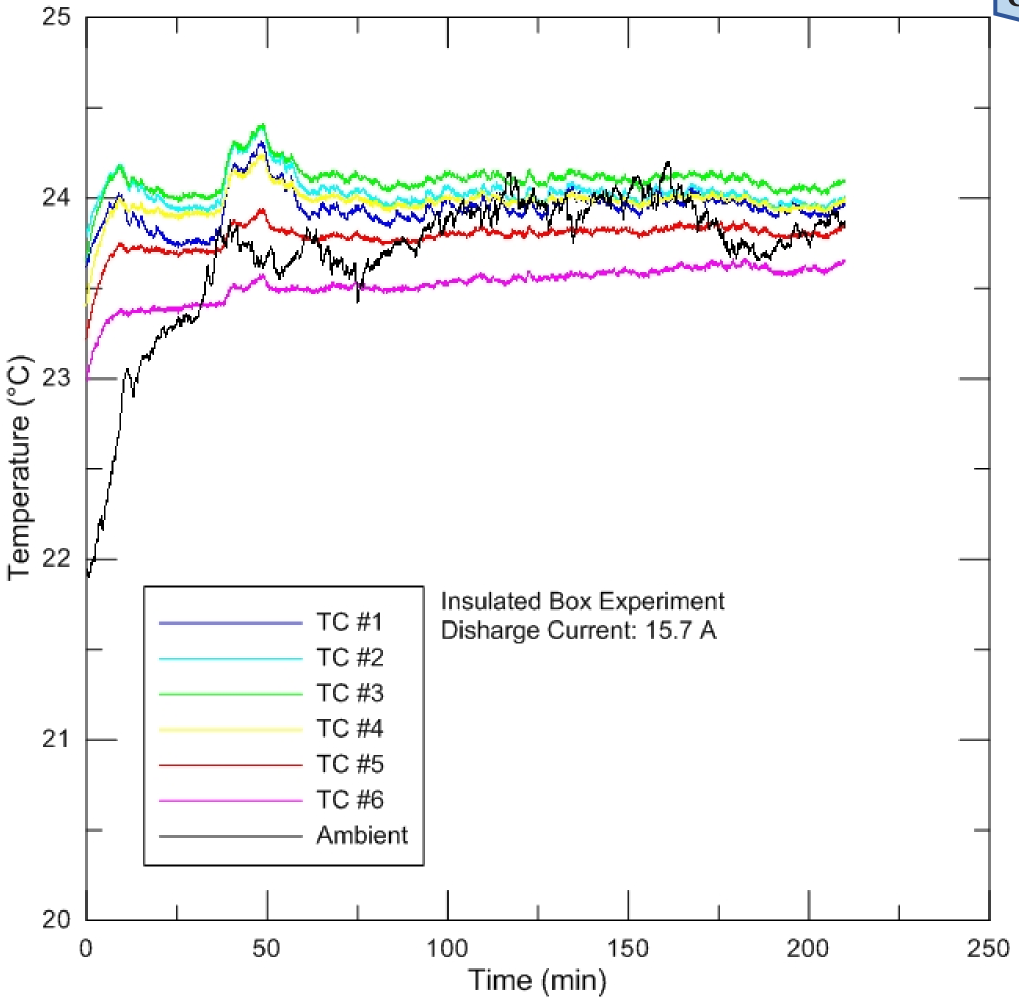
- One VRLA battery enclosed in a tight-fitting box made from half-inch RSI-0.5 extruded polystyrene (XPS).
- The battery was charged with a bench-top DC power supply set to 14.5 V and various charging currents.
- The temperature of the battery measured with fourteen adhesive T-type thermocouples.



1st Type of **Experiments:** Results



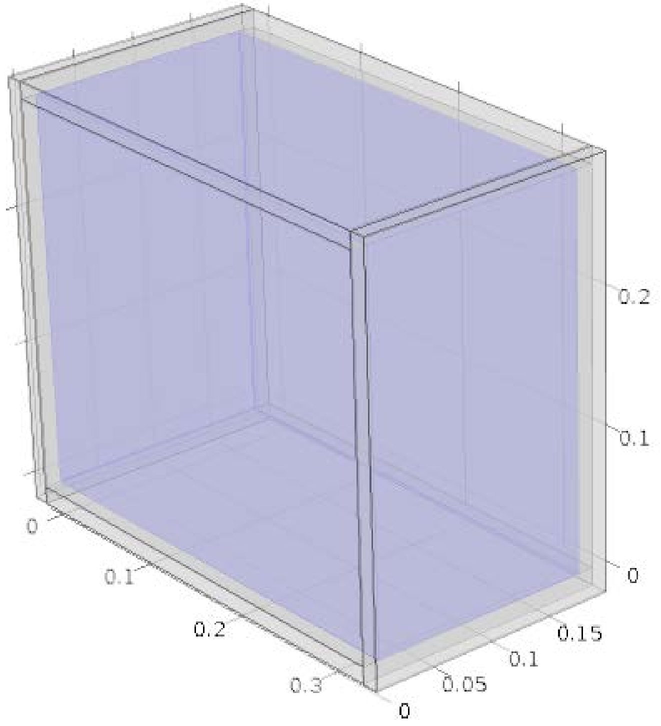
Charge experiment



Discharge experiment

COMSOL Model: Battery

- Modeled as two blocks, one representing the battery, the other representing the insulation.
- The battery domain is 287 mm tall, 342 mm long, and 172 mm wide.
- The insulation block is subdivided into six panels to make it easier to mesh.
- Geometry simplified, not including any of the surface features of the battery such as handholds and electrical terminals and internal geometries of the cells.



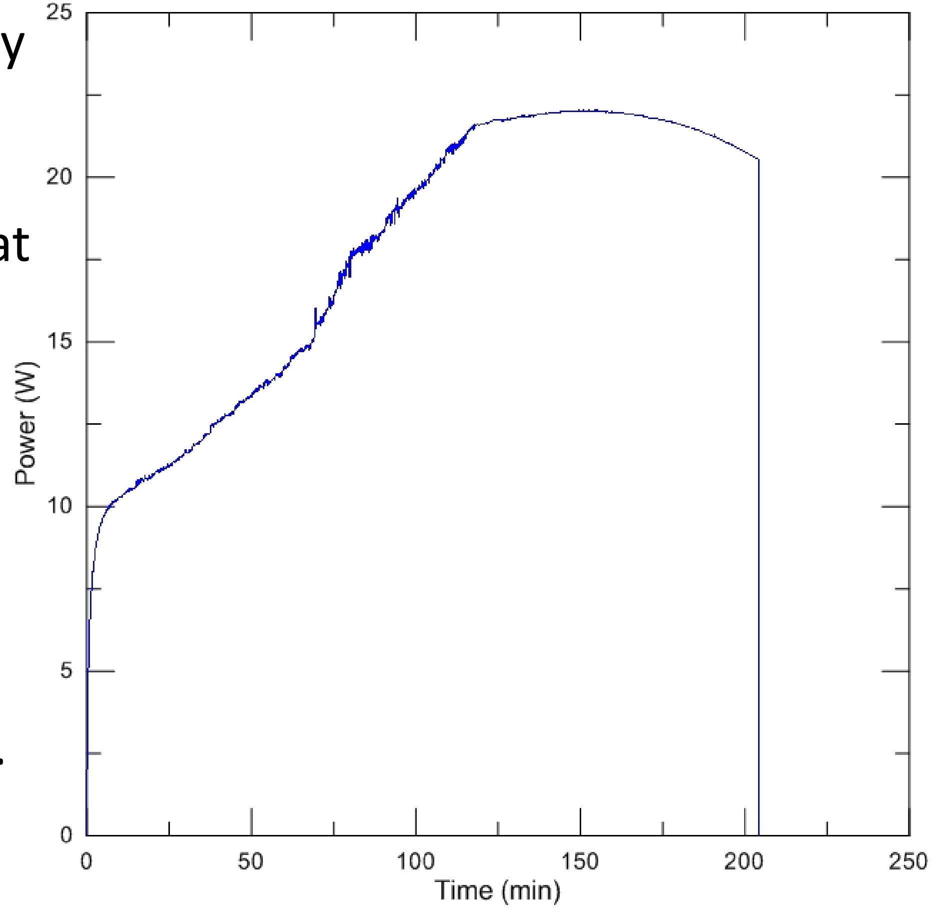
Material	Insulation	Battery
Thermal Conductivity (W/m·K)	0.0254	34
Density (kg/m³)	21	2841
Heat Capacity (J/kg·K)	1500	862.3

COMSOL Physics: Battery

- Only heat transfer by conduction through solids is present in this study;
- With a initial temperature and natural convection boundary conditions on outside surface to ambient temperature of 22.2 °C;
- How to determine the amount of heat generation? The entire battery volume is assigned as a heat source with heat generation related to internal resistance through the following function[1]:

$$P_{OV} = I \cdot DV$$

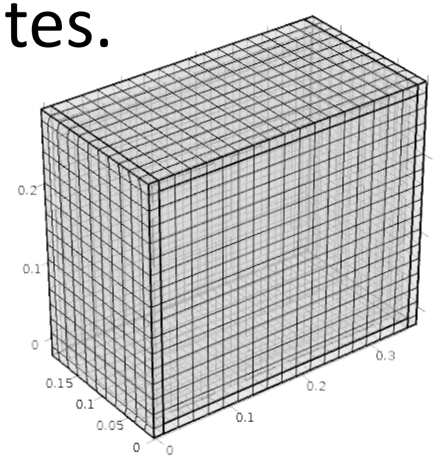
- P_{OV} is the heat generated (W), I is the current flowing through the battery (A), DV is the over-voltage (V)
- Over-voltage is the difference between the open circuit voltage of the battery before charging begins and the measured voltage at the battery terminals during charging.
- I and DV are taken from the experiment.

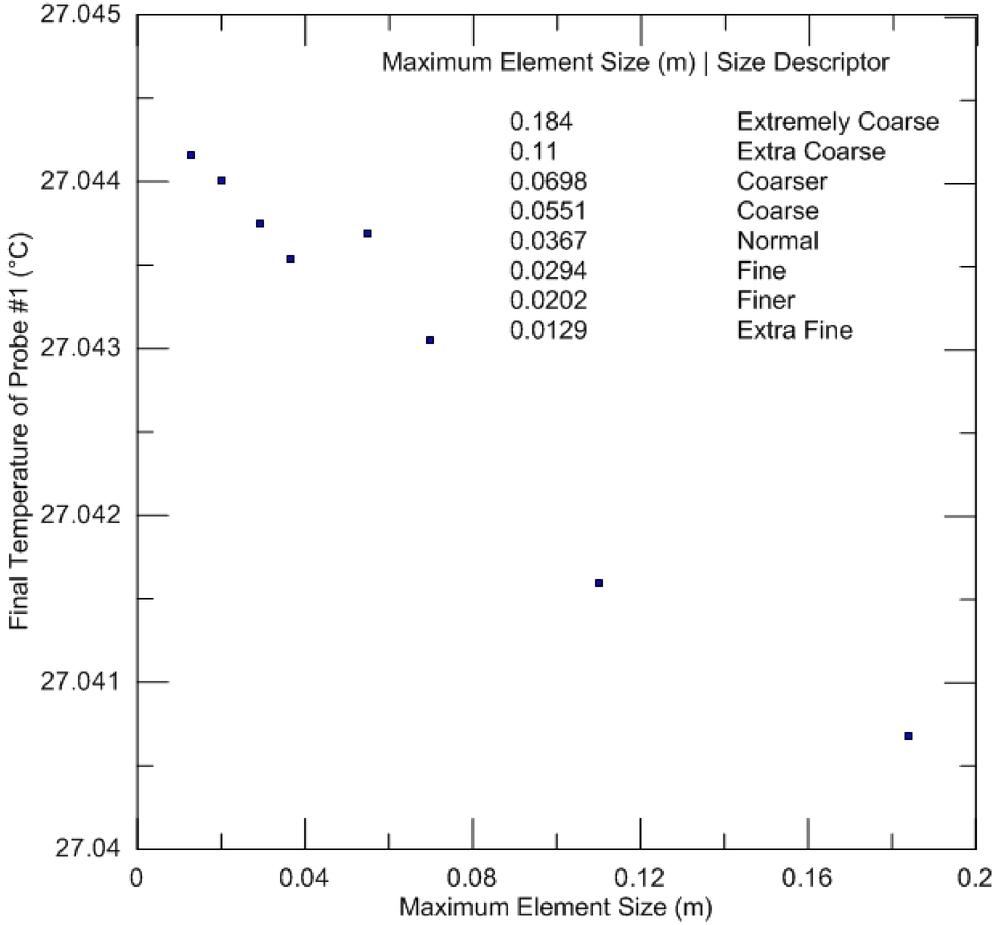


6. H. Giess, Investigation of Thermal Phenomena in VRLA/AGM Stationary Lead/Acid Batteries with a Thermal Video Imaging System, *Journal of Power Sources*, **67**, 49-59 (1997)

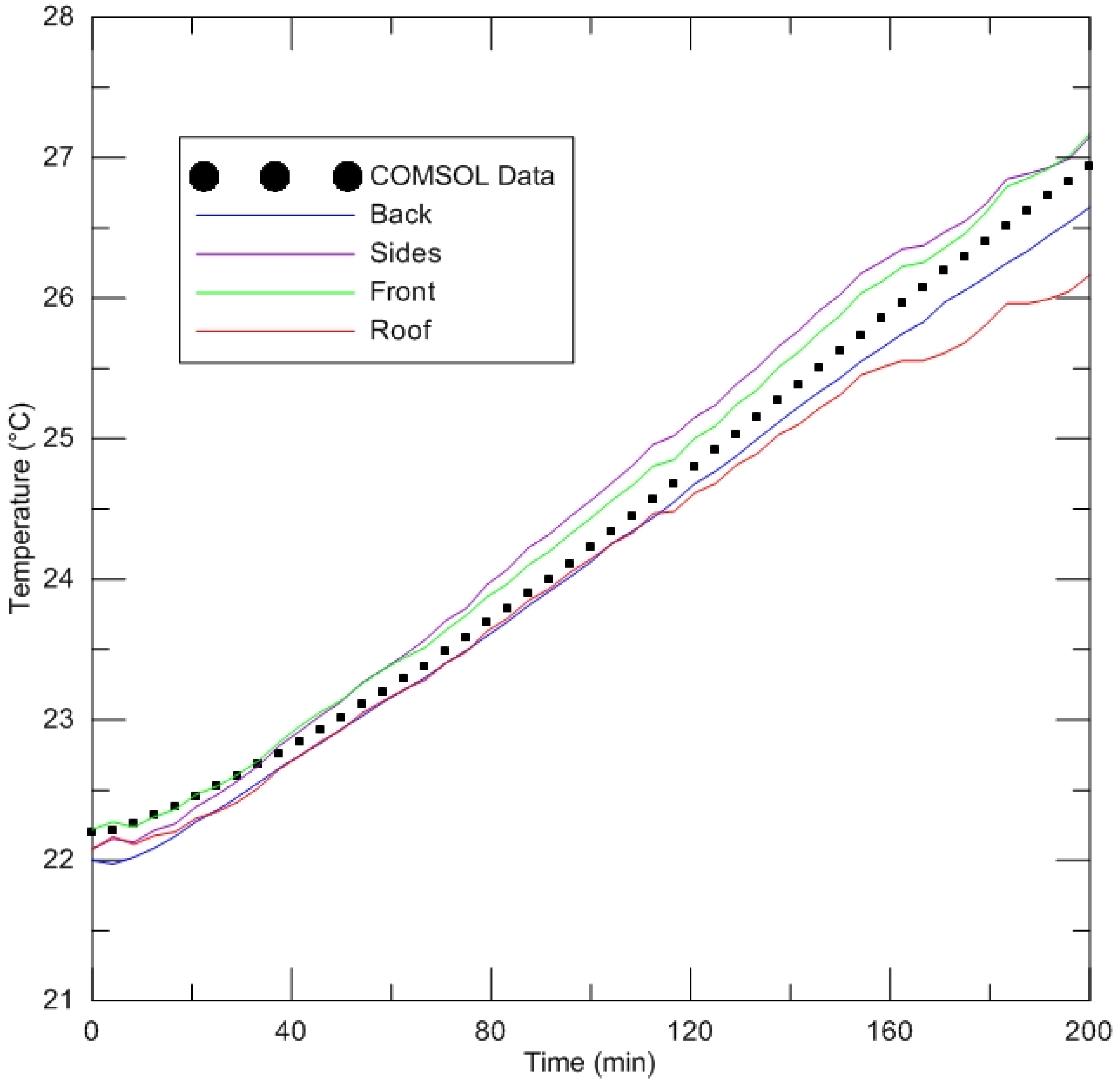
COMSOL Mesh: Battery

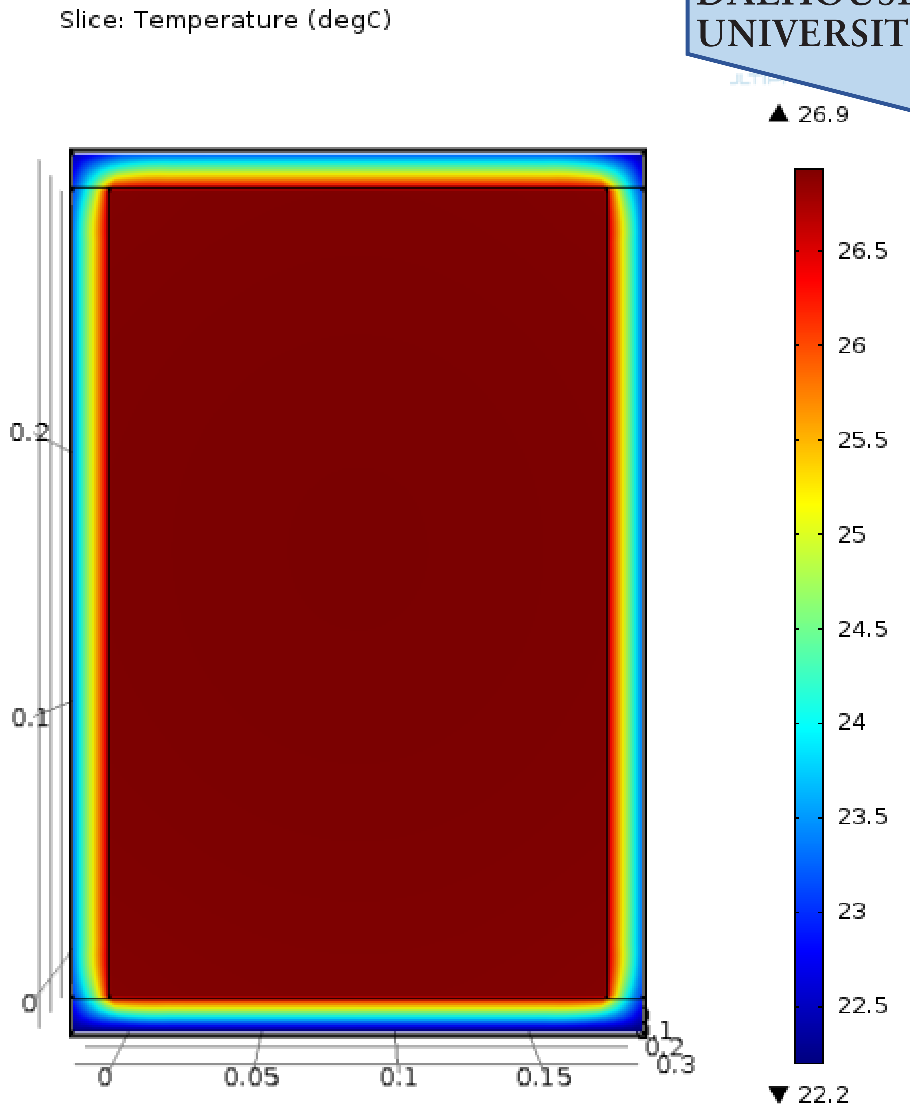
- Mesh with swept tetragonals.
- Mesh convergence study: difference in temperature between the finest and coarsest meshes less than 0.004 °C.
- The Normal predefined mesh setting was used with 3553 elements.
- At this mesh size, simulations ran in less than 5 minutes.





COMSOL Results: Battery

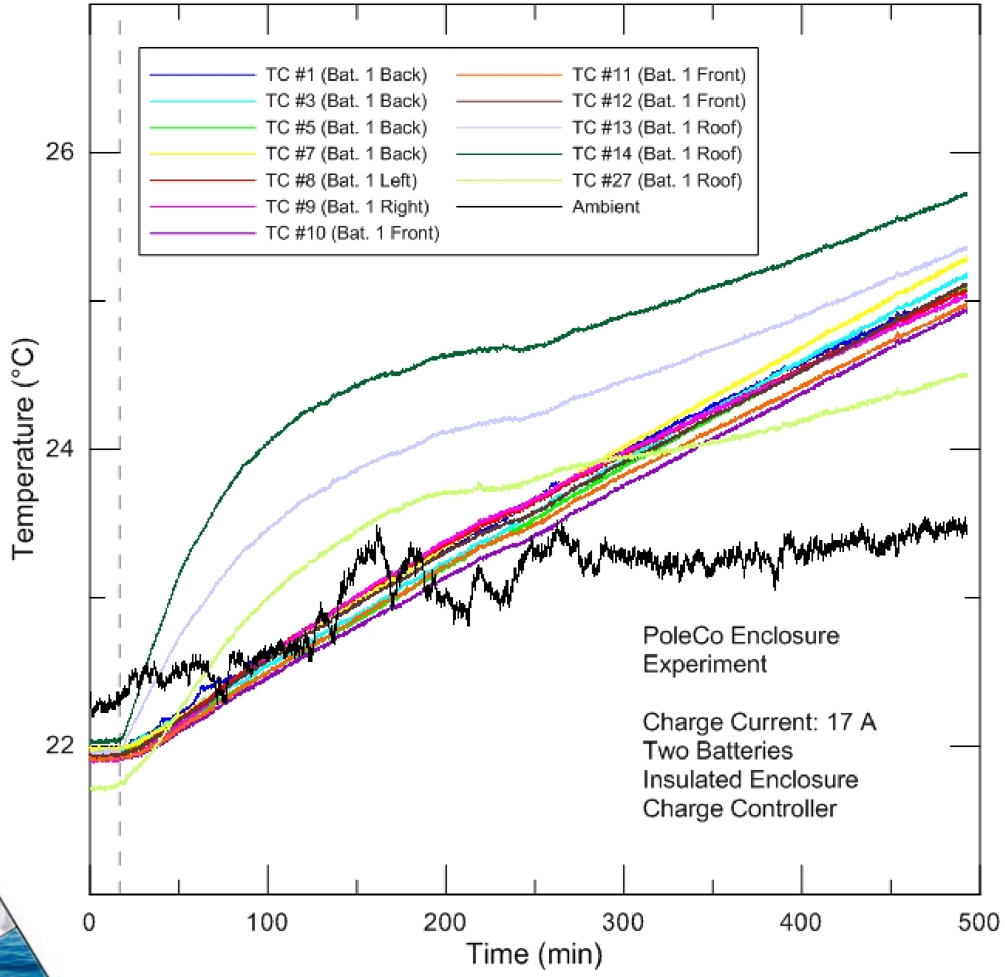


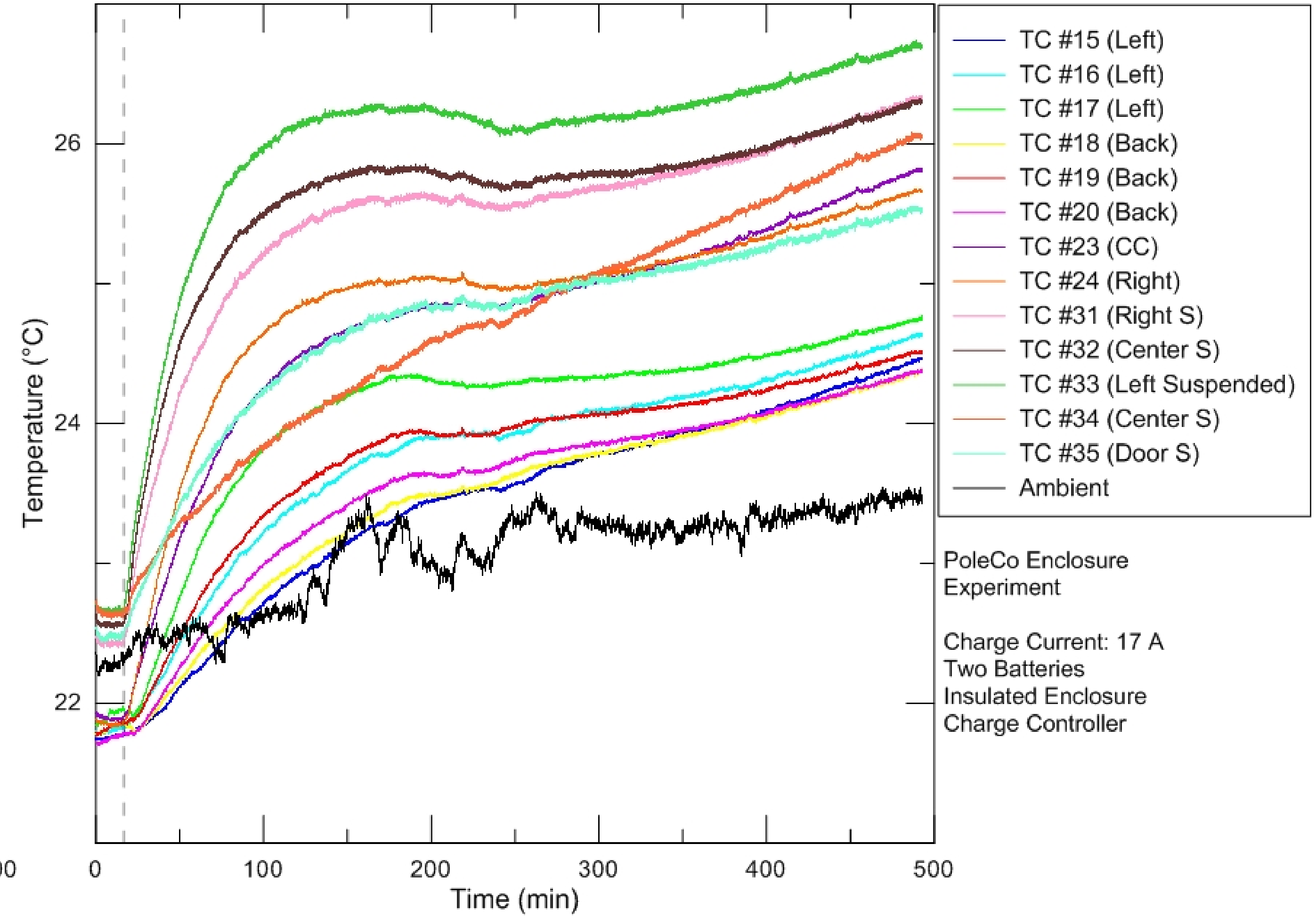


2nd Type of Experiments: Enclosure

- VRLA batteries in a PoleCo lighting installation are held within an 18 inch square aluminum enclosure.
- The air cavities within this chamber are large enough that convective currents are expected to have a noticeable effect on the temperature of the batteries.
- 40 mm gap between the batteries.
- 65 mm gap between the enclosure walls and the batteries on the four sides.
- 150 mm of space above the two batteries.
- The charge controller has a 128 mm square base and is 73 mm tall.
- Exterior of the enclosure was completely wrapped in polystyrene insulation.

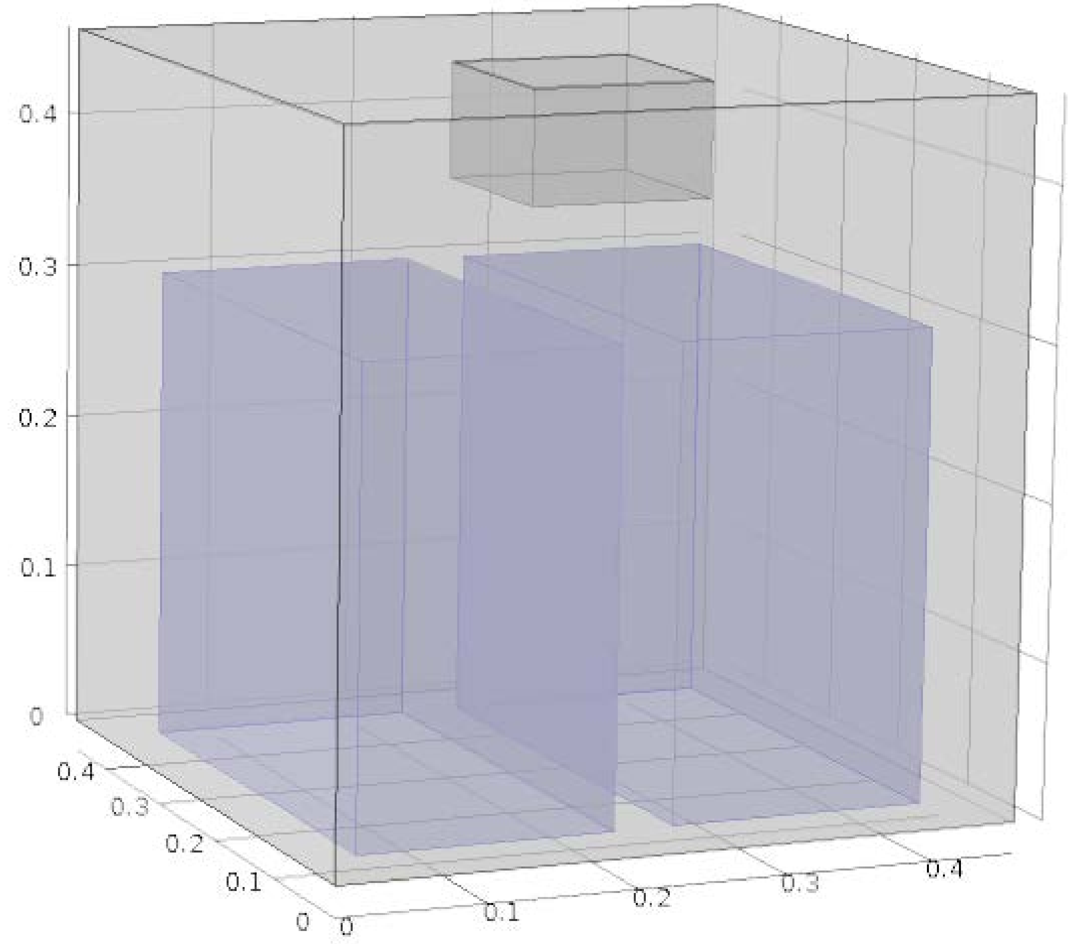
2nd Type of Experiments: Results





COMSOL Model: Enclosure

- This model is defined by four domains;
  - the aluminum box,
  - the air inside the box,
  - the two batteries,
  - the charge controller.
- The box and the air use the standard material properties from the COMSOL library.
- The batteries use the same material properties as the ones in the model of the insulated battery experiment.
- The charge controller modulates the current and voltage characteristics of the electrical energy from the solar panel; the electronic circuitry generates fair amount of heat. It is modeled as a mass with a predefined temperature



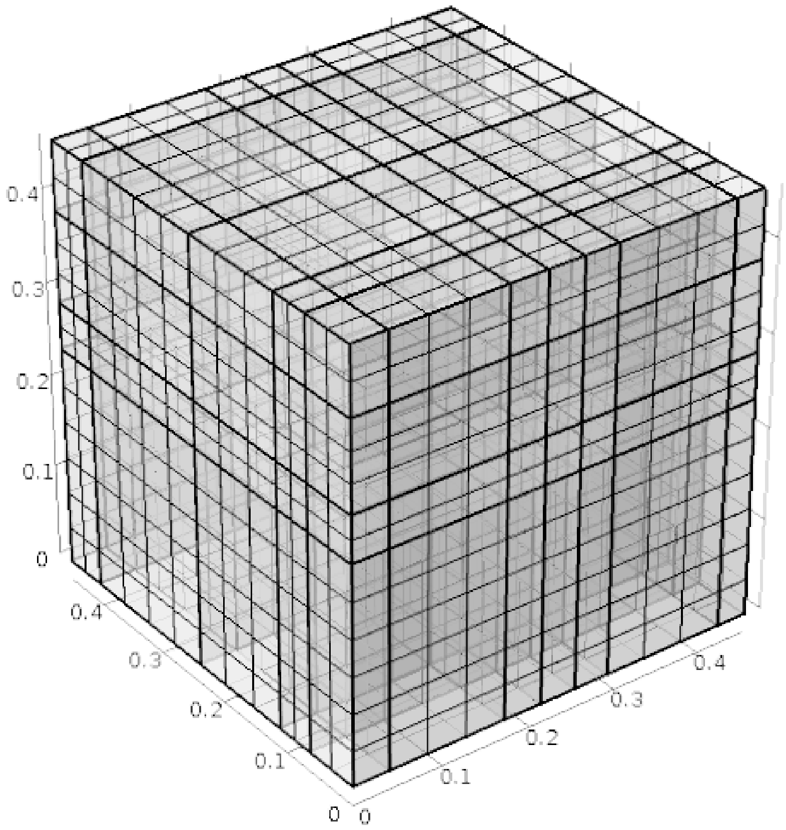
COMSOL Physics: Enclosure

- The batteries are defined as uniform masses, with the exception of the 50 mm air gap on the top surface.
- The heat generation is given by a function taken from experimental data.
- The outside faces of the box are thermally insulated, representing the polystyrene.
- An air domain is added, all air flow due to the natural convection (laminar). A buoyancy force is included in the model as a volumetric force given by:

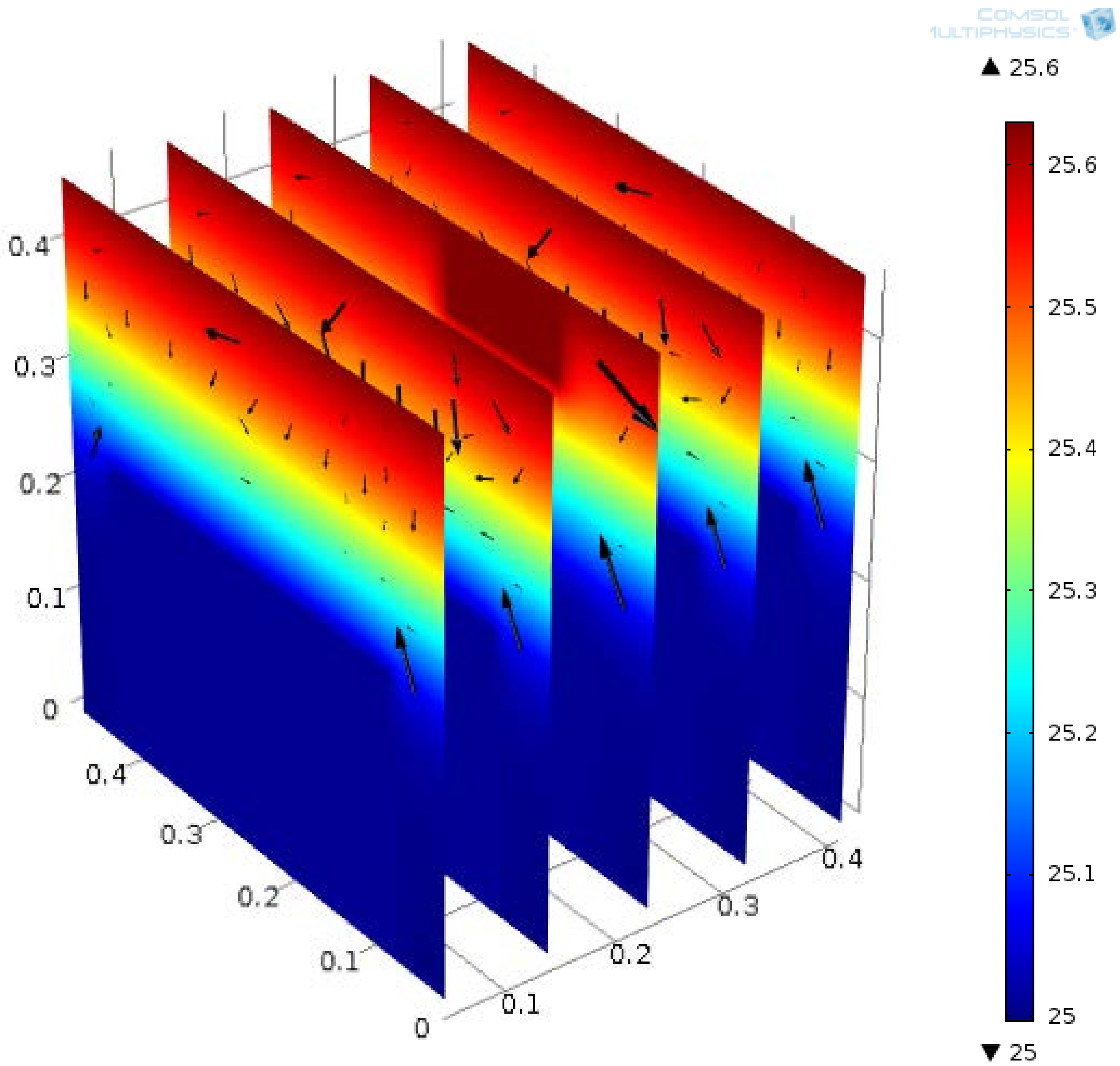
$$F_Z = -g \cdot (rho-rho\_ref)$$

COMSOL Mesh: Enclosure

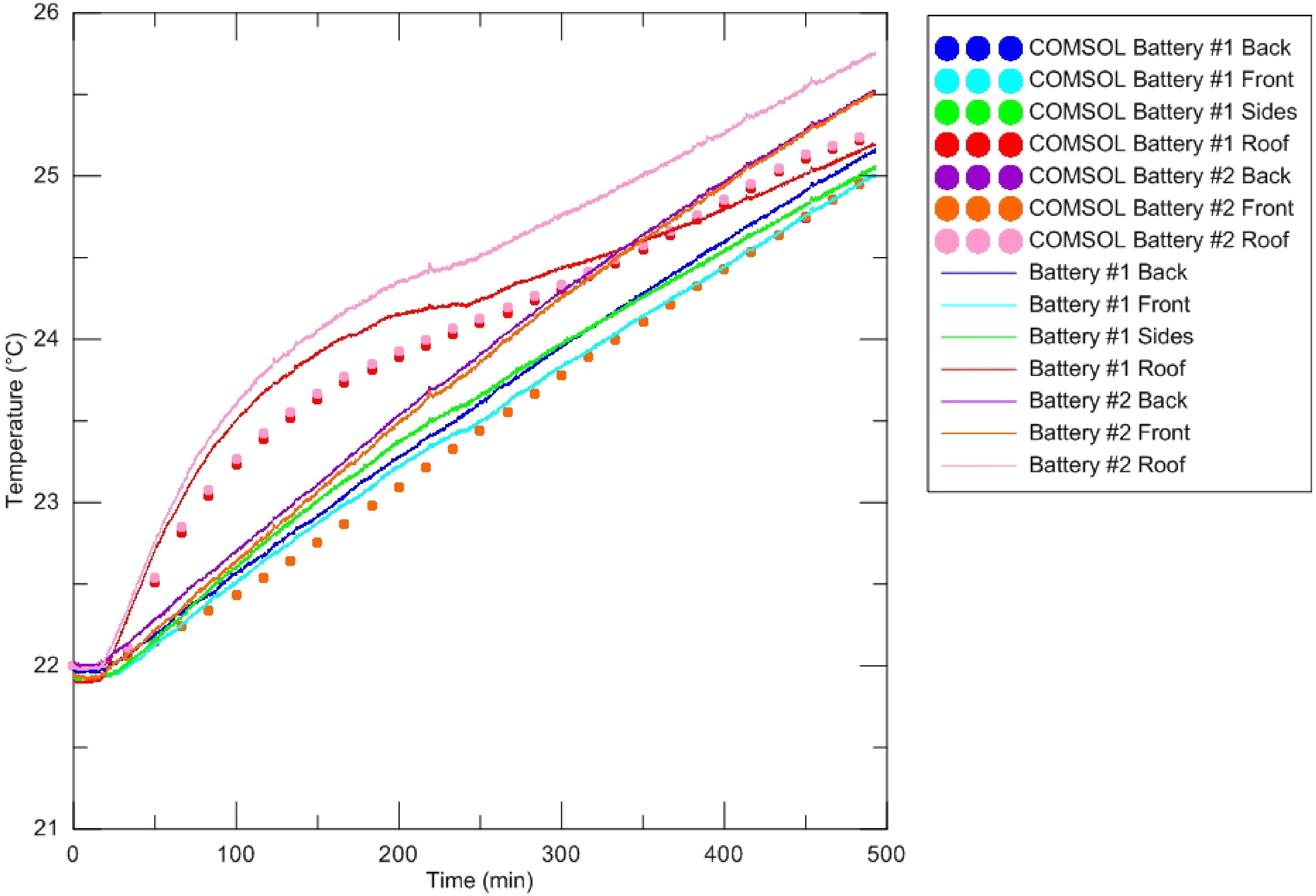
- Mesh with swept tetragonal elements.
- Several parametric surfaces were used to divide up the geometry in order to facilitate this.
- The mesh has 5760 elements.
- Simulation completes in a time of 30 to 40 minutes.



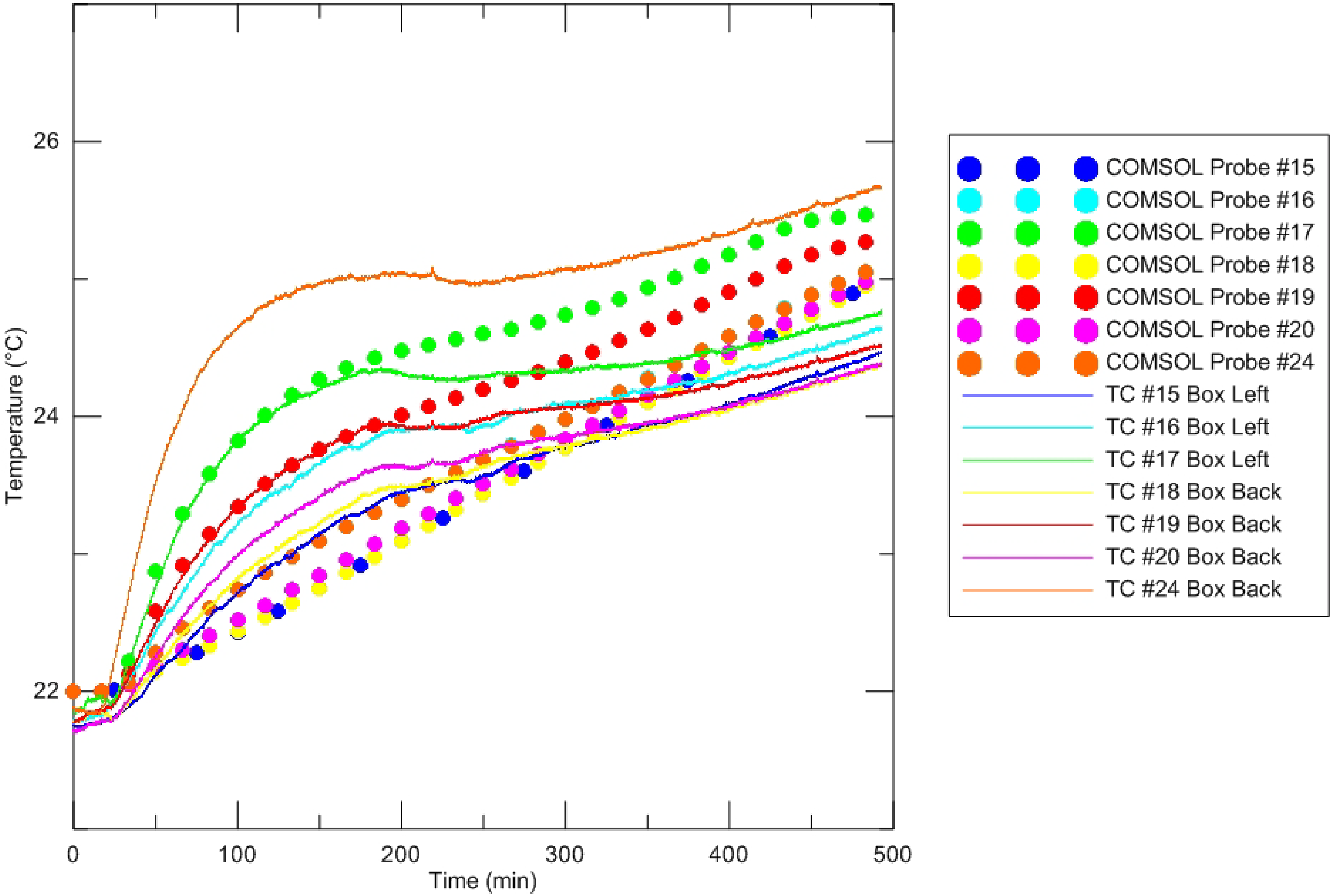
COMSOL Results: Enclosure



COMSOL Results: Enclosure



COMSOL Results: Enclosure



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Conclusions – Future Work

- The lead-acid battery tested generated heat during charging at a rate that followed the over-voltage published model;
  - **Well reproduced numerically;**

- A validated model of heat transfer within the batteries/electronics enclosure was produced showing the effect of natural convection within it;
- Some limitations where identified:
  - **Limitation in the understanding of heat generated from the charge controller;**
  - **Possible effects of radiation heat transfer within the enclosure;**

- Follow-up work using this model will look at the effect of external heat sources, *i.e.*, solar radiation, wind, cooling fans, etc.

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