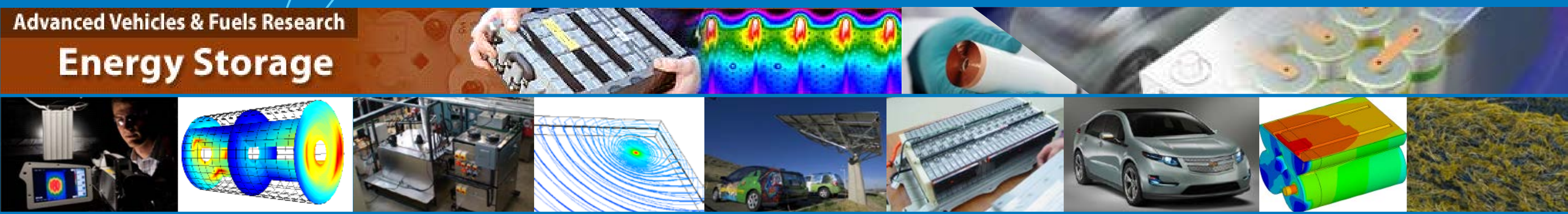
Analyzing the Effects of Climate and Thermal Configuration on Community Energy Storage Systems



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Motivation & Objective

- **Motivation:** Community Energy Storage (CES) is a high-potential application for grid-connected storage
- **Challenge:** Requirements for active thermal management systems may increase maintenance requirements beyond what utilities are willing to accept
- **Objective:** Assess the impact of different climates and thermal management strategies on Community Energy Storage (CES)

Approach

- Build a realistic lifetime model for CES that includes thermal, electrical, and degradation response characteristics
- Apply real-world climate data and residential load data with a representative peak-shaving control algorithm to investigate system response
- Analyze the impact of different climates and thermal configuration on CES performance

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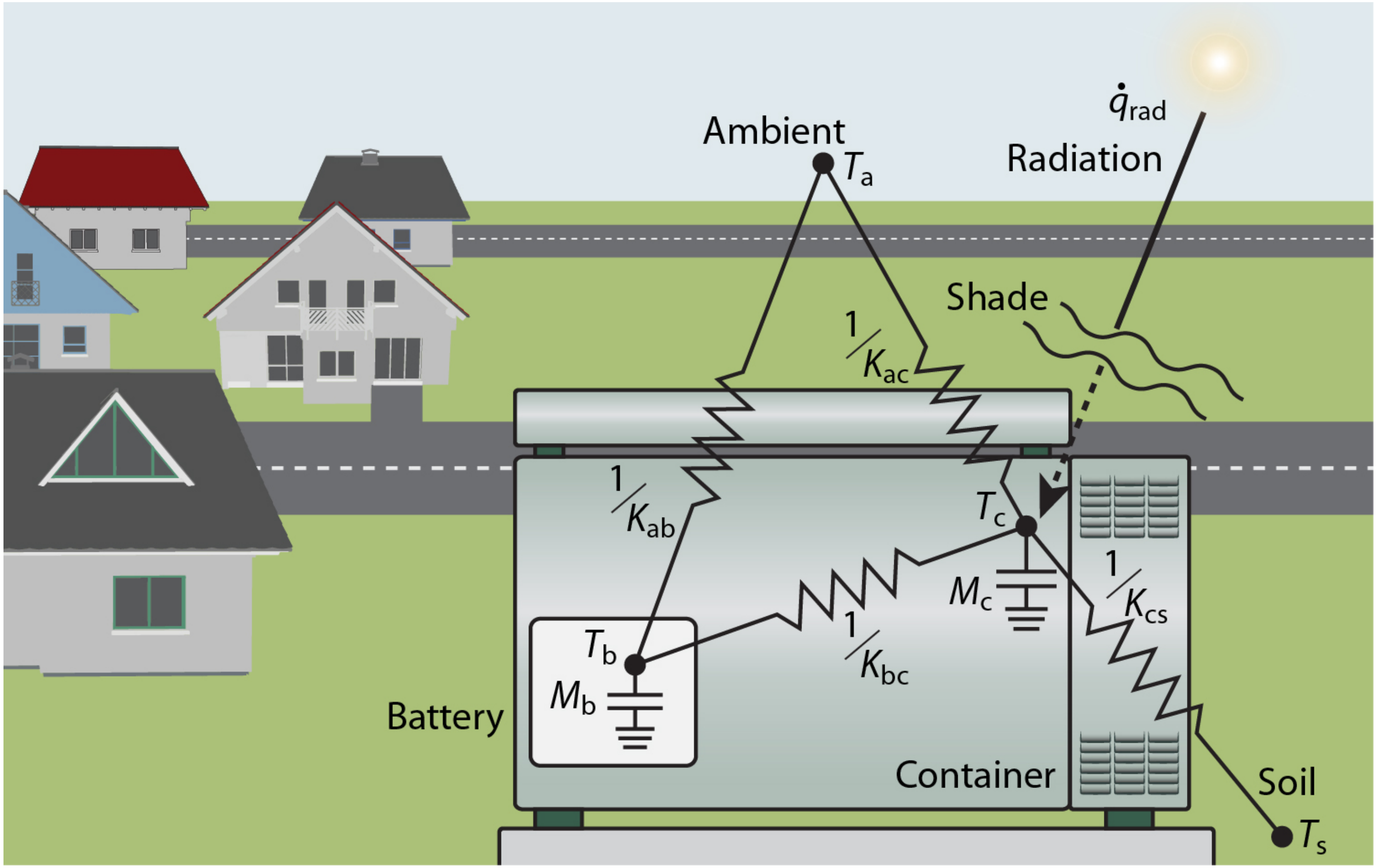
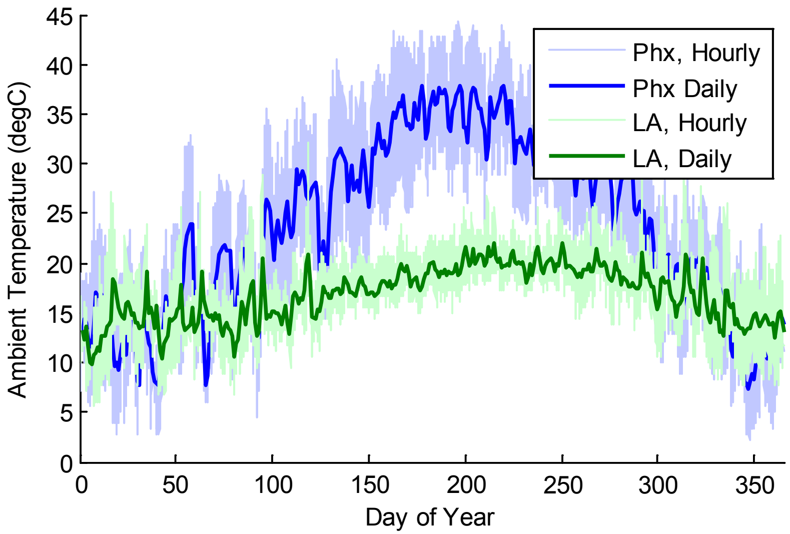
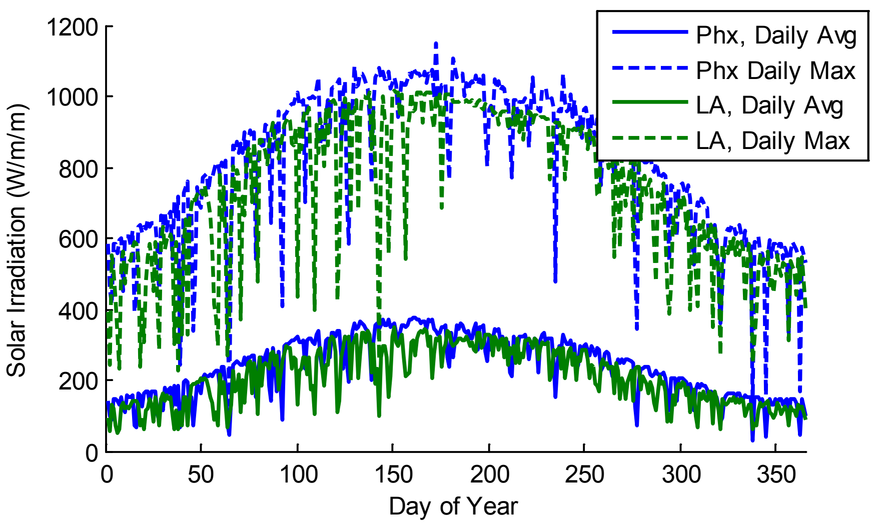
Lumped Capacitance Thermal Network



Climate Data





- **Apply typical meteorological year data to simulations**
  - Ambient temperature
  - Solar irradiance
  - Soil temperature at 40" below grade calculated using 20 day running average of ambient temperature
- **Select locations to provide a range of relevant conditions**
  - Minneapolis, MN: Low average temperatures and solar irradiance
  - Los Angeles, CA: National average ambient temperature and high solar irradiance
  - Phoenix, AZ: High ambient temperature and extremely high solar irradiance

Thermal Configurations

- **Greenhouse**
  - Parameters selected to be representative of a scenario where solar irradiation has a large effect on battery temperature
- **Shaded Greenhouse**
  - Same as *Greenhouse*, but with solar irradiance reduced by 60% to be representative of a scenario where ambient temperature is the main environmental factor affecting battery temperature
- **Vault**
  - Parameters selected to be representative of a best case passive thermal configuration where <u>battery temperature closely tracks soil temperature</u>
  - WARNING: Not all vaults are created equal! Poorly designed vaults may be more thermally similar to our greenhouse scenario (or even worse)

Electrical Configurations

- **One 75-mile BEV battery**
  - Modeled after Saft VL41M li-ion cells scaled to 60.5 Ah per cell, placed 100 in series yielding a ~22.1 kWh total energy
- **Two starting States of Health (SOH)**
  - Representative of a new or a used BEV battery as calculated using the average SOH after 10 years of Los Angeles BEV driving in a charge-at-home scenario by a set of 91 likely BEV drivers
- **One available power**
  - 50 kW inverter limit, but real-time battery power is limited by voltage and SOC factors as well.
- **Three available energies**
  - Varies the maximum DOD allowed, which will impact duty cycle and battery life.
- **Semi-empirical, physically justified battery life model**
  - Based on extensive laboratory life test data for a nickel cobalt aluminum (NCA) lithium (Li)-ion battery chemistry
  - Calculates capacity loss and resistance growth in both operational and storage conditions considering time, number of cycles, depth of discharge, state of charge (SOC), voltage, & temperature
  - See K. Smith, et al, "Comparison of Plug-In Hybrid Electric Vehicle Battery Life Across Geographies and Drive Cycles, SAE 2012-02-0666

Initial SOH

	New Battery	Used Battery
ΔQ1	0	-0.25
ΔQ2	0	-0.04
ΔR1	0	0.14
ΔR2	0	0.11

Available Energy	**Nameplate Max DOD**
17.7 kWh	80%
13.3 kWh	60%
8.9 kWh	40%

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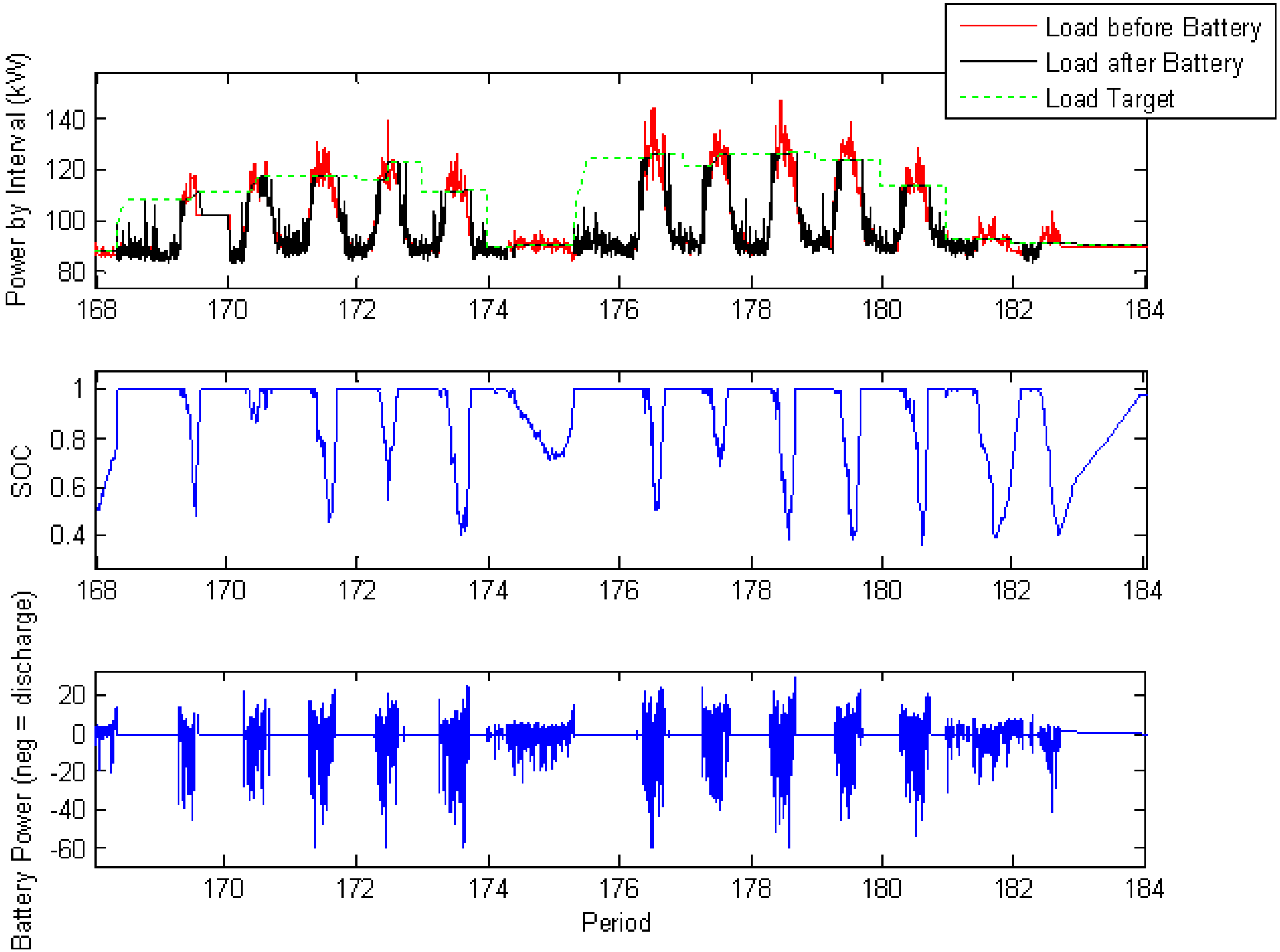
Peak Shaving Algorithm

- **Objective:** Maximize the reduction in peak load using the available power and energy of the battery on a daily basis

- **Approach:** Forecast future demand and PV production, then optimize peak load reduction within available battery energy and power constraints.

- **Notes:**
  - Perfect forecasts are assumed
  - Peak load reduction optimization uses a 48 hour time horizon and a memory only to the beginning of day.

Example Peak Shaving Algorithm Results



Example only. This is not demand data used throughout the rest of this study.

Residential Load Data

- **XCEL provided data from 58 houses in Boulder, CO**
  - >1 year of data at 1 minute resolution for each house on each transformer

- **Preliminary analysis suggests that CES service value is greatest when one unit serves many houses, so we aggregate the demand for all 58 houses into one single demand profile.**

No. of Houses	Average daily Energy	Average Power	Peak Annual Power
58	834 kWh	34.7 kW	88.5 kW

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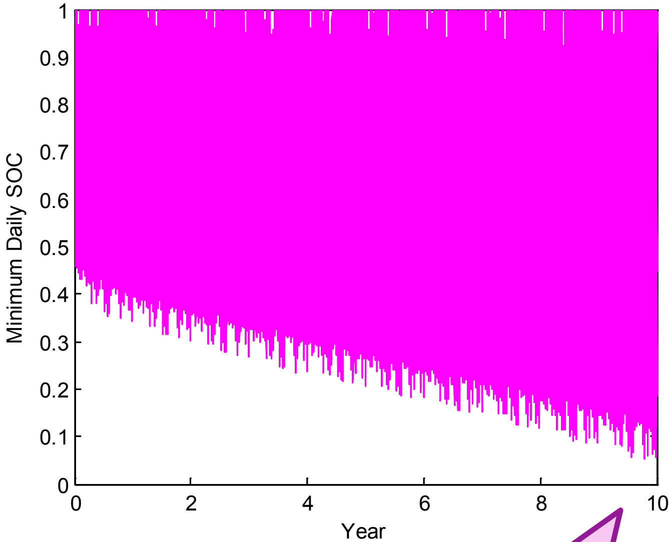
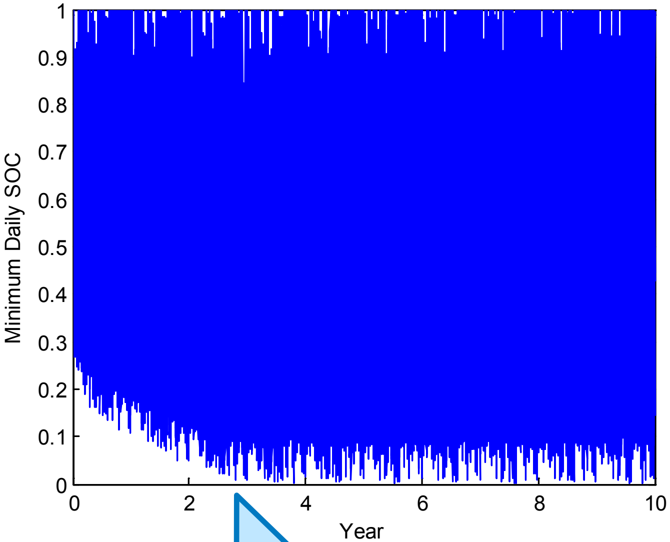
Minimum Daily SOC vs. Year

Example 1: New battery with a 13.3 kWh available energy window (60% DOD @ BOL)



System takes more than 10 years to reach 0% SOC. Duty cycle is consistent through life.

Example 2: New battery with a 17.7 kWh available energy window (80% DOD @ BOL)



System reaches 0% SOC in less than 3 years. Duty cycle becomes less aggressive.

Ability to Maintain a Consistent Duty Cycle

Years to first 5% thermodynamic SOC crossing

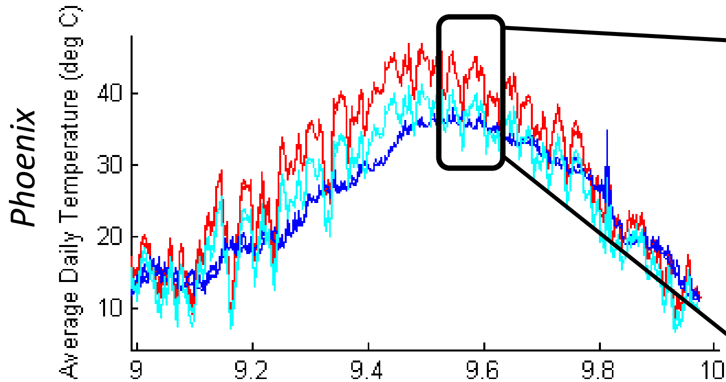
		80% DOD		60% DOD		40% DOD	
		New	Used	New	Used	New	Used
Phoenix	Greenhouse	1.8	0.8	6.8	3.8	10.0+	10.0+
	Vault	2.8	0.2	9.8	5.8	10.0+	10.0+
	Shaded Greenhouse	2.8	0.8	8.8	4.8	10.0+	10.0+
Los Angeles	Greenhouse	2.8	0.2	10.0+	6.8	10.0+	10.0+
	Vault	3.8	0.2	10.0+	7.8	10.0+	10.0+
	Shaded Greenhouse	3.8	0.2	10.0+	7.8	10.0+	10.0+
Minneapolis	Greenhouse	3.8	0.2	10.0+	7.8	10.0+	10.0+
	Vault	4.8	0.2	10.0+	9.8	10.0+	10.0+
	Shaded Greenhouse	4.8	0.2	10.0+	9.8	10.0+	10.0+

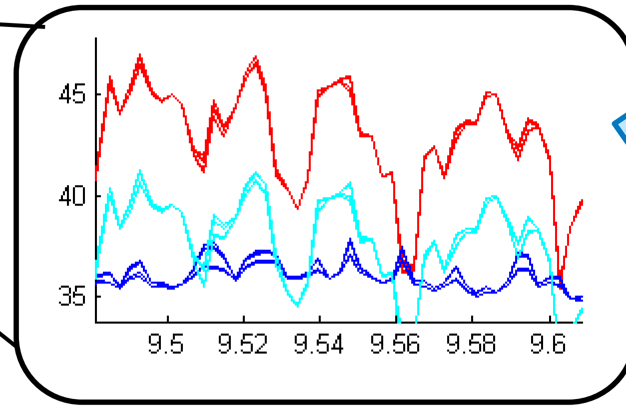
No 80% DOD cases can maintain a consistent duty cycle through all 10 years.

All 40% DOD cases and some new-battery 60% DOD cases maintain a consistent duty cycle through all 10 years.

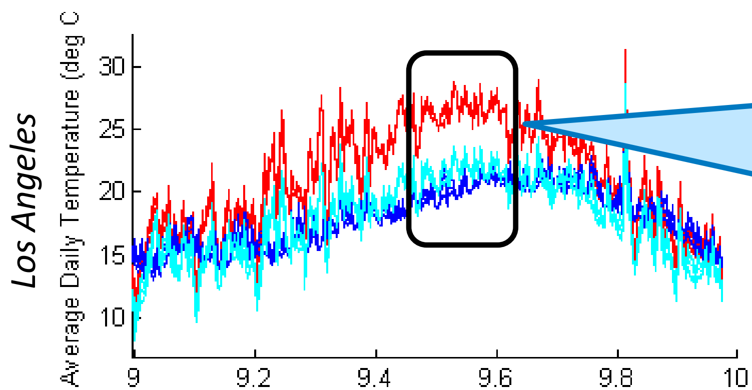
Average Daily Temperature

Greenhouse Shaded Greenhouse Vault

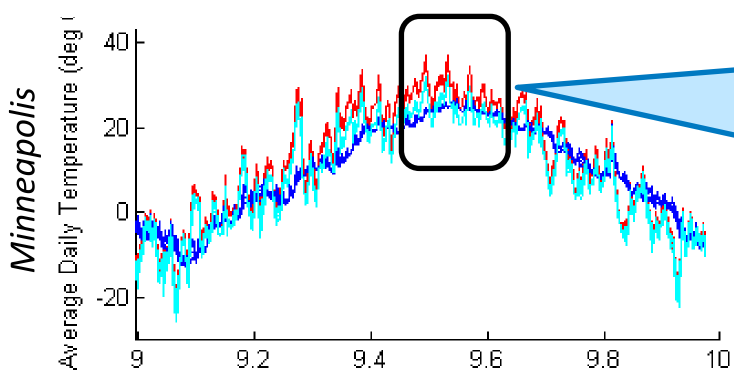




Effect of DOD and battery age on thermal response are small

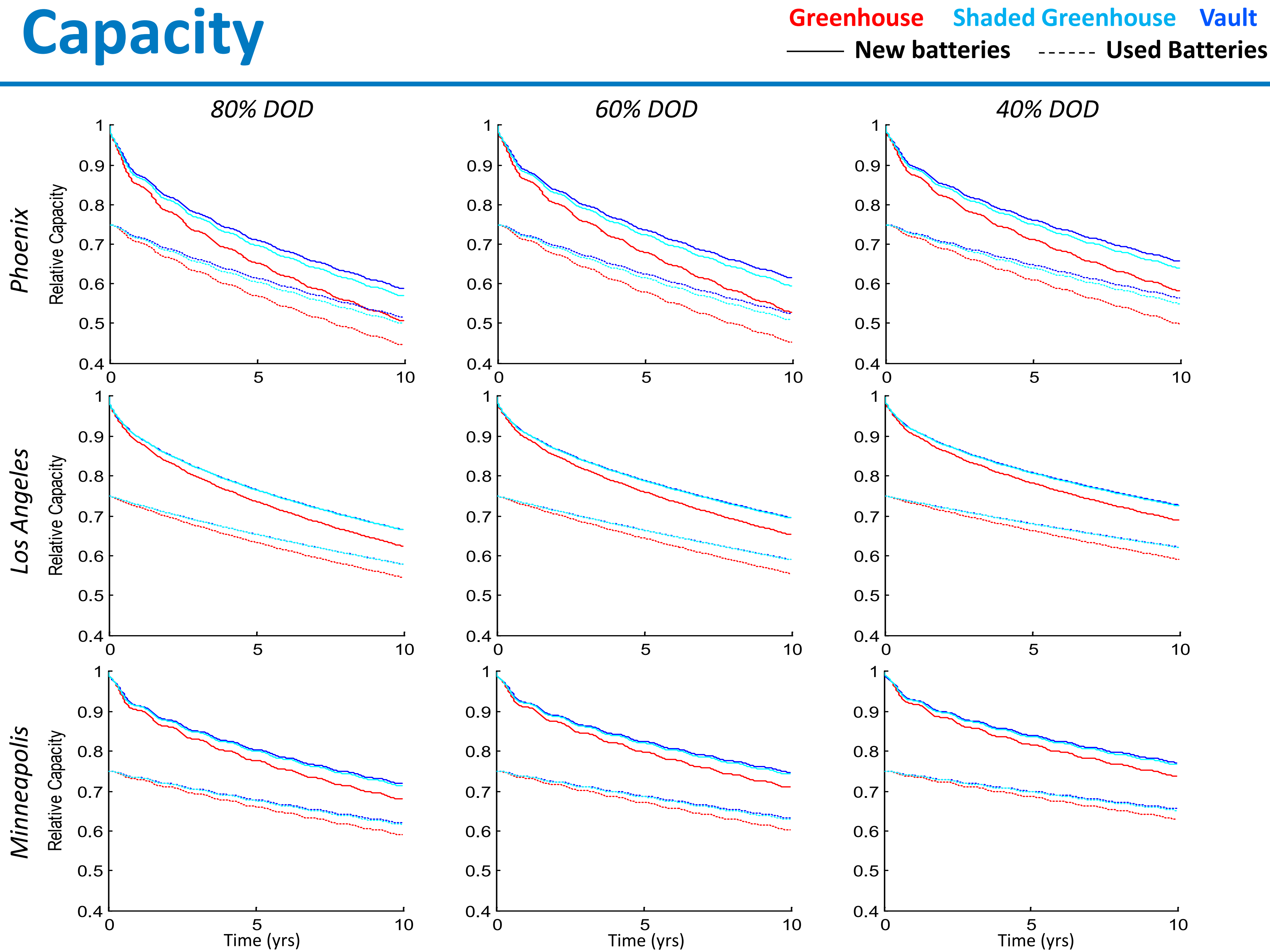


Greenhouse shows significantly elevated average temperatures in Los Angeles



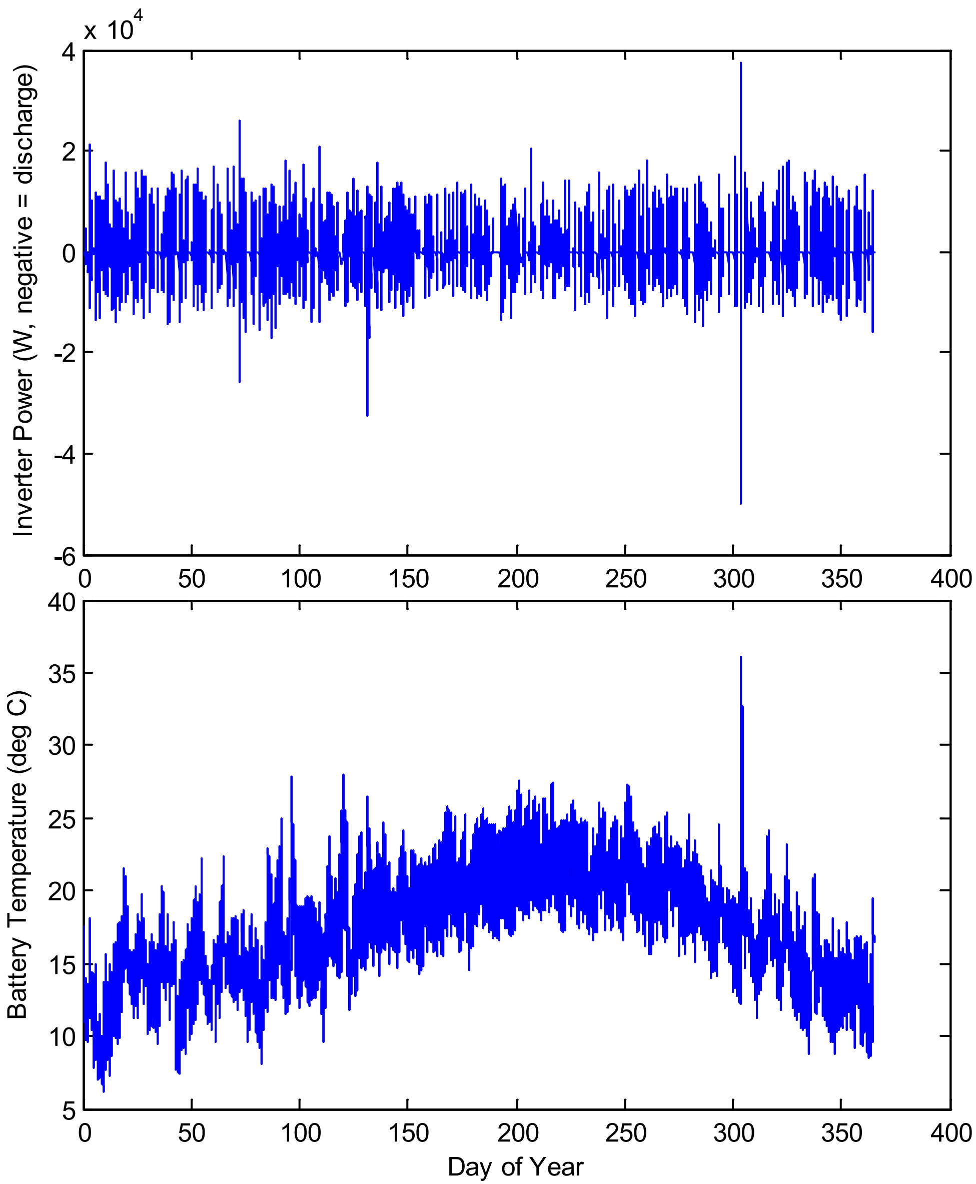
Minimal impact of thermal configuration on average temperatures in Minneapolis

Capacity



Greenhouse
Shaded Greenhouse
Vault
New batteries
Used Batteries
80% DOD
60% DOD
40% DOD
Phoenix
Los Angeles
Minneapolis
Relative Capacity
Time (yrs)

Power & Max Temperature



- **Case:** Los Angeles, 60% DOD, Shaded Greenhouse, year 1
- Very few power peaks outside of +/- 20 kW are observed
- Temperature spikes correlate with power spikes, which could induce operational limitations

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- Greenhouse effects can notably increase battery degradation (especially in warm sunny climates)

- Simple solar shading can work just as well as the best vault designs with respect to reducing degradation (up to ~8% additional capacity retention relative to our greenhouse scenario)

- Constraining inverter power could control temperature spikes and reduce hardware cost with minimal impact on peak-shaving duty cycle

- Difference in new and used battery capacity after 10 years of CES service varies by only 6 to 10%, suggesting there may be little difference in revenue generated by new and used systems.

Future Work

- **Instrument real-world CES installations to improve and validate thermal models**
- **Study the ability of active cooling systems to extend battery life**
- **Quantify impacts of battery degradation on service value**

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  - David Howell
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- **Technical questions regarding this project should be directed to Jeremy Neubauer at jeremy.neubauer@nrel.gov**

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