Thermal Energy Storage Solution to Increase Human Resilience in Extreme Weather

Thrust Area 3: Modeling and Analysis

Session Chair: Dr. Marco Pritoni (LBNL), Presenter: Dr. Chuck Booten (NREL), Key Contributors: Dr. Sajith Wijesuriya (NREL), Dr. Ravi Kishore (NREL)

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Stor4Build Annual Meeting
August 26–27, 2024
Oak Ridge National Laboratory
NREL/PO-5500-91042

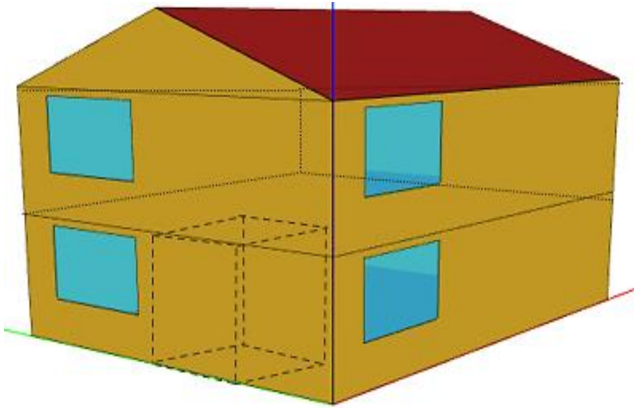
Objective

Quantify performance of a thermal "resilience room" with phase change materials (PCM) inside a building for extreme weather events with power outages

- Winter events presented here
- Summer events also modeled

Project Summary

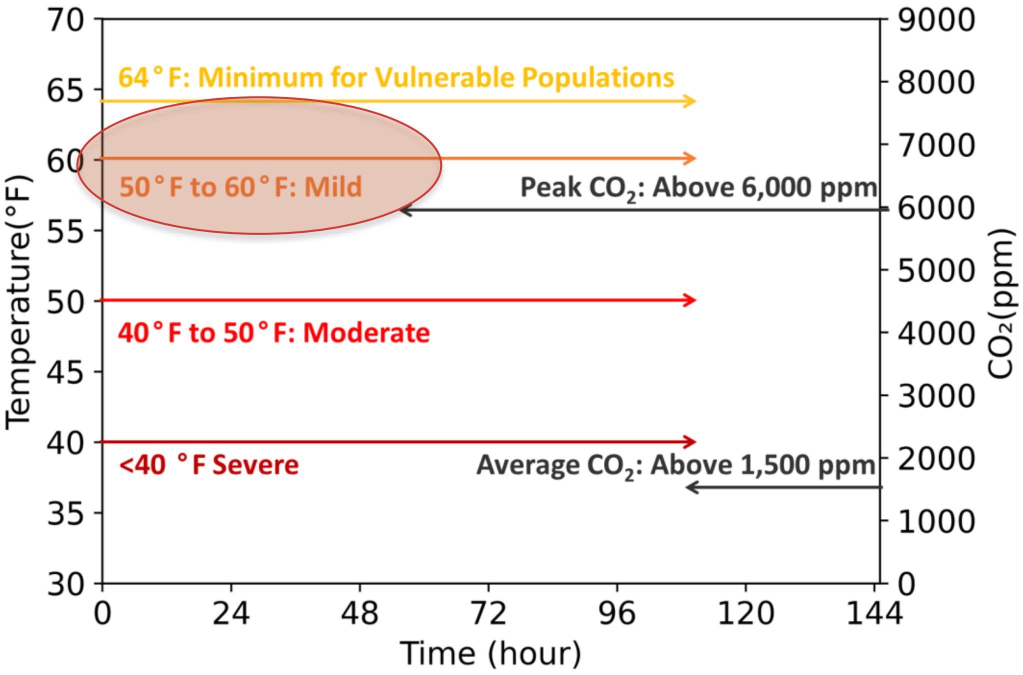
- Model a room inside a house with insulation + PCM + desiccant in the walls, “resilience room”
- Winter extreme weather + power outage
- Address known shortcomings of wall-integrated PCM
  - Low charge / discharge rates
  - No moisture control
  - Large surface area
  - Large thermal loads through exterior walls



- Identify key parameters for successful product design
  - Smaller area, internal to the house, faster charge / discharge , RH control, insulation, PCM

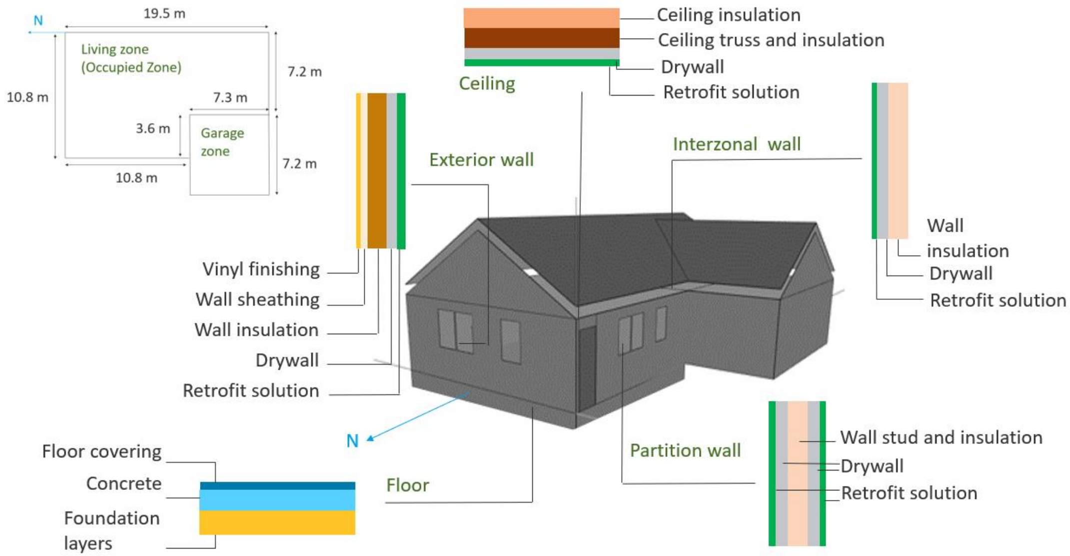
Resilience Threshold

- Moderate temperature threshold
- Goal is 72hrs above
- Peak and average CO_2 limits
- No humidity for cold weather



Whole Building Model

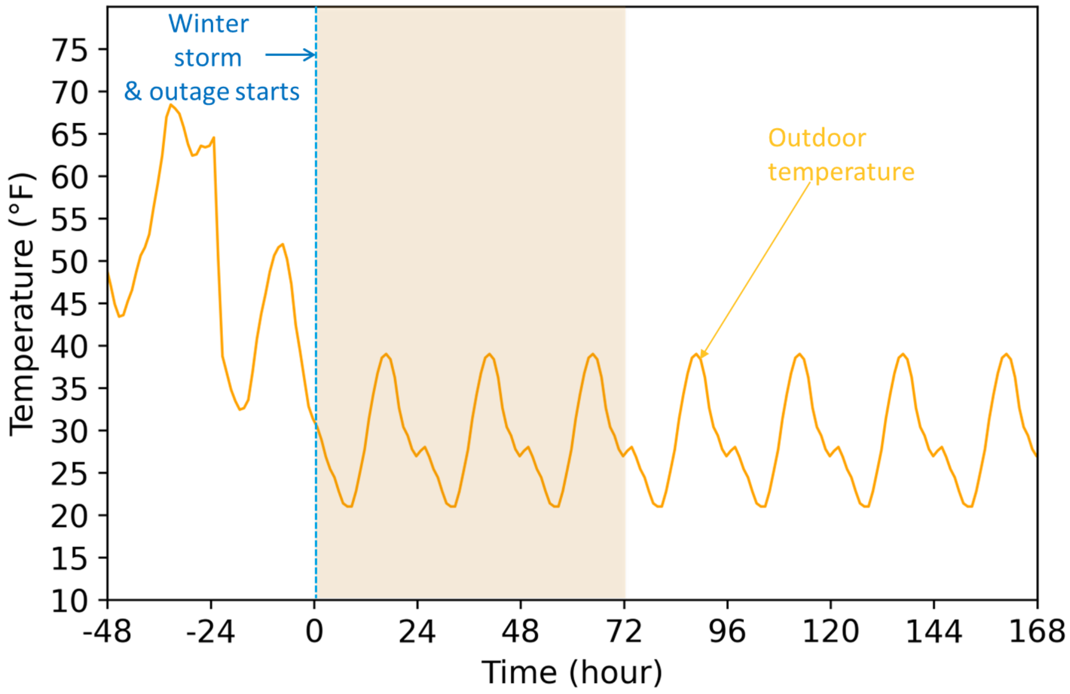
- Provides a baseline / starting point
  - Apply retrofit measures to entire house
- ResStock building model is used
- Houston, TX is used as the location
  - Recent extreme winter storm to model
  - Not accustomed to winter storms
- PCM and insulation retrofits are added as the interior most layer of opaque envelope
- Pre-heating of building



Wijesuriya, S., Kishore, R.A., Bianchi, M.V. and Booten, C., 2024. Enhancing thermal resilience of US residential homes in hot humid climates during extreme temperature events. Cell Reports Physical Science.

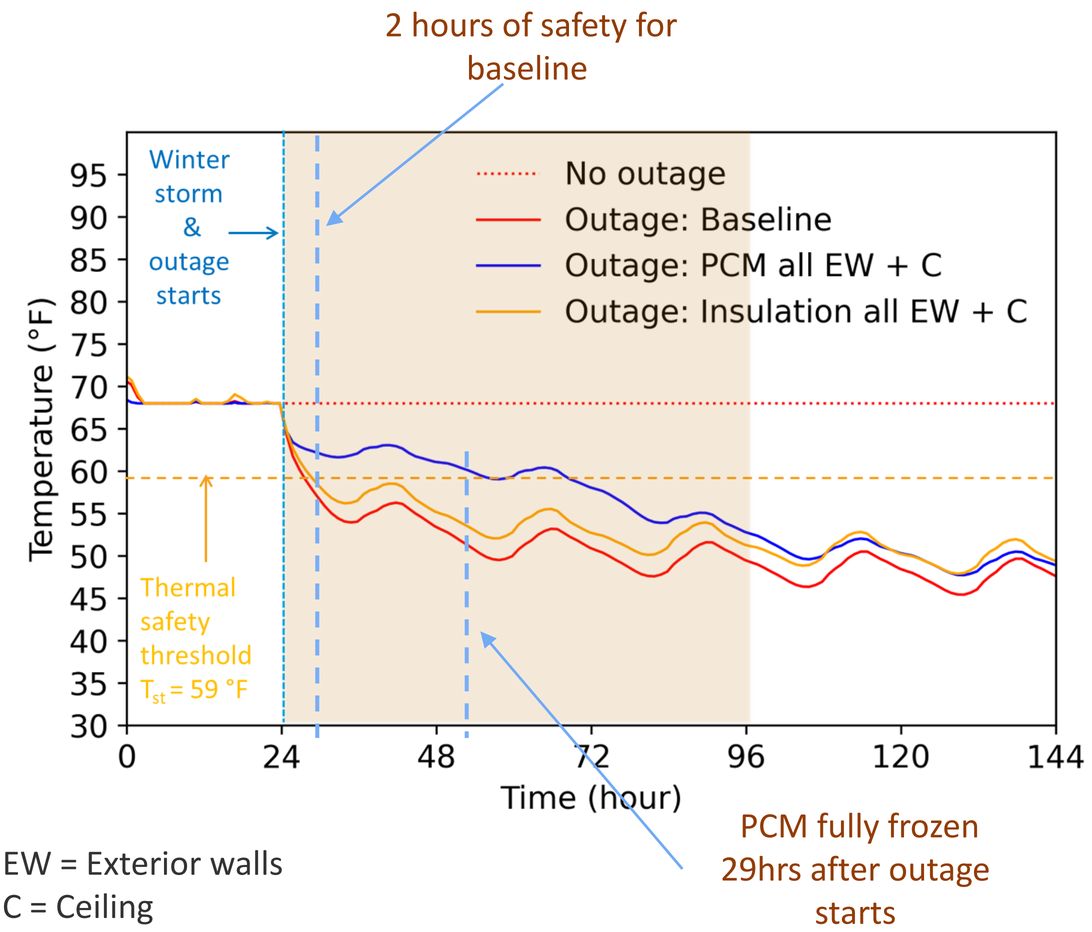
Weather Data

- Duplicate the worst day for an additional week – most extreme case
- Simulate before the power outage so the building is in a "normal" state at the start



Building Thermal Response

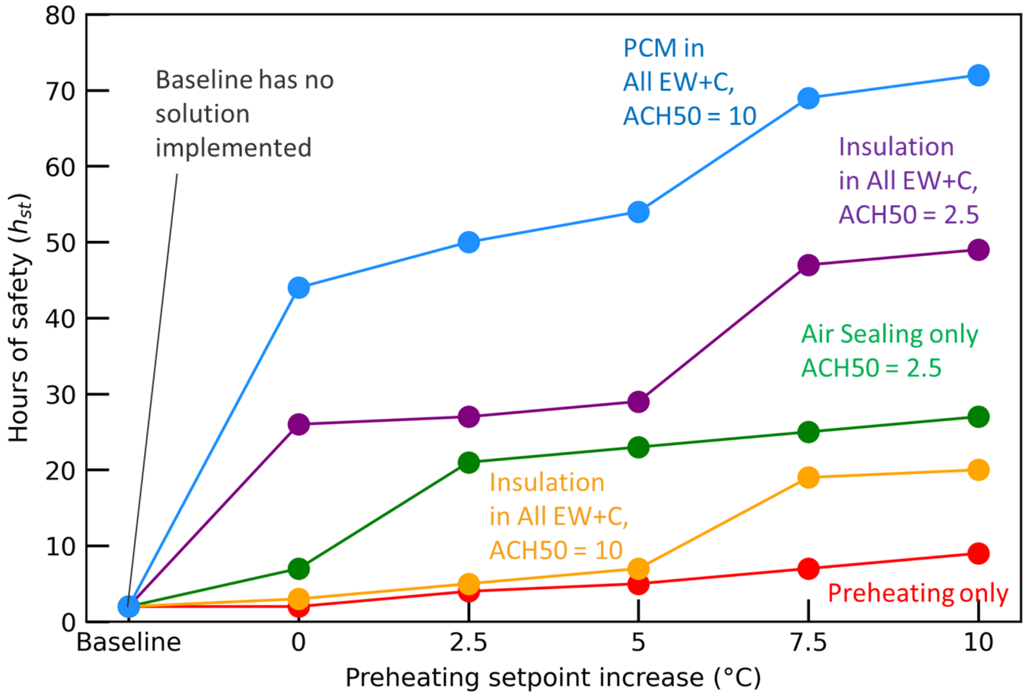
- Retrofit insulation: Upgraded to IECC 2021 standard
- Retrofit PCM: ½ inch
  - 17-21 °C melting range,
  - 200 kJ/kg latent heat
- Only 2 hours of safety without retrofits
- PCM and insulation help but not enough on their own
  - Need a LOT of both to make it work

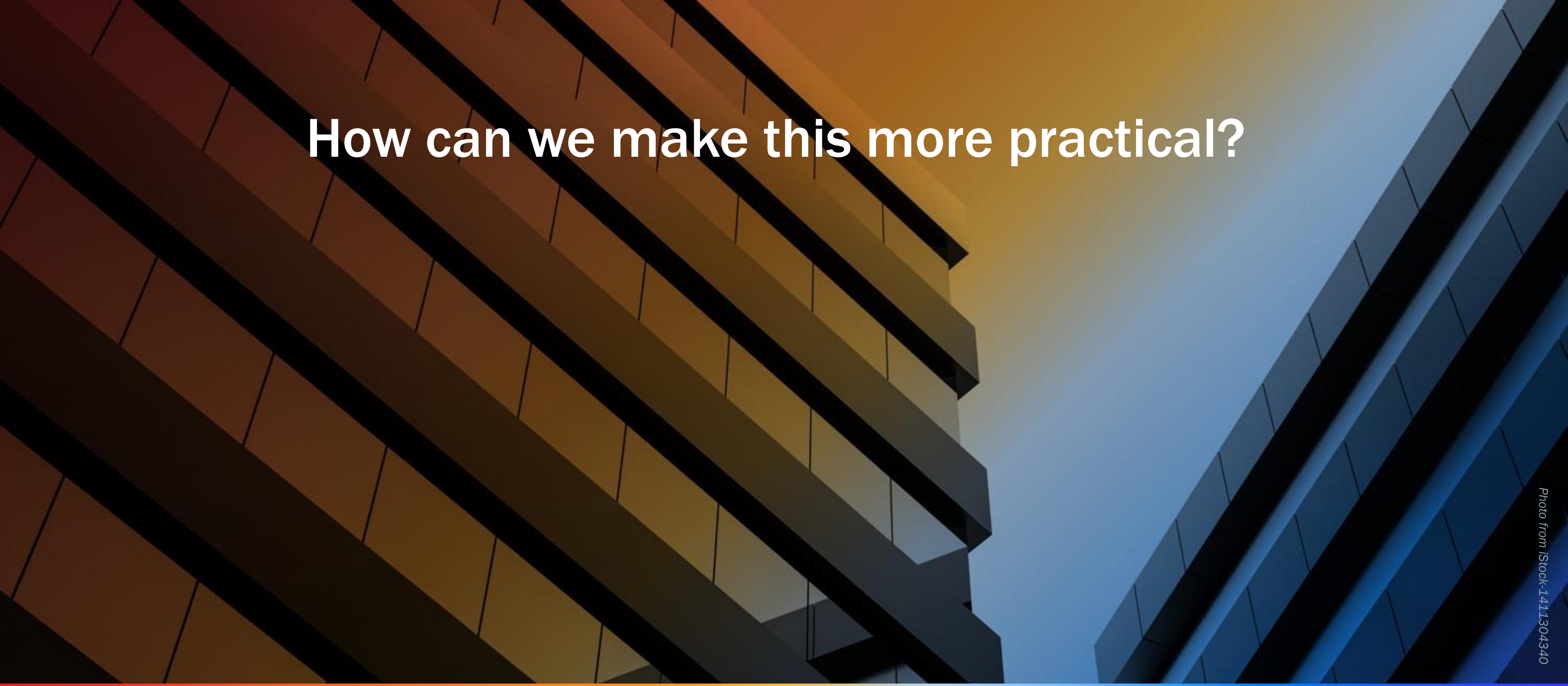


EW = Exterior walls
C = Ceiling

Parametric Whole House

- PCM provides higher safety at all levels
- Insulation, air-sealing, and precooling further enhance the resilience
- Maximum HoS is increased to 72
- It can be done, but it's expensive!
  - Not a low-cost solution
  - Not mass market
  - Need pre-heating / foreknowledge

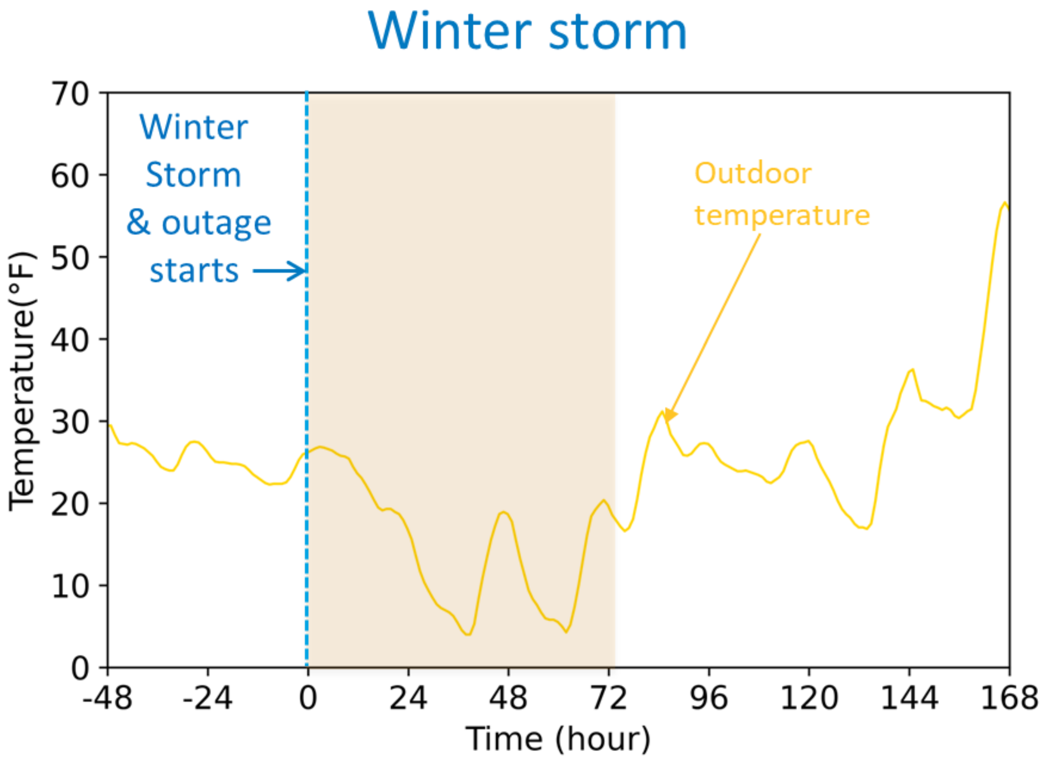




How can we make this more practical?

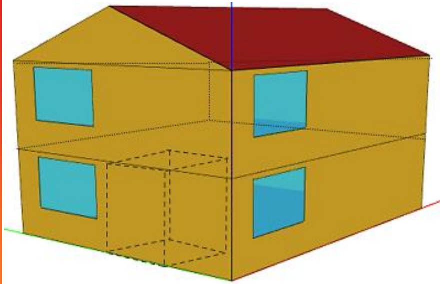
More Realistic Weather Data

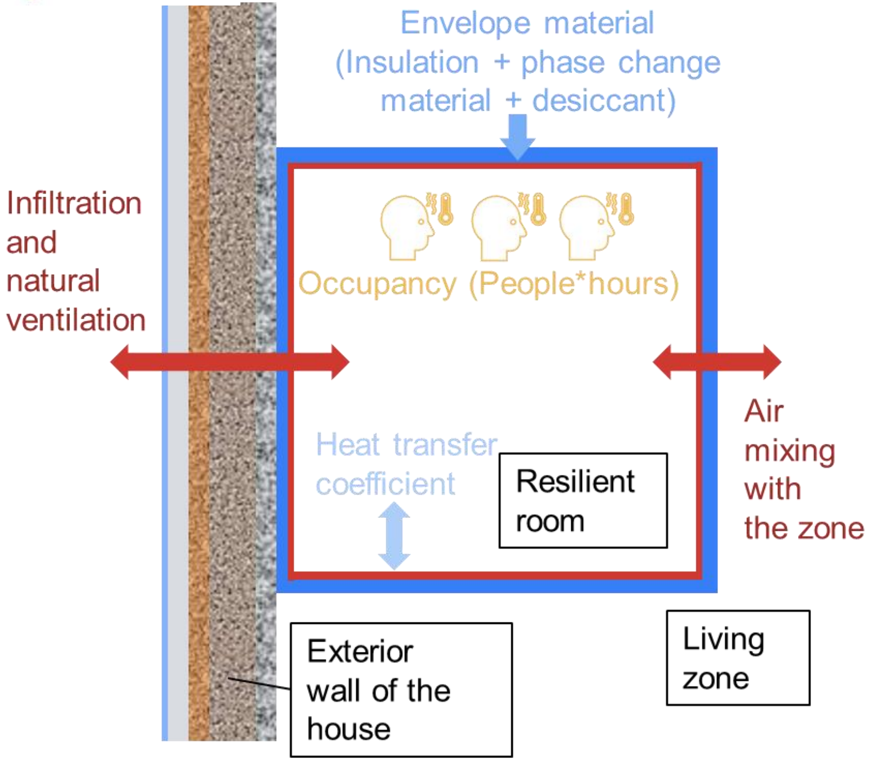
- Based on winter storm Uri February 2021
- Chose three coldest days to be the power outage
- Houston, TX
- Not as extreme as whole building simulation – more realistic/practical approach



Resilience Room

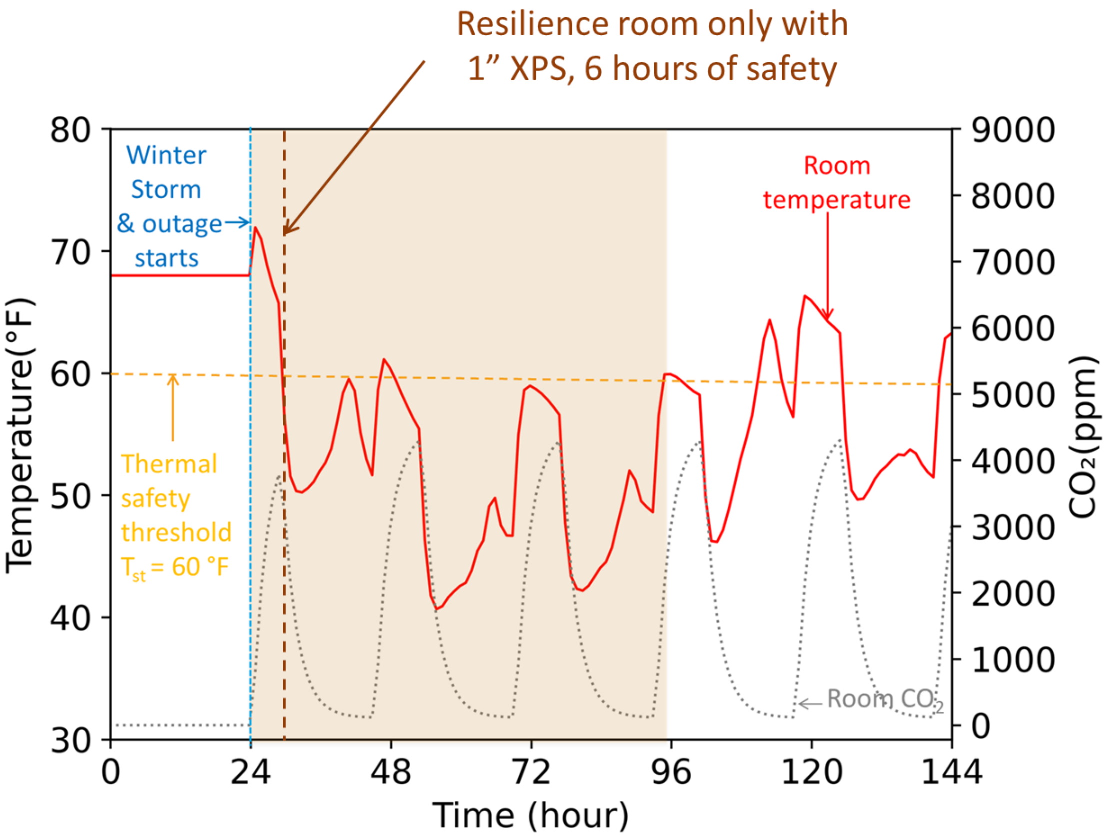
- Only a fraction of the whole house is really needed – this is an emergency after all
    - Already eliminate 90%+ of the total amount of whatever improvements are needed
- Need to address issues that are typically overlooked
    - Humidity
    - Occupancy
    - Dis/charge of the PCM
- Occupancy for 8 hours in the night.
    - Reduces PCM loading, focus on short term safety
    - Warmer temps most important at night





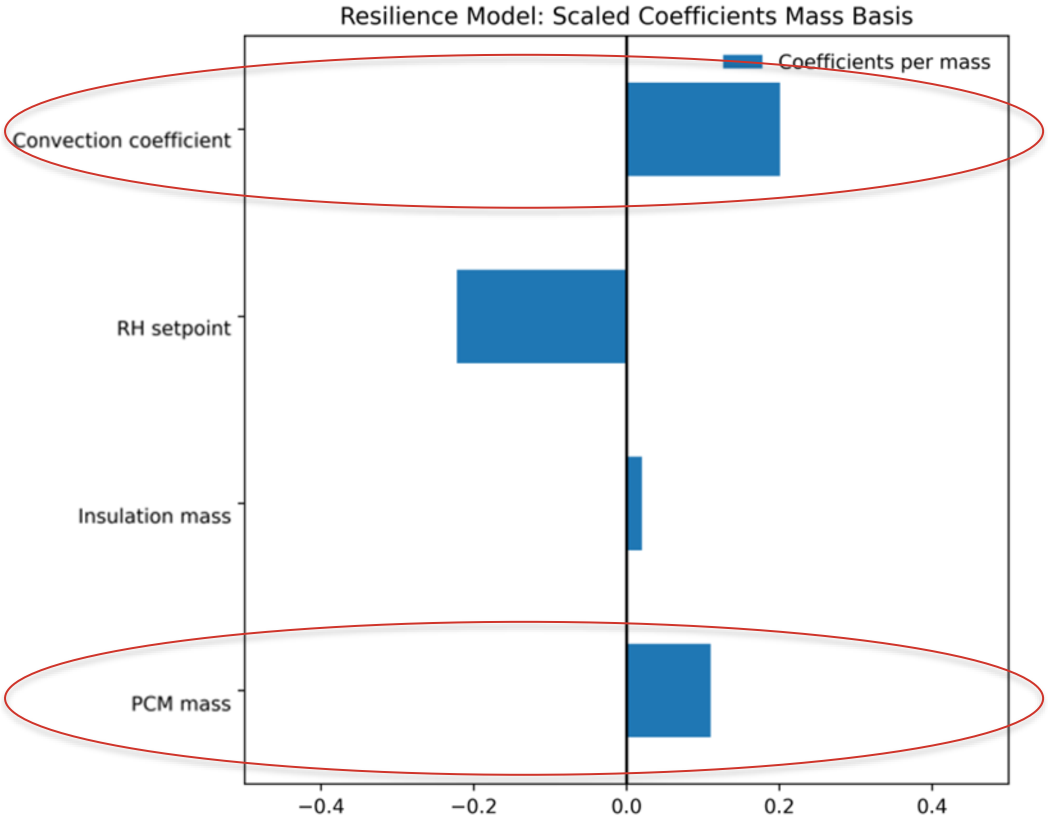
Thermal Response to Winter Storm

- Thermal safety threshold is at 60 °F
- CO_2 peak threshold is at 6,000 ppm and average at 1,500 ppm
- Baseline room if constructed with 1” XPS foam provides 6 hours of safety
    - Somewhat better than with the “super” extreme weather but not enough to provide much safety
- Need to go well beyond just an insulated room



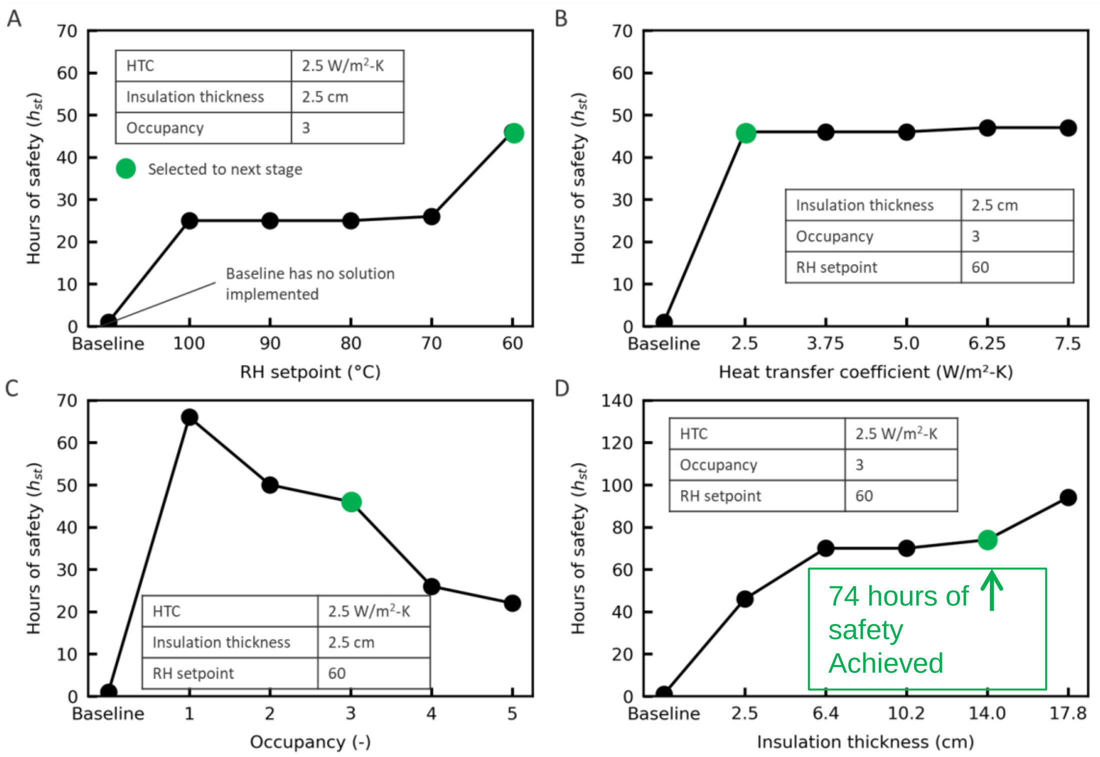
Regression

- Heat wave analysis- copy for winter storm except RH
- Normalize by mass
- Mass is a practical parameter
    - Impacts cost
    - Impacts ease of use/storage
- Controlling charge / discharge and adding PCM are best
- Need assumptions about the mass required to control HTC – assume a fan



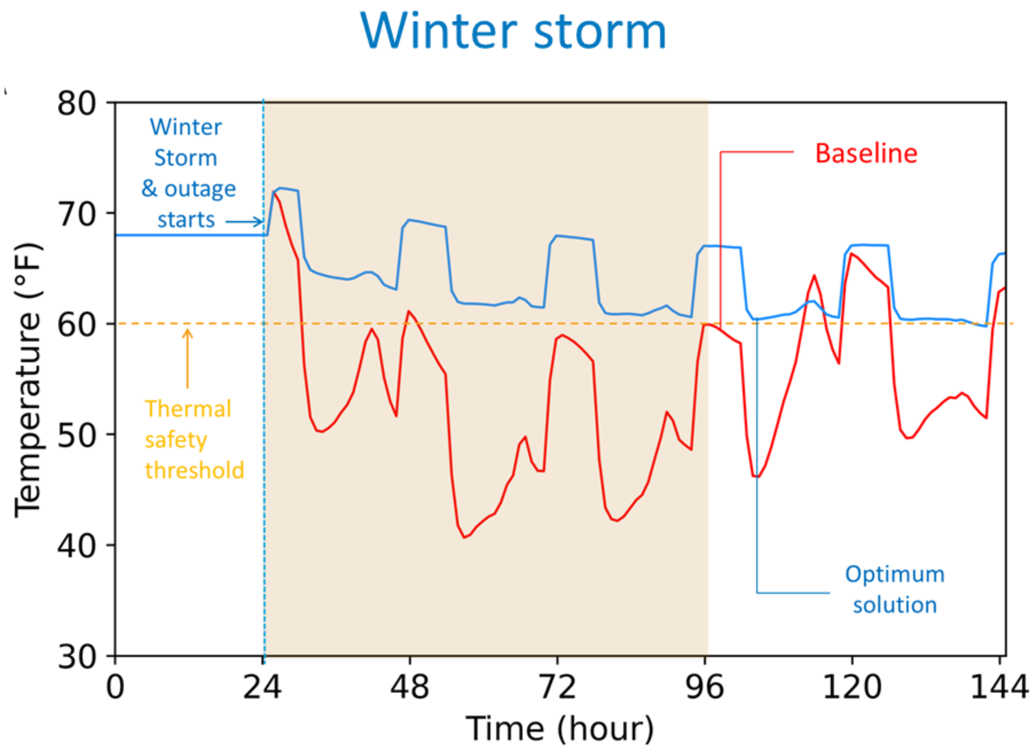
Parametric Assessment

- Relative humidity setpoint
    - In summer humidity is bad, but here not a problem
- Heat transfer coefficient
    - Need a minimum level of charge / discharge control
- Occupancy
    - Arbitrary choice
    - More people per house just need more rooms
- Insulation thickness
    - More is better performance, less is more practical



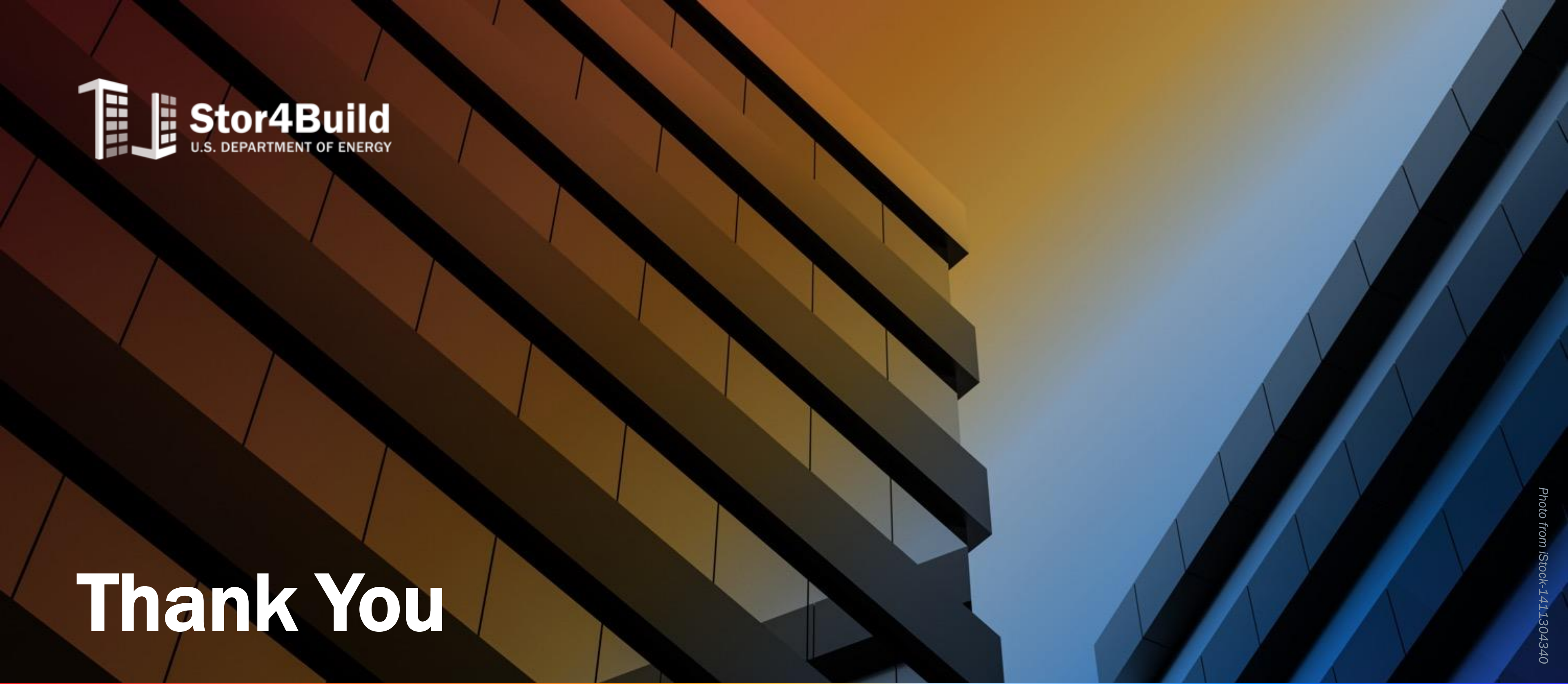
“Optimal” Resilience

- Min mass required to meet 72 hours of safety
- PCM
    - ~500kg,
    - Sounds like a lot but this is a 10x10 room, ½” thickness
- Charge / discharge rate of PCM fans to increase HTC – 18kg
    - Outage begins at night – assume occupancy and discharge starts then
    - Likely multiple fans for different surfaces along with a small battery and PV
- Insulation 2” XPS
- Occupancy 3 people, 8hrs each



Future Work

- More emphasis on comfort
    - Predicted mean vote, etc.
- Detailed heat transfer design
    - PCM/desiccant closer to the skin
    - Body placement matters (head/hands/feet, etc.)
- Design for both summer and winter
- Different buildings and climates
- Demonstrations



Thank You

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Relation to Blueprint

- Equity: thermal safety during power outages is most important for low-income households
- Resilience: enhance safety during extreme weather and grid failure
- Energy Efficiency: operates in low or no-power situations
- Onsite Emission Reductions: reduces/eliminates the need for fossil fuel backup generators for power outages
- Grid Edge: works with or without the grid, freeing resources for other needs during grid emergencies

Thermal Energy Storage Sizing, Benefits and Decision Tool (TESSBeD)

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Co-PI: Dr. Chuck Booten (NREL), Dr. Jason DeGraw (ORNL, presenter)

Key Contributors: Eric Bonnema (NREL), Amelia Bleeker (PNNL), Dr. Min Gyung Yu (PNNL), Dr. Srinivas Katipamula (PNNL), Dr. Xiaobing Liu (ORNL) Dr. Marco Pritoni (LBNL)

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NREL/PR-5500-91060

Objective

Develop a 3rd party validation tool for evaluating and sizing of thermal energy storage (TES) systems

The tool should estimate cost, energy and carbon savings as well as load shifting from adding TES to building HVAC systems

Project Summary

- <u>Collaborative effort among four national labs to create a TES design and sizing tool</u>
- Must be responsive to stakeholder needs
  - people should really use this
- Stakeholder engagement
  - Asked for this tool to be developed
  - Gather details about desired features and tool uses
- Tool development
  - Architecture
  - Integration – I/O, user interface
  - Validation
- Using the tool
  - Live demo available!
- Ahead of schedule
  - Stakeholder feedback a top priority
  - Tool still in development
- Fully functional and flexible tool will take some time

Stakeholder Engagement - Summary

- Meetings/ survey example feedback on TES types

4. **TES types.** What type(s) of thermal energy storage media should be considered with the tool?

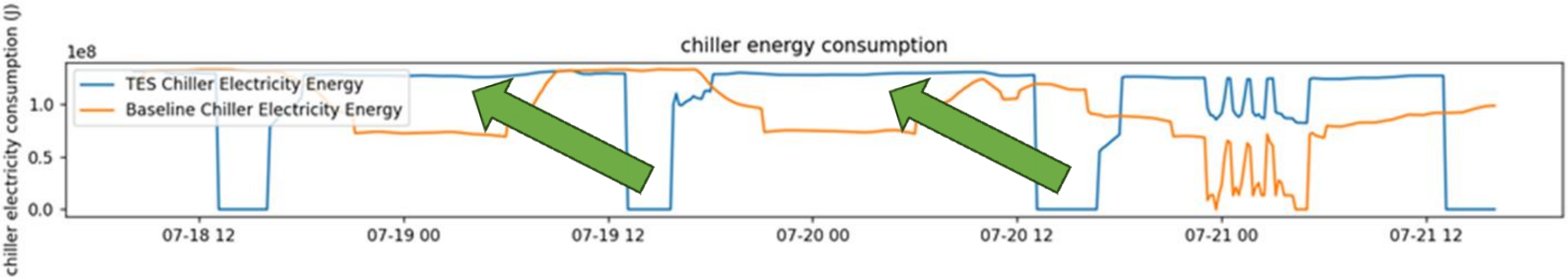
	Nice to have	High priority	Must have	Additional Comments
Water	1		3	
Ice	1	1	2	
Other sensible storage	2		2	- Ceramic brick, both central and fan/fan-less room units - For commercial not important, for Residencial likely important
Other PCM			3	Hybrid RTU-TES
TCM			1	Thermochemical storage with heat pumps

Stakeholder Engagement - Summary

- Preference for more of a screening tool
- Variety of intended users (designer, engineer, sales, OEM, consultants, etc.)
  - Slight preference for designers and sales people
- Building type – preference for commercial
- Equipment – heating most important
  - Cooling also of interest
- Variety of TES types
  - Slight preference for water or PCM
  - Started with ice for simplicity – leveraged recent investments

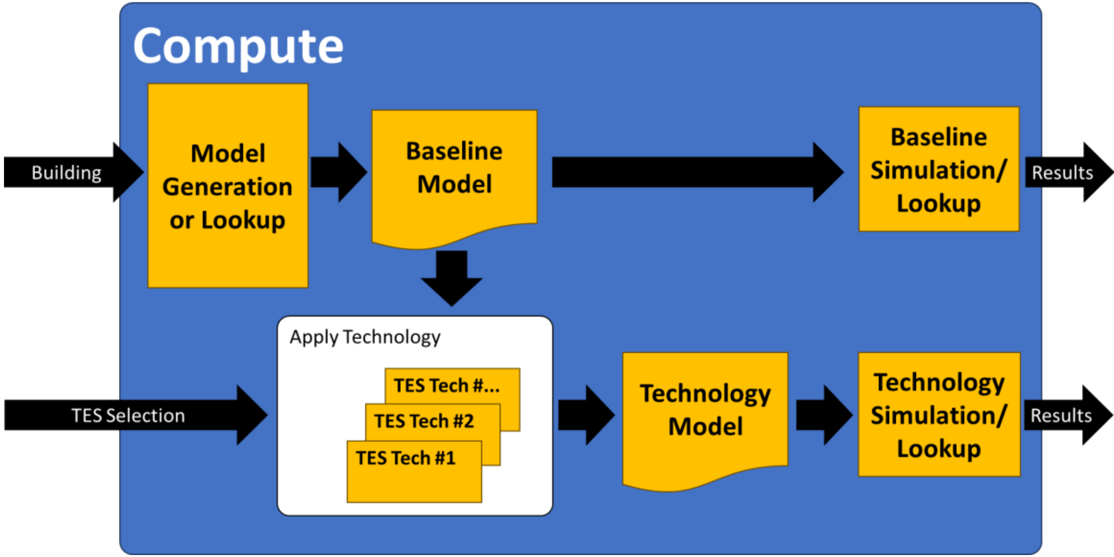
Tool Development - Summary

- The approach is made up of two parts
  - A web tool
  - A Python package managing EnergyPlus models
- The computational approach is well understood in the building energy modeling community



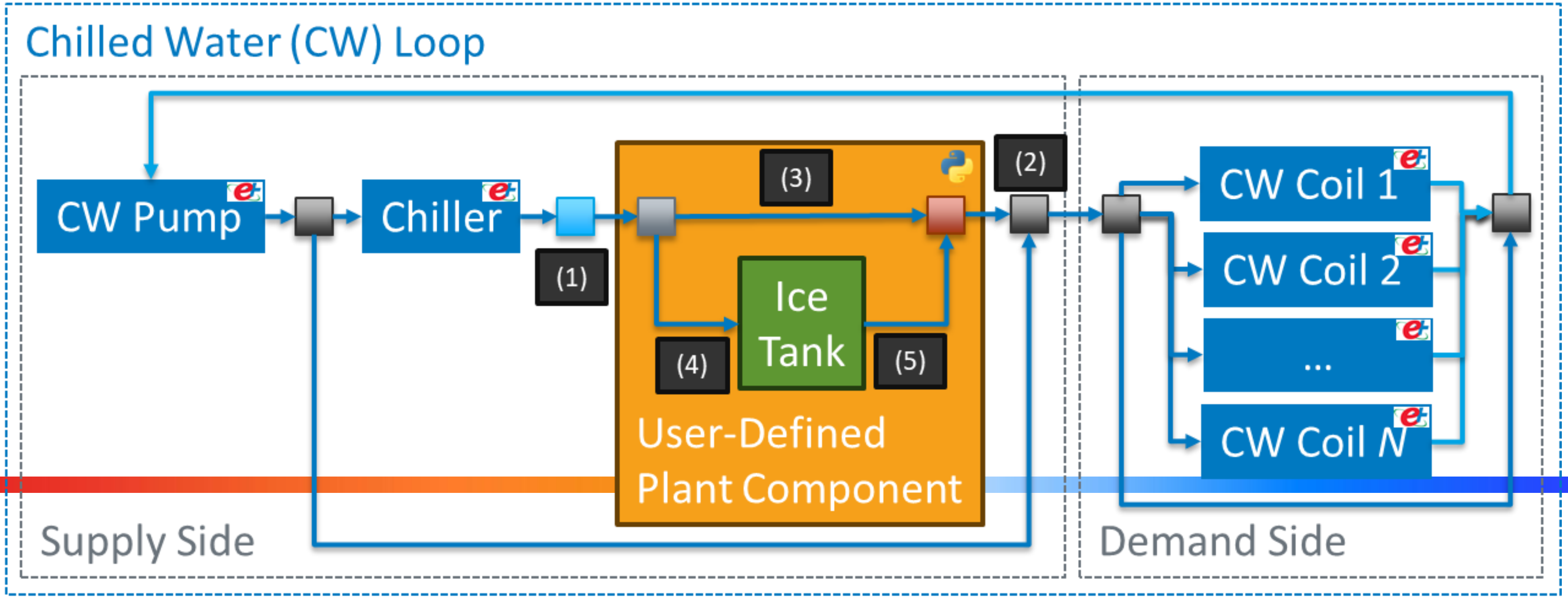
Tool Development - Architecture

- Compare baseline and TES results
- Current: retrofit ice tank system, sized by % peak reduction and utility schedule
- Future:
  - Other system types
  - Modify building systems (size, type, etc.)
  - Better control options
  - Sizing on other signals (carbon, demand, etc.)



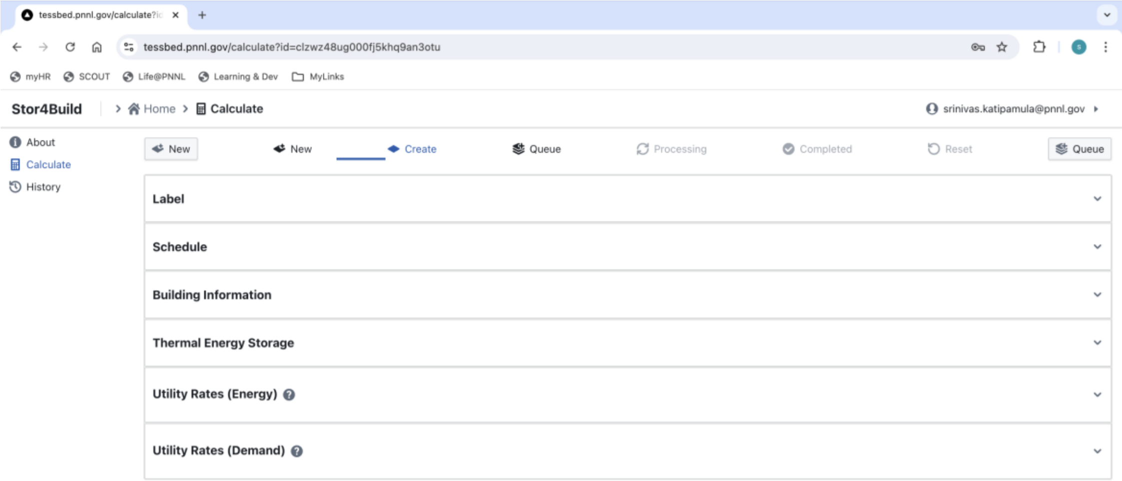
Tool Development – Architecture and Control

- Ice tank in series with chiller, has three modes: (1) charge (off-peak), (2) discharge (peak), and (3) hold/idle (mid-peak)
- Charge – chiller set to lower (configurable) temperature, -3.8°C [25°F] used
- Discharge – chiller set to higher (configurable) temperature, depends on number of tanks and discharge window length
- Hold (idle) – chiller set to normal operating (configurable) temperature, 6.7°C (44°F) used



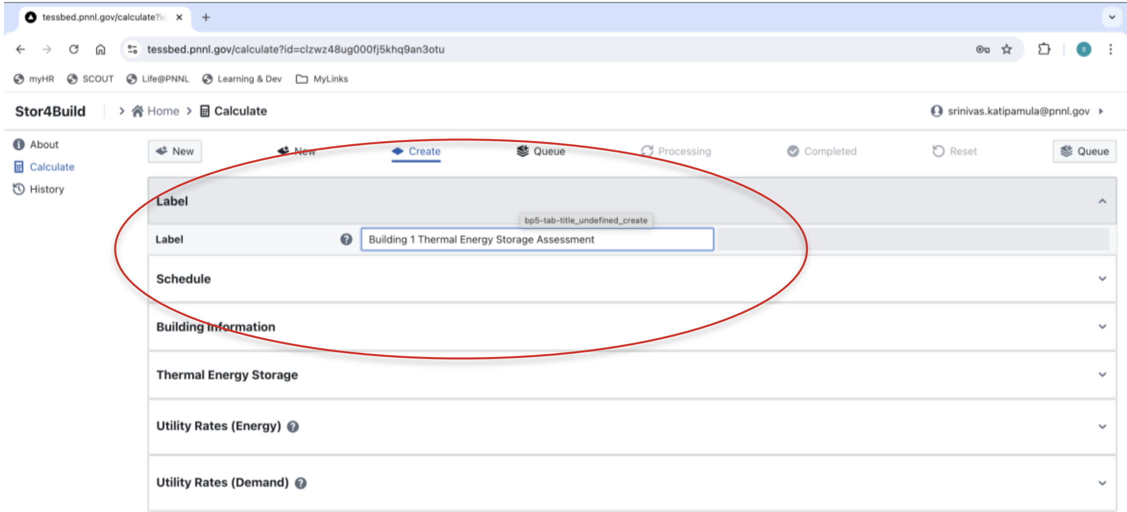
Web interface, Inputs

- Not yet live to the public (early FY25)
- Inputs are high level, types rather than details
- Not a full-featured interface to E+



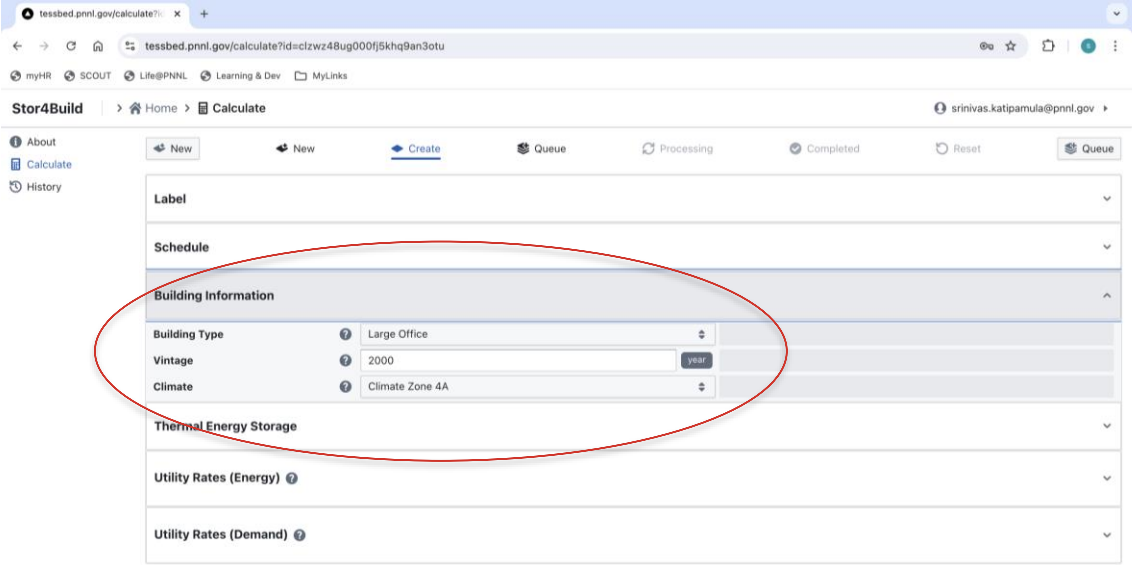
Web interface, Inputs

- Label the project/simulation
  - These can be archived for later retrieval
- Currently annual simulation
- Cooling season only for outputs



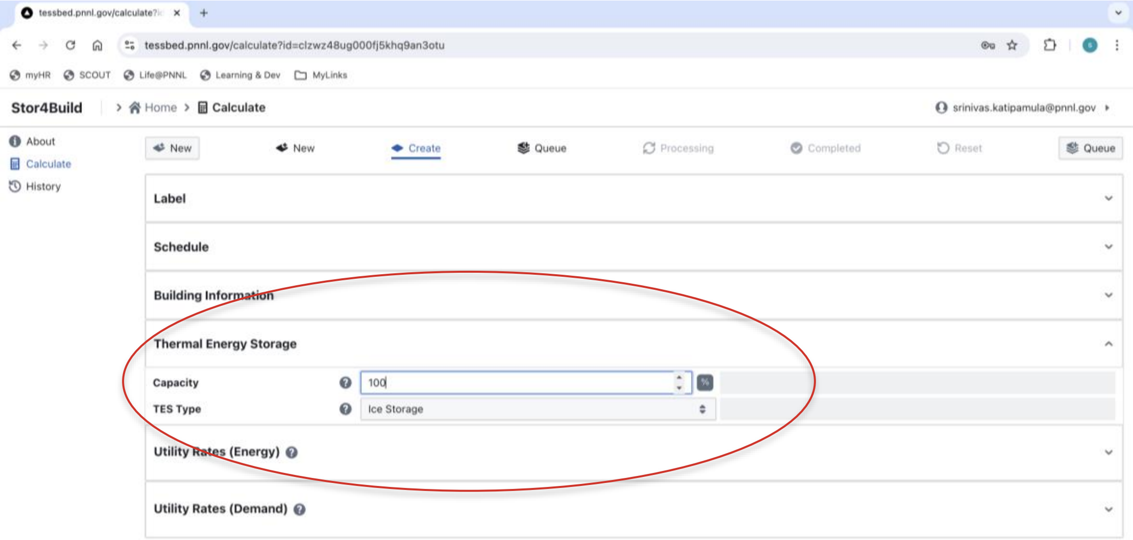
Web interface, Inputs

- Building
  - Currently Large Office is the only option
  - More to come later
  - Chiller system with ice tank
  - HVAC size is fixed
- Several vintage available
  - Automatically rounds to the nearest year available
- Climate zone
  - 4A for now
  - All IECC in US eventually



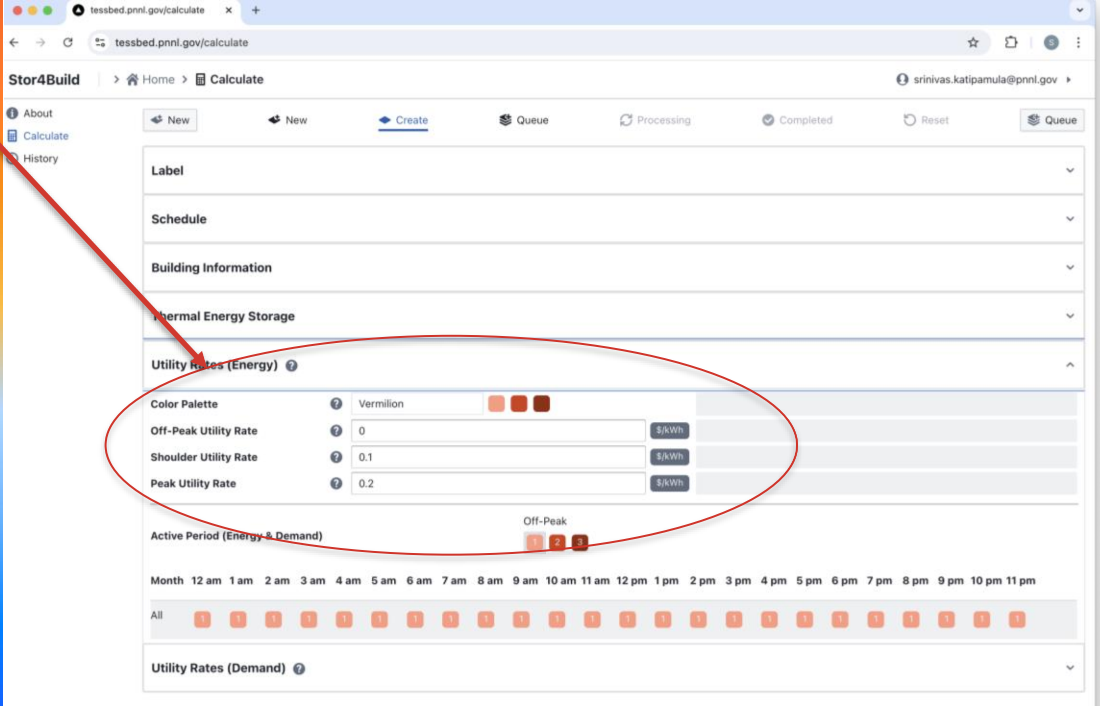
Web interface, Inputs

- TES sizing
  - Specify as a % of peak cooling load that the TES should offset
  - Limited to 25-100%, could be expanded if needed
  - Tool sizes TES based on needs during "peak"
- Only ice tank for now
  - Will expand to include hot or cold water, PCM in FY25



Web interface, Inputs

- Utility rates, energy
  - Off peak
  - Shoulder
  - Peak
- Currently only one peak period allowed per day for simplicity
- Scheduling interface still under development



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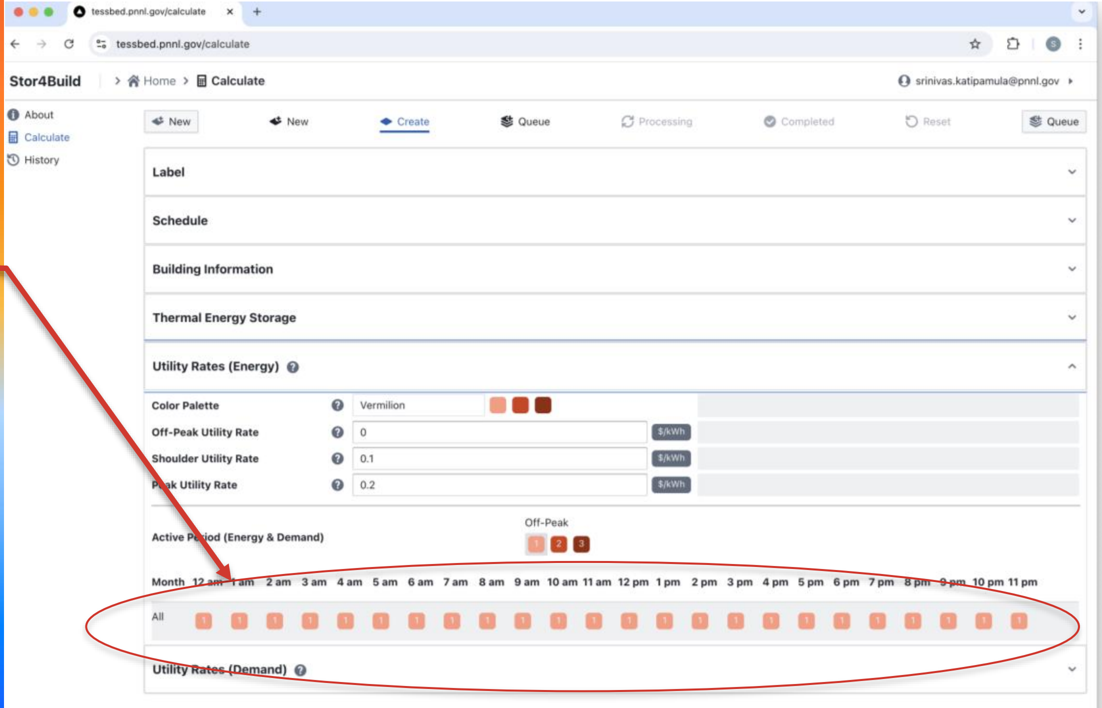

Web interface, Inputs

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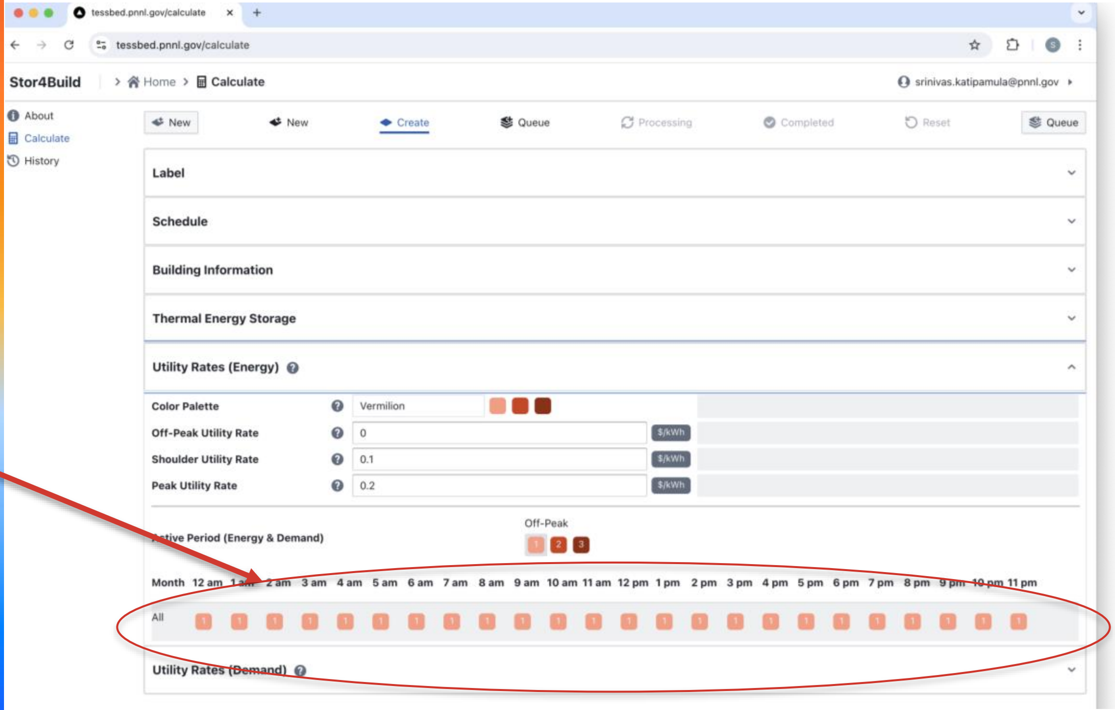
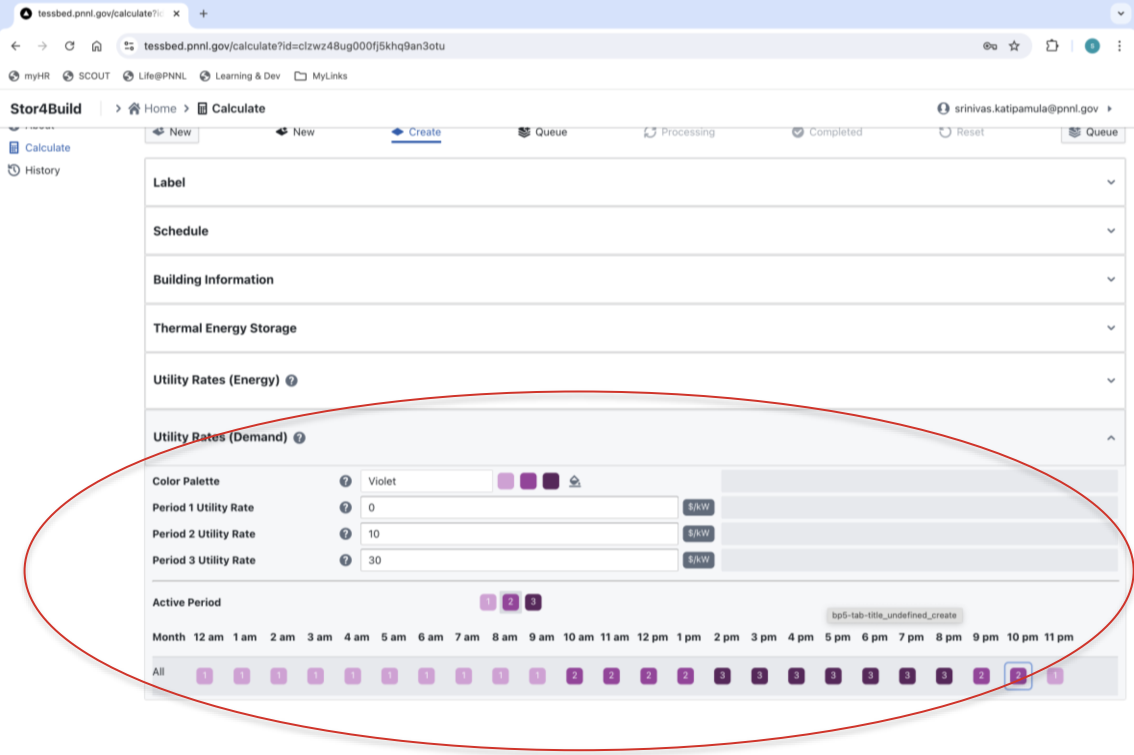


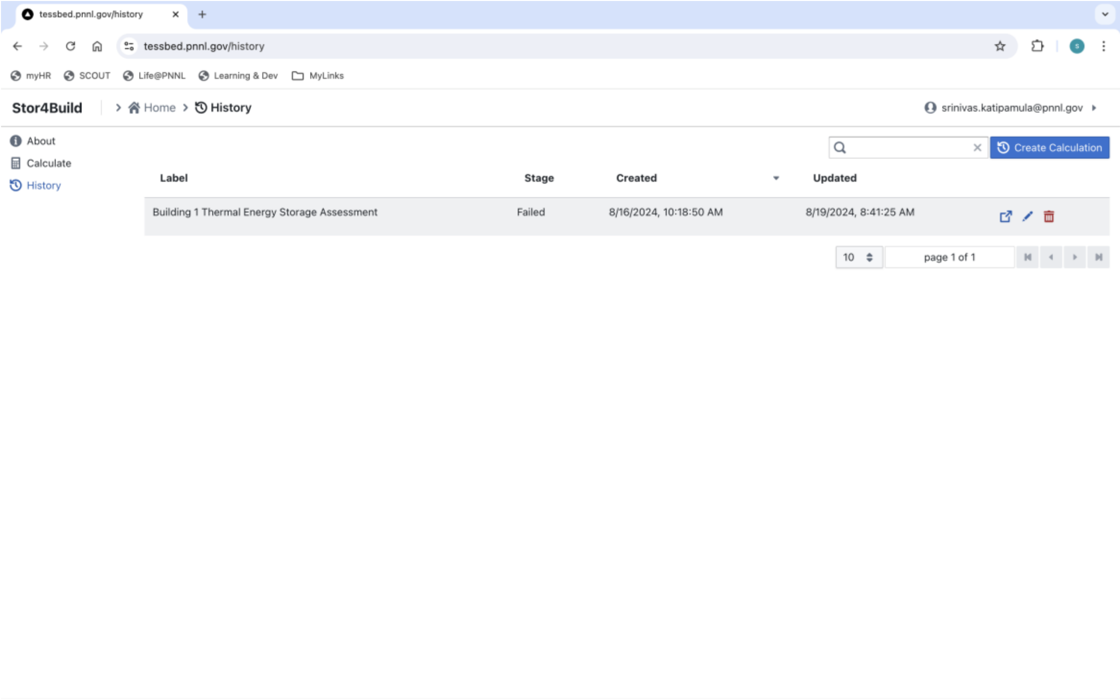
Web interface, Inputs

- Utility rates, demand
  - Similar format to energy schedule
- Doesn’t need to align with energy rates
  - Only used for post-processing / economic results



Web interface, Inputs

- Easy to run – one button
- Calculation could take a few minutes
  - As more features are added, time will go up
  - Increased compute resources can compensate
  - Shorter duration simulations will be faster



Web interface, outputs

- Demand and energy (can be different)
- Display utility rate inputs
- EnergyPlus output files available

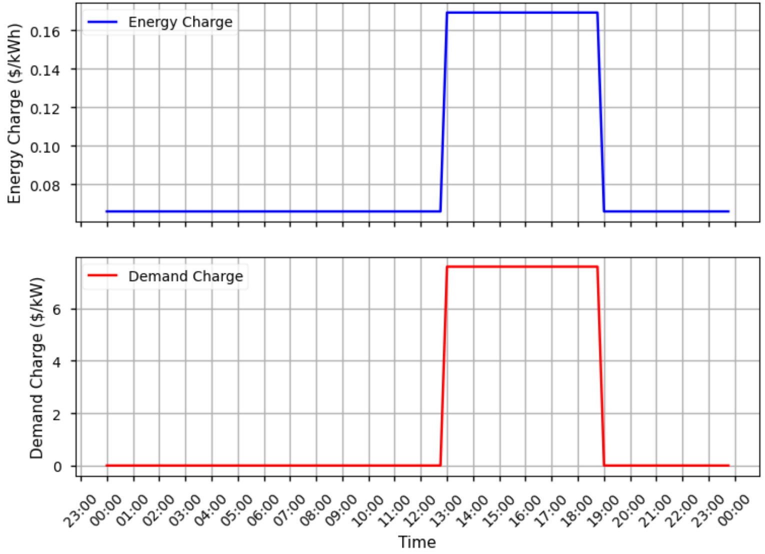
ME-OLGS-1-TOU

https://apps.openei.org/USURDB/rate/view/62c7415d7c7b95456b08d3b7

Period	Tier	Max Usage ?	Max Usage Units ?	Rate $/kWh ?	Adjustments $/kWh ?	Sell $/kWh ?
1	1		kWh	0.06497	0.01037	
2	1		kWh	0.06599	0.01037	
3	1		kWh	0.16913	0.01037	

Time of Use Demand Charge Structure

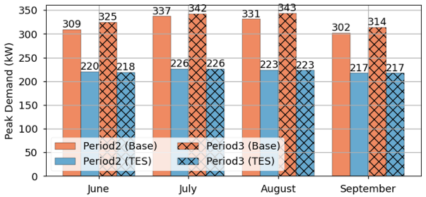
Period	Tier	Max kW Usage ?	Rate $/kW ?	Adjustments $/kW ?
1	1		0.26	
2	1		0	
3	1		7.6	



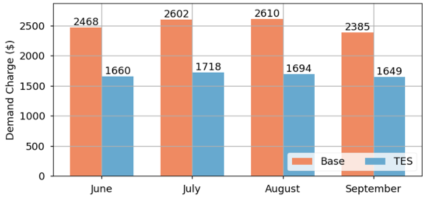
Web interface, outputs

One year (Summer season)

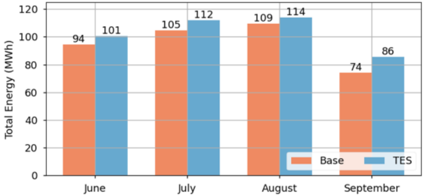
Peak Demand



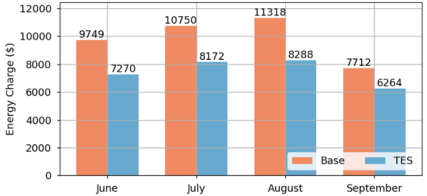
Demand Charge



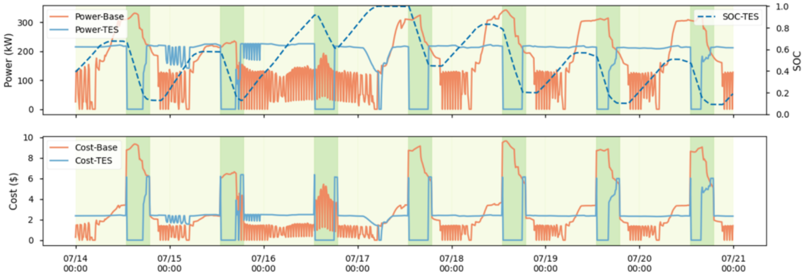
Energy Use



Energy Charge



Total Energy Use	BASE	382755 kWh
	TES	412182 kWh
Total Energy Charge	BASE	$39,529
	TES	$29,995
Total Demand Charge	BASE	$10,065
	TES	$6,721



FY25

FY25

- Model validation
- Proposed tool enhancement (FY25)
  - Climates
  - Buildings
  - TES sizing
  - TES materials
  - TES controls
- Feedback is important!

Thank You

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This work is supported by Stor4Build, a multi-lab consortium funded by the U.S. Department of Energy (DOE) Building Technologies Office (Awarded Under Lab Call L095). The consortium is co-led by the National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL), and Oak Ridge National Laboratory (ORNL). NREL is operated by Alliance for Sustainable Energy, LLC, for DOE under Contract No. DE-AC36-08GO28308; LBNL is managed by the University of California for DOE under Contract No. DE-AC02-05CH11231; and ORNL is managed by UT-Battelle LLC for DOE under contract No. DE-AC05-00OR22725. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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