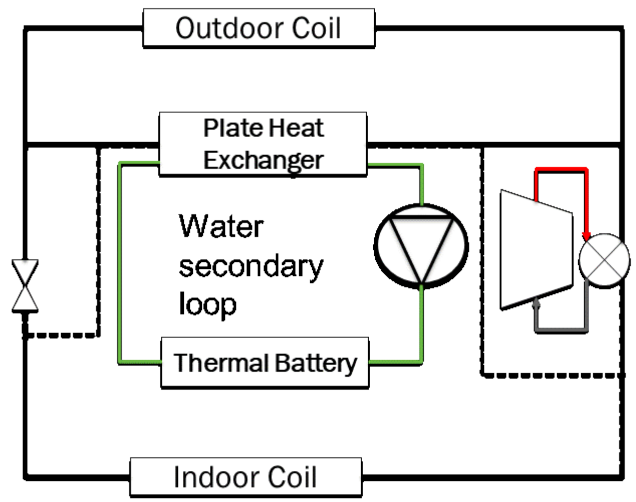
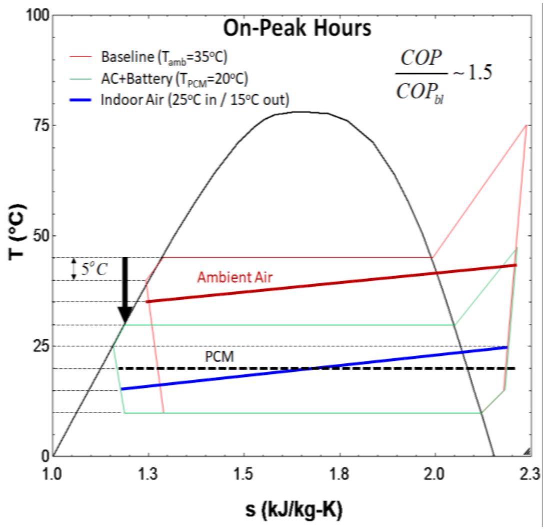
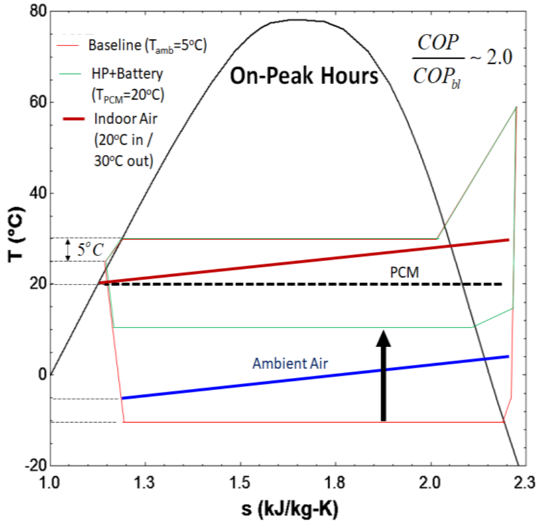
Dual-Purpose – Heating & Cooling - Thermal Battery to Enable Flexible and Energy Efficient Heat Pump Systems







Performing Organizations: University of Maryland, Oak Ridge National Laboratory, Electric Power Research Institute, Rheem Manufacturing, Insolcorp, Heat Transfer Technologies

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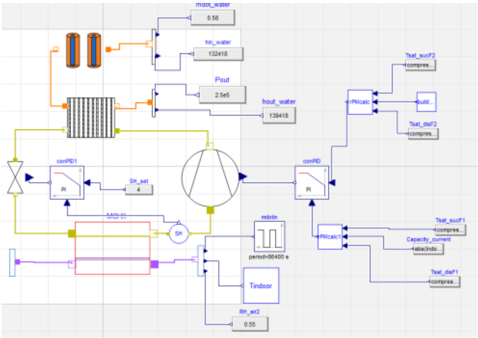
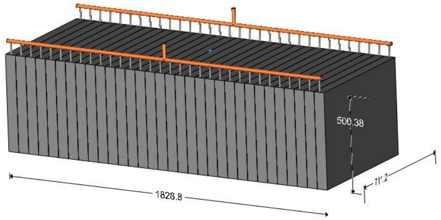
DE-EE0009681

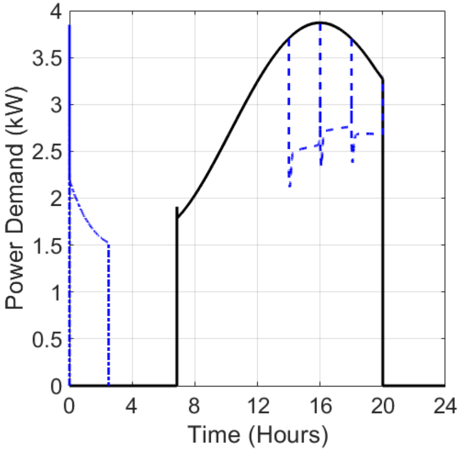
Project Summary

Objective and outcome

- Develop an integrated heat pump-thermal energy storage (HP-TES) for load shifting in cooling & heating modes
- Assessment of demand reduction potential in all US climate zones
- System model validation, laboratory testing and technology demonstration (field test & commercialization plan)







Team and Partners

University of Maryland Center for Environmental Energy Engineering

Oak Ridge National Laboratory

Insolcorp

Heat Transfer Technologies

EPRI Electric Power Research Institute

Rheem

Stats

Performance Period: 10/2021-09/2024

DOE budget: $3,000K, Cost Share: $750K

Milestone 1: Component & system design

Milestone 2: Laboratory testing & validation

Milestone 3: Technology demonstration

Problem

- HVAC&R equipment is responsible for 40-70% of residential & commercial building loads
- They are one of the main drivers of peak loads (30% peak electricity share), particularly in the summer season
- Systems in the range of 3-5 Tons correspond to the largest l**ight commercial rooftop units** market share (approximately 4 million units shipped in 2020)
- Thermal energy storage can be used in a plethora of different configurations with HVAC&R equipment and are 2-3x less costly than electrochemical batteries

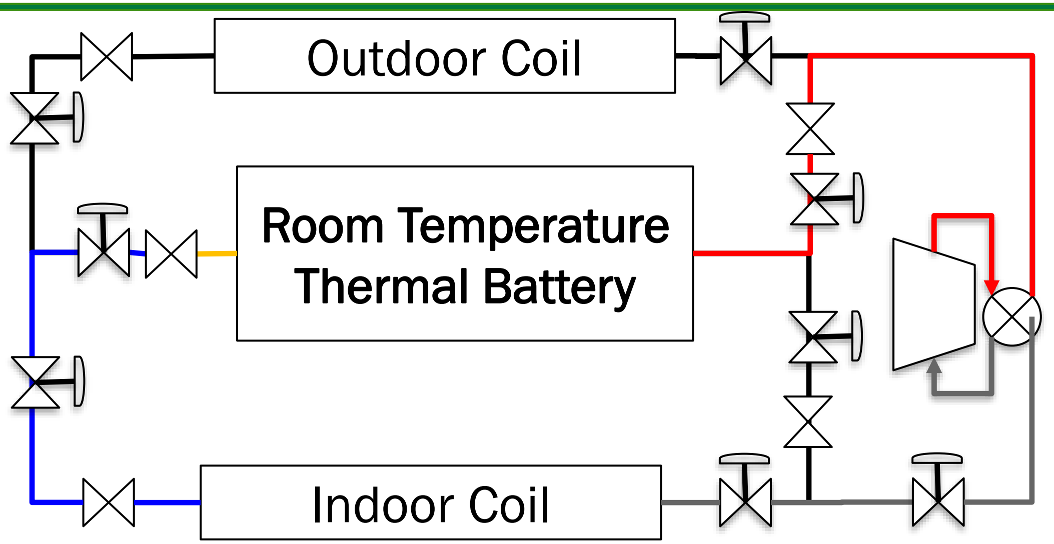
Project Objectives & Opportunities

- **Objective**
  - Develop & validate a single integrated HP-TES operating in both cooling & heating modes
- **Timeline**
  - Year 1
    - Component & system design
    - Prototyping & component testing
  - Year 2
    - System construction & lab tests
  - Year 3
    - Technology demonstration, field testing, & validation

- **Opportunities**
  - Use a single room-temperature TES replacing the outdoor coil suitable for both heat pump modes
    - Reduce system (capacity) size
    - Reduce added cost
    - Possibly competitive with other high-efficiency heat pumps
  - Reduce demand during the peak load use, thus operating costs
  - Reduce system performance degradation, e.g.,
    - Constant temperature lift (less cycling)
    - Less frost (cold climates)

Approach & Challenges

- **Original approach**
  - Direct refrigerant/TES system
  - TES operation: 5 tons, 4 hours
- **Challenges**
  - TES weight limits rooftop applications (6 x HP weight)
  - 5 x Refrigerant charge increase
  - TES aluminum HX are susceptible to corrosion from PCM salt hydrates
  - Demand reduction potential is dependent on location

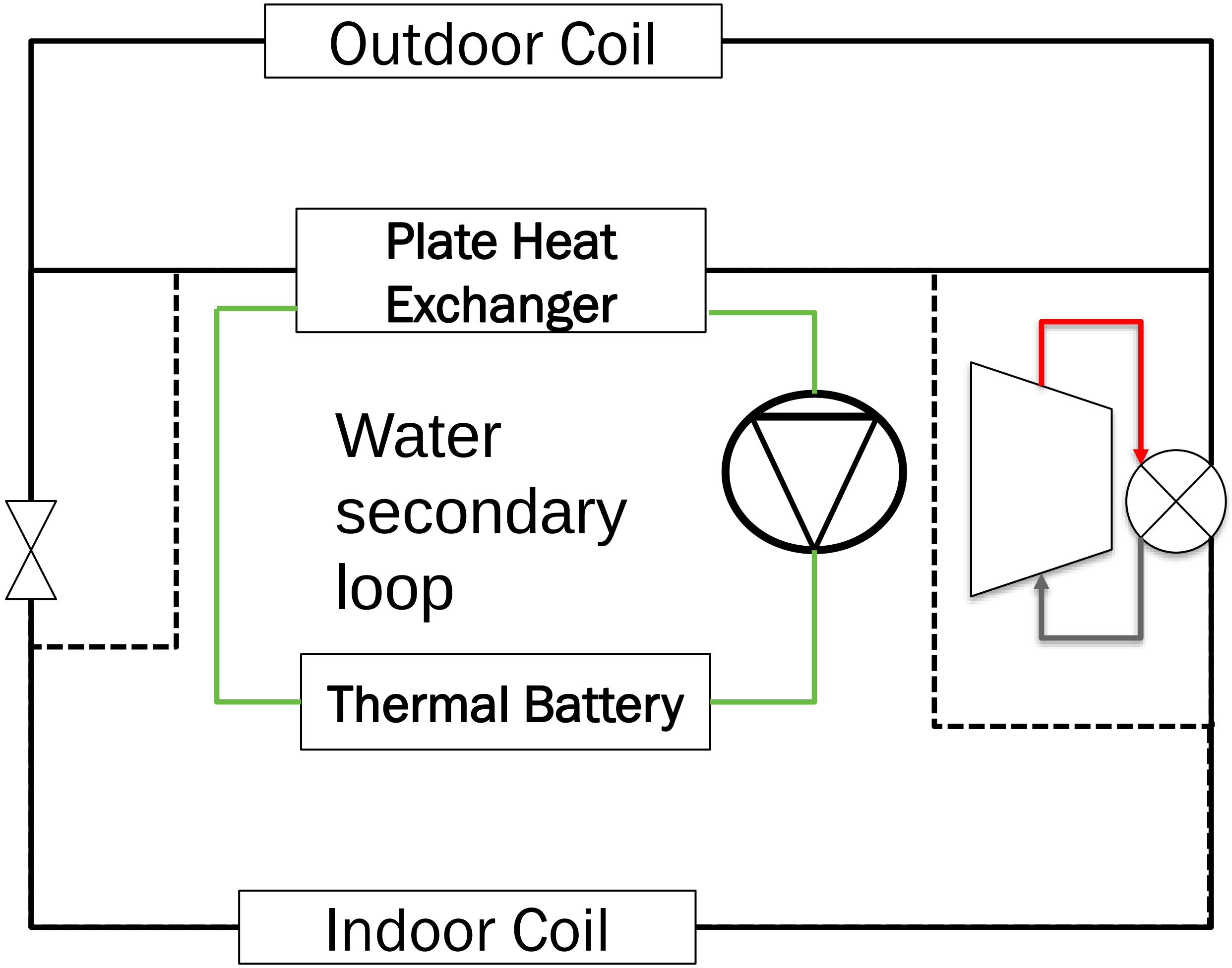


Targets	Metric	Unit	Target Values	Model-predicted performance
SOPO	System Capacity	Ton	5	5
SOPO & DOE	Demand Reduction	%	50+	20-80
	Period	hours	4+	4
	Volumetric Storage	kWh/m³	80	**72**
DOE	Volume Increase	%	10	**40**
Overlooked metrics	Weight Increase	%	No target set	Critical issue for RTUs
	Refrigerant Charge Increase	%	No target set	**500**

Adjusted Targets & Approach

Metric	Unit	Original	New
(Commercial) System Capacity	Ton	5	4*
Demand Reduction	%	50+	50+
Period	hours	4+	2+
Overall COP Improvement	%	20+	20+
TES Cost	$/kWh	15-	15-

- **Current TES weight is 3 x HP**
- **Lower refrigerant charge increase in PHX compared to direct ref/TES**
- **Water ΔT in PHX degrades the HPTES COP compared to direct ref/PCM**

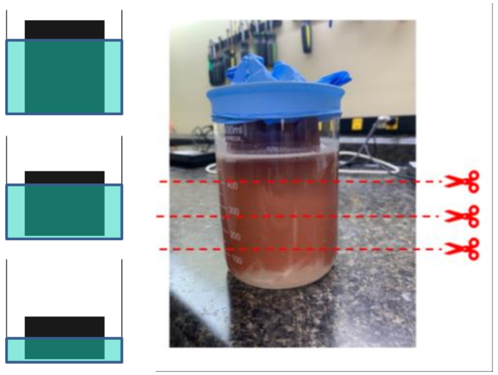


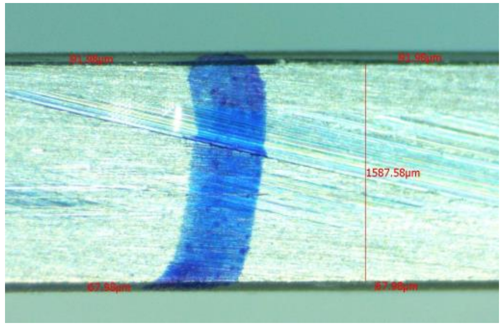
*Highest selling system by millions of unit shipped (Source: AHRI (Statistics | AHRI (ahrinet.org)))

TES Design, Assembly, & Material Durability

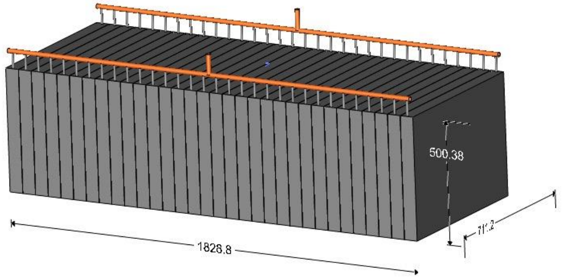
- **TES requirements**
  - Cooling mode: 16-17 kW
  - Heating mode: 10-11 kW
- **Storage requirement:** $V_{PCM} = 0.45\ \mathrm{m}^3$
- **Discharge rate requirement:** $\dot{Q} = 17\ \mathrm{kW}$
- **HXs types that meet TES requirements**
  - Microchannel HX
    - Small internal volume, low-cost and weight, high compactness
    - Difficult to assemble & package
  - ✓ Tube-fin HX (32 HX required)
    - ✓ Adequate compactness, low-cost and weight
    - ✓ Easy to assemble & package

- **Corrosion Testing**
  - All-aluminum tube-fin corrodes in salt hydrates
  - Heresite™ immersed coating applied and tested
- **Sampling Approach & Coating Results**





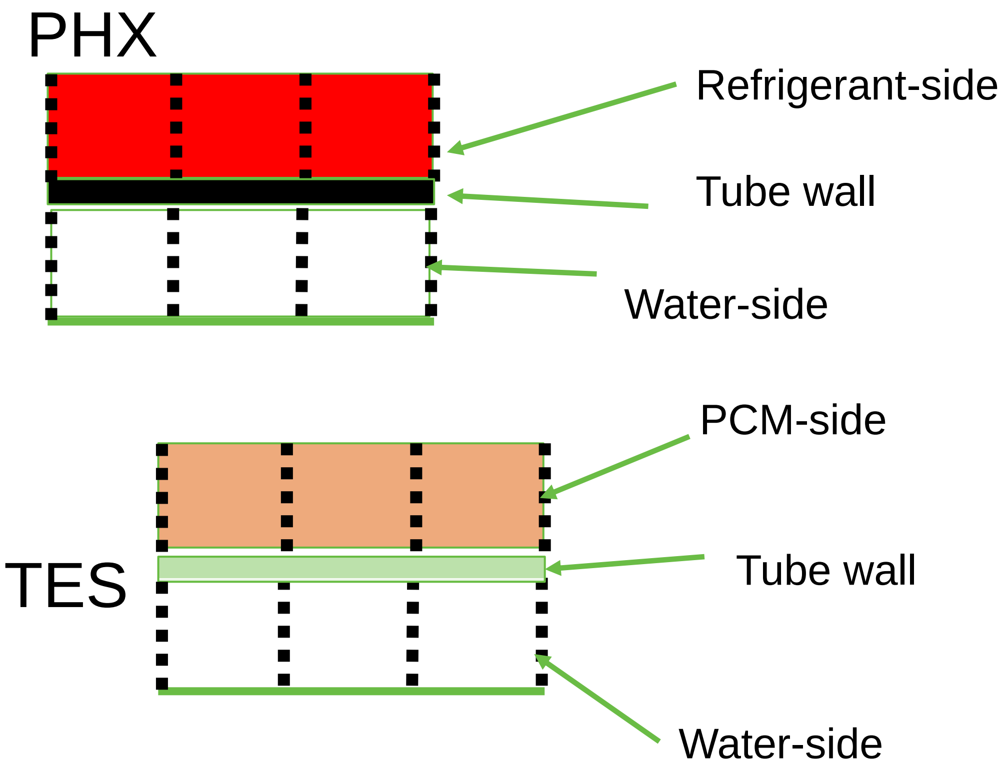
- **Packaged TES**



Transient Model Setup & Validation

- **Baseline HP cycle was modeled & validated in Modelica at AHRI A-test conditions**
- **Secondary loop components in Modelica**
  - Modelica results for selected plate HX in agreement with PHESim
  - Segmented TES model created using simplified resistance-capacitance model
- **System level modeling**
  - HP cycle: variable-speed rotary compressor with EXV
  - HP-TES cycle: created for charging and discharging, same as HP cycle

Metric	Unit	Experiment	Modelica	Abs. Diff.
Superheat	K	4.44	4.89	0.45
Subcooling	K	7.25	5.25	2.00
Suction T	°C	14.00	14.28	0.28
Discharge T	°C	71.11	74.94	3.83
Comp. Power	kW	3.22	3.18	1.24%
Indoor HX Capacity	kW	13.97	13.86	0.79%

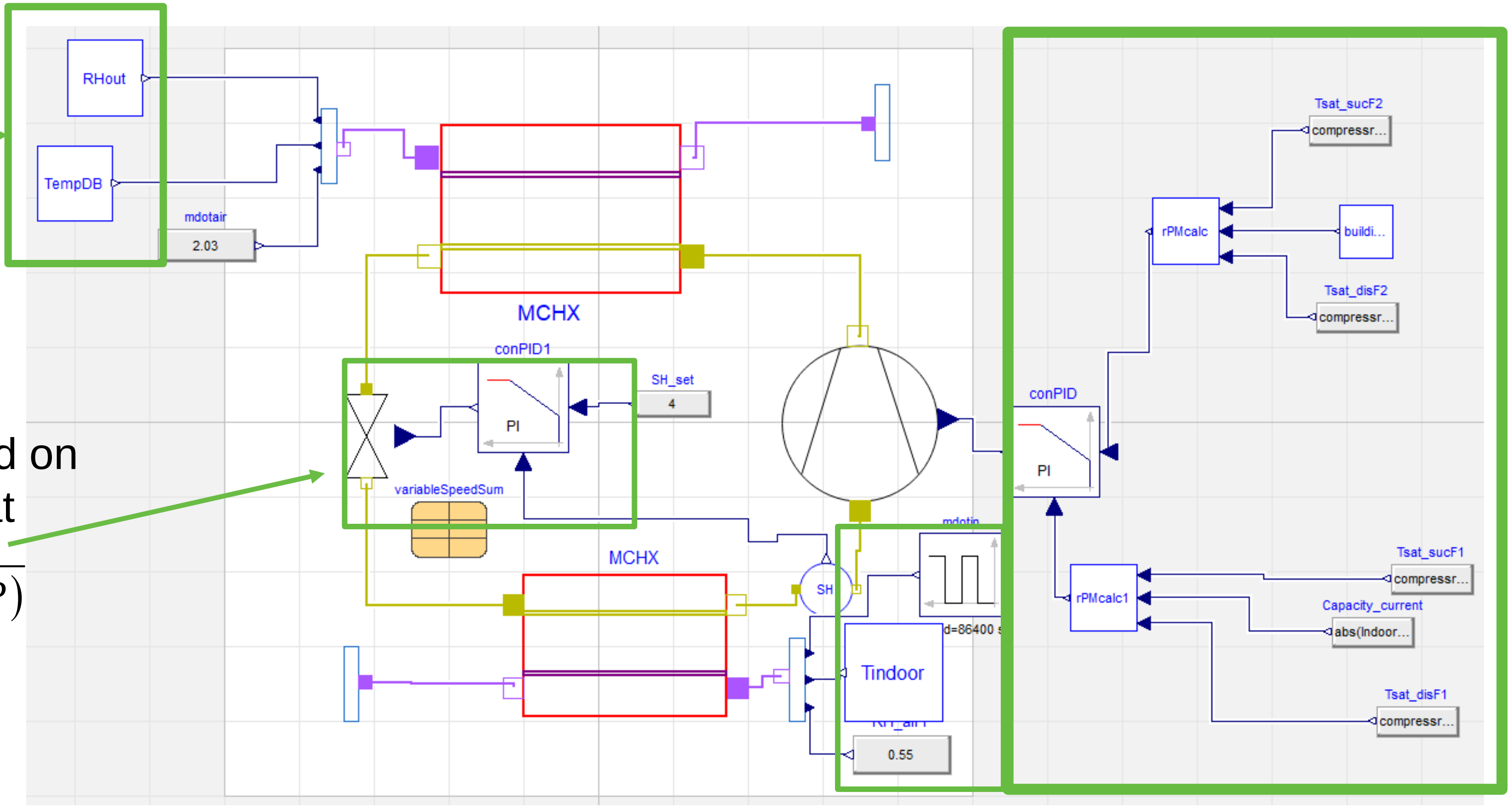


System Level Model with Weather Data & Building Loads

Outdoor weather TMY3, for summer and winter

EXV control, based on setting a superheat

$$\dot{m} = \frac{u}{u_{max}} C_v A \sqrt{\rho_{in} \left(\Delta P \right)}$$



Control of the compressor RPM, to match internal loads with the indoor HX capacity

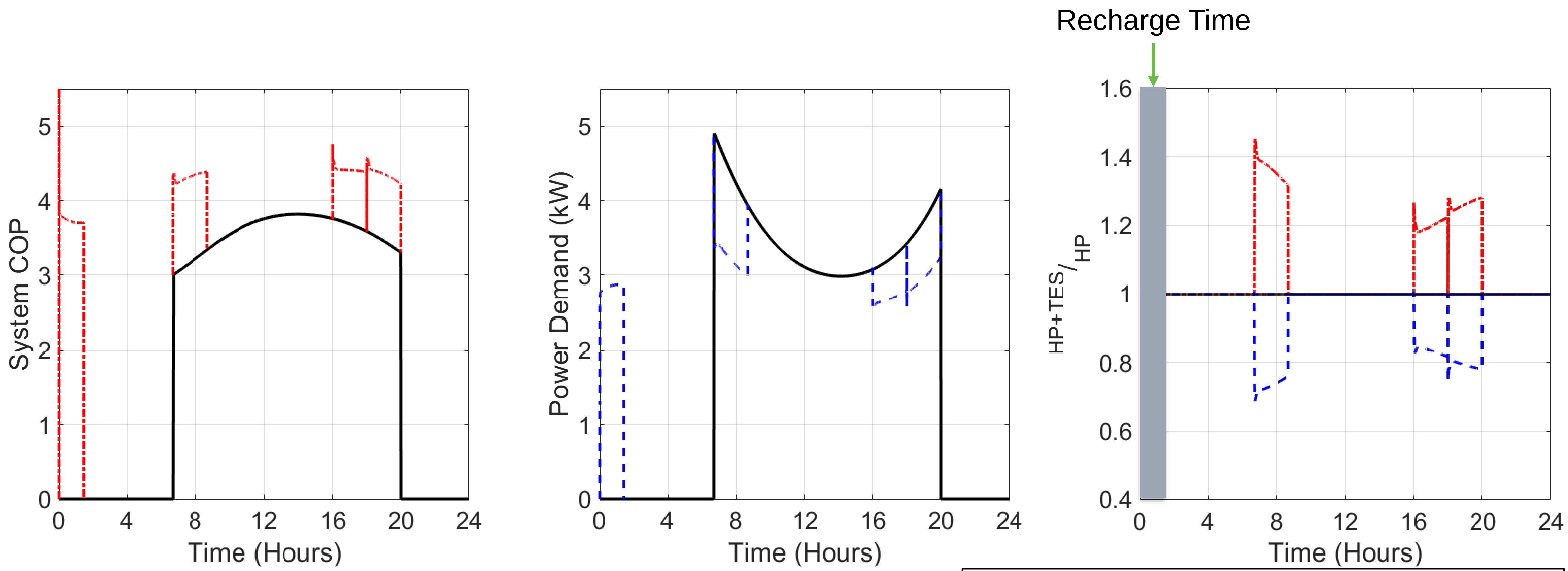
Indoor boundary conditions from building loads (Roth et al. 2022)

System Level Model with Weather Data & Building Loads

- **Similar HP system level components are available with the HP-TES except**
  - Discharging
    - Outdoor HX replaced with secondary loop
    - Only indoor weather data are used
  - Charging
    - Indoor HX replaced with secondary loop
    - Only outdoor weather data are used at nighttime

- **Lowest COP time slots during the day**
  - Cooling: 2:00 pm – 4:00 pm
  - Heating: 6:30 am – 8:30 am
- **Time slots for peak hours in Southern California TOU**
  - 4:00 pm – 6:00 pm
  - 6:00 pm – 8:00 pm
- **Key metrics: COP improvement & demand reduction**
- **Key assumption: HP-TES water pump power is the same as outdoor fan power**

Heating Mode

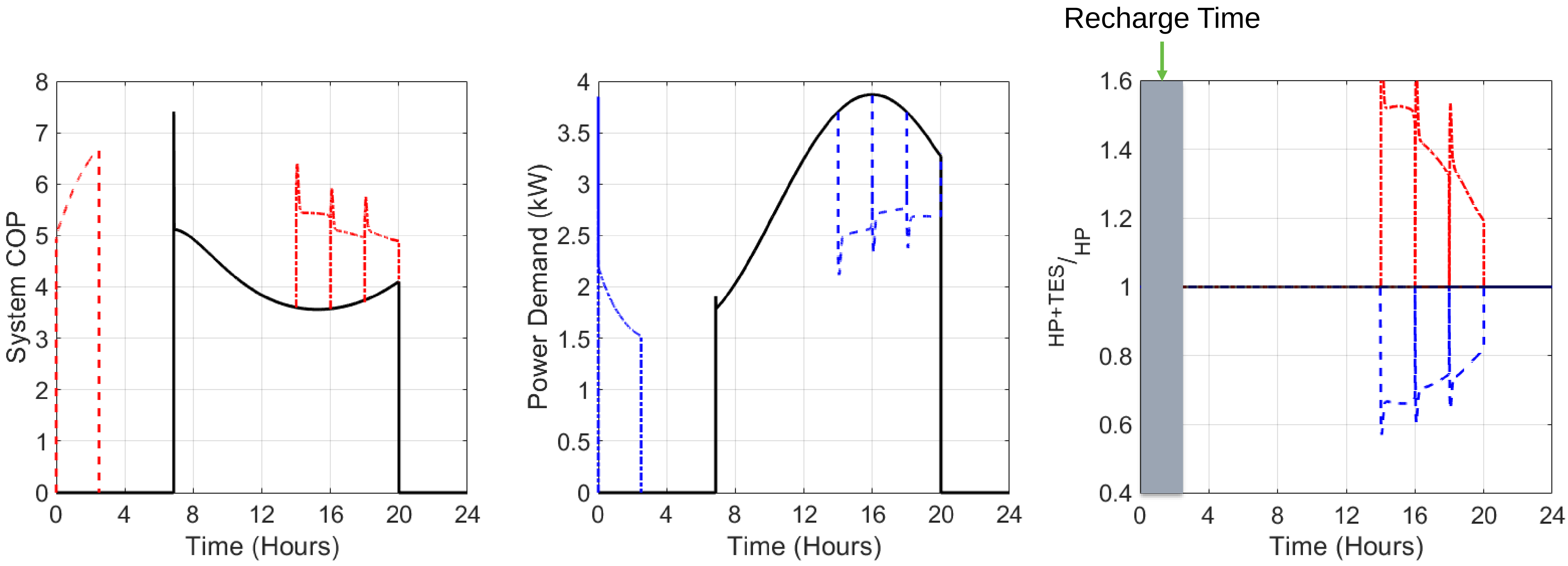


HP operation: 51.3 kWh
HP-TES (all): 51.2 kWh

HP+TES COP
HP+TES Power Demand
HP Operation

Slot 0: TES recharge time 12:00 – 2:00 am
Slot 1: TES operation time 6:30 – 8:30 am
Slot 2: TES operation time 4:00 – 6:00 pm
Slot 3: TES operation time 6:00 – 8:00 pm

Cooling Mode



HP operation: 42.4 kWh
HP-TES (all): 42.2 kWh

HP+TES COP
HP+TES Power Demand
HP Operation

Slot 0: TES recharge time 12:00 – 2:30 am
Slot 1: TES operation time 2:00 – 4:00 pm
Slot 2: TES operation time 4:00 – 6:00 pm
Slot 3: TES operation time 6:00 – 8:00 pm

Fabrication and Test Timelines

- **Thermal Battery Fabrication**
  - Fabrication & coating of 32 all-aluminum HXs (04-05/2023) (Rheem, Rahn)
  - Manifold construction & overall assembly (05-06/2023) (HTT, Insolcorp, ORNL, EPRI)
- **Baseline system testing**
  - ORNL Laboratory (03-04/2023)
  - EPRI Laboratory (05-06/2023)
- **Integrated system testing**
  - 06-09/2023 (ORNL, EPRI)
- **Field test site selection**
  - 09/2023

Stakeholder Engagement

- **Project partners (sub-recipients)**
  - Rheem Manufacturing
    - Baseline heat pump system hardware & test data
    - HP-TES components: all-aluminum tube-fin HXs for thermal battery, plate HX for secondary loop, compressors & expansion devices
    - Commercialization advisor
  - Insolcorp
    - PCM manufacturer
    - Thermal battery assembly
    - Commercialization advisor
- **Industry involvement**
  - Rahn Industries
    - All-aluminum HX coating for thermal battery

Next Steps

- Model smooth switch between HP & HP-TES operation
- Analyze the HP+TES for summer, winter, & shoulder season for all 7 climate zones
- Conduct full transient seasonal simulations
- Fabricate/assemble battery (Ongoing)
- Test baseline system (Ongoing)
- Test integrated system
- Validate model using laboratory test data

Thank You

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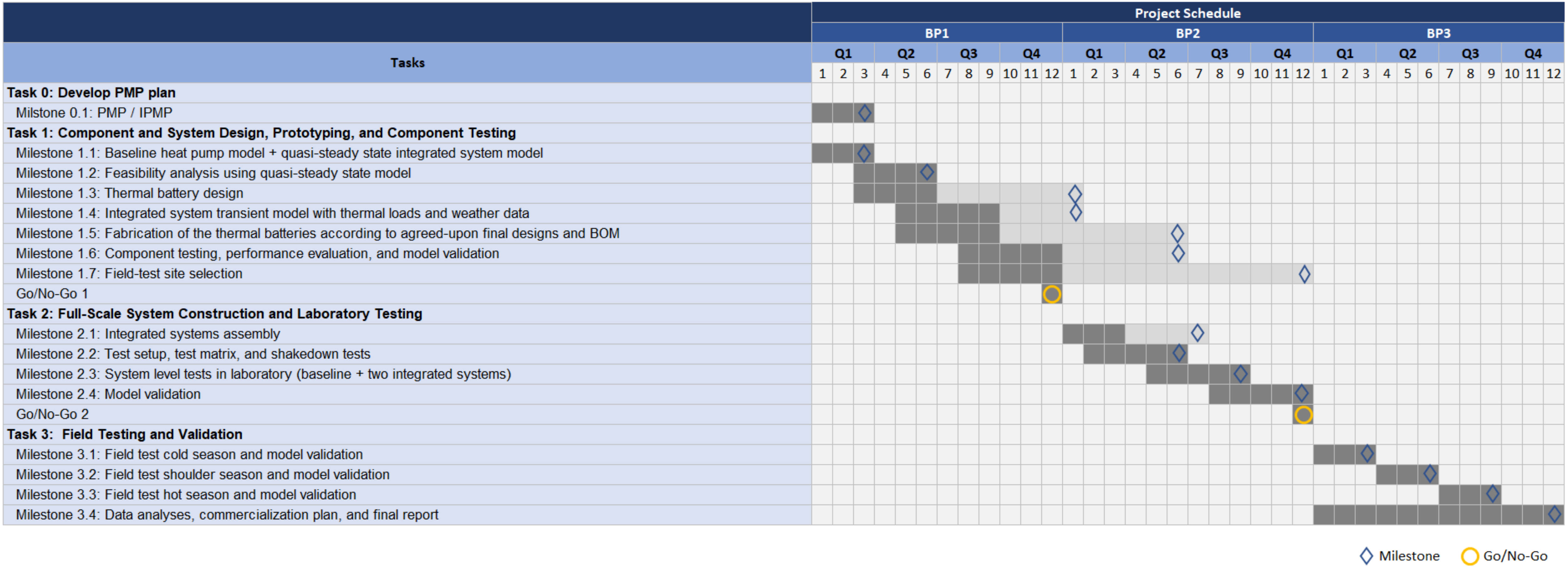
REFERENCE SLIDES

Project Execution



Team

- **University of Maryland (Prime recipient)**
  - System modeling/design, data analysis, project management
- **Oak Ridge National Laboratory (Sub-recipient)**
  - System modeling, system assembly, laboratory testing, technical advisor
- **Electric Power Research Institute (Sub-recipient)**
  - System assembly, laboratory testing, technology demonstration lead, technical & code/regulation advisor
- **Rheem Manufacturing (Sub-recipient)**
  - System/component supplier, technical & commercialization advisor
- **Insolcorp (Sub-recipient)**
  - PCM supplier, system assembly, technical & commercialization advisor
- **Heat Transfer Technologies (Sub-recipient)**
  - Thermal battery design, assembly, technical advisor
- **Southern California Edison (EPRI's partner)**
  - Cost share contributor, technology demonstration promoter
- **Rahn Industries (industry partner)**
  - Heat exchanger coating for thermal battery