Hybrid HVAC with Thermal Energy Storage Research and Demonstration

Performing Organization(s): LBNL, UC Davis, UC Berkeley, Emanant
PI Name and Title: Brett Singer / Spencer Dutton
PI Tel and/or Email: smdutton@lbl.gov
Project Summary

**Timeline:**
- Start date: October 2018
- End date: March 2022

**Remaining Milestones:**
1. Completion of system design tools, 7/2021
2. Lab characterization of Seeley HRV + IEC, 9/2021
3. Completion of “shovel ready” commercial building prototype, Fall 2021.
4. Competition of residential field installation, Fall 2021

**Budget:**
- DOE: $3050k
- Cost Share: $  
  - Sunamp (TES) $20k (equipment) 30k (support)  
  - Aermec (heat pump) $10k (equipment) 10k (support)  
  - LG (heat pump) $10k (equipment) 10k (support)

**Key Partners:**

<table>
<thead>
<tr>
<th>Team</th>
<th>Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>UC Davis WCEC</td>
<td>LG</td>
</tr>
<tr>
<td>UC Berkeley</td>
<td>Aermec</td>
</tr>
<tr>
<td>Emanant</td>
<td>Sunamp</td>
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**Project Outcome:**
- Package designs of thermal energy storage integrated with efficient heat pumps that can respond to supply and cost signals.
- Modeled and pilot physical installations to demonstrate feasibility.
- Demonstrate minimum peak load reduction of 20% and 30% annual HVAC energy cost savings, compared to state of the art all electric.
Challenge

Problem Definition:
Decarbonizing building energy use requires both electrification and load shifting to align with renewable generation. Thermal loads of space heating and cooling and hot water particularly important. Thermal storage offers advantages but needs to be packaged with efficient equipment for scale-up.

Solution
Grid-interactive HVAC and HW systems, with integrated active thermal energy storage:
- enable electrification of heating and DHW
- advance grid-interactive efficient building systems
- support broader use of renewables
- improve grid and building resilience
- reduce energy costs & emissions
Team

**Lawrence Berkeley National Laboratory**
- Spencer Dutton, Ph.D.
- Brett Singer, Ph.D.
- Armando Casillas
- David Blum, Ph.D.
- Dre Helms, Ph.D.
- Donghun Kim, Ph.D.
- Anand Prakash
- Alastair Robinson

**University of California, Berkeley**
- Van Carey, Ph.D.
- Alanna Cooney

**University of California, Davis**
- Vinod Narayanan, Ph.D.
- David Vernon, Ph.D.
- Subhrajit Chakraborty
- Caton Mande

**Emanant Systems**
- Jonathan Woolley

**NestWorks**
- Michael Woodcox
Opportunities:
- Lower cost (heading to below $50/kWh, high density)
- Non-toxic, non-flammable, >60k cycles.

Challenges:
- Lack of performance data
- Lack of models / system models
- Control of complex systems
- Cost / physical constraints

Approach: Inception

- Advanced heat pumps
- Phase change materials thermal energy storage
- Electrochemical energy storage
- DOAS with heat recovery + indirect evaporative cooling
Approach: Objectives

Develop and demonstrate packaged system designs:
- high performance air-to-water heat pumps
- thermal and electrochemical energy storage
- evaporative cooling and energy recovery
- grid-interactive, model predictive control strategies

Tools to accelerate implementation

Work with industry partners for commercialization
Approach: Key Steps

Foundational technology development
- Lab characterization of component technologies
- Simulation tools enable evaluation of techno-economic potential.

Techno-economic evaluation of market application
- Market viability analysis (DOE iCorps)
- Active industry partnerships
- Simulated designs for three applications and model-predictive controls

Demonstration of prototype
- Shovel ready commercial building prototype
- Plan for field demonstration as next step
- Installation in cold climate residence
Impacts: Simulations demonstrate savings

- Advance grid-interactive efficient systems through **demos and tools**
- **Enable electrification** of heating and DHW
- Simulated peak load reductions of: 58%, 44%, 55% for BBR, PSP and MFR respectively
- Simulated 20-50% energy cost* savings 3 simulated applications

*Preliminary TEA analysis in Helmns, D. et al., Towards a Techno-Economic Analysis of PCM-Integrated Hybrid HVAC Systems, HPB2021-3416
Impact: Advanced real-world demonstrations

Current projects continuing development of technologies, follow-on projects

Hybrid HVAC with TES
- Shovel ready prototype
- Demo in residence
- MPC tested in simulation
- Rule based hardware control

Hardware in the loop
- PCM TES model testing in virtual plant

Cal Flex HUB
- Laboratory testing
- Hardware control based on dynamic pricing signal based hardware control

HP Flex
- Field demonstration of PCM based TES
- Hardware MPC

New funding proposals

BENEFIT “Thermal Energy Storage Research and Demonstration for Multifamily Hot Water”
Progress: System Designs

Big box retail

Small/medium office

Multi-family residential

(Add citation for published paper)
Progress: Parametric Simulation Tool

Parametric simulation framework developed to easily configure different scenarios. Uses time series data to analyze demand reduction and operating cost savings.

Progress: Laboratory and field testing

Evaluating three core component technologies

- Thermal batteries that use phase change materials
  - 58°C (136°F), 48°C (118°F), 43°C (109°F), 11°C (52°F)
- Heat recovery ventilator with indirect evaporative cooling (ongoing)
- High temperature air-to-water heat pump (ongoing)

**Sunamp**

**Seeley International**

**LG**
Engagement of market actors

Manufacturers
- AERMEC
- Carrier
- LG
- Sunamp
- nyle systems
- neothermal energy storage

Deployment
- OAKLAND UNIFIED SCHOOL DISTRICT
- ROCKY MOUNTAIN INSTITUTE
- ASSOCIATION FOR ENERGY AFFORDABILITY
- REDWOOD ENERGY

Integrated Design
- harvest thermal
- Otherlab
- SMITHGROUP
- EMANANT

Codes & standards
- STATE OF CALIFORNIA ENERGY COMMISSION
- ASHRAE
Technology Transfer

- Tag meetings with industry partners + joint DOE iCorps
- Two ASHRAE seminars
  - “Integrated HVAC Systems for Small and Medium Commercial Buildings”
- Peer-reviewed papers
  - Development and Validation of a Latent Thermal Storage Model Using Modelica, 2020
  - Towards a Techno-Economic Analysis of PCM-Integrated Hybrid HVAC Systems, 2021
- Papers under development
  - Development and lab validation of a numerical model for PCM thermal energy storage.
  - Model development and lab validation of M-cycle type indirect evaporative cooler with heat recovery.
Monitored field evaluation of integrated system

Project details
• Residential installation (Massachusetts)
• Cold climate evaluation (−5°F heating design)

System and functions
• Air to water heat pump (R32)
• PCM thermal energy storage
• Heating, cooling, and DHW
• Fan coil units and radiant floors

Objectives
• Characterize HP
• Measure integrated system efficiency and demand reduction
• Validate simulation models
• Evaluate real world system behaviors
  ○ Intermittent performance at extremes
  ○ Defrost cycle

KEY HIGHLIGHTS
● All-electric heating and DHW in a cold climate without electric resistance
● Reduced heat pump size
● Reduced footprint for storage
● Monitoring real world performance
Next Steps: Field Installation & Demonstration

Objectives:

- Prove integrated system functions
- Demonstrate strategic controls
- Measure energy performance and savings
- Validate models and simulation tools
Thank You

Lawrence Berkeley National Laboratory
Spencer Dutton
smdutton@lbl.gov
Project Budget

Project Budget: Original budget $3,504k, Total now expected $3,005k

Variance: Scope adjusted in Y3 to postpone field installation to follow on funding.

Cost to Date: Full funding received

Additional Funding: Proposals for follow on funding in process.

<table>
<thead>
<tr>
<th>FY18-FY19 (past)</th>
<th>FY 19 - FY20 (past)</th>
<th>FY20- FY21 + 6 months (current + extension)</th>
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### Project timeline

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<tr>
<th>AOP Task</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
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<tbody>
<tr>
<td>Market Study</td>
<td>10/01/18</td>
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<td>03/31/21</td>
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<tr>
<td>Modeling</td>
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<td>12/31/20</td>
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<td>Equipment (Lab) Testing</td>
<td>04/01/20</td>
<td>05/31/21</td>
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<td>Parametric Analysis</td>
<td>04/01/20</td>
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<td>09/30/21</td>
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<tr>
<td>Complete lab prototype</td>
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<td>03/31/21</td>
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<td>09/30/21</td>
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<tr>
<td>Complete residential system</td>
<td>06/01/21</td>
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<td>12/31/21</td>
<td>02/28/22</td>
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<td>Final Report</td>
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<td>10/01/21</td>
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### Major corrections to original plan
- Continue simulation modeling of all three building applications.
- Build proto-type system in house to retain knowledge and enable rapid changes.
- Perform parallel development of simulation models and hardware prototype.
- Perform LG heat-pump characterization in a home (reduce cost and facilitate follow-on projects).
## Milestones

<table>
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<tr>
<th>Date</th>
<th>Milestone Details</th>
<th>Status</th>
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<tbody>
<tr>
<td>3/29/2019-</td>
<td>M1.1 -&gt; M1.5: Simulation tool development milestones resulting in simulated performance for one system with at least 30% annual HVAC energy cost savings and 20% peak load reduction.</td>
<td>Completed on schedule (all)</td>
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<td>&gt;12/31/2019</td>
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<td>3/30/2020</td>
<td>M2: Webinar presenting system performance results, and economic analysis.</td>
<td>Completed on schedule</td>
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| 6/30/2020   | M3: System designs achieve 30% annual HVAC energy cost savings and 20% peak load reduction.  
M4: Completed detailed TES characterization testing plan.  
M5: Complete initial techno economic analysis. | Completed on schedule |
| 9/30/2020   | M6: Begin TES characterization experiment in FlexLab                              | Completed on schedule |
| 12/31/2020  | M7: Complete development test plan for chamber testing of the IEC-HRV              | Completed on schedule |
| 3/30/2021   | M8: Complete SWEC testing                                                          | Completed on schedule |
| 5/30/2021   | M9: Competed hardware component characterization of TES                             | Completed on schedule |
| 9/30/2021   | M10: Complete parametric simulations  
M11: Competed hardware component characterization of IEC-HRV | ongoing |
| 12/31/2021  | M12: Complete “shovel ready” prototype suitable for commercial building            | ongoing |
| 12/31/2021  | M13: Complete installation and begin data collection for residential system        | ongoing |
| 2/31/2022   | M14: Final report draft                                                           | ongoing |