An air conditioner with composite phase change material (FY19 Technology Commercialization Fund project)

Composite phase change material:

NREL
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Project Summary

Timeline:
Start date: 2018 December
Planned end date: 2021 June

Key Milestones
1. Experiments complete on 5-ton system prototype; 06/30/2020
2. Experiments complete on next-generation thermal storage prototype; 06/30/2021

Budget:
Total Project $ to Date:
• DOE: $500,000
• Cost Share: $550,000

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Key Partners:
- NETenergy
- Emerson
- Trane Technologies

Project Outcome:
This project will develop prototypes of a new hybrid air conditioner with embedded thermal energy storage. It focuses on packaged air conditioners, which has limited thermal storage options despite it being the largest space cooling market in the US.

The goal is to develop an affordable and cost-effective thermal storage technology that enables load flexibility and reduced carbon emissions.
NREL
Dr. Jason Woods (PI)
Dr. Allison Mahvi
Dr. Anurag Goyal
Eric Kozubal
Dr. Wale Odukomaiya

Materials characterization
Thermal storage design/modeling
Laboratory characterization

NETenergy
Dr. Said Al-Hallaj
Mike Pintar

Material synthesis
Thermal storage sub-system build
Commercialization

Emerson
Dr. Rob Comparin
Dr. Juan Catano Montoya

Vapor-compression components build
Market analysis
Manufacturing cost analysis

Trane
Manlio Valdez
Scott Smith

Support on vapor-compression build
Support on market analysis
Challenge

- 77% of electricity is used at buildings
- 50-60% of that is for thermal loads
- Much of this is mismatched with renewable-electricity generation

Existing ice and chilled water storage are often cost-effective for these applications

US electricity generation for a 100% renewable grid compared to building thermal and non-thermal loads.

There’s no available solution for split and packaged systems (>80% of US floor space).

Fraction of US commercial floorspace cooled by HVAC type

Approach

A “hybrid” air conditioner where the thermal storage shaves the peak cooling demand, while the compressor operates at a reduced capacity.

Composite phase change material:
Impact: Creating a packaged air conditioner with TES that can succeed in the market

<table>
<thead>
<tr>
<th></th>
<th>Rooftop unit integrated ice system (previous state-of-the-art)</th>
<th>Proposed hybrid air conditioner integrated with c-PCM heat exchanger</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Cost</strong></td>
<td>5x higher cost than standard RTU</td>
<td>50% higher cost than standard RTU</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>2,700 kg in separate box</td>
<td>350 kg added to RTU</td>
</tr>
</tbody>
</table>

**Performance relative to baseline non-TES air conditioner**

<table>
<thead>
<tr>
<th></th>
<th>Electric demand (kW)</th>
<th>Electricity use (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>90% lower</strong></td>
<td>10% higher</td>
<td>10% lower</td>
</tr>
<tr>
<td><strong>35%–45% lower</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Previous approaches are way too heavy and expensive for packaged systems, which condition >80% of US floor space.

Significant potential energy, CO$_2$, and monetary savings.
### Progress

**Modeling, design, and experiments:**

- TES sub-system: 1\textsuperscript{st} generation, 1 tonh, glycol-glycol
- Air conditioning system: 1\textsuperscript{st} generation TES, 6-tonh, refrigerant-glycol
- TES sub-system: 2\textsuperscript{nd} generation, 1/10\textsuperscript{th} tonh, glycol-glycol
Progress: 1st generation, 1 tonh prototype

Finite-volume numerical model used to estimate contact resistance. Estimated at >50% of the overall resistance.
Progress: 1st generation, full-system

Charge subsystem – Condensing unit from Trane, modified by Emerson

Discharge subsystem - Built by Emerson
System installed at NREL ~ November 2019, with support from Emerson team.

Progress: 1st generation, full-system
Key findings:

- Controls were effective at modulating charge/discharge and keeping superheat at TES outlet near 0 °C (suction-line HX ensures adequate superheat into compressor).
- PCM leak observed due to expansion on solid-liquid phase change.
- Contact resistance a critical problem with serpentine design.
- Need to eliminate refrigerant migration at end of charge cycle, which leads to self-discharge of TES.
### Progress: 2nd generation, 1/10th tonh

<table>
<thead>
<tr>
<th>Material</th>
<th>Cycling performance – mass loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum foil</td>
<td>0.7% decrease after 1 cycle</td>
</tr>
<tr>
<td>Mylar film</td>
<td>4.3% decrease after 2 cycles</td>
</tr>
<tr>
<td>Sealed Mylar bag</td>
<td>0% decrease after ~60 cycles</td>
</tr>
</tbody>
</table>

![Mylar Bag](image)

**Diagram:**
- **Test section**
- **Temperature (T)**
- **Flow rate (V)**
- **Pump**
- **Heater**
- **Chillers**
- **16°C**
- **0°C**
Progress: 2\textsuperscript{nd} generation, 1/10\textsuperscript{th} tonh

Solid lines – experimental data
Dashed lines – model results

Net charging
Avg error = 0.34 °C
Max error = 1.16 °C

Net discharging
Avg error = 0.22 °C
Max error = 0.67 °C

Progress: 2\textsuperscript{nd} generation, 1/10\textsuperscript{th} tonh

\textbf{1\textsuperscript{st} generation – Copper tube}
Experimental data from Goyal et al. (2021)

\textbf{2\textsuperscript{nd} generation - Microchannel}
Results using current microchannel model

Progress: Energy and demand savings point to manufacturing cost targets

<table>
<thead>
<tr>
<th>Climate</th>
<th>TES design</th>
<th>PCM T_\text{°C}</th>
<th>Fixed-speed peak power kW</th>
<th>TES hybrid peak power kW</th>
<th>kW % change</th>
<th>kWh</th>
<th>Fixed-speed energy kWh</th>
<th>kWh % change</th>
<th>TES hybrid energy kWh</th>
<th>kWh % change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles</td>
<td>Serpentine</td>
<td>4.5</td>
<td>5.59</td>
<td>2.9</td>
<td>-48%</td>
<td>33.1</td>
<td>28</td>
<td>-20%</td>
<td>26.4</td>
<td>-24%</td>
</tr>
<tr>
<td></td>
<td>Microchannel</td>
<td>4.5</td>
<td>2.4</td>
<td>2.4</td>
<td>-57%</td>
<td>34.8</td>
<td>26.4</td>
<td>-24%</td>
<td>38.4</td>
<td>-14%</td>
</tr>
<tr>
<td></td>
<td>Microchannel</td>
<td>10.0</td>
<td>0.1</td>
<td>2.4</td>
<td>-57%</td>
<td>34.8</td>
<td>26.4</td>
<td>-24%</td>
<td>38.4</td>
<td>-14%</td>
</tr>
<tr>
<td>Baltimore</td>
<td>Serpentine</td>
<td>4.5</td>
<td>4.87</td>
<td>3.1</td>
<td>-36%</td>
<td>38.4</td>
<td>33</td>
<td>-14%</td>
<td>38.4</td>
<td>-14%</td>
</tr>
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<tr>
<td></td>
<td>Microchannel</td>
<td>10.0</td>
<td>2.4</td>
<td>2.4</td>
<td>-51%</td>
<td>38.4</td>
<td>33</td>
<td>-14%</td>
<td>38.4</td>
<td>-14%</td>
</tr>
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</table>

Added costs for 5 tonh storage
In a 5-ton system

- **Cu tubes C14H30 ref/gly**
- **Microchannel C14H30 ref/gly**
- **Microchannel C14H30 ref/ref**
- **Microchannel TBAB hydrate ref/ref**

**Cost target to achieve 3-yr payback with existing utility rates**

*This considers only the building owner’s costs; it does not include utility incentives or other benefits to the utility.*
Stakeholder Engagement & next steps

• Trane and Emerson: Customer discovery workshop
  • Focus on installers, building managers – make sure this technology looks familiar
  • Approach companies with large national accounts (i.e., that own a lot of buildings)

• Exelon corporation (electric utility)
  – NETenergy working with Exelon electric utilities for future demonstration in their territory

Next steps

• Scale-up of 2\textsuperscript{nd} generation thermal storage design
• Integration of scaled-up 2\textsuperscript{nd} generation design with vapor compression air conditioner for laboratory experiments and eventual field demonstration
• Development of technology that uses the c-PCM for cooling and heating
Thank You

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720.441.9727  |  jason.woods@nrel.gov
Project Budget: NREL received $500,000 from DOE Office of Technology Transitions in December 2018. NETenergy provided $175,000 in cost share (funds to NREL) and NETenergy, Emerson, and Trane provided $425,000 of in-kind cost share.

Variances: The project was completed as planned.

Cost to Date: All funds have been spent.

<table>
<thead>
<tr>
<th>Budget History</th>
<th>FY 2019 (past)</th>
<th>FY 2020 (past)</th>
<th>FY 2021 (current)</th>
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<tbody>
<tr>
<td>Start date: Dec. 2018</td>
<td>$500,000</td>
<td>$0</td>
<td>$0</td>
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<tr>
<td>DOE Cost-share</td>
<td>$165,000</td>
<td>$245,000</td>
<td>$140,000</td>
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<tr>
<td>DOE Cost-share</td>
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# Project Plan and Schedule

**Project start:** December 2018  
**Project end:** June 2021

## Completed milestones

<table>
<thead>
<tr>
<th>FY19Q1</th>
<th>FY19Q2</th>
<th>FY19Q3</th>
<th>FY19Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite PCM experimental results</td>
<td>Experimental results on composite PCM heat exchanger</td>
<td>Progress update on HVAC system design</td>
<td>System built and integrated with system-scale composite PCM HX</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FY20Q1</th>
<th>FY20Q2</th>
<th>FY20Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>System installed and commissioning of 5-ton prototype</td>
<td>Progress update on 5-ton system experiments</td>
<td>Report on system experiments</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>FY20Q4</th>
<th>FY21Q1</th>
<th>FY21Q2</th>
<th>FY21Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental data on next-generation HX prototype</td>
<td>Draft article on next-gen TES prototype, experiments and modeling</td>
<td>Building model and analysis for updated system design</td>
<td>Final Report for Project TCF-18-15537</td>
</tr>
</tbody>
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<table>
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<th>FY19Q2</th>
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<tbody>
<tr>
<td>Completed work</td>
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<td></td>
<td></td>
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<table>
<thead>
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<th>FY20Q1</th>
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<tr>
<td>Completed work</td>
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<table>
<thead>
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<th>FY21Q1</th>
<th>FY21Q2</th>
<th>FY21Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completed work</td>
<td>Future work</td>
<td></td>
</tr>
</tbody>
</table>

*Legend:*  
- **Completed work**  
- **Future work**