Demand Response for Everyone: Using Freezer Energy Storage to Balance the Grid

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Increasing Renewable Energy Use

Growing Adoption of Time-of-Use Rate Structures

Mitigate Impact of Supply Variability

Shave Peak Consumption

Cost-efficient Consumption
Highly centralized, site-dependent, mature incumbent technologies paired with a host of expensive and unproven technologies, mostly in pilot for utility-scale applications.
**Energy-Agile Refrigerator**

- Conventional fridges already have energy storage
- Storage enhanced by inserting phase-change material (PCM) into freezer
- Energy from latent heat of formation (freeze/thaw)
- Temperature and power sensors for monitoring and control
- Low-temperature “ice battery”
  - Delay compressor cycles
  - Aggregation potential

6 kg. NH₄Cl in 19.1% aqueous solution
Selecting a Material

- Thermal mass alone is not enough
- Latent heat of formation – not specific heat
- Choose phase change material that freezes above or within freezer guardband
- Avoid “slurry” – minimize phase separation → Eutectic solution
- Result: 19.1% NH₄Cl aqueous solution → salty “blue ice” freezes at -15.7 °C
Freezer with Ice Battery

![Graph of Temp and Power over time]

**Temp (°C)**
-0 to 0

**Power (W)**
-0 to 400

**Graphs show**
- Temp variations over time for Air and Liquid.
- Power consumption spikes at specific times.

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LoCal
Choosing the Setpoint

![Temperature Graphs]

**Graph 1:**
- **Temperature (°C)**
- **Time:** 00:00 to 03:00
- **Lines:** Red (Air) and Blue (Liquid)

**Graph 2:**
- **Temperature (°C)**
- **Time:** 00:00 to 03:00
- **Lines:** Red (Air) and Blue (Liquid)
Defrost Cycle

![Graph showing temperature changes over a 7-hour period. The graph displays two lines, one in red and one in blue, representing temperature variations at different times of the day. The y-axis represents temperature in °C, ranging from -25 to 0. The x-axis represents time from 00:00 to 07:00.]
### Steady State Comparison

<table>
<thead>
<tr>
<th></th>
<th>Duty Cycle (no defrost)</th>
<th>Defrost Duration</th>
<th>Post-Defrost Compress or</th>
<th>Duty Cycle (compress or only)</th>
<th>Defrost Energy (% of Total)</th>
<th>Daily Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>No PCM, coldest setting</td>
<td>55.5%</td>
<td>11.7 mins</td>
<td>81 mins</td>
<td>56.6%</td>
<td>7.2%</td>
<td>1.79 kWh</td>
</tr>
<tr>
<td>PCM, coldest setting</td>
<td>70.9%</td>
<td>13.7 mins</td>
<td>123 mins</td>
<td>70.3%</td>
<td>7.8%</td>
<td>2.18 kWh</td>
</tr>
<tr>
<td>PCM, next-to-coldest setting</td>
<td>63.8%</td>
<td>11.7 mins</td>
<td>126 mins</td>
<td>67.2%</td>
<td>7.3%</td>
<td>2.17 kWh</td>
</tr>
</tbody>
</table>
Avoiding Peak Electricity

- Freezers have predictable periodic electricity use
- Most consumers pay one price for electricity
- With time-of-use rates, electricity costs more during peak hours
- Leverage time-of-use rates to save money
Ice Battery Thaw Process

![Diagram showing air temperature over time for different PCM configurations: No PCM, Passive PCM, PCM + Fan/Pump Lo, PCM + Fan/Pump Hi.](image-url)
Temperature Stability

- **Air**
- **Liquid**

Graph showing temperature stability over time with two lines representing different conditions.
Future Work

• Minimum viable product

• Active thermal isolation

• Forced cooling of refrigerator compartment

• Commercial-scale prototype
CA: 3872 MW (3850 MW PH)

CA Residential Freezers: 575 MW

CA Commercial Freezers: 641 MW

Source: Fraunhofer Institute, EFRI
Questions?

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