
Building Technologies Office
June 2, 2020
I. GEB Overview
   - Monica Neukomm, Senior Policy Advisor
     • Building Technologies Office

II. GEB HVAC, Water Heating, Appliances, and Refrigeration Report
   - Matt Guernsey, Associate Director
     • Guidehouse Consulting (Navigant)

III. HVAC Flexibility Metrics
   - Nelson James, Science, Technology, and Policy Fellow
     • Building Technologies Office

IV. Quantifying Flexibility Potential
   - Nelson James, Science, Technology, and Policy Fellow
     • Building Technologies Office

V. Q&A Session
   - Antonio Bouza, HVAC, Water Heating, and Appliances Technology Manager
     Technology Manager
     • Building Technologies Office
<table>
<thead>
<tr>
<th>Topic</th>
<th>Date</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole-building Control, Sensing, Modeling &amp; Analytics</td>
<td>May 19</td>
<td>2:00pm - 3:30pm ET</td>
</tr>
<tr>
<td>Lighting &amp; Electronics</td>
<td>May 26</td>
<td>2:00pm - 3:00pm ET</td>
</tr>
<tr>
<td>Heating, Ventilation &amp; Air Conditioning (HVAC)</td>
<td>June 2</td>
<td>2:00pm - 3:30pm ET</td>
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<tr>
<td>Water Heating &amp; Appliances</td>
<td>June 9</td>
<td>2:00pm - 3:00pm ET</td>
</tr>
<tr>
<td>Envelope &amp; Windows</td>
<td>June 16</td>
<td>2:00pm - 3:30pm ET</td>
</tr>
<tr>
<td>Integration - Building Equipment</td>
<td>June 23</td>
<td>2:00pm - 3:00pm ET</td>
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<tr>
<td>Integration – Distributed Energy Resources (DERs)</td>
<td>June 30</td>
<td>2:00pm - 3:00pm ET</td>
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Technical Report Series:

- Overview of Research Challenges
- Heating, Ventilation, & Air Conditioning (HVAC); Water Heating; and Appliances
- Lighting & Electronics
- Building Envelope & Windows
- Sensors & Controls, Data Analytics, and Modeling
GEB is about enabling buildings to provide flexibility in energy use and grid operation.

~75% of electricity generation is used in buildings.
Potential Benefits of Flexible Building Loads

- Energy Affordability
- Improved reliability & resiliency
- Reduced grid congestion
- Enhanced services
- Environmental benefits
- Customer choice
Key Characteristics of GEBs

**EFFICIENT**
Persistent low energy use minimizes demand on grid resources and infrastructure

**CONNECTED**
Two-way communication with flexible technologies, the grid, and occupants

**SMART**
Analytics supported by sensors and controls co-optimize efficiency, flexibility, and occupant preferences

**FLEXIBLE**
Flexible loads and distributed generation/storage can be used to reduce, shift, or modulate energy use
Demand Management Provided by GEB

Efficiency

Load Shed

Load Shift

Modulate

Efficiency

Efficiency + Generate

Efficiency + Generate + Shed/Shift
Mapping Flexibility Modes and Grid Services

Buildings can provide grid services through 4 demand management modes.

**Grid Services Provided**

- **Efficiency**
  - Generation: Energy & Capacity
  - Non-Wires Solutions

- **Load Shed**
  - Contingency Reserves
  - Generation: Energy & Capacity
  - Non-Wires Solutions

- **Load Shift**
  - Generation: Capacity
  - Non-Wires Solutions

- **Modulate**
  - Frequency Regulation
  - Ramping

**Examples**

- Daylighting with sensors & controls
- Reduce plug loads
- Precool with T-stat; preheat water heater
- Rapid dimming of lighting
Importance of HVAC for GEB

U.S. 2018 Annual Electricity Use

HVAC electricity use in homes:
- 46% of peak
- 45% of total

HVAC electricity use in commercial buildings:
- 41% of peak
- 39% of total
Value of flexible HVAC

Electric Space Cooling

Substantial peak relative to trough, highlighting load shifting opportunity

Notable elevated load after sundown

- A/C load growth continues in most regions
- Utility concern: continued peak load growth on hottest days summer

Electric Space Heating

- Early morning peak before sunrise
- Substantially non-coincident with solar availability

- Common in the southeast; elsewhere gaining momentum via electrification trend
- Utility concern: switch to winter peak
• Greatest GEB opportunity is to use building thermal mass to proactively shift HVAC loads “ahead” in time. If done properly:
  – Minimize occupant impacts
  – Minimize “recovery” effects

• Assertion: shifting of HVAC loads should be provisioned at the highest level of coupling between thermal storage and HVAC system
  – Device level for residential AC
  – District level for district hot/chilled water systems
  – Building or zone level depending on configuration
What HVAC technologies can provide grid services?

Which have the highest potential?

What R&D is needed to overcome current challenges inhibiting their performance and/or adoption?
Process

Technology Evaluation
• Potential for shed, shift, and modulate

Technology Attributes
• Strengths, weaknesses, hurdles to market success

R&D Opportunities
• Needs and initiatives where DOE can add value
## Technology Flexibility Analysis Results

<table>
<thead>
<tr>
<th>HVAC Potential</th>
<th>HVAC</th>
<th>Cross Cutting</th>
</tr>
</thead>
</table>
| High Potential | • HVAC#1: Smart Thermostats  
• HVAC#2: Separate Sensible/Latent Space Conditioning  
• HVAC#3: Liquid Desiccant TES | • CC#1: Thermal Energy Storage  
• CC#3: Non-Vapor Compression (NVC) Materials and Systems |
| Medium Potential | • HVAC#4: Advanced Controls for HVAC Equipment with Embedded Thermostats | • CC#2: Modulating Capacity Vapor Compression |
| Low Potential | • HVAC#5: Hybrid Evaporative Cooling  
• HVAC#6: Dual-Fuel HVAC | • None |
We used 3 basic criteria to evaluate the technologies.

1. **Capability Rating for demand side management (DSM) strategy**
   - Based on Grid Services Technical Requirements

   ![Capability Ratings](chart)

2. **Number of demand-management strategies provided**
   - I.e., Efficiency, Load Shed, Load Shift, Modulate

3. **Weighting of demand-management strategies**
   - Efficiency and peak reductions (shed/shift) higher value than frequency regulation, voltage support, ramping (modulate)
## Technology Evaluation Details

<table>
<thead>
<tr>
<th>Technologies</th>
<th>Efficiency</th>
<th>Load Shed</th>
<th>Load Shift</th>
<th>Modulate</th>
<th>Overall Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC#1: Smart Thermostats</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High</td>
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<tr>
<td>HVAC#2: Separate Sensible and Latent Space Conditioning</td>
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<td></td>
<td>High</td>
</tr>
<tr>
<td>HVAC#3: Liquid Desiccant Thermal Energy Storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High</td>
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<tr>
<td>HVAC#4: Controls for HVAC Equipment w/Embedded T-stats</td>
<td></td>
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<td>Med</td>
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<tr>
<td>HVAC#5: Hybrid Evaporative Precooling</td>
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<td>Low</td>
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<tr>
<td>HVAC#6: Dual-Fuel HVAC</td>
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<tr>
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<tr>
<td>CC#1. Thermal Energy Storage (TES)</td>
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<td>High</td>
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<td>CC#2. Modulating Capacity Vapor Compression</td>
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<tr>
<td>CC#3. Non-Vapor Compression (NVC) Systems and Materials</td>
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<td>High</td>
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</tbody>
</table>
## HVAC Technologies Evaluated

### #1: Smart Thermostats

<table>
<thead>
<tr>
<th>Flexibility Mode</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td><img src="image" alt="Circle" /></td>
</tr>
<tr>
<td>Shed Load</td>
<td><img src="image" alt="Half-Circle" /></td>
</tr>
<tr>
<td>Shift Load</td>
<td><img src="image" alt="Circle" /></td>
</tr>
<tr>
<td>Modulate Load</td>
<td><img src="image" alt="Half-Circle" /></td>
</tr>
</tbody>
</table>

**Technology**
- Thermostats with connectivity, advanced algorithm controls, and compatibility with home automation systems

**Flexibility**
- Adding advanced controls and remote operation for relatively simple HVAC systems


### #2: Separate Sensible and Latent Space Conditioning

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</table>

**Technology**
- Desiccants, membranes for dedicated dehumidification; paired with a sensible cooling stage with separate controls

**Flexibility**
- Ramping down only the sensible cooling provides load reduction – maintains substantive occupant comfort

[https://www.nrel.gov/docs/fy13osti/57624.pdf](https://www.nrel.gov/docs/fy13osti/57624.pdf)
HVAC Technologies Evaluated Cont.

#3: Liquid Desiccant Thermal Energy Storage

**Technology:**
- Liquid desiccant storage for dehumidification in SSLSC; regenerated desiccants store energy chemically at ambient temp

**Flexibility:**
- Allows for shifting of dehumidification load to off-peak hours.

![Liquid Desiccant Tank](https://www.rheem.com/)

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<tr>
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<td></td>
</tr>
<tr>
<td>Modulate Load</td>
<td></td>
</tr>
</tbody>
</table>

#4: Advanced Controls for HVAC w/Embedded T-stats

**Technology:**
- Many small A/C do not connect to smart thermostats
  - They require their own advanced communications and connected controls

**Flexibility:**
- Wi-fi connectivity and mobile-app-based controls allow HVAC-ETs to communicate with utilities for curtailment

![Smart Thermostat](https://www.lg.com/)

<table>
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<td></td>
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<tr>
<td>Modulate Load</td>
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</tbody>
</table>
#5: Hybrid Evaporative Precooling

Technology
- Evaporative cooling can be combined with other primary cooling stages to increase efficiency, especially in low humidity regions.

Flexibility
- Controls can optimize use of one or both cooling stages

#6: Dual-Fuel HVAC

Technology
- Example configurations could include:
  - [Heating] Fuel-fired furnace + electric heat pump (residential split or commercial RTU)
  - [Heating] Gas/propane/oil boiler + ductless heat pumps

Flexibility
- Provide load shedding by temporarily switching fuels

https://peakplus.energy/
https://www.fujitsugeneral.com/
https://www.weil-mclain.com/
Cross Cutting Technologies Evaluated

**CC#1. Thermal Energy Storage (TES)**

**Technology**
- TES may be stand-alone or be embedded within other equipment. Examples:
  - Heating or Cooling: Water/Ice or phase change materials (PCMs) stored in tanks
  - Gas absorption: Separate storage of the sorbent and refrigerant mid cycle for long-term, no-loss, storage

**Flexibility**
- Off-peak recharging enables load shifting

**Flexibility Mode**
- Efficiency
- Shed Load
- Shift Load
- Modulate Load

**CC#2. Modulating Capacity Vapor Compression**

**Technology**
- Modulating allows for more granular control than provided by single-speed systems.

**Flexibility**
- Modulation increases precision of load control for load shifting and improves efficiency.

**Flexibility Mode**
- Efficiency
- Shed Load
- Shift Load
- Modulate Load

https://www.bradfordwhite.com/

https://climate.emerson.com/en-us
CC#3. Non-Vapor Compression (NVC) Systems and Materials

Technology
• Multiple types: may use unique properties of materials or new architectures.
• Examples:
  • Solid-state NVC: thermoelectric, magnetocaloric, electrocaloric
  • Other NVC: Membrane, thermoelastic, Stirling, liquid desiccant, thermoacoustic

Flexibility
• Modulating capacity, separate sensible/latent controls, and energy storage

Flexibility Mode | Capability
--- | ---
Efficiency | 
Shed Load | 
Shift Load | 
Modulate Load | 

Cross Cutting Technologies Evaluated Cont.
Controls Report Technology: Model Predictive Control

- HVAC demand is weather dependent, proactive load shifting relies on predictions of weather, occupancy, and grid needs

- Model predictive control (MPC)
  - Broad sense of the term: optimization over receding time horizon using predictions and updates
  - Already in use: district systems, some large buildings
  - Can optimize for multiple objectives
  - Can create for counterfactuals for bidding and M&V
  - Incorporate weather dependent generation, storage?
Poll

Based on potential grid flexibility impact and likelihood of adoption, of the evaluated technologies, select the two that you think DOE should prioritize:

• Smart Thermostats
• Separate Sensible and Latent Space Conditioning
• Thermal Energy Storage
• Liquid Desiccant Thermal Energy Storage
• Advanced Controls for HVAC Equipment with Embedded Thermostats
• Hybrid Evaporative Precooling
• Dual Fuel HVAC
• Modulating-Capacity Vapor Compression
• Non-Vapor-Compression (NVC) Materials/Systems
<table>
<thead>
<tr>
<th>All Connected Technologies</th>
<th>Challenge</th>
<th>Opportunity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interoperability</td>
<td></td>
<td>Standardized semantic and syntactic specifications for connected devices and software systems</td>
</tr>
<tr>
<td>Cybersecurity</td>
<td></td>
<td>Secure system architectures and cybersecurity best practices</td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td>New manufacturing processes with low capital cost or use of existing manufacturing equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>New materials and technologies compatible with scalable manufacturing methods</td>
</tr>
</tbody>
</table>
# Challenges & Opportunities: HVAC Technologies

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Opportunity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All HVAC GEB Technologies</strong></td>
<td>Limited understanding of duration/temp/humidity curtailment constraints</td>
</tr>
<tr>
<td><strong>Separate Sensible and Latent Space Conditioning</strong></td>
<td>Installation &amp; commissioning complexity</td>
</tr>
<tr>
<td><strong>Liquid Desiccant TES</strong></td>
<td>Installation &amp; commissioning complexity</td>
</tr>
<tr>
<td></td>
<td>Large footprint</td>
</tr>
<tr>
<td><strong>Controls for HVAC w/ Embedded Thermostats</strong></td>
<td>Lack of non-premium connected products</td>
</tr>
</tbody>
</table>
# Challenges & Opportunities: Cross Cutting Technologies

<table>
<thead>
<tr>
<th>Thermal Energy Storage</th>
<th>Challenge</th>
<th>Opportunity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installation &amp; commissioning complexity</td>
<td>Packaged systems with reduced installation/commissioning complexity</td>
</tr>
<tr>
<td></td>
<td>Large footprint</td>
<td>Materials with increased energy storage density and/or novel packaging</td>
</tr>
<tr>
<td></td>
<td>Limited year-round use</td>
<td>Dynamic manipulation of material transition temp and optimize operations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modulating-Capacity Vapor Compression</th>
<th>Challenge</th>
<th>Opportunity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High product costs</td>
<td>Lower-cost systems, focusing on heat exchangers &amp; compressors</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-Vapor-Compression (NVC) Materials/Systems</th>
<th>Challenge</th>
<th>Opportunity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High product costs</td>
<td>Lower-cost NVC materials, systems, and components</td>
</tr>
<tr>
<td></td>
<td>Limited field validation of architectures &amp; approaches</td>
<td>Development of NVC for a broad range of applications</td>
</tr>
</tbody>
</table>
Controls Report: Challenges and Needs

• **Occupant interaction**
  – Accurate, cost-effective, privacy-preserving methods of measuring comfort
  – Feedback mechanisms to register preferences, change uncomfortable conditions

• **MPC**
  – Model acquisition, training and calibration
  – Interpretability and acceptance by occupants and operators
  – Adaptation to changing conditions
  – Uncertainty management
Poll

Identify the 2 highest priority areas to improve the flexibility potential provided by HVAC?

• Advanced controls, connectivity, and communications
• Interoperability and cybersecurity
• Occupant behavior and ensuring comfort/productivity
• Improved individual end-use equipment flexibility
• Development of flexibility-specific equipment (e.g., thermal energy storage)
Technical Report Q&A?

Use the question feature to ask a question or provide a comment.
Flexibility Metrics for Heating, Ventilation, and Air Conditioning Equipment

Nelson James
Building Technologies Office
A variety of metrics have been traditionally used to quantify the performance of HVAC equipment. These can allow for the direct comparison of systems with one another.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>COP, EER</td>
<td>Coefficient of performance and energy efficiency ratio: Thermal power delivered divided by the electrical power input at a specified operating condition</td>
</tr>
<tr>
<td>SEER</td>
<td>Seasonal energy efficiency ratio: Cooling output during a typical cooling-season divided by the total electric energy input during the same period</td>
</tr>
<tr>
<td>IEER</td>
<td>Integrated Energy Efficiency Ratio: a measure that expresses cooling part-load EER efficiency for commercial unitary air-conditioning and heat pump equipment on the basis of weighted operation at various load capacities.</td>
</tr>
<tr>
<td>HSPF</td>
<td>Heating seasonal performance factor: ratio of heat output over a heating season to the electricity consumed.</td>
</tr>
<tr>
<td>AFUE</td>
<td>Annual fuel utilization efficiency: ratio of the annual heat output over the annual fuel energy consumed</td>
</tr>
<tr>
<td>Capacity</td>
<td>The quantity of heat that a system can add or remove from an enclosed space during a specified amount of time.</td>
</tr>
</tbody>
</table>
• HVAC’s ability to provide flexibility depends on equipment capabilities and associated characteristics of respective storage media (e.g. Building mass/state of charge, occupancy/usage)

• In a similar manner to efficiency, metrics are needed to compare the ability of systems to provide flexibility.

• Load Change During Event
• Duration of Response
• Resolution of Control
• Response Time

• Load Shift Capacity
• Load Shift Efficiency
• Lifetime Impacts
• Reliability of Response
Load Change During Event

• Equipment can be required to increase load when for example renewable energy is abundant and reduce load when the grid is constrained

• Quantification of how much the load can change in response to a signal.
  – Percentage change of rated load [%]
  – Load increase or decrease [kW]
Duration of Response

• The length of time that flexibility services can be provided without leading to unacceptable conditions for the occupants
• Generally depends on characteristics beyond the equipment’s capabilities such as the building thermal inertia and occupant behavior
  – Duration [hrs]
Resolution of Control

- Control interfaces are needed for communication with automation systems and grid signals.
- Additionally being able to operate at multiple power draws could increase options for flexibility.
  - Number of modes of control [-]
Response Time

• How quickly the equipment’s operation change once a control signal is received

• Equipment processes could delay responses to flexibility services
  – Defrost cycles [mins]
  – Compressor shutoff [hrs]
Load Shift Capability

• Measure of how much energy can be stored for shifting energy usage from the grid
• Dependent on thermal mass of building or active storage system
• Includes not only quantity of energy, but how quickly that energy can be utilized
  – Load Shift Capacity [kWh]
  – Load Shift Power [kW]
Load Shift Efficiency

- If energy is stored for shifting, inefficiencies of the storage and extraction process can lead to increase energy consumption
- Potential losses include heat gain or loss from the storage medium and thermal resistances between the storage medium and the HVAC equipment
  - Storage efficiency [%]
  - Energy usage increase [kWh]
Lifetime Impacts

- Extent to which providing services could impact equipment life from cycling, or running in non-standard operation
  - Maintenance cost [$]
  - Maintenance intervals [hrs]
  - System life [yrs]
Reliability of Response

- Depending on the severity of the impact on occupant services from a flexibility measure, the rate at which customers opt out of programs could vary.
- Building characteristics and occupant behavior can influence the reliability at which a desired flexibility response is provided.
  - Percentage of Opt-Outs [%]
Eight metrics were presented:

1. Load change during event
2. Duration of Response
3. Resolution of Control
4. Response Time
5. Load Shift Capacity
6. Load Shift Efficiency
7. Lifetime Impacts
8. Reliability of Response

Do you have recommendations for additional metrics, or changes to the current metrics?

Enter feedback into the Q&A box
Metrics Q&A?

Use the question feature to ask a question or provide a comment.
Quantifying Flexibility Opportunity of HVAC Equipment

Nelson James
Building Technologies Office

Jared Langevin, Lawrence Berkeley National Laboratory
Handi Putra, Lawrence Berkeley National Laboratory
Elaina Present, National Renewable Energy Laboratory
Andrew Speake, National Renewable Energy Laboratory

Researchers
Chioke Harris, National Renewable Energy Laboratory
Rajendra Adhikari, National Renewable Energy Laboratory
Eric Wilson, National Renewable Energy Laboratory
Quantifying Flexibility Opportunity

• A consistent framework is needed to assess the impact of energy flexibility measures (EFMs) on the ability of residential and commercial buildings to provide load flexibility

• Using this framework, energy savings and cost targets can be associated with respective flexibility enhancements
## DOE Tools and Resources

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIA</td>
<td>EIA provides a wide range of information and data products covering energy production, stocks, demand, imports, exports, and prices. The Electricity Market Module represents the capacity planning, generation, transmission, and pricing of electricity, subject to various factors including electricity load shapes and demand.</td>
</tr>
<tr>
<td>ResStock</td>
<td>A high level of granularity used to represent the diversity of housing stock characteristics and climates across the contiguous United States. The ResStock framework brings together the use of large public and private data sets, statistical sampling, detailed sub-hourly building energy simulations, and high-performance computing resources.</td>
</tr>
<tr>
<td>OpenStudio®</td>
<td>OpenStudio® is a cross-platform collection of software tools to support whole building energy modeling using EnergyPlus and advanced daylight analysis using Radiance. OpenStudio is an open source (LGPL) project to facilitate community development, extension, and private sector adoption.</td>
</tr>
<tr>
<td>Scout</td>
<td>Scout is a tool for estimating the energy and carbon impacts of various energy conservation measures (ECMs) on the U.S. residential and commercial building sectors</td>
</tr>
</tbody>
</table>
Proposed Analysis Process

• Establish baseline grid load shapes
  – For each of 22 EIA Electric Market Module (EMM) regions, determine how electricity demand varies over the year

U.S. EIA EMM regions

Jared Langevin¹, Handi Putra¹, Elaina Present², Andrew Speake², Chioke Harris², Rajendra Adhikari², and Eric Wilson²

¹ Lawrence Berkeley National Laboratory ² National Renewable Energy Laboratory
Proposed Analysis Process

- Define windows for peak demand and low demand periods
  - Based on seasonal load shapes, define windows of time where it could be beneficial to increase or decrease load
  - Peak demand windows currently set at 4 hours
  - Low demand windows based on when load is below a threshold percentage of the peak

Jared Langevin¹, Handi Putra¹, Elaina Present², Andrew Speake², Chioke Harris², Rajendra Adhikari², and Eric Wilson²

¹ Lawrence Berkeley National Laboratory ² National Renewable Energy Laboratory
Proposed Analysis Process

- Specify flexibility measures
  - How equipment will response to provide flexibility during the peak demand and low demand periods

<table>
<thead>
<tr>
<th>Measure</th>
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<tbody>
<tr>
<td>Global temperature adjustment</td>
<td>Adjusts zone cooling temperature setpoint upwards and zone heating temperature setpoint downwards during the peak hours</td>
</tr>
<tr>
<td>Pre-conditioning</td>
<td>Pre-cool/pre-heat starting 4 hours before the peak, then set-back/set-up setpoint relative to original setpoint during peak period.</td>
</tr>
<tr>
<td>Ice storage</td>
<td>Charge ice storage between off peak hours. Discharge ice storage during the peak period.</td>
</tr>
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Proposed Analysis Process

• Simulate measures across climate zones
  – Using ResStock and commercial prototype building models, determine 8760 end-use building loads
  – Implement the flexibility measures in EnergyPlus to determine demand impacts while maintaining comfort constraints
  – Utilize peak demand and low demand definitions for respective EMM region
  – Determine EFM savings fraction relative to baseline
Proposed Analysis Process

• National assessment using scout
  – Use Scout to assess the regional and national impacts of EFMs across future years
    • Energy savings
    • CO₂ savings
    • Cost Savings
    • EFM price premiums

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Proposed Analysis Process

1. Define energy efficiency (EE), demand flexibility (DF), and EE + DF measure portfolios
2. Develop 8760 hourly fractions of annual baseline load by climate, building type, and end use
3. Develop bottom-up EnergyPlus measure simulations and 8760 savings fractions based on regional system needs
4. Translate measures to Scout and assess regional/national portfolio potential, annually and sub-annually (2015-2050)

Building Simulations
- EMM load shapes
- Cambium hourly electricity pricing
- Cambium hourly CO₂ emission rates
- Energy flexibility measures
- Generate baselines for commercial and residential buildings
- Simulate impacts of EFMs
- Generate EFMs saving fractions relative to baselines

Analysis Inputs

Analysis Outputs
- Develop national and regional impacts with Scout
  - Energy savings
  - CO₂ savings
  - Cost savings
  - EFM price premiums
Poll

Does the analysis framework presented create a reasonable path to quantifying and comparing the capabilities of HVAC flexibility measures?

- Yes, the approach should be adequate to quantify the flexibility potential of HVAC equipment
- Almost, additional inputs are required in the analysis
- Almost, improvements are needed in EFM simulation approach
- Almost, relevant outputs are missing from the analysis
- No, analysis framework needs to be significantly altered
Open Q&A?

Use the question feature to ask a question or provide a comment.
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