U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

GEB Technical Report Webinar Series: Whole-Building Control, Sensing, Modeling & Analytics

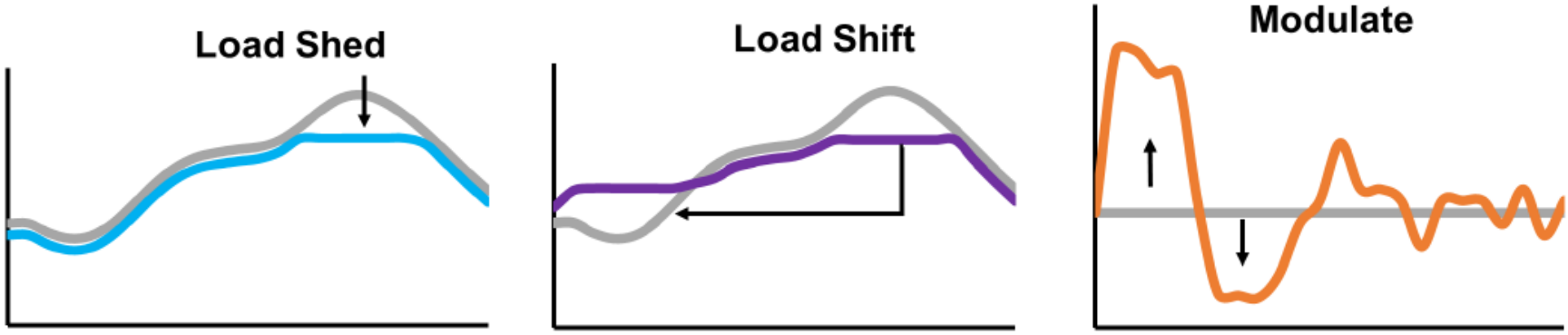
Amir Roth, BTO

Janet Reyna, Dane Christensen, NREL

Draguna Vrabie, Veronica Adetola, PNNL

May 19, 2020

Grid Management 101



- **Supply/demand matching at multiple time scales**
  - Bulk energy – day/hour/15-min ahead
  - Fast acting services to trim or follow around the edges
  - Primarily generator dispatch
- **Transmission & distribution constraint avoidance**
  - Primarily shedding by large customers or aggregators
- **Maintain power quality & support grid reliability**

Grid Management Trends & Implications

- **Trends**
  - More non-dispatchable generators
  - Generation variability at distribution level (e.g., cloud cover)
  - More frequent & longer peak-demand events
  - More frequent & damaging "disasters" → downtimes
- **What do these mean?**
  - Opportunity/need for behind-the-meter generation & storage
  - Opportunity/need for dispatchable demand flexibility
- **Buildings represent a significant opportunity**
  - Flexibility: setpoints, lighting, appliances, plug-loads
  - Storage: thermal mass, batteries, Evs
  - On-site generation

EE, DR & GEB

- **Energy Efficiency (EE)**
  - Persistently low annual energy use
  - For a given value, flat “shapes” are preferred
- **Demand Response (DR)**
  - Short term, situational grid services (typically load reduction)
  - Direct (event-driven) or indirect (price-driven)
  - Can be manual, occupant preferences are tertiary
- **Grid Interactive Efficient Buildings (GEB)**
  - Continuous, integrated, optimized management of EE & DR
  - Automation is necessary, occupant preferences are primary

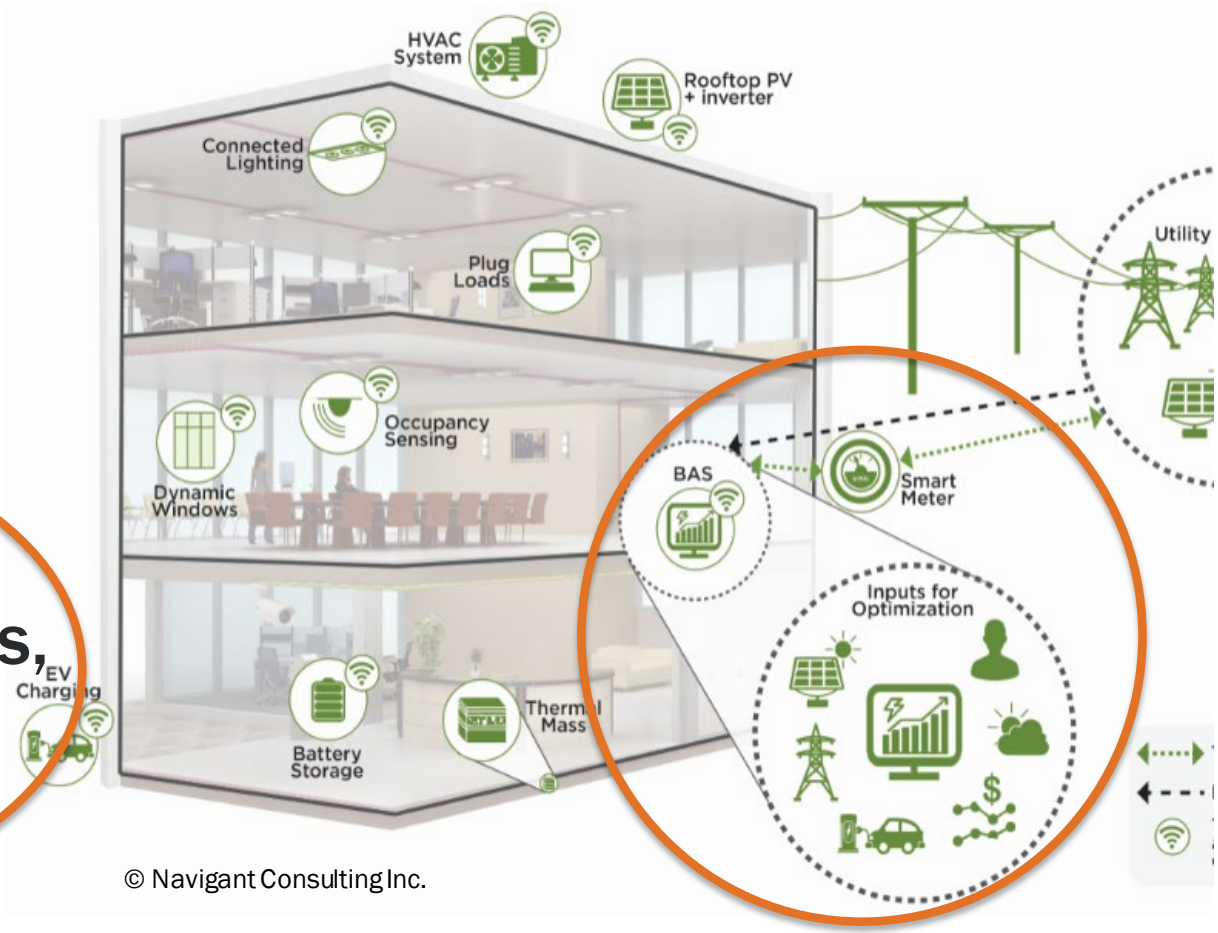
Benefits of GEB

- **For customers**
  - Improved comfort, level of service & choice
  - Reduced energy costs
  - Additional value streams from their asset
- **For utilities & grid operators**
  - Reduced generation operating costs
  - Reduced generation, T&D capital costs
- **For all**
  - Improved reliability & resilience
  - Environmental benefits

GEB Technical Report Series

http://energy.gov/eere/buildings/grid-interactive-efficient-buildings/

- HVAC, WH, & Appliances
- Lighting
- Envelope & Windows
- Whole-Building Controls, Sensors, Modeling & Analytics



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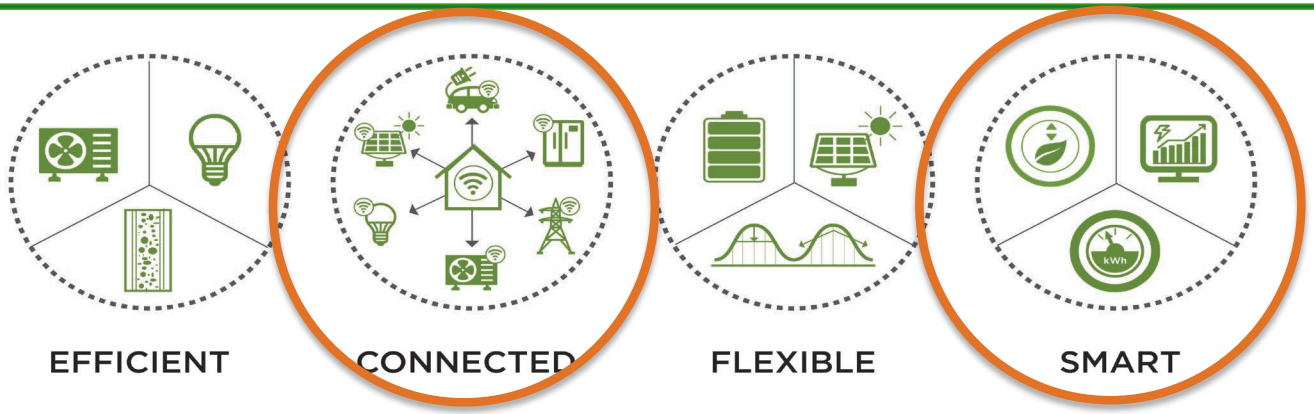
GEB Technical Report Webinar Series

Topic	Date	Time
Lighting & Electronics	May 26	2:00pm - 3:00pm ET
Heating, Ventilation & Air Conditioning (HVAC)	June 2	2:00pm - 3:30pm ET
Water Heating & Appliances	June 9	2:00pm - 3:00pm ET
Envelope & Windows	June 16	2:00pm - 3:30pm ET
Integration – Building Equipment	June 23	2:00pm - 3:00pm ET
Integration – Distributed Energy Resources(DERs)	June 30	2:00pm - 3:00pm ET

Whole-Building Controls, Sensors & Models



- **This report emphasizes integration issues**
  - How to integrate grid services via multiple end uses?
  - How to integrate multiple grid services with EE?
  - What are interoperability & security implications?

– EE – Shed – Shift – Modulate	X	– HVAC – Lighting – Appliances – Plug-loads

Integration Options

- **Device**
  - Aggregated outside the building, e.g., by manufacturer
  - Happening already, e.g., smart water-heaters
- **End-use**
  - E.g., Multiple HVAC devices provide space conditioning
- **Building**
  - Natural level of aggregation for metering & some control
  - In some cases, device/end-use level is also building-level
- **Multi-building**
  - Shared resources, e.g., district systems

Integration Criteria

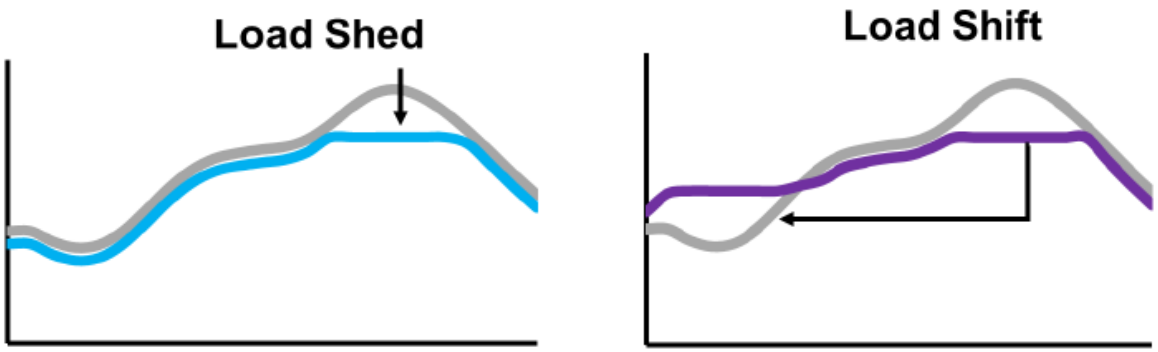
- **System performance**
  - Usually higher at greater levels of integration
  - Greater flexibility to trade off, larger optimization space
  - Important
- **Implementation complexity & cost**
  - Higher at greater levels of integration
  - Also important
- **Communication Latency**
  - Higher at greater levels of integration
  - At some point, too high for some services

Integration Criteria, Cont'd

- **Scalability**
  - How many "atoms" at each aggregation level?
  - How do algorithms scale at different aggregation levels?
  - Fairly neutral (we think)
- **Security**
  - How many entry points into the building (aggregation)?
  - How much connectivity within the building (aggregation)?
  - Also fairly neutral (we think)

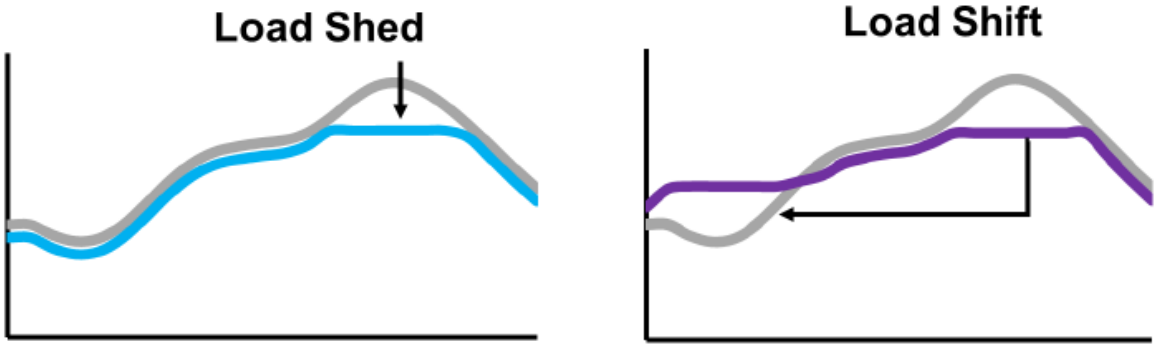
Assertion #1

- **Shedding and shifting of HVAC loads should be implemented at the building* level**
  - *In some cases, device or zone level is equivalent
  - Weather dependence and close coupling with building fabric
  - Occupant dependence and comfort implications
  - May need MPC for best results
  - May want to integrate PV because of weather dependence



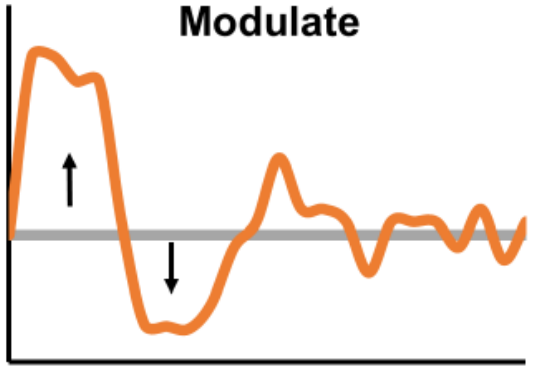
Assertion #2

- **Shedding and shifting of other end-uses can be provisioned at building, end-use, or device level**
  - No weather dependence
  - No physical interaction between end-uses (some exceptions) makes integration a resource allocation problem
  - Transactive or other economic coordination mechanisms
  - Another option for integrating DERs
  - System performance vs. integration complexity decision



Assertions #3 and #4

- **Energy neutral modulation services should be provisioned at the device level**
  - Negligible interactions with shedding and shifting
  - Latency concerns dominate
- **Open questions about non-energy neutral modulating services**



Implementation Aspects

- **Occupants, operators, and owners (O3)**
  - Which building stakeholders need to be involved & how?
- **Execution**
  - Implementation & integration
- **Estimation & M&V**
  - Does service have to be committed in advance?
  - How is service delivery verified?
  - Only applicable for some services in some contexts
- **Quantitative analysis**
  - How is service modeled for design & planning purposes?

Report & Webinar Agenda

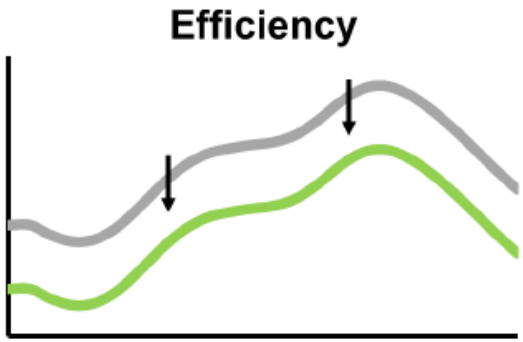
- **Overview**
  - Amir Roth, BTO
- **Energy Efficiency**
- **Demand Response**
  - Janet Reyna, NREL

Report & Webinar Agenda

- **Shedding & shifting HVAC**
  - Draguna Vrabie, PNNL
- **Shedding & shifting other end-uses**
  - Veronica Adetola, PNNL
- **Modulation**
- **Interoperability & Cybersecurity**
  - Dane Christensen, NREL

Energy Efficiency

Janet Reyna, NREL



Energy Efficiency (EE)

- **EE: same level of service for less energy annually**
  - Foundation of GEB
  - Initiatives that enhance EE directly support GEB

EE: 03

- **Occupants and Operators**
  - Behavior plays a significant role
- **Owners**
  - EE can be low on list of priorities
  - 3/30/300 rule

EE: Execution

- **Passive components + HVAC, lighting, plug-loads**
- **Building Automation Systems (BAS)**
  - Predominantly in large commercial
- **HEMS (Home Energy Management Systems)**
  - Smart thermostats + Home automation hubs
- **On-going advancements**
  - Wireless sensing
  - Control platforms
  - MPC, AFDD, BEM / controls integration
  - Point mapping, semantic modeling

EE: Characterization, M&V, Planning

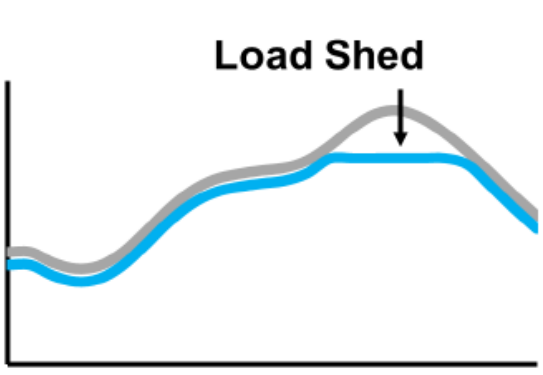
- **Characterization & planning**
  - BEM (physics-based energy modeling)
  - Specific buildings for design & certification
  - Prototypes for large-scale planning
- **M&V**
  - Monthly (sub-)metering
  - Counterfactual ← historical use, weather-normalized

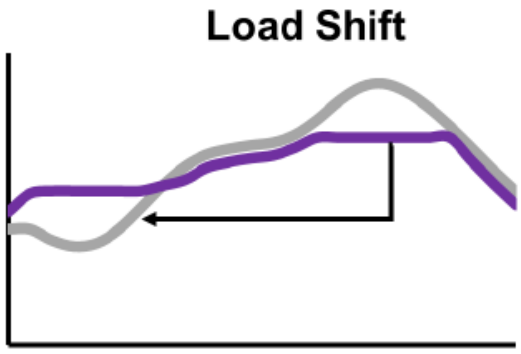
EE: Recommendations

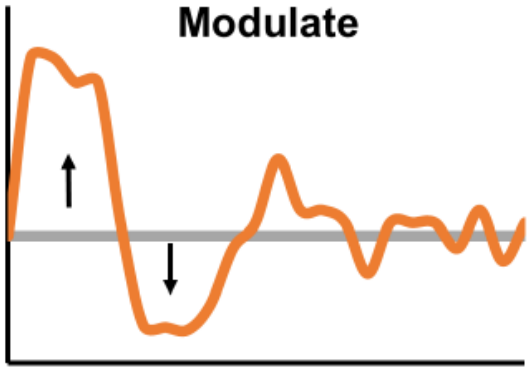
- Develop and deploy cost-effective controls, sensing, modeling and analytics to support EE throughout the building life cycle.
- Develop technical solutions that support the deployment and maintenance of digital monitoring and automation in both commercial and residential buildings.

Demand Response

Janet Reyna, NREL







Demand Response (DR)

- **Modify load in response to grid need**
  - Direct DR: event-driven equipment control (with overrides)
  - Indirect DR: voluntary price response
- **Initiatives that enhance DR also support GEB**

DR: 03

- **Direct DR**
  - No accounting for occupant preferences
  - Some programs allow occupant override
  - Acceptable for low-frequency events
- **Indirect DR**
  - Customer controls response magnitude & schedule

DR: Execution

- **Direct DR 1.0**
  - Large commercial/industrial customers ← phone call
- **Direct DR 2.0**
  - One-way communication to device (e.g., compressor switch)
- **Indirect DR**
  - Programmed or manual scheduling
  - Smart-thermostat based TOU optimization
  - Some MPC in the commercial sector

DR: Characterization, M&V, Planning

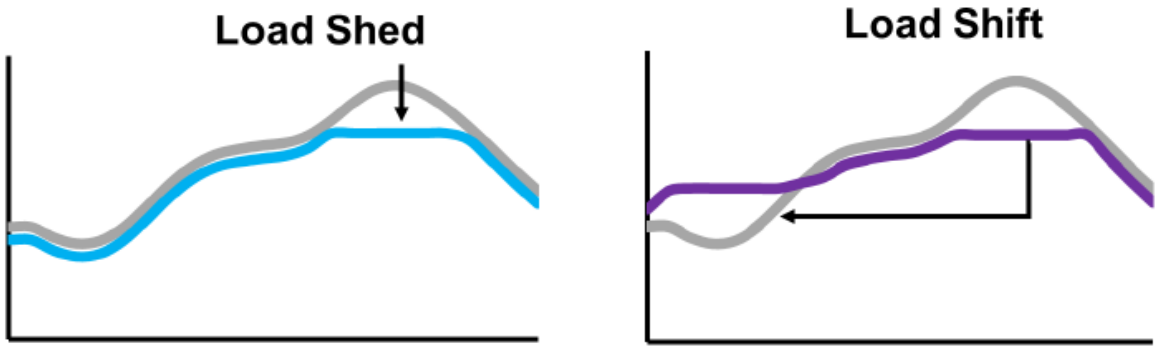
- **Characterization**
  - Engineering calculations for large buildings
  - Device characterization & aggregation for small buildings
- **M&V**
  - Comparison to historic use (e.g., day with similar weather)
- **Quantitative Analysis**
  - Buildings are not explicitly designed for DR
  - Can BEM accurately calculate peak demand?

DR: Recommendations

- Develop requirements for shared, trusted metering and sensing for measuring and verifying the delivery of grid services.

Shedding and Shifting HVAC

Draguna Vrabie, PNNL



Shed/Shift HVAC

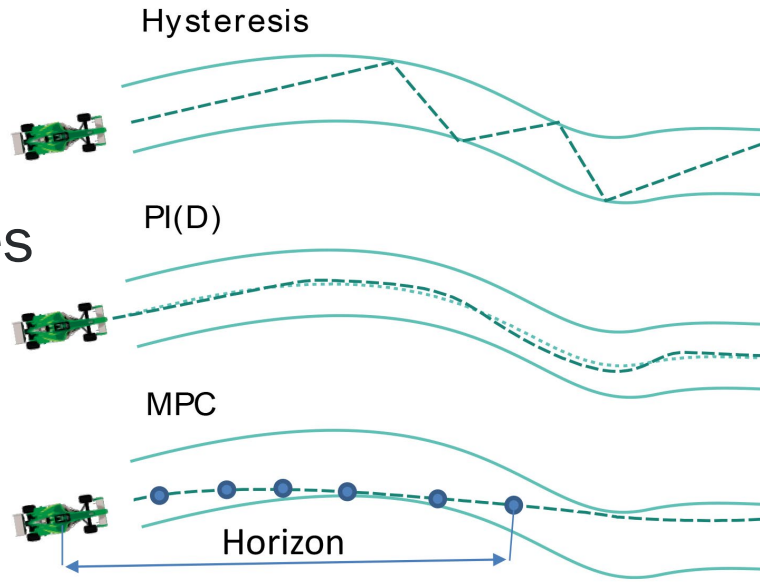
- **Use building thermal mass to shift HVAC load with minimal occupant impacts & "recovery" effects**
  - Significant opportunity
  - Weather & occupancy dependence
- **Enhancers**
  - On-site generation, electrical and/or thermal storage
  - District thermal storage

Shed/Shift HVAC: O3

- **Occupants**
  - Goal: no comfort impact
  - Need: accurate, cost-effective, privacy-preserving methods of measuring comfort measures
  - Need: feedback mechanisms to register preferences and change uncomfortable conditions
- **Owners and operators**
  - 3/30/300 rule

Shed/Shift HVAC: Execution

- **Key capabilities**
  - Optimize over time horizon
  - Incorporate predictions & updates
  - Support multiple objectives
  - Adapt to changing context
  - Manage uncertainty



- **Implementation challenges**
  - Training and calibration of models ($$$)
  - Acceptance by building operators
  - Computational limitations of BAS hardware

Shed/Shift HVAC: Execution

- **Model-based control and enablers**
  - Optimization horizon, re-evaluation interval, objective, algorithm
  - Model selection and calibration
  - Integration with fault detection, diagnosis, and prognosis
  - Adaptivity
  - Uncertainty management and robustness
  - Control interpretability
  - Advanced actuation
  - Integration with envelope and lighting control
  - Integration with electricity generation and storage control
  - Multi-building coordination

Shed/Shift HVAC: Characterization, etc.

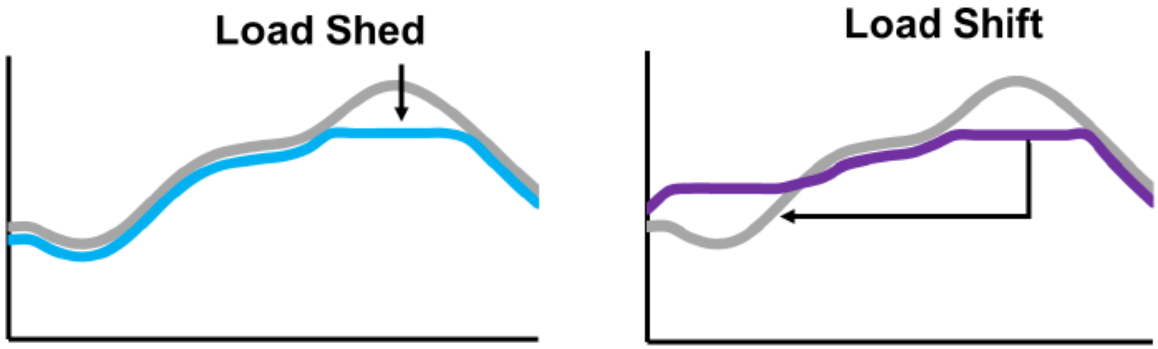
- **Characterization and M&V**
  - Counterfactual baseline uses shadow optimization that does not incentivize shedding and shifting
  - Explicit management of uncertainty can help estimate risk of not delivering on committed services
- **Quantitative analysis**
  - BEMs generally sufficient, especially ones that can calculate operative temperatures and thermal comfort
  - Enhancements needed in control sequence modeling, integrated district system modeling, occupant preference modeling and assumptions, weather data and extreme events and output metrics

Shed/Shift HVAC: Recommendations

- Develop fundamental and practical aspects of MPC.
- Develop methods of acquiring occupant comfort status and preferences.

Shedding and Shifting Other End-Uses

Veronica Adetola, PNNL



Shed/Shift Other

- **“Other” end-uses**
  - Mechanical (AC/DC): water heating, refrigeration, appliances
  - Electronics (DC): lighting (shed only), computing. batteries
- **Typical characteristics**
  - Independent of weather (& envelope)
  - Minimal contribution to HVAC loads (some exceptions).
  - Usage prediction is a challenge for some

Shed/Shift Other: 03

- **Goal: shed/shift without occupant impacts**
  - Lighting, appliances, some computing are occupant driven

Flexible
With "storage"
Shift ahead
Few impacts

- Water heaters
- Refrigeration
- Batteries

Flexible
No storage
Shift ahead, back
Few impacts

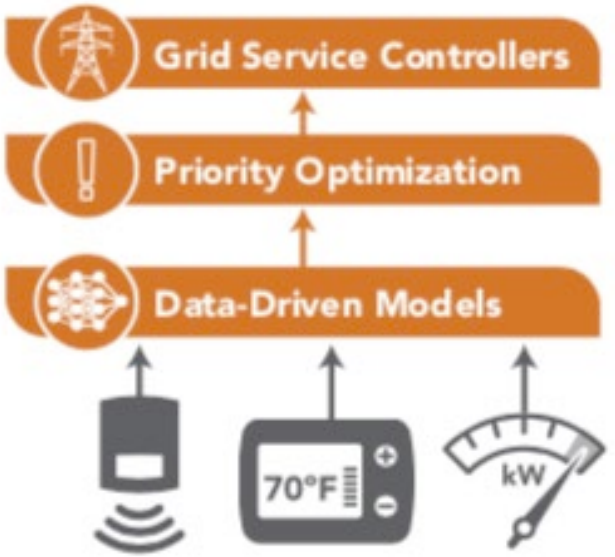
- Dishwashing
- Washing, drying
- Some computing

Inflexible
No storage
Shed only
Impacts

- Lighting
- Conveyance
- Entertainment

Shed/Shift Other: Execution

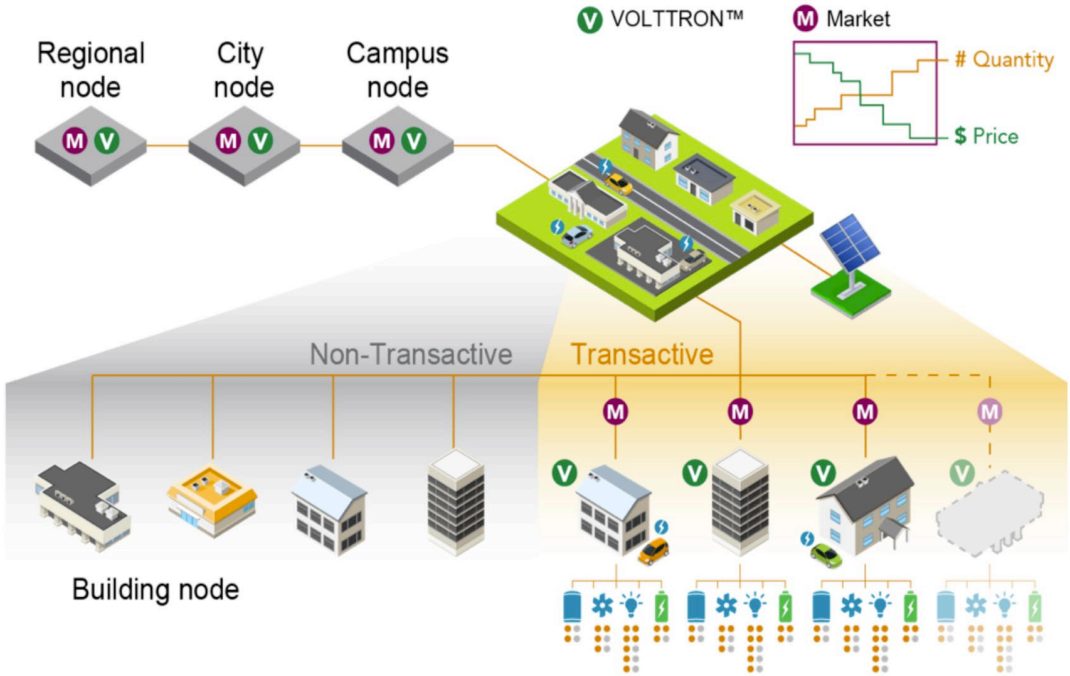
- **Occupant-centric methods are needed to quantify, prioritize & value end-use**
  - Preassigned, static priorities
  - Rule-based (day-time vs. evening)
  - Dynamic prioritization



- **Implementation**
  - Direct load control
  - Pre-programmed price-response
  - Proactive control based on historical use patterns & electricity price forecasts

Shed/Shift Other: Execution

- **Coordination / resource-allocation across end uses**
  - Price-based mechanisms establish priorities & service levels
  - Can incorporate HVAC & DERs
  - Scales to multiple buildings



Shed/Shift Other: Characterization, etc.

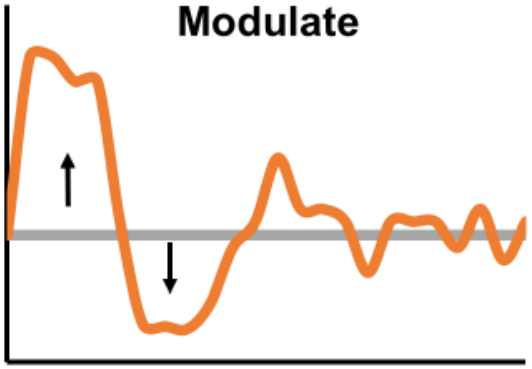
- **Characterization**
  - By manufacturer for device-level direct load control
  - Schedule/sub-meter analysis or manually for price response
- **M&V**
  - Trusted (by customer & utility) sub-metering
  - Trusted equipment-level or environmental sensing
- **Quantitative analysis**
  - More realistic, stochastic, sequentially ordered schedules at greater temporal resolutions

Shed/Shift Other: Recommendations

- Develop methods of registering occupant prioritization and valuation of different end uses.
- Develop methods of prioritizing different zones and end uses within a building and coordinating energy efficiency and grid service delivery across those zones and end uses.

Modulation Services

Dane Christensen, NREL



Modulation

- **Modulation services contribute to grid reliability & stability & delivered power quality by helping to regulate power characteristics (e.g., frequency)**
  - Can be signaled, e.g., frequency regulation (4-second signal)
  - Can be autonomous, e.g, contingency reserves
  - Considered energy neutral, do not typically impact occupants
- **Equipment**
  - VFD motors (cycling may limit)
  - SSL & electronics
  - Batteries

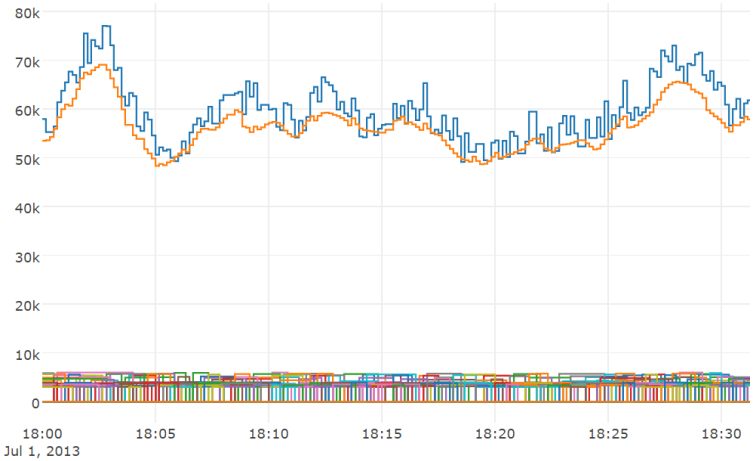


Chart from: Frequency Regulation Services From Connected Residential Devices https://www.nrel.gov/docs/fy17osti/66586.pdf

Modulation

- **O3**
  - Little or no occupant impact
- **Execution**
  - Uni-directional communication
  - Local control
- **M&V**
  - May require higher-fidelity meters than typical in buildings
  - Metrics are developing
- **Quantitative analysis & planning**
  - Does energy neutrality imply BEM is not needed?

Modulation: Recommendations

- Determine the degree of interaction between shedding and shifting, energy-neutral modulation, and non-energy neutral modulation services, and the feasibility of providing more than one of these services from within the same control domain.
- Determine the role that BEM plays in the provision of modulation services.

Interoperability and Cybersecurity

Dane Christensen, NREL

Interoperability

- **GEBs rely heavily on communication within the building & between building and grid**
  - Involve numerous previously separate industries
  - Protocols: BACnet, CTA-2045, OCPP, etc.
- **Interoperability: the ability of devices or software systems to reliably exchange (interpret/act on) data**
  - Reduces installation cost
  - Guards against vendor lock-in & fosters innovation
  - In GEB: maximizes service benefit
- **A device or software does not have to support every protocol & data schema to be usefully interoperable**

Cybersecurity

- **Cybersecurity is the practice of preventing unauthorized access to and use of electronic data, system, or service**
- **GEB cybersecurity is important because GEBs will be increasingly interconnected with the grid**
  - Vulnerabilities in building software and devices could be used to attack the larger grid
  - The grid could become an additional means of gaining access to building data and systems
- **Even if the grid is not directly compromised, a grid that is more heavily reliant on building-based services to maintain stability is indirectly made more vulnerable by greater building-level automation and interconnectivity**

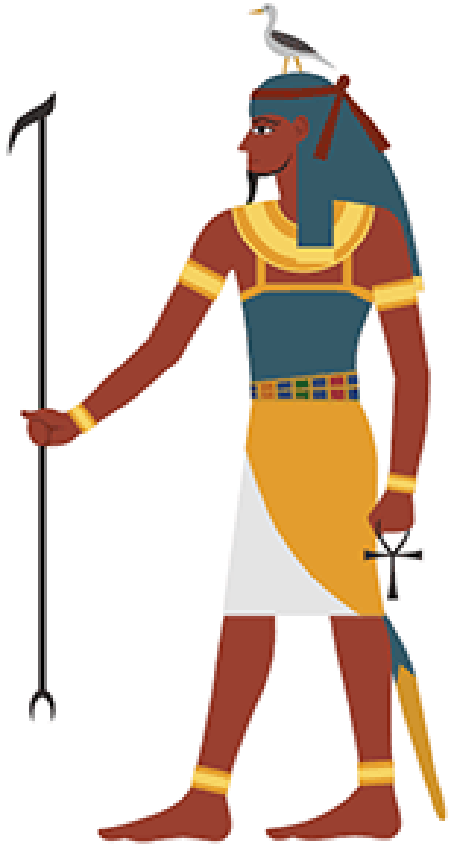
Cybersecurity

- **A cybersecure grid service is one in which the building and the service aggregator or utility know**
  - What service is being provided and when,
  - That the M&V information is accurate, and
  - That devices that support service delivery and M&V are available when needed.
- **GEB equipment should support cybersecurity now, and have facility for upgrade and/or component replacement to enable appropriate future cybersecurity**

Interop/Cyber: Recommendations

- Support development and adoption of standard data models and formats and communication protocols for building and behind-the-meter equipment.
- Support the adoption of secure system architectures and cybersecurity best practices.

Thank you!



- **Any questions? Contact us!**
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