Connected Homes of Today and Beyond

May 17, 2017
2:00 – 3:15 PM
According to a 2016 survey by Houzz and the Custom Electronic Design and Installation Association (CEDIA), nearly half of renovating homeowners are incorporating “smart” technology: systems or devices that can be monitored or controlled via smartphone, tablet or computer (45 percent).
Panelists

Emily Kemper, CLEAResult
Kurt Roth, Fraunhofer
Nora Wang, PNNL
Dale Hoffmeyer, DOE

- What are today’s smart and connected home devices?
- Do these technologies offer real energy savings?
- What do I need to know to make informed decisions about these products?
- What emerging solutions are being researched and tested?
Who is in the audience?

In 5 seconds:

- Name
- Organization
- One thing in your home you want to control or monitor from your phone.
Internet of things (IoT) is the inter-networking of physical devices, vehicles (also referred to as "connected devices" and "smart devices"), buildings, and other items—embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data.

Connected Home
- Internet connected devices
- Remote control & monitoring
- Smart/self learning
- Automation
Responding to an Evolving Market

SMART THERMOSTATS

For the average American household, almost half the annual energy bill goes to heating and cooling - more than $1,000 a year. Being smart about how you control your temperature settings will help you save money and stay comfortable in your home. What is a smart thermostat? A smart thermostat is a Wi-Fi enabled device that automatically adjusts heating and cooling temperatures settings for optimal performance. Smart thermostats that earn the ENERGY STAR label have been independently certified, based on actual field data, to deliver energy savings. These devices provide convenience, insight and control. While system designs vary, every ENERGY STAR certified thermostat must include:

- 70%
Improved sensors and controls and two-way, buildings-to-grid communication are needed to realize the full energy savings from the use cases identified in the report, which will also help to accomplish broader Grid Modernization goals.
Smart Home Devices: Can they Save Energy?

Emily Kemper, AIA
Senior Manager
EXCEPTIONAL DELIVERY

4,000+ GWH SAVED ANNUALLY

65M+ THERMS SAVED ANNUALLY

MEASURABLE RESULTS

900+ ACTIVE PROGRAMS

30,000+ CONTRACTOR PARTNERS

50M+ INCENTIVES PROCESSED ANNUALLY

SOPHISTICATED

SECURE

$350M+ REBATES PROCESSED ANNUALLY

10M+ CALLS HANDLED ANNUALLY

2,700+ CURRENT EMPLOYEES

60+ OFFICES ACROSS US AND CANADA

CLEAResult
Smart Stuff is the New Hotness
### Types of Connected Homes Products in HEMS

<table>
<thead>
<tr>
<th>Functionality</th>
<th>Category</th>
<th>Short Definition</th>
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<tbody>
<tr>
<td><strong>Control-based</strong></td>
<td>Smart Lighting</td>
<td>Lighting bulbs, controls, and fixtures that have automated control functionality</td>
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<td>Smart Plug</td>
<td>Single communicating piece of hardware that controls or provides feedback about connected energy consuming devices</td>
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<td>Smart Hub</td>
<td>Device that enables and manages interaction between existing smart hardware within a single home</td>
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<td></td>
<td>Smart Hub and Smart Switch</td>
<td>Dual function wall mounted smart switch that also enables and manages interaction between existing smart hardware within a single home</td>
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<tr>
<td></td>
<td>Smart Switch</td>
<td>Wi-Fi enabled wall switch that controls or provides feedback about connected energy consuming devices</td>
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<td></td>
<td>Smart Appliance</td>
<td>Communicating appliance which can be controlled remotely via various interfaces</td>
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<td>Smart Thermostat</td>
<td>HVAC Wi-Fi enabled control utilizing remote or rule based mechanisms</td>
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<td>Smart Home Platform</td>
<td>Software platform that enables multiple different hardware devices to operate as a home automation system</td>
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<td><strong>Information-based</strong></td>
<td>Energy Portal</td>
<td>Online dashboard that is consumer or program administrator facing</td>
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<td>Data Analytics Platform</td>
<td>Cloud based analytics platform that analyzes large volumes of data collected from existing smart hardware</td>
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<td>In-Home Display</td>
<td>Physical display that collects data from existing hardware and provides real time feedback and/or prompts</td>
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<td>Load Monitor</td>
<td>Single non communicating piece of hardware that displays energy consumption data of the connected appliance or devices</td>
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<td>Web Service Platform</td>
<td>Cloud-based platform that focuses on more than just energy</td>
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# A Note on Smart Thermostats

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Programmable thermostats</th>
<th>Wi-Fi thermostats</th>
<th>Smart thermostats</th>
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<tbody>
<tr>
<td></td>
<td>Retains basic thermostat capability, regardless of link status</td>
<td>Wi-Fi-enabled</td>
<td>Proximity sensing allows a user to accept and act upon external data (like the location of a smart phone).</td>
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<td>Can collect temperatures, HVAC run-times and HVAC performance information from field systems</td>
<td>Online dashboard and/or mobile app connected to the user account</td>
<td>Occupancy sensing directly detects and acts upon internal sensors (inside the thermostat).</td>
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<td>Temperature stability</td>
<td>Intuitive user interface (UI) that may include touchscreen or buttons</td>
<td>“Learning,” optimization, or adaptive control; algorithms that learn user behavior or track usage to improve performance</td>
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<tr>
<td></td>
<td>Programmable for schedules and setbacks</td>
<td></td>
<td>Basic demand response capabilities: allows remote connection with utilities, who, with authorization, can adjust thermostat settings during peak demand periods (optional).</td>
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</table>
Smart controls for DHPs

- Cielo Breezi
- Tado
- Sensibo
- Momit
Smart Outlets

- GE Smart Switch
- Belkin Insight Switch
- Cielo Control Switch
Smart Water Controls

Carina

Aquanta

Kenmore Smart WH
Smart home platforms

- Lowe’s Iris
- Samsung SmartThings
- Apple HomeKit
Home Energy Monitoring Products

- Neurio
- Curb
- Sense
Control Hubs

- **Amazon Echo**
  - $179 USD
  - Both a “product” and acts a control hub
  - Available online and in stores

- **Wink Hub**
  - $89 USD
  - Control hub only
  - Available online and in stores

- **Smart-Things Hub**
  - $99 USD
  - Control hub only
  - Available online and in stores

Control hubs do not “work with” each other
How much energy can connected devices save?

<table>
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<tr>
<th>Device Type</th>
<th>Electric Savings Range</th>
<th>Gas Savings Range</th>
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<tbody>
<tr>
<td>In-home displays</td>
<td>5–22%</td>
<td>5–22%</td>
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<tr>
<td>Energy portals</td>
<td>5.7–7.4%</td>
<td>5.7–13%</td>
</tr>
<tr>
<td>Smart thermostats</td>
<td>2–16%</td>
<td>8–12.5%</td>
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<tr>
<td></td>
<td></td>
<td>Can save energy in oil- and propane-heated homes, too</td>
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<tr>
<td>Smart plugs and strips</td>
<td>0.5 –1.0 kW per customer</td>
<td>1–4.58%</td>
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</tbody>
</table>

In the most heating dominated climates in the U.S., this type of product could save an average of 10 Million BTUs per year (that’s about 3000 kWh or 100 therms).
Smart Home Ecosystem

Customer can still purchase other products that work with their hub

Other products – consumer choice

Smart Thermostat

Package these items together

Smart Plug

Other products – consumer choice

Smart Power Strip

Other products – consumer choice

Smart Hub
Example!

Amazon Echo

- Neurio Home Energy Monitor
- ecobee
- Belkin Insight Switch
- Embertec APS
- CREE Connected LEDs
How much energy can we save?

Amazon Echo

- ecobee: $249.99
  - 1191-1237 kWh
- Belkin Insight Switch: $49.99
  - ~28 kWh
- Smart Home Bundle estimated savings: ~1430 – 1820 kWh

- 2-8% savings overall

Embectec APS: $59.99
- ~216 kWh

CREE Connected LEDs: $14.97
- ~72 kWh
Benefits

- Convenience
- Security and safety
- Health and comfort
- Energy Savings
- Planning for renewables
- Energy Balance - Path to net zero energy
- Resilience

Good for Homeowners

Good for Everyone

Production + Consumption = Return on investment

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Thank you!
Using Communicating Thermostats to Automate, Customize, and Scale Home Energy Assessments

Better Buildings Summit
May 17, 2017
Kurt Roth, Ph.D.
Acknowledgements

- **Fraunhofer Team:**
  - Co-PI Michael Zeifman, Ph.D.
  - Amin Lazrak, Ph.D.
  - Bryan Urban
  - Joana Abreu

- **Utility partners:** Eversource, Holyoke Gas & Electric, National Grid

- **DOE-BTO Project Funding from the Building America Program**
Project Motivation

- Space heating is the largest end use for homes in cold/very-cold climates
- Homes with poor/no insulation or inefficient heating systems have higher heating energy consumption
  - ~20-25 percent of homes
- Wall and/or attic insulation, air sealing, and HVAC system upgrades can significantly reduce space heating energy consumption
- Programs face high customer acquisition costs
- Slow market uptake of these proven measures
  - <1% of households/year in Massachusetts

Sources: DeMark Home Ontario. S. Edwards-Musa, Eversource Energy.
Project Objectives and Benefits

**Project Objective:** Develop a tool for utility energy efficiency (EE) programs that analyzes communicating thermostat (CT) data to automatically identify and quantify the benefit of targeted and customized retrofit opportunities.

**Customer and Utility Benefits:**
- Increase the uptake of home energy assessments
- Increase deployment rate of the target energy conservation measures (ECMs)
- Decrease the cost of EE programs via targeting
- Reduce retrofit performance risks using home-level remote EM&V
- Increase customer engagement
- Increase the value proposition for CTs – projected ~25MM installed circa 2019

**Ultimate Vision:** CTs deployed in most homes identify high-impact opportunities to reduce HVAC energy consumption and ensure retrofit performance.

Project Impact

Basic ECMs identified have significant energy savings potentials:

- Condensing Furnace or Boiler Retrofit: $165/year (avg. Mass. home)
- Attic and Wall Insulation: $165/year
- Air Sealing: $50-165/year
- National Impact: Consumer savings of $4-5 billion per year

Further savings from space cooling savings and deeper retrofits

CTs provide insight into a home’s thermal response.

### Table: System Settings and Thermal Response

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<tr>
<th>Date</th>
<th>Time</th>
<th>System Mode</th>
<th>Setting Mode</th>
<th>Calendar</th>
<th>Event Mode</th>
<th>Program Mode</th>
<th>Cool Set Temp (°F)</th>
<th>Heat Set Temp (°F)</th>
<th>Current Temp (°F)</th>
<th>Current Humidity (%RH)</th>
<th>Outdoor Temp (°F)</th>
<th>Wind Speed (km/h)</th>
<th>Cool Stage 1 (sec)</th>
<th>Heat Stage 1 (sec)</th>
<th>Fan (sec)</th>
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What is actually happening:

Sources: DOE, Ecobee, Fraunhofer CSE, Wikimedia Commons.

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A home’s thermal response reflects its characteristics.

Example of building parameter estimation by curve fitting using CT data from a single night

\[
R\text{-value} = 15.7; \quad Q = 982.3; \quad T_w(0) = 5.4° \quad C + \frac{1}{2}(T_r + T_a)
\]

Sources: DOE, Ecobee, Fraunhofer CSE, Wikimedia Commons.
Key Challenges

• Different physical parameters can create similar building thermal responses
• Different HVAC systems have different response times and characteristics
• Many homes have multiple CTs
• Thermal response “noise” from internal heat gains

Sources: DOE, Ecobee, Wikimedia Commons.
Project Approach: Overview

Analyze real-world CT, interval, and home energy audit data to successively refine home thermal response models to accurately estimate home physical parameters that correspond to the target ECMs in increasingly complex situations.

Sources: DOE, Ecobee, Wikimedia Commons.
Project Approach: Technical

Basic Approach:

1. Energy balances on the enclosure and indoor air
2. Fit real-world CT data sets to gray-box thermal models to determine the physical parameters
3. Compare physical parameters to thresholds indicative of retrofit opportunity

Approach to Overcoming the Technical Challenges: Data, Data, and More Data

Superior data quality and quantity enables a hybrid gray-box thermal modeling and machine-learning approach to develop and train algorithms

- CT and Home Energy Audit data for several hundred + homes
- Deep “ground truth” data from 80 homes with CTs
  - Home energy audit with blower door testing
  - Interval gas (hourly) and electric (5-minute) data

Source: Clearmeadows Community Association, DOE.
Scaling for Impact

1. Project Team: Two leading IOUs and innovative muni
   - Leverages data from existing CT programs

2. Project integrates randomized controlled trial (RCT) to validate key hypothesis of project:

3. Do targeted outreach and customized EE offers double the uptake of home energy audits and targeted ECMs?

4. Project Deliverables to Scale Impact
   - CT Data Specification
   - Best Practices Guide for EE Program Integration
   - Project completion in 2019

5. Near-term Outcome: Integrate with Eversource and National Grid EE programs

6. Target Future Outcomes:
   - CT data specification adopted by other utilities, EE programs, and EnergyStar
   - CT analytics used by other EE programs
Conclusions and Future Plans

Conclusions – Leverage data from HEMS technology to:
• Identify high-impact retrofits for largest residential end use
• Create customized retrofit offerings for individual homes to increase demand
• Validate retrofit performance
• Scale using through leading utility EE programs

Potential Extensions of Approach
• Expand to space heating with heat pumps
• Expand to space cooling applications
  • Deeper integration of electric interval data

Learn More:
• “Communicating Thermostats as a Tool for Home Energy Performance Assessment”
  • See: https://edas.info/p22259 .
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Connected Homes: Are We There Yet?
2017 Better Buildings Summit

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Problem Statement

Despite the projection of tremendous market growth of connected devices in the near future, the current technologies (especially for residential and small commercial buildings) have not been valued in the mainstream market due to lack of connection with fundamental consumer benefits and demonstrated grid benefits.

System-level research strategies that enable a full integration of fragmentally developed connected devices is important to enable a truly transactive utility network for residential buildings (the attributes of which are also shared with small commercial buildings).

Current Communication Between Connected Home Devices and Grid

Many home apps function as internet-based digital remote controls of IoT devices.

One-way control signal from the Grid leads to unpleasant consume experience.

Turn off! Set back!
Utilities Challenges

- Traditional Energy Efficiency (EE) programs are receiving less payback.
- Distributed generation is changing load characteristics.
- Variations among households make load controls difficult.
- Proprietary Demand Response Automation System (DRAS) with limited flexibility.
- Historically low participation rates in traditional DR programs.
- Existing DR schemes for large energy consumers do not work in the residential sector.
Volttron allows for disaggregated control – a common control platform for all available devices – and creates an in-home transactive network to respond to grid signals.

$20 for 2kW @ 2PM
What is Transactive Control?

- **Transaction Based Controls** – A means of executing transactions through automatic control of the operating state of building equipment and other energy systems in response to data and value streams. [PNNL 2014]
  - Most common signal is economics based: “price.”
  - Needs advancements in fundamental controls – like plug-n-play, FDD, auto-mapping, etc.

- **Transactional Platform** – a software platform (e.g. ICT & related physical hardware) that allow applications to be programmed and negotiate/act on the exchange of information.
  - VOLTTRON is fully supported throughout DOE (OE, EERE, others) & is open source.

- **Transactive Energy** - A system of economic & control mechanisms that allows the dynamic balance of supply & demand across the entire electrical infrastructure using value as a key operational parameter. [GWAC 2015]
  - The term “transactive” comes from considering that decisions are made based on a value to the parties involved. The decisions may be analogous to (or literally) economic transactions.

- **Transactive Devices** or **Connected Equipment** – Consumer products with the capability to receive and transmit digital signals, make decisions, and respond accordingly with physical action or informational content. [DOE 2015]
  - Available technologies are typically proprietary (e.g. vendor specific ICT)
  - Connected equipment also includes features that enable, for example, the projection of future states, measurement and verification (M&V), or maintenance needs.
How TC works in Homes

- Fully integrate the current and future IoT devices and automatically detect and connect to new devices
- Learn and adapt to unique home settings and embrace social interaction
- Driven by consumer desires and deliver what is most important to home users

Controller: The grid communicates that price will decrease from $0.5/KWH to $0.1/KWH from 2 to 6PM if we can remove 4 KW from the home.

AC: I will cool the house to 65 degree before 2PM. When kids get home at 5PM, the temperature will be 72. I will run after 6PM.

Water Heater: The kids will take a shower at 5PM after school. I will shut down until 4:30 PM.

Dishwasher: I don’t need to run until 8PM.

EV: I won’t start charging until 7PM.
Control Algorithm

• A home is asked to provide energy reduction for \( t \in [t_0 \ t_1] \)
• Individual devices submit their disutility function for providing energy reduction at the beginning of \( t_0 \)
• Controller clears the behind-the-meter market to select those devices with minimal disutility to provide energy reduction

Example: Air Conditioner

• Discomfort function as a function of setpoint and time duration
• Disutility function as a function of energy reduction (average power reduction multiplied by time duration)
Event-Driven Update

- Controller monitors the operations of individual devices that are selected to provide energy reduction for $t \in [t_0, t_1]$
- At $t = t_2$, the operation of one device is changed (for example, house owner adjusts the temperature setpoint) --- disturbance
- Controller needs to re-clear the market for the remaining period $t \in [t_2, t_1]$
How \textit{VOLTTRON} platform works

**R&D:** Validate the Transactive Control concept in homes, in addition to the traditional features delivered as agents using \textit{VOLTTRON}.
Open Source Platform such as Home Assistant can connect VOLTTRON platform to many components.

- Allow linking to IFTTT, weather information, or Amazon Echo device to controls from locks to lights to even a command line notifier.
- Pairs with both open sources and commercial offerings supporting over 600 components in 34 categories
- Easily to deploy on any machine runs Python
- Features easy-to-use user interfaces for all mobile devices
- Does not store all of the private information on the cloud ensuring data security
- Has a large community for technical support and trouble shooting

Number of devices/apps connected to Home Assistant by Category
Adapt VOLTTRON to Home Assistant and develop a transactive control-based load control and coordination platform.
Our vision
A open-source platform for home related information to enable the transaction of services.

Energy Related Services (DOE’s main use cases)
Consumer Services (Home related services, such as equipment upgrades, repairs and maintenance; household product supplies and replacements, and social interactions).

The common storage and collection of home related information on a centralized platform allows for analysis, targeted data, advertisements, and opportunity/action.

**Home** is a place for social.
**Home** is a vessel for activities, events, memories, other time based interactions.
**Home** is an investment, a place of use and maintenance.
**Home app** should capture all of these as a record, as an interactive member of the family dynamic.

Home is more than a collection of devices...
Who are you with and how far from home?

Just posted photo from race with friends 60 miles away... not likely to come home for another 30 min... maintain the thermostat setback.

Data about networks will help identify resources?

You’re following NFL and NFL tonight is on the TV tonight... likely to watch TV at home... charge EV after the NFL game.

What information are you receiving that may affect your future pattern?

Hi! I don’t think you will take a shower until 9PM. I will reduce your hot water temperature and save a few bucks. I noticed that you have been coughing. I increased the humidity in the house.

VOLTTRON Platform commingles all the available home data with the available control and device data.
BTO Building to Grid
Comprehensive, interoperable integration of devices, buildings, and grid with Transactive Controls utilizes software applications to monitor, control, and aggregate building resources.

Transactive Control & Smart Buildings Ecosystem...
• Enables Smart Buildings to be aggregated dynamically and ‘transact’ with the electric utility (i.e., Buildings provide benefit to the consumer, the utility, and the environment);
• Leverages applications on a Cyber-secure Transactional Platform (VOLTTRON) that enhances seamless interoperability (i.e., doesn't require new hardware or devices);
• Provides value from all aspects of the utility to the consumer domains (i.e., has capability to capture values from regulated and non-regulated markets).

Controls for Building Efficiency...
• Are defined by their inner building communication mechanisms (i.e., hardware and sensors for one building or system);
• Utilize Demand Side Management controls that optimize energy use for the consumer (i.e. measured by annual net consumption);
• Engage in direct load control or Demand Response for limited value to both the grid and building owner; and,
• Provide value to the owner or operator so they can recoup the investment.
Conducted industry status review and focus groups among realtors to gather market feedback and perceived value proposition (2016)

Organized an open challenge to inspire innovative market solutions (2016)

Formed a leadership network to create a joint workforce through collaborations among various sectors (2016-2017)

Next (2017)

- Develop system-level technical strategies for connected homes and neighborhoods
- Develop a prototype of a transactive-based home management system and validate through filed trials
Five teams took an eight-week challenge to develop a Connected Buildings solution using VOLTTRON. The solutions were demonstrated in Seattle (Smart Buildings Center) on August 03, 2016.

**Enerphant**
Demand response not widely known in residential sector

*Team Members:* Worodom Khampanchai, Thaninpong Cheiyammas, and Tony Chotibongs

- Electric utilities are struggling to engage residential customers to participate in demand response (DR) programs due to implementation cost as well as users’ understanding.
- Homeowners do not know what to do to participate in DR program as well as how to change appliances (e.g., thermostat) settings to save energy. Most of the time people forget to turn off appliances or lazy to do so due to savings benefit is not quickly realized.
- Many of existing demand response and energy saving

**Neighborhood Air-Conditioning Coordinator**
Reducing demand in homes

*Team Members:* Andy Hjortland, Donghun Kim, and Jim Braun

A supervisory control system for residential HVAC systems that uses web-connected thermostats to reduce peak electrical demand by coordinating when systems are used.

1. Learn a thermal model of homes to maintain comfort.
2. Optimize run-time of AC systems using model predictive control.
3. Reduce electrical demand by reducing time when many air-conditioners are running simultaneously.
Experience from the AEP Ohio gridSMART Demonstration Project

- A four-year project (2011-2014) to design, build, and operate an innovative system and an incentive-based approach to engage residential consumers and their end-use resources in a participatory approach to electric system operations.

- With a 35% penetration, a load reduction of about 5% can be obtained for a 3.5-hour system peak event.
- 5% reduction in the average household bill (due to incentives), with a slight increase in overall energy usage.
- Observed clusters of consumer preferred thermostats settings and verified consumer fatigue.

Thank You!
Thank You

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