NEW YORK STATE OF OPPORTUNITY | NYSERDA

Home Energy Management System Savings Validation Pilot

Final Report

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NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Mission Statement:

Advance innovative energy solutions in ways that improve New York's economy and environment.

Vision Statement:

Serve as a catalyst – advancing energy innovation, technology, and investment; transforming New York's economy; and empowering people to choose clean and efficient energy as part of their everyday lives.

Home Energy Management System Savings Validation Pilot

Final Report

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Notice

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Summary

The Home Energy Management System (HEMS) industry is rapidly growing with a worldwide market valued in the billions and hundreds of manufacturers selling smart products that provide an array of options within the Internet of Things (IoT). This technology represents the integration of mature hardware (sensors and controllers), internet connectivity, new software, and emerging powerful analytics. NYSERDA collaborated with LM Energy to provide an integrated HEMS solution to a pilot group of single-family homes and to analyze potential energy and cost savings.

S.1 What Is the Technology?

HEMS products are a combination of hardware and software that monitor and provide feedback about home energy usage. HEMS also enable advanced control of energy-using equipment, and/or other devices in the home.[1] HEMS hardware typically consists of sensors and controllers (e.g., smart thermostats, smart outlets, smart lamps, smart switches), while software features may include monitoring, notifications, demand response, home automation, energy management, security, and data analysis/visualization. Users typically interact with HEMS through a dashboard on a computer, or hand-held device.

S.2 Pilot Design and Objectives

This pilot deployed HEMS at 50 homes across Westchester and Albany counties in New York State. Over 1,500 sensors were deployed and collected over 106 million data points during the pilot test period. The stages of the pilot process included pilot design, reviewing and selecting a manufacturer and partners, identifying and training installers, recruiting participants, installing equipment, testing and commissioning, data collection, analysis, and reporting. HEMS installations were completed December 2016 through January 2017, and data were collected through May 2017. Each home was analyzed individually for the entire duration of data collection to identify interesting trends, snapshots of savings potential, and data anomalies. In addition, data collected from all homes during February 2017 through April 2017 was used for the average home savings analysis. The objective of the pilot was to use Base-Load Simulation methodology to validate HEMS energy savings potential; no smart controls were enabled during the pilot test period. Baseline energy consumption and occupant behavior were measured, while controls savings were simultaneously simulated for HVAC temperature setbacks, lighting

1 http://www.neep.org/initiatives/high-efficiency-products/home-energy-management-systems

occupancy-based controls, and plug-load occupancy-based controls. The Base-Load Simulation method was successfully demonstrated as a valid approach for HEMS measurement and verification (M&V) while minimizing the impact on homeowners. Base-Load Simulation method combines the International Performance Measurement and Verification Protocol Option B (Retrofit Isolation: All Parameter Measurement) for baseline analysis with Option D (Calibrated Simulation) for savings potential into the same time period, rather than a pre/post type analysis. By combining the measured baseline and simulated savings, the Base-Load Simulation Method eliminates several uncontrolled variables (weather, occupant behavior, schedules, etc.) that typically add uncertainty to other M&V approaches.

S.3 Results and Findings

LM Energy successfully used the Base-Load Simulation methodology to validate energy-savings potential for HVAC, plug load, and lighting control features for which HEMS can automate. The Base-Load Simulation model eliminated several of the uncontrolled variables by monitoring more base-load variables at smaller intervals to gain better resolution of how, when, and where energy was being consumed and saved. Uncertainty was reduced by monitoring climate data and behavioral variables, such as occupancy, presence, system status, and operating state. The system integration and data analytics in this pilot produced valuable HEMS performance results and key findings, which are described in detail in this report.

The average installation cost estimate for the 50 pilot homes was $1,853 and the estimated useful life (EUL) of HEMS is 15 years. A maximum energy savings potential of up to 16% (1,241 kWh/year and 52 therms/year) was found for a typical home. The maximum potential energy savings for a typical home are equivalent to 1 metric ton of CO2e savings per year and 15 metric tons of CO2e savings over a 15-year life of a HEMS.

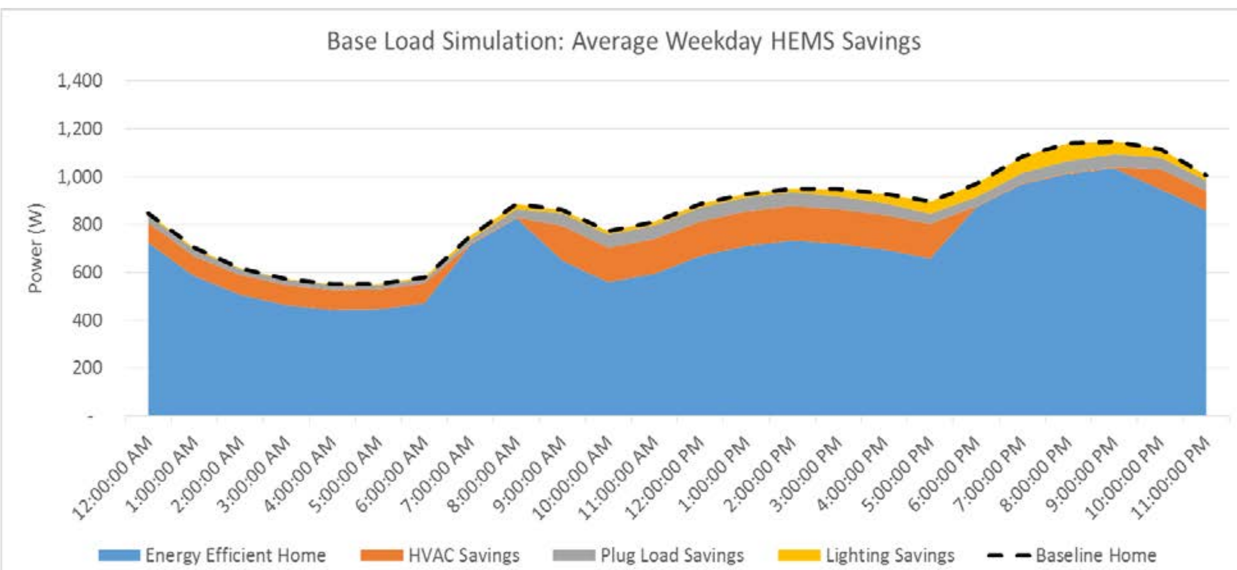
Table S-1. Base-Load Simulation Model Maximum Annual Savings Potential by End Use

Smart Device	Electricity Savings (kWh/year)	Heating Fuel Savings (therms/year)	Cost Savings* ($/year)	Assumptions
Smart Thermostat	688	52	$174	No existing setback controls
Smart Outlets	341		$58	15-minute occupied delay
Smart Lamps or Switches	212		$36	Controls only
Total HEMS Savings	1,241	52	$268	

* Assumes average utility rates in New York: $0.17/kWh and $1.10/therm

Simple payback periods ranged from seven to 12 years, depending on baseline conditions. Adding an incentive through a utility energy efficiency program for 25% of the installed cost could reduce consumer payback period to five to nine years.

Figure S-1. Base-Load Simulation Model Results for Average Home on an Average Weekday



Extrapolated total annual savings potential for HEMS in the NYSERDA territory[2] is estimated to be 57,305 MWh/year and 177,754 MMBtu/year. This assumes a 1% adoption rate per year for residential customers, a similar distribution of home characteristics as the pilot group, a similar distribution of thermostat settings observed during pilot, and a 60-minute delay on plug-load controls. Potential energy savings in the NYSERDA territory are equivalent to 40,921 metric tons of CO2e savings per year and 613,814 metric tons of CO2e savings over a 15-year life of a HEMS. Savings would displace some existing measure (e.g., advanced power strips, smart thermostats, and behavior change) savings, but would also create new savings potential and greater persistence through the integrated system.

Individual home savings varied widely based on a large range of baseline conditions. Table S-2 shows estimated utility bill percent cost savings by end-use for a representative sample of individual homes from the pilot group. The individual home cost savings chart (Table S-2) is intended to provide a sense of the range of cost savings that are plausible given a wide range of baseline conditions and is not intended to represent the average cross-section of homes.

Table S-2. Sample of Estimated Individual Home Percent Cost Savings by End-Use

Home ID	Heating Fuel	Cooling System	Plug-Load Cost Savings	HVAC Cost Savings	Lighting Cost Savings	Total Cost Savings
1007	Natural Gas	Central AC	3.3%	11.8%	3.7%	18.8%
1008	Natural Gas	Central AC	9.1%	11.2%	5.2%	25.6%
1011	Natural Gas	Window AC	1.0%	5.7%	2.5%	9.3%
1020	Natural Gas	Central AC	2.7%	10.1%	2.3%	15.1%
1022	Natural Gas	None	0.5%	0.0%	4.6%	5.1%
1024	Oil	Window AC	0.5%	7.2%	1.6%	9.3%
1025	Natural Gas	Window AC	7.4%	6.0%	2.3%	15.7%
1029	Natural Gas	Central AC	11.9%	4.0%	1.7%	17.5%
1036	Oil	Central AC	4.8%	15.7%	1.6%	22.2%
1038	Oil	Central AC	1.4%	4.9%	2.5%	8.7%
1046	Natural Gas	Central AC	3.0%	7.4%	3.4%	13.8%
1047	Oil	Window AC	0.1%	8.7%	2.3%	11.1%

2 Energy Information Administration data for NYSERDA estimates 7,270,114 residential customers

Several best practices and lessons learned were identified throughout the HEMS pilot. These findings help inform a critical knowledge gap in the industry regarding installation, data management, and technology selection. The results from this pilot and identified best practices provide an important step forward towards larger scale deployments. Recommended future work includes additional pilots, incorporating additional end-use equipment (e.g., appliances, water heaters, windows, and doors), identifying and training installers, and developing new HEMS control measures.

Other significant cost savings and potential program benefits from this HEMS pilot were identified, including: deeper customer engagement, factual data for evaluation and marketing, behavioral data, demand response, and load-shifting with time-of-use rate structures.

1 Introduction

The Home Energy Management System (HEMS) industry is currently in a state of significant growth and expansion. It is reported that by 2025 the HEMS worldwide market will be valued at $7.8 billion.[3] There is a growing number of manufacturers and brands of HEMS sensors and controllers (e.g., smart thermostats, smart outlets, smart lamps, smart switches, etc.). In addition, software application capabilities are giving consumers greater ability to monitor, visualize, and control energy-using systems and devices in the home. In order to capture and retain focus on the energy-saving features of HEMS, program barriers and market barriers that face the industry need to be addressed, including the following:

- minimal performance data published on HEMS savings
- published data lacking third-party validation
- large data streams difficult to manage
- interacting systems of data challenging to integrate
- behavioral data difficult to obtain reliably
- standard pre/post evaluation methodologies not accurately measure behavior-based control savings because of too many uncontrolled variables (weather, occupancy, schedules, etc.)

These barriers exist due to the large variation of HEMS configurations and consumer interactions and to the lack of an effective testing method that provides accurate and accountable savings information. With some input from NYSERDA, LM Energy designed and implemented this pilot in an effort to validate a new and simplified testing methodology for HEMS products. When compared to traditional pre/post monthly utility data-testing methods, this new Base-Load Simulation method eliminates several of the uncontrolled variables by monitoring more variables at smaller intervals to gain better resolution of how, when, and where energy is being consumed and potentially saved. Measuring behavioral variables such as occupancy, presence, system status, operating state, and other interactions eliminates a large portion of the uncertainty associated with energy savings from other M&V methods. While implementing the Base-Load Simulation test method validation, LM Energy was able to simulate HEMS energy-saving capabilities during the same time as the baseline. This pilot was designed to account for HVAC, plug load, and lighting control features that HEMS can automate.

The Base-Load Simulation testing methodology monitors baseline behavioral characteristics with real-time monitoring of energy consumption and simultaneously simulates operation and energy-saving potential of HEMS devices.

[3] https://www.navigantresearch.com/research/market-data-home-energy-management

1.1 Objective

The objective of the pilot is to validate Base-Load Simulation testing methods and simulate potential HEMS savings. Using occupancy sensors and geo-fencing capabilities, the HEMS devices installed essentially operated in manual mode, with the “smart” features or controls disabled. This method eliminated behavioral, household, environmental, and system variables to test for the real-time energy-saving capabilities of the HEMS. The specific HEMS control strategies tested in each home included the following:

- HVAC control via smart thermostat
- lighting control and scheduling via smart outlets, smart switches, and smart led lamps/fixtures
- home entertainment system plug-load control via smart outlets
- home office plug-load control via smart outlets
- system effectiveness when paired with occupancy sensors
- system effectiveness when paired with geo-fencing

1.2 Pilot Process

Due to the potential complexity and variations of HEMS and their components, LM Energy utilized core best practices methods of Test, Evaluate, and Adjust throughout the duration of the pilot. This approach allowed LM Energy to quickly adapt all steps of the pilot to ensure a successful implementation. The pilot was designed with the following milestones:

- Pilot Development – included the final hardware/connected device vetting of setup and structure to ensure connectivity, function, and dataflow.
- Manufacturer RFP Release – LM Energy issued a Request for Proposal (RFP) to HEMS manufacturers to obtain capable and reliable HEMS products that provided the necessary data to measure the potential savings.
- Installer RFP Release – a qualified and accredited installation team was required to meet electrical code requirements for installations of hard-wired smart devices, such as smart thermostats, and smart light switches.
- Consumer Recruitment – combined effort with NYSERDA to recruit and screen potential participants through social media and traditional marketing methods.
- LM Energy and Manufacturer Testing – entailed LM Energy conducting initial testing on the processes, systems, and data farming in three test homes. Lessons learned were applied to avoid technical issues or gross failures among the larger sample group, i.e., a small pilot design.
- Consumer Participation Selection – to ensure all participants understood their roles and the overall purpose of the pilot, LM Energy provided each participant with an overview that included guidelines, directions, and 24/7 customer support. Participants were encouraged to maintain their daily routines not to make any overt changes in behavior related to energy use.

- Data Collection, Analysis, and Reporting – included collecting data for a period ranging three-to-six months depending on the HEMS installation date. Analysis was conducted at the end of the pilot test period and the results are summarized in this report.

2 Methodology

This pilot deployed HEMS at 50 homes across Westchester and Albany counties in New York State. Over 1,500 sensors were deployed and collected over 106 million data points during the pilot test period. This section describes LM Energy's methodology for implementation, data collection/management, and savings analysis.

2.1 Timeline

System installation was completed in three phases from December 2016 through January 2017. Data were collected starting at the installation date through May 2017. Each home was analyzed individually for the entire duration of data collection for interesting trends, snapshots of savings potential, and data anomalies. In addition, all homes had overlapping data collected from February 2017 through April 2017, which was used for the average home savings analysis. This overlapping timeframe allowed the entire pilot group to be analyzed together, removing any uncertainty from time of year, holidays, weather, and other variables.

2.2 Pre-installation Survey

During the customer recruitment process, over 60 homes applied to participate in the pilot. A pre-installation survey was conducted to review applicant eligibility and inform the pilot methodology for sensor selection, targeted equipment, and behavior tracking. The applicant pool was pared down to a total of 50 homes that best represented the wide variety of home types, occupant demographics, square footage, systems, and utilities in the region. The following information was collected during the pre-installation survey, and the survey results are described in detail in the Summary of Findings and Conclusions section of this report:

- name
- address
- contact information
- gas utility company
- electric utility company
- average monthly gas and electric bill cost
- heating fuel type
- air conditioning (ac)
- type/brand of existing thermostat
- square footage
- number of occupants (adults/children)
- occupants with smart phone or tablet

- approximate household annual income
- occupations
- how do you value saving energy
- primary entertainment system
- adoption of household electronic products

2.3 Sensors and Equipment Installation Inventory

On average, approximately 30 metered points were monitored in each pilot home to measure the base-loads and occupancy behavior. Several diverse sensor types were deployed to collect different types of information. These sensors were selected to measure energy/power, behavior, and thermal comfort within the homes. HVAC, plugs, and lighting were specifically targeted as the primary end-uses a HEMS would control for energy savings. This section describes the various types of measurements, typical locations, and outputs from the sensors. Physical hardware and example of quantity per home is provided in Table 1.

Table 1. Smart Products Installed in Each Home

Smart Product Type	Quantity per Home
Hub	1
Smart Lights	10
Smart Switches	3
Smart Outlets	5
Whole Home Power Meter	1
Occupancy Sensors	5
Geo-fencing Sensors	4
Smart Thermostat	1
Total	**30**

All hardware was researched, tested, and tracked to ensure good interoperability. In addition, all hardware was screened to ensure commercial availability, positive reviews from early adopters outside of the pilot, and good data flow for M&V. Each piece of equipment typically integrated multiple sensors, allowing more metered points to be collected with the given equipment list. The following list describes the different types of data collected by the HEMS:

- Power – instantaneous rate of energy in Watts. Typically measured at the utility meter, outlets, or switch. Usually, a combination of measured amps and volts (sometimes voltage is assumed) through an electrical wire.

- Energy – time integral of the instantaneous power over time in Watt-hours. Typically measured at the utility meter, outlets, or switch. Usually calculated from measured power and aggregated over time.
- Presence – whether an occupant is within a virtual geographic boundary (geo-fence) defined by the home. It returns a binary indicator of whether an occupant is at home or not.
- Motion – whether an occupant is within a specific zone/room within the home. Typically measured in different space types, such as family room, bedroom, office, and kitchen. It returns a binary indicator of whether an occupant is in the room or not.
- Temperature – ambient air temperature in degrees Fahrenheit (°F). Typically measured in different space types, such as family room, bedroom, office, and kitchen.
- Humidity – ambient air relative humidity in in percentages. Typically measured in different space types, such as family room, bedroom, office, and kitchen.
- Thermostat Set Point – targeted ambient air temperature, in degrees Fahrenheit (°F). This is a control setting input by the occupant into the thermostat.
- Thermostat Mode – operating mode of the HVAC system. Typically includes options such as heating, cooling, automatic (heating and cooling), fan only, and off. This is a control setting input by the occupant into the thermostat.
- Thermostat Fan Mode – operating mode of the HVAC system fan. Typically includes options such as on or automatic. This is a control setting input by the occupant into the thermostat.
- Thermostat Operating State – operating state of the HVAC system. It returns a binary indicator of whether the system is on or off.
- Switch State – operating state of a switch that is either controlling a light circuit or outlets. It returns a binary indicator of whether the switch is on or off.
- Light Level – dimming state of a switch in percentages. Returns a value between 0-100 to indicate what percent of the maximum output is currently being used.
- Battery – charge state of the battery in percentages. It returns a value between 0-100 to indicate what percent of charge the battery has remaining.

2.4 System Integration / Interoperability

LM Energy researched and selected hardware for many reasons—principally interoperability. The Samsung SmartThings hub significantly reduced interoperability issues for this pilot, because it integrates a wide range of third-party manufacturers that use a variety of wireless protocols. The SmartThings hub has both Z-wave and ZigBee chipsets allowing wider product flexibility for both implementers and for consumers. Overall, the SmartThings system performed very well with 100% uptime if the customer maintained an Internet connection. The SmartThings hub was able to achieve perfect uptime because it is hardwired to the household router versus using a Wi-Fi connection like other hubs on the market.

Hardware setup and integrations were made quick and painlessly with all SmartThings branded and "works with" products.[4] One identified challenge was that data requirements for the pilot created the need for custom code or "device handlers" to be modified or created. However, this challenge was easily overcome with the SmartThings web based interface when needed. Table 2 shows specific brands of smart products tested during this pilot.

Table 2. Specific Smart Product Brands Tested During Pilot

Hub	Lighting	Plug-Load	Room occupancy	Dwelling occupancy	HVAC
SmartThings (ST)	Sylvania Smart Lamps	GE Plug modules	ST Motion Sensors	ST GeoFencing Sensor	Honeywell Lyric Smart Thermostat
	GE Connected switches	AEOTECH Whole Home Power Meter			EcoBee (customer provided)*
	GE Connected Dimmers				

* Two pilot homes used EcoBee thermostats provided by the participants

Some products required third-party integration due to a device having its own internet-connected "cloud" support. These devices can also be synced or "added" to the SmartThings user interface. This was accomplished through the SmartThings App by entering the username and password from this device and syncing directly to the SmartThings system. This feature provided access to the whole system through a single App instead of multiple touchpoints. LM Energy used the App to achieve a smoother installation process. Participants did not have any interaction with the HEMS system or SmartThings App during the pilot period, and were encouraged to maintain normal behavior for an accurate baseline.

2.5 Sampling Protocol

The sampling protocol describes the collection of relevant and sufficient data to validate the home energy performance and occupant behavior under real-world conditions. Data were collected at different intervals depending on sensors because interval settings varied from sensor to sensor and some sensors

4 Approved product list available at https://www.smartthings.com/products

did not have a regular interval because they only reported data when a state changed. The intervals ranged from one second to several hours. Raw data files from the various sensors and various homes were combined and resampled into 15-minute intervals, based on a time-weighted average to make the data more functional and usable for analysis.

2.6 Inventory Survey

During the HEMS installation, a detailed inventory of the monitored equipment and its location was recorded. Recording the type of equipment being replaced or controlled by HEMS informed the pilot baseline, savings profiles, and range of typical home equipment. Installation was categorized by space type, including family room, bedroom, office, and kitchen. In each space type, the applicable monitored lighting and plug loads were noted in a standardized format. Data collected included number of lamps, lamp Wattage, entertainment systems, computers, and other electronics. Smart product locations inside the home focused on capturing a good diversity of space types and the most frequently used equipment. Smart plugs were consistently installed for entertainment systems (living room and bedrooms) and offices in all pilot homes. Smart lights and switches were commonly installed in living rooms, dining rooms, kitchens, and bedrooms.

Figure 1. Sample of Office Lighting and Plug-Load Inventory Form

Home Office Lighting

Naming Convention:
Room/Device/number for example: Living room Lamp 1, Bedroom TV 1, Living room Switch 1
Note: All installed hardware must be named/labeled appropriately by location and connected device

Existing hardware lamps		
Floor/Table lamps	Number of lamps	Wattage
1		
2		
3		
4		
5		
6		

New hardware lamps		
Floor/Table lamps	Number of bulbs	Lamp Name
1		
2		
3		
4		
5		
6		

Existing hardware fixtures		
Pot lamp/fixtures	Number of lamps	Wattage
1		
2		
3		
4		
5		
6		

New hardware fixtures			
Smart switch		Lamps on circuit	Switch Name
Yes			
Yes			
Smart Dimmer			Dimmer Name
Yes			
No			

Home Office Plug load Tracking
Home Entertainment information

TV
Yes ________ No ________

TV Type
LED ________ LCD ________ Plasma ________ DLP ________

DVD
yes ________ No ________

Internet TV – Apple to, roku, chr
Yes ________ No ________

Game Console
Yes ________ No ________

Home Theater/Surround Sound
Yes ________ No ________

Sound Bar
Yes ________ No ________

Computer, Phone Chargers, Etc: ________

2.7 Data Management and Visualization Tools

Data management and visualization were critical components of the pilot that translated raw data into valuable and actionable insights. The LM Energy team utilized several tools to accomplish this process. Each tool had a specific function, described in the following section, allowing data to flow through the process until it became usable for energy-savings analyses. The key steps of the data management process included communication, storage, access, quality assurance, attrition, consolidation, resampling, analysis, benchmarking, and visualization. Lessons learned and recommendations for larger deployments are described in detail in the Summary of Findings and Conclusions section of this report.

2.7.1 Communication Protocol

A variety of smart devices were installed in each of the pilot homes, including lights, switches, thermostats, plugs, and occupancy sensors. Participants did not have access to the HEMS system and controls were disabled during the pilot period. Home occupants were encouraged to maintain normal behavior for an accurate baseline. Each smart device used wireless radio frequency communication protocol, Z-wave, or Zigbee to communicate with a hub connected to the home's Internet network. The communication protocol was important for gathering information reliably from several different brands/manufacturers of smart devices. A SmartThings Hub was installed in each home and connected to the various smart devices, thereby creating a wireless mesh network within the home. This network of smart devices communicates with the hub at different sampling rates as previously described. The SmartThings Hub collects/combines the data and serves as a router, regulating data traffic between the wireless mesh network of smart devices and the internet. All the different types of data collected from the smart products are routed through the hub to a secure database, via the Internet, where it can be accessed/controlled through the SmartThings application, or an application programming interface (API) by third-party data visualization software.[5]

2.7.2 Data Access, Monitoring, and Live Streaming—Proprietary Data Platform

LM Energy's proprietary data platform for the Internet of Things (IoT) was used to access data, monitor, and visualize data in real-time for each home. The LM Energy team had access to all homes through the LM Energy website, and each participant was given a login to view their individual home's performance. At the end of the pilot period, HEMS control was handed over to the participants, so they could use the smart and connected features of each HEMS device.

LM Energy downloaded pilot data through the platform website in comma-separated files (CSVs). Through the website's dashboard, data can be accessed anytime and instantly turned into interactive real-time charts, statistics, notifications, waveforms, charts, webhooks, and other infographics. LM Energy partnered with a third-party contactor to deliver a consistent, secure, and valuable experience for pilot participants. LM Energy also provided a set of interactive, real-time data visualizations built from the ground-up to provide a unique and powerful way to visualize data through any web browser.

[5] https://www.smartthings.com

Visualizations were used to monitor data collected during the pilot and identify sensor faults. Visualizing occupancy, equipment status, and power in adjacent charts on the dashboard allowed LM Energy to deduce trends and relationships between occupant behavior and energy consumption. For example, equipment power dropping to zero around the same time the room's motion sensor changed from active to inactive showed the occupants turned off equipment when leaving the room.

Figures 2 and 3 show examples of the data streaming and visualizations customized for LM Energy and the NYSERDA HEMS pilot. The "tiles" view shows time series data for office outlet power, whole-home power, living room TV power, living room lamp power, and bedroom motion status. The "waves" view shows a similar time series of stacked line graphs, which overlays energy and occupant behavior. These dashboard visualizations allow multiple product data streams to be viewed during the same time interval to determine when and where energy is being consumed in a home.

Figure 2. Example of "Tiles" Data Visualization

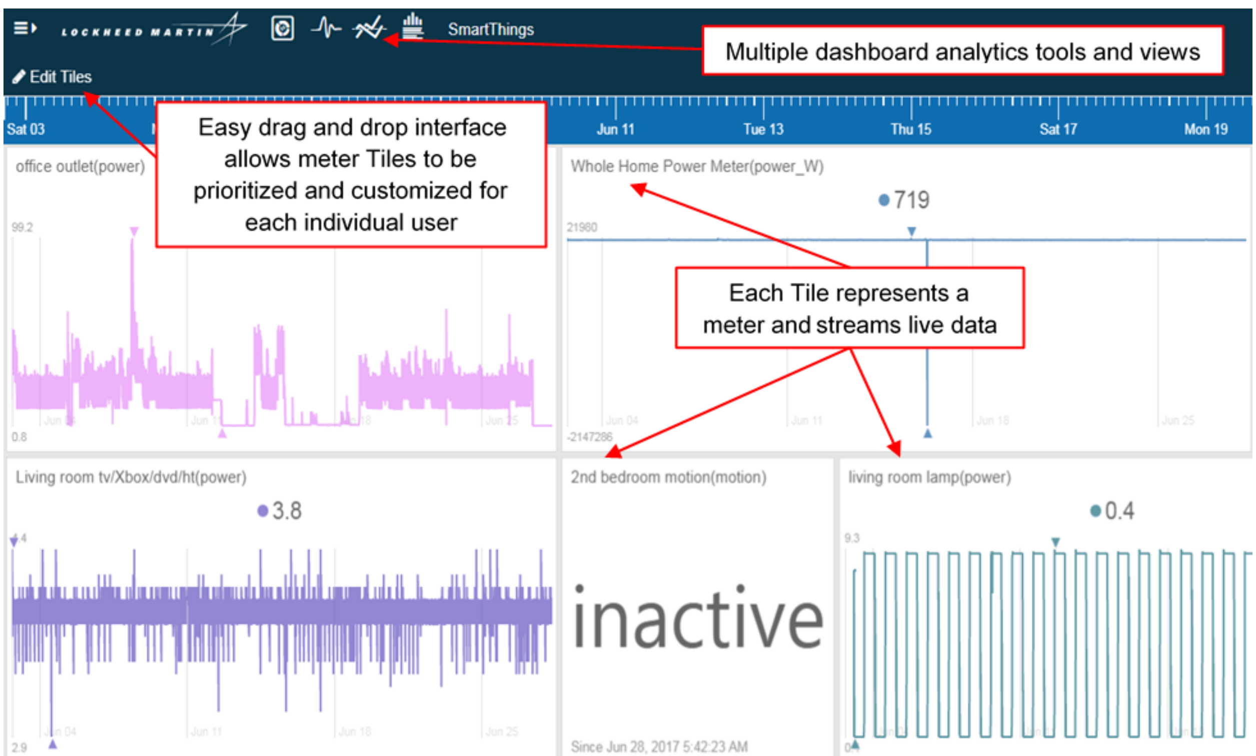


Figure 3. Example of "Waves" Data Visualization

2.7.3 Data Quality Assurance and Attrition—MS Excel and Visual Basic for Application (VBA)

Data for each pilot home were downloaded individually from the LM Energy website and processed for quality assurance, including relevant steps of attrition (i.e., removing missing or erroneous data that may skew results) to ensure data reliability. This section summarizes the methodology to overcome various hurdles encountered during the pilot. MS Excel was used, and customized VBA macros were written to automate and standardize quality assurance checks and data attrition steps for all the homes. Lessons learned and recommendations for larger-scale deployments are described in detail in the Summary of Findings and Conclusions section of this report.

The following list describes data-related issues that arose during the pilot and how they were addressed:

- File Size – several files exceeded the size limitation for the export and required direct download from the server. Upon further investigation, it was caused by plug-load power sensors reporting data every second, creating excessively large files. The size of several of the raw data files also exceeded the row capacity in MS Excel, and therefore, could not be opened without truncating the data. As a work-around, LM Energy engineers opened files exceeding one million rows in a text editor and separated the data into multiple files. Individual sensors reported more the one million data points during the test period were forced to be truncated.
- Time Period Attrition – HEMS were installed and collected data at different times. Each home was analyzed individually for the entire data collection period for interesting trends, snapshots of savings potential, and data anomalies. The average home savings analysis period was limited to three months when all HEMS were active (February–April 2017) to avoid uncertainties from holidays, weather, and seasonal changes. Data collected before or after those times were left out of the "average home" savings analysis.
- Timestamp Correction – timestamps were reporting at universal time coordinated (UTC) +0000 UTC. Therefore, the timestamps were four hours ahead of the local time in New York State. All timestamps were corrected by subtracting four hours.
- Non-Numerical Data – several sensors reported non-numerical data, such as "present," "not present," "active," "inactive," "heating mode," "cooling mode," "auto mode," "fan mode," "off mode," "on," and "off." Data reported as text were converted to numerical values so that a time-weighted average could be calculated in the resampling. Binary text values were converted to one ("present," "active," "on") and zero ("not present," "inactive," "off"). Operating modes ("heating mode," "cooling mode," "auto mode," "fan mode," "off mode") were converted to integers and a reference dictionary was established to translate between text and integer. Converting non-numerical data to numerical values was required to make the data usable when performing time-weighted averages in resampling, or averaging across multiple homes and did not affect the analysis or results.
- Missing Data Attrition – some sensors were found to have long periods of missing data caused by communication errors or battery failures. For example, some sensors are battery operated and while many performed flawlessly, some went through batteries so quickly that it interrupted data flow. LM Energy engineers did not attempt to interpolate or fill-in missing data. Missing data were identified, differentiated from zero values, and excluded from the analysis. Missing data accounted for approximately 15% of the total data in the analysis.
- Formatting – data exports were provided in a format that listed all sensors and values into the same columns. VBA macros were written to separate each sensor into an individual column which is required for the resampling software. In addition, the timestamp was reported through a combination of numbers and text. The VBA macro also parsed the timestamp and converted it into a time-value field recognized by MS Excel. These formatting macros were run on all pilot home data export files in preparation for the resampling software.

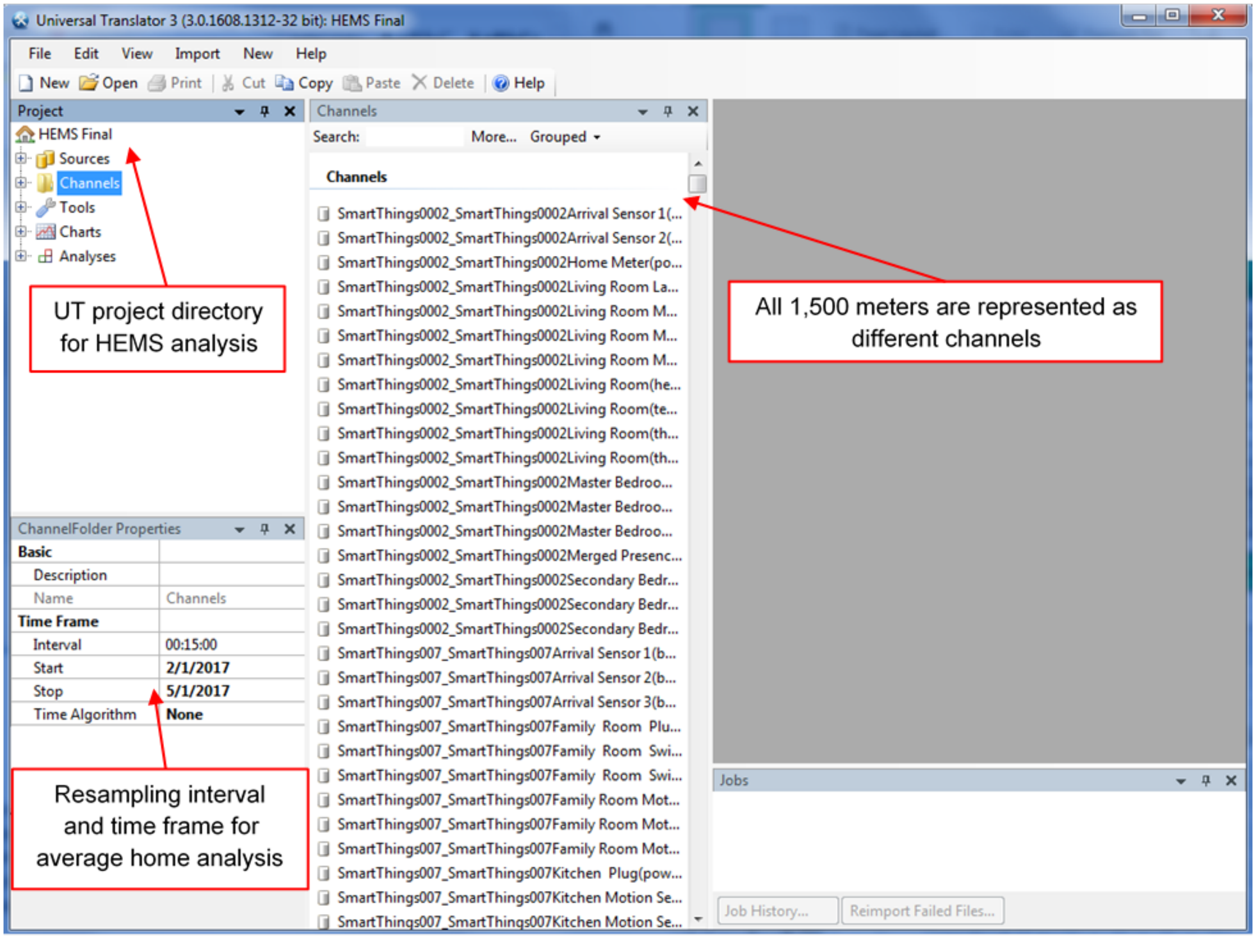
2.7.4 Data Consolidation and Resampling—Universal Translator (UT)

LM Energy used UT software to combine and resample the data from all pilot homes. Files were imported as CSV and resampled into 15-minute data time stamps. UT consolidated all individual home files and used a weighted average to resample data collected at various sampling rates.

UT is free software that runs on Microsoft Windows, designed by Pacific Gas & Electric and Lawrence Berkeley National Laboratory. UT was designed for the management and analysis of data from loggers and trend data from building management systems. UT has comprehensive import, graphing, and analysis routines, and is ideal for large data sets from multiple sources. The software has time correction features, including the ability to synchronize data sets with different recording rates. UT has the capability to provide meaningful calculations despite inconsistent or flawed raw data. For instance, it reconciles data from loggers whose recording intervals differ, and it compensates for calibration errors. UT also includes filter tools that allow you to look at just the data you need. In addition, a routine that calculates detailed statistics for each data set is available. UT also has the ability to export data to a transport file to make data available to other UT users, or into a standard spreadsheet format. UT solves the real-world problems that often arise in data collection, making originally flawed data sets more useful.[6] Figure 4 shows the UT interface with over 1,500 sensors from the HEMS pilot in the “Channels” list, uploaded from 50 different CSV files. The “ChannelFolder Properties” window in the lower left corner shows inputs for the average home savings analysis (February–April 2017) and a resampling interval of 15 minutes. UT software exported a CSV file with all homes and all sensors combined into one file with clean 15-minute timestamps.

[6] http://utonline.org/cms/

Figure 4. UT Data Consolidation and Resampling Inputs



2.7.5 Data Analysis – MS Excel and VBA

Once the clean data set was created, LM Energy used MS Excel and customized VBA macros to run energy savings analysis. Energy consumption profiles and occupancy behavior profiles were aggregated and averaged to create a “typical home” weekday and weekend profile. Savings were plotted against the time of day and compared to occupancy to show intuitive insights from occupancy-based control strategies.

In order to validate the new Base-Load Simulation test method, no HEMS smart controls were enabled during the pilot test period. Instead, the base loads of the 50 pilot homes and behavioral characteristics of the occupants were monitored in great detail to create an accurate model of an average home. The average base load was measured during the pilot and energy conservation measures associated with HEMS were simulated using the Base-Load Simulation method. Savings were simulated by overlapping occupancy simulate savings potential. Occupancy-based control strategies were simulated for plug loads, lighting, and HVAC systems with various presence delays to simulate magnitude and time-of-day savings potential. All adults in pilot homes were provided with presence sensors and the geo-fencing was assumed to capture the status of all occupants in a home, even though children were not given a sensor. Each pilot home was analyzed individually and aggregated into an average home base load. The average savings profile found using this methodology can be extrapolated to other homes to estimate market impact and potentially lead to increased HEMS adoption through utility incentive programs.

HVAC, plug load, and lighting were all analyzed individually to simulate their specific savings impact on the base load. The average base load of each end-use was compared to average occupancy to gain valuable insights into the potential savings from HEMS controls. Lighting power data were extremely limited and switch status (on/off) was determined to be unreliable because three-way switching requires data from multiple components, including non-smart lighting devices, to be correlated. Therefore, the lighting load profile had to be estimated, but could still be analyzed against pilot occupancy data for simulated savings. The average daily lighting load was calculated from the Energy Information Administration (EIA) Annual Energy Outlook from 2016.[7] The average lighting load profile is estimated based on the lighting profile in the Building America Benchmark Definition published by the National Renewable Energy Laboratory (NREL).[8] Lighting savings was then estimated based on the inverse relationship with measured occupancy profiles. HVAC setback savings were estimated using the monitored HVAC set points and occupancy data from the pilot homes and the ENERGY STAR® Programmable Thermostat Calculator.[9]

Peak demand was analyzed for time-of-day frequency during the three-month pilot period. Also, the pilot group was analyzed to determine peak day, rated-load factor for each pilot home, and coincidence factor for each pilot home. The methodology for peak demand analysis followed the guidelines in the DOE Uniform Methods Protocol.[10]

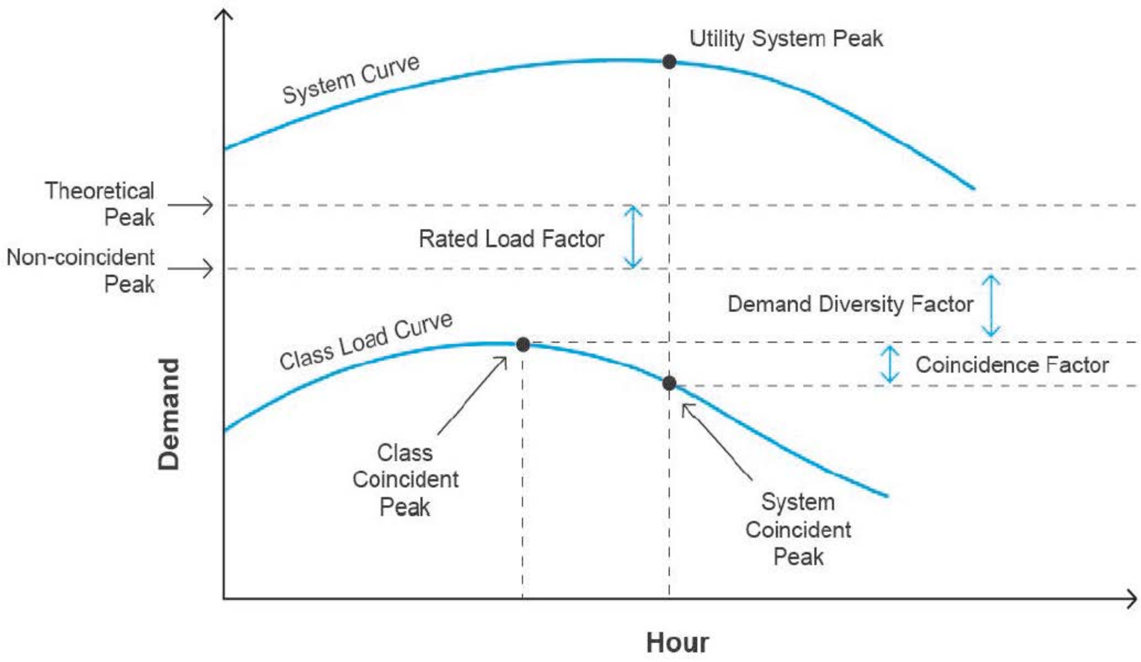
7 https://www.eia.gov/tools/faqs/faq.php?id=96&t=3

8 http://www.nrel.gov/docs/fy10osti/47246.pdf

9 https://www.energystar.gov/products/heating_cooling/programmable_thermostats

10 https://energy.gov/sites/prod/files/2013/11/f5/53827-10.pdf

Figure 5. Generic Peak Demand Analysis Referenced in the DOE Uniform Methods Project



The peak demand analysis provides insight into how each home preformed relative to the pilot group. The time of day when savings occur and coincidence with system peak is an important metric for utilities, and is usually an important consideration in cost-savings analysis. For this pilot, the System Curve was defined as the aggregate of the total amount of power calculated from the whole-home power meters in all the homes in the pilot group. Each individual home was then plotted as the Class Load Curve. The Theoretical Peak was determined by each individual home peak for the month. The Rated Load Factor was calculated as the ratio of the individual home peak for the month to the individual home peak on the peak day for the aggregate pilot group. The Coincidence Factor was calculated as the ratio of the individual home peak to the aggregate pilot-group peak day and the power demand at the time of day when the aggregate pilot-group peak occurred. A Conservation Load Factor can then be calculated as the ratio of average energy savings to the peak energy savings. Trends and insights from the pilot group peak demand analysis results are described in Section 3.3.

2.7.6 Data Benchmarking and GIS Visualization—Tableau

Tableau data analytics and visualization software were used to visualize the geographical relationships among pilot homes and compare normalized energy intensities (e.g., kWh/square foot, kWh/person). LM Energy plotted the geographical location for all 50 sites with demographic data depicting square footage in Albany and Westchester counties. Each home address was converted into geographic coordinates and plotted onto a map using Tableau. Icon size and color coding were used to denote square footage of the home.

Monthly energy usage, site area, and total occupants were used to normalize the energy per home. For home area data submitted as categories (e.g., 1,500-2,000 square feet), a set median value was used to calculate energy intensity. Energy intensity was calculated as monthly kWh used per occupant and per square footage of home. The 15-minute interval and whole-home power data were converted from Wattage into kWh to produce energy intensity calculations and make it possible to add values and generate monthly energy data.

3 Results

The following sections describe the results of the Base-Load Simulation model, specific end-use load, savings analyses, peak demand, and other results. The results focus on an average home savings analysis for the entire pilot group for wider applicability and extrapolation to other homes. Some individual home results are shown to identify specific examples of savings potential, data anomalies, or plausible savings ranges.

3.1 Base-Load Simulation for Maximum HEMS Savings Potential

The Base-load Simulation model eliminates several of the uncontrolled variables by monitoring more variables at smaller intervals to gain better resolution of how, when, and/or where energy is being consumed and saved. Uncertainty was reduced by monitoring climate data and behavioral variables, such as occupancy, presence, system status, and operating state. LM Energy was able to simulate energy-savings potential for HVAC, plug load, and lighting control features for which HEMS can automate.

The graphs in Figures 6 and 7 show the results for an average home baseline compared to an energy-efficient home with maximum savings potential using HEMS. HVAC, plug load, and lighting savings are shown on the time axis for an average weekday and weekend load profile. The HVAC savings are most prominent during the middle of the day and evening when temperature setbacks are implemented. Potential lighting savings were most prominent in the evening hours when a higher percentage of lights were in use and participants may not have been present, but rather left the house lit for extended periods of time. Plug-load savings were observed for all hours of the day, unlike lighting and HVAC that achieved savings primarily during specific time frames.

Figure 6. Base-load Simulation Model Maximum Potential Savings for Average Home on an Average Weekday

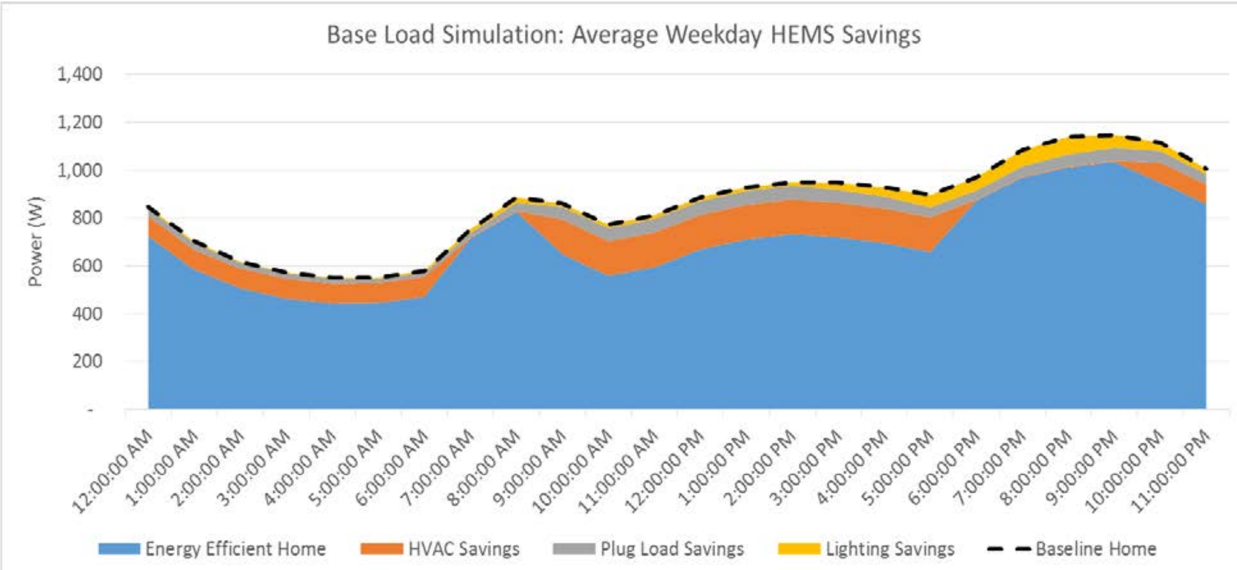
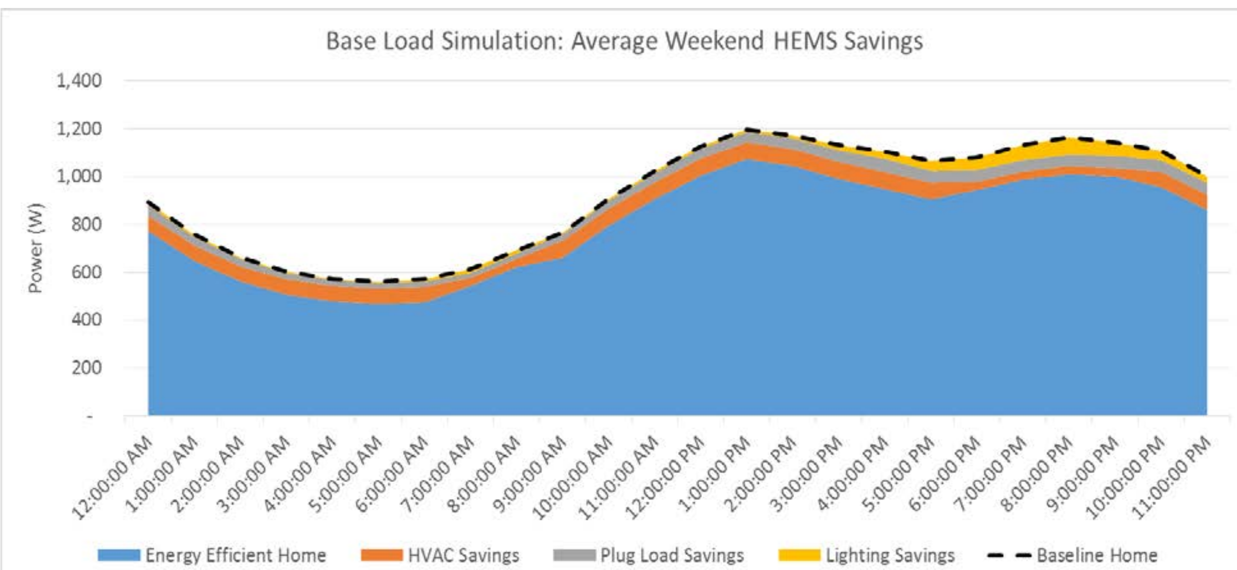
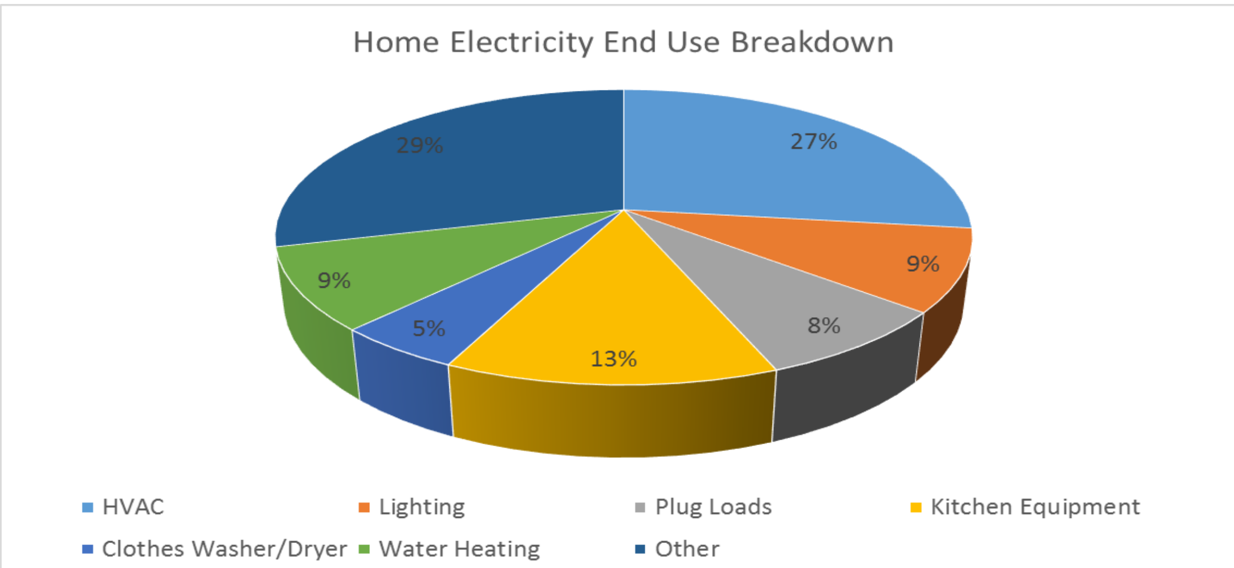


Figure 7. Base-load Simulation Model Maximum Potential Savings for Average Home on an Average Weekend



The results of this pilot and the Base-load Simulation model for an average home estimated a maximum savings potential of 1,241 kWh per year in electricity savings and 52 therms per year of heating fuel savings. HVAC savings also include fuel savings calculated from the ENERGY STAR® Calculator using set points and occupancy data measured during the pilot, even though fuel was not monitored during the pilot. The maximum potential energy savings were equivalent to one metric ton of CO_2e savings per year and 15 metric tons of CO_2e savings over a 15-year life of a HEMS. The HEMS only targeted HVAC, plug loads, and lighting, which accounted for approximately 44% of the total home electricity consumption, according to EIA 2016 data shown in Figure 8.[11]

Figure 8. EIA Average Home Electricity Breakdown by End Use



HEMS maximum savings potential was estimated to be 37% based on the connected loads of the three targeted end-uses. HEMS maximum savings potential was estimated to be 16% when compared to total home electricity consumption. Table 3 shows the energy savings by end-use. HVAC had the highest potential savings, followed by plug loads and lighting, which demonstrated significantly lower results.

11 https://www.eia.gov/tools/faqs/faq.php?id=96&t=3

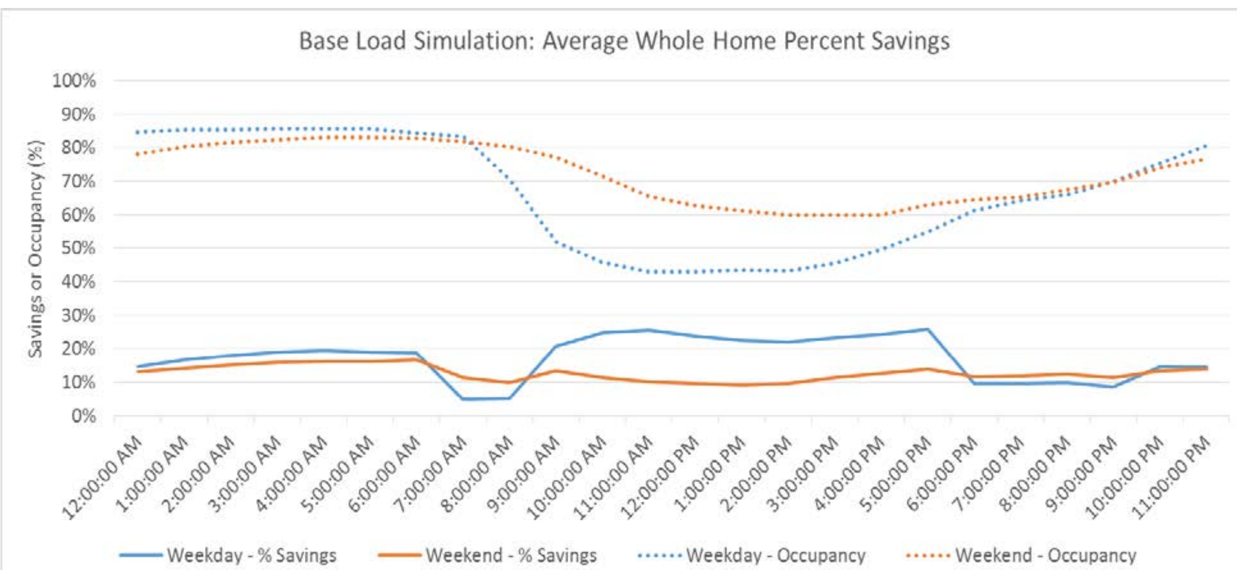
Table 3. Base-load Simulation Model Maximum Annual Savings Potential by End Use

Smart Device	Electricity Savings (kWh/year)	Heating Fuel Savings (therms/year)	Cost Savings* ($/year)	Assumptions
Smart Thermostat	688	52	$174	No existing setback controls
Smart Outlets	341		$58	15-minute occupied delay
Smart Lamps or Switches	212		$36	Controls only
Total HEMS Savings	1,241	52	$268	

* Assumes average utility rates in New York: $0.17/kWh and $1.10/therm

The following figure shows the maximum potential whole-home percent savings results from the Base-load Simulation model. Savings are shown to be coincident with lower occupancy rates during the daytime and typical nighttime sleep schedules. Weekdays are shown to have lower daytime occupancy and, therefore, higher savings potential when compared to weekends.

Figure 9. Base-load Simulation Model Maximum Potential Savings for Whole-Home Compared to Occupancy Profiles



3.2 Individual End-Use Energy Savings

Energy consumption and occupant behavior data for each of the pilot homes was analyzed by end-use. Average home load profiles, occupancy profiles, and savings profiles were created for the average weekday and weekend. The following sections describe the results for HVAC, plug loads, and lighting.

3.2.1 HVAC

The average HVAC set points and setback schedules were generated based on the existing thermostat settings for the group of pilot homes. Figure 10 shows the average thermostat heating set point schedule compared to occupancy. Heating setbacks are most prominent during nighttime, and more moderate during the daytime. Nighttime setbacks relate to when an occupant is asleep. Daytime setbacks relate more to when an occupant is not home during the work day.

Figure 10. Average Thermostat Heating Set Points Compared to Occupancy

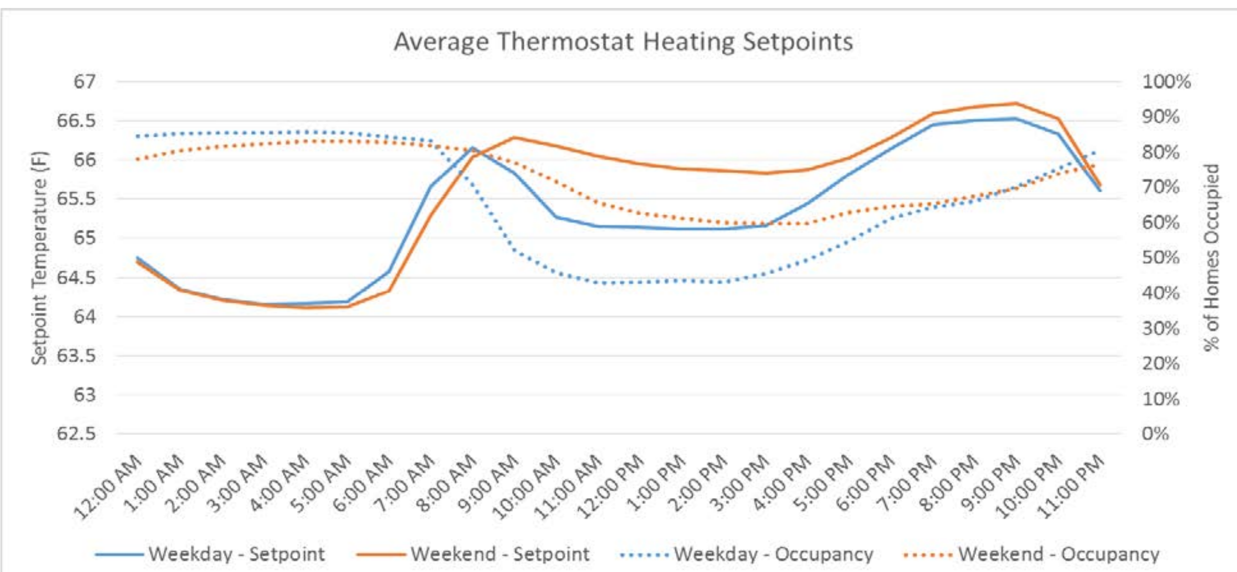


Table 4 shows the heating set point temperatures, setback temperatures, and setback duration for several of the homes in the pilot group. This data was monitored and reported through the smart thermostats installed in the pilot homes.

Table 4. Individual Pilot Home Heating Set Point Temperatures, Setback Temperatures, and Setback Durations

House ID	Setback Controls?	Occupied Set Point (F)	Night Set Point (F)	Night Setback Hours	Day Set Point (F)	Day Setback Hours
1008	Yes	68	62	5	64	6
1009	Yes	67	62	10		
1010	Yes	65	62	10		
1011	Yes	66	60	7		
1012	No	73				
1013	Yes	68	64	6	64	6
1014	Yes	66	62	7	62	8
1020	Yes	67	65	11		
1021	No	69				
1022	Yes	60	57	8	57	8
1024	Yes	69	63	6	64	9
1025	No	65				
1026	No	64				
1028	Yes	66	64	10		
1029	Yes	66	64	8		
1030	Yes	69	65	8	65	7
1031	Yes	65	60	8		
1033	No	65				
1035	Yes	62	59	7	59	7
1036	Yes	71	68	8	67	7
1038	Yes	67	62	7	62	10
1040	No	67				
1044	No	68				
1046	No	66				
1047	Yes	67	65	16		
0002	Yes	66	63	16		
007	No	66				
49	Yes	67	64	7	63	9
1004	No	67				
1005	Yes	65	60	8	62	6
1041	No	66				

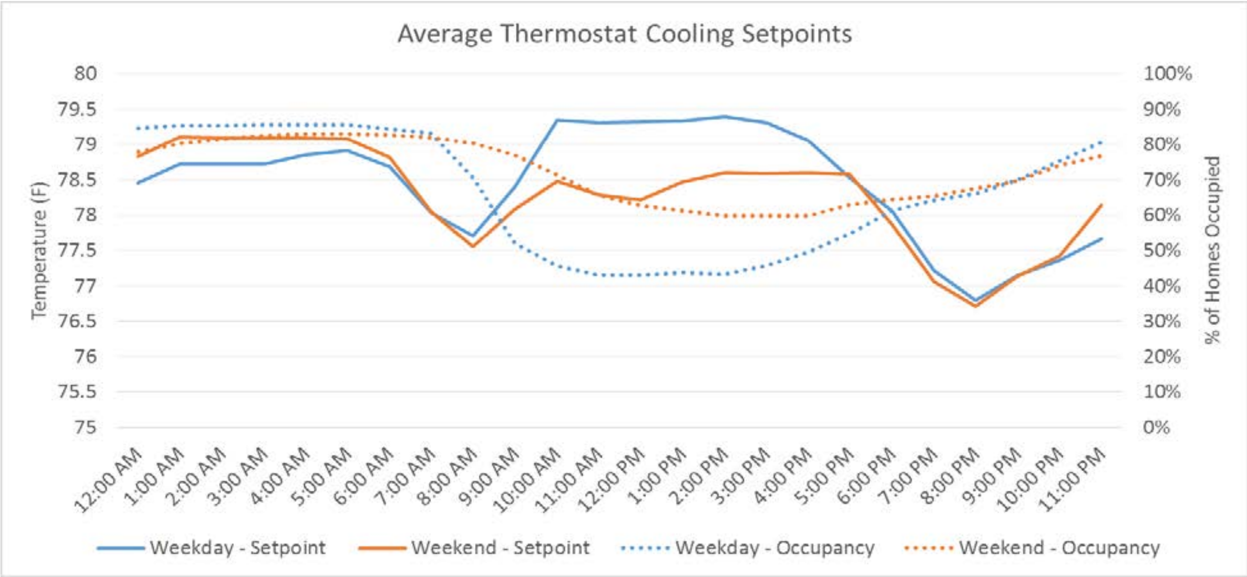
The next table shows the percentage of homes with heating setback controls. Also, this table displays the average set point temperature, setback temperature, and setback duration for each control approach. The average occupied heating set point is consistently between the control strategies at 66 to 67ºF. The homes with only nighttime setbacks tend to have a longer night duration (11 hours) than homes with both nighttime and daytime setbacks (seven hours at night). However, the total setback duration for homes with both is still the most aggressive (15 hours per day).

Table 5. Summary of Pilot Home Heating Set Point Temperatures, Setback Temperatures, and Setback Durations

Existing Control Approach	Percent of Homes	Occupied Set Point (F)	Night Set Point (F)	Night Setback Hours	Day Set Point (F)	Day Setback Hours
No Setbacks	35%	67				
Night Setbacks Only	29%	66	62.7	11		
Night and Day Setbacks	35%	67	62.8	7	63.1	8

Figure 11 shows the average thermostat cooling set point schedule compared to occupancy. In contrast to heating, cooling setbacks are most prominent during daytime and more moderate during the nighttime. Nighttime setbacks relate to when an occupant is asleep. Daytime setbacks were correlated to when an occupant is not home during the work day.

Figure 11. Average Thermostat Cooling Set Points Compared to Occupancy



Although the pilot analysis period was during the heating season, the smart thermostats reported all existing control points, including cooling set points and setback schedules. Therefore, cooling savings could be estimated using the ENERGY STAR® Calculator. Table 6 shows the cooling set point temperatures, setback temperatures, and setback duration for several of the homes in the pilot group. These data were monitored and reported through the smart thermostats installed in the pilot homes.

Table 6. Individual Pilot Home Cooling Set Point Temperatures, Setback Temperatures, and Setback Durations

House ID	Setback Controls?	Occupied Set Point (F)	Night Set Point (F)	Night Setback Hours	Day Set Point (F)	Day Setback Hours
1009	Yes	75	78	11		
1010	Yes	79	82	9	84	8
1020	Yes	73	77	10		
1046	Yes	78	80	13		
1047	Yes	79	84	18		
49	Yes	79	82	8	84	9
1037	No	75				
1039	No	78				

Table 9 shows the percentage of homes with cooling setback controls. Also, this table displays the average set point temperature, setback temperatures, and setback durations for each control approach. The average occupied cooling set point was higher for homes with both nighttime and daytime setback schedules. Similar to heating, homes with only nighttime cooling setbacks tend to have a longer night duration (13 hours) than homes with both nighttime and daytime setbacks (nine hours at night). However, the total setback duration for homes with both nighttime and daytime setbacks is still the most aggressive (18 hours per day).

Table 7. Summary of Pilot Home Cooling Set Point Temperatures, Setback Temperatures, and Setback Durations

Existing Control Approach	Percent of Homes	Occupied Set Point (F)	Night Set Point (F)	Night Setback Hours	Day Set Point (F)	Day Setback Hours
No Setbacks	25%	77				
Night Setbacks Only	50%	76	79.5	13		
Night and Day Setbacks	25%	79	82	9	84	9

This HVAC table shows the energy savings potential for HEMS applied to the three different existing control strategies. HEMS has the highest energy savings potential when applied to homes with no existing setback controls, approximately 688 kWh per year and 52 therms per year. Savings are significantly lower for homes with existing nighttime setback controls and are insignificant for homes with both nighttime and daytime setback schedules.

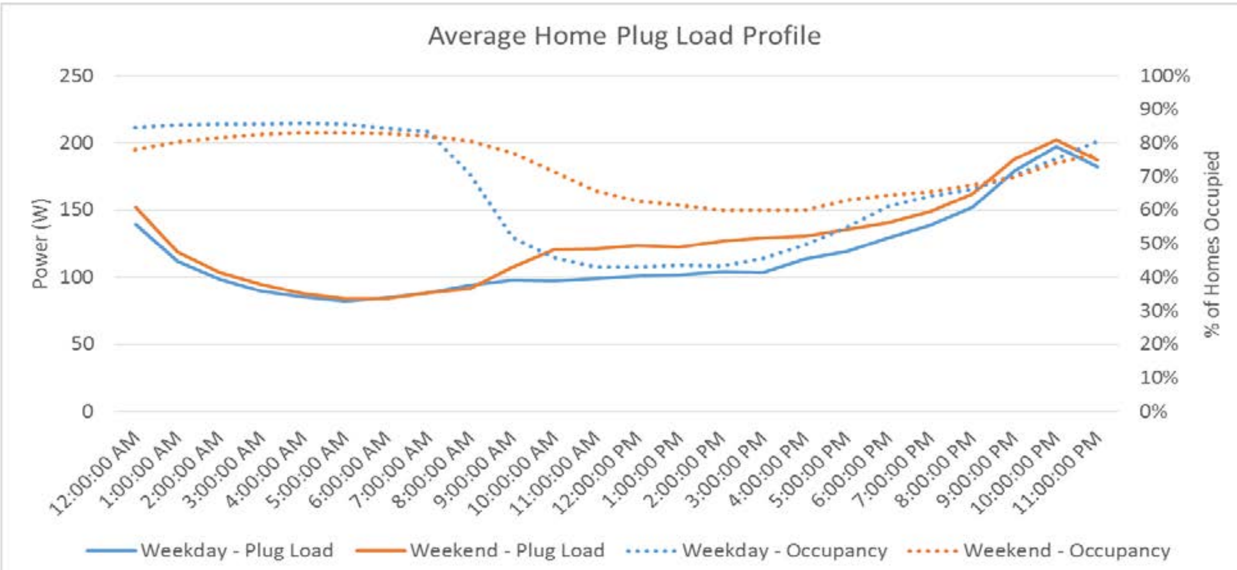
Table 8. HEMS HVAC Savings When Applied to Different Existing Programmable Thermostat Baselines

Baseline Existing Control Approach	HEMS Control Electricity Savings (kWh/year)	HEMS Control Heating Fuel Savings (therms/year)
No Setbacks	688	52
Night Setbacks Only	172	15
Night and Day Setbacks	5	5

3.2.2 Plug Loads

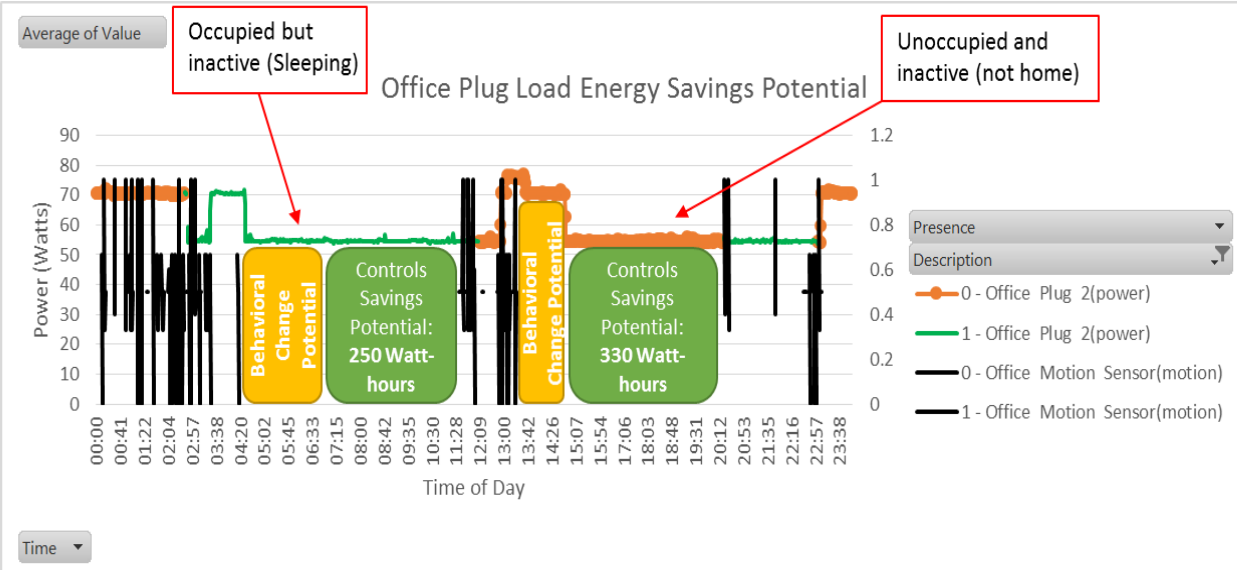
Pilot data was most comprehensive for plug loads, allowing for a deeper, granular analysis. Savings for plug loads can be broken down by space type within the home and analyzed specifically for different occupancy situations. Figure 12 shows the average home weekday and weekend plug-load profile compared to occupancy. The profile shows plug-load power remaining relatively flat throughout the day, rising slightly in the evening hours. Also, the weekday and weekend profiles are very similar with weekend use just slightly higher during the daytime.

Figure 12. Average Plug-Load Power Profile Compared to Occupancy



HEMS savings for plug loads can be attributed to different occupancy modes, such as occupied but inactive (sleeping), or unoccupied and inactive (not home). An occupied delay buffer (dead band) is required for occupant convenience during only short periods of inactivity. For example, a 15-minute delay buffer would prevent the HEMS from turning off equipment unless the occupant is out of the room for more than 15 minutes. This delay buffer represents the additional savings potential for behavior change. Optimal savings occur when occupants turns off equipment when leaving. However, occupant behavior observed in this pilot found many opportunities for HEMS controls to achieve savings. Figure 13 shows plug-load savings potential for an individual home office during different occupied modes over the course of 24 hours.

Figure 13. Single-Day Time Series of Office Plug-Load Power and Savings Potential versus Different Occupancy Modes



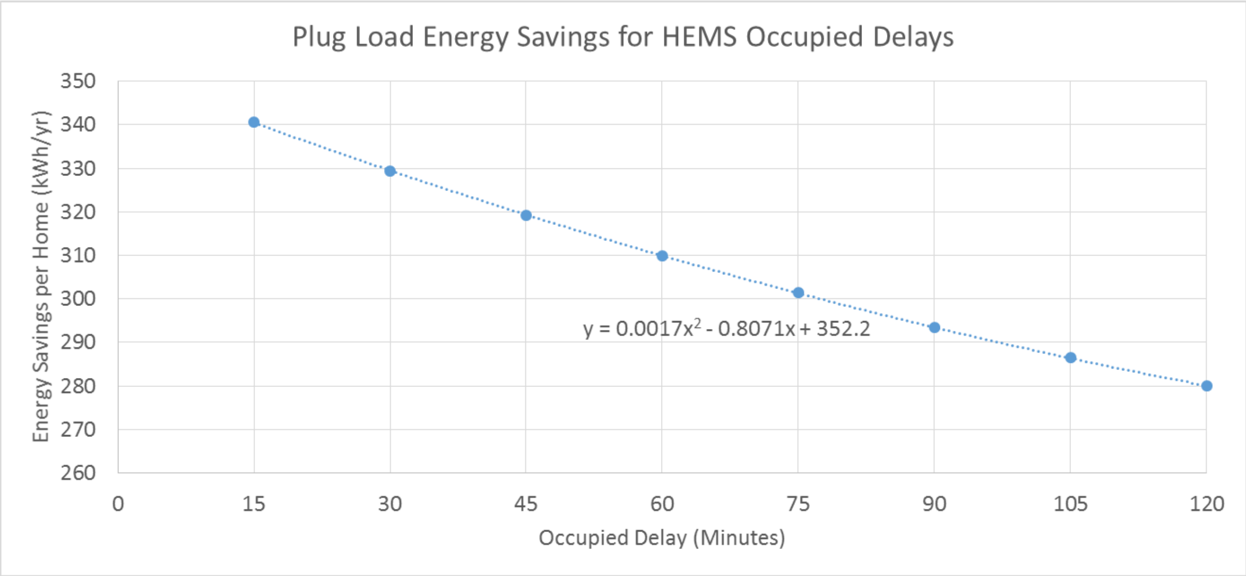
The occupied delay-buffer time can influence energy savings. A delay time should be selected to achieve both occupant convenience and energy savings. The following table shows the average home savings for HEMS plug-load controls for different occupied delay settings.

Table 9. Average Home Plug-Load Savings from HEMS for Different Occupied Delay Buffers

HEMS Occupied Delay	15 min	30 min	45 min	60 min	75 min	90 min	105 min	120 min
Average Plug-Load Savings (kWh/year)	341	329	319	310	301	294	286	280

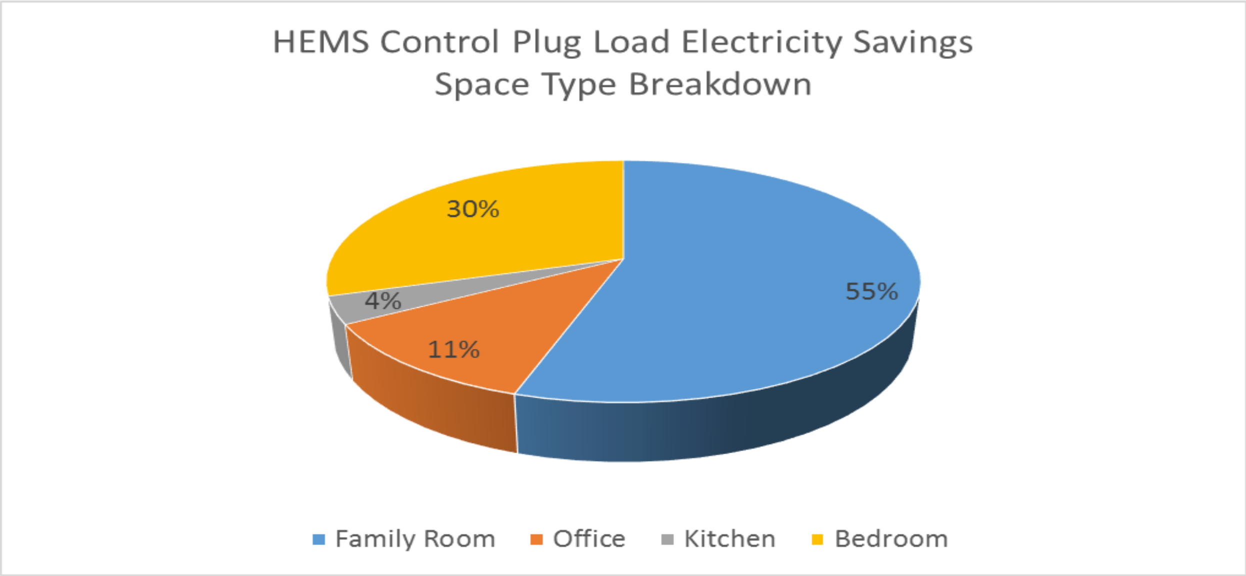
Figure 14 shows how HEMS plug-load control savings degrade as the occupied delay-buffer time increases.

Figure 14. Average Home Plug-Load Savings from HEMS Degrading for Longer Occupied Delay-Buffer Times



Pilot data collected for occupancy behavior were so detailed that plug-load energy savings could be broken down by space types within an average home. Family rooms had the highest energy savings potential (55%) because of the high load from entertainment systems. Bedrooms had the next highest savings potential (30%) from smaller entertainment systems and electronics. Offices had some energy savings potential (11%) from computers, and kitchens had the lowest potential (4%) because appliances were not included in the pilot.

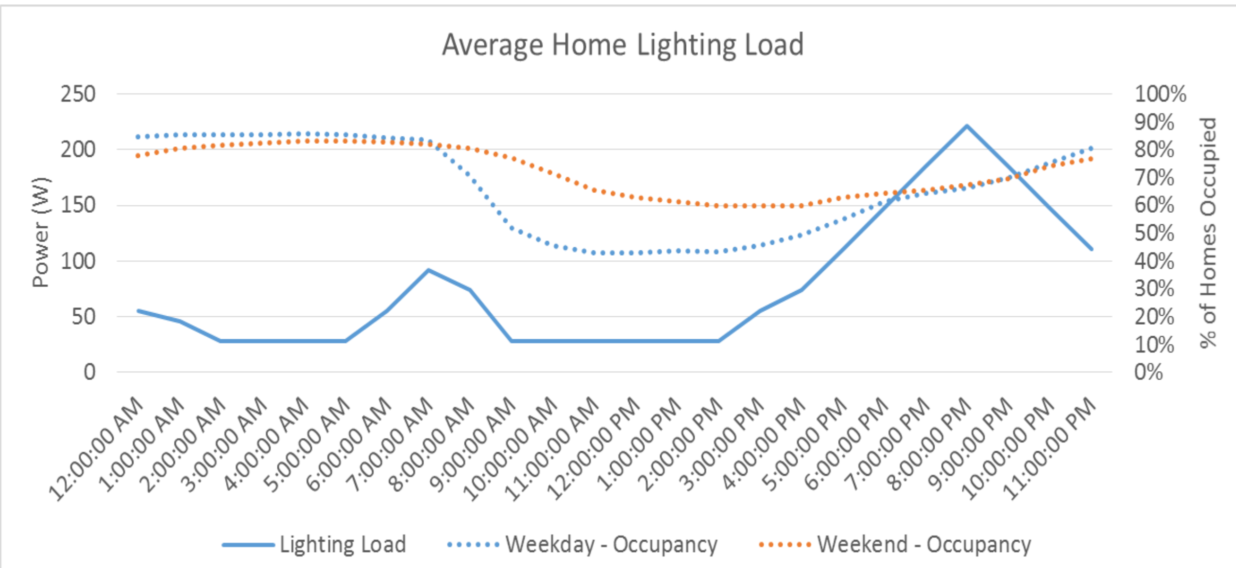
Figure 15. Average Home Plug-Load Savings by Space Type



3.2.3 Lighting

LM Energy was unable to collect lighting power and reliable lighting states data due to technology limitations. Smart lamps do not report power consumption. Also, both smart lamps and smart switches created three-way lighting circuits that required knowing non-smart component status to determine if a lamp was on or off, which was not possible. However, LM Energy was able to combine the limited data collected during the pilot with the average home lighting load published by EIA and a usage profile published by NREL to create an average home lighting load profile. Figure 16 shows the estimated average home lighting load profile compared to pilot occupancy profiles. The profile shows lighting power remaining relatively low and flat throughout the day—rising significantly during in the evening hours.

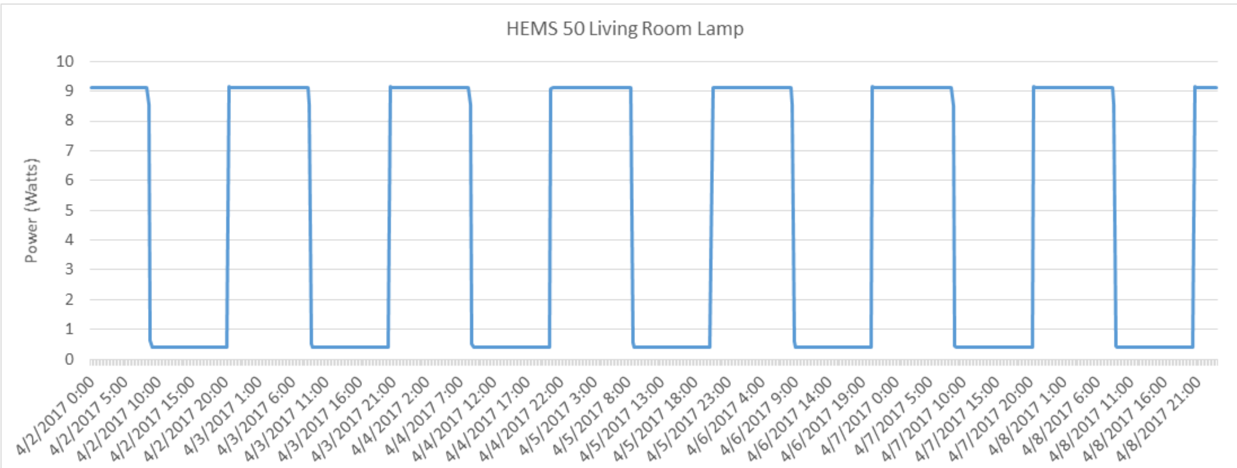
Figure 16. Average Lighting Power Profile Compared to Occupancy



Lighting savings were then estimated based on the inverse relationship with measured pilot occupancy profiles. Average annual lighting savings potential from HEMS were calculated to be 212 kWh per year. These savings are for controls only, and do not include savings from replacing less efficient lighting with LEDs.

Additional analysis was conducted to investigate standby energy consumption of smart lamps. A common misconception is that the standby energy consumption of a connected smart lamp will significantly detract from the energy savings. Figure 17 shows measured results from a smart LED lamp installed in one of the pilot homes, and configured to a standard schedule. The lamp was on roughly 25% of the time, and off the other 7% of the time. There is a small standby loss or “ghost load” of 0.4 Watts when the lamp is off, which would translate to approximately 2.6 kWh/year with the assumed runtime. However, this standby loss while the lamp is off is very small compared to the energy savings from retrofitting a 60 Watt incandescent to 9-Watt LED. In addition, the standby losses are only 1% of the savings potential from HEMS control of smart lamps. Therefore, the standby losses from a connected smart lamp are considered insignificant compared to the savings potential of the lamp retrofit and HEMS controls.

Figure 17. Smart Lamp Power Profile and Standby Power Consumption



3.3 Peak Demand Savings

Peak demand savings analysis was conducted using the DOE Uniform Methods Protocol to estimate savings potential for HEMS. For the three months during the test period, peak demand for each pilot home was analyzed in relation to the whole-home power meters.

The following two figures show the peak day profile for February compared to occupancy and outside air temperature, respectively. The peak demand for the pilot group occurred on February 2, 2017 around 8:30 p.m. The February peak appears related to both low outside air temperature and high occupancy.

Figure 18. February Peak Day for the Pilot Group Compared to Occupancy

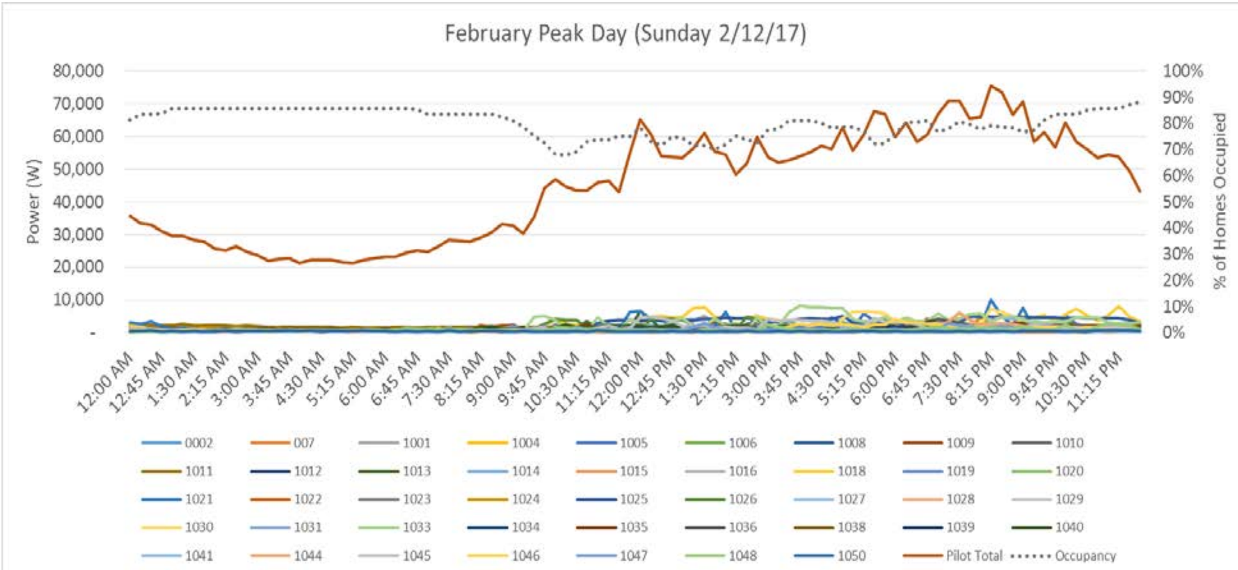
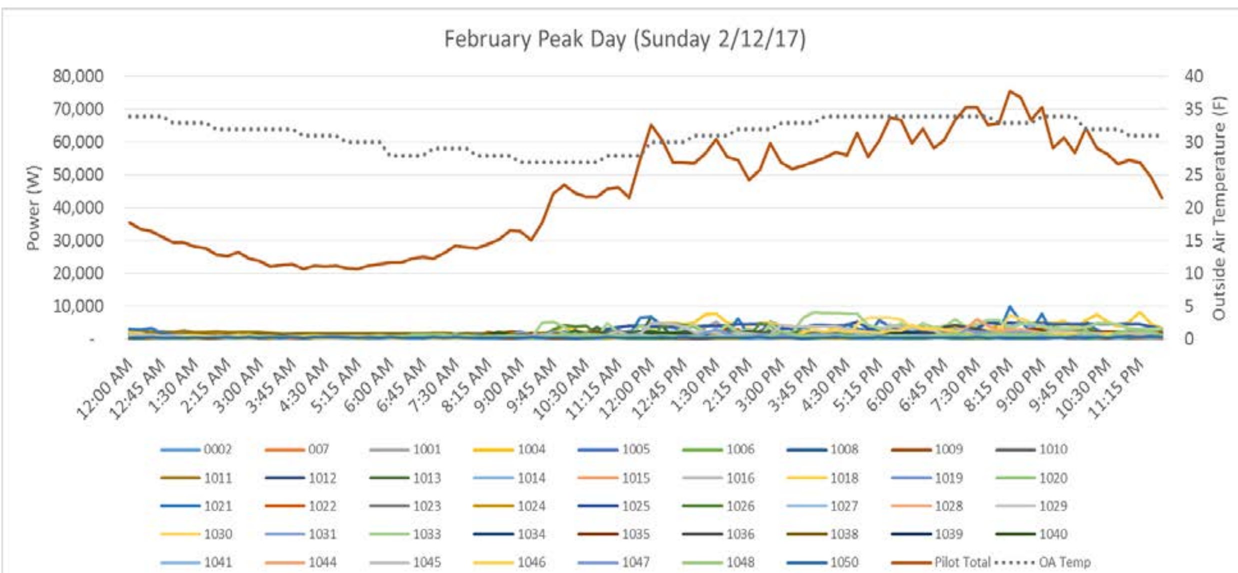


Figure 19. February Peak Day for the Pilot Group Compared to Outside Air Temperature



The next two figures show the peak day profile for March compared to occupancy and outside air temperature, respectively. The peak demand for the pilot group occurred on March 5, 2017 around 1:00 p.m. Similar to February, the March peak appears related to both low outside air temperature and high occupancy.

Figure 20. March Peak Day for the Pilot Group Compared to Occupancy

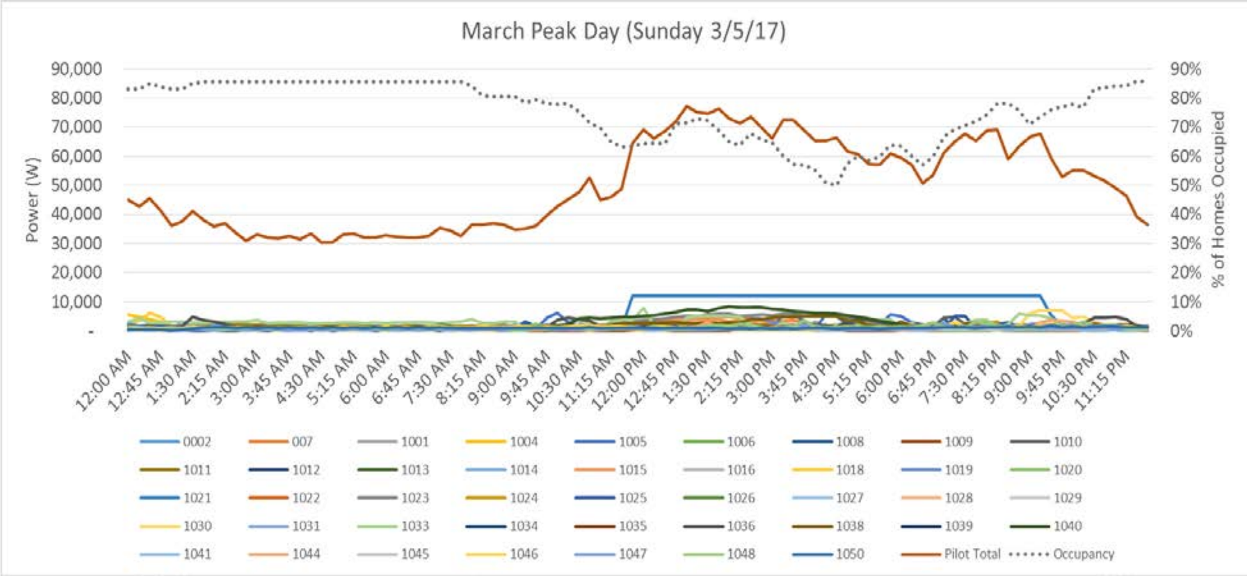
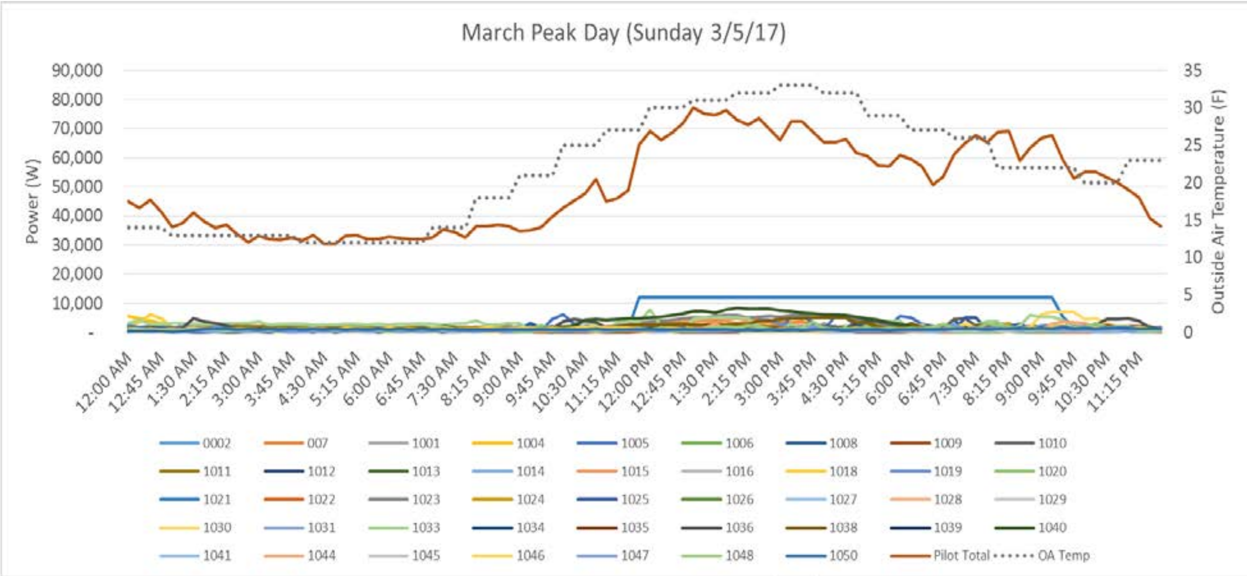


Figure 21. March Peak Day for the Pilot Group Compared to Outside Air Temperature



The last two figures in this section show the peak day profile for April compared to occupancy and outside air temperature, respectively. The peak demand for the pilot group occurred on April 23, 2017 around 3:00 p.m. The April peak appears to be more related to high outside air temperatures than occupancy.

Figure 22. April Peak Day for the Pilot Group Compared to Occupancy

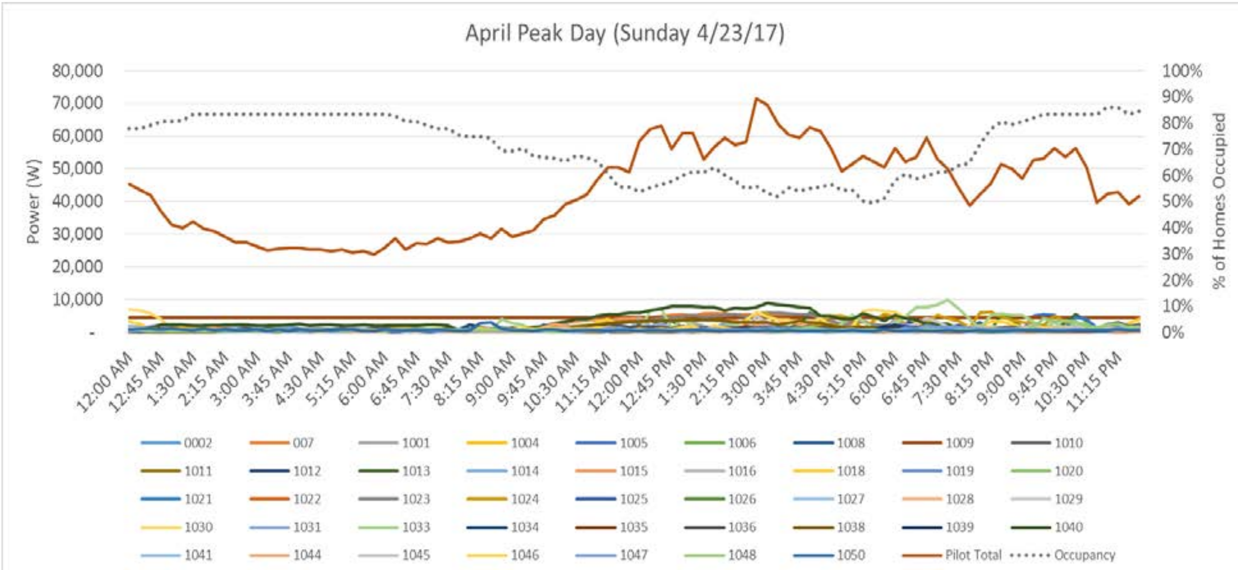
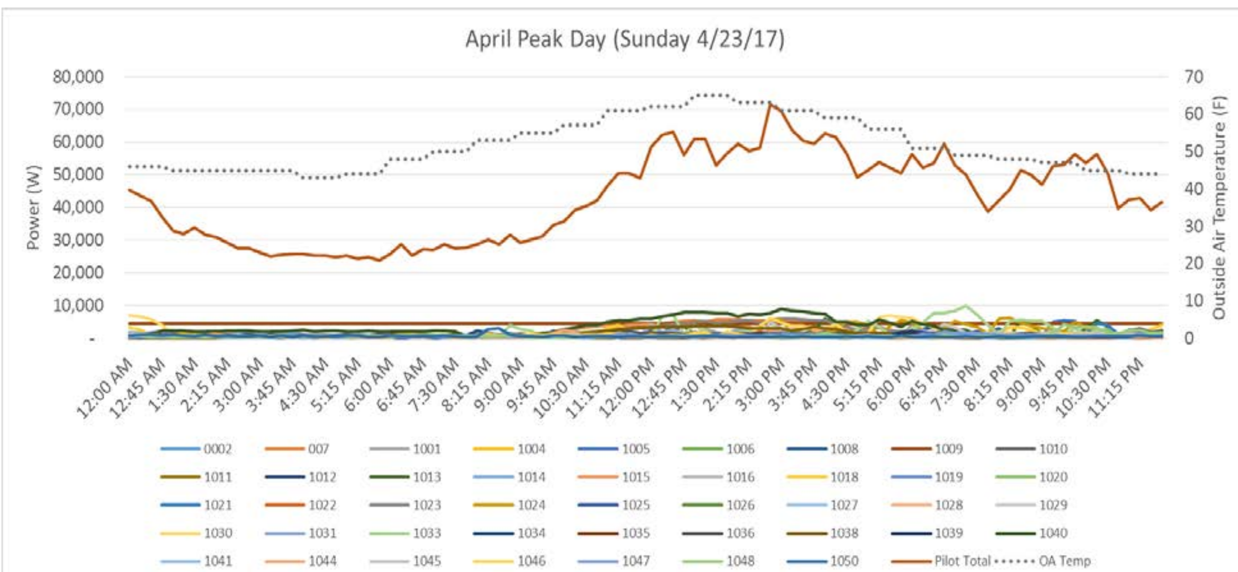


Figure 23. April Peak Day for the Pilot Group Compared to Outside Air Temperature



The rated load factors and coincidence factors were calculated for each pilot home. Table 10 shows the average rated load factors and coincidence factors for the peak days in each month during the pilot test period.

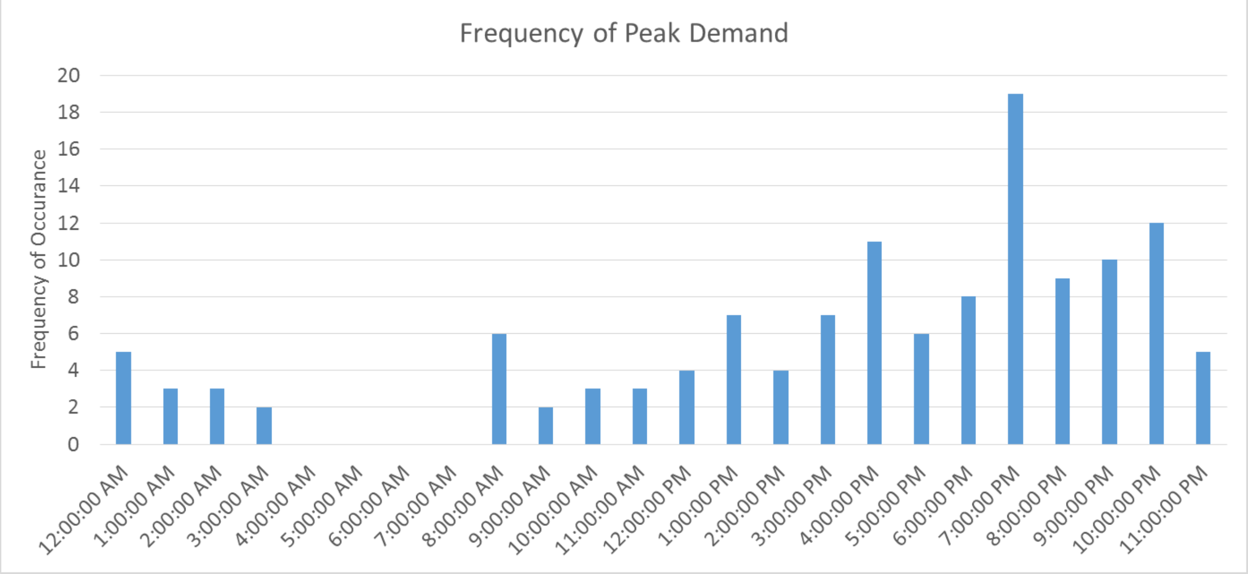
Table 10. Average Rated Load Factors and Coincidence Factors for the Peak Days in Each Month of the Pilot Test Period

	February	March	April
Average Rated Load Factor	64%	65%	58%
Average Coincidence Factor	45%	44%	46%

The average home HEMS peak demand savings is estimated to be 0.2 kW. The Conservation Load Factor for HEMS was estimated to be 70%.

The following figure shows the frequency of individual home peak demands occurring by hour of the day for all months in the pilot period. The figure shows a small frequency of home peaks occurring in the morning hours with higher frequencies ramping throughout the day, and increasing to maximum frequencies at 7:00 p.m.

Figure 24. Frequency of Peak Demand by Hour of the Day



3.4 Other Results

This section describes results from the pre-installation surveys, benchmarking examples, and fault-detection identification, which demonstrate the added benefits HEMS can offer.

3.4.1 Survey Results

The pilot homes were spread across multiple counties and represented several utilities, including Con Edison, National Grid, NYSEG (New York State Electric and Gas), and RG&E (Rochester Gas and Electric). Figures 25 and 26 show the geographical relationship of pilot homes in Albany and Westchester counties, respectively. Home size and color coding denote the square footage of the home. Dark blue represents the smallest sites, while fading blue and orange represents medium-sized homes, and dark red represents the largest homes in the sample. The majority of the homes are located in Westchester with even distribution across the county. Albany County had a smaller sample size and was less evenly distributed. The relationship between home size and number of occupants with energy consumption is explained in more detail in the following section, Benchmarking.

Figure 25. Geographical Relationship of Pilot Homes in Westchester County

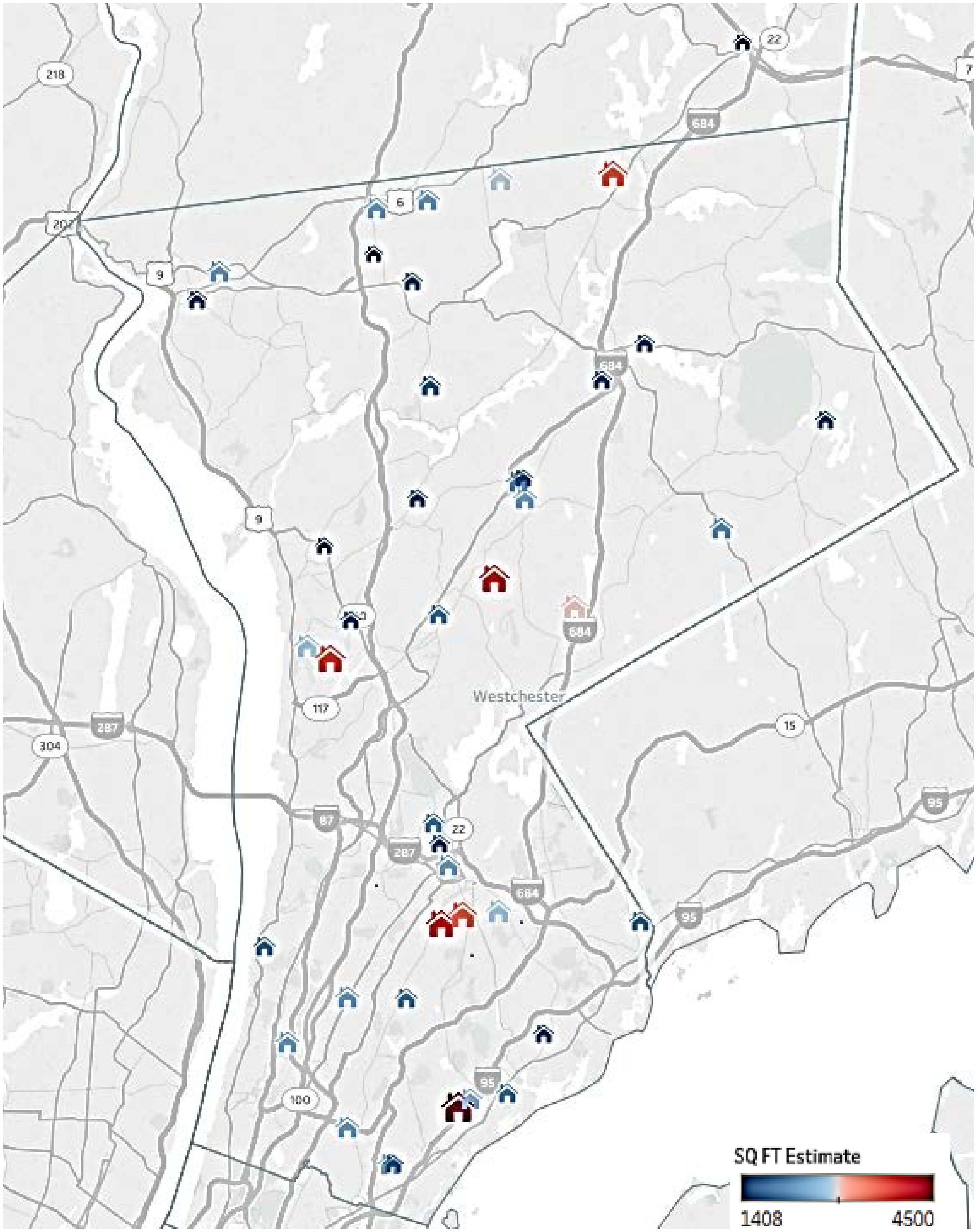
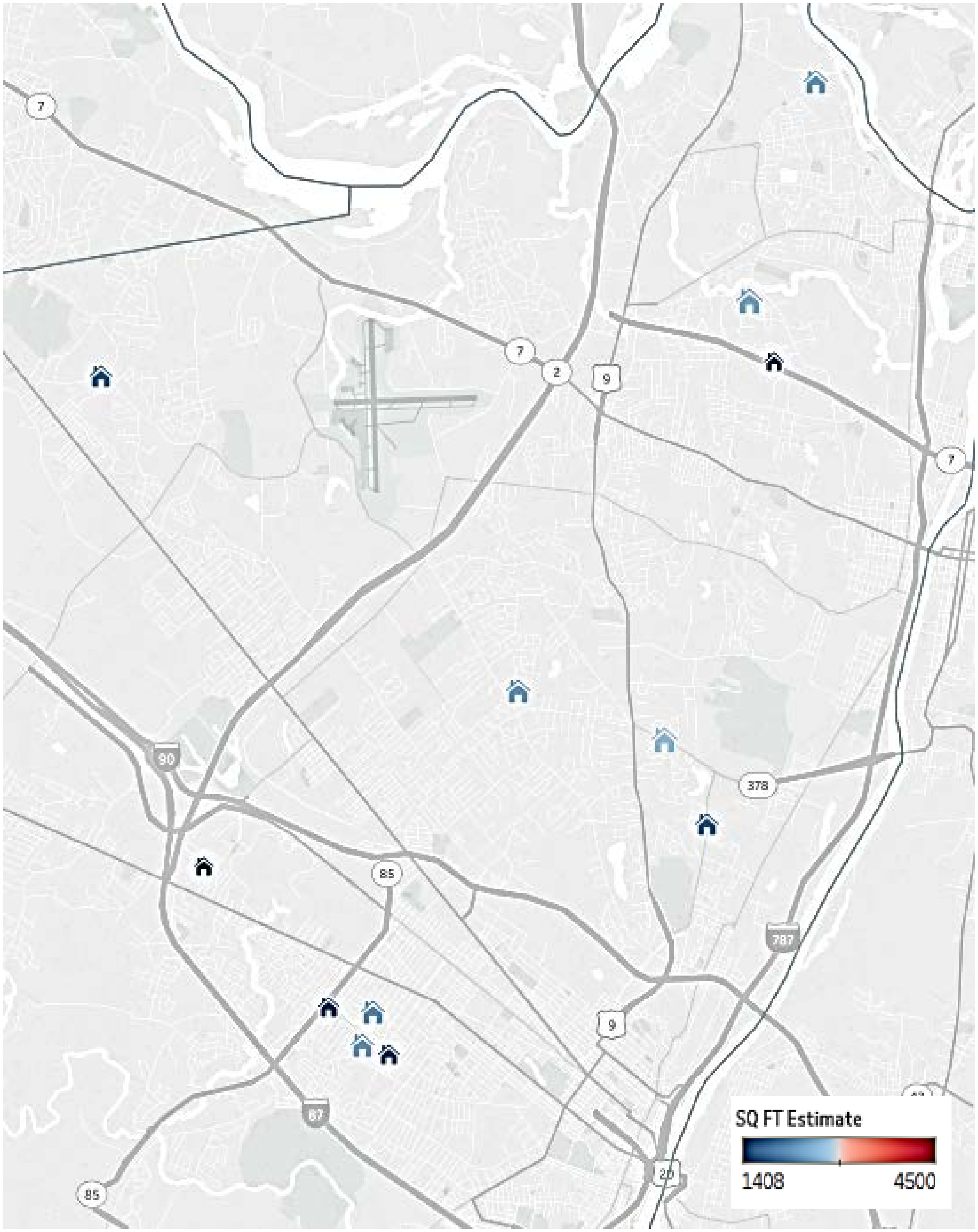
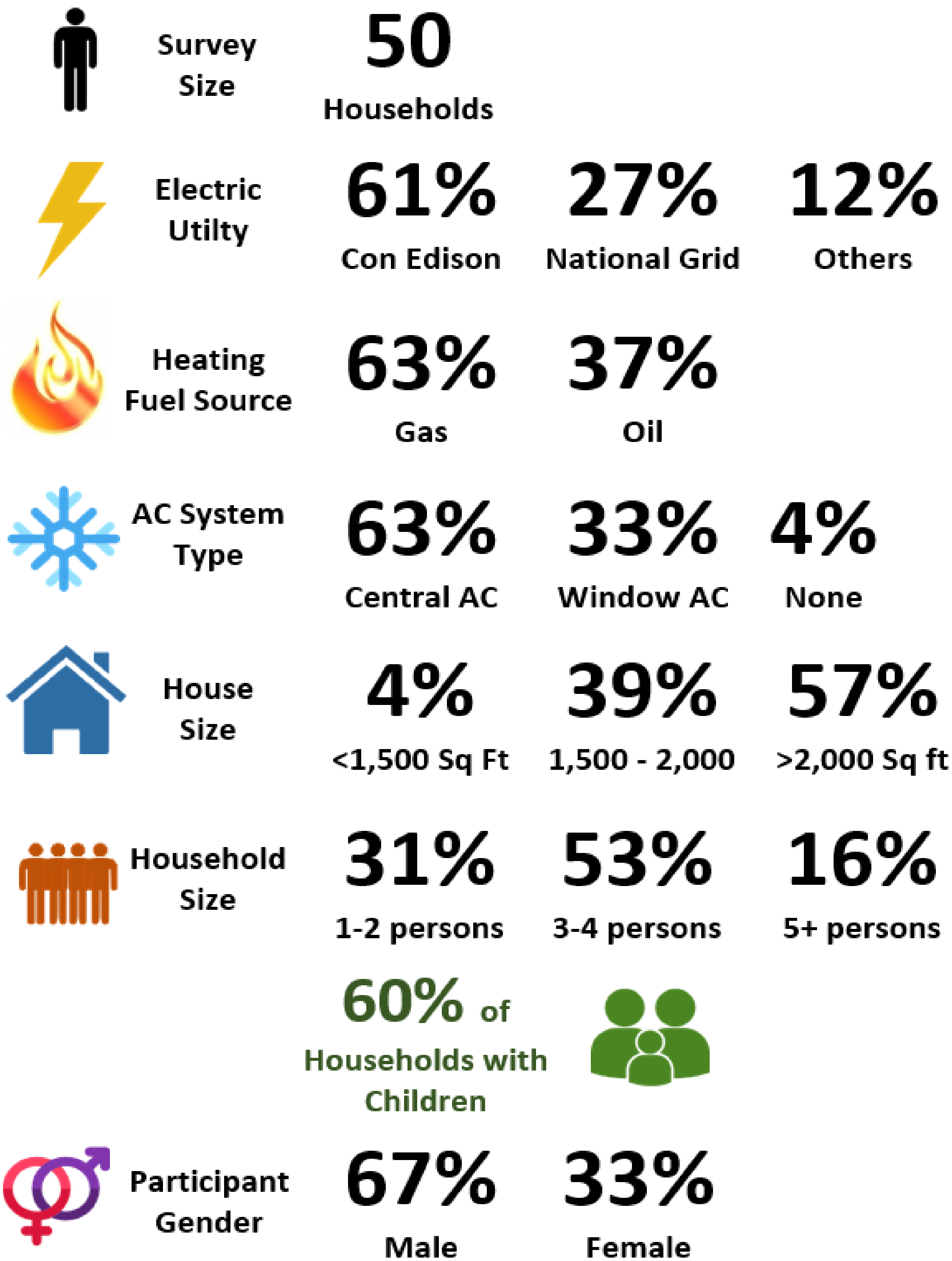


Figure 26. Geographical Relationship of Pilot Homes in Albany County



The participant screening survey contained information on 50 households with detailed information on physical house attributes and people factors. Out of our survey sample, 61% of the participants were in Con Edison territory, with 27% in National Grid, and remainder in NYSEG or RG&E. Approximately 63% of households use gas as the primary heating fuel source, with the other 37% using oil. Similarly, 63% of the households have central air conditioning and the rest have window units or no air conditioning. In addition, 76% of these houses have existing programmable thermostats; of those, 20% are already using Wi-Fi thermostats. Approximately 57% of the participants reside in houses over 2,000 square feet, while 37% have 1,500 to 2,000 square feet, and 4% are under 1,500 square feet. Over half of the households have three to four occupants, approximately one-third have two or less occupants, and only a few households have five or more occupants. The majority of entertainment systems included TV, cable, DVR, and surround sound with approximately one-third of homes having additional gaming systems. All pilot participants valued energy savings as “important” or “very important.”

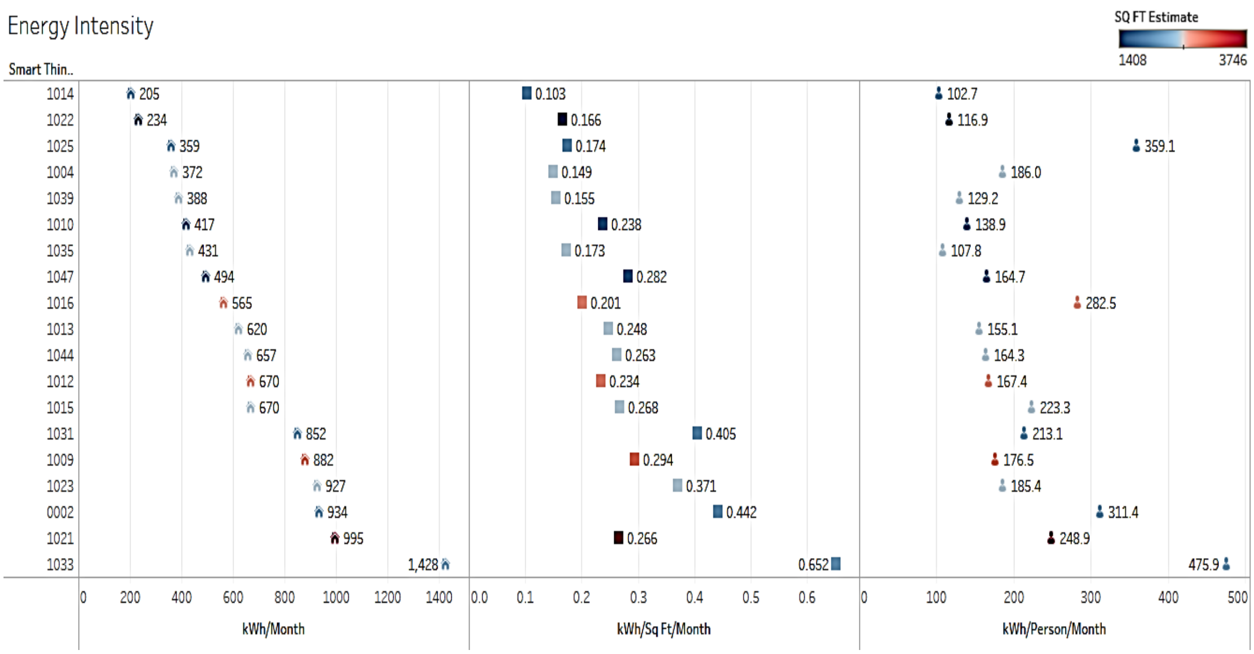
Figure 27. Summary of Pilot Demographics and Survey Results



3.4.2 Benchmarking

Benchmarking allows homes to be normalized and compared on the same terms. Some approaches to benchmarking include normalizing by variables such as square footage or number of occupants. Figure 28 shows trends from a sample of the pilot homes with different normalization criteria. Benchmarking can help prioritize home energy savings potential for business developers or marketing groups. For example, the pilot home ID# 1033 has a low square footage and very high energy intensity per square foot and per occupant. This would indicate high savings potential. Also, pilot home ID #1025 has a relatively normal energy intensity per square foot, but high-energy consumption per occupant, which may be an opportunity for behavior change.

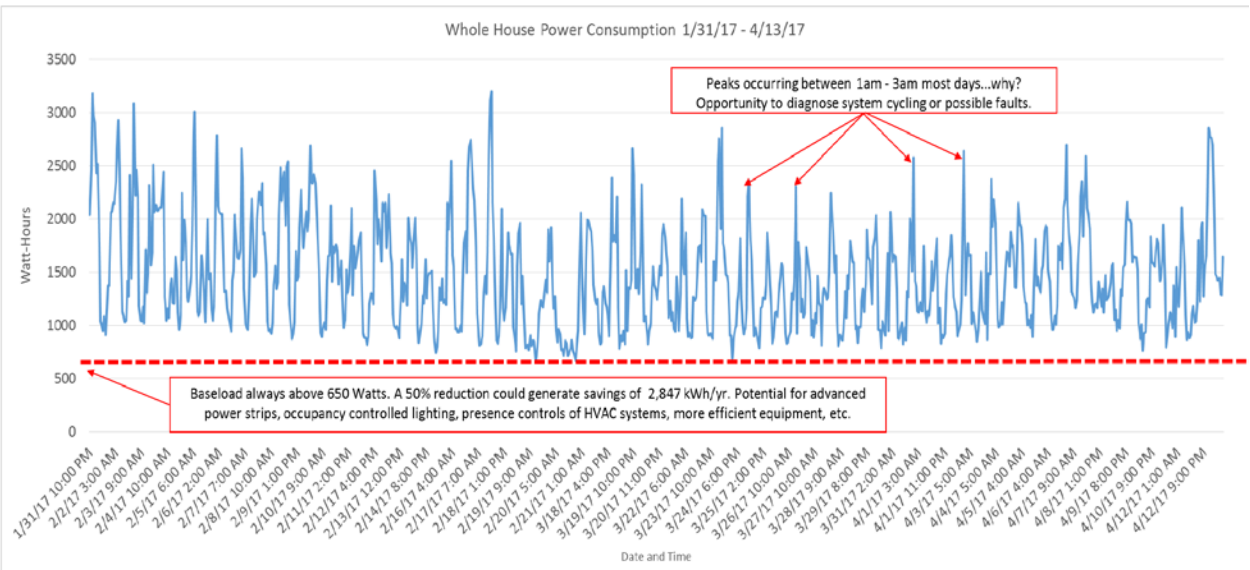
Figure 28. Monthly Electricity Intensity Normalized by Square Footage and Total Occupants



3.4.3 Fault Detection and Maintenance

Smart thermostats already have built-in logic that will schedule filter replacements. However, HEMS data can also measure trends and better identify faults and maintenance needs. For example, longer fan runtimes could indicate the filter replacement is needed more frequently than a set schedule, which if addressed, could lead to fan energy savings. Reoccurring peaks may indicate unnecessary equipment cycling or system faults to prevent energy waste. For example, Figure 27 shows the whole-home power meter reading high peaks between 1:00 a.m. and 3:00 a.m. and high base-load energy, which indicates that equipment is running continuously. This information provides valuable insight and feedback to occupants about system conditions and maintenance needs.

Figure 29. Whole-House Power Meter Reading Reoccurring Peaks between 1 a.m. and 3 a.m., and Continuous Equipment Operation



4 Summary of Findings and Conclusions

The HEMS industry is currently growing rapidly in available products and consumer interest. Several HEMS studies have been published on available technologies, market research, and program planning.[12] However, there is still a large gap in available information for implementation best practices and measured energy savings. This pilot provided an innovative approach for HEMS product testing, evaluation, and implementation best practices. This information is critical to scale HEMS into larger deployments through utility energy efficiency programs. This pilot attempted to fill existing knowledge gaps, provide detailed findings on implementation best practices, and validate savings through the Base-Load Simulation model.

4.1 Best Practices and Lessons Learned

Several best practices and lessons learned were gathered during this pilot. These findings are grouped into three categories: installation, data management, and technology selection.

4.1.1 Installation

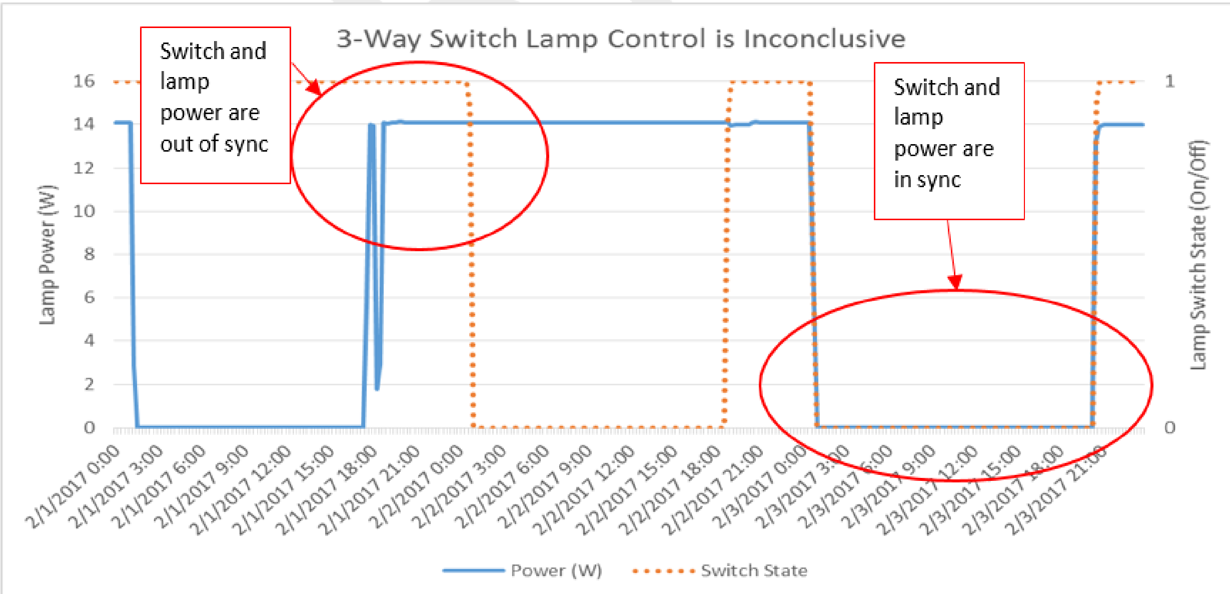
The LM Energy installation team encountered/addressed several barriers during the installation of HEMS on pilot homes. The pilot installation was accomplished in three phases, with each phase becoming more efficient from lessons learned, which informed future installation best practices:

- Thorough in-person training for installers is needed for successful integrations of all products.
- Connectivity resources are needed to ensure proper integration between multiple manufacturers of smart products.
- Certain products may require a custom-coded device handler to communicate with the Hub.
    - LM Energy found that although a custom-device handler was easy to implement, one of the smart products did not work as advertised out of the box.
- Participant education is required to differentiate motion sensors from cameras, and address privacy/security concerns.
- Meters must be configured with consistent sampling, reporting, and timestamp settings.
- Baseline thermostat set points should be collected prior or during installation.
- Smart lamps and smart switches should not be installed on the same circuit. Smart lighting products may result in three-way or four-way circuits (greater than one switch controlling the same lamps) and produce inconclusive results.

12 http://www.neep.org/initiatives/high-efficiency-products/home-energy-management-systems

- LM Energy found that communications between the hub/switch/lamp were not interactive and resulted in inconsistencies between switch state and lamp power

Figure 30. Example of Inconclusive Results from Lighting Circuit



4.1.2 Data Management

The pilot program was designed to collect detailed information about energy consumption and behavior. Larger scale deployments are expected to focus on specific data required to enable energy-saving measures through HEMS and automate evaluation reporting. The following list includes recommendations for future pilots and larger scale deployments:

- A database is required for data collection and storage.
- Automating data quality checks is recommended for handling common errors such as missing data, negative values, and misaligned timestamps.
- Alerts to administrators/customers are needed when there are data quality issues.
- Time frame selection and resampling features are recommended for exporting.
- Standardized regression analysis should be used to simulate baseline versus actual performance.
- Automated M&V of savings are required to reduce evaluation costs.
- Customer access to data through dashboards and reports are recommended for savings persistence and deeper customer engagement.

4.1.3 Technology Selection

There are several different manufacturers of smart products that can be integrated into a HEMS. Selecting the right technology depends on customer goals/behavior, climate, home infrastructure (e.g., electrical wiring, layout, construction, internet communications). While very few issues with hardware performance were encountered during the pilot, shortcomings were identified. The largest shortcoming was related to how some connected devices communicate or alert the hub of an action that has been taken. This report does not endorse any specific products, but the following best practices are recommended for technology selection to ensure quality data for utility programs and positive user experiences.

- The battery-life for sensors should be to be equal to or greater than one year.
  - Geofencing sensors had a very short battery life due to smaller size and frequent communication with the Hub.
  - LM Energy implemented a battery swap out schedule with all participants and provided customers with extra batteries and a "how to" email and video.
- Existing thermostat wiring should be known prior to selecting a smart thermostat, as installation costs may increase if a c-wire is required. C-wires provide continuous 24 Volt power from the HVAC system to the thermostats. Most smart thermostats draw power from the HVAC system wiring, however older thermostats (on/off) did not require power and may not have the wires required for a smart thermostat. If a c-wire with 24 Volt power is not existing, additional wiring from the HVAC system to the thermostat or a plug-in c-wire adapter may be required (depending on smart thermostat model).[13] None of the homes in the pilot group required re-wiring or adapters for the c-wire.
- Control settings should be accessible and easy to use.
- Manual overrides and access to troubleshooting assistance is recommended.
- Pre-testing products is recommended because not all available measures/hardware supply the data advertised by the manufacturer.
  - L2M Energy identified and replaced a piece of hardware before pilot installations began
- Consider that smart lamps can be more temperature sensitive than traditional LEDs.
  - LM Energy encountered a few lamp failures due to limited ventilation fixtures and the lamps entered protective mode, as designed, so no damage would occur.
- Third-party integrations, while easy to set up, can be difficult to maintain and troubleshoot because the communication protocol includes multiple products and manufacturers.
  - LM Energy found that back-end changes for the hub or any connected smart product requires customer notification and updates to ensure continuous data stream and positive customer experience.

[13] http://smartthermostatguide.com/thermostat-c-wire-explained/

4.2 Future Work

LM Energy identified several areas of future work to continue moving HEMS from pilot to full-scale for utility energy efficiency programs. For example, more information on HEMS lighting savings is required due to overlapping technologies and lack of communication between smart switches and smart lamps. Additional whole-home pilots could be conducted to improve savings estimates for different geographical areas, climates, home styles, etc. over longer durations.

The most common concern from participants was interoperability of buying new smart products to expand their HEMS. Initially, the most curiosity was regarding interaction with voice control assistants such as Amazon Echo or Google Home. However, once enrolled in the pilot, participants' interest focused more on the equipment being installed (thermostat, lamps, outlets, and motion sensors) despite having no control or interaction with the system. Conversations with participants during and after the pilot indicated that interest and knowledge about HEMS products increased because of a positive pilot experience and no negative impacts on their home or lifestyle. The HEMS solution offered through this pilot provided security, flexibility, and expandability to work with several products and home assistants. As the HEMS industry continues to grow, more smart equipment can be integrated. Savings from this pilot only targeted HVAC, plug loads, and lighting. Future HEMS pilots should include additional applications within the home such as appliances, water heaters, and windows and doors.

LM Energy recommends future HEMS-related pilots include identifying/training a network of installers and including new cost-effective measures (i.e., occupancy-based control sequences, weather-related setbacks, real-time behavior change, demand response, and load-shifting measures).

4.3 Market Potential and Cost Effectiveness

HEMS has the potential for substantial growth in the residential market and provides tangible value to consumers, utilities, and energy efficiency program administrators. HEMS integrates the IoT and smart products to provide access/control, convenience, security, energy savings, energy management, and behavior change. HEMS can be a vehicle for consumer education and deeper engagement with utilities or program administrators as well as provide programs with a new opportunity for integrated residential controls measures that have never been offered. Controls measures targeting unoccupied energy savings are likely to have larger savings and longer persistence than behavioral-change measures.

4.3.1 Market Potential

There are approximately 7.2 million residential customers in the NYSERDA territory.[14] Based on the quantity of residential customers and the savings found in this pilot, the estimated total annual savings potential for HEMS is 57,305 MWh/year and 177,754 MMBtu/year. This estimate assumes a percent adoption rate per year, a similar distribution of home characteristics as the pilot group, a similar distribution of thermostat settings observed during pilot, and 60-minute delay on plug-load controls. Potential energy savings in the NYSERDA territory are equivalent to 40,921 metric tons of CO_2e savings per year and 613,814 metric tons of CO_2e savings over a 15-year life of a HEMS. Savings would be replacing some existing measure savings achieved through existing energy efficiency measures (e.g., advanced power strips, smart thermostats, behavior change), but also adding new savings potential and persistence through additional measures in an integrated system.

4.3.2 Cost Effectiveness

A cost breakdown of the HEMS components is provided in Table 11. Approximately 30 sensors were installed per home totaling $1,253 for materials, and an estimated $600/home for labor. The costs do not include costs for additional data analytics software (optional) and internet service fees. Labor costs can be avoided for technology savvy home owners who are capable of self-installing. Self-installation requires the same skillset of replacing normal non-smart switches, lamps, plugs, and thermostats, but typically have one additional step to download the App and follow configuration instructions. The communication hub for the wireless mesh network can be plugged into the internet router and similarly configured following App instructions. Installations are becoming easier and more intuitive for homeowners purchasing smart products.

14 https://www.eia.gov/

Table 11. Cost Breakdown for HEMS for Average Home

Sensor Type	Quantity	Unit Cost
Hub	1	$99.99
Smart Lights	10	$14.99
Smart Switches	3	$54.99
Smart Outlets	5	$53.50
Whole Home Power Meter	1	$53.23
Occupancy Sensors	5	$39.99
Geo-fencing Sensors	4	$29.00
Smart Thermostat	1	$199.00
	Total Count	**Total Sensor Cost**
Sensors Total (per Home)	30	$1,253.02
Labor Total (per Home)	1	$600
Total Installed Cost (per Home)		**$1,853.02**

Based on the savings estimated in this pilot and average utility rates in New York State ($$0.17/kWh and $1.10/therm), the simple payback period for consumers is estimated to be between seven and 12 years depending on baseline conditions. Adding utility incentive or rebate for 25% of installed cost could reduce consumer payback period from five to nine years. The EUL of HEMS is expected to be approximately 15 years, similar to other controls measures. Limited product warranties for pilot equipment were one year for smart power/plug and communication equipment, two years for smart lamps and smart switches, and five years for the smart thermostat. Table 12 shows estimated utility bill cost savings for a representative sample of individual homes from the pilot group. The individual home cost savings are not to be interpreted as averages or extrapolated to other homes, but intended to provide a sense of the cost savings across a wide range of baseline conditions.

Table 12. Sample of Estimated Individual Home Percent Cost Savings by End Use

Home ID	Heating Fuel	Cooling System	Plug-Load Cost Savings	HVAC Cost Savings	Lighting Cost Savings	Total Cost Savings
1007	Natural Gas	Central AC	3.3%	11.8%	3.7%	18.8%
1008	Natural Gas	Central AC	9.1%	11.2%	5.2%	25.6%
1011	Natural Gas	Window AC	1.0%	5.7%	2.5%	9.3%
1020	Natural Gas	Central AC	2.7%	10.1%	2.3%	15.1%
1022	Natural Gas	None	0.5%	0.0%	4.6%	5.1%
1024	Oil	Window AC	0.5%	7.2%	1.6%	9.3%
1025	Natural Gas	Window AC	7.4%	6.0%	2.3%	15.7%
1029	Natural Gas	Central AC	11.9%	4.0%	1.7%	17.5%
1036	Oil	Central AC	4.8%	15.7%	1.6%	22.2%
1038	Oil	Central AC	1.4%	4.9%	2.5%	8.7%
1046	Natural Gas	Central AC	3.0%	7.4%	3.4%	13.8%
1047	Oil	Window AC	0.1%	8.7%	2.3%	11.1%

In addition to energy cost savings, there may be other significant cost savings and value from HEMS. Consumers and utilities may find additional value through demand response programs or load shifting within time-of-use rate structures. Utilities or program administrators may find additional value through reduced evaluation costs, deeper customer engagement, additional marketing, and behavioral data.

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