Smart Home Energy Monitoring: Data-Driven Opportunities and Customer Engagement

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ABSTRACT

A Midwest utility is conducting an ongoing, exploratory pilot investigating the uses of a customer-facing, broadband, device-level energy monitor. This pilot has three primary objectives: identify behavioral effects produced by homeowner awareness of energy use, derive estimates of energy savings achievable through replacement or servicing of inefficient equipment, and assess the impact that might be achieved with demand response initiatives. The first 100 monitors were installed in rural areas in 2018. Each year an additional 100 monitors are installed, as new participant segments are targeted for inclusion (e.g., low-income customers) and added research questions are explored. Initial findings show that new energy-savings opportunities were sought out by nearly one-third of responding participants, and 57% said their opinion of their utility had improved since entering the pilot. "Always On" loads present the opportunity to reduce participants' overall energy use by 9%. Customers who were most engaged with the technology reduced their electric use by 1-6% after interaction with the monitor app. This paper describes the ongoing pilot, including recruitment, installation, process and impact evaluation methodology, preliminary demand response impacts, and results to date. Multiple applications of device-level data are presented, including energy and demand savings potential, behavioral changes resulting from engagement with the monitor and its associated messaging, load profile development, and technology-assisted optimization of electric vehicle charging. Installation and connection challenges related to electric panel-mounted, broadband-connected devices will be discussed, as well as device identification hurdles and the specific barriers associated with low-income participation.

Background

The landscape of energy efficiency is rapidly changing. As standards continue to evolve, programs that target improving individual equipment efficiencies are becoming less cost-effective. Consequently, operational, behavioral, and market transformation efforts are gaining more traction. Program delivery and marketing have also evolved as utilities continue to place increasing importance on customer relationships and satisfaction. In addition to these programmatic changes, connected technology has continued to develop at breakneck speeds, and smart home devices are now flooding the residential market (Statistica 2022). Many of these devices purport to deliver energy savings; however, these savings are largely untested, preventing smart home devices from taking a larger role in programs and portfolios.

One technology that has seen great advancement in recent years is residential home energy monitors, which not only communicate overall energy use to customers, but also give them real-time feedback on the disaggregated energy use of specific devices within their homes. Early research suggests that direct, overall energy use feedback can produce whole-home energy savings of between 5% to 15% (Darby 2006). Lesic et al. (2018) found that customers tend to underestimate the electricity use of high consumption appliances and overestimate the use of low consumption appliances, which suggests that even greater savings should be obtainable with the addition of appliance-level granularity.

Home energy monitors present a personalized and detailed behavioral opportunity compared to existing, more generic approaches and recommendations. In addition to only being generally representative of energy use (versus providing specific household consumption feedback) many existing approaches have a long feedback loop. Changes to behavior and equipment may take many billing cycles before becoming measurable, if evident at all. Home energy monitoring technology also presents an opportunity to combine behavioral approaches with sustained customer engagement that can be used to suggest specific energy-saving actions and potentially raise program awareness, satisfaction, and participation.

Introduction

In its decision of December 20, 2016, the Public Service Commission of Wisconsin (PSC) stated that it was "particularly interested in examining the role broadband access could play in expanding access to energy efficiency programs and services". The PSC also directed "the development of additional Focus program offerings for rural Wisconsin that would support more equitable distribution of Focus benefits throughout all areas of the state, and also be designed to seek the additional benefits…by tying the use of the internet to increased energy efficiency measures." This decision created the opportunity and demand for new types of broadband-connected energy efficiency programs in the Wisconsin market.

Wisconsin Power and Light (WPL) and Cadmus designed the Home Energy Monitor Pilot to assess the feasibility of using energy disaggregation technology as a tool to inform and develop new energy-saving programs for Wisconsin homes. The technology utilized in this pilot is the Sense Monitor, a high-frequency whole-home energy meter that captures the shape of energy-use profiles by sampling 1,000 times per second. It is installed at the home's electric panel and uses machine-learning algorithms to disaggregate electric sub-loads throughout the home in which the device is installed. Sense Labs identifies the unique electric load signature of lights, appliances, and other end-use devices and labels them for viewing within an app that can communicate directly with the customer. This communication capability enables the technology to sidestep some of the traditional hurdles of residential load disaggregation. When a new device is detected, the app asks the customer to verify its identity, which increases detection reliability. The customer also receives regular reminders that have the potential to increase the persistence of associated behavioral savings.

The pilot is currently composed of four phases, each one designed to investigate a different subset of the customer population and/or application of the technology. The original phase of the pilot targeted 100 customers in rural areas to determine the feasibility of mitigating some of the inequities in access that have traditionally resulted in rural customers being underserved by energy efficiency programs. Phase II included 100 additional device installations in rural, suburban, and urban areas to more accurately represent overall customer demographics within the WPL service territory. Phase III is designed to test the ability of enhanced messaging campaigns to increase participation in Focus on Energy programs and deliver residential energy savings. Phase IV of the pilot focuses on income-qualified customers, with the objective of gaining a better understanding of the device-level energy use and appliance efficiency of this high-priority customer segment. In this paper we will present results from the first two completed phases of the ongoing pilot.

The pilot has three primary objectives: derive estimates of the energy savings achievable through the replacement or servicing of inefficient equipment, identify behavioral effects produced by homeowner's awareness of energy use and engagement with the device app, and assess the impact that might be achieved with demand response initiatives.

Implementation Activities

Participant Selection and Recruitment Survey

Participants were recruited from rural, suburban, and urban zip codes, to represent the general population of WPL customers. All selected participants were required to live in the WPL Energy service territory and have access to a broadband internet connection. For the first two pilot phases, Cadmus selected households with slightly above average annual energy consumption as an attempt to ensure greater opportunities for implementing energy efficiency measures. Filtering potential participants based on energy consumption also removed outliers that could bias the results of the pilot. Cadmus created histograms of annual consumption and bound selection to annual household energy consumptions between 10,000 kWh and 16,000 kWh, approximately the 3rd quartile of energy use. Homeowners in WPL territory with annual energy consumption in this range were sent recruitment surveys that included questions such as the following:

- Age of home
- Square footage
- Home type (e.g., ranch)
- Number of full-time occupants
- Distance between electrical panel and Wi-Fi router
- Access to an app-compatible device (i.e., smartphone or tablet)
- Internet latency

The recruitment survey yielded a population of eligible participants. Two hundred of those customers were then contacted to schedule Sense monitor installations during the first two pilot phases.

Technology Deployment

Cadmus schedulers contacted eligible participants and coordinated installation visits with a Cadmus field technician and licensed electrician. While the electrician installed the Sense monitor in the participant's electric panel, the Cadmus technician worked with the participant to sign the customer agreement, deliver a gift card incentive, and connect the Sense monitor to the homeowner's Wi-Fi. Cadmus technicians also collected field data on the characteristics and model numbers for major appliances in the home. Additional data was collected on the square footage of the home and the percentage of light fixtures using incandescent, CFL, and/or LED bulbs.

Evaluation Methodology

Multiple evaluation activities were undertaken to assess pilot design, implementation, customer satisfaction, behavior changes, and energy-related outcomes. These activities included interviews with program actors and technicians, customer surveys, analyses of disaggregated energy use data, and billing analysis. This paper describes a selection of those activities and their results through Phase II of the pilot. Complete evaluation reports (Kramer et al., 2019, Hicks et al., 2020, and Hicks et al. 2021) can be accessed online via the PSC Electronic Records Filing system).

Customer Surveys

Cadmus contacted all Phase I and Phase II participants via email and offered them an incentive for completing an online survey. The total number of complete responses was 112, of which 63 came from Phase I participants and 49 came from Phase II participants. Surveys were designed to gather data on a variety of topics, including satisfaction with WPL, estimated monthly energy savings, and behavioral changes due to participation in the pilot.

Appliance Efficiency Analysis

Cadmus analyzed appliance energy use for 153 pilot and expansion participants. For each customer and device type, Cadmus estimated expected annual consumption and classified these estimates according to relevant Wisconsin and Illinois Technical Reference Manual (TRM) values for baseline, inefficient, and efficient devices. In the absence of specific definitions of efficient and inefficient products, such as in the case of "Always On" loads, Cadmus defined a median wattage based on the data collected from all monitors in households participating in the Pilot and used this wattage to distinguish between efficient and inefficient usage levels. Potential savings are reported for replacement of all inefficient and baseline devices to achieve the efficient consumption level for all participating customers.

For refrigerators and electric water heaters, the analysis assumed low variation in daily consumption. Cadmus analyzed energy use for 153 customers in the pilot and expansion phases who had at least two months of complete data (on average, these customers had 377.9 days of data). Expected annual device consumption was estimated using the average daily consumption over the observed days for each customer and device type. In the analysis of electric dryer and dishwasher consumption, Cadmus used a cycle-based approach to estimate annual energy use. Cadmus analyzed data for 120 pilot and expansion participants who had at least five days of complete data (these customers had 109 days of data on average). We estimated each customer's energy consumption per cycle by identifying the mode of daily device consumption. Cadmus then multiplied the estimated per cycle consumption by the average annual number of cycles per household according to either the Illinois or Wisconsin TRM to estimate a cycle normalized annual consumption for each device.

For electric dryers, water heaters, and dishwashers, the analysis assumed that each home would not use more than one of each appliance type. However, the Sense disaggregation algorithm identified a greater number of these device types than one would expect (e.g., 1.4 electric dryers per home). Discussions with Sense have suggested that some appliances can have several unique duty cycle signatures (e.g., a clothes dryer may have a timed dry, air dry, or permanent-press setting). The associated unique signatures may then be classified by unique device IDs under the same device type category. Cadmus' chronological analysis of device activity generally indicated that unique device IDs of one type did not register loads at the same time. Therefore, when a customer had multiple device IDs within one of these device types, Cadmus combined their consumption to produce an estimate of the customer's total consumption for each device type.

Disaggregated refrigerator data was treated differently to account for some homes having multiple refrigerators. Each identified refrigerator was treated as a unique device. Cadmus restricted the analysis to refrigerators with non-zero consumption on at least 95% of the days in the analysis.

Behavioral Energy Savings Estimation

App access analysis. Home Energy Monitor Pilot participants can access a mobile app that provides information on real time and historical energy consumption in their homes. For participants in Phase I, access to the app was withheld for several months after the monitors were installed so Cadmus could observe participant consumption prior to any behavioral impacts related to app access.

Cadmus estimated the effect of app access on the average daily consumption of these participants using a differences-in-differences model, which allowed for variation in the date of app access. The model used customer and date fixed effects. Customer fixed effects control for variation in individual customer average consumption. Date fixed effects control for variation over time (e.g., average weather impacts). Cadmus adjusted the resulting standard errors to account for clustering at the individual participant level according to industry best practices for panel regression models.

Billing Analysis. Cadmus used monthly billing data to examine changes in electricity consumption between the periods before and after participants received a Sense monitor for Phase I and Phase II participants. To conduct this evaluation Cadmus procured the following data to conduct the impact analysis:

- Monthly billing data for Phase I and Phase II participants as well as for a group of nonparticipants. Available billing data generally ranged from January 2017 to February 2020.
- Daily weather data from the National Oceanic and Atmospheric Administration (NOAA)
- Sense monitor participation/installation dates

Participants were removed if they had fewer than 300 days of pre-period billing data, or if they had no post-period billing data available. Cadmus had to remove participants from the analysis for a variety of reasons; both phases had attrition of approximately 30%. For Phase I the largest reason for dropping participants was due to the account not having a first session date. For Phase II the largest source of attrition was having insufficient pre period data.

Due to the nature of the pilot program, there is not a designated randomized control design where participant and non-participant groups are designated prior to the delivery of the treatment. Cadmus used a quasi-experimental design to attempt to control for changes in energy consumption unrelated to the installation of the Sense monitor. Cadmus selected a matched comparison group using billing data from nonparticipants using a propensity score matching approach. Customers in the participant group were matched to nonparticipants based on seasonal pre-period energy consumption and weather.

Propensity score matching produced a set of non-participants that are similar to the participants in relation to the chosen explanatory variables, in this case pre-period consumption, weather conditions, and geographic location. Cadmus confirmed that none of the differences were statistically significant using analysis of variance (ANOVA).

Cadmus evaluated savings for both phases using a difference-in-difference model specification. Difference-in-difference models estimate savings by comparing the changes in pre- to post- energy consumption between treatment and comparison groups. The difference between this difference is the estimated savings.

Peak Demand Reduction Assessment

To determine which end uses represented the largest contributions to peak system loads, Cadmus aggregated device-specific consumption across all program participants during the eight on-peak weekday hours (11 a.m. to 7 p.m.) of the 2019 Midcontinent Independent System Operator (MISO) peak day (July 19). Device-specific aggregated loads were also compared to Wisconsin Power and Light's residential service time of use rates, to assess device-level demand response (DR) potential.

Results

Participant Survey

Customer Satisfaction. Cadmus asked respondents if their opinion of WPL had changed since participating in the pilot. As shown in Figure 1, 57% said their opinion of their utility had improved.

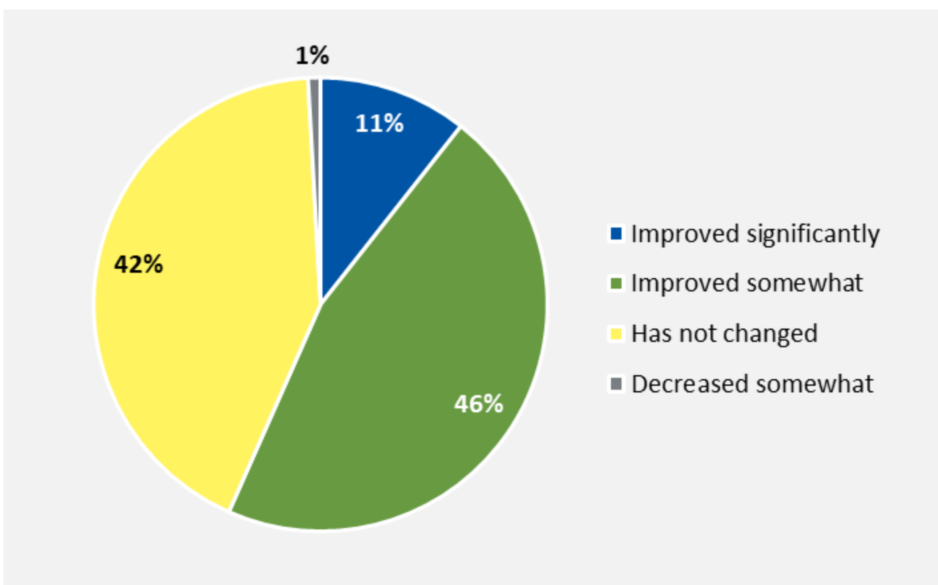

Figure 1. Opinion of Wisconsin Power and Light. *Source:* Cadmus.

Energy Savings Estimates. Over half of respondents (51%; N=112) said they saw a decrease in their monthly energy costs since accessing the Sense monitor app. Of these respondents, 57% said they noticed a decrease in monthly energy costs between $5 and $15 (Figure 2). Eighty-four percent of respondents were satisfied with the decrease in energy costs after accessing the Sense app, with 51% very satisfied and 33% somewhat satisfied (N=44).

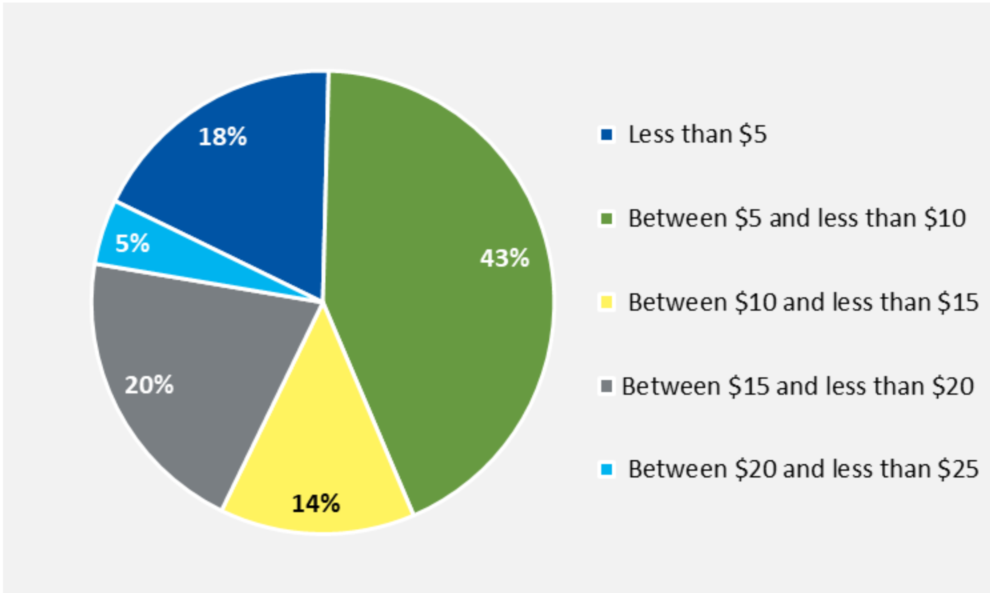

Figure 2. Participant-estimated monthly energy cost savings. *Source:* Cadmus.

Behavioral Changes. Cadmus asked respondents about their energy-saving habits before and after participating in the pilot. Of 112 respondents, all but 5% said they used energy-saving habits to reduce their energy consumption before participating. After participating, 60% of respondents said they had made additional changes to their daily behavior to reduce energy use. Approximately 30% of respondents said they had sought out additional energy-saving opportunities as well. Figure 3 presents energy-saving behaviors before and after participation in the pilot program.

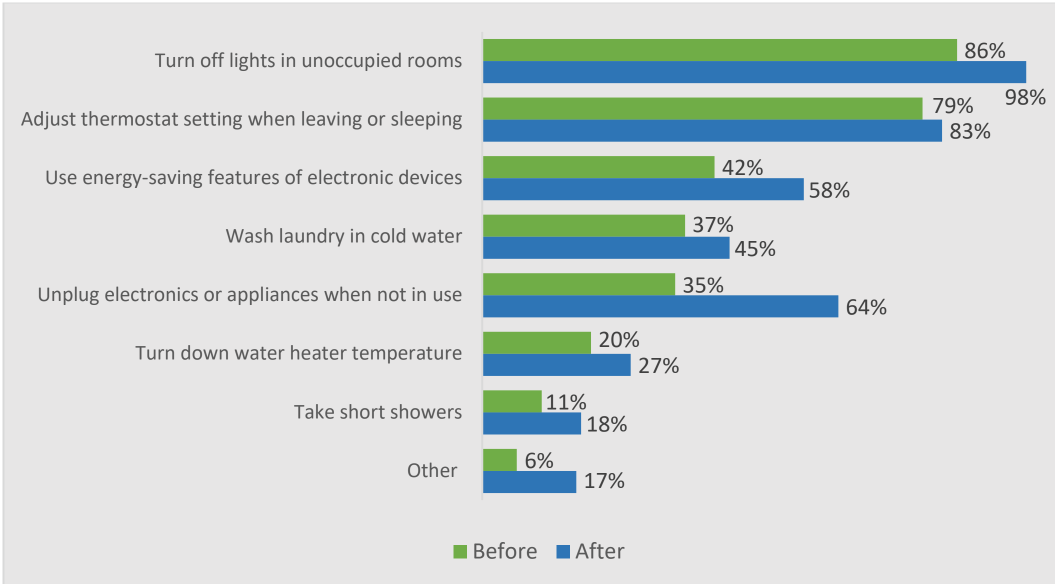

Figure 3. Energy-saving behaviors. *Source:* Cadmus.

"Always On" Savings Potential

"Always On" load reflects the baseline consumption of devices that are plugged in and draw current 24 hours a day regardless of whether they are being actively used. An analysis of the data from all pilot households reporting electric loads in February and March 2020 found a median home total wattage of 1.14 kW and a median "Always On" wattage of 0.24 kW. Overall, loads designated as "Always On" contributed 25.2% of pilot participant consumption, which is consistent with Sense Labs' reported national average (Walton 2019). Figure 4 shows the potential for savings if customers with high "Always On" loads were reduced to the median among all pilot households. Results indicate that total aggregated energy consumption among pilot participants could be reduced by approximately 8%, if half of participants reduced their consumption to the median.

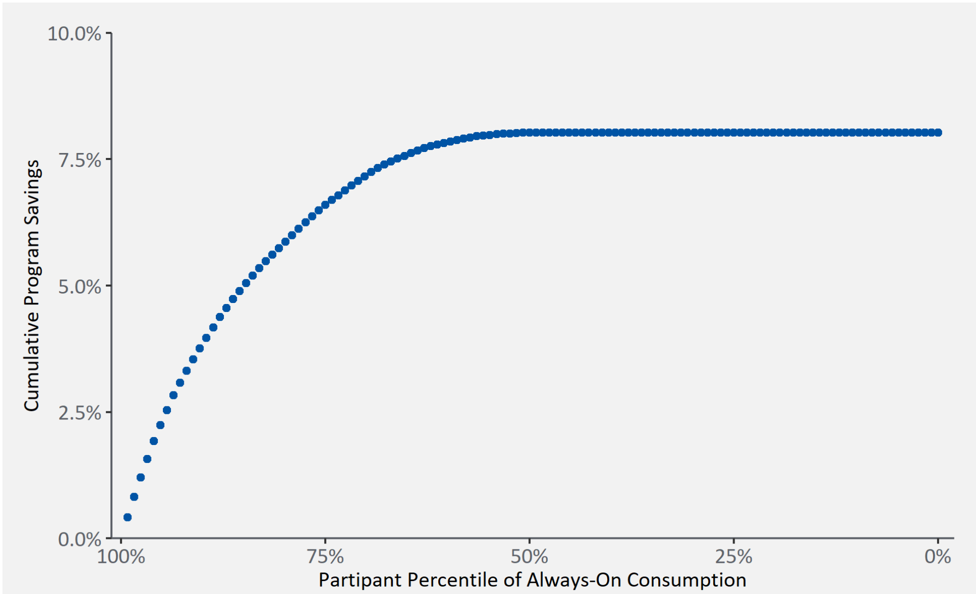

Figure 4. "Always On" Savings Potential. *Source:* Cadmus.

Appliance Replacement Analysis

This section presents findings regarding the potential for device upgrade savings from electric dryers, refrigerators, water heaters, and dishwashers.

Electric Dryers. Energy use disaggregation identified electric dryer consumption for 120 customers. The Wisconsin TRM defines the maximum baseline and efficient annual electric dryer consumption as 768.9 kWh and 608.5 kWh, respectively (Wisconsin Focus on Energy 2019, 897). The electric dryer energy consumption of 30% of participants was above baseline levels. Another 18% of participants exceeded the efficient consumption level. For customers in the inefficient category, a dryer upgrade to the efficient level would save an average of 324 kWh per year. These savings correspond to a 2.9% average reduction relative to average participant total annual consumption[1].

Refrigerators. Cadmus conducted savings analysis with refrigerator consumption data for 238 devices identified by disaggregation that registered non-zero consumption on at least 95% of analysis days (i.e., days for which disaggregated loads were available). The Illinois TRM indicates baseline and efficient annual refrigerator consumption of 534 kWh and 483.8 kWh, respectively (IL TRM Technical Advisory Committee, 2020).

Sixteen percent of refrigerators exceeded the baseline consumption level. Another 7% of refrigerators exceeded the efficient consumption level. Four refrigerators were identified as having unusually large energy consumption (greater than 1,000 kWh per year). In the inefficient category, a refrigerator upgraded to the efficient level would save an average of 178 kWh per year. These savings correspond to a 1.6% average reduction relative to average participant total annual consumption.

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[1] The estimated annual average per-household consumption, for Phase I and Phase II participants is 11,147 kWh.

Water Heaters. Energy use disaggregation identified electric water heater consumption for 51 participants. The Wisconsin TRM indicates baseline and efficient annual heat pump water heater consumption of 3,160 kWh and 1,499 kWh, respectively (Wisconsin Focus on Energy 2019, 836)[2]. Figure 5 shows the distribution of customer electric water heater consumption relative to TRM-defined levels.

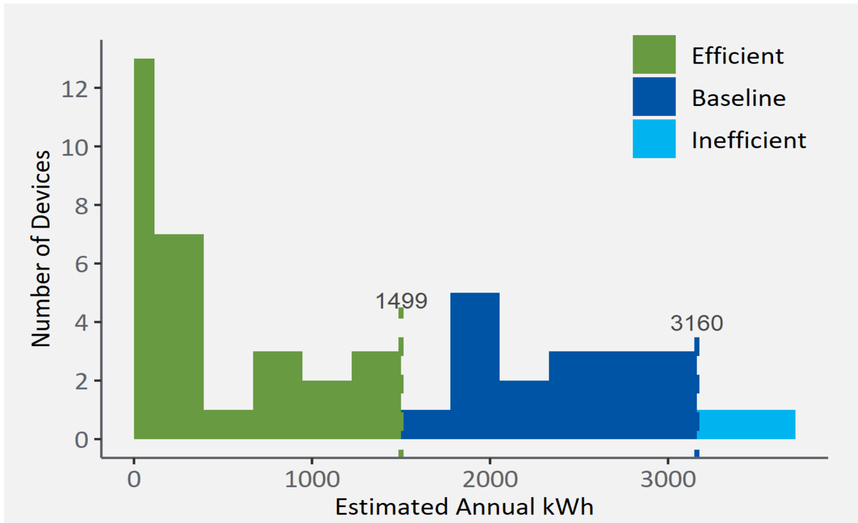

Figure 5. Water heater energy consumption. *Source:* Cadmus.

The annual projected water heater consumption for 10% of participants exceeded the baseline consumption level. Another 33% of customers had annual water heater consumption levels exceeding the efficient consumption level. For devices in the inefficient category, a water heater upgrade to the efficient consumption level would save an average of 2,489 kWh per year. These savings correspond to a 22.3% average reduction relative to average participant total annual consumption.

Dishwashers. Energy use disaggregation identified dishwasher consumption for 72 participants. The Illinois TRM indicates baseline and efficient annual dishwasher consumption levels of 307 kWh and 270 kWh, respectively (Illinois TRM Technical Advisory committee 2019, 20). Consumption for 4% of identified dishwashers exceeded the baseline consumption level. The average estimated annual consumption of the efficient devices was 151 kWh, or less than 50% of the maximum annual consumption of baseline devices. This suggests that dishwasher signatures may not be accurately identified, likely due to the wide range of device operating modes. For devices in the inefficient category, a dishwasher upgrade to the efficient consumption level would save an average of 1,775 kWh per year, corresponding to a 15.9% average reduction relative to average participant total annual consumption.

Table 1 shows the distribution of inefficient appliance replacement opportunities across all investigated device categories.

Table 1. Inefficient appliance replacement opportunities by device category

[2] The baseline heat pump water heater has an energy factor of 0.945. The efficient heat pump water heater is ENERGY STAR certified.

Device Category	N	Homes with Inefficient Devices	Average Annual Savings [kWh]	Average Annual Consumption Savings
Electric Dryers	120	30%	324	2.9%
Refrigerators	238	16%	178	1.6%
Water Heaters	51	10%	2,489	22.3%
Dishwashers	72	4%	1,775	15.9%

Source: Cadmus.

Behavioral Savings

App Access. An analysis of consumption for Phase I participants before and after their first app access date found that an estimated savings of 1.8 kWh, or 6% of average daily consumption, could be attributed to app use, however, this result is not statistically significant ($p = 0.30$). Figure 6 compares hourly consumption for app and non-app users during the pre- and post-access periods. These groups were not randomly determined; participants self-selected into the app user group by responding to the encouragement. The analysis tested whether customers who responded to app access encouragement were representative of the whole pilot participant population. The left panel (Pre) shows alignment in hourly load shapes during the period prior to app access, indicating that those who responded to app use encouragement were representative of the whole pilot population. The right panel (Post) shows a reduction in consumption for participants with app access relative to those participants who did not access the app.

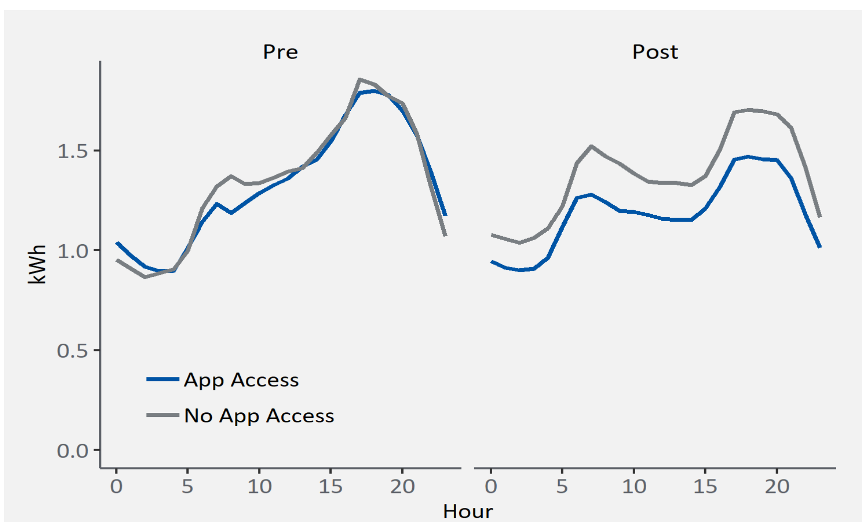

Figure 6. Average hourly consumption pre- and post-app access for Phase I participants. *Source:* Cadmus.

Billing Analysis. Cadmus found savings of approximately 1.1% for Phase I and 1.6% for Phase II participants. Neither result was statistically significant at a 90% confidence level, with both savings estimates having relative precisions of over 100%. Phase II savings were estimated as slightly higher than phase I participants, however given the lack of statistical significance it is difficult to draw any conclusions about the differences in savings between groups. Additionally, Phase II monitors had an average installation date of 11/1/2019, which left a limited amount of post-period data for half of the participants (i.e., 3-4 months in some cases). Table 2 shows modeled savings estimates by phase.

Table 2. Savings estimates by phase

Group	N	Baseline Usage	Model Savings	Percent Savings
Phase 1	74	32.70	0.36	1.1%
Phase 2	43	30.60	0.48	1.6%

Source: Cadmus.

Load Shifting Potential

Cadmus assessed the device-specific potential for demand response savings by isolating device-level consumption during peak demand events. Figure 7 depicts the distribution of each device type as a percentage of aggregate program load during the eight on-peak weekday hours (11 a.m. to 7 p.m.) of the 2019 Midcontinent Independent System Operator (MISO) peak day (July 19). The device types that provided the greatest opportunity for demand savings were, in descending order of savings, air conditioners, dryers, water heaters, and pool pumps. This list excludes unidentified loads and devices with static loads (i.e., refrigerators and "Always On").

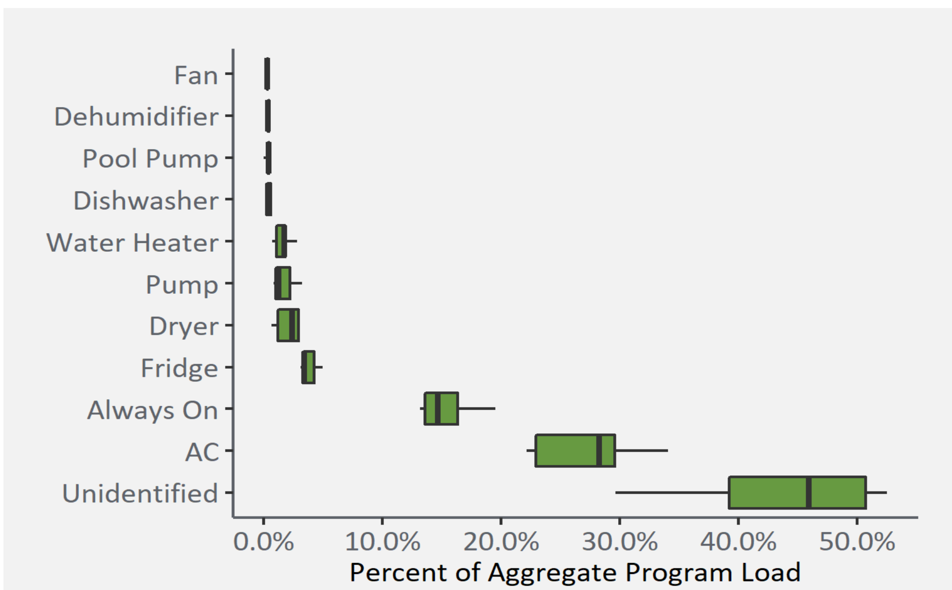

Figure 7. Percentage, by Device, of Aggregate Pilot Program Load during MISO August Peak Hours. *Source:* Cadmus.

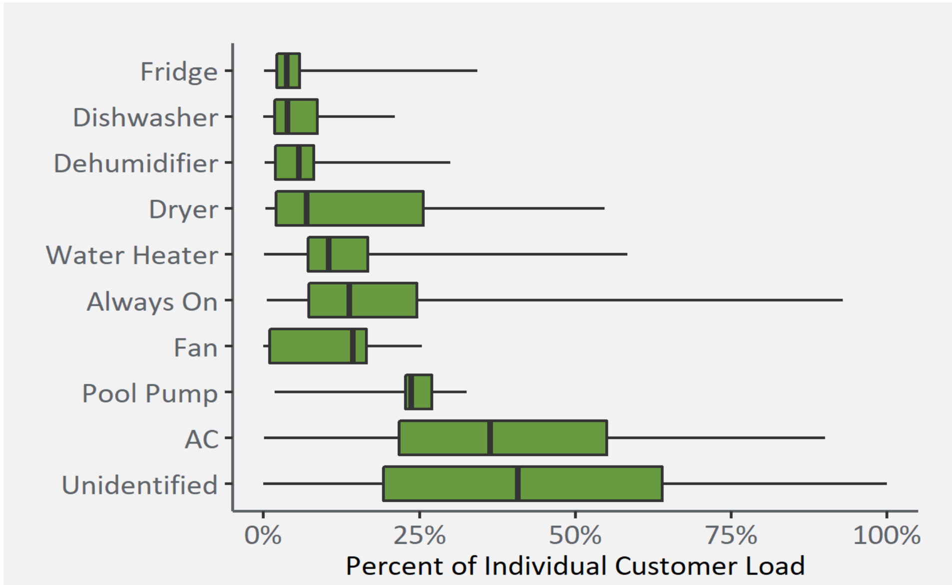

Figure 8. Device Percentage of Individual Customer Load during MISO August Peak Hours. *Source:* Cadmus.

Figure 8 depicts the distribution of each device type as a percent of individual customer load during the same eight on-peak weekday hours (11 a.m. to 7 p.m.) of the 2019 MISO peak day (July 19). This figure highlights the potential for demand savings from devices that are used in a minority of homes but contribute a large percentage of customer total demand. Pool pumps contribute less than 3% of aggregate program peak load but contribute an average of 25% of individual participant load, for those that have them. Thus, pool pumps may present the second-best opportunity for per-device demand savings after air conditioners.

Device Demand Analysis

Cadmus has structured its demand reduction analysis based on the WPL time-of-use hours for residential service, summer high rate weekday times. We decomposed the summer high rate interval into high-peak (2 p.m. to 5 p.m.) and mid-peak (11 a.m. to 2 p.m. and 5 p.m. to 7 p.m.) periods. The following sections describe the analysis for each device.

Air Conditioners. Figure 9 depicts the average summer air conditioner demand profile on non-holiday weekdays. Air conditioner consumption was identified in 81 (N=81) unique Sense monitors during the three monthly MISO summer peak days of 2019. During high peak (2 p.m. to 5 p.m.) and mid-peak hours (11 a.m. to 2 p.m. and 5 p.m. to 7 p.m.), air conditioners present an average potential peak demand savings opportunity of 0.53 kW and 0.49 kW per device, respectively.

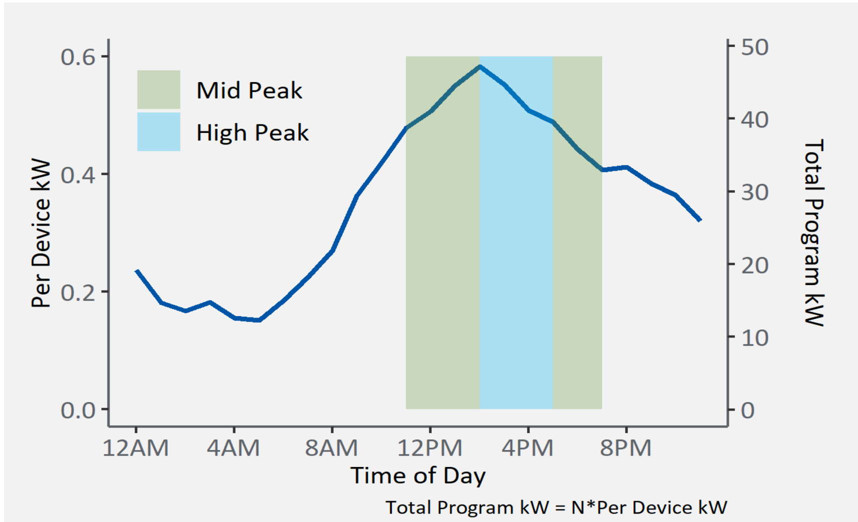

Figure 9. AC Average Summer Demand Profile. *Source:* Cadmus.

Electric Dryers. Figure 10 depicts the average summer dryer demand profile on non-holiday weekdays. Electric dryer consumption was identified by 85 (N=85) unique Sense devices during the three monthly MISO summer peak days of 2019. During high peak (2 p.m. to 5 p.m.) and mid peak hours (11 a.m. to 2 p.m. and 5 p.m. to 7 p.m.), dryers present an average potential savings opportunity of 0.05 kW per device. Peak electric dryer demand did not typically coincide with the defined peak hours.

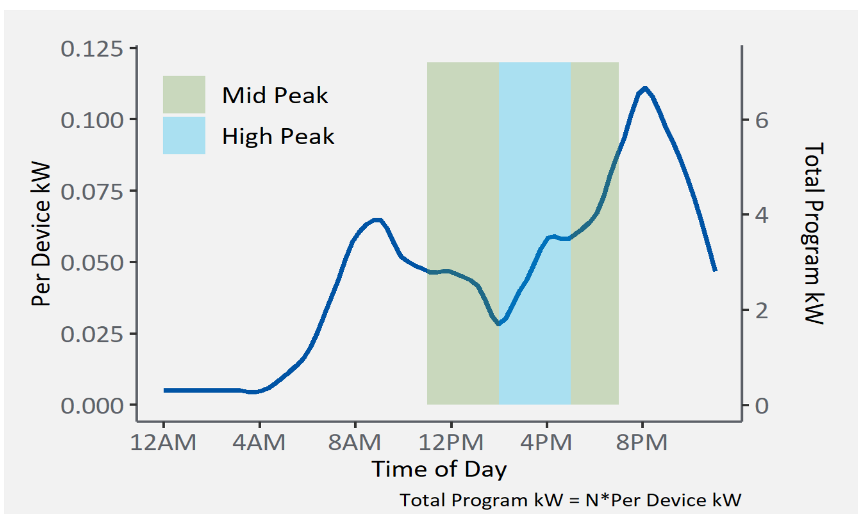

Figure 10. Dryer Average Summer Demand Profile. *Source:* Cadmus.

Pool Pumps. Figure 11 depicts the average summer pool pump demand profile on non-holiday weekdays. Pool pump consumption was identified by one (N=1) unique Sense monitor during the three monthly MISO summer peak days of 2019. During high peak (2 p.m. to 5 p.m.) and mid peak hours (11 a.m. to 2 p.m. and 5 p.m. to 7 p.m.), pool pumps represent an average potential savings opportunity of 0.35 kW and 0.26 kW per device, respectively.

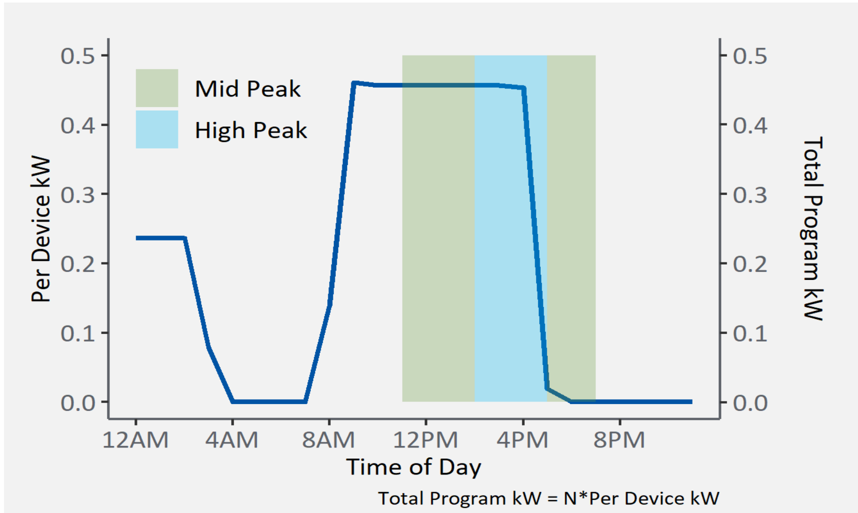

Figure 11. Pool Pump Average Summer Demand Profile. *Source:* Cadmus.

Table 3 shows the distribution of inefficient appliance replacement opportunities across all investigated device categories.

Table 3. Peak demand reduction opportunities by device category

Device Category	N	High Peak Demand Reduction Potential [kW per Device]	Mid Peak Demand Reduction Potential [kW per Device]
Air Conditioners	81	0.53	0.49
Electric Dryers	85	0.05	0.05
Pool Pumps	1	0.35	0.26

Source: Cadmus.

Conclusions

Device-level home energy monitoring delivers opportunities and insights in several areas of interest such as behavioral and resource acquisition energy savings, customer engagement, and demand response initiatives. The results of a subset of evaluation activities, conducted to assess pilot design, implementation, customer satisfaction, behavior changes, and energy-related outcomes are summarized below. These findings will continue to be updated as future pilot phases are executed and additional data becomes available.

Participant Survey Findings

- 57% of Phase I and Phase II pilot survey respondents said that their opinion of WPL had improved since participating in the pilot.
- Over half of participating respondents reported a decrease in their monthly energy costs since accessing the energy monitor app.

- After participating, 60% of respondents said they had made additional changes to their daily behavior to reduce energy use, and approximately 30% of respondents said they had sought out additional energy-saving opportunities.

Energy Use Data Analysis Findings

- An analysis of participants' "Always On" consumption identified the potential for an 8% reduction in pilot consumption by reducing "Always On" consumption to the median level.
- Analysis of energy consumption by appliance category identified opportunities for energy savings through targeted replacements of water heaters, dryers, and refrigerators. The expected annual average kWh savings are 1,690 kWh, 725 kWh, and 412 kWh per replaced unit, respectively.
- A billing analysis of total household consumption before and after program participation indicated that participants in phase I and phase II saved 1.1% and 1.6% of daily consumption, respectively. These point estimates are in line with the typical savings for residential behavior programs, but the treatment population is relatively small for detecting an effect of this magnitude and therefore the results are not statistically significant.
- Disaggregation analysis of device consumption during MISO peak days in summer 2019 indicated that, after air conditioners, the devices that contributed the most peak coincident load were "Always On" loads, refrigerators, and dryers.

Acknowledgements

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References

Darby, S. 2006. "The Effectiveness of Feedback on Energy Consumption." Prepared for Environmental Change Institute, University of Oxford. www.eci.ox.ac.uk/research/energy/downloads/smartmetering-report.pdf.

Hicks, A., A., Kornelis, and A. McLeod, 2020. "Sense Home Energy Monitor Pilot Program.", PSC REF# 392790. apps.psc.wi.gov/pages/viewdoc.htm?docid=392790.

Hicks, A., A. Kornelis, A. McLeod, K. Miller, and C. Bushey, 2021. "Home Energy Monitor Pilot Program.", PSC REF# 414799. apps.psc.wi.gov/pages/viewdoc.htm?docid=414799.

Illinois Technical Reference Manual (TRM) Technical Advisory Committee, 2019. 2020 Illinois Statewide Technical Reference Manual for Energy Efficiency Version 8.0, Volume 3: Residential Measures. Chicago, IL: Vermont Energy Investment Corporation (VEIC).

Kramer, C., A. Kornelis, A. Hicks, A. McLeod, and A. Jackson, 2019. "Sense Home Energy Pilot Program.", PSC REF# 371354. apps.psc.wi.gov/pages/viewdoc.htm?docid=371354.

Lesic, V., W. Bruine de Bruin, M. C. Davis, T. Krishnamurti, and I. M. L. Azevedo, 2018. "Consumers' perceptions of energy use and energy savings: A literature review." Environmental Research Letters 13 (2018) 033004. iopscience.iop.org/article/10.1088/1748-9326/aaab92/pdf.

Public Service Commission of Wisconsin, 2016. PSC Dockets 5-FE-100 and 5-FE-102 Final Decision, PSC REF#: 295732. apps.psc.wi.gov/ERF/ERFview/viewdoc.aspx?docid=295732.

Statistica, 2022. "Digital Markets. Smart Home." www.statista.com/outlook/dmo/smart-home/worldwide.

Walton, R., 2019. "Sense targets $41B of 'always on' loads as traditional energy saving measures diminish." Utility Dive. www.utilitydive.com/news/sense-targets-41b-of-always-on-loads-as-traditional-energy-saving-measur/554284/.

Wisconsin Focus on Energy, 2019. 2019 Technical Reference Manual. Madison, WI: Cadmus.