The Promised Land: Making Use of Data from Smart Meters

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ABSTRACT

Government policy and utility investments are rapidly creating a 'smart' electric grid. The deployment of advanced metering interfaces (AMI) is creating interval data for a segment of electric accounts where previously consumption was only captured monthly. In Vermont, federal funding has provided the resources for utilities to install AMI at most customer locations.

Access to this data is regulated at the state level. Regulatory concerns of security and privacy may limit the availability and ease of access in some jurisdictions. However, there are data standards being adopted that will allow evaluators to directly access AMI data.

AMI data provides evaluators with opportunities for improving the estimates of energy savings and coincidence factors. The paper discusses how AMI data was used in an impact evaluation for the New England Independent System Operator (ISO-NE) Forward Capacity Market (FCM). Some examples include assessing seasonal and diurnal consumption patterns, deriving load profiles for specific accounts or end uses, and conducting billing analyses for specific populations. The impact on understanding residential consumption patterns may be even more important as load data for this sector is expensive to collect. Initial research suggests that it is possible to identify the "signature" kW use for specific end uses when AMI data is combined with site specific information.

This paper will cover the following topics: the deployment and availability of the AMI technology, the uses of AMI data in a forward capacity market evaluation and how analysis can be focused on peak hour savings.

Introduction

The deployment of technology to create a 'smart' grid has the potential to dramatically change how consumers of electricity interact with their utility. The data from AMI meters also provide some unique opportunities for evaluators as well. Data from these meters can be very granular and provide a level of detail about hourly use that was previously available only for some large industrial facilities with interval meters.

As the forward capacity markets[1] have moved the focus to reducing peak demand consumption, the widespread availability of this time-of-use data allows evaluators to expand their toolbox and develop new methods for this purpose. For instance, understanding temperature dependency for heating and cooling measures becomes far easier when both the usage and temperature reading are hourly. There is also the potential to incorporate "big data" analytics into measurement and verification activities. Fifteen minute consumption data, at least for residential and small commercial accounts, contains clear signatures that can be associated with specific end uses. This type of analysis has the

[1] Forward capacity markets have been created by independent system operators to allow generation, efficiency, demand response and other capacity resources to be bid into electric markets under standardized market rules

potential to improve our understanding of energy consumption without the need to perform expensive on-site metering.

Of course, in order for AMI data to be used extensively in evaluation, there are numerous hurdles to overcome. First, AMI technology needs to be installed in the study area. Second, the data needs to be available to evaluators and legitimate concerns regarding customer privacy need to be addressed.

Availability of AMI data has become increasingly important in the context of the ISO New England's (ISO-NE) Forward Capacity Market (FCM). Efficiency Vermont and Burlington Electric Department bid the winter and summer peak reduction from their efficiency portfolios into FCM and the Vermont Department of Public Service (VDPS) is responsible for the evaluation. West Hill Energy led the team that won the competitive bid to conduct the FCM impact evaluation of the entire portfolios. The Evaluation Team members include Cx Associates, Energy and Resource Solutions, GDS Associates and Lexicon Energy Consulting.

In the following sections, this paper discusses the state of AMI deployment and some of the approaches that jurisdictions have taken to address privacy issues in an evaluation context. Early work using AMI data to evaluate Vermont projects to ISO-NE FCM standards will also be discussed.

Background

Title VIII of the Energy Independence and Security Act (EISA) makes it the policy of the United States to support the development of the Smart Grid to achieve a number of goals, which include development of demand response and energy efficiency resources, 'smart' technologies to allow real-time, automated metering, and integration of 'smart' appliances and consumer devices, and offering consumers access to timely information and control devices. (11th Congress 2007, 293) In 2009, the US Congress passed the American Recovery and Reinvestment Act (ARRA). One of the provisions of this act provides incentives for utilities to install advanced metering interface (AMI) meters for all customers. The public policy objectives of ARRA are to provide demand reduction and efficiency opportunities, real time feedback to the grid operators, and allow for the integration of smart appliances.

Advanced metering interface is a critical lower level component of the Smart Grid concept as it provides not only the interface with the consumer but also gathers the granular time-stamped consumption data that can possibly be used to improve system load factors[2]. One of the perceived benefits of this deployment is that the utilities can create real time pricing structures and allow customers to interface directly with heating and cooling equipment and appliances to respond to those price signals. Moving load from system peak periods to off-peak periods should improve the system load factor. Realizing this potential requires the deployment of a number of integrated metering information technologies. (Mohassel 2014)

Deployment

The deployment of AMI systems is dramatically increasing the quantity of data that a utility collects on most consumers. As AMI technology is a basic building block of a smart grid, it is being rapidly deployed in many jurisdictions. As a part of ARRA, the Department of Energy was provided with $4.5 billion to modernize the electric power grid. A large part of this funding was used to install smart meters.

As a result of the ARRA funding, over 16.3 million smart meters are installed and operational as a part of Smart Grid Investment Grant (SGIG) projects, and an additional 270 thousand smart meters as

[2] The ratio between peak and average demand on an electric grid

a part of Smart Grid Demonstration projects. (OE 2015) In total, there have been about 50 million smart meters installed in the U.S., covering 43 percent of households. (Giambusso 2015)

In 2010, Vermont utilities, the VDPS, the Office of Recovery and the Vermont Electric Power Company were awarded $69 million in Federal grant funds, as part of the SGIG. AMI technology has now been deployed at over 305,000 or approximately 75% of all metering locations in Vermont and many locations now have AMI data available for several years. Previously in Vermont, consumption data at this level of granularity was only available for a relatively small number of large industrial customers.

Security

Securing detailed data about the system load factor and consumer consumption is an important consideration in the design, deployment and operation of any Smart Grid. How access to AMI data is regulated may well decide the extent that highly granular data on energy consumption can be used to improve savings estimates for program implementers and the evaluation community.

There are legitimate security concerns with AMI data at the consumer level. Using data analytics, it is as easy to ascertain occupancy patterns as it is to ascertain the pattern of hot water use. Periods of vacancy can be easily identified and it may even be possible to ascertain one's political ideology by combining consumption information with other demographics. A study of a California behavior program concluded that "In response to receiving the [home energy] report, liberals reduce their electricity consumption by a larger percentage than conservatives." (Costa & Khan 2010, 22) This information was gleaned from the list of utility customers who received the report, political party registration, participation in renewal energy programs and community demographics. Residential data is particularly sensitive as it is reflective of occupant activities. (Haramati 2014)

Currently, states set policies concerning the availability of AMI and other utility billing data, leading to inconsistent policies from one state to another. The State and Local Energy Efficiency Action Network has provided regulators a guide to inform regulators about issues and policies related to energy data access. (SEEACT 2015) Current state regulations run the gamut from requiring the customer's permission to obtain their data to not having any regulation at all. Vermont regulators have allowed access to AMI data for evaluation purposes to occur either through Efficiency Vermont or as a request from the Vermont Department of Public Service (VDPS) to the utilities. The information is treated as confidential at all times.

Access to this data in Vermont has allowed the use of AMI data to improve the accuracy and the efficacy of our evaluation efforts. In contrast, New York regulators require each individual consumer to consent to the use of their data. While this requirement does not preclude the use of AMI data, it greatly increases the cost of obtaining the information. Other restrictions on data use can make certain types of analysis impossible, as some information such as address, size, or building that allows identifying particular houses is important for housing characterization studies. (McKibben 2014)

AMI Data for Impact Evaluation

For the FCM, efficiency is valued based on the average kW reduction in demand during specific peak hours in the course of a year. The summer peak hours are 1:00 to 5:00 PM on non-holiday weekdays and the winter peak hours are 5:00 to 7:00PM on non-holiday weekdays. AMI data can expand and improve the FCM impact evaluation in the following ways:

- Billing-based, time of use analysis can be conducted for more projects, which may reduce evaluation costs particularly in comparison to on site measurements

- AMI data can be used to calibrate simulation models to actual consumption for new construction projects
- AMI data allows the evaluator access to interval measurements for the entire facility rather than relying on in-project sampling to meter a much smaller subset; this reduces the sampling error and potential for bias
- AMI data can augment short term metering by allowing a comparison of the metered period load shape to the longer term energy use of a facility to assess whether the time period of the metering is representative of a facilities operation over the longer term
- For small commercial establishments, residential homes and even some larger industrial facilities, AMI data could be useful for developing aggregate load profiles for common end uses, such as lighting and air conditioning.

The potential for exploring residential consumption patterns could lead to more reliable and defensible load profiles for the residential sector without the prohibitive costs of large metering studies.

ISO-NE has issued guidelines on acceptable M&V methods to use for the impact evaluations. The four M&V approaches (similar to the International Performance Monitoring and Verification Protocol) are listed below with an explanation of how the availability of AMI data could be used to improve the reliability of the impact evaluation results and/or reduce evaluation costs. Table 1 lists the allowable FCM M&V methods with the potential AMI applications.

Table 1. Use of AMI Data by Evaluation Method

Evaluation Method	When to Use	Without AMI Data	With AMI Data	AMI Advantage
Option A: Partially Measured Retrofit Isolation	When spot or short-term metering or measurement of a proxy variable in combination with stipulated values are appropriate	Use of regional studies for stipulated load profiles	Develop load profiles for common end uses across the population	Load profiles are specific to the region Expands the analysis base to the whole population
Option B: Isolation Retrofit	When direct kW measurement of retrofit measures can be conducted and savings are small relative to the building load	Short term metering In-project sampling for large projects	Compare short term period to longer term trends AMI data available for entire project and may be used to find data signatures for specific measures	Improve reliability by • ensuring short term metering reflects long term operation and • reducing or eliminating need for in-project sampling
Option C: Whole Facility Regression	When whole building analysis or regression is appropriate (retrofit)	Limited to the few customers with interval meters	Expands the number of projects with 15 minute interval data	Reduces costs by allowing this approach to be applied to more projects
Option D: Calibrated Simulation Modeling	When savings are estimated by computer simulation models (often new construction)	Calibration to monthly bills; hourly calibration limited to customers with interval meters	Calibration to hourly data	Improves reliability of time-sensitive savings

AMI data was requested for all of the projects in the custom C&I sample and also for some large residential projects, and the evaluation team was instructed to use the data when possible. Although we anticipated that AMI data could be used for all of the M&V approaches specified in the FCM guidelines, some initial setbacks occurred. AMI data sets for any population study quickly become very large. Generally, we have found it to be relatively easy to obtain data for a single account. However, when even a small population of accounts is needed, obtaining the data has been far more difficult. The time commitment for utility staff to pull the data increases and other job responsibilities can take precedence. Over time, these processes should improve and we expect to have fewer issues in the 2014 evaluation cycle.

Overall, we were only able to obtain AMI data for 58% of locations and, in most cases, there were insufficient AMI data to cover the analysis period. In a few cases, the AMI data replaced the15-minute interval data that had been previously available. For other projects, the AMI data was used for review and assessment of the short term metering results rather than as the primary vehicle for estimating savings.

AMI data was not appropriate for some applications. There were many projects were the magnitude of the savings was lost in the noise of the facility as a whole. For instance, an attempt to augment truncated equipment metering with AMI data failed as the signal from the equipment was only a small fraction of the changes in energy intensity across 15 minute periods. Also, within a facility, multiple pieces of equipment operating on the same schedule may have an AMI usage profile consistent one larger device . For instance, a supermarket might have multiple refrigeration compressors that are the same size and it would not be feasible to differentiate one from another in the AMI data.

The sections below discuss the use of AMI data for two separate analyses: 1) a large multifamily building with HVAC heat pumps, and 2) 24 single family homes with domestic hot water (DHW) fuel switching, i.e., the electric DHW tank was removed and replaced with a DHW tank that uses a different fuel, usually natural gas. These data were used in a number of ways:

1. to estimate the peak savings for heat pumps in both heating and cooling mode
2. to assess the overall load shape of the electric use at the sites
3. to develop a load profile for electric DHW use
4. to identify data signatures associated with other specific residential end uses

Additional detail is provided below.

Multifamily Building Load Shape Analysis

AMI data was obtained for a large multifamily project with heat pumps installed for cooling and supplemental space heating. Eighteen months of AMI data was available for 52 units in the gas heated building. The alternative to AMI data for the building would have been to meter a smaller sample of the units; obtaining metered data for both the heating and cooling season would have required two separate metering periods and only a sample of the units would have been metered to stay within budget parameters.

Part of the initial analysis was to develop monthly load profiles for the units. AMI data provides evaluators and other professionals the ability to create 15 minute load shapes for individual accounts, specific time periods, populations of accounts and combinations of factors. The ability to create these load shapes represents a powerful tool for understanding and presenting results as well as deriving additional insights from an analysis.

The graphs in Figure 1 show the weekday load profile for four months in 2014 for the multifamily apartments. The months show a fairly consistent pattern all year, with a peak in use starting slightly after 5 AM and the lowest use between midnight and 5 AM. A schedule where most of the residents are working a first shift or regular business day would result in this type of shape absent large heating or cooling loads.

The dashed lines on the charts show the ISO-NE summer and winter peaks and it can be seen that the highest use in these apartments (in all months) is coincident with the winter peak. Although there is increased use in the summer throughout most of the day, likely due to cooling, the peak loads still occur after 5pm when residents return home from work, possibly turn the air conditioning on, but also turn on lights and other appliances or electronics. The pattern clearly indicates that time of day is an important component in verifying savings for the ISO-NE peak periods.

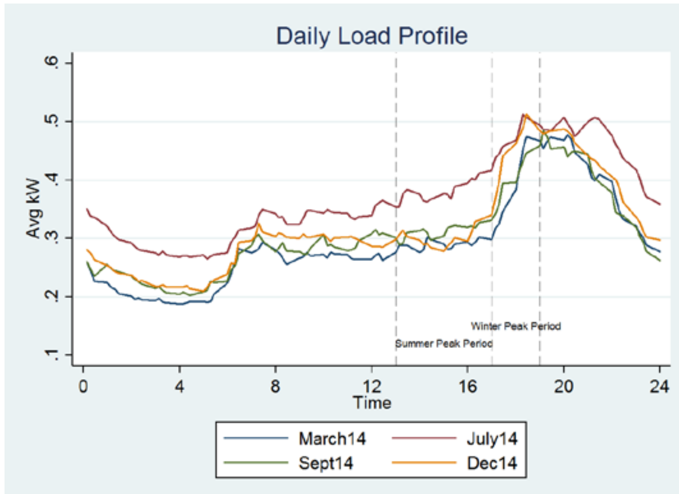

Figure 1. Fifteen Minute Average Weekday Use for March, July, September, and December 2014

Multifamily Building Heat Pump Analysis

Previous analysis of cooling load savings using AMI data has been done in California and showed clear daily savings patterns. (Metoyer & Dzvova 2014) In Vermont, the granularity of AMI data allowed for the regression model to be based on weekday heating and cooling peak hours, enabling us to fully understand the operational characteristics of the apartment during the ISO-NE peak periods. The AMI dataset included over 6.5 million 15 minute consumption records. To evaluate the usage of the installed heat pumps, the data set was collapsed to one record per hour. Collapsing the data allowed the evaluators to correlate to available temperature data from the local weather station.

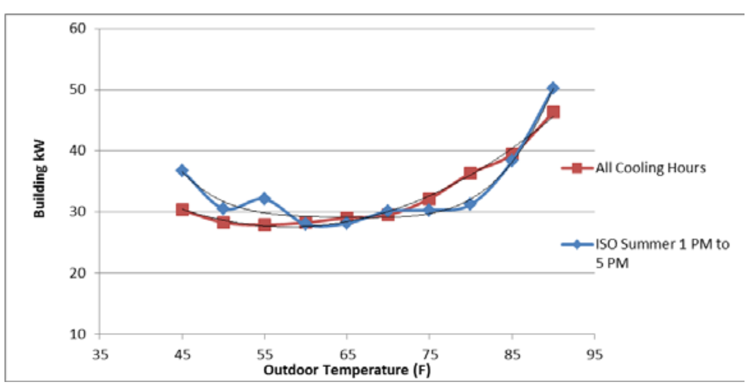

Figure 2. Heat Pump Cooling kW by Temperature Bin

As can be seen in Figure 2 above, when all hours of building operation are included, the building load begins increasing when the outdoor temperature is between 70° and 75°F. All cooling hours include weekends and evenings when one would expect higher occupancy. During the ISO-NE summer peak period, air conditioning (AC) use is also clearly occurring, however the AC load does not start to increase greatly until outdoor temperatures reach 80°F, suggesting that residents are more likely to use the AC during nonpeak hours at relatively moderate temperatures and thermostat set points are higher during the ISO-NE summer peak hours. At very high temperatures (~90°), the total building load is about 8% higher (50 kW) on weekday afternoons than in the dataset that includes all hours (~46 kW).

The AMI data allows us to identify this consumption pattern but, as with any billing data, does not explain the reasons for the pattern. The increased load at high temperatures could be caused by the heat pumps cycling more due to increased latent heat or residents arriving home early on very hot days. The important point is that the AMI data provides evaluators with the means to quantify these important time and temperature effects.

A similar analysis was performed for the ISO-NE winter peak hours for heating related use. The primary heat for these apartments however, is natural gas, so the results are quite different and more difficult to interpret.

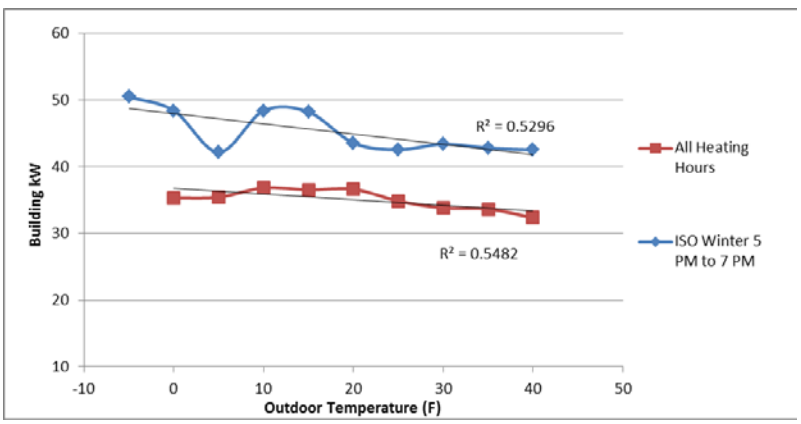

Figure 3. Heat Pump Heating kW by Temperature Bin

In the Figure 3, All Heating Hours (red line) include all hourly data through the heating season and shows a relatively flat load that has little dependence on temperature. Building demand only increases by 3kW for all 52 units as the temperature goes from 40˚F to 0˚F which is less than 60W per unit or constant use of one 60W incandescent light bulb. During the ISO winter peak period of 5 PM to 7 PM, consumption does show some variation, but there is little temperature dependency except perhaps at the very coldest temperatures. It seems possible that there is some heat pump use for comfort in this time frame, but it is likely minimal as the overall magnitude of the change is slightly over 150W per unit.

Using AMI data for this analysis allowed the evaluation to account for how the heat pumps are being operated during the ISO-NE peak hours. From an FCM perspective, the results are a more reliable estimate of the efficiency benefits realized by the grid than would have been possible through metering of a sample of apartments.

Domestic Hot Water Fuel Switch Load Profile

AMI data can also be used to derive site or population specific load shapes for individual end uses. The graphs in Figure 5 were created from AMI data from 24 homes where electric DHW was converted to an alternative fuel, typically natural gas. The AMI data allowed the creation of load profiles based on 15 minute increments for weekday, non-holiday usage and aggregated over all 24 homes. The graph on the left is the pre-conversion daily profile compared to the post conversion daily profile. Hot water use in this population clearly ramps up from the early morning hours, peaks around 8AM and trails off until late afternoon when there is again a spike in use the trails off until midnight. There is very little use between midnight and 5AM.

The graph on the right is the result of subtracting the post use from the pre-use. The result is a load profile of the savings from removing the electric DHW. It is interesting to note that, due to the diversification in use across even this small population, the savings profile for the population never reaches the 1.5 kW that an individual water heater element may draw.

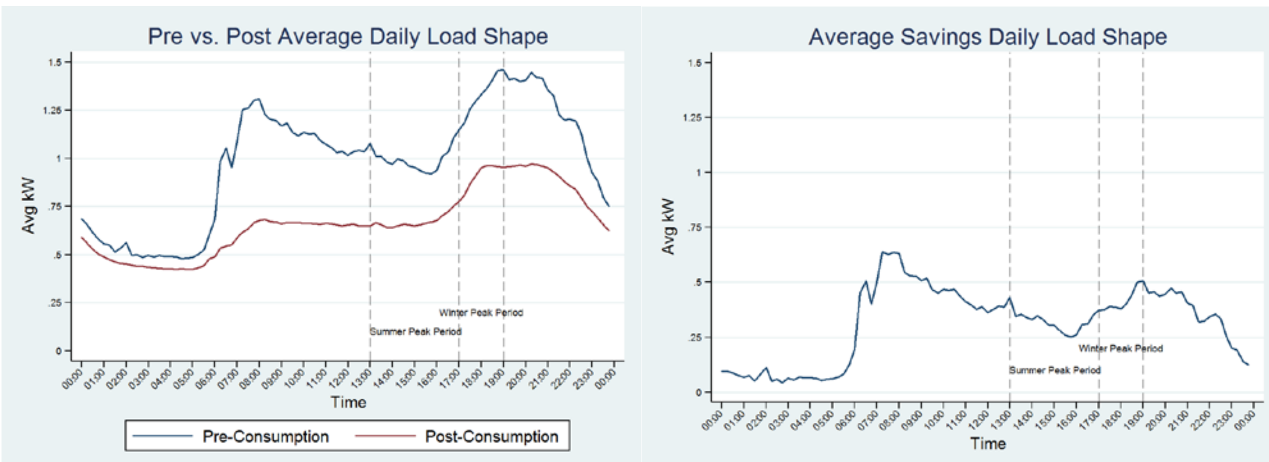

Figure 4. DHW Load Shapes

The dashed vertical lines in each profile bound the ISO-NE summer and winter peak hours respectively. Based on the time-of-day differences, it is apparent from the combined profile that the average peak kW reduction during the ISO-NE winter peak is higher in magnitude than the reduction during the summer peak period as the highest afternoon kW draw (summer peak) is just slightly than the lowest kW during the evening hours of 5 to 7PM (winter peak). While DHW use may vary seasonally, these variations would not be expected to be substantial, unlike heating loads. More detailed monthly profiles could be developed to investigate seasonal variations.

Identifying Residential End Uses

AMI data provides a sufficiently robust data set, allowing other analysis strategies beyond regression techniques that may provide meaningful information regarding energy consumption. We were able to identify the magnitude of kW draw and the turn on and off times for a number of residential end uses from the AMI data of the 52 multi-family units. The analysis required several steps. First the data were collapsed so that one record existed for every change in energy intensity (drop or increase in kW) recorded by the meter. The primary data points in the resulting data set consist of a time stamp, duration of the usage level and the increase or decrease in energy intensity.

Trend analysis shows a clear pairing of increases and decreases in energy use with a large clustering of usage change occurring at less than 100 W (Figure 5) over a 16 month period. There were additional intensity changes that occurred very infrequently and were removed from the charts as they likely represent periods where multiple devices started or stopped.

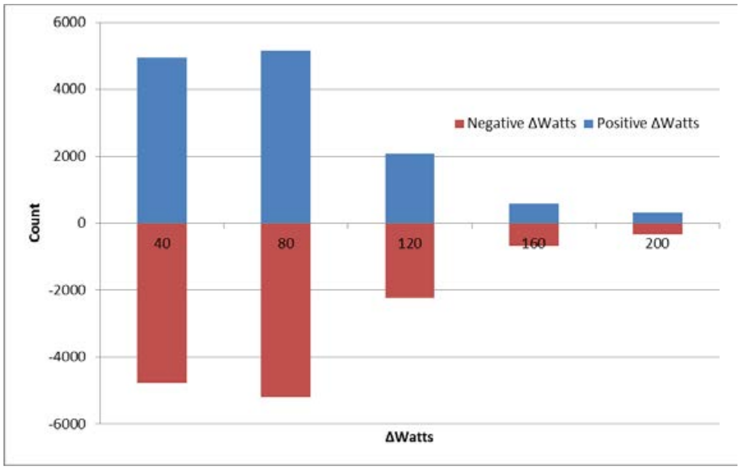

Figure 5. Frequency of Low Level Watt Intensity Changes

Figure 5 shows a very high frequency of paired 40W and 80W changes in energy intensity. According to project documentation, the apartments have automatic ventilation fans that operate 20 minutes every hour at two different levels. A close examination of the data indicates that the 40W and 80W changes in energy intensity are likely due to these fans and the timing of use can be identified in the AMI data: a clear demonstration that AMI data combined with additional information about electrical devices can be used to identify patterns of use at the device level.

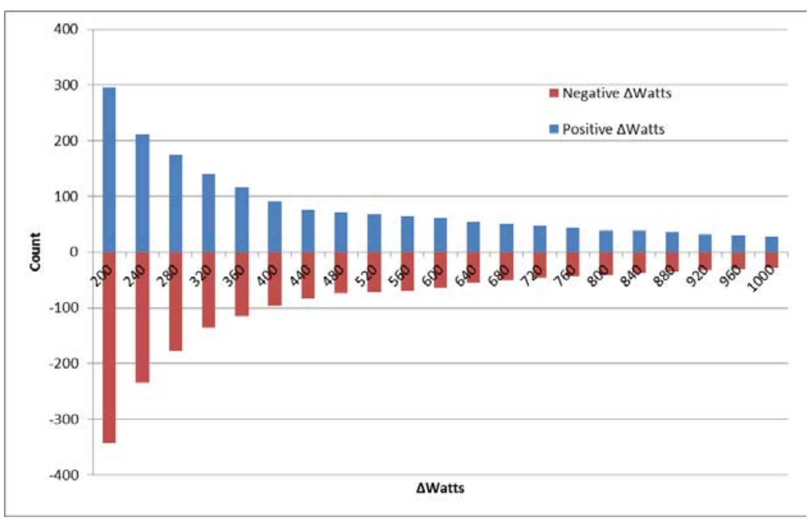

Figure 6. Frequency of Higher Level Watt Intensity Changes

Figure 6 above provides the same frequency data as Figure 5 for kW changes from 200 to 1000 W, with increasing Wattage from the left to right. Again, changes that only occurred infrequently were excluded. There continues to be a clear matching between increases and decreases in energy intensity that indicate the changes are due to the same devices starting and stopping. This graph shows a clear and consistent pattern of higher frequency for lower kW changes and lower frequency for higher kW changes. This result implies that there is less cycling for devices with a higher kW draw, which is an unexpected finding that warrants further investigation.

The paired data shown in Figures 5 and 6 includes 94.3% of all the data points and 97.7% of data points with a change of 1 kW or less. The clear pairing of relatively equal numbers of increases and decreases in magnitude indicates that these pairings are likely individual items within the residences. It should be possible to identify these items with some additional information regarding the stock of appliances and electronics within a home and compute the energy consumption for all of the homes subcomponents.

To test this theory, we collected some 15 minute data from a home where we knew some of the major equipment and when it was being used. In the graph below, the two red circles are times when the warm air furnace is cycling and it shows in the data as increases and decreases of two magnitudes, one for the fan and one for the burner. In contrast the area circled in blue is the time period when an electric car is being charged. The pattern is flatter with only small variation in energy intensity. The high spikes can be attributed to the occupants arriving home, turning up the heat and using the microwave to make dinner.

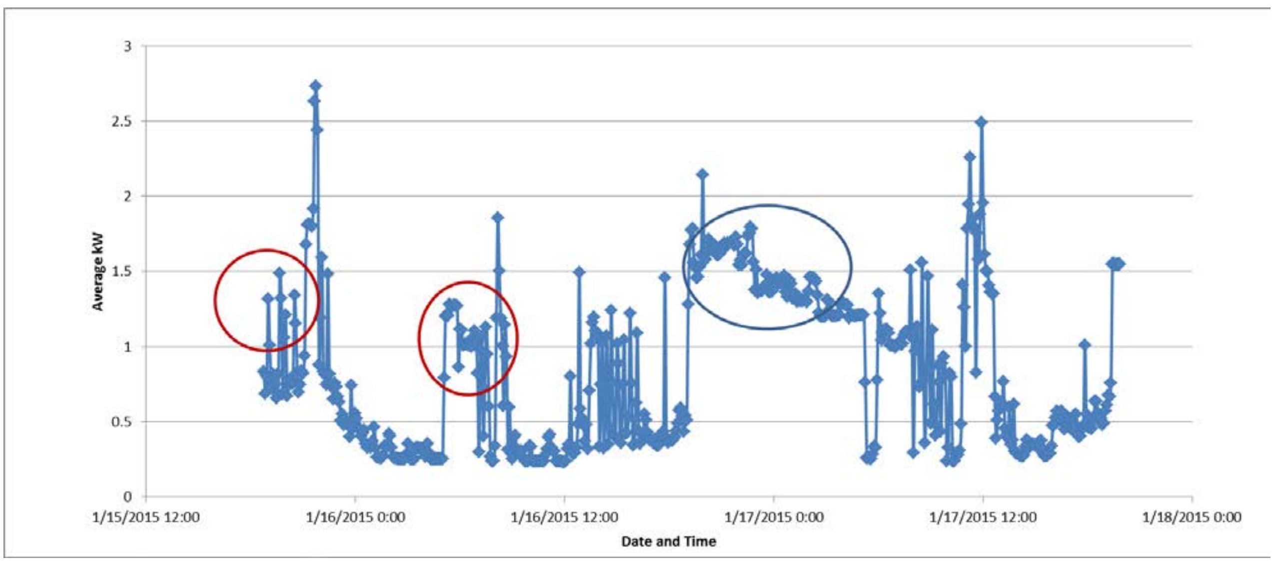

Figure 7. AMI Data Coupled with Site Specific Information

The analysis suggests that a combination of AMI and survey data could create a powerful tool for developing a deeper understanding of residential energy consumption. While the data shown in Figure 7 was from in-home metering, this same information is now available from most of the residential homes in Vermont. Combining the currently available AMI data with a residential telephone survey could provide a rich data set that would allow us to identify the data signals and improve our strategies for analyzing residential time-of-day use. Additionally, fuzzy logic could be used to derive a probability of a data signal being associated with a particular device based on its operating parameters.

Conclusion

The creation of a 'smart' grid and the widespread adoption of AMI create a rich new data source for evaluators. Utilizing this data, particularly in combination with on-site or survey data, provides evaluators the opportunity to improve the savings estimates. The powerful mix of 15-minute consumption data with direct information about end uses and operating conditions can greatly expand the tool box and allow the use of analysis methods that were previously available only for very large industrial sites.

Access to AMI data has turned out to be more complicated than expected. While widespread deployment of the AMI technology suggests the equally widespread availability of the data, there may be a steep learning curve to bridge the gap. Utilities found that providing AMI data required a substantial time investment and the volume of data is extensive for both utilities and evaluators to manage. In addition, the regulatory framework will dictate whether explicit permission from each customer will be required to release the AMI data, which could greatly increase the transaction costs of obtaining the AMI data. Going forward, the evaluation community may need to learn to use the standardized web based protocols, such as Green Button, and work directly with programs and participants to tap into this data source.

The availability of AMI data also raises issues of data access and security that will need to be addressed. Schedules and the presence of specific end uses can be gleaned from this data. In this paper, we used only aggregated data to help anonymize the data. As an industry, addressing the issues around data access and security proactively will allow us to maximize the benefits of AMI data from an evaluation perspective.

Despite these potential hurdles, AMI data can provide evaluators with new and more precise tools. It greatly increases our ability to identify when savings are occurring, which is particularly relevant in the context of the recent focus on quantifying savings during specific times of day. For C&I projects, AMI data could reduce evaluation costs where whole facility modeling is appropriate and also provide a cross check of results derived by other means. At least in the case of measures that are a large share of the overall load, it is possible to use the data to generate load shapes for specific equipment.

Impacts in the residential sector have the potential to be even more substantial. Prior to the availability of AMI data, the high cost of collecting load shape information in the residential sector severely limited the options for developing residential load shapes by end use. AMI data coupled with survey data holds the promise to allow detailed analysis of many of the appliances and electronics in a home or business. The analysis completed to date shows clear signals in the data of devices turning on and off. Developing a granular understanding of the data signal from residential devices could lead to new evaluation methods in this sector.

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