End-Use Data Development: It's Time to Better Understand our Customers

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Table of Contents

EXECUTIVE SUMMARY

The world of *big data* and its promised opportunities could not have come soon enough. Utility planners have always needed, but never really had, detailed end-use data to help them understand how various customers contribute to the overall profile. Accurate and robust end-use data can benefit utility activities across the value chain. The information is invaluable for energy efficiency program design and evaluation, demand response planning and evaluation, load forecasting, integrated resource planning, generation resource acquisition, transmission and distribution planning, transformer load management, rates and regulatory policy, marketing, and customer service operations.

The end-use data that is currently available is inadequate and incapable of capturing the customer-to-customer variation inherent in actual end-use energy use. Modelled data provides a useful starting point; however, we believe that only metered data captures the true variability inherent in actual consumption.

Capturing end-use data is complex, often intrusive, and expensive to collect. One challenge is to ensure that data are valid and robust while being cost-effectively collected. A well-designed and leveraged end-use metering strategy is the best vehicle for obtaining representative consumption patterns at an hourly level. It is also important to collect data over a significant time period.

There are many ways to collect and develop data, from statistical disaggregation and modeling approaches to integrated sampling using conventional or advanced metering techniques. Each approach has its own set of pros and cons. DNV GL believes that the most effective strategy is to match the approach with the utility's overall objectives, likely linking several strategies in an integrated framework.

Given the complexity of this effort, any end-use business model must be extremely cost-efficient and supported by multiple users. It must also take advantage of the hardware, software and methodology improvements that have been developed in the past 20 years. Adding validated energy consumption simulation models of every building in the sample would greatly enhance data transferability and usability.

We believe that any national effort must start at the regional level in order to effectively capture the localized building characteristics and HVAC requirements in the region. The key is to start small by working a proof of concept with one or more utility partners in the region or regions of interest. DNV GL is seeking interested partners to help the industry gain a better understanding of this most fundamental component, the customer. We are driven by our vision of an industry rich in meaningful data and insight on how and when consumers are using electricity.

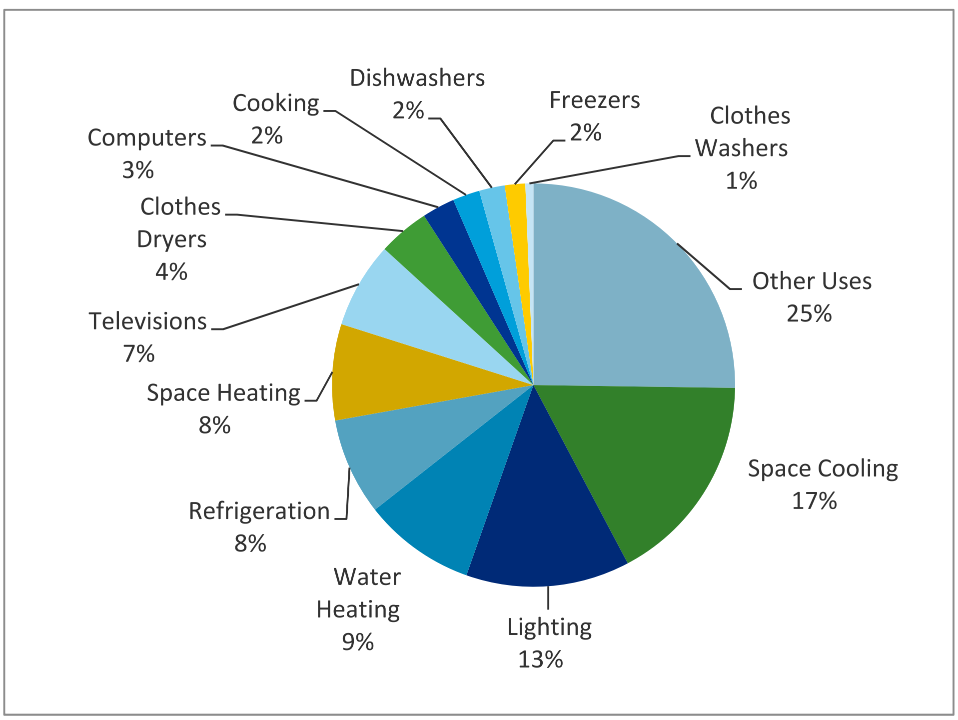
INTRODUCTION

End-use information refers to the energy and demand characteristics that separate the customers' total household or facility energy into the various end-use components (Figure 1).

As an industry, we are moving to a much more time-differentiated planning horizon where loads and costs vary hourly. The utility planner needs detailed end-use data to understand how the various components contribute to the overall profile. End-use data benefits numerous utility activities from forecasting and planning to program design and pricing. Despite the range of applications and potential benefits, data collection and dissemination has stagnated.

This white paper explores the need for more-descriptive information and the strategies that could move us from an industry of *have not's* to an industry of *haves*. The challenge is to effectively combine the interval load data available through the automated metering infrastructure (AMI) with innovative data collection and analyses strategies to provide sufficient detail for effective business planning and decision making. This includes answering the question: How good is good enough? This paper suggests a framework for cost-effective strategies for understanding in detail how the customer uses energy.

Figure 1 Average Residential Electricity Consumption by End-Use
(Source: EIA Annual Energy Outlook)



HOW CAN UTILITIES APPLY END-USE DATA?

End-use data benefits numerous utility activities, including program design and evaluation, load forecasting and management, rates and pricing, transmission and distribution planning, integrated resource planning, marketing, and customer service operations.

Energy Efficiency and Demand Response. End-use load shape data can be used in several aspects of energy efficiency (EE) program design, monitoring and evaluation, including:

- Estimating hourly program impacts, by end-use, customer class and/or market segment
- Demand-side resource planning studies of benefits and costs, based on hourly impacts on the system load shape
- Program evaluation studies of realized impacts from programs up and running in the field
- Ex-post benefit/cost studies based on measured savings over season, monthly, daily and hourly load intervals

End-use load data is a critical input in managing and estimating the impacts from demand response (DR) programs, most notably calculating peak hour/interval impacts[1]. Accurate and up-to-date interval load data, including data collected on equipment and appliances controlled by the program, are key to determining the Customer Baseline Load (CBL) that serves as the reference load profile for DR curtailment periods. Examples of this equipment include:

- Electric Water Heating
- Pool pumps
- AC Cycling
- Lighting systems controls (commercial buildings)
- Motors and drives (industrial loads on curtailment)

Load Forecasting. A utility can use detailed end-use data to develop end-use load forecasts. In turn, the utility can use these forecasts to assess the impacts of changes in customer load resulting from downstream changes in standards (e.g., continued improvements in the efficiency of HVAC equipment), increases in future program participation (e.g., increasing weatherization incentives result in accelerated participation) or technology change-outs (e.g., replacing conventional water heating with heat-pump water heating). The load forecaster can use the data to isolate and measure weather-driven changes in load, separated from other non-weather sensitive end uses/equipment categories.

Rates and Pricing. End-use load data is used for rate and tariff design. Time-of-use (TOU) rates are typically designed based on hourly load profiles collected from representative samples of customers and/or end uses. For example, hourly household load shapes are a minimum requirement to design a TOU rate targeting electric heat or electric vehicles. Custom rates designed around specific energy-efficient technologies (e.g. high efficiency electric heat pumps or

[1] Peak demand impacts are most-often measured in 15-minute intervals, but can also be monitored at 5-minute time intervals within a 60-minute window.

electric vehicles) benefit from end-use-specific hourly load profiles, which allow the analyst to better understand the amount of energy consumed in specific periods.

Such data is used to estimate the impacts of introducing TOU rates, as well as rate and tariff design derived from cost of service studies. Since many costs to serve electric load vary widely by time-of-use, end-use and class-level load data is often used in the allocation of costs to serve. Time-differentiated rates and tariffs are derived from this set of cost allocations.

Transmission and Distribution Planning. Interval load data is used to determine capital requirements and investments for a wide range of system-level investments. To size distribution feeders serving a small geographic location, a planner will need estimates of peak hourly loads, which are typically driven and/or correlated closely with major end-use loads (e.g. AC/Heating). The growth of conservation voltage reduction (CVR) load reduction measures is adding to the need for interval load data at the substation/feeder level. Information about the end-use loading of appliances will help planners to size distribution transformers.

Resource Acquisition and Integrated Resource Planning. Most resource acquisition and integrated resource planning studies require modifications to the system load shape associated with one or several competing alternative resource portfolios, each of which implies a different set of modifications to the hourly system profile. This analytical activity requires end-use level load data to properly execute.

Customer Service and Operations. End-use data can produce important insights for use when dealing with customer inquiries. Insights on how customers use energy can lead to programs of mutual benefit to both the utility and the customer helping to strengthen customer satisfication and overall customer relations. The end-use insight can be invaluable when it comes to devloping customer messaging, e.g., when hot weather is about to hit, to help stem off customer inquiries before they begin.

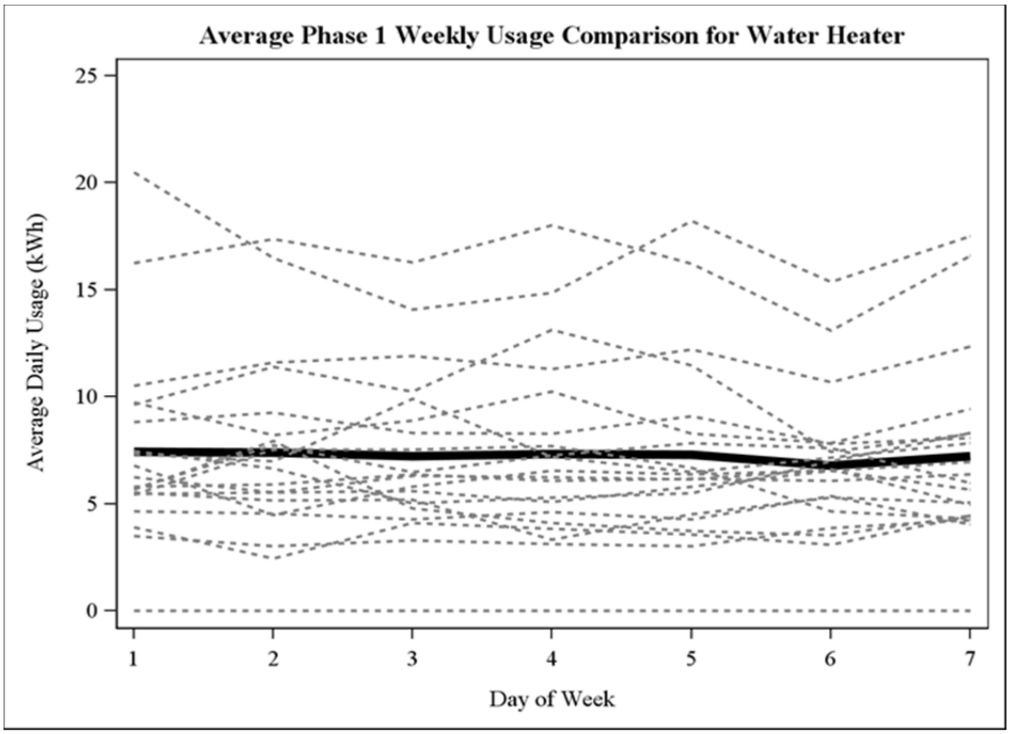
DON’T WE ALREADY HAVE END-USE INFORMATION?

The answer to this question is “kind of.” End-use information is available in various forms such as appliance saturation surveys, laboratory ratings, and modelled energy consumption, which includes some limited metered data (e.g. load shapes). But this data is inadequate and incapable of capturing the customer-to-customer variation inherent in actual end-use energy use. While modelled data provides a useful starting point, we believe that only metered data captures the true variability inherent in actual consumption.

Depending on the segmentation strategy employed, actual consumption data can be highly variable; representing both the wide variation in connected loads found in various households/buildings as well as the unique manner in which individual customers interact with those loads.

As shown in Figure 2, the water heater energy consumption is considerably variable across the sample of 20 residences. In the figure the individual customer loads are shown as dashed lines with the overall average displayed as a heavy, solid line. Individual use ranges from 3 kWh/day to more than 20 kWh/day.

Figure 2 Average Daily Water Heater Use
Source: Glasgow Electric Power Board



Many loads, such as residential refrigerators, are also quite predictable once a few basic parameters have been established. By definition, end-use metered data can capture the variation of consumption over a specified timeframe, generally in annual terms of 8,760 hourly intervals, fulfilling the expressed need for defining energy efficiency impacts on an interval by interval basis. The key challenge for any end-use data set is to capture both the high degree of variability and the predictable end-use components within an easy-to-use framework.

Existing Resources Offer a Starting Point

With regard to the availability of end-use metering data, EPRI has one of the most significant resources in the data acquired for the Center for End-Use Energy Data (CEED). Much of that data was derived from the End-use Load and Consumer Assessment Program (ELCAP[2]) and other sources (end-use data and modelling efforts from around the country). However, ELCAP data was collected in 1980s through the early 1990s, and included sites from Washington, Oregon, Idaho, and Western Montana. Of primary concern is that much of the data and energy utilization intensities of HVAC equipment and appliances have changed dramatically over the last 20 years.

Other large scale end-use metering efforts have included the Sierra Pacific Power Company's (SPPC) comprehensive Energy Information Project (EIP) conducted in the mid-1980s on single

[2] End-use Load and Consumer Assessment Program (ELCAP) is also known as the End-use Load and Conservation Assessment Program and the Regional End-use Monitoring Program or REMP.

family and multi-family residential and selected commercial segments. PowerSouth's (formerly Alabama Electric Cooperative) residential-marketing oriented end-use metering project from 2003 through 2005 examined residential water heating and a wide array of HVAC systems. Two other recent efforts include a commercial unitary HVAC study and a commercial lighting end-use data development project completed by the Northeast Energy Efficiency Partnership (NEEP).

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Most other recent end-use metering activities have been conducted as part of demand response or energy efficiency evaluation projects and tend to be projects with relatively small, localized samples focused on single end uses, e.g., a sample of 100 residential air conditioners included in the XCEL Energy SaversSwitch program evaluation. Examples of other sources include California data from the DEER database or the CEC-CEUS database.

The overarching challenges are that most of these projects are narrowly focused in a single region, the data are not available outside the specific utility, or the collected data are simply too old to be of use.

WHAT IS HOLDING US BACK?

Capturing end-use data is complex, often intrusive, and expensive to collect. It is important to ensure that data are valid and robust while being cost-effectively collected. As end-use data comes from a sub-set of the overall population, it is absolutely critical to employ robust statistical sampling techniques when designing and selecting the sample. This approach includes properly defining and adequately segmenting the population. The sample must be representative of the larger population, with minimal bias and measurable precision. For example, several large end-use metering efforts have effectively used nested sampling and leveraged end-use data with whole facility data, including SPPC's EIP and the PowerSouth projects.

The samples must reflect the diversity of end-use loads and the building and usage variation found in the overall population. In addition, a useful end-use strategy should include the collection of a full range of associated population characteristics, including a database of consumption and building/occupant characteristics in an easy-to-use analytical framework.

Consumption for some end uses can be highly variable and dependent on individual consumer behavior, which poses a big challenge. Simply having the end-use device is not necessarily a good predictor of the usage of that device. Furthermore, connected loads themselves can be highly variable. Prior studies have identified residential sites with large numbers of computers, professional size ceramic kilns and semi-commercial heated and fully lit greenhouses. In the SPPC's EIP, the project team monitored all major residential end uses, except lighting, that were thought to constitute at least 10% of the total annual use of the household only to find out that they had captured approximately 50% of the annual household consumption. This meant that the remaining use came from lights and other miscellaneous plug-in appliances.

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Considering these challenges, the best vehicle for obtaining representative consumption patterns at an hourly level is well-designed and leveraged end-use metering. It is expensive and time-consuming to develop such a robust framework, but it is critical to ensure that the foundational data are accurate and the associated population characteristics are understood.

A truly useful end-use data collection project requires data collected over a significant time period, e.g., two to five years. The world is a dynamic place and no piece of equipment operates perfectly for extended time periods. Accordingly, a robust end-use business model requires a way to support data collection over time. That model must support close to real time data verification, identification of problems, problem correction, maintenance, data archiving and user support. The best way to assure accuracy and representativeness is to verify every piece of data using robust yet cost-effective methods.

A long-term end-use project requires a long-term sampling perspective. There are modelling applications like Nielson ratings and political polling that have long-term perspectives. End-use projects rarely have this perspective. Longer term sampling strategies common to other fields should certainly be considered.

A viable end-use business model requires the ability to transfer results into different climates and potentially different characteristic subsets like building size and end-use mix. This would mean that the business model would not only have the data, it would include key tools and techniques that would enable the transfer of data across climates and potentially across time.

ELCAP, perhaps the preeminent end-use metering project ever conducted, was extremely expensive, costing over $30 million dollars (in 1990 values). Bonneville Power Administration (BPA) justified the cost based on a number of factors, but principally to prevent a recurrence of forecasting errors like the one that had cost the region about $10 billion dollars in abandoned nuclear power plant construction bonds. The information and insights gained from ELCAP have been used countless times over the past three decades and, in some sense, could be considered priceless.

A new end-use project would be expensive and it would be difficult to duplicate the ELCAP justification argument. Therefore, we need to assume that any end-use business model must be extremely cost-efficient and supported by multiple users. It must also take advantage of the hardware, software and methodology improvements that have been developed in the past 20 years. Data transferability and usability would be greatly enhanced with the addition of validated energy consumption simulation models of every building in the sample; however, this is no small undertaking.

Methods for Collecting and Developing End-use Data

Statistical Approaches. Statistical approaches, in particular conditional demand analysis, have been used for years to identify the end-use loads within more aggregate data. Typically, responses from a large market saturation survey (i.e., several thousand respondents) are coupled with billing data. Statistical regression techniques are built to estimate the monthly, seasonal, or annual usage of customers with various appliances. While there is limited experience with the application of conditional demand analysis to short-time integration power-consumption data, it has the potential to provide additional end-use detail compared to traditional monthly billing data approaches.

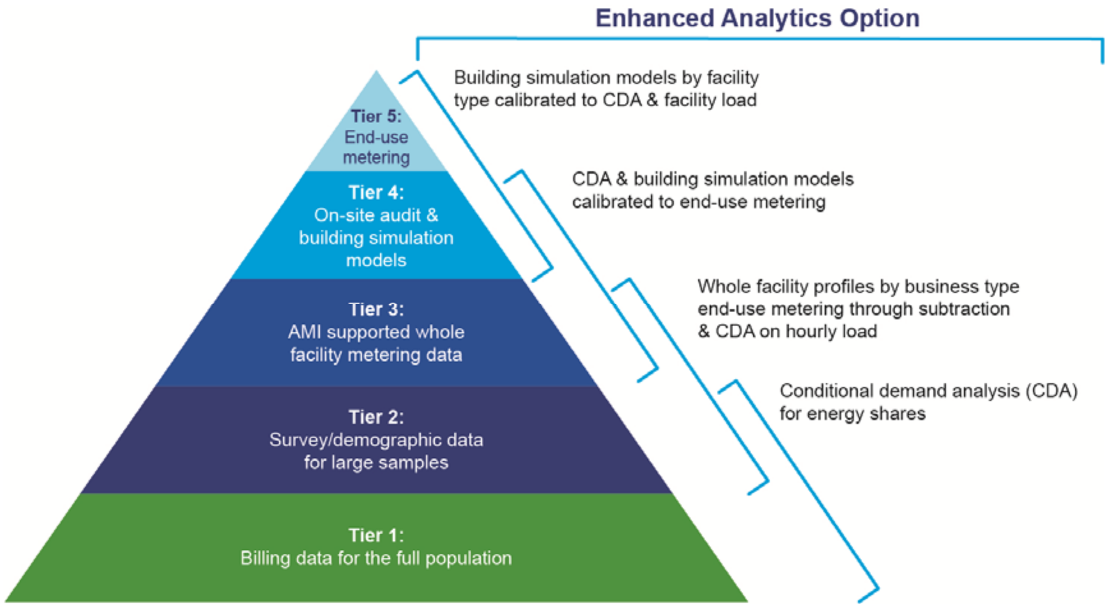
Prototype/DOE2 Engineering Simulation Modeling. When reliable end-use load data are not available, an hourly building energy simulation approach may be used to create the loads. Popular computer tools capable of hourly building load simulations include DOE2 and its user-friendly derivative (eQuest), EnergyPlus, TRNSYS, and BLAST. Currently, DOE2 is the most popular tool and used throughout the world, but EnergyPlus is gaining rapidly. One clear advantage of the DOE2 modeling approach is the ability to quickly and easily update end-use estimates by utilizing different (or updated) weather files.

Short-term Energy Efficiency Metering. Several projects have directly metered individual energy efficiency measures, such as chillers, ductless heat pumps and water heaters. Typically, these projects use direct measurements on reasonably sized samples. A limitation to the typical evaluation approach is that the metering is commonly implemented for a relatively short period of time, (i.e., one week to several months), and focuses on the energy efficiency measures in question, which may or may not be end uses of interest. There is a non-residential lighting project being conducted in the Northeast that is examining the veracity of the estimates made with short time periods, e.g., four weeks, with longer measurement periods, e.g., one year. These types of studies will provide insight into the appropriate time period needed to catch the seasonal variability of end-use loads.

Pre/Post Metering. Many projects have tried using pre/post metering to assess energy efficiency measure performance. The challenge is to get the meter installed sufficiently in advance of the equipment upgrade. There is always pressure on the evaluation not to interfere with project implementation and many of the prescriptive program designs do not lend themselves to an adequate lead time. There is currently a non-residential variable speed drive evaluation project being completed in the Northeast and a non-residential lighting controls project under consideration using pre/post metering.

Integrated Nested Sampling. Hybrid approaches that link several strategies warrant careful consideration in any future end-use metered data collection effort. Improvements in the "signal-to-noise" ratio are achieved at a greater increased cost and complexity. Figure 3 presents one possible construct.

Figure 3 Enhanced Analytics Strategy



In this construct, utility customer billing data provides the foundation. The second tier could be a large demographic survey that is conducted to better characterize and segment the general population. This step creates specific categories for further development. For example, the residential market may be segmented by dwelling type, e.g., single family, multi-family and manufactured homes. Other supporting information could be used to filter out low-income or financially-assisted consumers, energy efficiency or demand response program participants, etc. With AMI and the proliferation of smart meters, the third tier could become hourly (or 15-minute) whole-premise metering data. This would allow interval load profiling of the various segments and provide the foundation of a first order estimate[3] of some selected end-use loads.

The fourth tier would be the development of building simulation models for selected segments supported by the collection of detailed on-site audit data. The building simulation models provide a way to simulate the end-use loads and to run a host of *what if* scenarios (e.g., What if weatherization levels were increased?). Building simulation models may provide the best strategy for developing detailed estimates of energy efficiency measures.

The top tier is detailed end-use metering, which could be broadly defined to *stand on its own* or more narrowly defined helping to calibrate one or more element of the building simulation model. Each of these analytical layers provide elements to meet our overall needs as we proceed up the pyramid and can be linked statistically through nested sampling so that the highest point of inference is the actual end-use metering data, which has the best signal-to-noise ratio (or precision of estimate).

[3] Simple subtraction algorithms could be used on segments of like customers with and without a particular end-use, e.g., central air conditioning. Alternatively end-use profiles could be developed just from customers with a particular end-use by subtracting non-weather sensitive load profile from the weather sensitive profiles, i.e., a moderate spring/fall day from a hot summer day.

Conditional Demand Analysis. Conditional Demand Analysis (CDA) may be considered a hybrid approach wherein statistical measurement methods are applied to load data, informed by engineering relationship defining one or more end-uses. In some instances, CDA provides a low-cost alternative to end-use load data metering through the disaggregation of system or class-level load data into major end-use load profiles.

CDA also provides a bridge or mechanism for leveraging end-use load data from secondary sources, which can be reconciled or (re-)calibrated to aggregate load profile data for the native system. Such techniques depend heavily on the ability of the model to accurately true-up secondary end-use data to load profiles for the target area(s).[4]

The principles underlying CDA are best represented by the following equation description:

EQ1) **Total Metered Energy Use** $_{\textbf{[Customer – I, Period-t]}}$ **=**

$\boldsymbol{\Sigma}^{\textbf{All-j}}$ **(End Use – j)** $_{\textbf{[\textit{Customer –I}, Period-t]}}$ *for each Customer-i*

Where - **j** represents the set of energy-using end-uses, for *customer* (or premise) – **i**.

The focus of CDA methods is the estimation of a mean parameter value, or estimate, for each (End Use – j), in the above, most often using a sample(s) of premise level data:

EQ2) **(End Use – j) =** $\boldsymbol{\alpha_j + \beta 1_j}$***(Attribute 1 of j) +……+** $\boldsymbol{\beta N_j}$***(Attribute N of j)**

For households, end uses represent the stock of appliance holdings (e.g. refrigerators, freezers, dishwashers, clothes washing/drying), and energy systems distinguished by fuel types (e.g. HVAC and water heating). For commercial buildings and facilities, energy consumption by end-use, is often measured by *energy use intensity per square foot*, or end use *EUI* (lighting, HVAC, water heating, refrigeration, cooking, computer use, etc.), also distinguished by fuel type(s).

In EQ2 above, this translates into the number of parameters and attribute variables required to accurately define the energy utilization properties of each **(End Use – j)**. For example, lighting end use (=j), may only require one attribute variable (hours of use during *time-t*), such that **β1** in EQ2 above, would define the mean value for average lighting wattage in-use by *customer – i, over period – t*. By contrast, EQ2 for an HVAC end-use technology, may require multiple attribute variables (*multiple js*), including weather conditions, building hours of operation, square footage, thermal properties and other attributes most often represented by more complex engineering relations defining heating/ventilation/air conditioning system loads.

It is also worth noting that CDA methods and models can be structured and applied to metered usage data measured over almost any time period, limited only by the requirement that *time-t* be represented in the same units (annual, monthly, daily, hourly etc.), on both sides of *EQ1*.

Traditional Metering. Traditional approaches involve installing a load recording device directly on the load(s) of interest. This form of data collection is very customer intrusive; it requires access to the customer’s facility/home to install the monitoring devices on the appliance or

[4] Statistical theory and principles play a large role in CDA in both defining the modeling framework (ex ante) and assessing the statistical precision and validity of the results (ex post).

circuit. Cost of the traditional approach was high, which often limited the sample size; however, data quality and the signal-to-noise ratio[5] were also very high.

Advanced Metering. New metering technology may overcome traditional obstacles to residential end-use data collection. The Single Point End-use Energy Disaggregation (SPEED) and Non-Intrusive Load Monitoring (NILM) devices permit the collection of a multitude of appliance end-use loads without the wiring nightmares of past years. These hardware/software systems purport to allow for the collection of appliance-specific load data without entering customer premises and without installing metering devices on appliances. The analysis software seeks to recognize appliance signatures in the data. For example, an electric water heater with a 3,500 Watt heating element would look significantly different than a 100 Watt light bulb. However, when appliances have relatively similar electric signatures the ability of the software to distinguish between 3,500 Watt water heater element and a 3,500 Watt stove burner is somewhat suspect.

Supporting Information. An end-use metering project needs to effectively leverage other supporting information, such as:

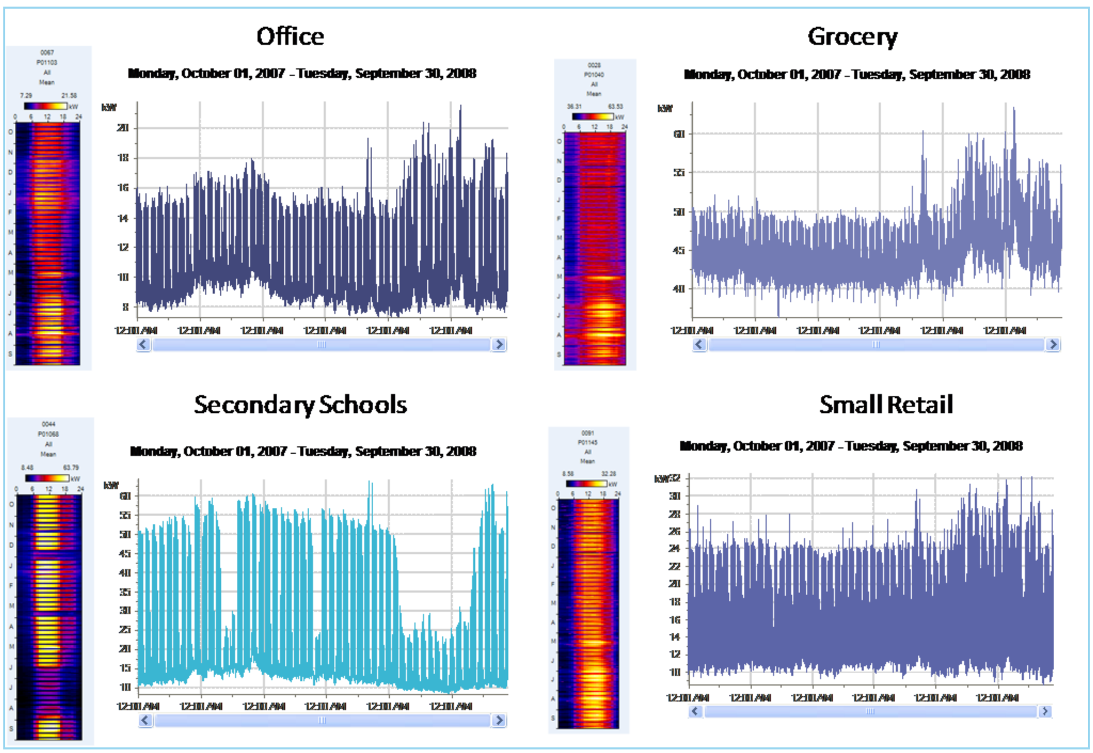
- Utility billing records
- System SCADA and delivery point load information
- Whole facility metering collected by the utility for pricing, load research or automated metering infrastructure
- Hourly weather data from the utility or NOAA Class A weather stations
- Appliance saturation surveys collected in the residential and non-residential markets
- Energy efficiency tracking system databases
- External data sources including Google Earth
- External purchased datasets, e.g., Epsilon, Harte Hanks, D&B, InfoUSA, CoStar, etc.
- Laboratory ratings and manufacturer specifications
- Modelled energy consumption through EIA and other organizations
- Modelled interval load data from third-party or consulting organizations

As an example, whole facility metering information coupled with utility billing data and information on the specific type of facility can be used to generate average load profiles for specific domains of interest. Portland General Electric has been developing market segment load shapes using statistical techniques for several years.

[5] In this context, the signal-to-noise ratio” refers to how well the end-use load is isolated from other household loads.

Figure 4 presents an example of the type of information generated by combining several sources of information. The figure presents four segments, office, grocery, secondary schools and small retail. One year of hourly data are presented in two forms. First, a vertical EnergyPrint is presented that shows time on the x-axis, day of the year on the y-axis, and the magnitude of load is shown in a color gradient with low levels of load in the black-blue spectrum and high levels of load in the yellow-white spectrum. The data starts on October 1, 2007 and ends on September 30, 2008. The two-dimensional graph simply shows the hourly load profile in a condensed form. The secondary school segment show the winter holiday and summer shut downs. The office, grocery and retail all show some summer sensitivity. These data can be coupled with weather data to further investigate the temperature-load relationships. In addition, base and variable load levels can be established. Statistical analysis can yield first order estimates of air conditioning (or weather sensitivity) and hours of operation. Idaho Power and Portland General Electric have thousands of non-residential accounts with interval load data that have been identified by market segment.

Figure 4 Whole Facility Load Profiles by Market Segment



HOW CAN WE HELP ADVANCE THE INDUSTRY?

We believe that any national effort must start at the regional level in order to effectively capture the localized building characteristics and HVAC requirements in the region. Of course, one or more simultaneous regional efforts are possible. Utilities in the Pacific Northwest, the Southwest, the Southeast and the Northeast have expressed interest. One possible strategy is to coordinate with regional organizations like the Pacific Northwest Regional Technical Forum, the Southeast Energy Efficiency Alliance (SEEA), the Midwest Energy Efficiency Alliance (MEEA), the Northeast Energy Efficiency Partnership (NEEP)[6], or the New York State Energy and Resource Development Authority (NYSERDA). The U.S. Department of Energy and the national labs are natural partners in any regional or national effort.

We believe that working with a utility with some existing data will reveal the strengths and weaknesses of the various approaches and provide the foundational building blocks to suggest a larger, more focused project.

The key is to start small by working the proof of concept with one or more utility partners in the region or regions of interest. The proof of concept is structured to reveal the strengths and weaknesses of the various approaches and provide the foundational building blocks to suggest a larger, more focused project. To that end, the project team has held discussions with several potential partners and plans to announce an initiative to advance the industry. We are excited about the prospect of working with one or more innovative utilities to explore the right blend of data and analyses to help answer the questions: “How accurate is accurate enough?” and, “At what cost?”

Our vision is of an industry rich in meaningful data and insight on how and when consumers are using electricity. A current, national database would be invaluable in helping the industry enhance its strategic business planning and decision making processes.

This white paper is the first in a series on end-use information including:

- Glasgow Electric Power Board – Grid Smart Appliance Project
- Electric Power Research Institute – Non-Intrusive Load Monitoring
- Applications in Conditional Demand Analysis

[6] NEEP has launched several end-use data development projects in the past three years including commercial lighting, commercial unitary HVAC, and commercial refrigeration.

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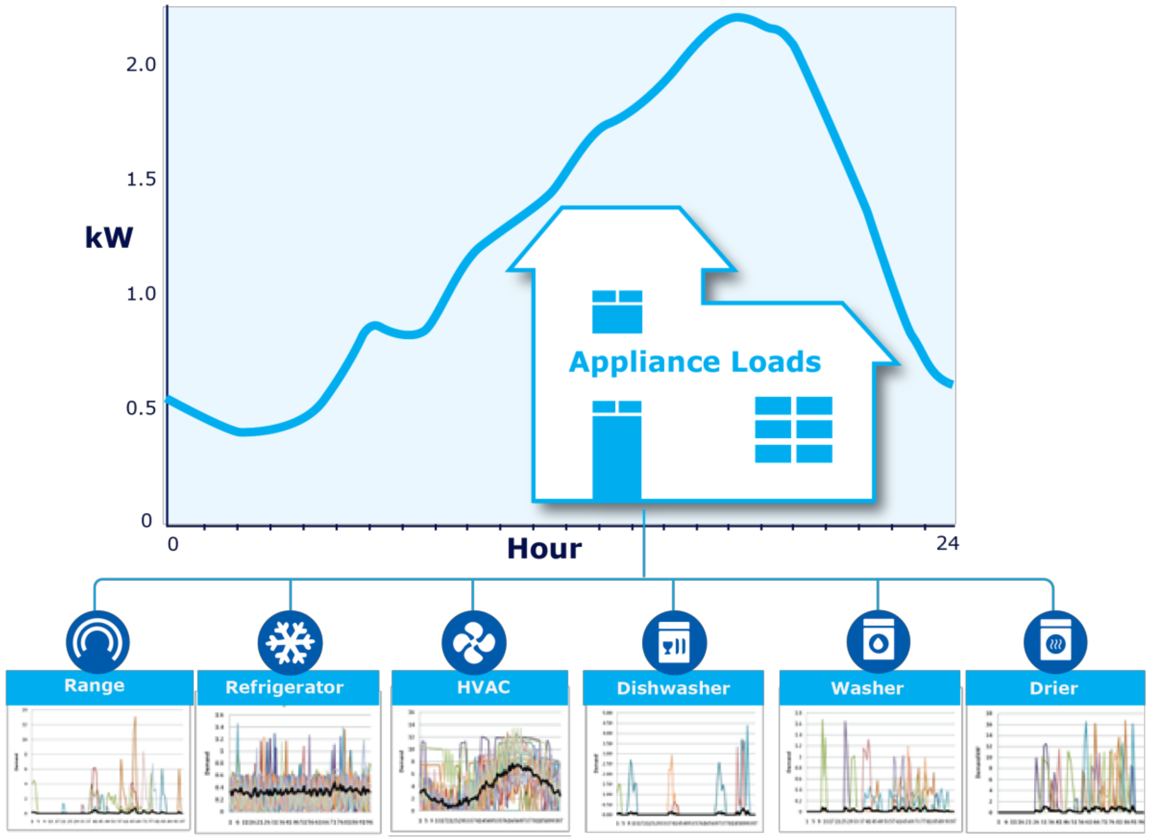
WHAT LIES BELOW THE CURVE?
WHAT OPTIONS ARE AVAILABLE TO RESEARCHERS LOOKING TO GAIN INSIGHTS ON HOUSEHOLD END-USE LOADS?

Finally! The quality of load profile data from advanced metering infrastructure systems (AMI) is sufficient to provide reliable data for advanced utility analytics. But, what if the researcher wants to get below the total premise load profile curve and understand and quantify the major household end uses that make up that total load. Possible, yes, but accomplishing this next level of investigation depends on how much funding the researcher has and what level of accuracy the researcher requires.



End-Use Load Shapes and aggregated Load Curve

Direct measurement

The first option, direct measurement is the costliest, most intrusive but, likely, the most accurate. Direct measurement has been with us a long time and typically involves instrumenting individual household appliances and major end uses with specialized metering and data logging equipment that captures energy consumption on a relatively high frequency basis—typically 15-minutes or even shorter intervals. End uses can be instrumented either at the end use itself or at the customer panel. Metering at the customer panel requires using specialized split core current transformers, and further requires the end use load to be isolated on a single circuit. You can see the problem with this option already! Although direct measurement gives the researcher the most accurate data, it is the costliest option, and can run in the ten to fifteen thousand dollars per household range. Moreover, the technology is highly intrusive and requires a high degree of interaction with the end customer.

Non-intrusive

So what's next? Well, if you have some budget for hardware and resources to install equipment, and are willing to sacrifice a little accuracy to save significant dollars, maybe you should investigate non-intrusive load monitoring (NILM). NILM technology comes to us in two flavors. The first are business to consumer products (B2C) that are designed to be installed and used by consumers looking to get a fuller understanding of their energy consumption. These technologies are designed not only to monitor end-use utilization but to act on inefficiencies via snazzy mobile apps. The mobile apps give the user the capability to control/modify specific end uses using remote control switches. At the other end of the spectrum, we have utility grade hardware and analytical software systems that are designed with the utility researcher in mind. These devices are designed to provide quality end use data at a reasonable cost.

So how does it work? Fundamentally, both the B2C and utility-grade systems rely on high frequency load measurements at the premise level that identifies and records transitions in energy consumption. In turn, these transitions or edges are stored and transmitted back to a central processing system where the data is processed using proprietary algorithms that convert the collected data into individual load shape components. The level of accuracy is very reasonable with an expectation of 80% or better on major loads. Of course, the accuracy can vary and depends on knowledge on the type of loads present and their associated patterns. The output available from the various technologies depends on the vendors sophistication in the measurement device, the intricacy of a given vendors' processing algorithms and the ability to correctly "label" a load.

B2C technologies have an edge in labeling loads as most technologies allow the end user to train the system by turning loads on and off and labeling the loads directly once the loads are recognized by the system. Utility grade systems don't have this luxury but some are using direct measurement to capture some loads, helping reduce the overall uncertainty. By definition, utility researchers use NILM technology because they don't want to go inside the consumer's home, i.e., they want to be non-intrusive. To compensate for this, utility-grade vendors give the researcher a high degree of flexibility in system configuration by providing initial reference load shape libraries that can be calibrated for a given region or household type.

Individual equipment and installation cost for a B2C device along with a specified amount of "cloud-based" data storage and a mobile application are low compared to their direct measurement counterpart. The cost for the B2C deployment ranges from a one-time fee of $200 to $300, with additional monthly fees based on selected functionality. Utility-grade systems are a bit costlier, running around $1,500 for the measurement device and additional licensing fees for the vendor's data collection and analytical software. Installation costs are dependent on whether the device is installed at the customer panel or at the utility meter where the measurement device sits between the utility meter and the customer service panel.

A new technology is emerging in the NILM category that uses harmonic signatures as the basis for identifying end uses. This technology is very promising, but unfortunately requires individual loads be turned on and off for the system to label specific loads, which makes the use of the technology somewhat more intrusive to use.

Statistical Based Algorithms

Statistical–based load disaggregation has been with us for some time now. These algorithms range from simple subtraction strategies to more sophisticated conditional demand analysis (CDA). Historically, CDA used multivariate regression models with annual energy consumption and saturation survey data as inputs to generate reasonable annual energy shares for major end uses. More recently, the availability of high frequency AMI data and powerful machine-learning algorithms have opened the possibility that a similar approach can be applied to develop end use load shapes. The clear advantage is a lower investment in hardware with a higher investment in software. Clearly, the end-use profiles provide the researcher more robust information than simple energy shares developed from annual consumption. However, the jury is still out on how well these techniques can generate accurate end use load shapes—albeit, there is some promise that using higher frequency premise level data (1-minute versus 15-minute), will provide reasonably accurate results.

The bottom line is that it all boils down to the amount of money you're willing to invest and the accuracy you require. In future blogs, we will explore work being done to combine a variety of approaches to create and end-use data development strategy that is both accurate and cost effective.

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