white paper

Impact of Energy Disaggregation on Consumer Behavior

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ABSTRACT

Energy Disaggregation is called the Holy Grail[1] of energy efficiency. You cannot improve what you cannot measure. Energy Disaggregation allows us to measure how much energy goes into each major appliance, which can be further analyzed to identify and eliminate inefficiencies. This disaggregated information has two major impacts: increased utility customer engagement and reduced energy usage. This paper highlights results from two case studies conducted in real life – one in California and the other international. The study in California, using a standard experimental methodology, shows a statistical proof of average 6.0% energy reduction in users exposed to Bidgely's Energy Disaggregation-based solution with a maximum of 7.4% and a minimum of 4.7%. The international study shows high levels of customer engagement, favorable consumer reaction and an 86% approval from users on making this solution available to all. These studies aim to support the introduction of policies that open up real time data access from smart meters. Millions of these smart meters installed in field are already equipped with the right hardware but have not been enabled to deliver the above benefits.

Introduction

While Advanced Metering Infrastructure generates operational efficiency for utilities, the societal benefits are far from reality; especially in the residential sector, where behavioral barriers exist that impede the realization of significant energy savings. Consumers, today, have *Motivators* such as neighborhood comparisons, competitions and social platforms, but lack the *Engagement Tools* to help them make informed energy saving decisions. The tools that exist are either relatively expensive or target one-time appliance-related efficiency gains only. Traditional energy dashboards present consumers with historical consumption and generalized energy saving tips, but lack specific actionable recommendations. Consequently, the energy savings delivered by these dashboards are limited to 1-2% of household consumption.

Bidgely's leading customer engagement platform allows energy distributors and retailers to increase customer satisfaction and meet energy efficiency and demand response goals. Underlying Bidgely's software is Energy Disaggregation, which itemizes a consumer's energy bill, analyzes energy use and cost for each of their household appliances, and makes truly personalized and prioritized savings recommendations – all this without any plug-level sensors or in-person audits, at a massive scale, and at a lower expense level than ever possible before.

Bidgely was engaged in two utility consumer studies in 2013 that sought to validate two key benefits of Energy Disaggregation –energy savings and customer engagement.

[1] Carrie Armel, K., et al., Is disaggregation the holy grail of energy efficiency? The case of electricity, Energy Policy (2012), http://dx.doi.org/10.1016/j.enpol.2012.08.062

a) The goal of the energy savings consumer study in California was to quantitatively and objectively estimate the savings from Energy Disaggregation.
b) The consumer engagement study was conducted across 150 homes with a leading energy retailer in an international market. The goal was to explore the possibility of using Energy Disaggregation to increase utility customer engagement and thus reduce customer attrition in a highly competitive, deregulated electricity market.

This paper introduces Energy Disaggregation and discusses the approach and results of the studies.

What is Energy Disaggregation?

Energy Disaggregation refers to a set of statistical approaches for extracting end-use and/or appliance-level data from an aggregate, or whole building, energy signal without any plug-level sensors. It is one of the most anticipated energy data analytics technologies in the residential and small commercial sector. An energy policy paper by Stanford researchers[2] calls Energy Disaggregation the "Holy Grail of Energy Efficiency" that can leverage substantial smart meter investments to deliver significant low-cost energy reductions by engaging consumers more effectively. With smart meters capturing granular data from millions of homes around the world, and the data being available through Home Area Network and Green Button initiatives, Energy Disaggregation can create a new paradigm in energy management with its non-intrusive and cost effective benefits.

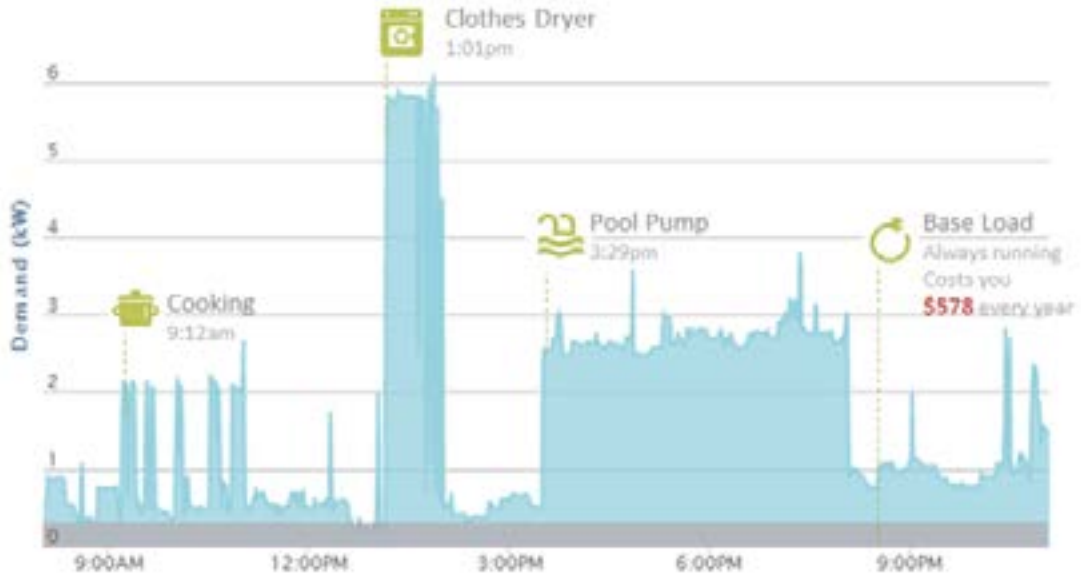


Figure 1: Appliance signature-based Energy Disaggregation

[2] Carrie Armel, K., et al., Is disaggregation the holy grail of energy efficiency? The case of electricity, Energy Policy (2012), http://dx.doi.org/10.1016/j.enpol.2012.08.062

Bidgely's approach to Energy Disaggregation is based on a non-intrusive pattern recognition technique. Every appliance when turned on or off leaves a signature on the energy waveform. Bidgely specializes in extracting those signatures using patented algorithms and machine learning systems, and presents the energy consumption by each appliance category.

Case Study 1: Behavior-based Energy Savings in California

California has one of the most advanced open energy data access utility grids in the world. With billions of dollars invested in smart meters, utility consumers can access their energy consumption data in two ways:

a) Home Area Network (HAN)
b) Green Button (GB)

Home Area Network: Every smart meter installed in California (also applicable to most smart meters across the globe) has a ZigBee radio that when turned on by the utility can communicate directly with the home. Numerous In Home Display (IHD) pilots have been performed by utilities across the globe using this interface. Most of those pilots only showed real time usage, cost, and some historic usage to the consumers. The California IOUs turned on the ZigBee radios of the smart meters in 2013, thus allowing consumers to directly access their real-time energy consumption data. The data streams every few seconds (vary from 7.5 to 30 seconds) from their smart meter.

Green Button: Thanks to a White House initiative called Green Button (www.greenbuttondata.org), utilities across the United States have been adopting a standard that allows energy consumers to either download or share their data with third parties for innovative energy management services. The data is available every 24 hours - at one-hour sampling intervals – in the consumer's utility account.

What were the goals of the Study?

Leveraging open HAN and GB data access in California, Bidgely conducted a consumer study in 2013 with the following two objectives:

a) Quantitatively and objectively estimate the energy savings of its Energy Disaggregation-based customer engagement and utility intelligence platform; and
b) Demonstrate the benefit of the smart meter HAN and GB interfaces to consumers and policy makers.

How was the data collected?

Bidgely is compatible with both HAN and GB data available from consumers' utility accounts. Both interfaces were used to collect data for study participants.

For HAN, some participants bought in-home gateway devices, while others were given free devices through a qualification survey. These in-home gateways act as bridges that stream data from the home's smart meter to remote servers every few seconds. Consumers access the cloud-based Bidgely solution using web and mobile apps.

For GB, consumers connected their utility account to Bidgely (similar to a consumer connecting their bank and credit card accounts to Mint.com for personal financial solutions). Bidgely then automatically accessed the consumer's meter data for the previous 12 months (on the first connection) and every 24 hours thereafter.

How were study participants recruited?

Participants were selected from all Bidgely account holders who met the following criteria:

a) Live in CA;
b) Live in a single family home;
c) Have and energy bill more than $50 and less than $250;
d) Were able to provide their past 12 months of pre-Bidgely usage data upon sign up;
e) Do not operate an Electric Vehicle;
f) Do not operate a Solar PV facility at their home;
g) Do not use more than 60kWh per day.

Filters (a) through (e) were applied at the time of survey. Filters (f) through (g) were applied at the time of data analysis.

How was the study designed?

The study comprised two groups - Treatment (consumer using Bidgely's solution) and Control (consumer not exposed to Bidgely) – and a rolling quasi-experimental design as depicted in Figure 2 below. Instead of assigning users to a standalone control group, historical consumption data for the treatment group was used as the control condition. For example, for users signing up and joining the treatment group in September, the previous 3 months of consumption data - July, August and September - was used as the control group data. This simplified design allowed for a statistical comparison to determine whether the treatment group participants saved more energy than those in the control group.

Recruiting		2013												2014							
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Wave 1 - Recruit July '13		h	h	h	h	h	h	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Wave 2 - Recruit Aug '13		h	h	h	h	h	h	c	x	x	x	x	x	x	x	x	x	x	x	x	x
Wave 3 - Recruit Sep '13		h	h	h	h	h	h	c	c	x	x	x	x	x	x	x	x	x	x	x	x
Wave 4 - Recruit Oct '13		h	h	h	h	h	h	c	c	c	x	x	x	x	x	x	x	x	x	x	x
Wave 5 - Recruit Nov '13		h	h	h	h	h	h	c	c	c	c	x	x	x	x	x	x	x	x	x	x
Wave 6 - Recruit Dec '13		h	h	h	h	h	h	c	c	c	c	c	x	x	x	x	x	x	x	x	x

Legend:	
Experimental condition	x
Control condition	c
Historical data	h

Figure 2: Rolling experimental study design

Statistical Calculations & Results

Figure 3 below shows user analysis from July 2013 to November 2013. Notice this is a rolling experimental design, so the number of treatment group and control group participants is changing every month. September 2013 is the best month from which to draw conclusions for this period, where both the treatment group and the control group have equal users - 135 each.

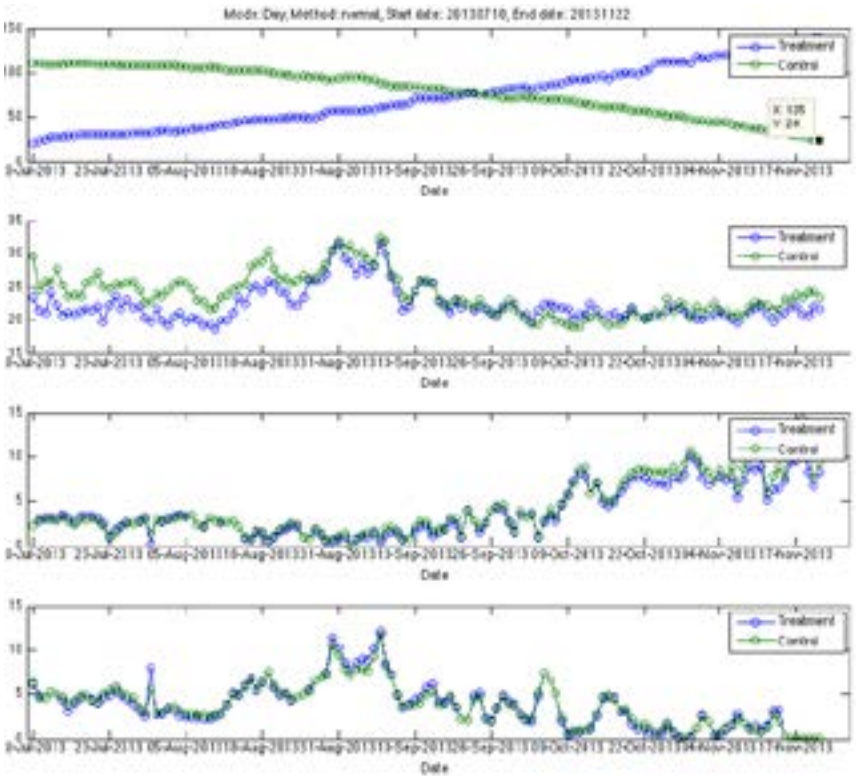


Figure 3: Comparison between control and treatment groups for number of participants, energy usage, HDD & CDD

Figure 4 below details the month of September 2013. The distribution of daily kWh consumption and boxplot show the difference in consumption between the control and treatment groups. The distribution of HDD (heating degree days) and CDD (cooling degree days) compared between the control and treatment groups show that the two groups have equal distribution and do not have any weather based systematic bias.

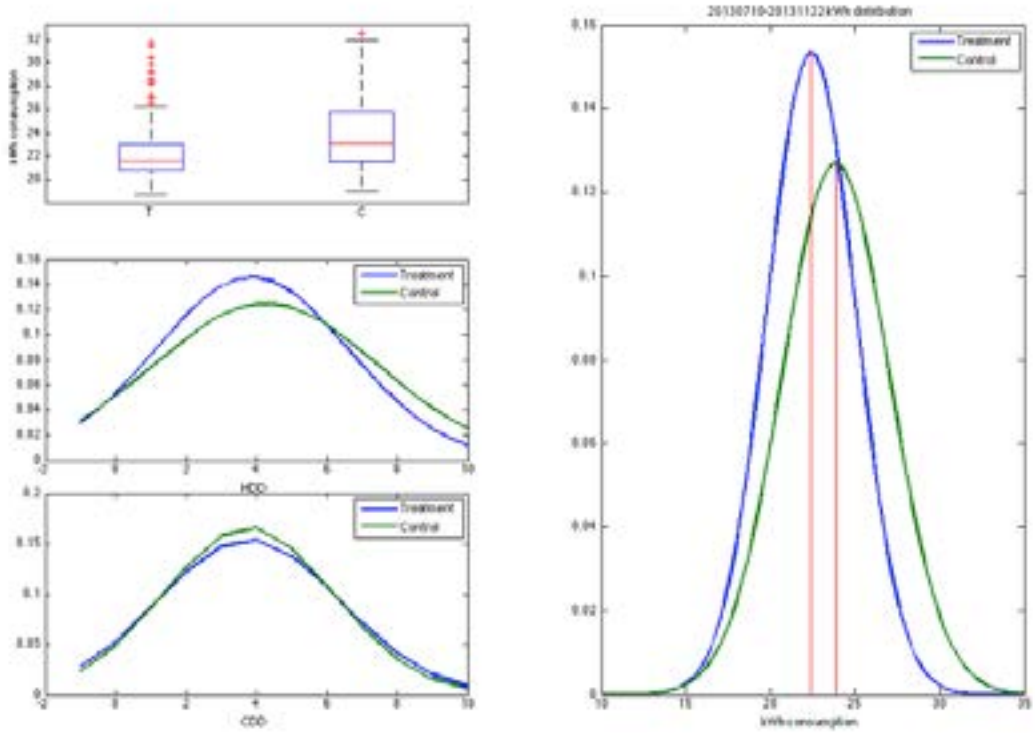


Figure 4: Energy usage (kWh) and HDD/CDD comparison between control and treatment groups for the month of September 2013

The statistical distribution of average energy consumption per day for the month of September 2013 is shown in Table 1 below.

	Control Group	**Treatment Group**
Mean	23.86267	22.41858
Standard Deviation	3.14195	2.59764
SEM	0.27041	0.22356
Number	135	135

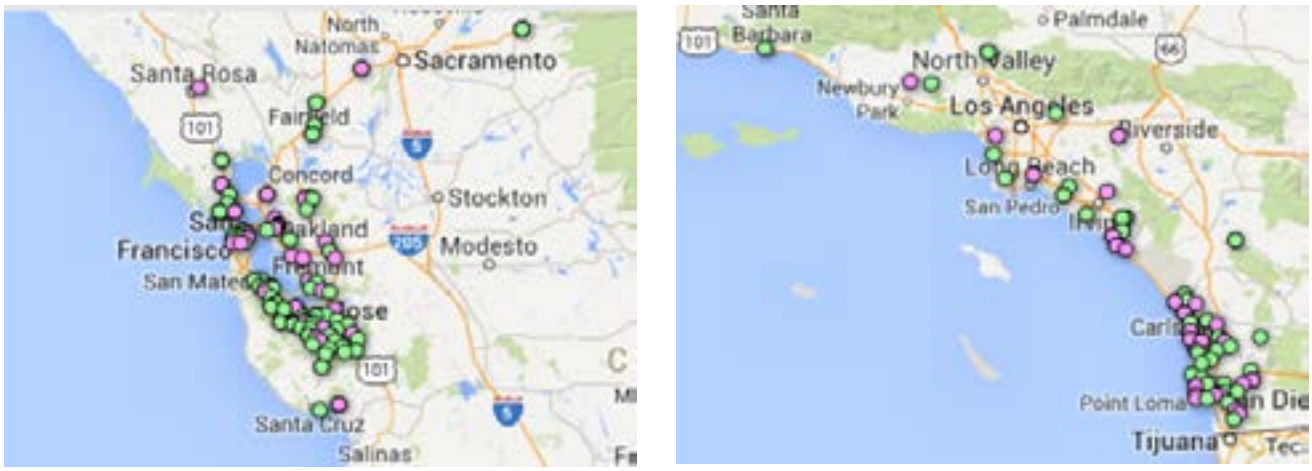
Table 1: Average energy consumption per day for the month of September 2013

The two-tailed P value equals 0.0001. By conventional criteria, this difference is considered to be very statistically significant.

The mean of Control Group minus Treatment Group equals 1.444. This is equivalent of an average of 6.0% reduction in energy consumption.

A 95% confidence interval of this difference lies between 1.1137 and 1.7740. This means that with 95% confidence the energy reduction is between 4.67% and 7.43%.

Figure 5 below shows the geographical distribution of the control and treatment groups for the month of September 2013. The green color dots represent the control group users and pink color dots represent the treatment group users. The equal distribution (note: the color dots may be hidden behind other color dots to an extent) of the two colors supports the HDD/CDD distribution and further confirms that there is no systematic geo-bias between the control and treatment group users.



Northern CA

Southern CA

Green = Control, Pink = Treatment

Figure 5: Geographical distribution of study subjects

Conclusion and Next Steps

The current results show that, for September 2013, utility customers exposed to Bidgely's Energy Disaggregation solution were consuming on average 6% less energy than non-Bidgely users. It is expected that a majority of these savings came from behavior changes and not from appliance upgrades or dwelling insulation upgrades, due to the relatively longer duration and higher effort entailed in such upgrades. It's noteworthy, however, tht utilities can achieve significantly higher long-term energy savings targets if they expose customers to Bidgely's solution over longer periods and layer appliance and building-envelope energy efficiency incentives atop immediately accessible behavioral recommendations.

The current results are an intermediate step in an ongoing study. Future analysis will include more users over a longer time span, and will also evaluate the persistence effect, i.e. measuring the degree to which consumers continue their behavioral energy savings efforts after the first few months.

Case Study 2: Consumer Engagement in Deregulated Retail Markets

Bidgely ran a utility customer study in 2013 with one of the leading energy retailers in an international market with strong retail competition. About 150 consumers received access to Bidgely's energy management platform for a period of five months from June to December.

The goal was to explore the possibility of using Energy Disaggregation to increase customer engagement, and thus reduce attrition in a highly competitive deregulated electricity market. Engagement was measured through customer surveys and Google Analytics (i.e. activity within Bidgely's application)

How was the data collected?

In the absence of advanced metering infrastructure, whole house consumption data was collected using current transformer clamp ("CT clamp") style hardware. The hardware consisted of:

a) A CT clamp for the whole house - an electrical device with "jaws" that open to allow clamping to an electrical wire – installed on the main circuit of the house.
b) A transmitter that transmits energy consumption data to a gateway.
c) A gateway that receives the data from the transmitter and sends the energy consumption readings to the Bidgely cloud every 10 seconds.

About 90% of the total data (all users and all days combined) received met the quality standards established for the study, as measured for each house by assessing the number of data packets received per day.

How engaged were customers?

Utility energy consumers received direct feedback on their consumption behavior through real-time information on web and mobile dashboards (once the customer logged into their account), and periodic usage alerts and summaries via email.

The following figures show screenshots of usage-based alerts and a monthly summary report.

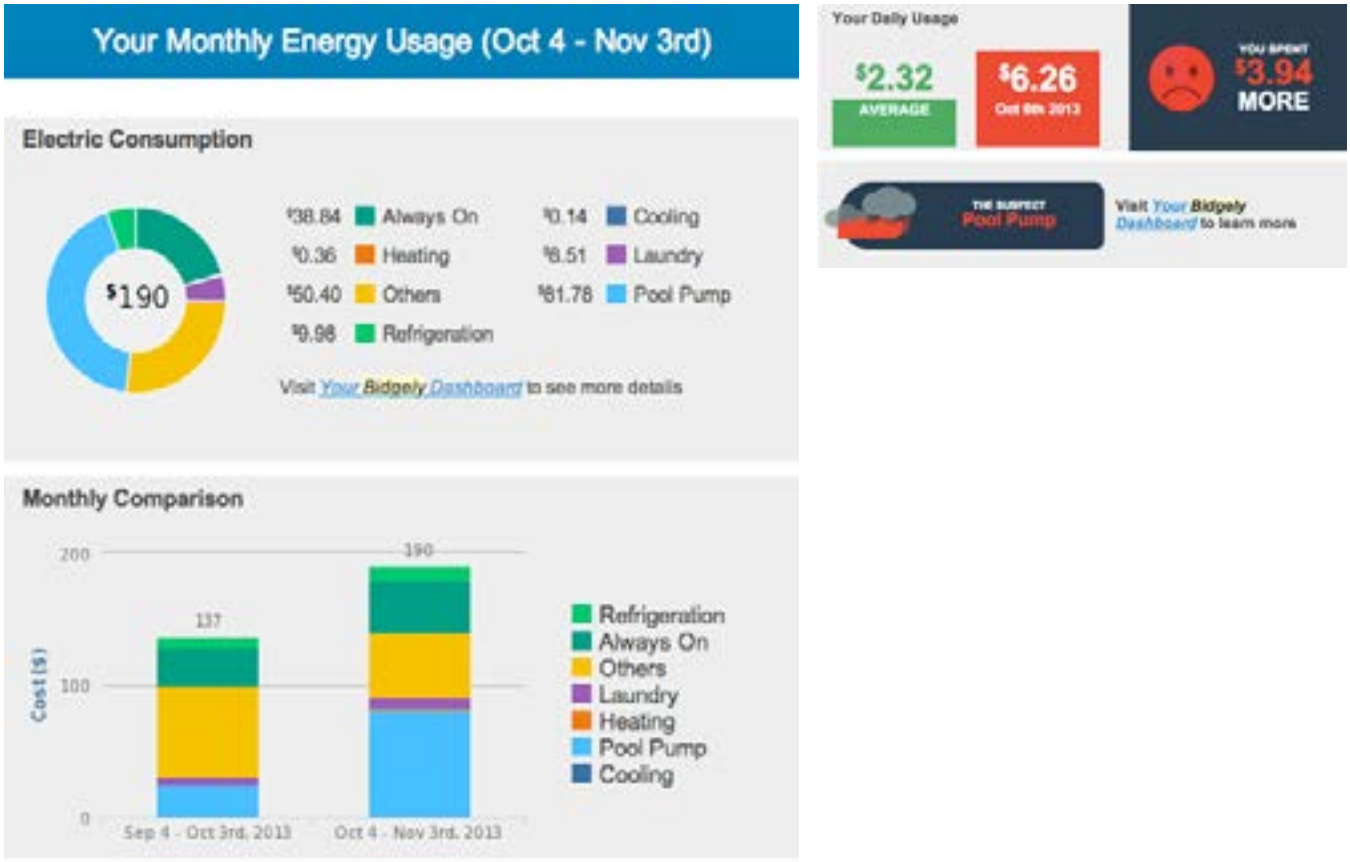


Figure 6: Bidgely emails and alerts

Energy Itemization Results at a Glance

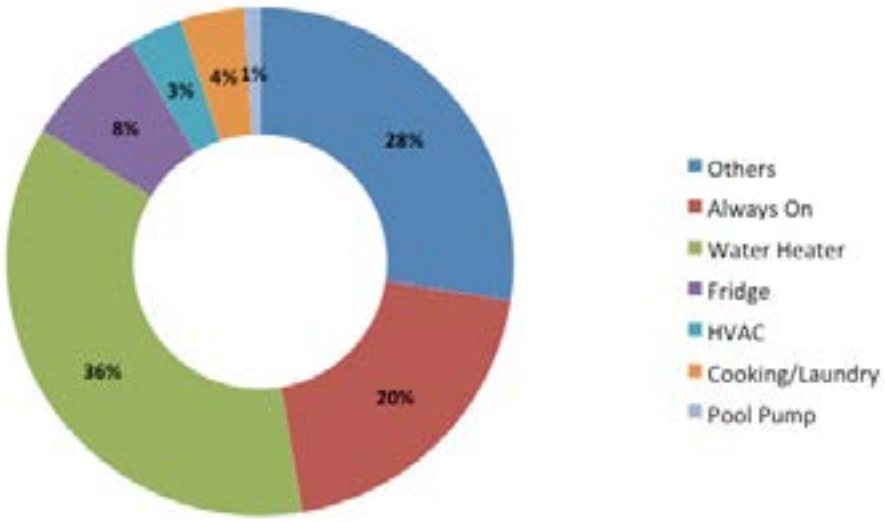


Figure 7: Disaggregated average energy consumption across all users over the course of the study

What are the expected and unexpected outcomes?

In addition to running Google Analytics on web traffic, a 20-question survey was sent to the study participants during the month of October. The survey focused on user interaction and user experience with Bidgely's energy management platform and what aspects about the services engaged customers the most and why.

41% of participants discovered inefficiencies and changed their behavior based on Bidgely consumption feedback and savings recommendations. The inefficiencies fell under three main categories:

1. Appliance-related: such as confirming non-performance of a refrigerator, or learning that the heater in the spare bedroom is always on, or checking the efficiency rating of the water heater.
2. Dwelling-related: identifying poor insulation in homes and how it affects energy consumption.
3. Energy Use-related: how often and when major appliances – such as air conditioners, ovens and dryers – are run.

A number of customer used the Bidgely platform – especially its real-timeliness – to raise awareness in their families and engage kids in a more energy-efficient lifestyle, such as turning off lights and air conditioners when not in use. In general, families with kids had higher engagement during the study than families without.

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The three aspects of Bidgely's platform that customers liked the most were:

1. Real-time usage information - direct instantaneous feedback: 86% of the users rated this as their top feature.
2. Appliance-level itemization – the ability to identify the energy costs of running different appliances: 74% of the users rated this as the top most feature.
3. Personalized energy saving tips: 88% of the users who implemented at least one recommendation said that the tips worked and saved them money.

90% of the customers visited the Bidgely platform at least once every week, spending on average 8 minutes during each visit. 75% of the customers preferred accessing the application via a mobile application over a web-based one as the primary means of communication, mirroring a recent consumer trend towards more mobile-friendly engagement approaches.

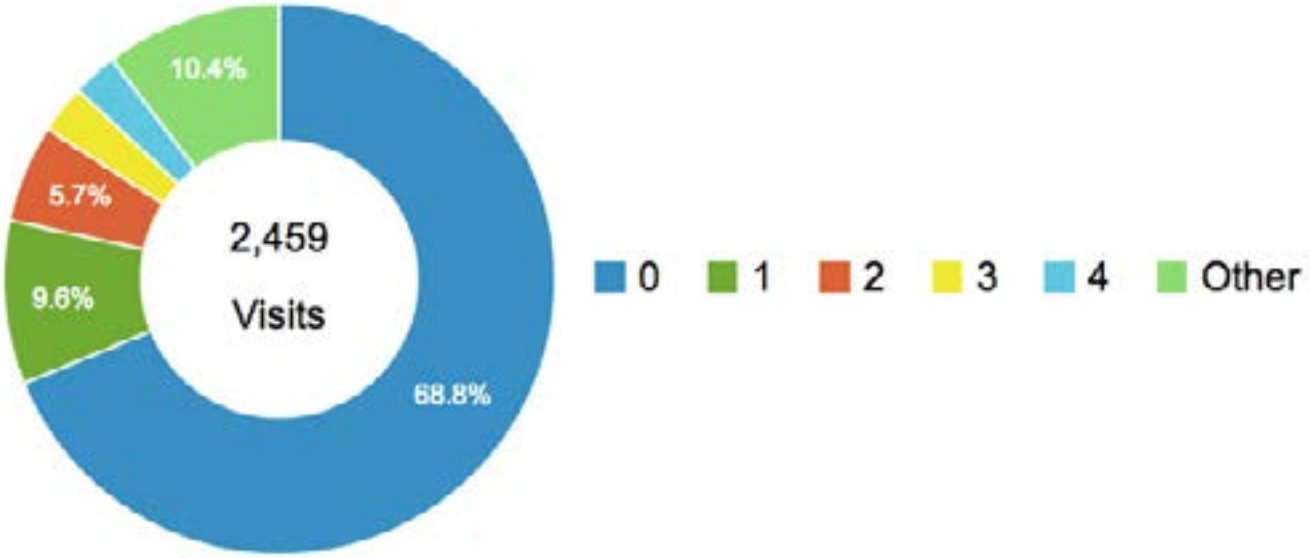

Figure 8: Google Analytics on Days Since Last Visit for study users

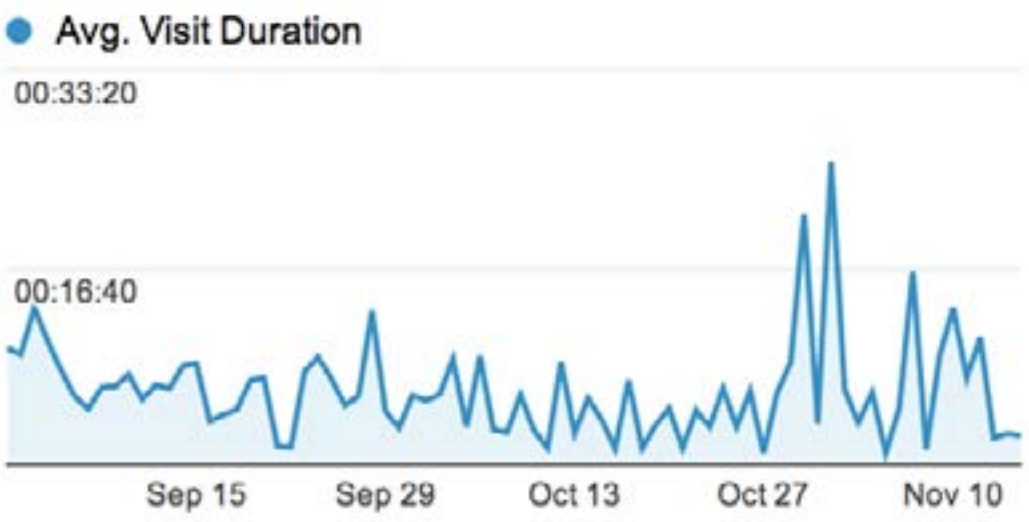

Figure 9: Google Analytics on Average Visit Duration for international study users

86% of users recommend rollout of the service to all utility customers.

a) **Permanent behavior shift:** "It gives people the option to track their usage and even if the customer just sees it as a fad and stops using it after a couple of months, it may have already changed habits."
b) **Reduce call center calls:** "It may prevent call center calls regarding high consumption because customers have the information available to work this out themselves."

c) **Raise Awareness:** "This service can be very useful to customers to identify the power usage per appliance and how much difference any power saving change makes when compared to historical usage graph."

d) **Low-income benefit:** "It will alert customers increased consumption within 24 hours so they can do something about it. I also believe these should be installed in homes, the alert email should be sent to case managers as well as consumers to help manage power account for low income families through winter periods."

Implication on Behavior Program Policy and Other Applications

An itemized energy bill shows consumers which appliances consume how much energy – a great first step that identifies the energy hogs in homes. However, consumers are unlikely to take significant action without actionable information regarding their energy itemization. For instance, consumers frequently do not know what the efficiency metric is for an appliance and how much energy each appliance should efficiently consume. A prudent approach would be to build applications using this technology that provide the data, comparisons, and recommendations that deliver benefits to both consumers and utilities.

This study provides strong proof of how a real-time Energy-Disaggregation based solution can influence customer behavior to increase savings and drive engagement. In addition, Energy Disaggregation can also:

- Enhance targeted marketing, by selecting homes with specific appliance-level energy usage (e.g. inefficient refrigerator, pool pump),
- Perform virtual audits,
- Measure and validate utility programs,
- Avoid unexpected high bills by providing high-usage alerts in real time to customers, and
- Resolve high bill disputes without truck rolls, by providing immediate audit details and recommendations that avoid future usage over-runs.

Additional messages for policy makers include the benefits of:

a) Making appliance level information available to consumers.
b) Making real-time energy usage information available to consumers.
c) Enabling the ZigBee radio chips in smart meters such that consumers can access their energy use data in real time. Since most meters in the field already have the radio-enabled hardware embedded within them, it would not require incremental capital investment.

References and Endnotes

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