Title
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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 consumer engagement and reduced energy usage. This paper highlights results from two case studies conducted in real life – one in California and other international. The study in California, using an experimental design, shows a statistical proof of average 14% energy reduction in users exposed to Bidgely's Energy Disaggregation-based solution with a maximum of 24% and a minimum of 3.5%. The international study shows high levels of consumer engagement, favorable consumer reaction and an 80% 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 *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 consumer engagement platform allows 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 your household appliances, and makes truly personal savings recommendations. All this without any plug-level sensors or in-person audits, at a massive scale and low cost never accomplished before.

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

a) The goal of the energy savings consumer pilot in California was to quantitatively (and objectively) estimate the savings from Energy Disaggregation.

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

b) The consumer engagement pilot 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 consumer engagement, thus reduce attrition in a highly competitive deregulated electricity market.

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

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 as the Holy Grail of Energy Efficiency that can leverage the Smart Meter investment to deliver significant low cost energy reductions by engaging consumers more effectively. With Smart Meters capturing granular data from millions of homes, 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 approach.

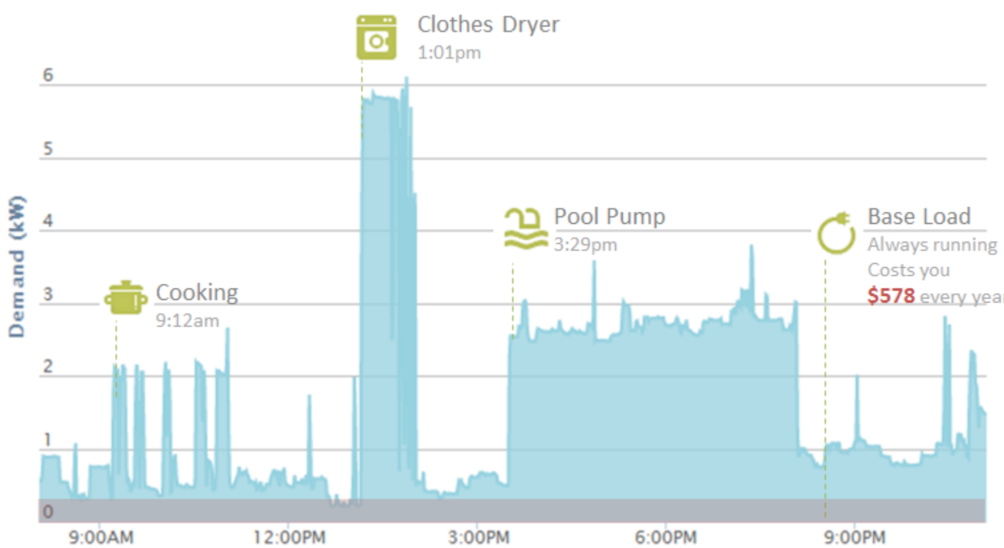

Figure 1: Appliance signature-based Energy Disaggregation

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.

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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

Case Study 1: Behavior-based Energy Savings in California

The open energy data access in California is one of the most advanced across the globe. With billions of dollars invested in Smart Meters, 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 the consumers to directly access their real-time energy consumption data. The data streams every few seconds (vary from 7.5 to 30 seconds) from Smart Meter to the home.

Green Button: Thanks to a White House initiative called Green Button (www.greenbuttondata.org), utilities across United States have been adopting a standard that allows 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 utility account.

What were the goals of the Pilot?

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

a) Quantitatively and objectively estimate the energy savings of its Energy Disaggregation-based energy management 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 account. Both interfaces were used to collect data for pilot participants. All participants found Bidgely through word of mouth.

For HAN, some participants bought in-home gateway devices, while others were given free devices through a qualification survey. These in-home gateways are a bridge that stream data from Smart Meter to cloud 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 consumer connecting their bank and credit card accounts to mint.com for personal financial advisor solution). Bidgely then automatically pulled the consumer data for last 12 months (on first connection) and every 24 hours thereafter.

How were pilot participants recruited?

The pilot participants were selected from all Bidgely users who met following conditions:

a) Live in CA;
b) Live in single family home;
c) Have energy bill more than $50 and less than $250;
d) Provide past 12 months of pre-Bidgely use data on sign up;
e) Do not have Electric Vehicle;
f) Do not have Solar PV generation;
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 of two groups - Treatment (consumer using Bidgely) 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 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 causes participants saved more energy than those in the control group.

		2013												2014							
Recruiting		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 October 2013. Notice this is a rolling pilot design, so the number of treatment group and control group is changing every month. September 2013 is the best time to draw conclusions for this period where both treatment group and control group have equal users - 165 each.

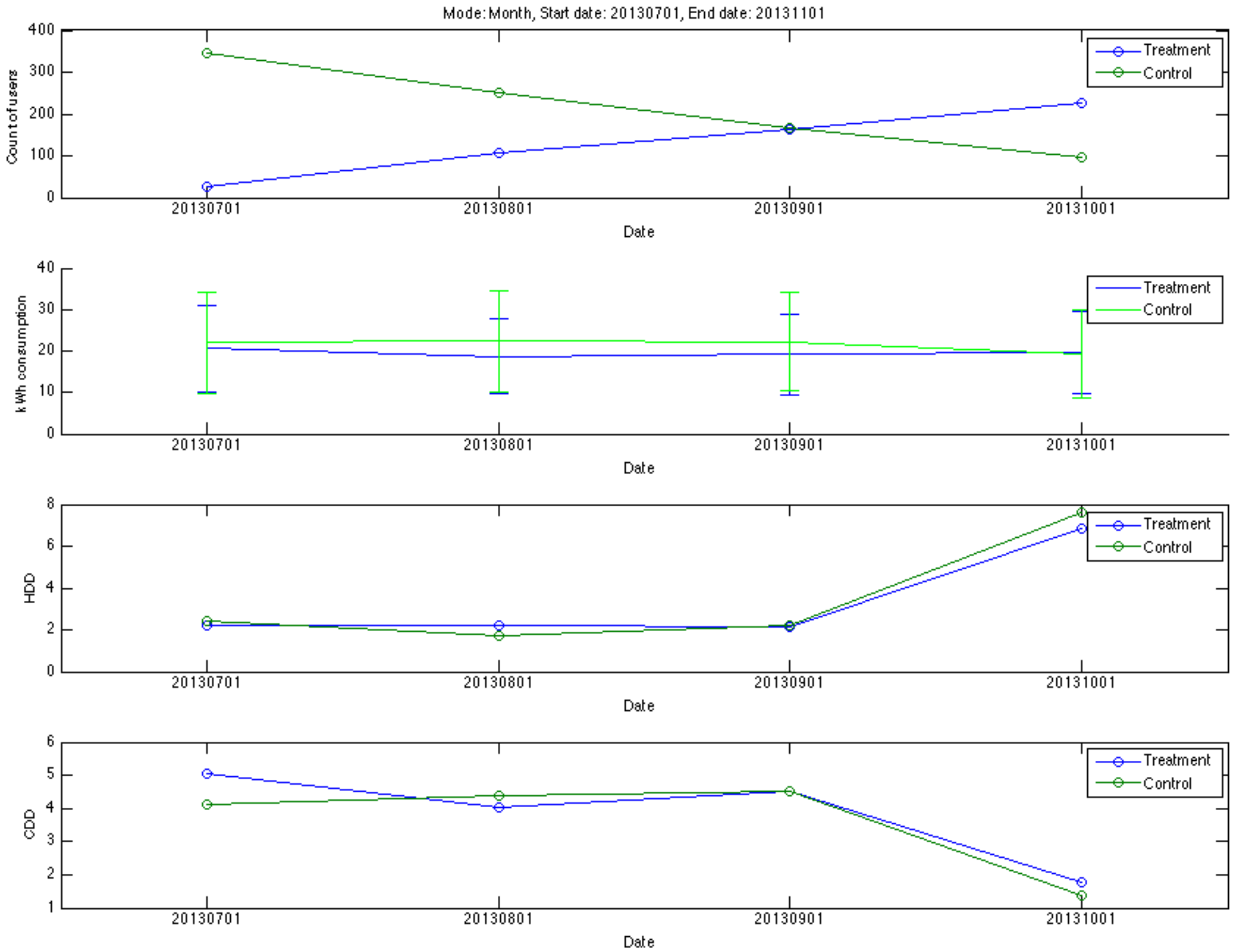


Figure 3: Comparison between control and treatment groups for number of participants, energy usage, HDD and CDD

Figure 4 below zooms into the month of September 2013. The distribution of daily kWh consumption and boxplot show the difference in consumption between control and treatment group. 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.

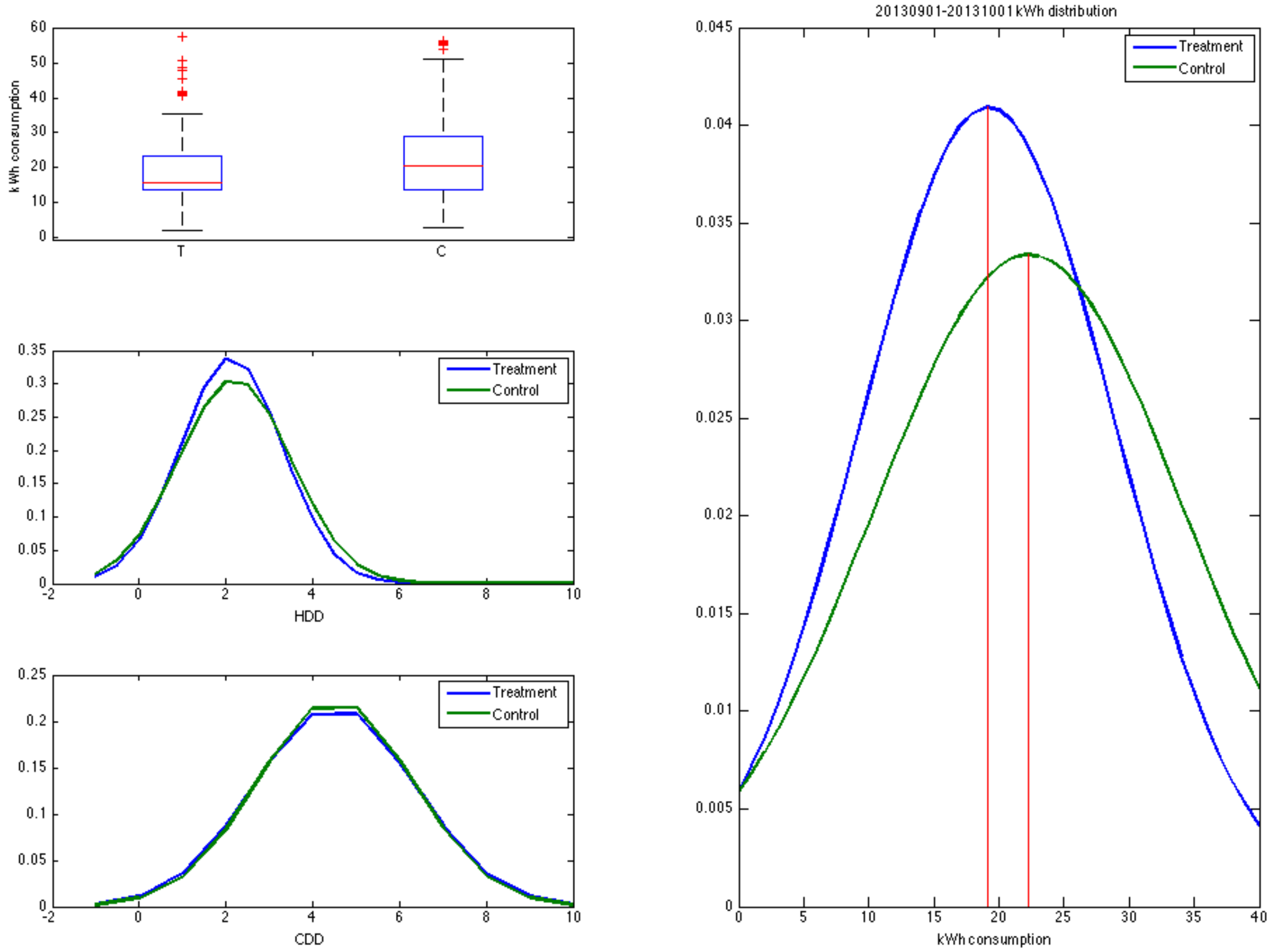


Figure 4: Energy usage (kWh) and HDD/CDD comparison between control and treatment groups for the month of September 2013

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

	Treatment Group	**Control Group**
Mean	19.15300	22.29400
Standard Deviation	9.74700	11.95000
SEM	0.76344	0.93031
Number	163	165

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

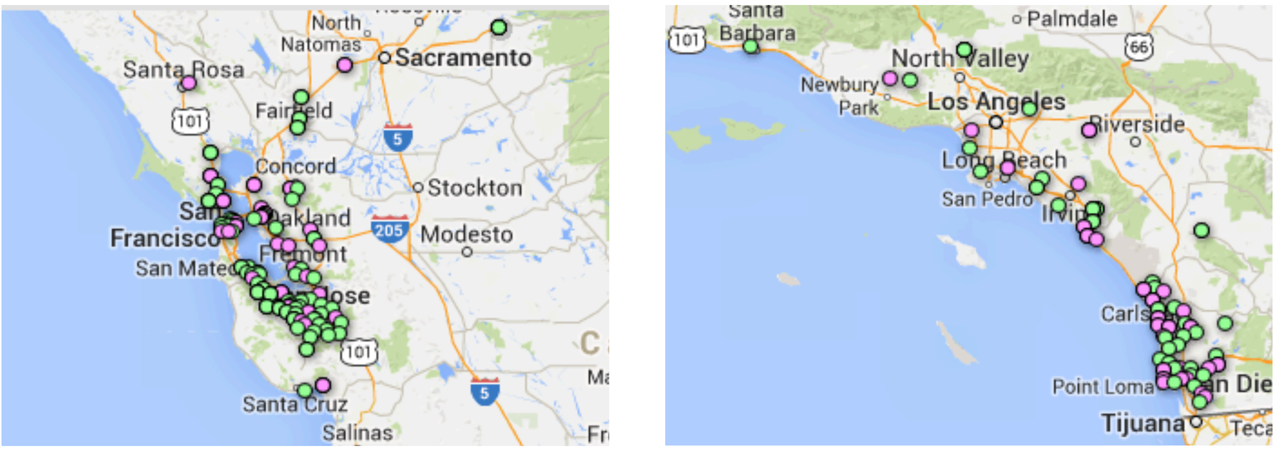
The two-tailed P value equals 0.0096. By conventional criteria, this difference is considered to be very statistically significant.

The mean of Group T minus Group C equals -3.14100. This is equivalent of an average of

14.09% reduction in energy consumption.

95% confidence interval of this difference: From -5.51144 to -0.77056. This means that with 95% confidence, the difference is a reduction of -24% to -3.45% (at max 24% savings and at least 3.45% savings).

Figure 5 below shows the geo-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: one color dots may be hidden behind the other color 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
Green = Control, Pink = Treatment

Southern CA

Figure 5: Geo-distribution of pilot subjects

Conclusion and Next Steps

The current results show that, for September 2013, users exposed to Bidgely's Energy Disaggregation solution were consuming on average 14% 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. Adding those two on top can increase the total savings further.

The current results are an intermediate step in the ongoing pilot study. Future analysis will include more users over larger time span, will provide higher confidence to the results and will also evaluate the persistence effect – does the savings continue to persist after the first few weeks or months.

Case Study 2: Consumer Engagement in Deregulated Retail Markets

Bidgely ran a consumer pilot 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 consumer engagement, thus reduce attrition in a highly competitive deregulated electricity market. Engagement was measured through consumer surveys and Google Analytics.

How was the data collected?

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

a) A CT clamp for the whole house - an electrical device with two jaws that open to allow clamping on 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 Bidgely cloud every 10 seconds.

About 90% of the total data (all users and all days combined) received was of good quality. The data quality was measured for each house by looking at the number of packets received per day.

How were the consumers engaged?

Consumers received direct feedback on their consumption behavior through real-time information on web and mobile dashboards (once customer logs into their accounts), and periodic usage alerts and summaries via emails.

Following figures show screenshots of usage based alerts and monthly summary report.

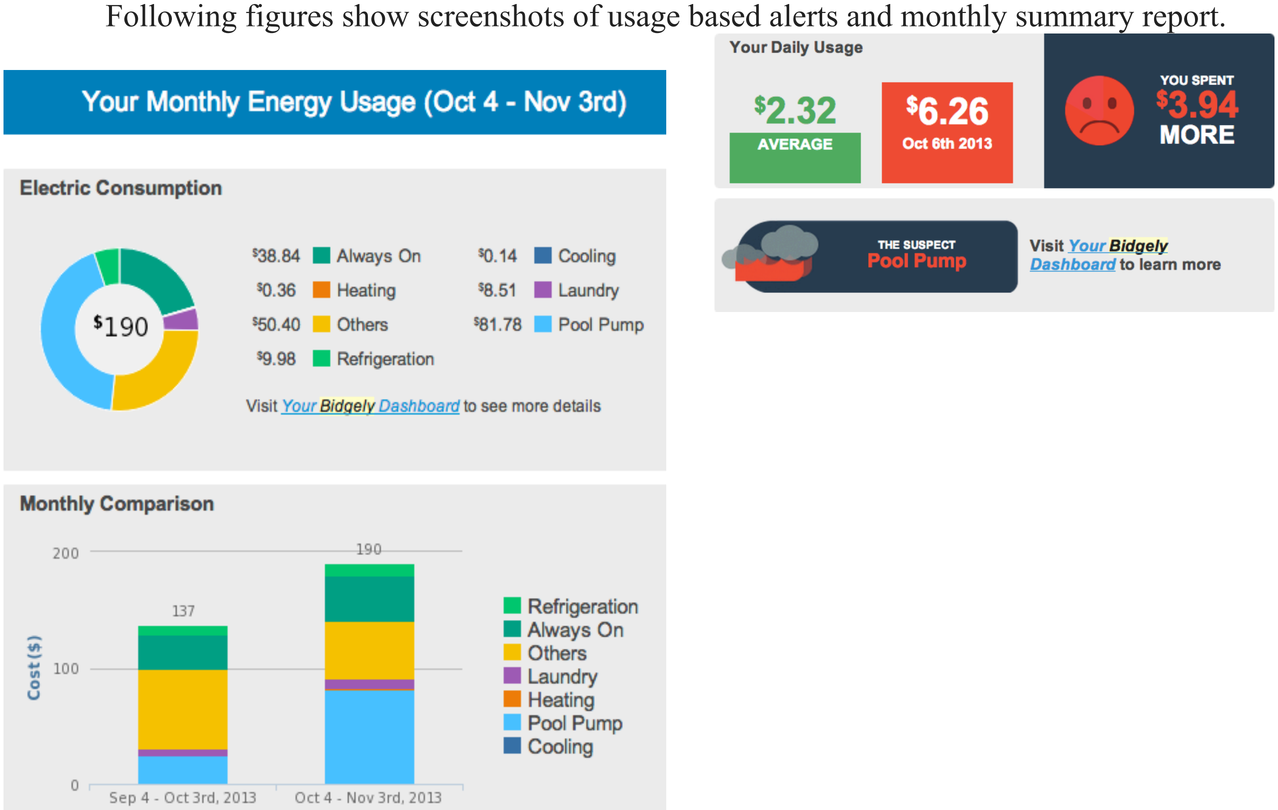


Figure 6: Bidgely e-mails and alerts

Energy Itemization Results at a Glance

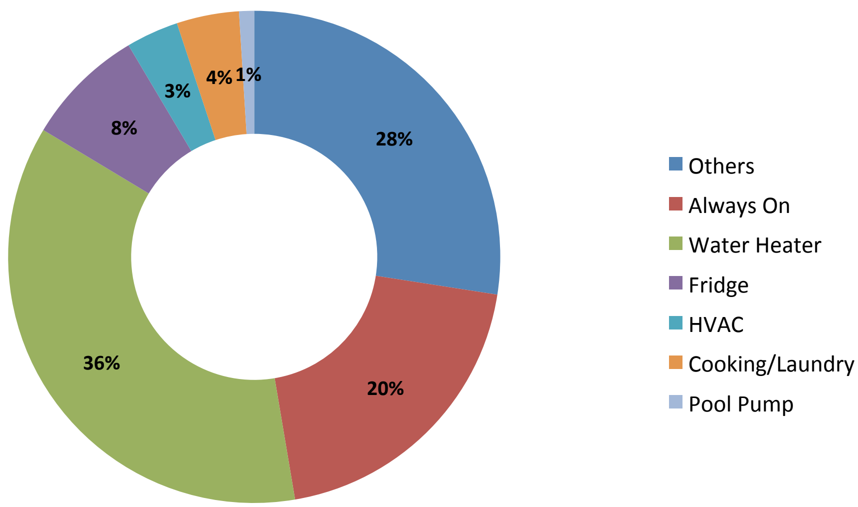


Figure 7: Average breakdown of energy consumption across all users over the course of the study

What are the expected and unexpected outcomes?

In addition to running Google Analytics on web traffic, a 20-question survey was sent to the pilot consumers 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 excited them the most and why.

41% of pilot consumers discovered inefficiencies and changed their behavior based on Bidgely consumption feedback and recommendation. The inefficiencies fell under three main categories.

a) Appliance-related: Such as confirming non-performance of a fridge, or learning that the heater in the spare bedroom is always on, or checking the efficiency rating of the water heater.
b) Dwelling-related: Identifying poor insulation in homes and how it affects energy consumption.
c) Energy Use-related: How often and when big appliances – such as air conditioners, ovens and dryers – are run.

A number of consumers used the Bidgely platform – especially it's 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 pilot than families without.
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The three aspects on the Bidgely platform that consumers liked the most were:

a) Real-time usage information - direct instantaneous feedback;
b) Comparison with historical usage – Explain variations in energy bills from one month to another;
c) Appliance-level breakdown – Energy cost to run different appliances.

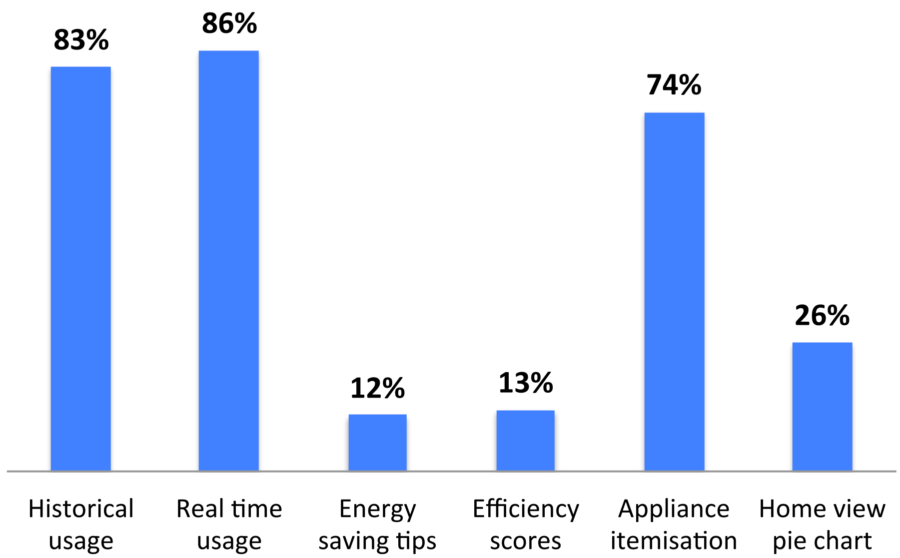

Figure 8: Consumer preference for Bidgely features

While only 12% of the consumers were interested in the personalized energy saving tips, 18% of them at least implemented one recommendation during the pilot and 88% out of those said the tip worked and saved them money. On probing further through direct consumer outreach, we learnt that while the each recommendation provided a personalized breakeven analysis to help consumers make an informed decision, a number of these recommendations were less relevant in the local Kiwi context.

90% of the consumers visited the Bidgely platform at least once every week spending 8 minutes on an average during each visit. 75% of the consumers prefer mobile to web as the primary platform of communication confirming a recent consumer trend towards more mobile-friendly engagement approaches.

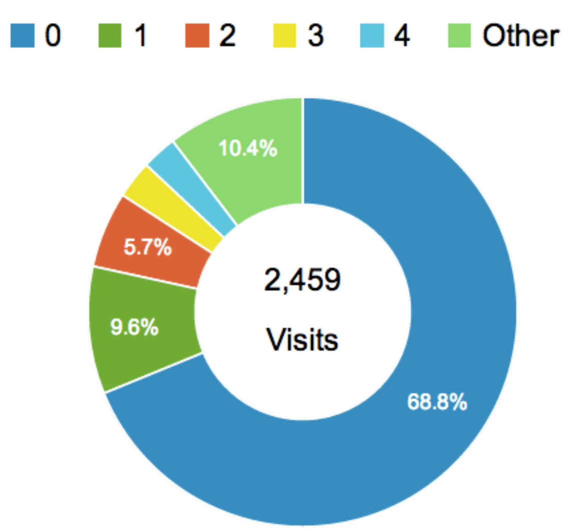

Figure 9: Google Analytics on Days Since Last Visit for pilot consumers

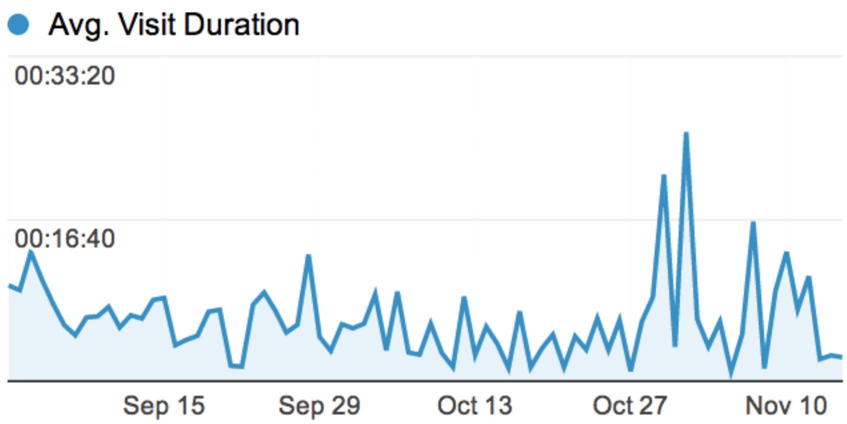

Figure 10: Google Analytics on Average Visit Duration for international pilot consumers

86% of users would recommend the service to others. Here are some interesting insights from what consumers had to say.

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 would most likely not do anything further since there is no actionable information in the energy breakdown. Consumers do not know what the efficiency metric is for an appliance and how much energy they should efficiently consume. Energy Disaggregation is a means not an end. A prudent approach would be to build applications using this technology to deliver benefits to both consumers and utilities.

This paper provides a strong proof of how real time energy information and Energy Disaggregation based solution can influence consumer behavior to increase savings and drive engagement. In addition, Energy Disaggregation can also enhance targeted marketing, perform virtual audits, measure and validate utility programs, and resolve high bill disputes without truck rolls, among others.

The overarching goal of this paper is to influence the policy makers to:

a) Make appliance level information available to consumers.
b) Make real time energy use information available to consumers.
c) Enable the ZigBee radio chips in Smart Meters such that consumers can access their energy use data real-time. Most meters already have the hardware in field; it would not cost any additional capital.

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