DATA-DRIVEN INSIGHTS

THE NATION'S DEEPEST EVER RESEARCH ON CUSTOMER ENERGY USE

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In 2009, the University of Texas-based Pecan Street Inc. launched an ambitious long-term research trial in Austin, Texas. The purpose of the trial is to understand with unprecedented clarity how, when and for what purpose people use electricity, gas and water in their homes, businesses and schools.

Now — two years and nearly eight billion rows of data into this research — the Pecan Street Inc.'s research division (now called the Pecan Street Research Institute) is releasing a progress report analyzing residential electricity and gas use at a scale and depth of detail that has never been publicly available before.

Researchers have installed and operate research instrumentation in over 500 volunteer homes. While Green Button and other consumer electricity use data reveals only whole-home electricity use from the utility meter, the Institute's instrumentation records electricity use and voltage levels for the whole home, plus eight to 23 circuits at data intervals ranging from one minute to one second.

Each day, the Pecan Street Research Institute's data operations acquire and manage over 89.5 million unique electricity use and voltage reads. To put this scale of data in context, a utility reading smart meters at one-hour intervals to reach this level of daily electricity use data would need to have 3.73 million smart meters in operation.

In nearly 200 of the homes, the Institute has also recorded natural gas use at 15-second intervals, and in over 50 homes, it records water use at 15-second intervals. Researchers have carried out highly detailed home energy audits in 200 of the homes, and they regularly conduct detailed customer surveys.

The new report, "Data-Driven Insights from the Nation's Deepest Ever Research on Customer Energy Use," focuses on slightly over a year of electricity and gas use in 200 of these homes. One hundred of the homes are less than five years old and have a green building certification (LEED, Austin Energy's Green Building certification or both). The other 100 homes range from 10 to 90 years old, and they represent a broad spectrum of home conditions, sizes and appliance configurations.

This report does not imply a final conclusion on customer electricity use or claim to be a definitive statement of the truth — it is a progress report. The scale and complexity of the data means that even as research data from the Pecan Street Project continues to grow, researchers will continue to analyze it continually and discover surprising new insights and causal relationships.

That said, some realities on residential energy use that are non-obvious at the whole-home level reveal themselves when electricity and gas use are measured at the Pecan Street Project's depth of detail. Some of these can be quite surprising.

ELECTRICITY USES BY DEVICE

As Pecan Street's consumer research reveals, home electricity use generally falls into four categories. That's important to understand, because tools that might impact electricity use in one category could be largely ineffective in addressing electricity use in another.

While much smart grid commercial and research attention has centered on commercial and industrial use, residential electricity demand can exert a significant demand on electric systems. For example, ERCOT has calculated that during summer peak demand periods, residential customers can comprise over 50 percent of total system demand on the Texas Interconnect.

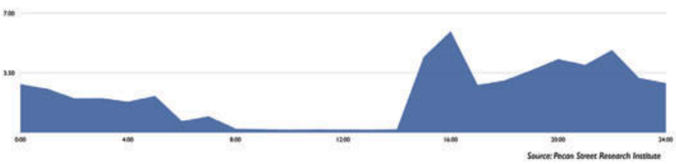

Figure 1 – Electricity demand (kW) for one of the authors' homes viewed at hourly intervals, July 31, 2012. At this resolution of data — which is typical of many smart meter deployments — determining which devices are being used is not possible. (Source: Pecan Street Research Institute)

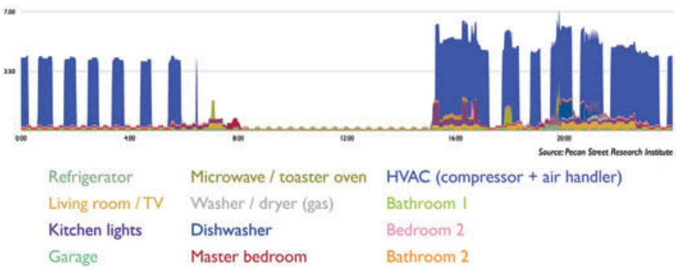

Figure 2 – Disaggregated electricity demand (kW) for same home at 1-minute intervals measured using Pecan Street research instrumentation, July 31, 2012. (No utility smart meter deployments are able to obtain this data granularity.) At this resolution of data, it is possible to identify when specific appliances are being used and to measure how these appliances are performing compared to performance benchmarks — a key capability for diagnostic services using non-intrusive load monitoring. (Source: Pecan Street Research Institute)

Whole-home electricity use data masks a critical reality: customers use electricity to accomplish a wide variety of specific jobs in their homes. Some of these jobs are highly seasonal; others remain relatively constant over the year. Some of these jobs need to be accomplished at specific times; others are carried out through "set and forget" systems that involve very little conscious customer activity. Still others are jobs for which customers have considerable flexibility on when they are conducted.

At a high level, there are two important measures for evaluating electricity use: total use (consumption) and instantaneous load. Total use is central to measuring the cost impact of using specific applications over a defined period (such as a year or month). From a family budget perspective, this is typically the more impactful measure. It's also a measure to which a typical family has virtually no simple, reliable access.

Instantaneous load is the calculation of how many kilowatts a given appliance is drawing when it is on. This figure is important for understanding the potential peak demand impact of individual devices. It is also important to understand when such devices are used; a device with a high instantaneous load can have a benign impact on electric system stability, for example, if it is used primarily during late evening hours.

To date in the Pecan Street Project, the Institute has identified the following as the top instantaneous loads found in participants' homes:

Device	Top range instantaneous loads
Electric dryer	>6 kW
Pool pump	>4 kW
Air conditioner compressor	nearly 4 kW
Electric oven	+/- 3.5 kW
Electric vehicle charger (240 V)	3.3 kW
Electric vehicle charger (120 V)	1.45 kW
Air handler (HVAC)	+/- 0.8 kW

Always on

A portion of home electricity use comes from devices that are always on. These include the numerous set and forget devices such as bedside clocks, Wi-Fi routers, microwave oven clocks, cable boxes and refrigerators.

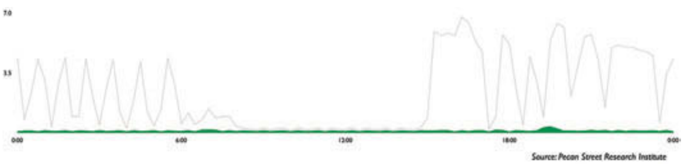

Figure 3 – "Always On" electricity demand (kW) compared to whole-home electricity for one of the authors' homes viewed at 15-minute intervals, July 31, 2012. The minor variations are caused predominately by refrigerator cycling. (Source: Pecan Street Research Institute)

Impact and applicability of:	
Green building	Green building codes typically target improvements such as insulation levels, air conditioner compressor sizing, duct leakage and other improvements to a home's thermal systems. As such, green building efforts are not typically targeted to always on devices.
Behaviour response	Many always on devices such as refrigerators and alarm clocks cannot be turned off without substantial disruption to residents. Others, such as Wi-Fi routers, may need to be always on to enable the performance of other systems, such as programmable thermostats.
Appliance efficiency	While most always on devices use somewhere between 1 W and 10 W, there are exceptions, such as refrigerators and cable boxes. Given the ubiquity of these devices, even modest efficiency standard improvements could in the aggregate have meaningful impacts.

While all electricity use has system and family budget impacts, "Always On" electricity in most homes comprises a comparatively low level of demand, both from total annual demand and from instantaneous load perspectives. The most significant Always On device in most participants' homes is the refrigerator; it typically represents approximately 10 percent of total annual electricity use, with little variation in total annual consumption among homes.

Thermal

Thermal electricity use typically comes from just two circuits: the air conditioner compressor and the air handler. Where homes have electric heat, the furnace (which is typically on the same circuit as the air handler) also uses electricity to impact thermal conditions in the home (i.e. to make it warmer than the outside). Where gas space heating is installed, the air handler fan will run but otherwise electricity is not used.

Figure 4 – "Thermal" electricity demand (kW) compared to whole-home electricity for one of the authors' homes viewed at 15-minute intervals, July 31, 2012. (Source: Pecan Street Research Institute)

Even in areas with seasonally extreme temperatures (including, of course, Texas in summer) thermal electricity circuits go virtually unused for months at a time. But when they are on, they are the dominant source of electricity use — so dominant, in fact, that the two thermal circuits in Pecan Street Project homes represent over 50 percent of total annual electricity demand in older homes and slightly over 40 percent of total annual demand in the green-built homes.

This leads directly to two of the most significant insights arising from the research data.

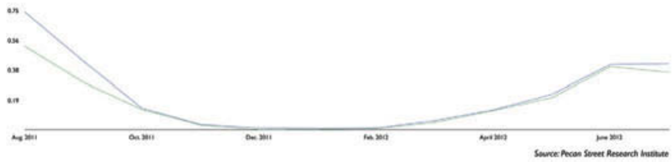

Figure 5 – Watts per square foot electricity demand (kW) from HVAC between green-built homes (green) and non-green-built homes (blue). (Source: Pecan Street Research Institute)

Impact and applicability of:	
Green building	Green building codes generally focus exclusively or largely on home thermal performance. Tools include insulation "R" levels over 30 (basically, blowing more insulation into the attic), solar film on south and west facing windows, maintenance of heating/air conditioning ducts, replacing air filers and installing air conditioners with higher SEER (seasonal energy efficiency ratio) ratings.
Behaviour response efforts	Behaviour response efforts (such as demand response programs) are generally concentrated on the periods when thermal loads represent the dominant source of residential electricity use. Compared to green building tools such as higher insulation levels, behaviour response programs' advantages include more certainty of system-wide load reductions during peak demand periods. Comparative disadvantages include the potential for greater resident discomfort (actual or perceived).
Appliance efficiency	Given the enormous impact of heating and cooling on customer electric and gas bills and on utility system sizing (and therefore cost structure), higher efficiency standards for air conditioner compressors in particular can produce significant benefits to customers and utilities alike.

First, for the homes in the Pecan Street Project, green building improvements such as more insulation and air conditioners with higher SEER ratings correlated with reductions in cooling electricity use per square foot that exceeded 25 percent in the hottest months.

Second, home energy audits demonstrate that even homes less than five years old had elevated levels of duct leakage. In all of the cases, the homeowners were unaware of this condition. This suggests that, particularly over time, green building investments will best hold their value when homes have feedback systems such as nonintrusive load monitoring that detect degradations in home thermal performance and alert the homeowner.

Electric-gas substitutes

For a handful of residential appliances, customers can choose between electric and gas options, if the home is so equipped. Appliances in this category — which generally use energy to produce heat — include clothes dryers, ovens and ranges, water heaters and space heaters.

Figure 6 – Electricity demand (kW) from electric-gas substitute appliances compared to whole-home electricity for one of the authors' homes viewed at 15-minute intervals, July 31, 2012. The blue area in the evening represents the gas dryer running a single load. (Source: Pecan Street Research Institute)

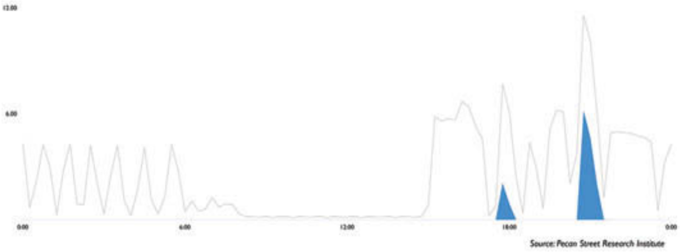

Figure 7 – Electricity demand (kW) from the same home, but with electric dryer and electric oven consumption from a different home substituted. The first blue area represents use of an electric oven, and the second represents an electric dryer running a single load. (Source: Pecan Street Research Institute)

As reflected by the ranking of top residential instantaneous loads, electric versions of electric-gas substitute appliances represent the top and two of the top four instantaneous loads in observed homes. Specific observed examples include:

Max kW draw	Clothes dryer	Oven
Electric version	6.24 kW	3.54 kW
Gas version	0.36 kW	~ 0 kW

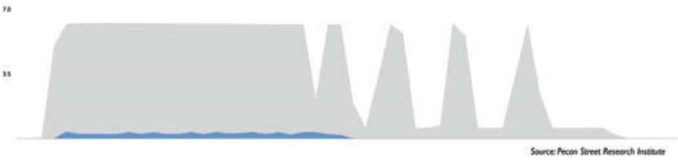

Figure 8 – Comparative electricity demand (kW) from an electric dryer and a gas dryer in two Pecan Street Project participants' homes. Each was for operating a single dryer load. In addition to the differing instantaneous loads, the operating cycle for the gas dryer was shorter (23 minutes) compared to the electric dryer (46 minutes). Using Energy Information Administration average electric ($ 0.1172/kWh) and gas ($1.103/ccf) rates, the cost to dry a load of laundry with an electric dryer was $0.38, while the combined gas and electricity cost to dry a load of laundry in a gas dryer was $ 0.06. (Source: Pecan Street Research Institute)

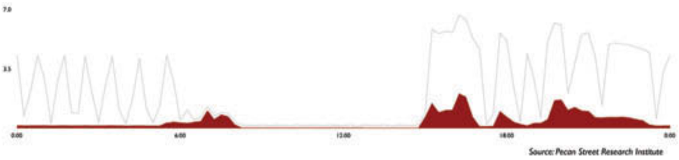

Figure 9 - Intentional electricity demand (kW) compared to whole-home electricity for one of the authors' homes viewed at 15-minute intervals, July 31, 2012. (Source: Pecan Street Research Institute)

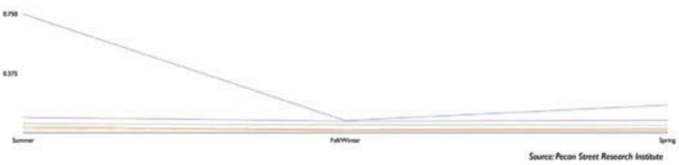

Figure 10 – Seasonal variation (kW) of air conditioning compressor (blue), clothes dryer (green), dishwasher (yellow), microwave (red), refrigerator (purple) and washing machine (gray) in Pecan Street Project. (Source: Pecan Street Research Institute)

Impact and applicability of:

Green building While green building codes typically target home thermal improvements, some green building codes incorporate appliances. Arguments for incorporating gas-electric substitute appliances in green building ratings include that these appliances frequently are attachments (particularly furnaces, ovens and water heaters) and that these devices also use energy for thermal applications.

Behaviour response efforts For homes with all-electric versions of gas-electric substitutes, the inconvenience and discomfort of not using the device during peak demand periods is typically low, and the instantaneous peak load reduction per device can be significant.

Appliance efficiency Two measures of appliance efficiency arguably apply. By one measure, improved efficiency of all-electric appliances could produce significant cost savings and instantaneous load reductions. By another measure of efficiency, substituting from electric to gas versions of appliances can produce significant reductions in electric instantaneous loads and operating costs to consumers.

Intentional

The bulk of electricity-using applications in people's homes are devices that people intentionally turn on or plug in when they are home. Examples include lights, televisions, microwave ovens, hair dryers and fans.

Intentional uses of electricity are significantly particularized to the demographics and daily schedules of each home's occupants. Unlike thermal loads, intentional use patterns are also relatively stable throughout the year. MI

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REFERENCES

1. http://www.ercot.com/content/news/presentations/2013/ERCOT_SmartEnergySummit_2-28-12.pdf

Impact and applicability of:

Green building Because green building codes typically target improvements to home thermal systems, green building improvements would not be expected to impact consumption levels of intentional devices. This also means that during the periods of the year when homes use relatively little electricity for heating and cooling (and therefore use far less electricity in many regions), green built homes will not perform appreciably different from non-green built homes. In fact, to the extent investments in more insulation and new air conditioning correlate with higher incomes, it is possible that green built homes might show slightly higher electricity use compared to non-green built homes in temperate months use to the extent higher incomes also correlate with plasma televisions and more electricity using devices.

Behaviour response efforts During peak demand periods, intentional use devices do not comprise a significant portion of residential electricity use. However, customers do start turning on these devices during peak hours (when they arrive home in summer or wake up in winter). Therefore, efforts to persuade customers to avoid turning on or plugging in devices during peak demand periods could be a way to reduce peak demand with relatively little discomfort or inconvenience.

Appliance efficiency As with always on devices, given the ubiquity of intentional use devices such as TVs and light bulbs, even modest efficiency standard improvements could in the aggregate have meaningful impacts.