Testing the Value of Energy Efficiency in the Renewable Ramp Challenge

EFFICIENCY VERMONT, DSS TECH DEMO REPORT: 000-049

Michael Fink
Efficiency Vermont

December 2017

Contents

ABSTRACT

In his 10-step proposed solution for solving the "Duck Curve" distributed solar generation problem, Jim Lazar's first step is to implement energy-efficiency measures that are time-targeted to peak hours. Here we present findings from retroactively examining groups of Vermont residential energy accounts that have implemented Efficiency Vermont's incentivized energy efficiency measures to determine whether those measures have alleviated or exacerbated the Duck Curve problem. Seven different energy efficiency measures were examined among residential accounts. Among examined efficiency measures, major LED lighting installations were the closest match to the hoped-for time-targeted energy efficiency measures in Lazar's paper. LED installations significantly lowered consumption during both the morning and evening peak periods of the wider ISO-New England grid, while reducing the off-peak baseload by a more moderate amount.

Introduction

What's a Duck Curve?

The "Duck-Curve" problem refers to a specific loadshape curve observed on a power grid, usually caused by distributed solar power generation. Specifically, the "Duck-Curve" manifests as a loadshape with greatest electricity usage leading up to sunrise and just after sunset. *Figure 1*(below) exemplifies a pronounced example of Vermont's Duck Curve shape on a sunny weekday (Wednesday, June 7, 2017) compared to a cloudy weekday with similar day length and temperature (Tuesday, June 6, 2017) (data from ISO-New England).

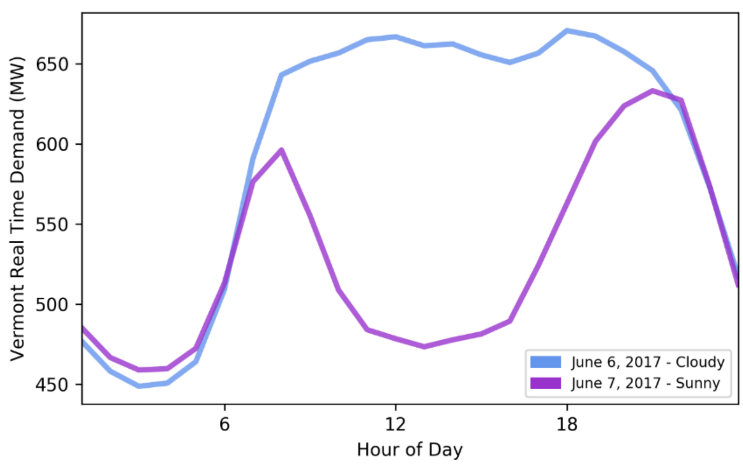


Figure 1. Comparison of sunny and cloudy weekday real-time demand for Vermont's portion of the ISO-New England power grid (data from ISO-New England).

The shape of the June 7 day in *Figure 1* is known as the 'Duck Curve' because of its resemblance to the belly of a duck in flight.[1]

---

[1] In Vermont, it has sometimes also been referred to as the 'Champ Curve' as an homage to the mythical sea monster rumored to inhabit Lake Champlain. It has also been suggested that the 'Champ Curve' is an apt moniker because it is possible that if the pace of distributed solar installations continue on their current trajectory, Vermont may soon see the sea monster's belly (the time of peak production) dip underwater – pushing Vermont's real-time demand at peak solar production into negative territory.

Duck Curve Problems

As the Duck Curve shape becomes more pronounced with time, there are two problems that are likely to manifest: overproduction and steep ramp-up conditions.

The island of Oahu is experiencing overproduction problem (Groom 2013). As a relatively small, isolated grid, Oahu's distributed solar production can cause substantial voltage swings if a cloud moves across the island. The local electric company[2] claims these voltage swings could be damaging to their customers' property or even endanger their line workers. As a result, grid-tied residential solar installations have been curtailed in Oahu.

For now, an Oahu-type overproduction problem is not a concern for Vermont's power grid. Although Vermont and Oahu have similar total electricity consumption, Vermont benefits from being tied into a much larger grid on to which Vermont can sink excess production. If the larger New England grid (that Vermont is part of) starts to have a "Duck-Curve" loadshape that resembles Vermont's, overproduction may become a more serious problem.

California already suffers from the "ramp-rate" problem. In the case of California, it is predicted that by 2020, the state's demand in the three hours surrounding sunset will increase by 13,000 MW (Lazar 2016). A ramp of this steepness requires flexible peaking power plants to meet demand. Given a ramp of this magnitude, California has two possible solutions:

1. Meet this demand by leaving baseload and intermediate plants idling during the day, even though they are not necessary because solar is handling the load.
2. Close baseload plants and some intermediate plants and replace them with flexible plants that can be used to satiate the sudden post-sunset demand.

We have one major problem with solution (1): the primary benefit of distributed solar power is that it has a very low carbon footprint. If it becomes necessary to use peaking natural gas plants or other carbon-intensive plants that may have to idle during the day in preparation for the sudden sunset-related demand, much of this low carbon footprint benefit is wiped out. For example, peaking natural gas plants in California have a heat rate[3] that is about 40% worse (higher) than the standard combined-cycle natural gas plant in California (Nyberg 2014).

The problem with solution (2) is simply that it would be very expensive to replace our baseload fleet of generation plants with clean peaking plants. It would be difficult to convince either taxpayers or ratepayers that a large upfront investment in peaking plants or energy storage (either batteries or pumped storage) is worth the benefit.

State of the Duck Curve in Vermont

Currently in Vermont, the Duck Curve appears to be most pronounced on the very hottest and very coldest weekdays. The characteristic Duck Curve shape has become more severe with each passing year.

---

[2] Hawaiian Electric

[3] The 'heat rate' is a measure of efficiency for steam power plants. It is the ratio of thermal heat input to electrical energy output. It is usually reported in units of British thermal units divided by kilowatt hours (Btu / kWh).

On the hottest days of summer:

Vermont's peak consumption is nearly identical on the hottest weekdays of summer and winter, but the shape of the duck is a bit different. Shown in *Figure 2* is the average loadshape of the fifteen hottest days of 2017:

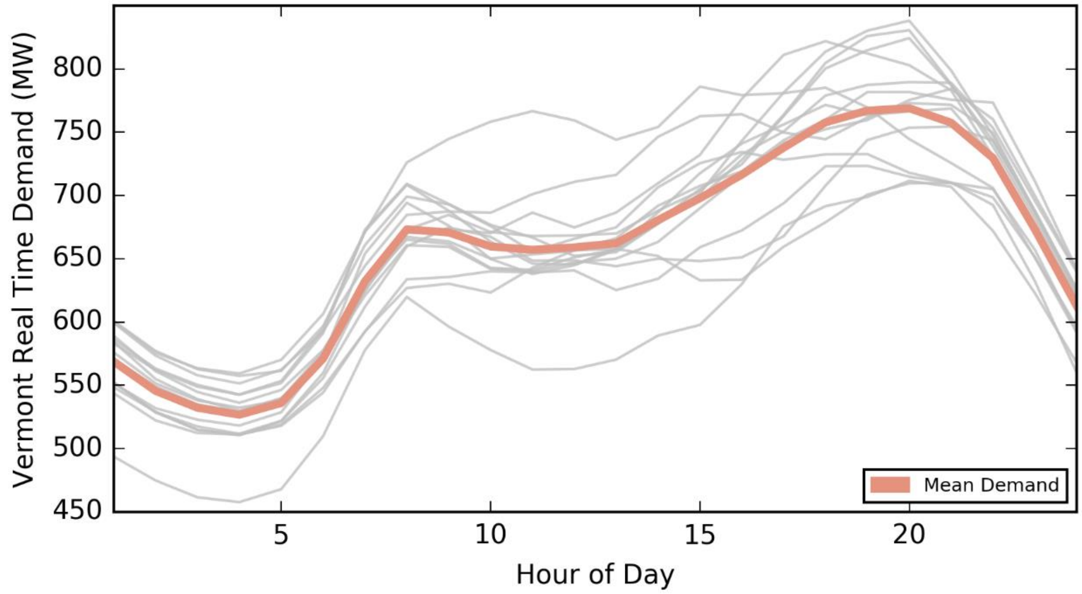


Figure 2. Vermont's average loadshape of the fifteen hottest days of 2017. The fifteen individual days are shown in light gray.

There are three important points to note from this plot[4]:

1. There is a steep ramp-up of demand in the morning hours.
2. There is a less steep ramp, but higher peak in the evening.
3. Even among the hottest days of 2017, the loadshape varies considerably.

On the coldest days of winter:

While exhibiting a similar magnitude of peak consumption as in the summer, the winter's morning and evening peaks are much closer in magnitude than the lopsided summer curve. *Figure 3* (below) is analogous to *Figure 2*; it shows Vermont's real-time demand on the fifteen coldest days of 2017:

[4] One more important point to note: for this entire paper and appendices, when a specific hour or a value is referred to or a specific hour is plotted on a graph, the value refers to the hour ending at the indicated time. For example, if we were to indicate a house used 1.8 kWh at 20:00 that would mean that 1.8 kWh of energy was used between 19:00 and 20:00.

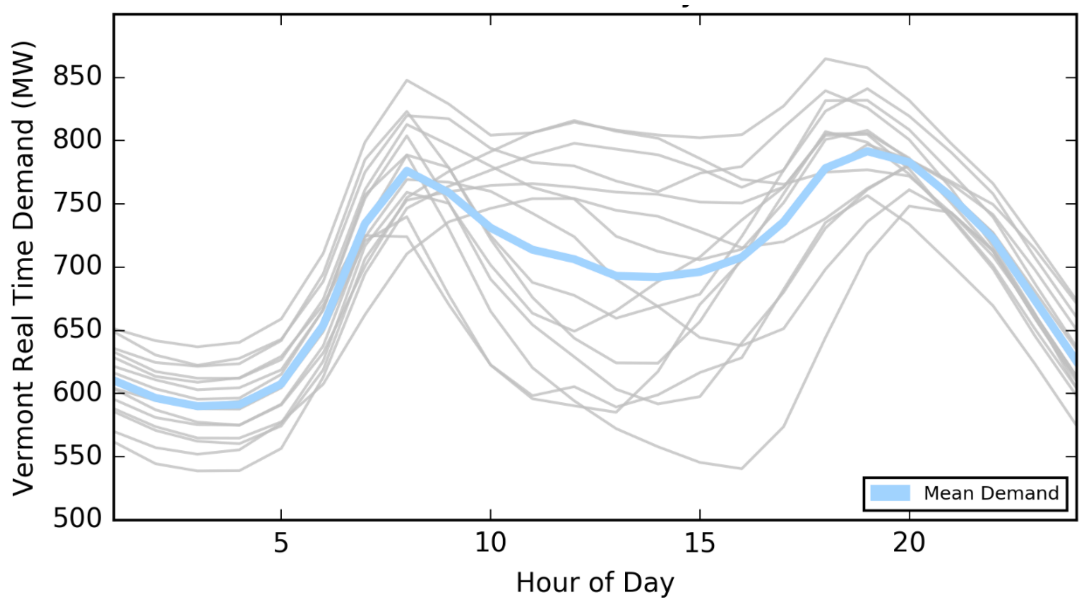


Figure 3. Vermont's average loadshape of the fifteen coldest days of 2017. The fifteen individual days are shown in light gray.

Especially evident in *Figure 3* is how much the loadshape changes depending on the cloud cover. While Vermont's coldest days are typically clear, the cloudy days included among the fifteen are obvious – they have peaks during the midday hours. Also worth noting here: the average evening peak demand is slightly earlier in the winter compared to the summer. One possible explanation is that the need for lighting occurs earlier in the evening than it does during the summer.

During the shoulder season:

For the sake of comparison, here (*Figure* 4) is the behavior of Vermont's grid during the fifteen days that required the least climate controlling (sometimes called the 'shoulderiest days').

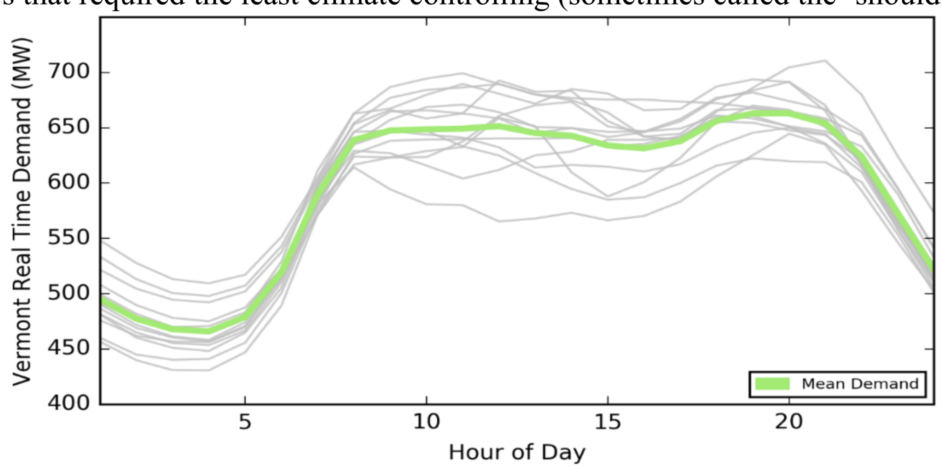


Figure 4. Vermont's average loadshape of the fifteen days of 2017 requiring the least climate-controlling. The fifteen individual days are shown in light gray.

Notice that demand is nearly flat during the normal waking hours of your average Vermont human. Those days among these fifteen shoulder days that were sunny still exhibit a mild Duck Curve shape, but because there is no need for climate control, the morning and evening peaks are much lower than in both the "hot duck" and "cold duck" cases.

Vermont's growing duck

Vermont's Duck Curve is becoming more and more accentuated. With each passing year, more distributed solar generation is installed on our grid and midday in-state generation grows, but our air-conditioners and heating systems remain largely unchanged, creating the same demand every year.[5] The result is a chunkier duck. Here are plots (*Figures 5 and 6)* showing the growth of Vermont's hot and cold Duck Curves over the past 14 years:

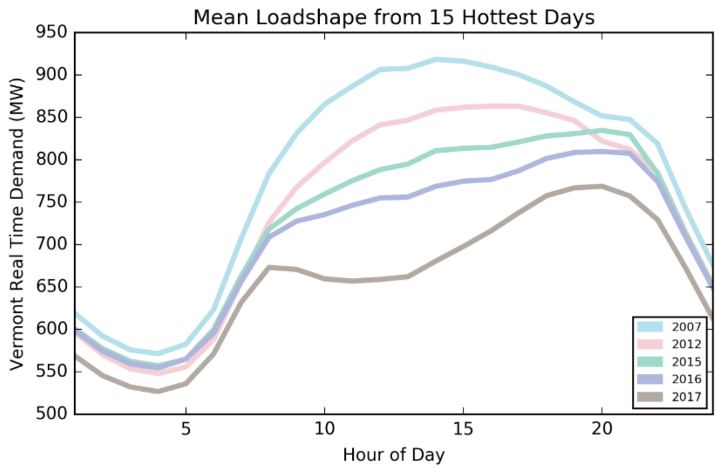


Figure 5. Mean real-time demand loadshape for Vermont's 15 hottest days, calculated in the years 2007, 2012, 2015, 2016, and 2017.

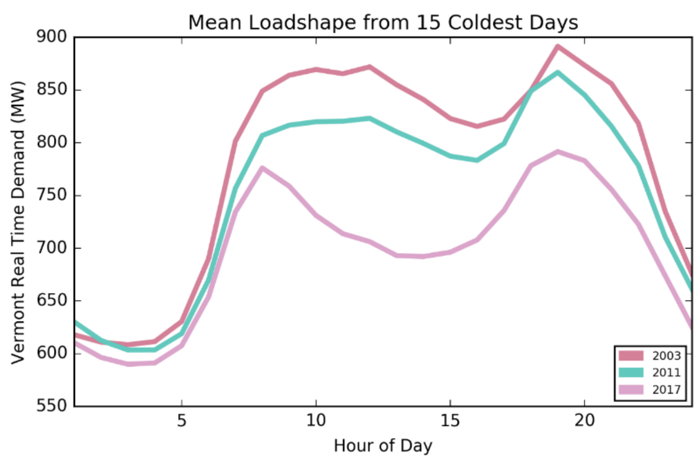


Figure 6. Mean real-time demand loadshape for Vermont's 15 coldest days, calculated in the years 2003, 2011, and 2017.

[5] This isn't *entirely* true – demand peaked in the late 2000's and has diminished very slightly since then. The change in demand is relatively small compared to the effect of distributed solar on in-state grid demand.

The most obvious feature of both *Figure 5* and *Figure 6* is a good one[6]: demand is decreasing. Unfortunately, the reduced demand has also brought with it steeper ramps than Vermont has experienced before. As distributed solar generation becomes more widespread, we should expect the ramps to get steeper and steeper.

How does Vermont's situation compare to others?

While our Duck Curve problem is definitely getting worse, Vermont has a couple advantages that make our situation easier to deal with than either Hawaii's overgeneration problem or California's ramp/peaking problem.

With both problems, Vermont has one big advantage over Oahu and California: Vermont is a very small part of a much larger grid. Vermont's grid is similar in size to Oahu's grid, but because Oahu is an island (electrically) overproduction results in voltage swings. If Vermont were to overproduce slightly, it could likely push the current back on the larger ISO-New England grid which, as a whole, does not suffer from distributed overproduction problems.

California's grid ramps are concerning because 1) they are steep and 2) California is the biggest fish in their pool. That is, if California has a steep demand increase, they will have to supply the electricity for that demand increase themselves because it is unlikely that there will be sufficient reserves elsewhere on the grid for purchase to satisfy their demand. Fortunately for Vermont, Vermont represents only 4% of the larger ISO-New England grid. If Vermont's demand increases by 20% or 40%, that's a tiny blip in the overall grid that is easily satiated (Belarmino and Jones 2017).

Intention of this Examination.

This is intended only as an examination of how employed residential efficiency measures in Vermont are currently affecting Vermont's Duck Curve. For reasons that are discussed in the Methods section of this paper, this should not be considered a proper *experiment*; rather, we urge the reader to consider this an examination of existing efficiency measures already in the wild.

Energy efficiency: a first step to solving the Duck Curve Problem

Jim Lazar has written a comprehensive plan to address the Duck Curve problem. In that paper, Jim suggests ten strategies that take a Duck Curve loadshape and turn it into a relatively flat loadshape curve. The first of his ten strategies is energy efficiency measures that are targeted to "hours when the load ramps up sharply". We aim here to examine existing energy efficiency measures and examine their efficacy at lessening (or increasing) the severity of the Duck Curve in Vermont.

Methods

As mentioned in the previous section, this is not a proper experiment with randomly selected residences comprising the experimental and control groups. Instead, a review of electricity use change among those who employed efficiency measures is presented here. Of course, this increases uncertainty and introduces systematic error.

[6] At least for those of us in the energy-efficiency business!

Experimental Group

The group referred in this paper as the 'experimental' group is comprised of all Green Mountain Power residential customers that employed the examined efficiency measure (eg. refrigerator replacement or LED lighting) during 2016. This group size varied among efficiency measure groups, but usually numbered between 200 and 1000.

Control Group

The control group was selected using a custom-written computer program to select 1000 residential accounts from Green Mountain Power at random. The same control group was used to compare to each of the efficiency measure experimental groups. Of course, it is possible (or even probable) that members of the control group may have the efficiency measure being examined; despite this possibility, the overlap should have minimal effect on the outcome – GMP's residential service points outnumber the largest experimental group by a ratio of nearly 200 to 1.

Quality Check

Some accounts in both the control and experimental groups were discarded for poor data quality. For a residential account to be retained and included in the study, it must meet the following criteria:

1. The account must be active before January 1, 2015.
2. The account must be active as of December 31, 2017.
3. The account must have "good" AMI data for at least 90% of the days between January 1, 2015 and December 31, 2017.
4. For a day to qualify as 'good', at least 87 of 96 daily AMI energy readings must be present.

Method for Comparison

A difference-in-differences (DID) technique was used to compare the efficacy of different efficiency measures against the control population. Here's how the energy savings or loss was calculated, with a quick example of use of the DID method (*Figure 7*):

Suppose we'd like to calculate the "difference in differences" of average energy change for homes with heat pump dryer installations. The formula for the calculation is:

$$\Delta E = \left(E_{exp:post} - E_{exp:pre}\right) - \left(E_{control:post} - E_{control:pre}\right)$$

So if the heat pump experimental group changed from 19.3 kWh of consumption in the pre-period to 16.2 kWh of consumption in the post-period, while the control group changed from 24.1 kWh to 23.8 kWh. In this case, our calculation would be:

$$\Delta E = (16.2\,kWh - 19.3\,kWh) - (23.8\,kWh - 24.1\,kWh)$$

$$\Delta E = (-3.1\,kWh) - (-0.3\,kWh)$$

$$\Delta E = -2.8\,kWh$$

Figure 7. Example of difference-in-differences method.

In this case, our heat pump experimental group is calculated to have saved 2.8 kWh of electricity.

The same technique is also used to create entire residual loadshapes, where the procedure outlined above is repeated for each hour of the day. These loadshapes are used extensively to determine whether a measure is saving energy or expending more energy than would be expected if the measure had not been installed. Here is an example of a plot with residual loadshapes to describe the increase/decrease in energy usage over the day, as a result of the efficiency measure installation:

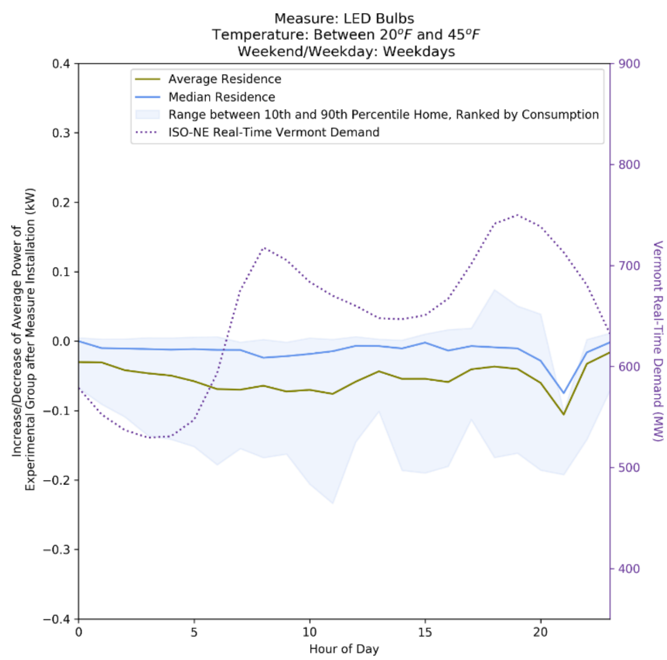


Figure 8. Use of difference-in-differences technique to find change in electricity usage for residences that installed efficient lighting compared to a control group. Vermont's real-time demand is plotted on the right axis for reference to peak times. All data is for weekdays with an average temperature between 20^{o}F and 45^{o}F.

Shown here are data relating to LED lighting replacements. The purple-dotted line uses the right axis. This is the average ISO-New England data real-time demand in 2017 for all days that meet this bin's temperature and weekday criteria (in this case, weekdays with an average temperature between 20^{o}F and 45^{o}F. This ISO-New England data is here only for quick reference, so it is easy to see how the efficiency measure might affect the Duck Curve shape.

The green trace uses the left axis (as do all of the remaining graph features). The green trace uses the average energy usage of the experimental and control groups and, using the DID method, computes a "loadshape residual" for this temperature/weekday/efficiency measure combination. For example, suppose that at hour 6, the green line has a value of -0.07 kW; this means that on weekdays with an average temperature between 20^{o}F and 45^{o}F, the average home in the experimental group is using 70 W less power between the hours of 5:00 and 6:00.

The blue trace is identical to the green trace except that it is for the *median* residence rather than the average. Finally, the light blue shaded area bounds the 10th percentile home to the 90th

percentile home (percentiles are in energy usage for that hour, *not* in the value of the DID; this means that the median and average values can (but rarely) fall outside of the blue shaded region).

Also used here are bar chart plots that use the DID method for other descriptive metrics. For example, consider this plot (*Figure 9*) showing system coincident peak value changes on LED lighting replacements:

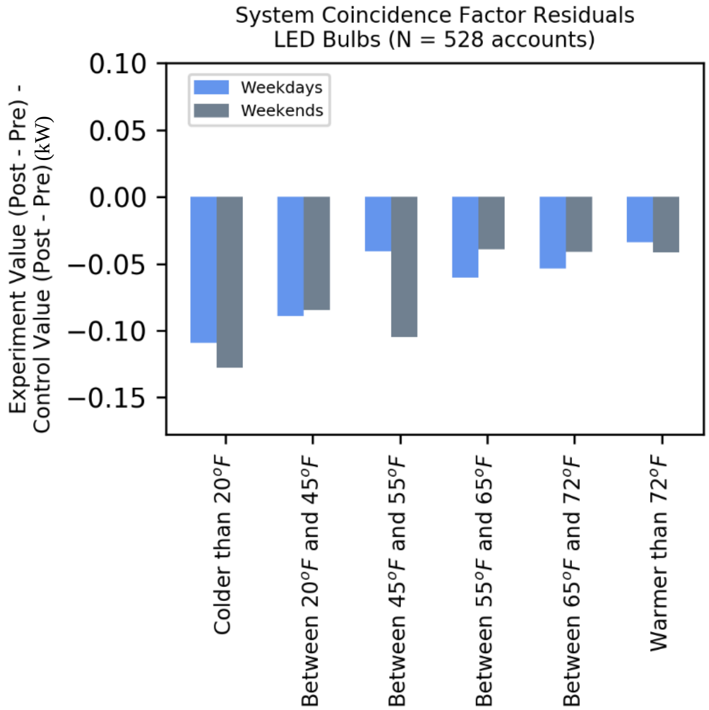


Figure 9. Change in system coincident values for residential LED installations by day of week and temperature category.

In Figure 9, for example, the blue bar having a value of -0.1 kW in the "Colder than 20°F" category means that the coincident peak value for houses with LED Bulb installations dropped by about 0.1 kW on weekdays that had an average temperature of 20°F or colder.

Results and Discussion

Among the seven efficiency measures investigated, seven temperature bins, two weekday bins, and several different metrics calculated, there are too many individual results to include here. Instead, truncated results limited to the two most interesting efficiency measures are presented below.

Cold Climate Heat Pumps

Cold-climate heat pumps are undoubtedly the most interesting efficiency measure investigated here. These are devices that are usually used for space-heating sections of homes, but usually not relied on for whole-home heating. Their efficiency changes with outdoor (sink) temperature. Their output capacity also drops precipitously as the sink temperature drops[7]. At moderately cold temperatures, they are often one of the most economic means of space heating.

The ramifications of widespread heat pump installation on Vermont's Duck Curve are complicated. If measured by coincident peak value (the consumption of a house while the grid is peaking), heat pumps are damaging to the Duck Curve; homes that have them installed use significantly more energy when the ISO-New England grid is peaking:

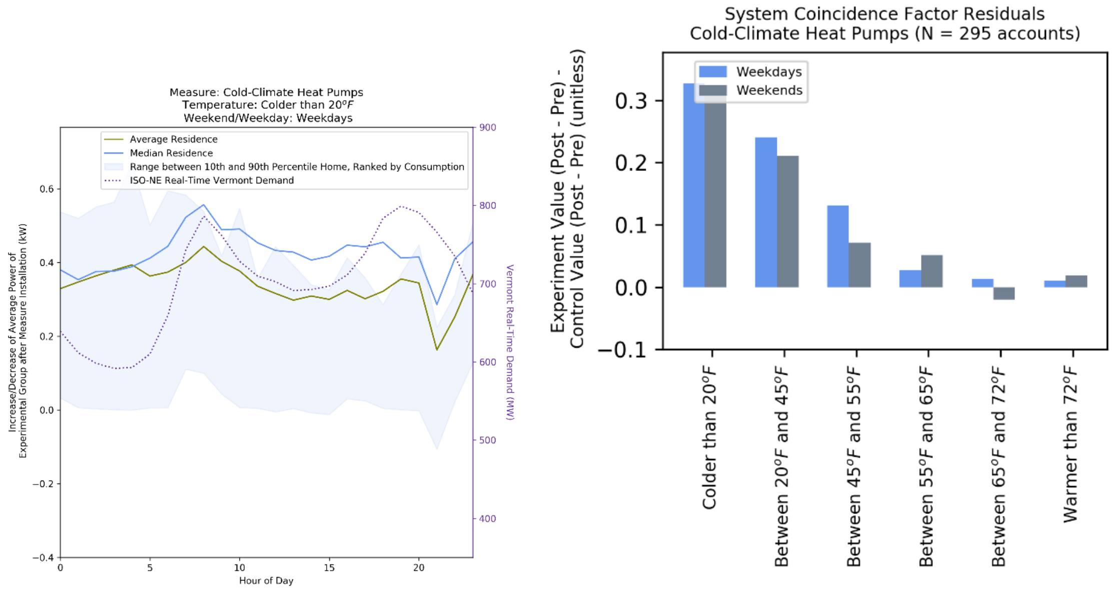


Figure 10a and Figure 10b. At times of greatest grid demand in Vermont, heat pumps are causing an increase in consumption. Figure 10a (left) shows that during both the morning and evening peaks, residences employing heat pumps use more energy. Figure 10b (right) indicates that the increase in usage at peak periods among heat-pump households is greatest at lowest temperatures.

Alternatively, if one were to use a metric like $\frac{P_{peak}}{P_{baseload}}$, smaller values of this ratio of powers indicate a flatter loadshape. Because the cold-climate heat pump pushes up consumption uniformly at all hours, this metric would become smaller or closer to the ideal flat loadshape. So, despite the fact that cold-climate heat pumps tend to increase consumption and increase system coincident peaks, depending on what is most important to grid operators, this efficiency measure could be a help or a hindrance to solving the Duck Curve problem.

Lighting Measures

LED lighting installations were the closest thing to a sure-fire help to the Duck Curve problem of the measures investigated here. Here (*Figure 11)* are the loadshape residuals at cold temperatures on weekdays:

[7] Most cold-climate heat pumps shut off between -5°F and -20°F

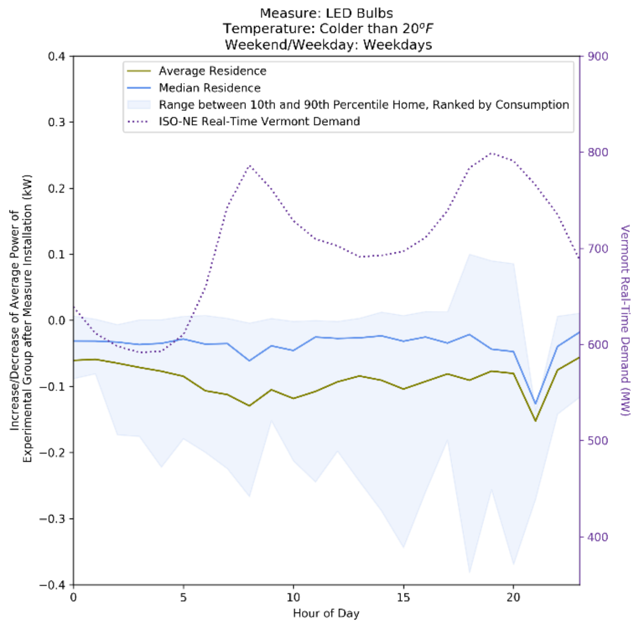


Figure 11. Efficient lighting installations showed decreased consumption over the entire day.

In cold weather, there is consistent savings, especially at the time of the morning Duck Curve peak. Savings associated with this measure are much less pronounced during warmer weather, probably because temperature is an effective proxy for day length. When the days are warmer (longer), there is less need for lighting. When the days are colder (shorter), there is greater need for lighting.

Unsurprisingly, LED bulb replacements offered consistent alleviation of the system coincident peak (*Figure 12).*

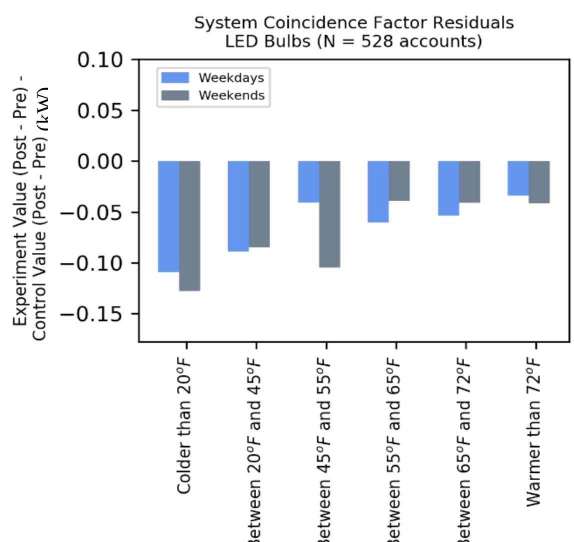
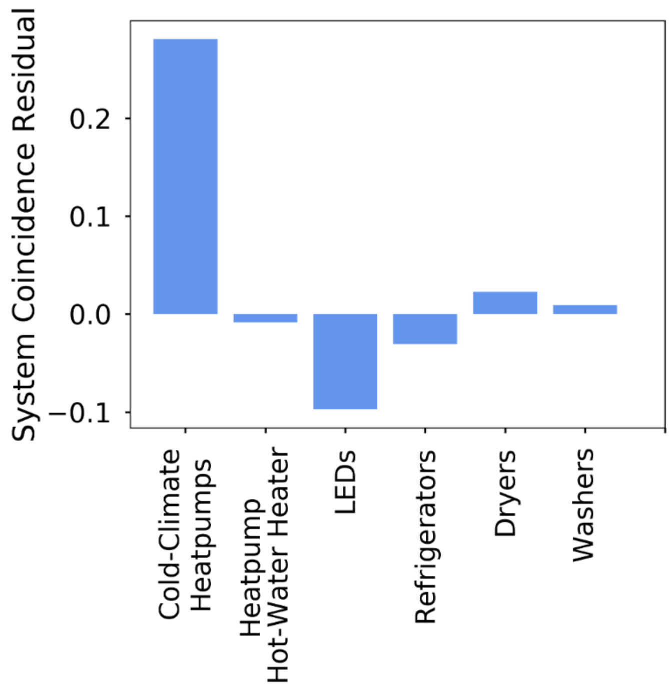


Figure 12. System coincident residuals for efficient lighting replacements

Other Results

Relative to cold-climate heat pumps and LED lighting installations, the other metrics had little effect at the grid peak times. Summarized in the chart below is the behavior of all metrics in cold weather/weekday conditions at Vermont's peak hour of consumption.



References

Belarmino, Dan and Kim Jones, Green Mountain Power Distribution Engineers. Personal Interview. March 21, 2017.

Groom, Nichola. "Clouds over Hawaii's Rooftop Solar Growth Hint at US Battle". *Scientific American*. December 16, 2013.

Lazar, Jim. *Teaching the "Duck" to Fly, Second Edition.* Montpelier, VT: The Regulatory Assistance Project.

Nyberg, Michael, *Thermal Efficiency of Gas-Fired Generation in California: 2014 Update.* http://www.energy.ca.gov/2014publications/CEC-200-2014-005/CEC-200-2014-005.pdf, Retrieved March 28, 2018.