Residential Load Control – How Efficiency Programs Can Help Integrate Renewables

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ABSTRACT

This paper quantifies the benefits that could be provided in the future by a large deployment of load control in residential products that are commonly incentivized by utility efficiency programs. Greater penetration of renewable energy generation will likely require additional efforts to integrate their more variable output with electric system demand. While battery storage is frequently referenced in conjunction with this role, the aggregation of large numbers of controllable devices in homes will likely be able to fill some of this need. This analysis studied the potential impact of controlling five products frequently incentivized by energy efficiency programs - water heaters, refrigerators, freezers, dishwashers, and pool pumps - in order to shift demand and reduce the impact on the grid of a home's consumption and PV production. For the study area, New York and New England, the hypothetical suite of controllable products could theoretically provide a 25-30% reduction in peak demand for a net-zero home, and a 5-12% reduction in maximum power exported to the grid. Given this potential, it is recommended that energy efficiency program administrators take steps to pilot load management and ensure that currently incentivized products are capable of being controlled in the future.

Introduction

Dramatically lower prices and rates of deployment of renewable energy are increasing the need for a more responsive grid that can manage the more intermittent nature of solar and wind generation. Battery storage has been a large part of the discussion around the integration of renewables, and will likely play a large role as costs continue to decline. The use of the battery packs in electric vehicles has tremendous potential in the future to fill this role as well. However, like solar PV's less visible and less glamourous cousin energy efficiency, there also exists large potential to integrate renewables and optimize the electric grid through more dispersed and less tangible means - Active Load Management (ALM). ALM, the control of end use devices in order to shift demand can help avoid the need to build new infrastructure on the grid by better utilizing the existing infrastructure. Advances in technology are bringing new potential to expanding the reach of ALM resources to the residential sector. Battery storage will most certainly play an important role in the future electric grid, but ALM can also provide some portion of the load-matching need. This study examines the potential for intra-day shifting of load to better align a home's consumption with daily PV output.

Policy Considerations

This study discusses the policy options for ALM implementation and then investigates a suite of products and what their potential impact could be if their usage was optimized to align with PV production.

Product selection. To assist in choosing the products to analyze, a classification mechanism was developed. This mechanism also is helpful in understanding the potential barriers – in particular customer acceptance – that controllable devise might experience when programs are developed and brought to market.

Table 1. Classification of ALM technologies

Category	Degree of Impact to customer	Description of application
1	Minimal	Not readily apparent to customers and have no loss of services provided
2	Low	Customer might see changes, but no loss of services
3	Medium	More visible to customer and moderate change or loss of service
4	High	Visible to customer and loss of service

Slight changes (generally increases) in energy consumption that could result from subjecting devices to ALM control were not considered in the classification process but instead should be examined as part of cost-effectiveness testing for a given measure. If the loss in efficiency that could result from pre-cooling (due to higher temperature differentials), for example, resulted in slightly higher electric consumption, this should be subtracted from the compensation mechanism for participation rather than be considered a change in service.

The following ALM products were selected for inclusion in the study:

Category 1

- Hot water heaters. Controllable electric hot water heaters that are capable of being heated higher than their set point can have increased electric load at one time and a corresponding decrease at another. Assuming tempering valves are used to regulate output temperature, there would be no apparent change to customers
- Refrigerator defrost cycle. Refrigerator defrost cycles can be deferred or accelerated within reasonable limits with no impact to customers.
- Standalone freezers. Unlike refrigerators, freezers can precool at one point in time in order to coast through to another time with no significant impact to the service provided.

Category 2

- Pool pumps. Pool pumps need to run for enough time to provide proper cleaning to a pool, but not 24 hours a day. The timing of when pool pumps cycle could be controlled to align with grid needs. Changing this cycle would result in a change visible to customers, but without any significant impact on them.

Category 3

- Dishwashers. Dishwashers can be controlled to delay their cycle if they are started during a time when grid use is high. This delay would be quite apparent to users, as the machine would not start immediately under these circumstances. In some instances, users might have a need for clean dishes quickly, resulting in a loss of service. Smart dishwashers would be equipped with an override switch to allow immediate operation (at some potential loss of compensation for participating in the ALM program), but this still a more visible change in service.

Hot water heaters present an additional challenge due to the continued growth of high-efficiency heat pump hot water heaters in the market. Efficiency programs are generally incentivizing these units, which use approximately 1/3 of the energy of the resistance water heaters they replace. The analysis was run with separate scenarios for substituting a traditional resistance water heater with a connected resistance and a connected heat pump hot water heater in order to better understand the impacts of each option.

While there are certainly other controllable appliances and equipment that could be considered for inclusion, there are two that were specifically considered but not included: air conditioning and laundry. These both have significant potential for inclusion in ALM programs, but they have higher impacts to customers - both would be considered category 4. Air conditioning control, even with precooling, results in a noticeable loss or change of service for customers – higher indoor air temperatures and/or greater fluctuation in those temperatures. Both air conditioning and laundry delays would also likely be subject to a greater degree of overrides, making analysis of potential more dependent on predictions of consumer behavior.

To be clear, both have real and significant potential for ALM; they were simply not included in this analysis due to these differences. Air conditioner control in particular has a very large potential because if its large contribution to peak demand. It has also been studied and piloted in many places.

Delivery mechanisms. There are many possibilities for getting ALM products to customers and connecting them in a way that can respond to grid needs. Existing demand response programs are generally focused on large customers that can make significant load reductions when grid needs are high. These programs are generally run by utilities or third parties that are participating in markets. Because the demand reductions are high, the programs can incur significant transaction costs without impacting their economic viability. The communications technology can be a phone call between two people.

While significant in the aggregate, the amount of load control enabled by any single one of the devices in this study is very small. Transaction costs need to be very low for the economics to work. All of the products included in this study are a part of some efficiency programs around the country. Those programs are incentivizing customers to purchase the more efficient versions of these products, and in some cases to retire inefficient but operable old models. Thus a delivery mechanism for changing purchasing decisions for these products already exists in many places and in a way that is cost effective based on the energy savings. Adding a requirement that incentivized products also be capable of grid connection would not dramatically impact the price. EPRI has estimated that the incremental cost for adding grid-connected capability to appliances is $10-$20 and declining to near zero over time.

While a robust open market approach, whether through private aggregators or individual customer action, might theoretically be successful with the right electric rate structures sending the right price signals, the low transaction costs made possible by piggybacking on existing energy efficiency programs make it the most attractive approach, especially in the near-term.

Good efficiency programs are also designed to change customer purchasing behavior, encourage adoption of new and sometimes unfamiliar technologies, and eventually transform markets to widespread adoption. This similarly makes them an excellent fit to introduce and promote grid connected devices that provide ALM.

Compensating participants. Traditional demand response programs have a fairly straightforward compensation mechanism. A customer is offered a payment or credit for enrolling in the program and/or participating in an individual event. Since these are business customers, they simply weigh the benefit against the costs of participation. Residential ALM, particularly for the products in this study, is a substantially different situation. Because the amount of energy shifted is relatively low for an individual customer, the potential savings, particularly on an event or daily basis, is similarly low. However, at high levels of renewable deployment in the future, much more frequent participation is possible. In addition, the load shifting in this study all has a relatively low impact on customers, so the perceived cost (or loss of value) of participation is relatively low.

Before considering methods of compensation, potential revenue sources need to be considered. Aggregated load shifting could be used to participate in energy and capacity markets (in deregulated states), with revenue going to either the aggregator or efficiency program administrator. Vertically integrated providers could use the value of avoided generation infrastructure and/or fuel. In addition, the potential value to the distribution network should also be considered. Active load management can be a non-wires alternative to infrastructure, avoiding substation or other upgrades due to load or distributed generation growth.

Given these considerations, a range of options are available for methods of compensating customers for participation. Customers could simply be paid the value of participation by a program administrator, or value less an administrative fee. Alternatively, the amount offered to customers could be matched to the market need, similar to the way efficiency rebates are set at levels high enough to get desired participation levels without over-incentivizing. The difference between the amount paid and revenues generated could provide an additional funding stream into energy efficiency programs. For some of the devices, particularly those for which the ALM is not visible to the customer, participation could be a requirement for receiving the rebate. This would be the lowest cost option, but also would make it more difficult to ensure continued connection of the product to enable control.

Aggregator. While a utility efficiency program administrator tasked with deploying ALM products appears as the most obvious choice for this role, there are also other options that should be considered. Utility-administered aggregation has several benefits, including ease of integration with product distribution, coordination of messages to customers for both deploying and encouraging participation, ease of access to billing for delivering credits, and regulatory oversight. A for-profit third party administrator might lack some of these advantages, but would also have a strong incentive to encourage participation. A non-profit third-party could also serve this role, potentially in a way that would emphasize consumer benefits. Third-party efficiency program administrators such as Efficiency Vermont would be logical candidates for the role of aggregator. Since the aggregation role is effectively providing distributed energy grid resources as an alternative to infrastructure, a non-profit in this role could form the core of a “Sustainable Energy Utility” that would provide the non-infrastructure services that complement those of a traditional utility in a more distributed and optimized energy system (Parker 2013). Finally, there is possibility of no aggregator. With more granular rate structures, customers could simply operate their devices in a way (or more realistically, allow a Home Energy Management system to operate them) that minimizes their costs.

Analysis of Potential

Each of the five products was analyzed to determine its potential contribution to ALM and load shifting for residential PV integration. As such, the study was not aimed at optimizing the current system-wide peak for the region, but rather at the typical load shape of a single home with rooftop PV. A cluster of five homes in which one had a PV system but all five participated in ALM was also analyzed. Since the analysis was focused on New York and New England, a scenario was created by blending the load shape and consumption characteristics of homes from Rhode Island and upstate New York. The analysis focused on the average consumption and PV production for the month of July.

Average hourly residential load profiles for homes in National Grid service territory in both New York and Rhode Island were averaged to create representative hourly consumption on a typical July day (National Grid 2016). Similarly, the PVWatts model was used to simulate production from a 5.25 kW rooftop solar array in both locations and combined to create a composite result (PVWatts 2016). The array was sized to result in a home that was approximately net-zero in terms of consumption and production over the course of a year. The figure below shows what both the consumption and production look like for this representative home.

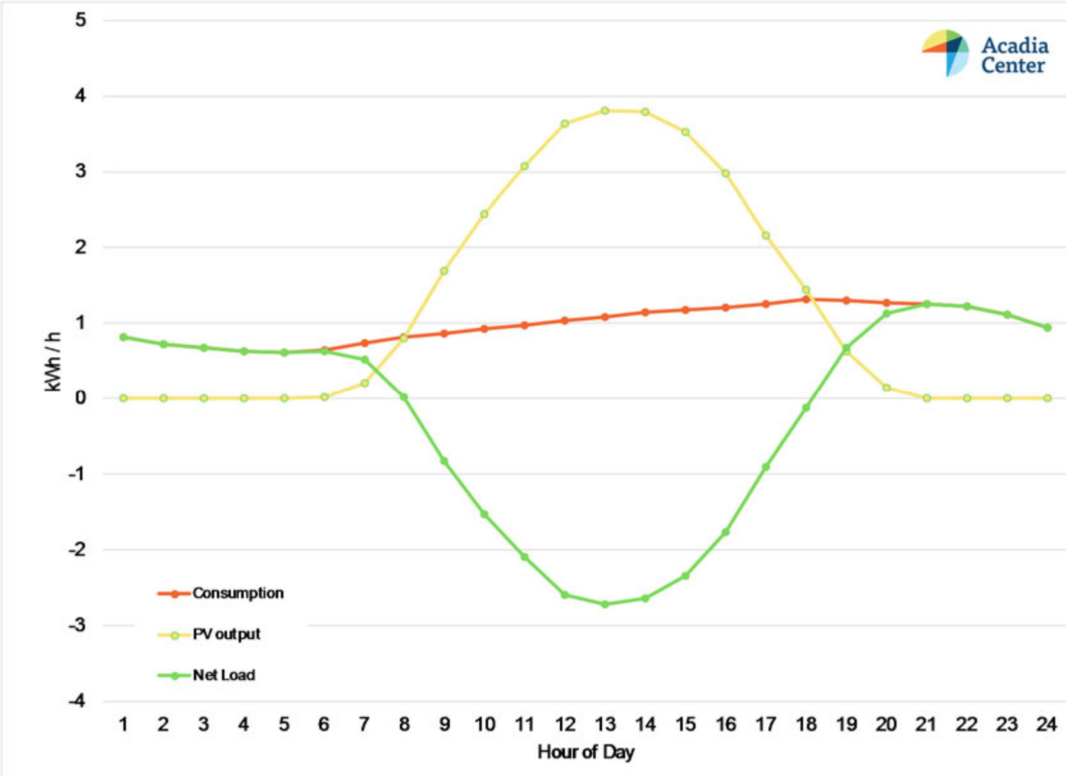

Figure 1. Load profiles for single home.

Hourly load profiles for the five products were analyzed in order to assess the potential for load shifting (ADM Associates 2002; Steven Winter Associates 2012; Sastry, C et al. 2010). Similar to the demand profiles for the home, these are average load profiles for a large number of homes, not those of individual units. The consumption of a single metered appliance would look quite different and would not reflect the difference in usage patterns that occurs in a large number of installations. The individual data, however, was used to determine how much load can potentially be shifted and to what degree. For refrigerators, for example, the load, frequency, and duration of defrost cycles were needed to determine how much of a refrigerator's total load could be shifted.

The load shifting strategy was not the same for all five products due to differences in their inherent characteristics and usage patterns. Since the freezers used precooling, all of the load was shifted to a period before the load reduction time. Similarly, hot water heaters were storing energy in order to coast later, so that load was also shifted forward. Dishwashers use a delayed start, so all of the load was shifted to the future. Refrigerators and pool pumps were shifted to both before and after the target period. The following figures show the load curves with and without the active load management.

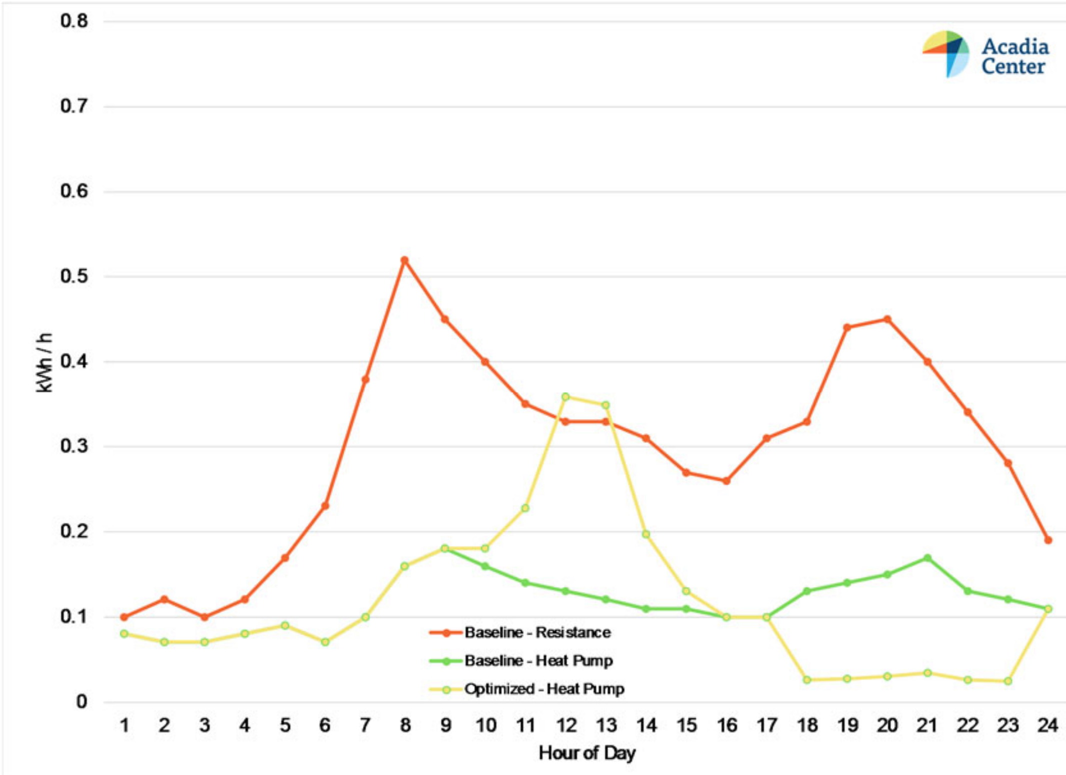

Figure 2. Hot water heaters.

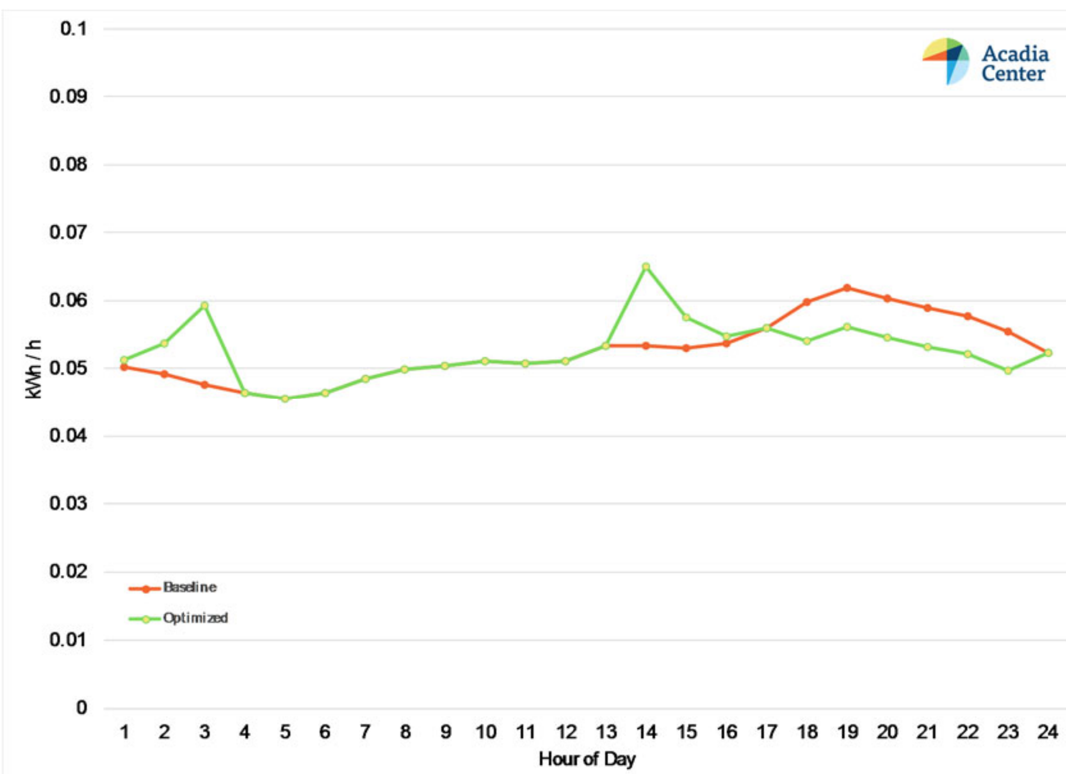

Figure 3. Refrigerator

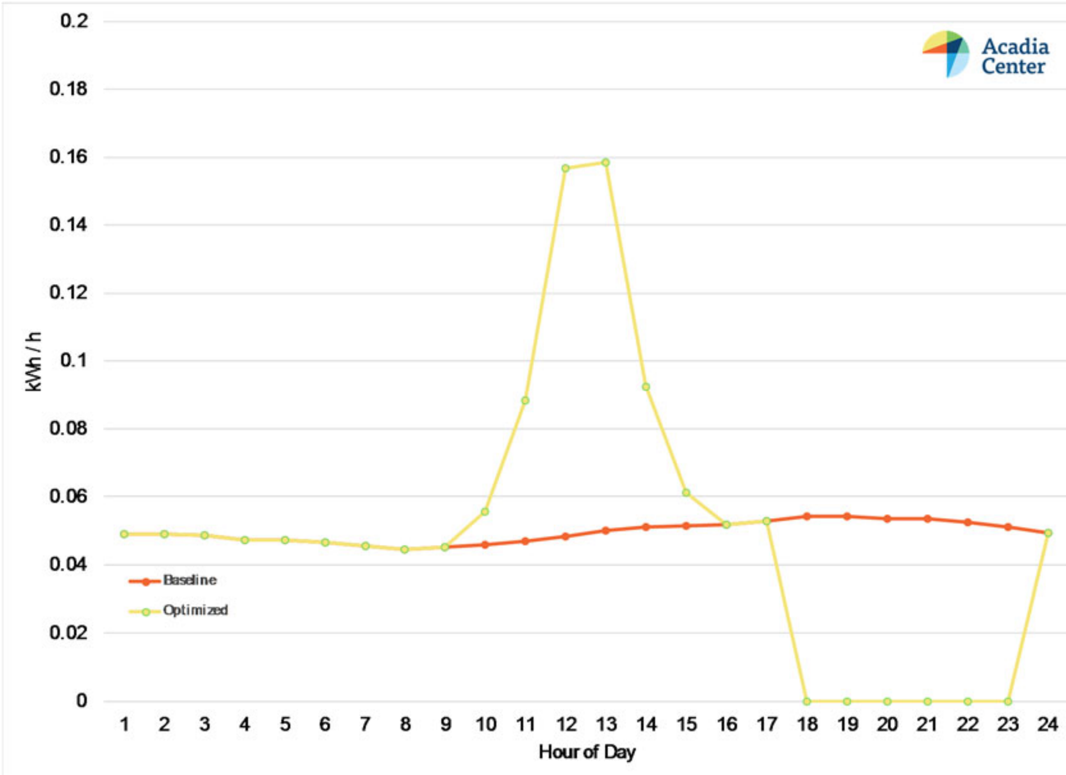

Figure 4. Freezer

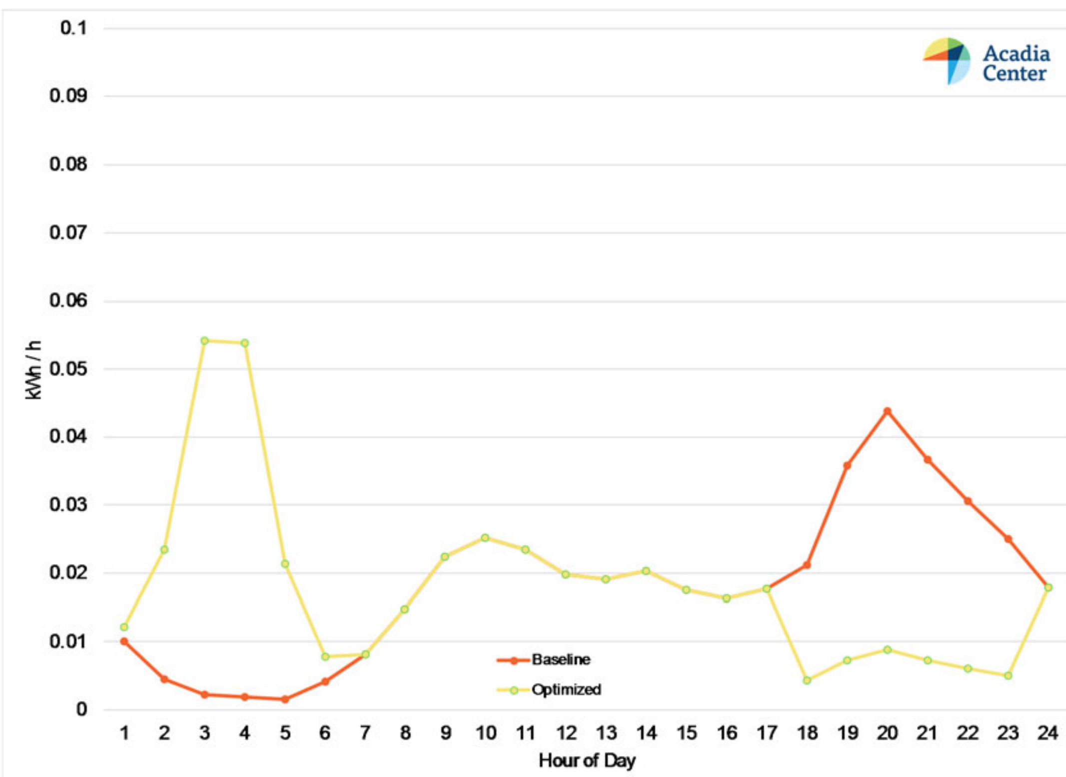

Figure 5. Dishwasher

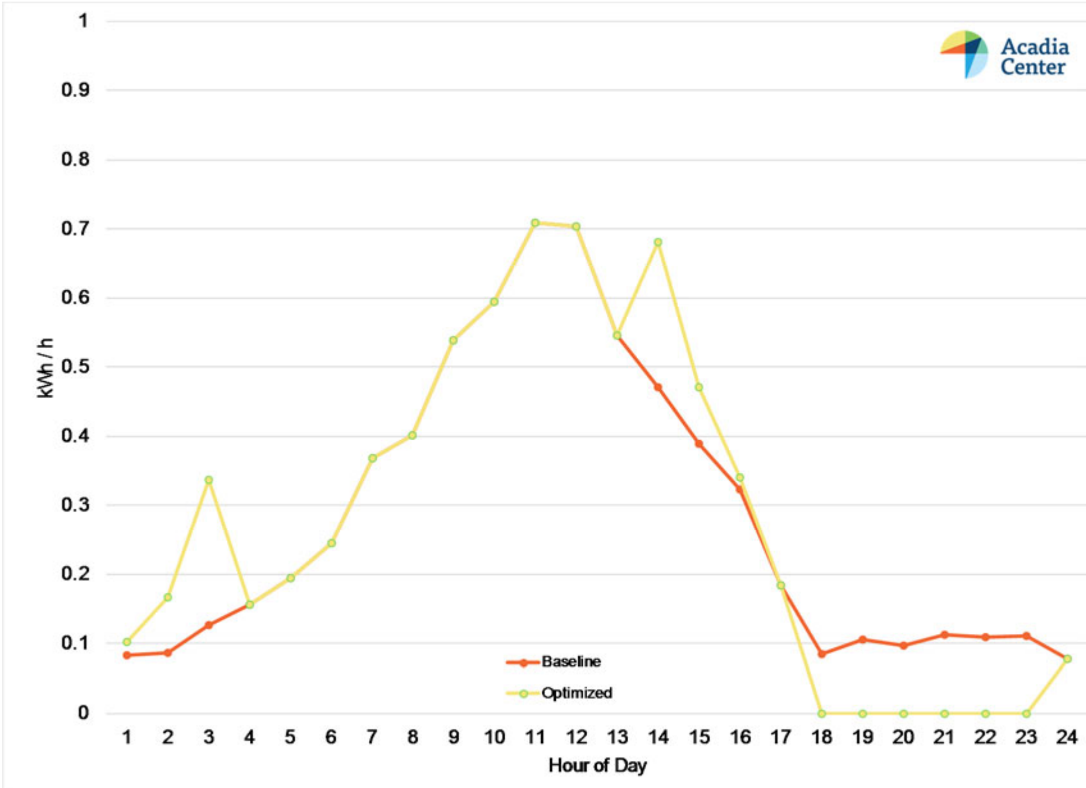

Figure 6. Pool pump

Results

The combined impact of optimizing the use of all five products was applied in two ways. First, it was compared to the single net zero home with the PV array. In this instance it is assumed that the home contained all five products. The overall result is a 25-30% reduction in peak load, and a 5-12% reduction in maximum power exported to the grid on an average July day, depending on the treatment of water heating.

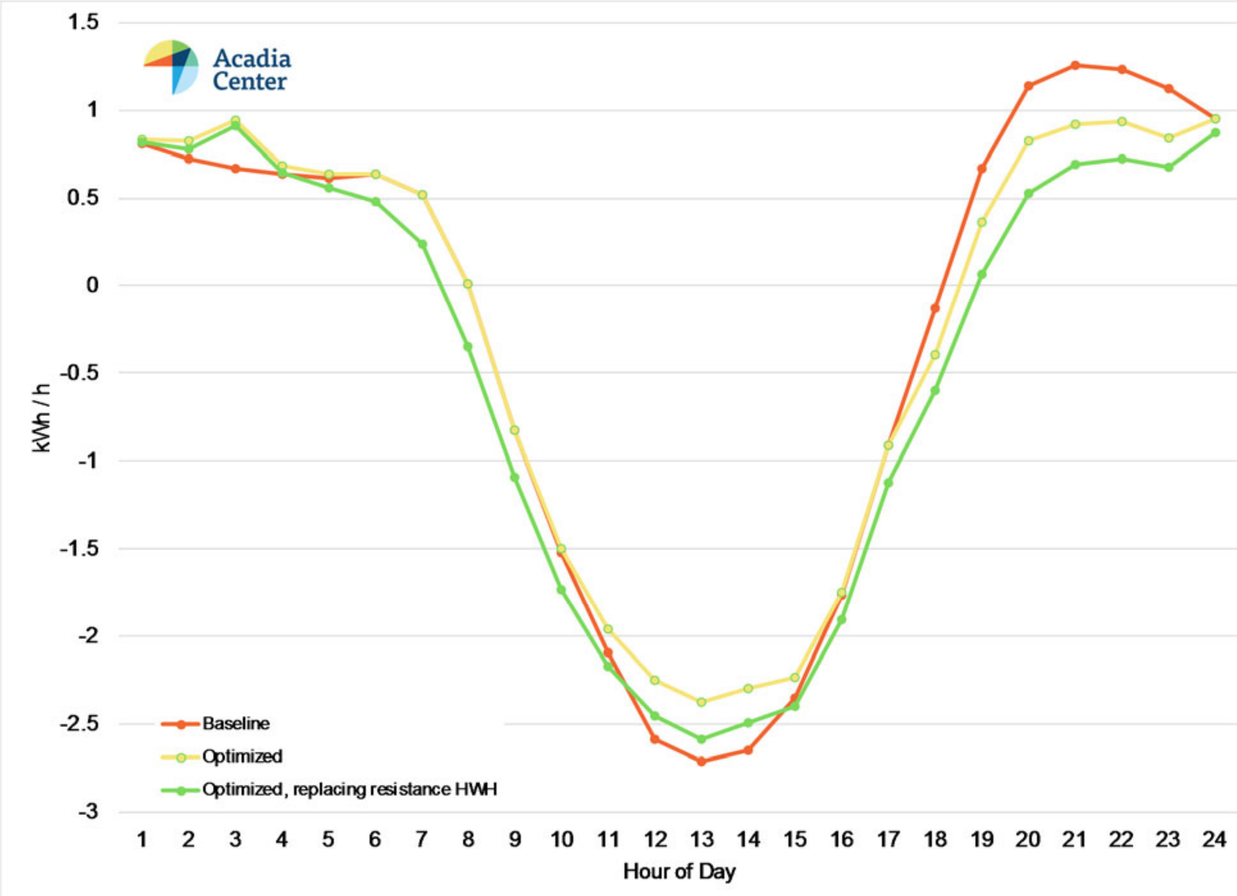

Figure *7*. Single home with ALM

The results were also applied to a cluster of five homes, with one home having the same 5.25 kW PV array. In this analysis, the not all of the homes had all five products. Instead, they were assumed to exist at the average penetration rate for each product in the combined New York / New England region (EIA 2009). This analysis attempts to replicate a more common situation with PV – a smaller subset of homes with PV potential, but most homes have the ability to participate in energy efficiency and active load management. These results show a promising potential to help integrate PV and reduce grid infrastructure needs – a 13-22% reduction in peak demand on an average July day.

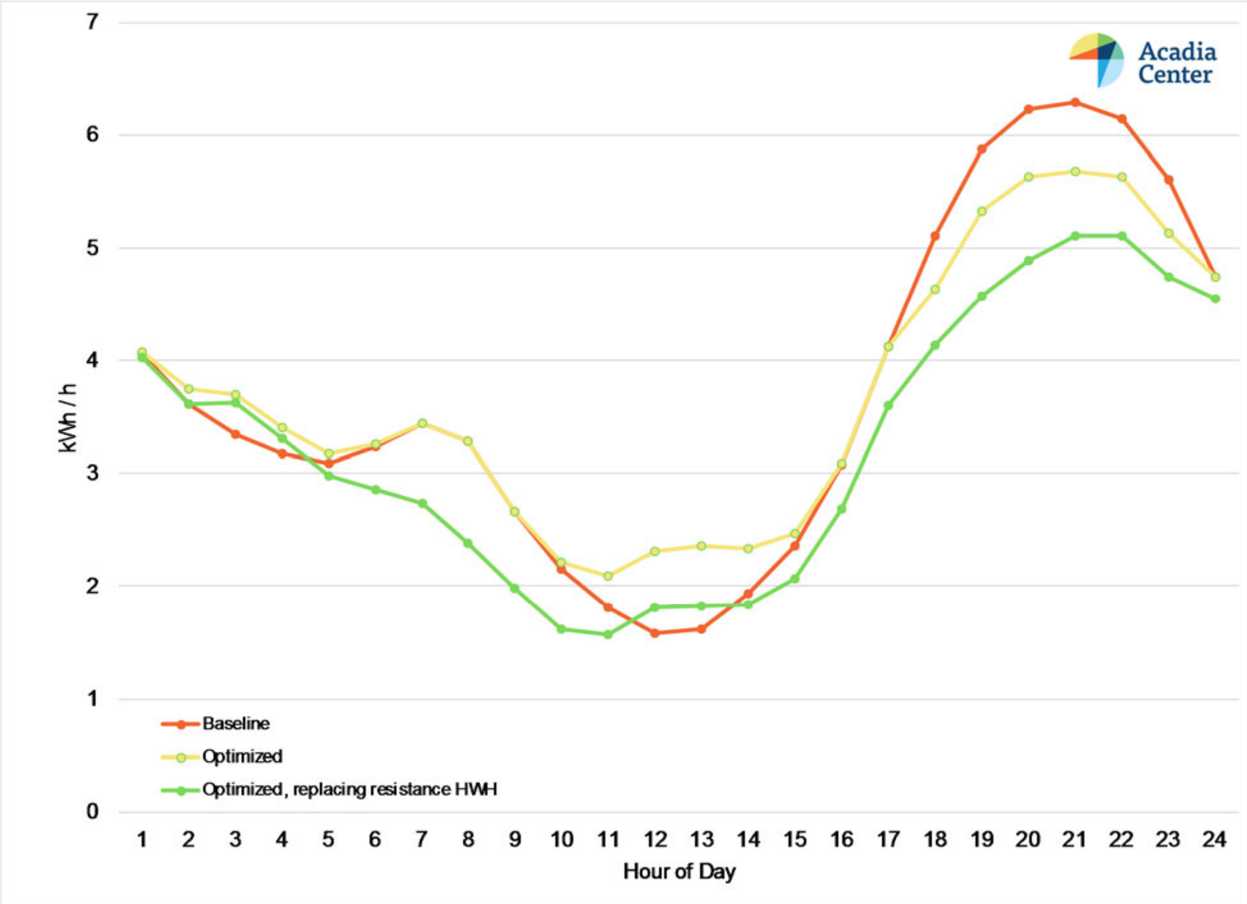

Figure 8. Five homes with ALM, one with PV.

Recommendations

The analysis shows that ALM can play a role in integrating renewables and optimizing the use of grid infrastructure. Other research has shown that this can be done cost-effectively (Sastry, C et al. 2010). While the products studied here do not have the large reductions in load that can be provided by controlling air conditioning, they have the benefit of being less visible to customers and therefore potentially easier to achieve widespread participation.

Given this potential, energy efficiency program administrators should begin to investigate and implement ALM programs. In particular, they should seek to avoid a new lost opportunity by incentivizing products that are not ALM capable when communicating/controllable versions are available, if costs are comparable. In this way even if program administrators are not yet ready to roll out a full ALM program they will be placing the building blocks in the field that can be activated in the future without significant new costs.

There are many unknowns regarding what it will take to get customers to participate in ALM programs and how they respond. Program administrators should pilot multiple models for compensating customers in order to determine what is most effective.

The amount of new PV coming on to the grid in New York and New England is dramatically increasing every year. While not yet at the levels of California or Hawaii, it has already begun to have in impact on the region’s load shape. The region’s energy efficiency program administrators have had a large role in dramatically lowering energy consumption and peak demand. They now need to leverage this role to also become leaders in ALM to help integrate the continuing increases in renewables.

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