Are You Ready for Plug and Play?
Insights from Holistic Electrification Program Evaluation

J. McWilliams, L. Getachew, G. Sadhasivan, A. Watkins, DNV, Oakland, CA

ABSTRACT

Electrification programs are gaining ground as utilities increasingly rely on these programs to help achieve their aggressive decarbonization targets. This paper showcases findings from a comprehensive evaluation conducted on Sacramento Municipal Utility District's (SMUD's) electrification programs. This utility is a vanguard energy provider in the state that recently accelerated its carbon reduction goals, pledging to be zero carbon by 2030. During the period covered by the evaluation (2018 and 2019) the programs installed 3,440 heat pump space heaters (HPSHs) and 1,353 heat pump water heaters (HPWHs), which involved gas-to-electric conversions of 24% and 96%, respectively. While one program employed comprehensive energy audits followed by installation of a suite of recommended measures, the other programs provided individual equipment rebates. Evaluation objectives include not only assessment of energy impacts using a robust consumption data analysis, but also development of measure load shapes using traditional end use metering and non-intrusive load monitoring (NILM) measurements on a sample of participant homes. The evaluation included quantitative surveys of 200 program participants to support a process evaluation and a market characterization using surveys of over 500 non-participants that were demographically matched to program participants to equip SMUD with customer insights for more effective targeting of future efforts.

This paper presents findings from the evaluation focused on the following questions:

- How do the barriers to electrification vary by customer segment?
- What is the willingness of customers to electrify water heating and space heating end uses?
- What are the energy impacts and greenhouse gas reductions from these programs?
- What are the peak demand implications of the space and water heating load shapes?
- What is the effectiveness of NILM algorithms to capture end use load shapes?
- Will electrical panels need upgrades to support electrification of space heating and water heating loads?

While standard methods developed to study energy efficiency programs are an important component, a full understanding of the impact of electrification programs requires a more expansive view. Considerations must include not just the annual energy or greenhouse gas impacts, but also the time and locational aspects of increased electric demand and how this interacts with system capacity and distribution constraints. This presentation is relevant to evaluators, utilities embarking on electrification programs, regulators, and policy makers with aggressive carbon reduction goals.

Introduction

SMUD's Equipment Efficiency (EE), Home Performance Program (HPP), and Multifamily Energy Efficiency (MF) Program offer incentives that offset the cost to switch from gas water and space heating equipment to electric heat pumps. These programs also offer incentives for related measures such as sealing and insulation, whole house fans, electric panel upgrades, induction cooktops, and windows replacements.

During the period covered by the evaluation (2018 and 2019) the programs installed 3,440 heat pump space heaters (HPSHs) and 1,353 heat pump water heaters (HPWHs), which involved gas-to-electric conversions of 24% and 96%, respectively.

Methodology

The study approach included multiple forms of data collection to provide a robust view of both how the programs are performing and critical information to use for planning significant increases in program activity as SMUD has adopted more aggressive carbon goals and committed to efficient electrification since launching the programs evaluated. The key research objectives of this study were to:

- Conduct a baseline study of gas and electric energy use for space and water heating, including penetrations of energy efficient space and water heating equipment, building characteristics, panel conditions, and customer demographics.
- Conduct M&V of energy savings, carbon reduction, and increased electric usage for gas-to-electric conversion of heat pump water heating and heat pump space heating installations incentivized through SMUD's 2018 and 2019 programs.
- Collect consumption load shapes of participant HPWH and HPSH equipment and identify and evaluate key load disaggregation technologies, also called non-intrusive load monitoring (NILM) devices.

Table 1 summarizes the data gathered and analyzed through our baseline and impact studies to inform each of the key research objectives.

Table 1. Summary of baseline and impact study data

Baseline study	Impact study M&V	Impact study load shapes and NILM
Participant surveys (n=207)	Consumption analysis quasi-experimental design	Onsite data collection (n=66)
Non-participant surveys (n=1,213)	Matched comparison group	NILM installations (n=10)
Property manager interviews (n=30)	Difference in difference model to estimate savings	

Baseline Study Methods

The baseline study included a survey among the combined set of participants in SMUD’s three programs that provided incentives to offset the cost to switch from gas water and space heating/cooling equipment to electric heat pumps. DNV also conducted research among non-participants (occupants and property managers) to gauge the penetration of natural gas appliances and customer interest in electrification.

DNV undertook a multi-prong research and analysis effort to meet SMUD’s key research objectives. This effort involved three key components:

- **Participant and non-participant (occupant) customer surveys.** We conducted surveys among program participants and non-participants (occupants) in SMUD’s service territory to gather detailed information regarding equipment and other relevant dwelling information. This data provides insights on the participant experience and inform SMUD’s estimates of technical, social, and economic potential.

- **In-depth interviews with multifamily property managers of participating buildings.** We conducted interviews with property managers to provide a complementary perspective to the customer surveys where occupants are not the decision makers. These interviews will also provide information regarding customer segments where residents are not the decision makers and do not have agency over equipment replacement and often do not pay their utility bills.
- **Secondary data analysis.** We augmented the data collected for multifamily properties by analyzing building and unit-level characteristics for all the multifamily properties in SMUD's service territory. We purchased this data from CoStar Property, a third-party provider that offers comprehensive information on multifamily properties such as property contacts (owners/managers), building vintage, square footage, total number of units, amenities (heating, cooling), rent type (market rate/affordable housing), and construction type among others.

Table 2 summarizes the approach to data gathered, the sample size and the sample frame for each of the components in our baseline study.

Table 2. Baseline study data source approaches for each study component

Approach to data gathering	Sample size	Sample frame
Web survey among residential customers – Participants and Non-participants	Census approach	Program participants with email contact information on file
		Non-participant matched comparison group and random sample of unmatched non-participants with email contact information on file
In-depth phone interviews - Multifamily property managers	n = 30 multifamily property manager interviews	Stratified random sample drawn from third-party list (CoStar) of multifamily property managers
Secondary data analysis – Third-party (CoStar) multifamily property data	Population level analysis of third-party data	Population level analysis

DNV post-stratified survey responses by consumption level and building vintage to ensure that the sample was balanced on these key relevant dimensions. We computed sample weights in proportion to known population counts by strata, which corrects for any bias introduced due to over or under representation of customer groups in the survey sample.

We used weighted sample responses in the survey analysis for participants and non-participants. Multifamily buildings are segmented separately from single-family and we use property manager interview responses to inform our analysis, appropriately weighted to reflect the number and type of multifamily units they represent. Weighted responses were analyzed to provide SMUD with insights on:

- Market penetration of space and water heating systems, gas or other fuel appliances, furnaces, stoves, etc.
- Customer experience on the program (participants only)
- Barriers to program participation (non-participants only)

Impact Study Methods

The consumption data analysis of SMUD's EE, HPP, and MF programs quantified the impacts of the program-related heat pump space and water heater installations and quantified the GHG reductions associated with the installations of heat pump measures. The EE and HPP involved single-family homes and had sufficient participation to enable program-level consumption data analysis with a comparison group. Our analysis was based on a two-stage modeling approach that estimates the effect of program measures on energy consumption. The approach uses variable degree-day PRISM-inspired site-level models combined with a matched comparison group to estimate program-level effects in a difference-in-difference (DID) framework. In addition to the conversion of gas space and water heaters to electric heat pumps, the EE, HPP, and MF programs also offer incentives for a variety of additional energy-efficiency measures that we account for in the analysis.

Since multifamily program participation was limited, we used site-level consumption data analysis to evaluate the impact of that program. Two multifamily sites participated in SMUD's MF program. The first site (referred to as "Site 1" hereafter) has 89 units, each of which received individually metered gas and electric service. The second site (referred to as "Site 2" hereafter) has 28 units with individually metered electric and master metered gas service. Site 1 converted both its space and water heating equipment from gas to electric heat pumps while Site 2 only converted its space heating. Due to Site 2's limited occupancy during the analysis window, its data was not used in the analysis.

For both electricity and gas multifamily datasets, we used the average pre- to post-period weather normalized consumption change during shoulder months with limited weather sensitive load (March, April, and November) as an estimate of average baseload savings that we applied to the whole year. We estimated heating and cooling load changes as the difference in pre- to post-period energy consumption during heating and cooling months minus the estimated baseload changes. The estimated electric and gas baseload changes indicated the electric load increase and gas load decrease due to the conversion of gas water heating systems to HPWHs. Electric heating and cooling, and gas heating load changes served as estimates of the electric and gas consumption effects of gas space heating conversions to HPSHs.

GHG emissions

Energy savings and associated GHG emissions savings from the measures installed through this program are important not only to SMUD, but to the larger statewide community working to reduce greenhouse gas production on a large scale. We calculated gas and electric emissions factors specific to the SMUD service territory and used them to calculate the GHG impacts of the electrification measures (HPWHs and HPSHs), SMUD program-level impacts, and SMUD territory-wide impacts. We report first-year and lifetime savings of the measures using an electricity emissions factor that decreases in the future as SMUD's electricity becomes cleaner.

Load shapes

Whole-home and appliance-level load shapes are an important focus of this evaluation and are generated in several ways with different data sets. Whole-home load shapes are generated using AMI data that are compared to those generated by the NILM technologies (Sense and Smappee). We developed AMI-based whole home load shapes using hourly regression models that are specified to explain change in hourly kWh consumption resulting from electrification. The hourly models are estimated as a function of daily cooling and heating degree days that are based on the optimal degree-day bases chosen by the first-stage daily data regressions used in the consumption data analysis. Model estimates are used to normalize hourly energy consumption using typical winter and summer weather conditions that provide typical participant pre- and post-program load shapes. These average program participant electric savings shapes demonstrate how the program impacts SMUD's electric grid.

Appliance-level load shapes were measured for heat pump space and water heaters for the sample of 66 participant sites using Onset current transducers and spot power measurements. To characterize the energy consumption of each HPWH or HPSH, DNV measured the amperage draw of the appliance as a function of time over 5-12 months. The load shapes are also measured for the 10 NILM sites using Smappee current transducers and real time Smappee power measurements. The Sense and

Smappee disaggregation algorithms estimate not only the heat pump appliance-level load shapes, but those for additional large appliances in the household.

Baseline Study Results

Non-participants were asked to indicate the appliances in their home that used natural gas including for space heating, water heating, clothes drying, cooking etc. Water heating, space heating, and cooking were the most mentioned natural gas fueled end-uses (Figure 1). Given that over two-thirds of these appliances currently use natural gas, there is tremendous opportunity for electrification of these end-uses for SMUD customers.

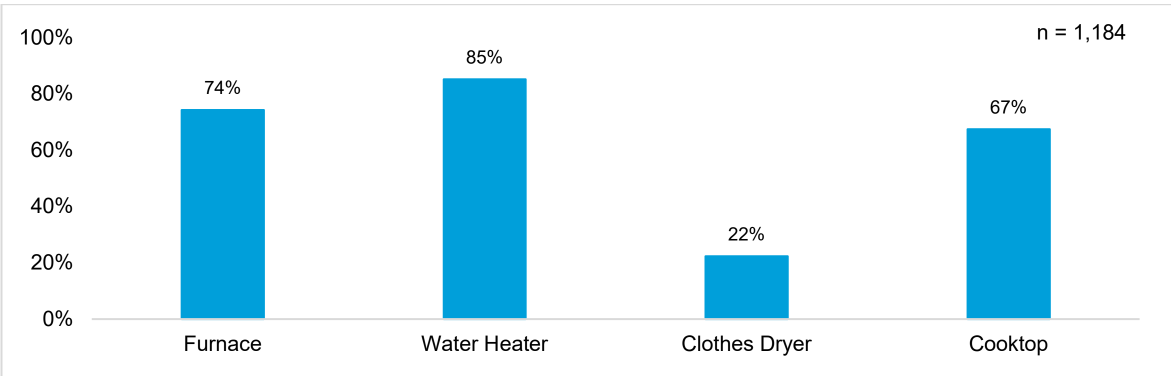

Figure 1. Penetration of natural gas using appliances in the homes of non-participants

Respondents were asked about the barriers and challenges they may have faced related their heat pump or HPWH installations. While approximately one-third (32%) of those installing HPs and two-fifths (42%) of those installing HPWHs indicated that they had not faced any barriers or challenges related to installation, the top mentioned barriers were costs, panel upgrade requirements, building permit or compliance (i.e. HERS compliance) process, space constraints, and downtime (Figure 2).

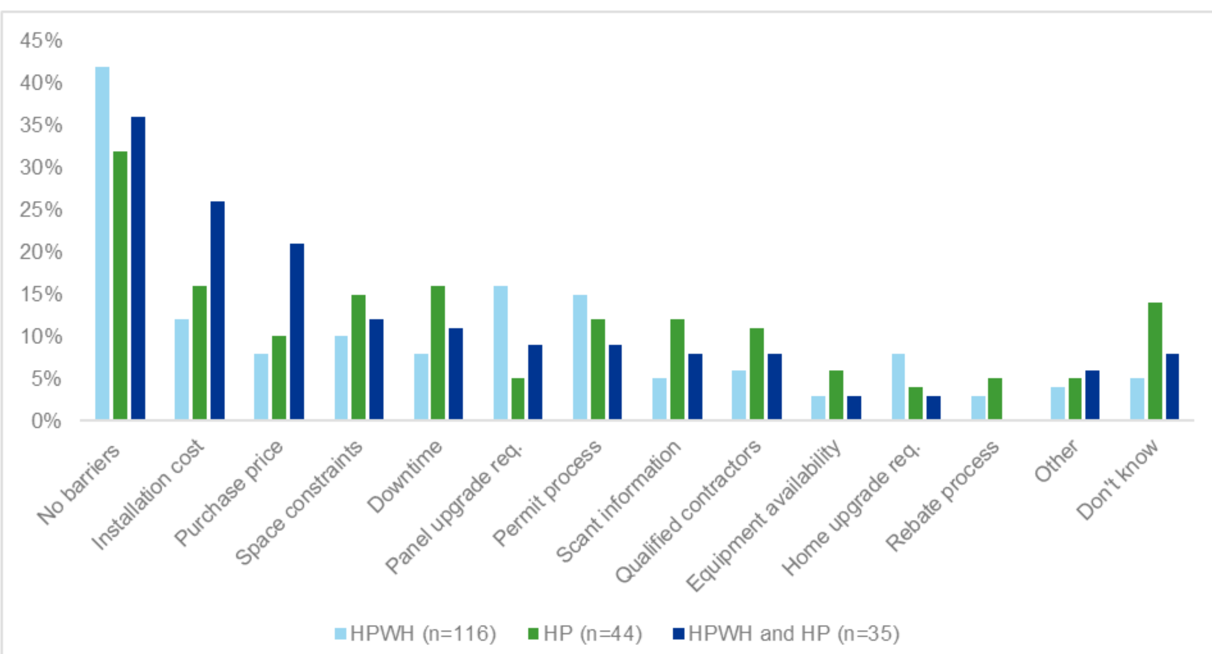

Figure 2. Barriers or challenges related to equipment installation

Property managers and owners were asked if they were aware of SMUD's gas-to-electric replacement program for multifamily buildings and only 23% of property managers had heard of the program. Low level of program awareness is currently a barrier to participation among other reasons.

When thinking about replacing heating and water heating equipment, we asked what barriers or challenges would prevent their company from converting gas-to-electric appliances for water heaters or space heaters. Survey results show cost and inconvenience are the primary concerns (Figure 3). The survey further uncovered and verbatim responses corroborated that property managers are more reactive then proactive to equipment replacements. Equipment upgrades are seldom motivated by energy efficiency and/or non-energy benefits. Replacements are piecemealed rather than undertaking a fleet of equipment upgrades all at once.

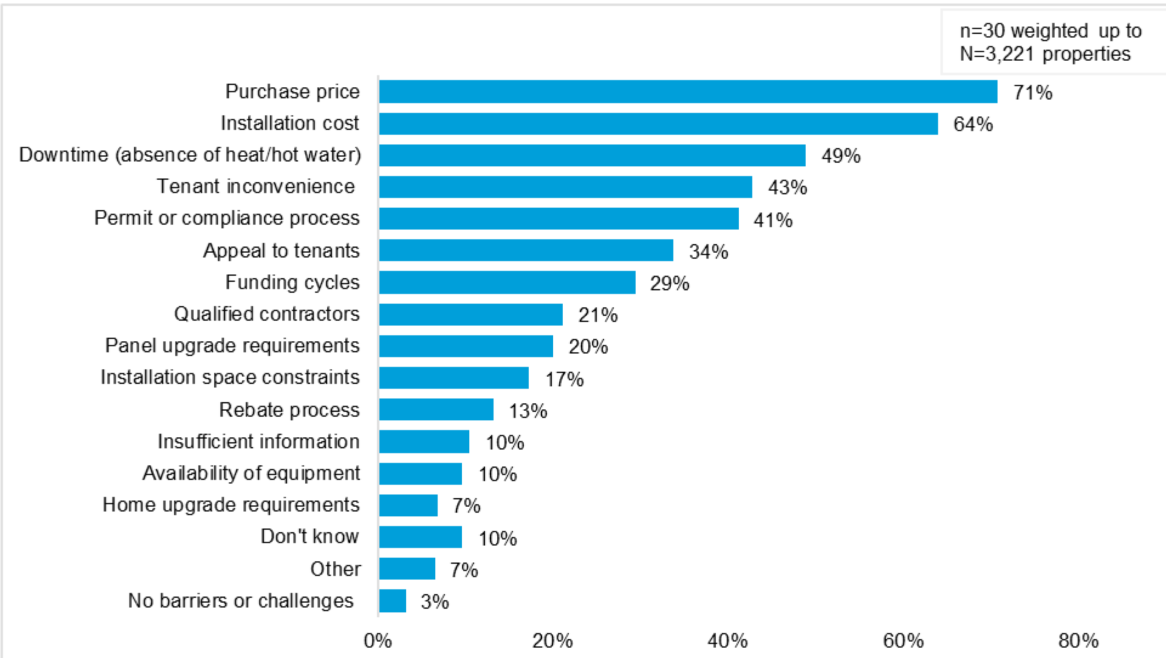

Figure 3. Multifamily property barriers to electrification

That said, the survey results also indicated some possibility to incent property managers to adjust their habits. Just eight of the 30 property managers stated they would *only* replace equipment on burnout. These property managers represent 30% of all properties and 22% of all dwelling units. Replacements, once decided on as a need, may not be hindered by a gas-to-electric conversion so long as the costs are the same and there are minor to no ancillary costs to support the installation such as structural, electrical, panel, or permit upgrades. Permit or compliance processes were among the top five barriers to electrification at 41%. Streamlining the permit process so that it is less time-consuming or costly and clarifying guidance on requirements will minimize any potential dampening effect on customer adoption of electrification projects. In an open ended question regarding barriers to electrification of space and water heating equipment, twenty percent of property managers indicated that panel upgrade requirements were a barrier to electrification. Incentivizing installation of low-amp technologies may help circumvent the need to upgrade the electrical panel.

More than one-third of customers indicated a moderate level of interest in fuel switching for either system after being made aware of incentive opportunities from SMUD (Figure 4). Results reported below are at the total non-participant sample level, as the level of interest was largely similar between the "matched" group and the "random" group. When respondents were asked about their interest in electrifying their HVAC systems (Figure 4, left) and water heating systems (Figure 4, right), respectively 37% and 38% of all respondents said that they were either "very interested" or "somewhat interested".

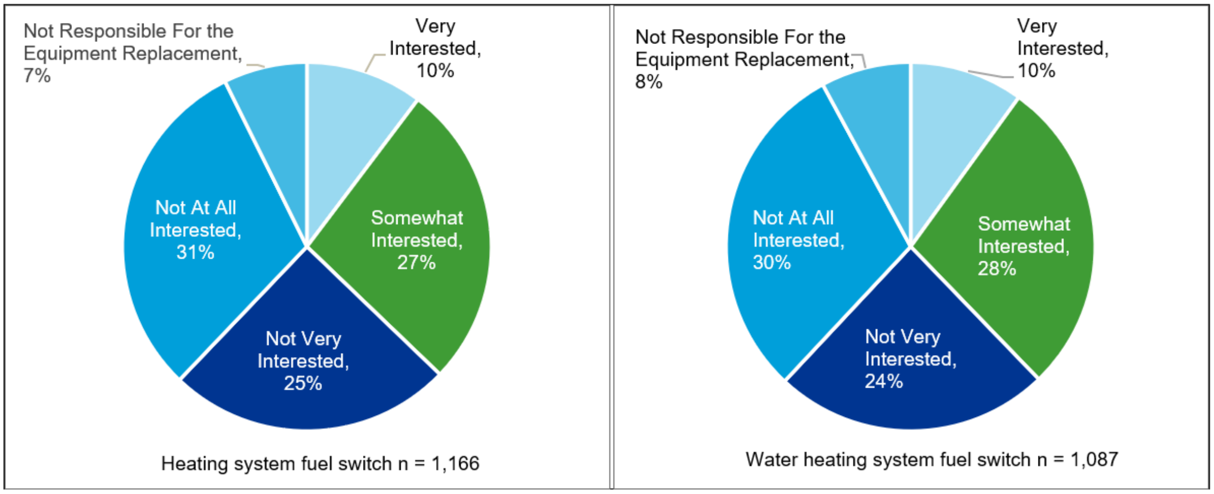

Figure 4. Non-participant interest in heating system fuel switch incentive, all respondents

Impact Study Results

As mentioned above, the energy impact of the programs was determined using program-level consumption data analysis with a comparison group for the single-family home programs (EE and HPP) and using site level consumption data analysis for the multifamily (MF) program. Table 3 provides savings (decreased gas consumption minus increased electric consumption expressed in kWh for comparison to increased load) associated with these gas-to-electric conversions as well as the load increase and carbon reduction from the electrification for all three programs. The load increases and energy savings per unit are the same over time while the reduction in carbon per metric ton increases over time as SMUD's grid becomes cleaner and as program participation ramps up. In addition, the carbon reductions in 2019 include the second year of carbon reductions from the 2018 program year. Both energy and carbon reductions are expected to be higher for HPSHs than for water heaters.

Table 3. Savings, expected load increase, and carbon reductions from gas-to-electric heat pump conversions

Savings	Measure	Single Family	Multifamily
Savings per unit (kWh)	HPSH, gas baseline	5,244	3,171
	HPWH, gas baseline	2,921	4,500
Increased load per unit (kWh) *	HPSH, gas baseline	-1,169	905**
	HPWH, gas baseline	-1,156	-1,470
First year carbon reduction per unit (metric tons)	HPSH, gas baseline	2.03	1.63
	HPWH, gas baseline	1.23	1.02

* Negative numbers indicate increased load; positive numbers indicate savings.
** The cooling savings for this multifamily project were greater than the increased heating consumption load

The single-family consumption data for program participants was also used to generate annual load shapes before and after program participation. Figures 5 and 6 present electric and gas weather normalized average daily energy consumption pre- and post-installation for single-family customers that participated in gas to electric HPSH conversions through EE and HPP. In Figure 5, electricity consumption is lower in the post-period cooling season compared to the pre-period reflecting the greater cooling efficiency of heat pumps compared to the technologies they replace. Electricity consumption is notably higher in the non-summer post-installation months for these customers as the heat pump replaces the gas space heat. In Figure 6, it is evident that gas consumption is substantially lower during post-retrofit months when space heating would be taking place. That gas consumption does not go to zero indicates that not all households are completely electrifying. The effect of installing HVAC heat pumps is to lower summer peak demand when the air conditioning efficiency of the new units is significantly better (on average the new units were SEER 18) than that of the replaced units.

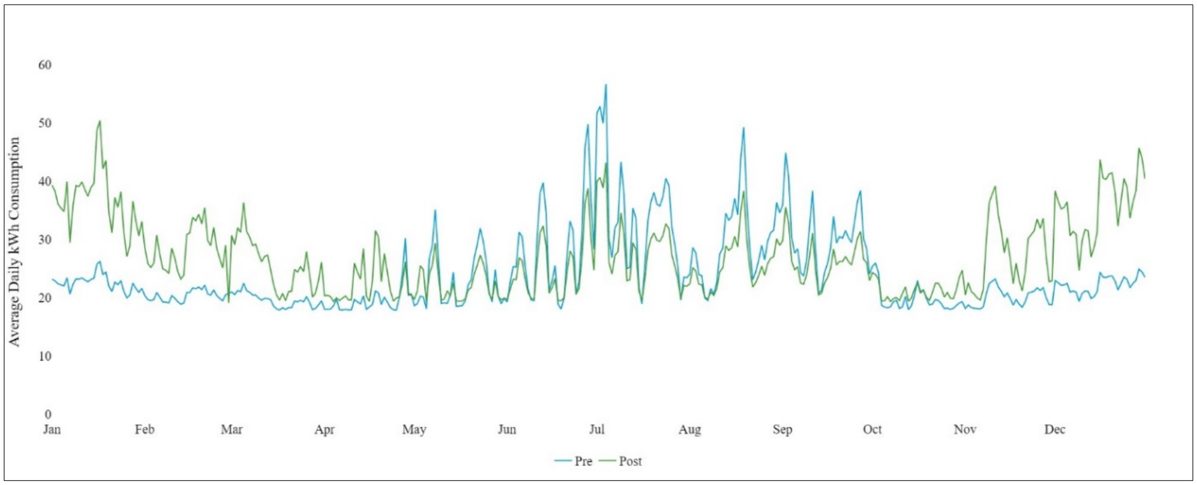

Figure 5. Electric weather normalized average daily single-family consumption pre- and post-HPSH conversions

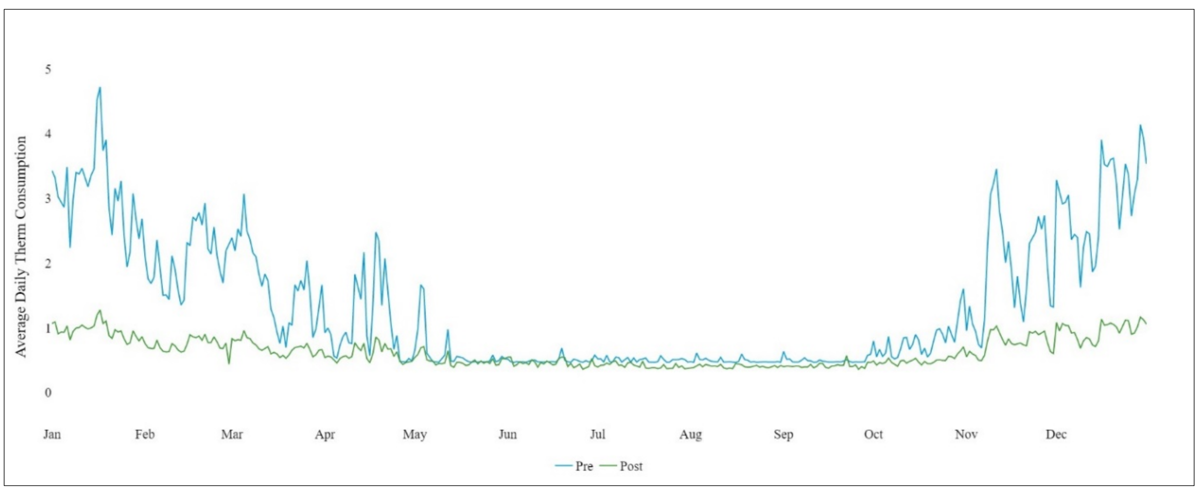

Figure 6. Natural gas weather normalized average daily single-family consumption pre- and post-HPSH conversions

Figures 7 and 8 present electric and gas weather normalized average daily energy consumption pre- and post-installation for single-family customers that participated in gas to electric HPWH conversions through EE and HPP. Electricity consumption is higher in almost all months following gas to HPWH conversions. Water heat consumption tends to be higher during cooler months because of some combination of ambient air temperature, water temperature and usage characteristics. That these load shapes appear to show a slight decrease in electric consumption in the summer may reflect decreases in cooling load (through a decrease in waste heat production by gas water heaters and an increase in waste cool production by HPWHs) or the presence of some customers who also replaced heat pumps for space conditioning.[1] Although one might think the installation of HPWHs would increase summer peak demand, the data from these programs does not support that conclusion.

In Figure 8, gas consumption is also lower across all months in the post-period compared to the pre-period. While it is obscured by the greater overall variability during the winter months, the decrease in gas consumption is greater there. It is clear these customers still heat their homes with gas in the heating season.

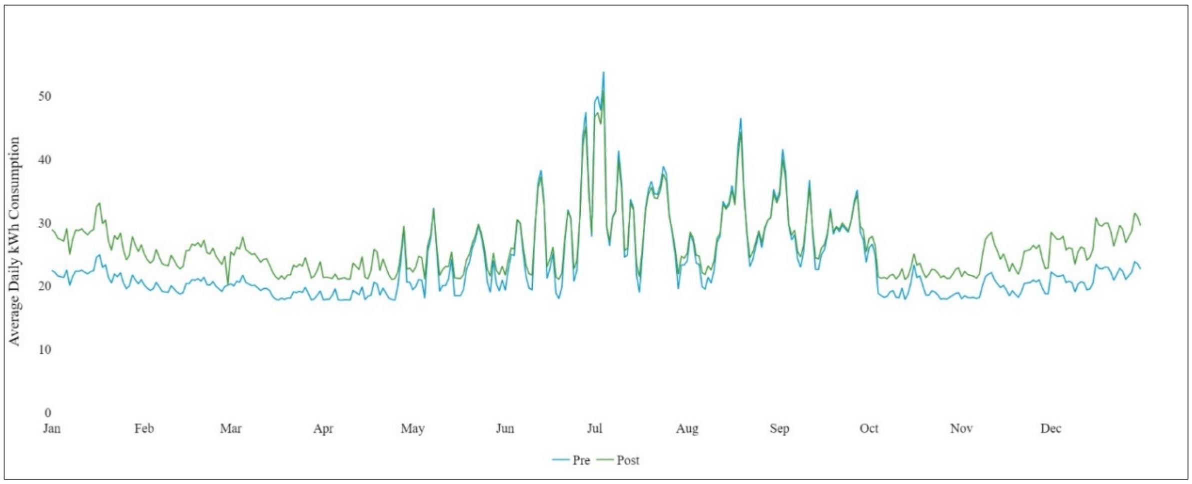

Figure 7. Electric weather normalized average daily single-family energy use pre- and post-HPWH conversions

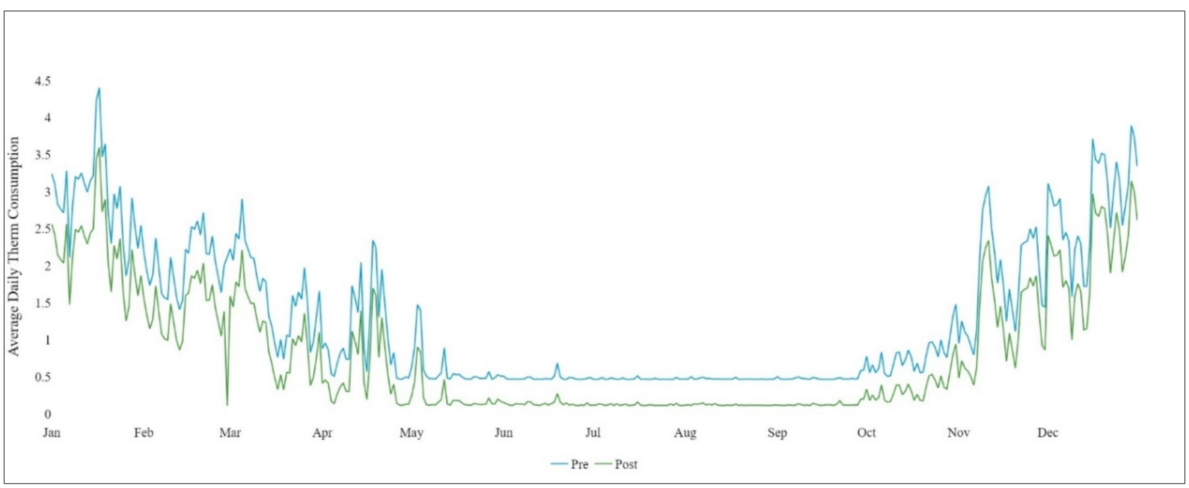

Figure 8. Natural gas weather normalized average daily single-family energy use pre- and post-HPWH conversions

Through this evaluation, two types of non-intrusive load monitoring devices were installed to gather appliance level: Sense and Smappee. Significant installation challenges were found with both types of devices. In six of nine homes there was insufficient space to install current transducers (CTs) on the main power legs in the accessible side of the electrical service panel. We coordinated with SMUD meter technicians who opened the SMUD side of the panel so we could install the CTs. In three of nine homes

[1] Note that these figures and the ones before them are largely for homes with heat pump water and space heater conversions respectively. However, each includes a small subset of households that undertook both conversions.

a Wi-Fi booster was required to provide sufficient Wi-Fi signal at the service panel. The Smappee equipment required manufacturer technical support to successfully install the equipment in 8 of the 9 homes. Also we found it did not incorporate algorithmic load disaggregation; it required individual current transducers to measure appliance level loads, making it not truly a NILM device.

The Sense disaggregation algorithms were accurately able to identify some appliances such as refrigerators and coffee makers after a one-month time period.

The Sense equipment measures power at a sample rate of one million times a second (1 MHz) in order to capture the unique waveform signatures of household appliances. Figure 9 shows an example of the Sense measurements sampled at one-minute intervals compared to hourly AMI measurements for one 24-hour period at an example home.

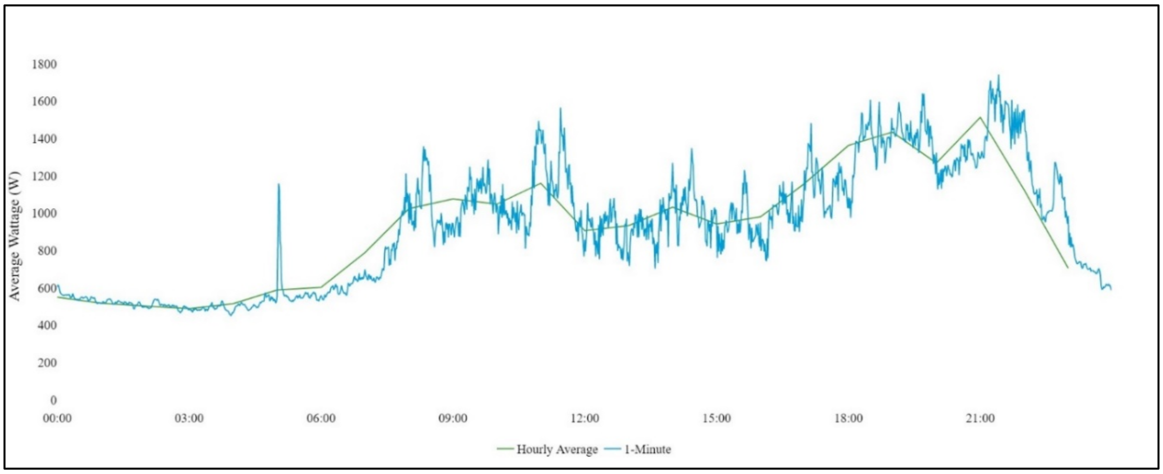

Figure 9. Hourly average data compared to the same load sampled at one-minute intervals

The fast sample rate allows us to capture short time duration / large power draw events. These are the type of events that will likely trip the main circuit breaker if the load exceeds the limit of the main breaker. Figure 10 shows an estimate of the maximum current draw compared to the observed main breaker capacity. We used the maximum power measured by the Sense equipment installed in the homes to estimate the maximum current amperage. The results are based on only a two month data collection period, and hence are preliminary, yet they suggest that in most cases these maximum events use less than half the available capacity. All sites had a 200-Amp main breaker except Site 31 with a 125-Amp main breaker.[2]

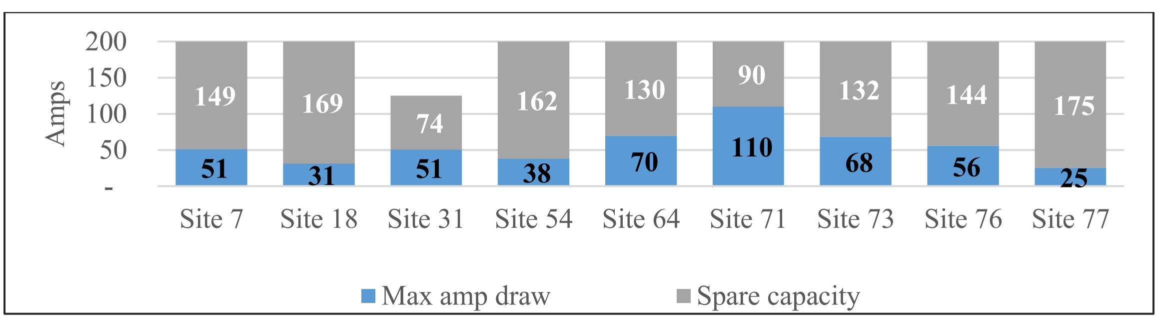

Figure 10. Estimate of electric service panel spare capacity

[2] It's important to note that this is not a random sample of homes. These homes were chosen for the NILM installation because they had newer, more spacious panels. Newer residential panels are most often 200A.

At some of the sites, the Sense equipment allowed us to identify the load causing the maximum power event. Site 64 had a maximum event most likely caused by simultaneous electrical vehicle (EV) charging and air conditioner operation. During the onsite interview the customer mentioned their intention to purchase an EV. Figure 11 shows the EV charging during the wee hours on Thursday April 15 and Sunday April 18 (2021). The air conditioner cycling is visible during the daytime and intermittently through the night. The warm weather shown in Figure 12 confirms air conditioner operation likely.

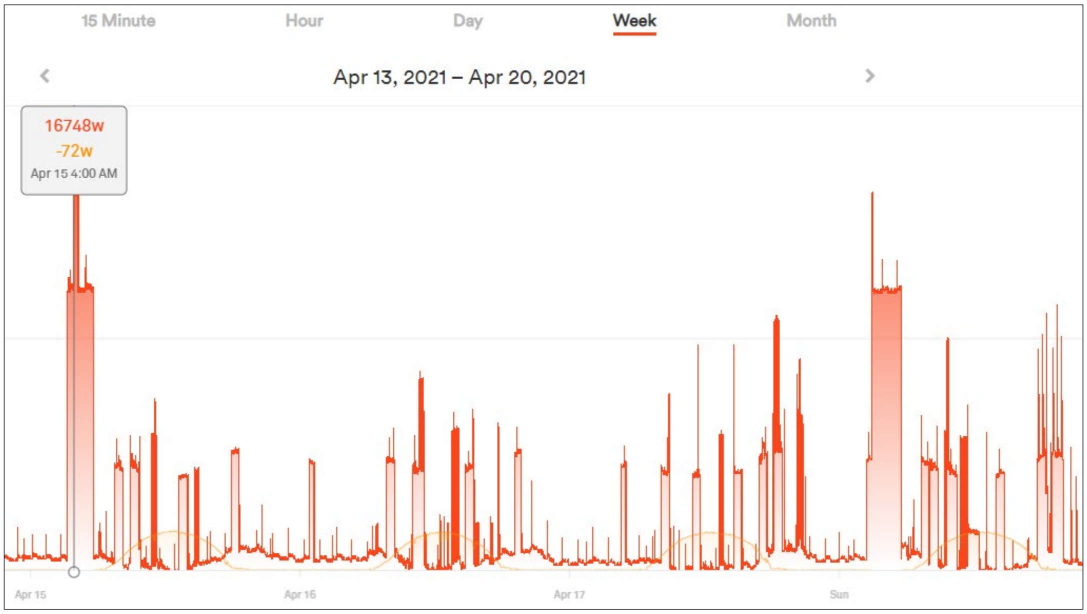

Figure 11. Site 64 diurnal power production (yellow) and consumption pattern (orange)

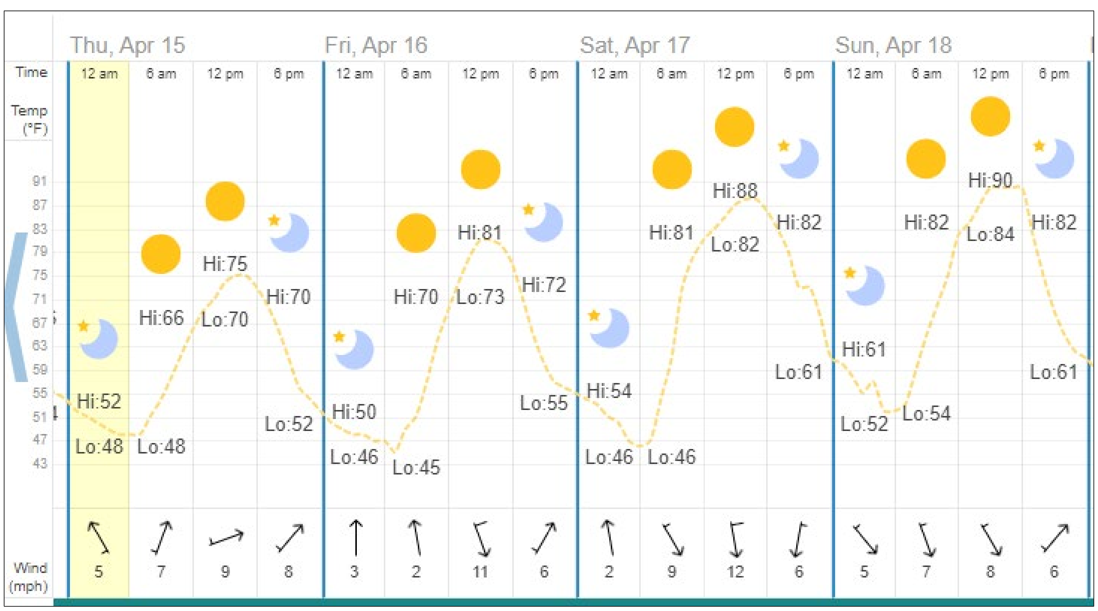

Figure 12. Sacramento weather conditions April 15-18, 2021

The maximum power event at site 71 occurs during the same heat wave, in the afternoon on the warmest day, Sunday April 18. Figure 13 shows multiple stacked loads and a power spike coinciding to form the maximum power event. It is very likely that one of the contributing loads is air conditioning. A

HPWH was installed through the SMUD program at this site, and that may have been another of the contributing loads.

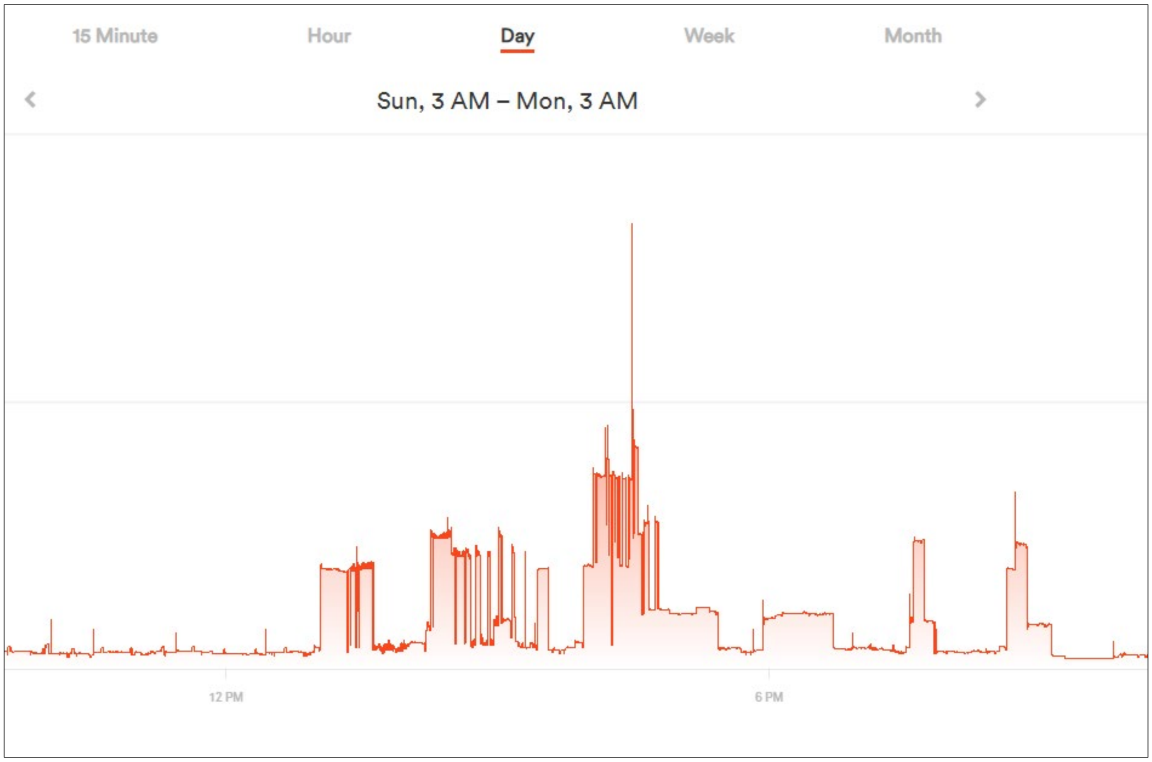

Figure 13. Site 71 maximum power event 4:24 PM April 18, 2021

Conclusions

While standard methods developed to study energy efficiency programs are an important component, a full understanding of the impact of electrification programs requires a more expansive view. The results of this study show the major barriers to installation of heat pump space and water heaters are costs, permit or compliance process, and downtime in both single and multifamily buildings. Further multifamily barriers include tenant inconvenience and additional single-family barriers include panel upgrade requirements and space constraints. Just over one third of customers are interested in electrifying water heating and space heating end uses. The energy impacts of HVAC heat pumps in single family homes in Sacramento are about 5,000 kWh (gas saved minus electricity used) and 3,000 kWh for HPWHs while greenhouse gas reductions are 2.03 and 1.23 metric tons of CO_2e respectively. While winter peak electric impact is increased when heat pumps replace a gas furnace, if they also replace an inefficient AC unit the summer peak demand is reduced. Although further research is needed, preliminary results show that in most cases a 100 A panel could support these types of heat pumps.

References

McWilliams, J., G. Sadhasivan, L. Getachew, and A. Watkins. 2021. "Residential Space and Water Heating Electrification Measurement Verification, and Market Characterization Study Report." Sacramento Municipal Utility District.